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Kekang He

A Theory of Creative Thinking

Construction and Verification of the Dual Circulation Model

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Kekang He
Beijing Normal University
Beijing
China

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Foreword I

In modern society, there is a general recognition of the great value of creative thinking. Advancing ideas, products, services, and methodologies require new concepts and the generation of new methods. For societies, traditional learning is currently seen as most important, but it focuses principally on the existing understandings, on a logic of linear thinking and ideas. Seldom do educational institutions seek to develop in their students the skills needed for innovation. They focus on developing lower level skills while paying less attention to more complex skills and capabilities.

While the focus of much of education is on learning and remembering declarative information, the skills of the learner, specifically the capability for creative and generative thought, are often ignored. How every society can bring forth creative talents is a challenge for all in education and is important for all in society. We know creativity is three times stronger as an indicator of lifetime success than is intelligence (Plucker 1999).

With this background, Dr. Kekang has developed a detailed exploration of creative thinking and thought. This book examines the nature of human thought, beginning from basic understanding of thinking, and progressing to the development of new ideas and theories of creativity. It is important, detailed, and encyclopedic. Kekang presents important comprehensive exploration of the idea of creative thinking.

Much of this work is based on an understanding of the value and dominance of verbal thought in cognition. Language is the beginning, the *material* of logical thinking. This, for those interested in creativity, is both a basic structure and a limitation, for this stable structure also engenders a set of limits on our own patterns of thought. Language is inherently linear, sequential, and symbolic and sets specific constraints on understanding through time and space.

Language is not neutral and may inherently limit different forms of thought. It imposes a logic of thought process, one which has low efficiency and one which is not adaptable to the visual realm or dynamic situations. It prejudices its own forms of expression and, more importantly, a sequential, ordered mode of thinking, which

directs the forms of ideas. As Dr. Kekang points out, it is limiting to our more inventive spatial and temporal conceptions.

Important to Dr. Kekang's exploration is the recognition of the role of the subconscious in the development of new ideas. Modern research has investigated the value of the subconscious mind in developing new ideas, with concepts coming to our consciousness from a deep well of possible connections and combinations.

Dr. Kekang builds on this understanding with and exploration of two forms of creative thinking which are less well recognized in creativity research and training. And they should be. They are *incidental* creative thinking and *intentional* creative thought. Most people have experienced the divergent thinking that springs from the subconscious, with unusual ideas or wide-ranging dreams. This is incidental creativity, a form that is ephemeral and elusive, and difficult to harness.

The other form, intentional creativity, is a challenge in and of itself, one which seeks creativity at specific times, such as when professional efforts require creative outputs and when one's domain demands creative output. We know through research that the thought processes needed for creative output and generation are seldom available when required.

Kekang's description of *initiative reflection* connects well with the idea of *abductive reasoning*; both are a recognition of the future orientation of creative thought. And this is where the importance of his writing begins; how creative thinking, how creative thought can be directed to improve the skills of individuals to be of value to society.

December 2016

Brad Hokanson, Ph.D.
University of Minnesota, Minneapolis, USA

Reference

Plucker, J. A. (1999). Is the proof in the pudding? Reanalyses of Torrance's (1958 to present) longitudinal data. *Creativity Research Journal*, *12*(2), 103–114.

Foreword II

A strategy for rejuvenating the country through science and education is one important measure, as President Jiang Zemin said that, in the speech of the centennial celebration of Peking University, we should train and bring up high-quality creative talents. To achieve this goal, we must be clear that the basic approach in training and bringing up high-quality creative talents lies basically in education; therefore, quality education today must have the strength of innovation as the core and must adhere to building up innovative will and innovative ability of the new generation. Why this? Because in rapid development of science and technology of today's world, knowledge economy is commencing, international competition becomes more and more severe. Therefore, it is imperative to cultivate and bring up high-quality creative talents.

Creative talents consist of two distinctive features: One is creative intelligence or creative thinking; the other is non-intellectual factors of creativity or creative personality. Creative thinking is intelligence factor in creative talents. Therefore, international research on creativity starts with creative thinking, exploring it both in theory and in practical methods to be applied in actual educational practice.

In front of me lays a quite an important manuscript, which is Professor He Kekang's monograph *A Theory of Creative Thinking—Construction and Verification of the Dual Circulation Model*. I'd like to call your attention to the fact that Professor He Kekang is a famous computer education specialist and modern educational technology specialist. He is not a psychologist. However, as a respected educational technology specialist, he 'breaks into the ground' of psychology to study creative thinking, from a novel and unique stance, and makes a considerable contribution to creative thinking. It is admirable in the field of psychology, education, and academics in general, reflecting the power of cross-disciplinary research.

I carefully read the manuscript and found that the prime quality of Mr. He Kekang's monograph is the courage to innovate and think creatively. He reviewed the history and present status of comprehensive research on creative thinking—covering two dimensions of human thinking: time and space; two modes of thinking: both consciousness and unconsciousness; both left and right brain

functions; both types of creative activities: artistic and scientific. Imagery thinking and intuitive thinking are the base to construct the mental model of creative thinking, i.e., mental operation model of intentional creative thinking, labeled by Mr. He as the 'inside and outside circulation model' referred to as Double Circulation or DC model. In the DC model, he sums up the findings: divergent thinking points to thinking direction, imagery thinking, intuitive thinking, and logical thinking are main part of creative thinking, and dialectical thinking and horizontal–vertical thinking are a guide for highly complex problem-solving thoughts and strategies. Mr. He's mental model of creative thinking does not just stay in theoretical exploration, but also has great practical value. He not only dedicates a chapter introducing methods of training creative thinking, but also cites results of experiments from master's and doctoral dissertations as well as the improvement of students' achievements in primary and middle schools to verify the suitability and feasibility of the theory.

However, a new theory to be accepted needs time. Mr. He's creative thinking model from its proposition to the acceptance by majority of psychologists, logicians, artificial intelligence workers, and educators will take some time. For such a new theory, we should first keep an open-mind and ready to learn about it, and look at it with an inquiry eyes. We should learn from Mr. He to update old theories, dare to challenge authorities, and stand out at innovation. This book may be the best embodiment of spirit of innovation and creative thinking; it is a most beautiful drop of water in the tide of knowledge innovation. Academic research should adhere to the principle: 'letting a hundred flowers blossom and a hundred schools of thought contend' so that the thoughts are more active and new ideas, new theory emerge; knowledge innovation starts growing.

May 2000

Lin Chongde
Beijing Normal University, Beijing, China

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Chapter 1
Introduction

The term innovation means activities that create valuable, unprecedented new material products and intellectual products for the civilization and progress of human society. Innovation is a process of creative labor, without which innovation cannot be created. In order to survive and to develop, human society must innovate. Having created production tools, human beings moved far away from the animal world; having created language, human beings developed from the primitive state of ignorance gradually into *homo sapiens*, highly intellectual moderns. Every victory in the struggle against the natural world could not be attained without innovation. At the International Conference on Innovation, held in October 1991, the delegates achieved consensus that developing creativity is key to the survival of the nation. In a speech in February 1998, President Jiang Zemin also pointed out that innovation is the soul of a nation's progress and an inexhaustible motive force for the prosperity of the country. A nation without innovative ability is hard to stand in the world of nations. In June 1999, on the third National Education Conference, President Jiang Zemin further stated that facing the challenge of rapid development of science and technology we must build up national innovative ability and regard it as a matter of rise and fall of the Chinese nation. He stressed that education shoulders the special mission to cultivate innovative spirits and creative talents. So how to cultivate a large number of talents with innovative spirits is a crucial task faced in education.

A talent with innovative spirits refers to the talent with innovation consciousness, creative thinking, innovation ability. In other words, this kind of talent is usually called as "innovative talents", and the core of innovative talents is creative thinking. That is because innovative consciousness refers to, the will for contributions to the progress of human civilization and lofty ideals, the spirit of devoting oneself to the development of science and technology, and the aspiration of creating and inventing; innovation ability refers to the practical ability of transforming innovative ideas, theories and designs into valuable and unprecedented intellectual products or physical products. Innovation consciousness mainly deals with the issue of "why to innovate", i.e., the impetus of innovation. Obviously, innovation

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consciousness can only be cultivated by long-term, persistent education of the value and outlook on life; creative thinking and innovation ability answer the question of "how to innovate". The former (creative thinking) answers how to form innovative ideas, theories and designs; while, the latter (innovation ability) answers the questions of how to transform innovate ideas, theories and designs into actual intellectual products or physical products (i.e., written literary works, composition of music, painting or invention of patent products). Obviously, innovation consciousness is the premise and impetus of creation and invention, and innovation consciousness is essential for the cultivation of innovative talents, which is the one side of the question; as for the other side of the question, creative thinking is the indispensable basis for innovation consciousness and innovation ability. Without creative thinking, innovation consciousness will become unrealistic empty talk; without creative thinking, the producing of intellectual products and physical products will become the water without source and the tree without roots, and the so-called "innovation ability" is no more than a slog or being foolhardy. So in this sense, creative thinking is also the basis and core of innovation consciousness and innovation ability. In order to produce large number of talents with innovation ability, we should deeply research the creative thinking, deeply analyze the psychological processing of creative thinking as well as the physiological mechanism during the producing of creative thinking, and find out the main factors which influence the the producing and developing of creative thinking. Only the appropriate employment of educational practice can get good results. Otherwise, one could only be blinded by trivial, individual phenomenon mistaken for universal laws; or biases as the complete whole, or lack of scientific evidence to speculate on as absolute truth. To produce a large number of talents with innovation ability has been battlefront of our educational efforts for many years. The poor results in the battle completely confirmed this poor practice.

At the beginning of 1999, a large scale survey[1] on creative ability was conducted, jointly sponsored by China Ministry of Education, the Central Committee for Youth, and China Association for Science. 31 provinces, cities and autonomous regions, about 2000 high school students were involved (Mainland students around 16,000, students from the Hong Kong Special Administrative Region more than 3000). for the question of *whether you have curiosity, abundant imagination, self-confidence and strong will power*, only 4.7% of the population taken the survey answered yes. Another question of "what attitudes will you hold if a student disagrees openly with the teacher in classroom", 48.1% of the people think most of the students in the class will remain silent, unwilling or afraid to stand by the student), 16.5% more people think that most of the students will be criticized by the teacher, the two groups adding up to 64.6% (nearly 2/3 of the population). As is known to all, curiosity and imagination are basic conditions to creative thinking, however, only 4.7% of our students have curiosity, abundant imagination, self-confidence and strong will. In classroom, it is crucial to cultivate divergent thinking to let

[1]Hai (1994).

student be free to raise objections or dare to challenge the teacher. And disagreement with the teacher is deemed as challenging the authority, which is indispensable premise for divergent thinking. It's plain to see the problem in China's current education system, as shown in its educational thought, teaching conceptions, modes, and methods. The fundamental problem is, over the years, most of the students we have trained are all applied talents with a gift of memorizing and using the previous knowledge and experience, but not good at creating new knowledge. They are not creative talents who can create new knowledge with innovative spirits.

Hence how can we effectively train large number of (not a few individuals) creative talents with innovative spirits (i.e., Innovative talents)? Apparently, for students, we need to pay attention to the education of the value and the outlook on life, helping students gradually establish the lofty ideals and ambitions and enhance innovation consciousness of their own will. At the same time, we need to carefully change traditional educational thought, teaching conceptions and modes. Besides, such change must be guided by proper theories of cultivating innovative talents. As mentioned above, the so-called creative talents with the innovation spirits are those who have innovation consciousness, creative thinking and innovation ability, and the core is creative thinking. Therefore, the core of the theory of cultivating innovative talents is effectively cultivating creative thinking. The construction of the theory is based on analyzing psychological processing of creative thinking and related physiological mechanism: first, establishing a theoretical model, based on psychology and neurophysiology, for creative thinking and finding the main factors which constitute the creative thinking structure in the model; second, on the basis of these, founding brand new teaching models and methods of teaching design which is corresponding and beneficial to a large number of growth of innovative talents.

In order to construct a theoretical model of creative thinking, we ought to first and foremost understand connections and differences between creative thinking and other forms of human thinking. To this end, we shall first of all turn to the basic forms of human thinking.

Reference

Hai, D. (1994). *Do Chinese children dare to question the new century*. Beijing: Beijing Evening News.

Chapter 2
Basic Forms of Human Thinking

2.1 Diverse Classification of Basic Forms of Human Thinking

In terms of forms of thinking, diverse categorizations were proposed according to different principles.[1,2] For example, in terms of abstraction of contents, thinking can be divided into concrete imagery thinking and abstract logical thinking; according to the intelligence of thought, there may be reproductive thinking and creative thinking; according to thinking process in terms of thinking direction, it can be divided into divergent thinking (i.e., divergent thinking, reverse thinking and multi-dimensional thinking) and convergent thinking (i.e., focused thinking, convergent thinking and positive thinking); according to thinking depth, it could be divided into conscious thinking and subconscious thinking and so forth. Each of the above principles of classification has its own rationality, and it's indispensable to study different aspects of thinking. However, thinking is not a general category. In order to seek survival and development in the struggle with the nature, the humans developed this unique function of the brain, after million years of evolution process. Therefore, if we consider the classification of thinking from basic forms of human thinking, there would be only one principle of classification—principle of epistemology, following the law of human understanding of motion and change; that is, to recognize the thinking forms from philosophical point of view. Unfortunately, majority of psychologists and philosophers seem to have not been aware of this. Hence, we shall turn to the basic forms of human thinking—views from academia, domestic and foreign.

On the classification of thinking, the first view believes that the basic form of human thinking is abstract-logic thinking, while imagery thinking and other forms of thinking are secondary. Some went even further to deny the existence of imagery

[1]Zhu et al. (1991).
[2]Dong (1993).

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thinking. For example, as a considerable influential course book for China's liberal arts colleges, *Psychology of Thinking* defines the task of thinking psychology as such[3]: "it's trying to answer the main question: how do people think? If thinking concerns with concept, judgment and inference, then psychology of thinking research agenda would be the process of concept, judgment, and reasoning, which would not be the contents that correct concept and judgment follow; instead focusing on "*how does a concept form, how do people master them, how do people make judgments, how to make an inference, how do people solve problems and as a process, how does thinking occur, change, and develop with its laws*?" Obviously, the author of the book takes thinking as "the use of the concept, the process of reasoning"; that is, thinking is considered only as logical thinking. As a matter of fact, in this book of teaching thinking, one finds no mention of imagery thinking in more than 400 pages. Some psychological monographs, though admitting the existence of imagery thinking, still try to play down the role of imagery thinking. For example Yang Yuhui,[4] in *Unravel the mystery of consciousness—working principles and mechanism of the brain*, points out "Imagery thinking can only be achieved by accepting and grabbing a variety of specific, special things here and now, which cannot be separated from particular things, or not beyond understanding of specific things now, not moving from the particular to the general, not generalizing from now to the past and future, nor can it go from here to there. In the end, the nature and law of things cannot be mastered". Imagery thinking is "just at the primary stage of conceptual thinking". This view, while recognizing imagery thinking, still considers it only as a primary stage of logical thinking, denying that imagery thinking is also one of the basic forms of human thinking. Therefore, this view can be placed in the first group of thinking classification.

The second group of thinking classification holds that basic form of human thinking is not abstract-logical thinking, but visual thinking. The representative who holds this view is professor Rudolf Arnheim from Harvard University, who is founder of international scholar of aesthetics and art psychology. He deems that the basic material of thinking is imagery, rather than what people often say the concept or language.[5] "Language is only an auxiliary to the main material (imagery), and a clear imagery can represent the relationship between objects better". He also believes that, "grasp the overall structural features of things is the basis for all primary cognitive activities and all kinds of perceptions".[6] The most important perception is visual perception, because visual perception is a clear media that can provide a wealth of information about things in the outside world. Visual perception can be "readily used by consciousness". Arnheim proved that, based on a large number of facts, visual perception itself has cognitive ability, comprehension ability and the ability of problem-solving, which has thinking function, and thus visual

[3]Wang (1992).
[4]Yang (1996).
[5]Arnheim (1969).
[6]Arnheim (1969).

perception is of not a lower level of thinking. On the contrary, it's one of the most basic forms of human thinking. On the basis of this understanding, Arnheim put forward the famous concept "visual thinking" for the first time, and used it as the title of the book written many years ago, studying human thought. From this view of thinking, he differs with the division of imagery thinking and abstract thinking; just as Mr. Teng Shouyao points out[7]: "In his view when people see an image (imagery perception and mental imagery), abstract activities begin; and when people think about a problem, there's a specific image as the starting point and foundation. According to common sense, thinking is thinking because it's proceeded through concepts of general nature; imagery is imagery, because it's concrete and specific. If this specific image comes into thinking, it will interfere with the general nature of concepts". As mentioned above, the basic material of thinking is imagery, in other words, people think on the basis of a specific image. Therefore, in Arnheim's opinion, such thinking is neither pure imagery, nor pure abstract, but visual thinking.

The third view holds that abstract-logical thinking and imagery thinking are basic forms of human thinking. However, before three years of age, children use mainly "intuitive action thinking" (or "action thinking"),[8,9] which is a more popular view among social psychologists and the lay population. This view is basically the same with the first view of abstract-logical thinking, though both maintain that thinking is "a process of using concept to judge and reason", while the abstract-logical thinking relies on action and imagery, the main materials of thinking is concept.[10] Abstract (logical) thinking subdivides into formal-logical thinking and dialectic-logical thinking: the former is deterministic in nature in contrast with the self-contradictory thinking process of dialectic-logical thinking; the latter is flexible and emphasizes the things of inherent contradictions. The two views are different, yet interrelated. Dialectic-logical thinking, gradually developed on the basis of formal-logical thinking, belongs to the advanced stage of abstract-logical thinking. These two are not in opposition to but complement to each other. About imagery thinking, the third view holds that the main material of thinking is representation or imagery, with two different stages, concrete imagery thinking and general imagery thinking.

The fourth point of view believes that in addition to imagery and logical thinking, the basic forms of human thinking should also include creative thinking.[11,12] The spokesperson of this view is Professor Qian Xuesen, a famous scientist in China. Here it should be noted that Professor Qian published articles in the early and mid 1980s, advocated the division of thinking into intuitive-imagery thinking,

[7]Teng (1987).
[8]Zhu and Lin (1991).
[9]Ye and Zhu (1992).
[10]Zhu and Lin (1991).
[11]Qian (1986).
[12]Yang (1997).

abstract-logical thinking and inspiration-insight thinking as three basic forms of human thinking.[13] Later after more study and discussion with an academician namely Dai Ruwei, his ideas developed. The original division was modified. In a letter to Professor Yang Chunding in June 28, 1995, Professor Qian pointed out that "the field of thinking focuses on the process and product of thinking, regardless of the process in the human brain, so I prefer imagery-intuitive and inspiration-insight thinking. The imagery and inspiration/insight are the same in thinking images in different brain states. In addition, creation needs imagery thinking and then verifies the results with logical argument. This is dialectical unity of the two types of thinking, a higher level of thinking. It should be named creative thinking. This is the flower of wisdom! So thinking should be summed up as logical thinking, imagery thinking and creative thinking. Social thinking and specific thinking, and so on which were mentioned above, belong to the three basic types of thinking, because they are just under different brain states.[14]

As can be seen from the introduction above, the first view is to stress and highlight abstract-logical thinking, the second is to stress and highlight visual thinking. Arnheim disagreed about the demarcation between imagery thinking and abstract thinking. He was not too willing to use the two terms as well. However, as long as we carefully read his masterpieces, it's not difficult to find that visual thinking actually refers to visual imagery as the main materials of thinking, so in essence the second view emphasizes and highlights the thinking in imagery. Arnheim, also, through the concept of visual thinking, greatly expanded the connotations of imagery thinking both in depth and breadth. The third view argues that "one cannot say which kind of thinking is good or not. Scientists, philosophers, writers, and engineers all need to have abstract thinking ability, but also need to have the ability of imagery thinking".[15] In other words, the third view avoids leaning toward either imagery thinking or abstract thinking. The fourth view is basically the same as the third view, adding creative thinking apart from imagery thinking and logical thinking. Creative thinking was put forward in the field of psychology years ago, and has been studied carefully. As early as in 1945, Wallas' proposed the famous "four-stage model" of creative thinking process; in 1960s, Guilford carefully analyzed, summarized creative thinking, and produced great influence. However, in the past, creative thinking has always been considered as a distinguished feature of scientists, inventors and artists alone, and most people are not qualified for possessing it. Therefore, in the past, creative thinking was mostly used as a special phenomenon to explore while studying the unique thinking process of gifted children in minority. In 60's and 70's, the United States conducted creative thinking experiments in a few schools, such as Myers and Torrance creativity gymnastics teaching procedures and Field Husen creative thinking teaching experiments, but these experiments are basically under the guidance of Guilford's

[13]Qian (1984).

[14]Yang (1997).

[15]Zhu and Lin (1991)".

theoretical framework and the so-called creative thinking experiments were closely the same as divergent thinking (this is the core idea of Guilford's theory). In fact, divergent thinking is only an element of creative thinking structure, which cannot reflect the profound connotation of the whole creative thinking process. At the end of 70's, more and more people began to notice this issue. Therefore, taking divergent thinking as the general form of thinking is a different kettle of fish from taking creative thinking as the common form of thinking for ordinary people. Making creative thinking come down the unattainable mysterious altar, believing that it is possible for more people to acquire, and making common people possess this thinking, which is a new idea appearing after the mid-80 s. Professor Qian made an indelible contribution as he played a big role in changing people's understanding of this issue.

2.2 New Thoughts on the Basic Forms of Human Thinking

Some major views on the basic forms of human thinking at home and abroad were briefly introduced above. Although some of views are obviously biased, such as the first and second, yet in general, these views have certain basis and rationality, and some even have great impact (such as the third), while others are quite innovative, such as the fourth. But as noted earlier, these views basically ignore a fundamental issue: they all failed to understand the division of basic forms of human thinking from philosophy or according to principles of epistemology (only the fourth view originally tried to explore basic forms of human thinking, but from many published articles one failed to see concrete exposition about it). They just consider the thinking processes or thinking contents from the specific psychology. Thus the conclusions may have some scientific and practical value, yet lack theoretical generalization efforts; as a result, its universal significance and practice guiding role will be greatly reduced; and reasonable explanations cannot be made for important thinking process and phenomenon. The theory faces an awkward situation.

Here we try to analyze the issues of basic forms of human thinking from epistemology of Marx's theory.

On thinking, philosophers and psychologists believe that the brain's unique function evolved over a long period of time[16,17] and they define it as "[thinking] made by humans to generalize and indirectly reflect physical world, the essence of things, and inherent relation among things".[18]

In order to survive and develop, humans must struggle with nature, and understand and master the basic characteristics of things in the physical world and basic laws of mutual relation among things. In order to cope with nature, further

[16]Zhu and Lin (1991).

[17]Ai (1978).

[18]Zhu and Lin (1991).

transform the physical world and to reach the expected purpose, human thinking becomes indispensable intellectual function. According to dialectical materialist view of philosophy, the physical world is matter; and matter is always in motion and change; movement is basic attributes of matter, and space and time is the moving material form; specific things are just matter of all different forms of nature and society.[19] Therefore, to comprehend and grapple essential rules of things in the physical world and their mutual relation, one only needs to study in-depth and analyze of the form and feature of different motion states of all things, namely the essential attributes. The movement of things, as Mao Zedong points out, has "two states—relatively static state and significant changing state". The relatively static state is also called "the state of being", and state of significant changing is usually "the state of motion". So we shall, in terms of nature of things, attend to the distinction between nature of two different states of motion; namely, the nature of current state (relative static state) and nature of motion state (marked by changes).

Since matter exists in space and time, it could be concluded that no matter in the universe moves out of space and time. The inseparability of matter from space and time is not only the view of dialectical materialism, but also scientifically proven by Einstein's special relativity and general relativity. So when we talk about the existence of a thing, first of all, we allocate where it exists, in what form, involving the form of the thing in space and time, as well as the spatial position of one thing in relation to other things, their structural features in combination or arrangement. This is what is referred to as "characteristics of spatial structure"; that is the current state of the thing (relatively the stationary motion state), the essential attributes and regularity of internal link of things. The motion of matters always shows as a process, and the process must have sequence and duration. Therefore, when we consider the movement of things and relation of things we can never leave out time factors; that is to say, we can never leave out sequence and duration. This is a feature of "temporal sequence", significantly changing state (commonly referred to as dynamic state), i.e., essential attributes and regularity of things in internal relations.

Karl Marx's epistemology believes that matter is primary, consciousness is secondary. Consciousness is the reflection of the human brain on the existence of physical world.[20] The core of Marx's epistemology is *Reflection Theory*. Thinking is the main content of consciousness, and, of course, is also secondary in nature. The definition of thinking above is based on Reflection Theory. Thinking is generalization and indirect reflection of human brain on laws of the physical world (the nature and inherent relations are the features of dynamic movement of things). Nothing in the universe exists out of time and space, so in order to effectively generalize and indirectly reflect things, thinking, as a secondary process, must be able to adapt to the needs of consciousness, which are primary in nature (the movement of things happens in time and space); that is to say, thinking must meet

[19]Li et al. (1995).

[20]Li et al. (1995).

requirements of things moving in space and time. According to the principle of Marx's epistemology, human thought should have at least two basic forms of reflection.

The first is the form that is able to effectively generalize and reflect spatial-structural features of things; i.e., the status of things (or relatively static state, the essential attributes of things and regularity of internal relations between things).

The second is the form that can effectively generalize and reflect the nature and regularity of internal relations, the time sequence of things (in state of motion, or significantly changing state).

The characteristics of spatial-temporal thinking should be analyzed next, but in order to better understand the problem in this area, we might as well first discuss how to realize the requirements in the definition of thinking proposed earlier, "to generalize and reflect on the nature of things and relation between things" and then necessarily reflect on the dominant positions of logical thinking.

2.3 Reflection on Dominant Forms of Human Thinking

2.3.1 Formal Structures of Logical Thinking

Dialectical materialism holds that[21] the essential attribute of things is the fundamental nature of things, which is determined by the special contradictions inherent in the thing itself. This special contradiction not only specifies the fundamental nature, but also determines the development of things.

Dialectical materialism also believes that[22] all things in the physical world do not exist in isolation, but mutually connected and interacted as a unity. Everything in the universe exists as an individual, but also interrelates to each other; everything is a link in the universal connection. Therefore, for the sake of understanding the nature of objective entity (the essence of things), it's necessary to appreciate particularity of things, apart from which it also be necessary to recognize mutual connections between them (i.e., the intrinsic law between things).

The view of dynamic nature and universal connection of things are the most fundamental and core of dialectical materialism. It's the cornerstone of Marx's philosophy. The reason why definition of thinking provides these two aspects: the nature of things (reflecting the movement and change of things) and internal relations (reflecting universal relations of the physical world), is just based on dialectical materialism of the fundamental viewpoint.

In order to generalize and indirectly reflect such two aspects of things: the nature of the things in dynamic motion and interrelations, language has been created (including oral form and written form) as the material of thinking (oral language

[21]Li et al. (1995).

[22]Li et al. (1995).

uses sounds as the material, written language uses graphic forms as its material). Based on these materials language gradually developed a system of concepts, judgment and inference, in order to generalize and indirectly reflect the world around us. The reason for "language indirectly reflecting the world" is that this reflection is done indirectly by using "concept", "judgment", and "reasoning", rather than directly on things (just like a camera that reflects). The reason for "language generalizing the word" is that this reflection is not a replication of all attributes of objective things, but the nature of movement of things, and abstraction of the internal links of things (abandoning non-essential attributes). We shall explain the function of concept, judgment and inference below.

The concept is a reflection of the nature of things, particularity of contradiction movement, which is based on analysis and synthesis of various attributes of things, and further, abstracted and generalized from things. It's the gradual understanding of particularity of contradiction movement of a variety of things that humans develop in long-term process of practice. The more extensive and thorough the understanding of things is, the richer and clearer the accumulation of concepts is. The concept is not only the summary of human understanding of the physical world, but also the material of human thinking or the object of human thinking. In thousands of years of civilization progress, mankind has established a huge concept system of different levels, from philosophy, natural sciences, social sciences, the specific subject to daily life, which laid the foundation for the human correctly reflecting the physical world.

Judgment of a certain (or certain type of) thing has a certain attribute, but also to make a decision on whether there's an internal connection between things. The judgment in thinking is made up of several concepts. In order to give details of classification and structure of judgment, it's necessary to know how things relate to each other. As is known, dialectical materialism stresses not only the movement of things and relation between things, but also emphasizes conditions, under which things move and relate; i.e., things always develop and decline under certain conditions; and properties, structures and features of links between things also change under different conditions. All develops in time, in place and under certain conditions. "Time" and "place" (space) is the forms that matters exist. They cannot be separated from motion; and conditions are the premise or external objects of movement, thus its importance equals with time and space. In short, change and link of all things is conditional; condition is absolute. In this sense, general relation theory of dialectical materialism can also be called *conditional theory*.[23] The condition is not only the premise or the external cause of change or movement of things, their mutual connection, but also the effect of the premise or external factors; namely, the results. This builds on our knowledge and informs us of condition-result relations (in most cases, shown as cause-effect relation) is the most common relation of physical world. Generally, mutual relation and interaction between things is condition-result relations in different situations.

[23]Li et al. (1995).

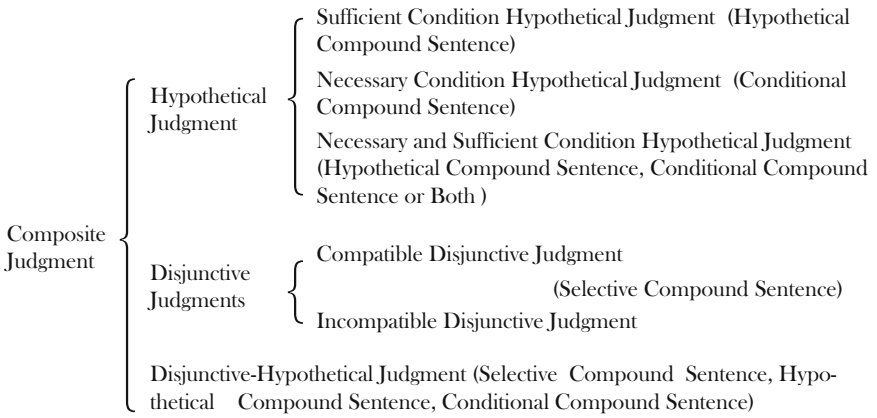

Fig. 2.1 Judgment system

The specific conditions of actual situation are complex and diverse, ever-changing, but according to condition types, one can divide them into three categories: sufficient conditions, necessary conditions, and necessary and sufficient conditions. Besides, conditions related to things can be single individual (singular) or a part of a class (specific), which can also be all of a kind (plural); and conditions corresponding to the same results can be one selected from a number of them. In order to reflect different condition—result situations, the study of logic establishes a set of "judgment system" as shown in Fig. 2.1.

Various hypothetical judgments are specifically designed to respond to different condition-result relations; disjunctive—hypothetical judgment is suitable for two or more alternatives. A variety of forms of complex sentences to achieve the corresponding judgment through language expression is given in the parentheses.

In addition to the above judgment reflecting the rules between interrelated things hypothetical and disjunctive judgments, direct judgment is used to determine whether something has certain properties. Because judgment is of positive and negative nature and can be single, special and universal, there are six types of direct judgment: referred to as single affirmative judgment and single negative judgment, special positive judgment, special negative judgment, universal affirmative judgment and universal negative judgment.

Reasoning is used to make a reflection of more complicated relations and interaction between things. The premise of reasoning can be direct judgment, hypothetical judgment, disjunctive judgments or disjunctive-hypothetical judgment. Therefore, according to the premise used, different reasoning can be classified as direct reasoning, hypothetical reasoning, disjunctive reasoning and disjunctive-hypothetical reasoning respectively.

From the above analysis, it's obvious that through establishment of language-based system of concepts, judgments and reasoning, it can meet the requirements of making generalization and indirectly reflection of the nature and rules of the internal

connection of things. As to how to define concepts, make judgment and reasoning, it's the area of general logic; it's usually called logical thinking, which is based on language, using concepts, making judgments, and reasoning.

2.3.2 *Limitations of Logical Thinking*

Language (either spoken or written) is the material of logical thinking. Its essence is to use linear-sequence of symbols (sound sequence or graphic sequence) to represent contents of thought (the relationship between things, and the essential attributes of things). Since it's a linear, symbolic sequence, there're issues of time, order and continuity. In other words, to use language-based symbols to conceptualize, to judge, and to reason, it can only be in accordance with the different word symbols in linear order, step by step, to carry out the task. For example, in hypothetical judgment of composite judgment, it normally contains several simple judgments. The conditional parts are called "front parts", while the results parts are called "after parts", in addition to the parts linking front and after parts, there are connectors. The judgment process must necessarily scan sequentially the three parts one after the other (one graph after another, or one sound segment after another), only in this way it may determine whether condition-result relation exists. Obviously, this judgment process should last for a long time, so efficiency is relatively low. The efficiency of reasoning process is lower—due to the involvement of major premise and minor premise and conclusion, and each part contains one or even several judgments. And thinking in accordance with such a step-by-step, sequential scan, time duration will be longer.

In addition to low efficiency, it's difficult to reflect dynamic events and visual scenes with the linear nature of language. Even in one of the simplest, direct judgments (i.e., declarative sentences), the influence of language can be clearly revealed. Susan Lange used a statement as an example, which vividly shows the problem[24]:

> A fact, if it's shown in the form of language, it's subjected to such a distortion, in which the dynamic relationships (or connections) became static relationships. Take 'A kills B' as an example. The scenario described in this statement does involve a sequence of activities between A and B. In the first place A appears, then there's a 'killing' behavior, after which B appears. In fact, A and B appear at the same time, and 'killing' behavior appears at the same time as well. However, due to the fact that language symbols are linear and disconnected in nature, as beads of pearls, they can only appear successively.

Arnheim[25] commented on this example, "A rational concept is shown by language in linear order, so what is described is often an intuitive grasp of the situation, and re-structuring of the scene. The statement, "The tree is laden with cherries", is an intuitive image coming from the speaker or the writer about an orchard scene,

[24]Lange, S (1960). *New interpretation of Philosophy*. Cambridge: Harvard University Press.
[25]Arnheim (1969).

which evoked the same imagery in the mind of the reader or listener. In the same way, 'A killed B' can evoke an imagery of a murder. In these cases, we see that language is actually a bridge between the speaker's imagery and the recipient's imagery. Because the medium itself is linear, it cannot but affect the representation of imagery. For example, 'a simultaneous interaction' cannot be directly described by words".

Lessing has a brilliant exposition of this issue in the monographs on poetry and painting. Lessing[26] pointed out that "painting, dealing mainly with shapes and color in space, can be used to describe the presence of objects of all kinds in space; or to describe each part of an object appearing at the same time space. As for 'activities', they're carried out in chronological order, it's only the object of the poem. Painting can indirectly describe 'activities' through description of human body. Poems can describe human body indirectly through description of 'activities'. If poems (including all languages) are not used to describe the 'activity', but rather to describe a visual scene, it can only be described by one of the various components of the scene. In this case, the recipient's mind is often not able to make the sequence of bits and pieces into a representation that is consistent with the original visual imagery".

Examples cited by Susan Lange and Lessing's comments show that when the description is a direct use of parts of the scene, the description of the spatial-visual scene will often fail to make the readers re-construct the author's representation. In other words, logical thinking under this situation is not complete and not true to the space-visual scene. Can this kind of situation be changed to make logical thinking reflect space-vision scene, as is the case with time sequence processing? The answer is affirmative. This is to use the usual method of writers—through a series of events (activities)—to describe the visual scene. That is to say, to some kind of vision, not simply to decompose it into a number of components, but on this basis to further transform the static scene into an activity scene. Because activities are developed according to time sequence, language, on such occasions, can play the role, present local relations between each event with rich details, and use linear features throughout the whole event. As a result, description of the visual scene is transformed into connected frames in a movie (discussion of a point of view, procedures follow similarly); a three-dimensional space of the visual scene, convert to a one-dimensional time axis expanding a series of activities in event sequence.

Obviously, such a conversion is indeed effective, because it really solves the problems proposed by Susan Langer and Lessing et al. Precisely because of this, many psychologists and philosophers overjoyed that logical thinking solved all the problems faced by the human mind, believing that only logical thinking can achieve rational knowledge, and it's advanced thinking, and imagery thinking can only stay in the perceptual stage of cognition, which is a lower form of thinking. What is more, some went so far as to say that only logical thinking, based on language armed with concepts, is the real human thinking, while the others, based on imagery thinking, are not considered as thinking. Those who strongly advocate "left brain

[26]Arnheim (1969).

prominence" theory are the representatives. At present, China's academia of philosophy, psychology, and even the whole society, is still dominated by this view.

We cannot agree with this view. We think that this is over-valuation of logical thinking. As you can see from the analysis above, real and complete realization of visual space scene through logical thinking is not unconditional, but through transforming three-dimensional space to one-dimensional time axis, at the expense of efficiency. It should be realized that such a price is heavy, especially in the requirements of overall grasp of features of spatial structure in a brief moment (such to act on an urgent need according to circumstances), or to make major decisions on the complex relationship between things as soon as possible (such as getting out of hardship or danger in urgent need). In such occasions, the linear order of logical thinking will become powerless. And the spatial structure of thinking, then based on another kind of imagery thinking can play an important role in such occasions, thus making up for the inefficiency of logical thinking. In the following sections, we will discuss this kind of thinking in detail.

2.4 Main Features of Spatial Thinking and Temporal Thinking

In the section "New thinking on human basic thinking classification", we inferred that the human mind shall at least have two forms of thinking, spatial and temporal, according to the dialectical materialistic epistemology of space and time. The former is used to generalize and reflect spatial-structural features, and the latter is a generalization of time sequence, characteristic of movement of things. Below we shall, first of all, analyze the main features of these two kinds of thinking.

Spatial thinking generalizes and indirectly reflects spatial-structural features of things (that is, the features of spatial location, and existential form and nature as well as the relations of things and association, combination or sequence of things in space). Obviously, this form of thinking is to grasp things as a whole in space, their existence, form, nature, and basic attributes in space (this is done mainly by various imagery, which reflect the attributes of things, especially spatial-visual imagery), and also to grasp the interrelation between things, their spatial location and structural relations (this is done mainly by the visual imagery which reflects the spatial-structural relation between things). Due to characteristics of the two (the basic attributes of things and the interrelation between things i.e., structural relation between things), which should be grasped through visual-spatial imagery (or we can say they should be grasped mainly through visual-spatial imagery), and visual-spatial imagery is integral and structural. The features of these two aspects are known for the characteristics of spatial structure. Reflecting the features of spatial structure is the most basic feature of spatial thinking. In order to emphasize this feature, we can also name this form of thinking as "spatial-structural thinking" or simply as "structural thinking". As a matter of fact, this "spatial-structural features" is not only the concrete embodiment of visual imagery, but also the direct

visual perspective of intrinsic links between things. People have such experience: if something is separated from its background (i.e., spatial structure), the intrinsic link between things changes, and the things will become completely different thing. For example, "legs" in the human body has walking function as an organic part of the body, but if the legs are separated from the body (legs amputated), they're no longer walking legs, but a bunch of very soon rotten muscle. To grasp spatial structure feature is not only to know the visual attributes of things, but also to make fast comprehensive judgment about rules of internal connections. This is to grasp the nature of the specific meaning of things in existence (relative static state of motion). We must clearly recognize this point.

Temporal thinking generalizes and indirectly reflects the basic attributes of "time sequence"; that is to say, the nature of motion state (or significantly changing state). Obviously, the basic features of this thinking is to grasp the essence of things, from one-dimensional linear time axis. Language based logical thinking is most suitable for this occasion, because logical thinking can conveniently use means of analysis, synthesis, abstraction and generalization, to extract "the concept" from various attributes. As mentioned above, on this basis one can process more complex judgments by using these concepts; through judgments relatively simple rules can be determined; for more complex interrelated rules, one can make inferences through judgments. It can be seen that logical thinking can deal with generalization and indirect reflection of the essence of things, and also can deal with the internal links between things. The materials logical thinking uses (i.e., the objects of processing) are concepts expressed by words of language; methods (means) of processing include analysis, synthesis, abstraction, generalization, judgment, reasoning, etc. It was pointed out earlier that logical thinking, based on sequential and linear sequence of language symbols, has advantages of being responsive to events on one-dimensional time axis. However, a visual scene on a three-dimensional space can be transformed into a series of events along one-dimensional time axis, so long as no time limit that requires to make instant decisions. The principles of logical thinking can satisfy the needs of all human thinking. That is to say, logical thinking is suitable for the occasions of temporal thinking, and also for the occasions of spatial thinking. According to the essence of logical thinking, since it's built on the basis of sequence of language symbols with one-dimensional and linear features, it is the most suitable reflection of a sequential, continuous variation process of movement. Then, obviously logical thinking is more suitable for temporal thinking. However, we disagree with the view held by the majority in the current academic community that names it "abstract thinking" or "abstract-logical thinking", or even briefly "abstract thinking". We believe that it should be scientifically called "temporal-logical thinking" or "linear-logical thinking", which might be briefly referred to as "logical thinking". The reasons for the naming are as follows.

First, abstraction and generality are the characteristics of all thinking, not only with logical thinking. If logical thinking prefixed with a descriptor abstract, or simply known as abstract thinking, it's easy to make people mistakenly believe that only this thinking is abstract, which inappropriately raise logical thinking to a more

abstract level while belittle the other forms of thinking. And this is precisely a major ailing in the current academic community (especially in the philosophical and psychological academic community).

Second, logical thinking is based on sequence of language symbols, as indicated earlier, it's linear and sequential; therefore, it's the most suitable way to reflect the variation process of movement in which things unfolded in one-dimensional linear time axis. As a result of the analysis, the thinking is most reasonable, most logical to be named linear logical thinking or temporal logical thinking.

Finally, we can draw a conclusion from the analysis above regarding the definition of thinking. Human thinking is generalization and indirect reflection of the essential attributes and interrelations between things. This is achievable through spatial-structural thinking and logical thinking; these are two basic forms of thinking.

Spatial-structural thinking mainly reflects things' existence in space and the spatial-structural features, such as their forms and nature, their combination or arrangement, as well as the order and relation with other things in spatial positions. And mainly through this visual-spatial imagery to achieving the grasp of spatial-structural features; that is, achieving the grasp of essential attributes of things as well as the regularity of intrinsic links between things in a relatively static state (state of things).

Temporal-logical thinking (linear-logical thinking) mainly reflects essential attributes of motion of things (significantly changing of the state of things), and through the use of words to express concepts as well as to grasp essential attributes of things. Under the circumstance of no time constraints temporal-logical thinking can also respond to regularity of intrinsic links between things, mainly through components of concepts of judgment and inference to achieve this purpose.

It's true that two forms of thinking have their specific features from their respective distinct states (significantly changing state of motion and relative stationary state of existence), reflecting on things and the essence of the things, in their regularity of internal links. The two forms of thinking are indispensable, either of which cannot replace the other. They're equally important, and complementary to each other. Due to the fact that we know quite well about temporal-logical thinking, in the following section, we only take spatial-structural thinking for further analysis.

2.5 Processing Objects and Processing Methods of Spatial-Structural Thinking

2.5.1 Processing Objects of Spatial-Structural Thinking—Imagery

The object of thinking (thinking materials) has an important impact on the process and methods of thinking. Spatial-structural thinking material is mainly imagery. The translation of the term *imagery* (or *images*) in psychology in China, usually

uses the two renditions imagery or representation (表象/imagery 意象). Most psychologists believe that these two are just different in translation; their basic meanings are the same. However, there are a few scholars who believe that 表象 and 意象 have different meanings.[27] Yet, we do not distinguish between these two words and follow the popular translation, that is imagery (表象), in this book.

The so-called imagery (表象) is a reflection of things' images that have been perceived before (but not present to the sense organs at the present time), only a representation traces left in the past.[28] Things in the physical world act on human sense organs are sensations; perceptions are organization and interpretation of sensory information. They are produced on the basis of sensation, but different from sensation. This is because the formation of perception depends not only on the current sensory information, but also on human beings' knowledge and experience of the past. While sensations can only reflect individual attributes of things, perceptions can reflect various attributes of things; that is, the entirety of things. Having a common characteristic of intuitiveness, sensation, perception and unprocessed imagery are the visual reflection of things in the brain, parts of perceptual knowledge category as well as three different forms of perceptual knowledge from levels of low to high.

In addition to the common features above, imagery and perception are different from each other in the following ways.[29]

2.5.1.1 Imagery Can Exist Separately from Specific Things

Imagery is the trace left by the perception in the past; that is, the concrete imagery of things that are kept in the minds of the people. Unprocessed imagery belongs to perceptual knowledge, but a big step forward than perception; unprocessed imagery can exist apart from specific things (and without sensory stimulation from specific things is no longer called sense perception), and may process imagery in the mind directly from specific things, and enable imagery to become more and more accurate and stable.

2.5.1.2 Imagery Has the Feature of Generality

Imagery is not only intuitive, but also has a certain degree of generality. It's due to the fact that imagery can reflect things intuitively with generality; therefore, by gradually processing an image (analysis, synthesis, abstraction and generalization, association and imagination etc.), it's possible to grasp the essence of things, so as to enable us to come to overall understanding of the nature of things from

[27]Yang (1997).

[28]Zhu and Lin (1991).

[29]Zhu and Lin (1991).

superficial local understanding; or under the regulation and control of words in language, and enable us to develop an understanding based mainly from perceptual knowledge to conceptual knowledge of cognition by means of concepts.

Imagery can be divided into many types, such as visual imagery, auditory imagery, tactile imagery, and gustatory imagery, etc. In the process of spatial-structural thinking, it's often not one kind of imagery, but a variety of imagery that occurs, i.e., spatial-visual imagery. In other words, spatial-visual imagery is the main material for spatial-structural thinking. This is because:

First, the brain gets information from the world mainly through the visual sense. The American experimental psychologist Treicher showed human brain obtained 83% information from the visual sense, 11% from the sense of hearing, and less than 6% from all other sensory channels, including tactile, kinesthetic, olfactory, and gustatory channels.

Second, the overall and intuitive nature of visual imagery is conducive to spatial-structural thinking. Visual imagery presents overall, intuitive, spatial scenes for people to make an overall grasp of the spatial-structural characteristics of things, through intuitive perspective, spatial integration and comprehensive judgment, which is needed for spatial thinking. Other types of imagery (for example: auditory imagery and tactile imagery) can hardly do this.

Third, the structural and integrated nature of visual imagery is conducive to storage, recall and processing of thinking. Although sometimes visual imagery is fuzzy or not clear, yet always remain unbroken, and there's a certain structure. Even fragments of imagery reflect the local structure of things. This is easy to encode memory, which is conducive to the storage, recall and processing of thinking.

Due to the three reasons above, visual imagery is most conducive to the realization of the goal of spatial-structural thinking, so it's worthy to become the main material for this form of thinking.

As described in the beginning of Sect. 2.4, the spatial-visual imagery used in spatial thinking is of two types: one type reflects the attributes of things (referred to as "attribute imagery" or "object imagery"), the other reflects the structural relations between things (referred to as "relation imagery" or "spatial imagery"). According to the differences of the two types of imagery, spatial-structural thinking can be further divided into two categories: one class uses "attribute imagery" as the material of thinking (i.e., object of thinking processing), called for "imagery thinking"; the other uses "relation imagery" as the material of thinking, known as "intuitive thinking". In other words, the basic form of human thinking (or basic types) can be divided into three categories, namely, imagery thinking, intuitive thinking, and temporal-logical thinking.

2.5.2 Processing Methods of Spatial-Structural Thinking

The processing methods, according to whether the material of thinking (i.e., object of thinking processing) is attribute imagery or relation imagery, will be different.

This chapter will first introduce the processing methods which use attribute imagery as material of thinking (i.e., the processing methods of imagery thinking). As for the processing methods which use relation imagery as material of thinking, it will be discussed, together with intuitive thinking, in Sect. 2.1, Chap. 6.

The processing methods, which use attribute imagery as material of thinking, usually include analysis, synthesis, abstraction, generalization, comparison, classification and imagination, each of which uses imagery as the object of mental operation.

Analysis is a mental operation that breaks down complete imagery into a number of components (each component is also an independent imagery). For example, rabbit imagery can be decomposed into the imagery of rabbit's eyes, ears, mouth, fur, claws, tail or other parts, which is imagery analysis.

Synthesis is the process of mental operation that combines the same kind of imagery to make it complete and more accurate. For example, the imagery of a rabbit's produced from the combination of a rabbit in static or dynamic states and in a variety of different situations.

Abstract refers to the mental operation that draws out attributes of the same things with the same nature, and discards the non-essential attributes. This is a huge misunderstanding since it was traditionally believed that logical thinking can achieve abstraction only through language presentation. A typical manifestation of this mistake is to call logical thinking as abstract (logical) thinking (the implication is that only logical thinking can abstract). Arnheim strongly criticized this by pointing out that[30] the use of imagery can achieve various levels of abstraction, and also may sometimes reach the level of abstraction where other general concepts cannot reach. Arnheim cited several examples[31]:

- When the baby, tells apart an object (such as identifying a bottle), from numerous objects in the complex external world, it's an initial abstraction. The baby has caught the essence of the things using visual imagery, otherwise it would be impossible.
- When being able to extract a simplified form that represents an object in the physical world from the external stimulus, the abstraction (using imagery to abstract) of the representation reaches a relatively high level; for example, recognizing a reverent attendant with a bowing imagery, aside from other specific characteristics, such as the figure, face, and clothing.
- A clock exhibits at the Nagasaki Museum in Japan is a case with a particular and abstract meaning difficult to express with concepts of language. An ordinary clock with a high degree of abstract meaning cannot be a manifestation of its master or the character of its master. The damaged clock at Nagasaki Museum stops at two past eleven; its abstract meaning is shocking. Since time freezes at this moment, people immediately recall the atomic bomb explosion of the terrible moment and the tragic scene, so as to inspire people to maintain a strong

[30]Arnheim (1969).

[31]Arnheim (1969).

sense of peace and to oppose war. This is the essence of the problem as well as the significance of atomic bombing which is what and also the museum wanted to show to the masses, and the clock will become the representative of the "abstract thing". Obviously, on this particular occasion, the abstract meaning and social effect generated by the clock is unable to be surpassed by long winded speech concept.

Summary is a kind of mental operation that generalize from things with the same essential attributes. Currently influential psychology textbooks in China[32] stated that summary "has two forms: one is comparison between different things, according to the external characteristics of things, abandoning features different from each other and generalizing from their common features. This is the primary stage of generalization, perception and imagery. The second form of summary is generalization of an object and a phenomenon, or a series of objects and phenomena to be summarized, according to the essence of things. This is generalization of the thinking level, an advanced form of generalization".

According to this view, spatial-structural thinking with imagery as object of mental processing can only achieve the primary form of summary, only logical thinking can realize the advanced form of summary. This really is a misunderstanding. We would like to ask that in the ever-changing battlefield, where every complex situation that the enemy and us are facing, by what means does a brilliant commander can make a decisive decision in the moment. Never a step-by-step logical reasoning is followed. Only a dull commander mainly relies on logical thinking to command the war. With overall war situations, a commander must use spatial-structural thinking, which can help to judge the situation from the big picture, grasp the situation of both sides, and have a global picture in mind. In so doing, a commander will not be confused by local, specific facts or the surface features of a phenomenon. Here "having a global picture in mind" refers to the grasp of features of spatial structure of the war situation as a whole; namely, the state of both sides in a war, related factors, mutual antagonism, interaction (such as the troops deployment, collaboration with neighboring troops, ammunition supply, rear support, combat morale of both sides and other elements of mutual confrontation situation). Is it not a reflection of the nature of things with spatial-structural features, such as spatial imagery (attribute imagery and relation imagery)? How do you think that generalizations based on imagery are either inferior or second-rate?

Arnheim[33] refuted the argument cited above using imagery as a high level summary, which is very convincing. This case in point describes an imagery of mathematical theory of cone cutting as the key role of the theory. Arnheim pointed out that[34] in the process of establishing the "cone cutting theory", Kepler and others found some common properties in the images of circle, ellipse and hyperbolic. These three kinds of basic geometric patterns have existed since ancient times, but

[32]Ye and Zhu (1992).

[33]Arnheim (1969).

[34]Arnheim (1969).

they're not related to each other. Through cone cutting with formation of new imagery, Kepler et al. found that common characteristics exist between circle, ellipse and hyperbola—as a result of cone cutting, with the difference only lies in different ways of cutting. So three originally uncorrelated geometric elements are now closely linked together by cone cutting theory, forming a certain spatial-structural geometric system. Generalization of this higher level theory does not rely on words and concepts as basic logic, but totally dependent on imagery to generalize—the three basic geometric figures as the original imagery through cone cutting forming a new image and discovering common attributes of the geometric figures, extending to all the three kinds of figures. How can it be said that this imagery of important theoretical findings is inferior or second-rate?

Of course, it cannot be denied that any theory of innovation is not separable from logical thinking, and it's equally important that any theoretical innovation cannot be separated from spatial-structural thinking. On this issue we will make an exhaustive demonstration in Sect. 2.1, Chap. 6 "six elements structure of creative thinking model".

As mentioned above, in the process of abstraction and generalization, essential attributes of things are involved. Spatial-structural thinking reflects only essential attributes in things in their existential states (namely the essential features of relative static state), though essential attributes can be individually reflected through temporal-logical thinking, it's more effective to grasp the attributes through spatial structure, or by blending spatial-structural thinking and temporal-logical thinking. We must learn this by heart.

Imagination is the mental processing of original multiple images through adjustment, integration and reconstruction. Through imagination, all participating images in integration are more or less changed from the original components (and in the process of synthesis and analysis, the components of the original imagery does not change) and form a new image, "imagination imagery". Goddess on the moon and other typical characters of novels are examples of the integration of new imagery; that is, imagery of imagination. Due to imagination, the original imagery is transformed from a variety of images, and there's a certain novelty and even creativity in the new imagery. According to different degrees of novelty, it can be further divided into two kinds: *reconstruction imagination* and *creative imagination*. Reconstruction imagination is a new imagery of what others described and you did not experience before (such as dinosaur in the ancient times); creative imagination is from no ready-made basis, not described by anyone and is independently created imagery. Obviously, reconstruction imagination and creative imagination are of special significance to planning of writing, artistic creation, theoretical construction and other creative activities.

To accomplish imagination, the following conditions are necessary.

1. *There should be a wealth of images reserves.*

Imagery is the basic material for imagination. The fuller the imagery, the richer contents imagination will have. As imagery is obtained through perception, it calls for more observation and accumulation.

2. *One should be good at association.*

According to Aristotle's law of association, we can form association from three aspects: ***similar association***, such as similar shapes; ***reverse association*** (contrast association) to think from things contrary in nature or from the appearance with stark contrast; ***associative association***, such as things that are not similar, though not opposite, in nature, function or shape but logically connected in some way.

It has been seen that association is easier if things are similar in nature, in function, in shape or in logic. According to association of the three aspects, more images will bring more benefit to imagery integration and reconstruction (because integration and reconstruction are always in accordance with the things between certain connection and structure), and imagination.

3. *Regulation and control of the second signal system are needed.*

According to Pavlov's theory, imagination (especially creative imagination) is the result of cooperative activities of two kinds of signal systems. Usually the first signal system refers to the external stimulus received directly from sensory organs. Language is the second signal system. This kind of mental processing activity uses imagery as the material for processing, so it should be the main function of the first signal system. But in order to expand and deepen contents of imagination, concepts and language of the second signal system should be used, and the regulation and control of language cannot be divided. Even association is inseparable from language concepts. For example, to achieve similar and reverse association, we often have to know which attributes are similar, or opposite; to get hold of association, we need to know whether or not there's a logical connection between things. These are inseparable from the guidance and control of language concepts. As for the formation of creative imagination, due to the novelty of its contents, innovation has a higher requirement. The two signal systems are necessary to cooperate. On this issue, we will also make further discussion in Sect. 2.5, Chap. 3 "the thinking process and features of artistic creative thinking".

We have introduced spatial thinking in five main psychological operations (analysis, synthesis, abstraction, generalization, imagination). In addition, there are other operational methods, such as comparison and classification. Since they're relatively simple, we will not specify them here.

2.6 Comparison of Spatial-Structural Thinking and Animal Thinking

Since spatial-structural thinking materials (object of thinking) are mainly images; and images are intuitive, people tend to confuse it with animal thinking. We believe that the confusion must be clarified.

As mentioned before, human thinking is a special function obtained through evolution of millions of years in the process of great effort with nature, in order to

seek survival and development. The basic purpose of thinking is to solve all problems faced by human beings. In other words, thinking is always linked with problem-solving, and even many psychologists believe that thinking is problem-solving. The premise of problem-solving is to be able to make correct judgment of things, to discriminate things, to determine the nature of things, to make decisions under the situation encountered, and so on. Different situations require judgment of different forms. Therefore, the ability to make a correct judgment has become problem-solving ability; that is the main symbol of thinking ability. From this view, many psychologists believe that animals are similar to humans in terms of thinking, and they cited numerous examples. For example, animals generally have the ability to avoid disadvantages, quickly find their food, and judge whether they're in time to escape from danger (such as a mouse sees a cat). The closer the genetic relationship between humans and animals is,, the more powerful the ability is. Calvin William[35] pointed out that, average dogs cannot untie the belt tied to a pole, but a chimpanzee may be able to do so. In a cage locked by a dog belt, monkeys can be locked safe inside since they cannot reach the buckle and unlock it. However, a chimpanzee may be able to open it. So for chimpanzees, a real lock will have to replace the dog buckle, and you should never leave the key in the cage.

All examples above prove that many animals (especially primates) have certain abilities to solve problems; that is, having ability to think. However, we believe that this kind of animal thinking is too different from human spatial-structural thinking on a fundamental level. Animal thinking is based entirely on the basis of direct perception and the use of the specific imagery for thinking (materials of thinking). Once things present disappear, the perception of imagery no longer exists, thinking disrupts. While spatial-structural thinking of humans not only relies on specific imagery of current perception of things as thinking materials, but can also use imagination (mainly imagination). As mentioned above, imagination comes out of perception, but it can exist independently from current specific things and undergo further processing (such as analysis, synthesis, abstraction, generalization and imagination). It's impossible to do this type of processing, using only specific shape of the current perception as thinking materials. We can prove this, using chimpanzees as an example, which are primate, closest to humans with the most advanced thinking skills.

Famous psychologist Kohler once conducted a large number of experiments[36] for 4 years about animal thinking on the Tenerife islands with chimpanzees. During the experiment, he put a banana or other food on top of an iron cage, and then gave the chimpanzee a certain condition, and made it use the condition to get the food. Such conditions could be a long bamboo pole, or a few segments that could be connected to the short bamboo pole but also piled up in order to climb up the box. After a period of exploration, trial and error, and thinking, the chimpanzees

[35]Calvin (1996).

[36]Bigge (1982).

eventually learned to use a long bamboo pole, or a few short bamboo rods connected, or a few boxes on top of each other for climbing to obtain the food hanging on top of the cage.

The experiment proved that chimpanzees have the ability to think by using simple tools to solve a problem (some people think this does not belong to logical thinking, and they simply deny or not recognize this as ability to think. We believe that this is not a materialistic attitude). However, Kohler was confused that he failed to make the chimps learn to break down a twig on the tree and use it to reach the food.[37] Kohler did not find the answer. Half a century later, many psychologists are still unable to make a convincing explanation of this phenomenon. In fact, the reason is not complicated—Chimpanzees use direct perception of specific things as their thinking material, rather than imagery. In chimpanzees' perception, the branches and the trunk are connected as a whole. Without using imagination in thinking, a chimp will never decompose the image of "tree" in its brain (the image of the branches decomposing from a tree); while, humans do not rely on the current specific perceptual objects as the object for thinking. Therefore, humans can easily do it (it can be done only by a simple mental operation of "imagery analysis"). This is the fundamental difference between human's spatial-structural and animal thinking. For a long time, psychologists at home and abroad have debated fiercely for many times about whether animals have thinking, and what differentiates animal thinking from human thinking. Various volumes appeared and some of them were plausible (e.g., some argue that squirrels store nuts in winter, so that animals have advanced planning, which is superior to human thinking[38]). Tracing the reasons for the arguments, it's found that most arguments focus on the fact, the phenomenon, and the behavior, yet fail to tightly grasp the essence of thinking materials. Therefore, it's hardly possible to understand the similarities and differences between animal thinking and human thinking.

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[37]Arnheim (1969).

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Chapter 3
Past and Present of Creative Thinking Research

3.1 Development of Creative Thinking Research

3.1.1 Wallas' Four-stage Model

The international research on creativity can be traced back to more than one hundred years ago. It is generally believed that *Hereditary Genius*, published by the British physiologist Golden in 1869 was the earliest scientific and systematic documents on creativity research.[1] But creative thinking, which is the core of creative mind, has been systematically studied in a scientific way, much later than that. We believe that the real mark of research in this field is the American psychologist Joseph Wallas, who published the book *The art of thinking* in 1945. In this book, Wallas, for the first time, concerned with psychological processes of creative thinking. On this basis, he proposed a four-stage model of creative thinking, including preparation, inoculation, assurance and verification, which still have a great impact on the world today.

Since then, the study of creative thinking has caused attention in the field of psychology, especially in 1950, Guilford delivered a famous speech entitled *Creativity* at the APA annual meeting; research in this field became more flourishing. A review of more than half a century research on creative thinking, though pages after pages of papers and volumes after volumes of books came out, those really left a deep impression, and had great theoretical and practical value are few. In addition to the groundbreaking research of Wallas, the other prominent achievements are presented in the following.

[1]Dong (1993).

K. He, *A Theory of Creative Thinking*, Lecture Notes in Educational Technology, DOI 10.1007/978-981-10-5053-4_3

3.1.2 Werthermer's Structural Model[2]

In 1945, Germany psychologist Werthermer published a monograph entitled Creative thinking, which explicitly proposed the concept of creative thinking. The main achievement of this book is to analyze the creative thinking process using Gestalt theory of psychology. In the book, a simple mathematics class and the genius of Einstein has been carefully analyzed psychologically. Werthermer thought the process of creative thinking was not a step-by-step formal logic operation, nor blind connection of associationism, but a Gestalt "structure". And he further pointed out that the Gestalt structure was not from mechanical exercises neither, which could not be attributed to a repeat of the past experience, but through insight. These ideas are valuable and worth learning.

3.1.3 Guilford's Divergent Thinking[3]

In 1967, the American psychologist J.P. Guilford, on the basis of a detailed analysis of factors of creativity, put forward a model of intelligence: a 3-dimensional structure. Guilford believed that the factors of human intelligence were composed of three dimensions. The first dimension were intelligence contents, including graphics, symbols, semantics and behavior; the second dimension were intelligence operations, including cognitive, memory, divergent thinking, convergent thinking and evaluation; the third dimension were intelligence products, including unit, classification, relation, system, transformation and implication. So, by four kinds of content and five kinds of operation and six kinds of product combined come $4 \times 5 \times 6 = 120$ kinds of independent intellectual factors (later in 1971 and 1988 Guilford revised the model twice, supplemented and modified, and thus eventually the 3-dimensional structure of 180 factors).

Guilford believed that the core of creative thinking in the 3-dimensional structure model is the second dimension of divergent thinking. Then he and his assistants (Torrance et al.) made a profound analysis of divergent thinking; as a result, they put forward four main characteristics of divergent thinking:

Fluency: the number of ideas and ideas that can be expressed continuously in a short time;

Flexibility: thinking flexibly from different angles and different directions;

Originality: solving problems with new ideas and new approaches;

Elaboration: imagining and describing specific details of things or events.

Guilford believed that these were the main features of creative thinking, and worked out a set of specific methods of measuring these characteristics. Then they

[2]Dong (1993).

[3]Bai (1997).

put this theory to educational practice, developing divergent thinking around the index (according to Guilford's theory, this is also cultivating creative thinking), developing the training of divergent thinking into teaching programs. Although to equate creative thinking with divergent thinking is simplistic, for the research and application of creative thinking, after all, it played an immense role in promoting creative thinking. Guilford and Torrance's contribution should not be overlooked.

3.1.4 Liu Kuilin's Unconscious Inference

In 1986, a Chinese extraordinary researcher on thinking science, Liu published a significant paper *New exploration of inspiration.*[4] He explored the nature, characteristics and induction of inspiration, and tried to make more precise argument based on scientific achievements, especially on the achievements in brain science, psychology and modern physics in the mechanism of inspiration in the 1980s. It is worth noting that this paper proposed a theory labeled "unconscious inference", and used this theory to establish Inspiration Generation Model. Because Liu believed that inspirational thinking "occupies an important position in the process of creative thinking",[5] we can also suggest that Liu's "Inspiration Generation Model" as a creative thinking model. Because the model is based on the theory of subconscious inference, it can also be identified as a creative thinking model based on subconscious inference. In the work of domestic and foreign relevant literature, it is a model which is relatively complete and theoretically deep by far. In particular, the author tried to clarify the process of creative thinking based on brain science and modern physics, which is unprecedented. Although this model still has obvious deficiencies, compared with the previous model, it broke away from the limit of traditional practice of studying creative thinking in domain of psychology and gave the field of theory a refreshing feeling.

3.1.5 Sternberg's Theory of Intelligence[6]

In 1988, Yale University Professor Sternberg used implicit theories for analysis of creativity, and proposed 3D model of creativity on the basis of creativity study, which had a great impact on the world. The first dimension of the model refers to intelligence-related creativity (intelligence dimension); the second dimension refers to cognitive style (style dimension); the third refers to personality (personality

[4]Liu (1986).
[5]Liu (1986).
[6]Lin (1996).

dimension). In the first dimension, intelligence was divided into three types: internal type of intelligence, experience-related intelligence and external type of intelligence.

Internal-related intelligence is the intelligence which is related to the mental processes of the individual. It was composed of three components:

Meta component serves the role of planning, monitoring and evaluating in the creative problem-solving process. Meta component has certain functions of finding and identifying problems, defining problems, forming problem-solving strategies, selecting the problem-solving mental representation and organization, monitoring, giving feedback as well as commenting on the problem-solving process, etc.

Executive component executes the process of problem-solving set by meta-components, including coding, inference, schema, application, comparison, judgment, reaction, and so on.

Acquisition component is the main component of insight in creative thinking. It contains selective coding, selective binding and selective matching.

Experience-related intelligence is the intelligence which is connected with the existing knowledge experience.

External-related intelligence refers to the ability to relate to the external environment, including the ability to adapt, transform, and select the environment.

From the introduction above, it is not difficult to see that Sternberg, in the 3D-model of creativity, discussed intelligence dimension and was actually closely related to creative thinking because it involved both mental process of creative thinking (executive component), and the creative core elements—insight—(acquisition elements), and dealt with creative problem-solving in the process of planning, monitoring and evaluation (meta-components). So we can also consider Stenberg's theory of 3-dimensional model of creativity as a creative thinking model.

3.1.6 Robin's Model of High-level Thinking

In 1995, Nina Robin, Department of psychology, University of California, who published an article entitled *Relational Complexity and the Functions of Prefrontal Cortex.*[7] This paper, based on the premise that prefrontal cortex was the basis of control of higher-level human thinking, tried to explore the link between the most advanced thinking model and the neural mechanism of human brain. Robin, who believed that human thinking, reflected the nature of things and relations between things; In fact, it could be considered as a reflection of relations between things. According to mathematical logic and representation of predicate logic, the essential attribute of things can be regarded as one of the simplest relations: unary relation. The relations of one predicate and the other can be regarded as the *n-nary relation*. *N* is the dimension of relations, the greater the *n*, the more complex the relation is.

[7]Robin and Holyoak (1995).

In other words, *n* can be used as an indicator to describe complexity of relations. On this basis, Robin et al. proposed a theoretical framework for determining the complexity of relationship. And according to the achievements of contemporary neuroscience: new understanding of prefrontal cortex structure and function; different levels of complexity of relational complexity of processing linking prefrontal cortex in different parts of the control function, our understanding of human higher mental processes, was not only established on the basis of psychology, but went deep into the neural mechanisms of brain. So it has a more scientific and more solid foundation. Robin et al. did not, in the paper, use the term of creative thinking, instead, used "higher-level thinking", "the most unique form of thinking" or "high level cognition" and other similar concepts. From this thesis, the author tried to deal with the relationship between the highest complexity, with emphasis on higher-level and the most unique. The term author used as "the higher-level thinking" may very well mean "creative thinking". However, in respect of the real meaning thesis on the higher-level thinking, Robin et al. proposed a theoretical framework of relational complexity; essentially it was constructed on brain science and on the basis of logical thinking. Although it is not a model of creative thinking, it is enlightening to the establishment of the real creative thinking model.

Through the review of research literature on creative thinking, it is not difficult to see that so far in the field of creative thinking research, the results can basically be divided into two categories: one is based on the traditional psychological theory/model (only with theory of psychology to study the active process of creative thinking), such as theory/model of Wallas, Werthermer, Guilford and Stenberg et al.; the other category is the theory/model based on Neuroscience (not only with the use of theory of psychology, but also with the use of brain science and other modern scientific achievements in creative thinking), such as the models of Liu and Robin et al.

3.2 Evaluation of Several Typical Creative Thinking Models

In Sect. 3.1 we briefly introduced the results of contemporary influential creative thinking research. Each of these achievements has their own distinctiveness, and they have made a contribution, from different aspects, to theoretical and practical exploration of creative thinking. But considered from the aspects of theoretical innovation and the role of profound and practical guidance, we believe that Wallas, Liu and Robin's models seem to be more valuable for the future researchers. This is because that Guilford's research on divergent thinking involved only a factor of creative thinking; which is too narrow; Werthermer's structural model, though rational, did not make concrete analysis of the process of creative thinking, so lack of operability to cultivate creative thinking for practical guidance, thus with little significance; Sternberg's intellectual dimension, though gave out psychological

processes of creative thinking (including coding, inference, icons, application, comparison, judgment, reaction steps), did not to clarify why these psychological operations must include from view of theory? What is the necessary connection between these operations? So it is not yet convincing, and not easy to guide practice. Below we will further analyze Wallas' and other three scholars' theoretical models.

3.2.1 Wallas' Four Stage Model[8]

Wallas believed that any creative activity should include, at least four stages, i.e., preparation, inoculation, assurance and verification. Each stage has its own operational contents and objectives.

1. Preparation stage: be familiar with the problem to be solved, to understand the characteristics of the problem. To collect and analyze relevant data, and on the basis of data, we should solve the problem step by step.
2. Inoculation stage: the creative activities must face the problem of failure to be solved by the preceding people. Try to solve it by using traditional methods or experience will be difficult to work, and the thinker had to temporarily put aside the problems which need to be solved. On the surface, the thinker no longer consciously thinks about it and turns to other aspects; but is actually using the right brain to unconsciously think about the problem. This is the gestation period of problem-solving, also called the subconscious processing stage. This period of time may be shorter, but also may last for many years.
3. Assurance stage: after a long time inoculation, the thinker became gradually clear about the problem to be solved, so some random factors or an event suddenly become clear; as a result, all of a sudden, he/she found the solution to the problem. Because this solution comes often suddenly, it is commonly known as inspiration. In fact, inspiration/insight is not a momentary whim, or incidental acquisition, but a result of careful preparation and long-term pregnancy in the first two stages.
4. Validation stage: solutions obtained by inspiration/insight may also be wrong, or not feasible, so it will be tested by logical analysis and validation for its correctness and feasibility.

The principal characteristic of Wallas' four-stage model is subconscious thinking (preparation and verification stage) and the integration, rather than one-sided emphasis on unconscious thinking (brooding and assurance stage). This is the key to occurrence of creative thinking, and it is also the reason why the model still has enormous impact.

[8]Blakeslee (1980).

It should be noted that Wallas back then originally created, for general creative activities, a four-stage model, but due to the first and fourth stages mainly involved logical thinking (conscious thinking) process; the second and the third stages involved intuition, creative imagination and insight thinking (subconscious thinking), and the relations and interaction among the four stages, so in essence it dealt with the process of creative thinking. We think it is appropriate to consider the four-stage model as the earliest creative thinking model.

3.2.2 *Liu Kuilin's Model Based on Unconscious Inference*[9]

Liu's creative thinking model was based on the theory of subconscious inference, which needs to be understood first. The 19th century German physicist and physiologist H. Helmholtz, when coming to consciousness, often used the term unconscious inference.[10] Liu borrowed the term (generally "unconscious" and "subconscious" are considered synonymous), but with a new meaning.

Liu believes that the so-called unconscious inference is a kind of special inference that has not been consciously realized. It is the process of development of interaction and mutual restriction between isomorphistic information and the functional structure of the brain. Here the isomorphistic information (information co-structure) refers to an integration process between the perception of information about objective things (hereinafter referred to as "perceptual information" or "input information") and the original experience information stored in the brain (hereinafter referred to as "experience information").

Here the "construction of functional structure of brain nervous system" refers to the role of information of objective things acting on the individual senses, so as to generate a perception, that is, different degree of electric current, stimulating brain cells of large molecules, which causes changes in electric potential and chemical change, and causes changes in the structural function of the nervous system. So one of the molecules of brain cell produces a temporary or fixed connection with a certain type of information, and became a carrier of information and a signal to be determined. This completes the construction of the function structure of a brain cell.

In the process of information co-construction, through the integration of identifying, matching and mapping between the current perceptual information and the original experience information, the functional structure of the brain cell is drove to constantly change. This is the neural basis of the subconscious inference.

Conscious reasoning and subconscious inference are two basic types of human consciousness. The difference between unconscious inference and conscious reasoning is that the former has less strong consciousness, without clear concepts for analysis, synthesis, induction and deduction of logic reasoning, and without new

[9]Liu (1986).

[10]Crick (1994).

perceptual information and past experience information integrating with each other, and related to brain physiological, functional, and structural construction, a dialectical development process. Therefore, subconscious inference is a rational, non-inductive, non-deductive and non-logical inference.[11]

After explaining the above principles of unconscious inference, Liu put forward the following model of insight generation.[12]

1. First of all, consciousness delivered a solution to current issue to the subconscious as mandatory information, which was actively thought and hit upon by the thinker. This is the premise of inspiration; the subconscious inference is around this main line. The mandatory information, whether in the form of light waves, acoustic waves, pressure and temperature, or in the form of imagery, language, concepts, shall be converted into bio-current pulse signal and sent to right brain by nerve fibers (Liu believed that unconsciousness was on the right side of the brain).
2. The consciousness passes mandatory information to the subconscious, due to the requirements of self-consciousness, electrical pulse signal of the temporal and spatial distribution of present "light" (much stronger than usual); thus contributing to acceleration of co-construction between the new sensory input information with the existing experience information, and the reconstruction functions of the right brain neural network with more cohesiveness; as a result, the resultant unconscious inference after the "new information" or "good graphics".
3. The results of second step of integration were sent to consciousness as feedback. The conscious of feedback information was often shown in the form of abstract thinking, imagery thinking and other forms of comprehensive analysis. After identification, if the result did not meet the requirements, and the new mandatory information would be sent to the subconscious again.
4. After the process above was repeated many times, once of inference fitted the purpose, the result would flock to the subconscious mind, immediately getting a fresh feeling. This suggests that inspiration burst.

Liu believed that inspirational thinking, as a basic form of human thinking, together with abstract thinking, imagery thinking, belong to special materials of higher level of reflection of the human brain. Inspirational thinking also went through a process, but not in the conscious mind, but in the subconscious. Subconscious gestation of inspiration, except by unconscious inferencing, often has significant functions of conscious accommodation, when ripening or sudden communication, emergence in consciousness, they became inspiration thinking. It can be seen from this discussion, what Liu called the inspiration of thinking is essentially creative thinking.

[11]Liu (1986).

[12]Liu (1986).

3.2.3 Robin' Model Based on Relational Complexity[13]

Robin's model higher-level thinking was based on the proposed theoretical framework "relational complexity". The so-called "relational complexity" was determined by the number of the independent variables n in the relationship, so the complexity level of relations can be given according to the size of n.

Level 1—one dimensional function, describing attributes of things (in Robin's term "attribution schema");

Level 2—two-dimensional function, describing relations between two objects (in Robin's term "relation schema");

Level 3—three-dimensional function, describing relations among three objects (in Robin's term "system schema");

Level 4—n-dimensional function ($n > 4$), describing n relations among things (in Robin's term "multi-system schema").

Robin et al. believed that of all knowledge humans used more than two categories to solve practical problems: explicit knowledge and implicit knowledge. Explicit relation knowledge was based on conscious, but could be the base for gradual logical reasoning; implicit knowledge was based on unconscious (subconscious) and fast intuitive thinking. Robin et al., through cranial nerve anatomical and electrophysiological measurements, confirmed that the main function of prefrontal cortex is to acquire and use "explicit knowledge" (in other words, prefrontal cortex is the main base for neural and physiological realization of logical reasoning). "Relational complexity theory" is a theory dealing with explicit relation knowledge. So the following discussion focuses only on this kind of knowledge.

According to the definition of Robin, explicit knowledge referred to knowledge that distinguished the role and filler region, and links filler region and the role. The so-called role refers to abstract concepts derived from a class of things summarized with certain attributes. For example, the "red thing" is a role (according to "red" attributes of things to be summed up after abstract concepts), which represents all objects with red attributes. As for this thing actually referring to red apple, red bricks, red clothes or something else was the filler role. Explicit knowledge was to be able to separate various roles and their corresponding filler areas, but also linked the two types of knowledge. For example, one dimensional relation (attribution schema):

Red (Apple) could separate the attributes from the filler and links them at the same time; it also indicated that the property of the apple was red. And the following two dimensional relations (relational schema): greater than (A, B)

It did not only show the difference and relation between A and B: that the role is greater than so-and-so and so-and-so relates to its filler A, B, but also described the specific relationship between A and B, i.e., that is greater.

Robin pointed out that even babies could put an apple in the same class with another apple according to the overall similarity; but if required to put things of the

[13]Robin and Holyoak (1995).

same color (considering only color attributes and ignoring other attributes) into a class, red apples and red building blocks into a class, it would need to be a little older in age. Robin believed that this was because the former was the use of the knowledge of relation for an implicit unconscious processing, and in the latter case children were asked to separate the role of fillers. As mentioned above, distinction of the role of a particular class of things was a process of generalization, and it actually was logical thinking (although the most elementary logical thinking). Babies born shortly after birth could have a holistic, intuitive thinking, but for logical thinking it was learned at juvenile age and even 16–17 years of age. It is in this sense, logical thinking of Robin et al. as higher-level form of thinking.

So-called relational complexity theoretical framework was established on the basis of predicate logic, devoted specially to the set of explicit knowledge of knowledge representation system, which can easily determine the levels of complexity in knowledge processing (from the most simple to the most complex, in four grades, 1, 2, 3, 4).

On the basis of the framework of relational complexity theory, Robin et al. used evidence of contemporary neuro-anatomical and brain cell electro-physiological measurement to make in-depth research on the structure and functions of prefrontal cortex. They pointed out that prefrontal cortex mainly included three components: cerebral sulcus and around the dorsal portion, cerebra arch groove and surrounding areas and orbitofrontal, each part has the function of processing complex relations between things, namely, essential for realization of logical thinking.

The dorsal part of cerebral sulcus was responsible for controlling attention, working memory, making plans, and has a certain effect on stimulus-response accidental learning. In other words, if this part of the brain was damaged, the mental operations that were closely related to logical thinking will not be performed.

Cerebral arch groove and surrounding areas played a decisive role on the stimulus-response of conditional contingency learning, especially essential on response and treatment of emergency.

Orbitofrontal was responsible for selective reaction and emotional control. If this part of the brain was damaged, it would affect the selective operation (selecting the target from the background and the ability to resist interference), leading to emotional fluctuations, emotional disorders and even character mutation.

For the behavior control with time sequence and target orientation, it is necessary for the above three parts to work together.

Robin et al. analyzed levels of complexity of different information processing situation in the process of thinking. For example:

In order to integrate multiple-information at certain time, it would inevitably increase the complexity of operation of relations. First of all, order or separation in time hindered different information forming into larger chunks, so they would process the original information divided into several independent but related unit. It would appear binary relations (relation schema), the ternary relations (system schema) and *n*-nary relations (multi-system schema). At the same time, in thinking process, each dimension of information needed temporary working memory, to wait for the *n*-nary relations in the last dimension of information to arrive (at this time *n*-

nary relations could be dealt with). Obviously, this would greatly increase the burden on working memory and attention distribution in prefrontal cortex.

In addition, Robin et al. used relational complexity theory for sequential memory operations and non-sequential memory operation between levels of complexity for quantitative and comparative analysis. The conclusion was the former was much higher than the latter.

In short, Robin et al. established a framework of relational complexity theory, based on the highest-level thinking model, and because of the strong support with evidence from neuroanatomical and electrophysiological measurements; humans had a profound understanding of the whole logic thinking process. So far this is a model of the brain science and a very impressive thinking model indeed. An inadequacy of the model is that it is just a logical thinking model, rather than a model of creative thinking. But it has a certain value to the construction of creative thinking model; it is worth making a serious study of it.

3.2.4 Evaluation of the Above Three Models

Through the introduction and analysis of the above three models, it is not difficult to see that each of the three models has great advantages, but also apparent deficiencies.

We shall first look at the advantages:

1. The creative thinking research broke away from traditional psychological point of view to begin research in combination with brain science research and psychological research, and more and more attention on brain science research. The development trend can be clearly seen from the last two models mentioned above.
2. The three models believe that creative thinking is not only related to the conscious mind, but also related to the subconscious, and believe that the occurrence of creative thinking depends on the interaction between conscious thinking and subconscious thinking. Therefore, attention is paid to both conscious thought research and subconscious mind research, and the three models try to combine the two researches organically (since the third model above is not a model of creative thinking but a model of logical thinking, there is no need to consider the combination of these two researches). This is another important development trend, which is the main advantage of the above models.
3. The three models lay importance to theoretical basis of creative thinking (basic psychology and brain science foundation), and value the active processes of creative thinking and models that are operational. Because operational models can be used to guide the practice of training creative thinking, it has great application value, so it not only has the same importance as theoretical basis, but also is of practical value. In the first two models mentioned above, there is a clear manifestation of this point.

The deficiencies of these models:

1. The mechanism generating creative thinking is attributed significant interaction of the conscious mind and subconscious mind, which is an original idea. What is less convincing is that the authors and supporters of the models all believed that the conscious mind was on the left side of the brain, the subconscious mind on the right side of the brain. In Liu's model, it had been made clear. In Wallas' model, although unstated, psychologists in favor of this point thought that the model actually implied this view. For example, quite influential psychologists Blakeslee had pointed out[14]: the model at the beginning and the final stages (preparation and validation stages) were usually learnt in school, completed by the left brain. The two stages (gestation and assurance) were not so easy, because they contained the unconscious (i.e., subconscious) process. If a person in these two stages gave the left brain some other work or stood aside, the right brain would give a full play. In the end, the question of whether the consciousness was fully on the left hemisphere and whether the subconscious mind was fully on the right hemisphere remained to be revealed. Jumping to this conclusion too early is not appropriate. This will make the model unreliable.
2. It is important to pay attention to research on the process of conscious thinking and to pay more attention to research on the process of subconscious thinking. But in fact, in the above models, the research on the unconscious part is obviously weak. Basically, it is not able to describe clearly physiological basis of the subconscious mind, as well as mental operation processes and characteristics of the subconscious process, but it makes people feel a sense of mystery. This is a common problem in the above models, and it is also a big problem to be solved in the research of creative thinking.
3. It is important to pay attention to the combination of processes of conscious and subconscious thinking, but also pay attention to the interaction between the two (this thought is prominent in Liu's model), which is a very insightful. Regrettably, the interactions of neurophysiological mechanisms have not been scientifically demonstrated. And this interaction is still a hypothesis in nature, and is not yet a scientific theory; it is difficult to convince people.

We briefly reviewed the merits and demerits of several main models of creative thinking. Regardless of the merits or deficiencies, they are important as guidance and references for the construction of creative thinking theories/models,. Therefore, the construction of creative thinking theory/model will be based on the reviews above. Making use of the merits and abandoning the weaknesses, we will make new explorations on the basis of previous efforts.

Through the analysis of the original creative thinking models, we find that the most important advantage is that the occurrence of creative thinking can be attributed to the interaction between conscious thinking and subconscious thinking. This view is far-sighted, which can be used as a key to solve this problem. But

[14]Blakeslee (1980).

recognizing this alone is not enough, and it only solves the problems of direction and research aim. To really build a scientific theory/model of creative thinking, we also need to thoroughly understand the essence of the conscious and subconscious mind, understand how specific interaction between the two, and their neural and physiological basis. On this basis of understanding, it is possible to establish a more scientific theory of creative thinking model, which can reflect the psychological process of thinking and can be used to guide the training of creative thinking in practice. The main deficiencies of the previous theoretical models lie precisely in the failure to understand the nature of the conscious and subconscious mind, just simply attributing different functions of the two types thinking to laterality, because of the unclear understanding of the nature, the interaction, between conscious and subconscious thinking, and the neurophysiological basis are not clear.

In the following sections and in the Chap. 4, we will gradually clarify these issues.

3.3 The Nature of Conscious Thinking and Subconscious Thinking

In order to understand the nature of conscious and subconscious thinking, we must first understand the nature of consciousness, so first we discuss the definition of consciousness.

3.3.1 Definition of Consciousness

A famous contemporary thinker D.C. Dennett believed[15] that the human consciousness was probably the last mystery to solve. Of consciousness, we still fell in the darkness today; consciousness was the only topic that often makes the wisest thinkers tongue tied, and confused. Awareness was one of the most confusing concepts among many concepts that had been established in human endeavors. In William Calvin *How the brain thinks*, a book listing eight kinds of different understanding of consciousness.[16] Francis Crick in the *Astonishing Hypothesis, The Soul Of Scientific Exploration* also introduced three kinds of "black box" based on methods of definition of consciousness (Crick and Watson had won Nobel Prize due to the discovery of DNA double helix structure). There has been a heated debate in the field of psychology and philosophy in the field of consciousness. A comprehensive survey of domestic and international discussions on the issue of consciousness has been divided into different opinions, which have not been able to

[15]Dennett (1991).

[16]Calvin (1996).

get a consistent understanding on the nature or definition of consciousness. However, despite definitions of consciousness are various, yet few of them are genuine and profound with theoretical basis, some of which has many subjective apocryphal statement, while others are obviously biased, even idealistic or mystical element. Here we choose only some representative views to make a brief introduction, and then put forward our own views on this.

3.3.1.1 Hirst's Definition of Consciousness[17]

In an influential paper *Cognitive Level of Consciousness*, William Hirst defined the consciousness as people's awareness of mental objects, such as perception, representation, or feeling. In the use of the word perception, Hirst included, in the meaning of the word, the ability to verbally report this awareness. He believed that people not only have the awareness of perception, imagery and feeling, but also have the awareness of the whole process above. They knew they were watching, imagining and feeling. Any conscious activities included awareness of the external world and mental imagery, and also included self consciousness.

3.3.1.2 Farber's Definition of Consciousness[18]

I.B. Farber, who discussed the concept of consciousness from three levels in his article *Consciousness and the philosophy and theory of neuroscience*.

The first level is ***awareness***. There are four kinds of awareness including: ***sensory awareness*** (refers to the awareness of external stimulation by sensory channels); ***generalized awareness*** (refers to the awareness, which is not connected to any sensory channels, of the internal state of the body, such as fatigue, dizziness, anxiety, comfort, hunger, and so on); ***Metacognitive awareness*** (refers to the awareness of all things within the scope of their cognition, including current and past thinking activity) and ***conscious recollection*** (which is able to be aware of what happened in the past).

Here the indicator of awareness was to verbally report the things in language. This can make it easier to detect, and can exclude animals that are unable to speak.

The second level is higher faculty; that is, the faculty can passively perceive and be aware of information, but can also have higher role of control faculties. These faculties include attention, reasoning and self control (such as the rational or moral in inhibition of physiological impulses).

The third level is the state of consciousness, which can be understood as a person's mental activity.

[17]Hirst (1995).

[18]Farber and Churchland (1995).

The first two levels of consciousness of Farber's definition are quite inspiring, but the third level lacks substantive content.

3.3.1.3 Definition of Consciousness in the Field of Psychology and Philosophy in China

The domestic academic circles have different views on the consciousness as well, the most important point of difference being consciousness considered to be human recognition activities (or cognitive activities) or other psychological activities. For example, the famous psychologist Pan Shu[19] believed that consciousness refers to people's cognitive activities; that is, people's awareness activities. Hu Jinan,[20] another psychologist, stated that a person's awareness was developed from social practice, thinking and language as core, the unity of mental activity of cognition, emotion and will. Despite these differences, it has generally more commonalities than differences compared with the foreign countries. About the notion that consciousness is the unity of cognition, emotion and will, it has been widely acknowledged by the current academic circles in China. There are many people who hold this view not only in the psychological field, but also in the philosophical circles,[21] and even the current philosophy course books in Liberal Arts College also accepted this way of expression. It can be seen that the impact is widespread. The following is a summary of this point of view.

This view[22] holds that consciousness is the human brain mental activities based on the first signal system and the second signal system. Usually the first signal refers to the perceptual imagery directly receiving external stimulation, the corresponding sensing system called the first signal system, which is the signal system that animals also have. Humans, except the first signal system, also have the second signal system—language system. This is uniquely human; through the second signal system humans can accept the experience of forefathers indirectly. Human activities, based on the two signal systems, have depth and breadth that are unmatched by animals.

Consciousness is the unity of knowledge, affection and will. *Knowledge* refers to the human knowledge of the objective world and the rational pursuit. Its connotation is consistent with cognition (or understanding); *affect* refers to the emotion that humans feel and evaluate the objective things. It is the psychological experience, psychological activities of love, hatred, yearning, regret, satisfaction, discontent, and for their own happiness, anger, sadness and joy of; *will* means the willpower; that is, people are trying hard to turn an ideal, or a goal into action, determination and perseverance. Consciousness, as crystallization of the

[19]Zhang (1993).
[20]Hu (1984).
[21]Li et al. (1995).
[22]Li et al. (1995).

knowledge, affects and will, is not equal to the cognitive or cognitive process, and also different from general mental activities, but highly rationalized mental activities, which differs from animal mental activities.

3.3.1.4 Scientific Definition of Consciousness

Through the above discussion, it is not hard to see that, at present time, the definition or nature of consciousness has two fundamentally different points at home and abroad. As mentioned above, foreign researchers' debate on the definition and nature of consciousness is more perplexed than that in our country, some diverse and even absurd. Here what we mean by the definition of consciousness by foreign researchers is one that we carefully examined and selected from the representatives as Hirst, Farber, on behalf of such point of view.

1. Researchers at home take consciousness as objects of consciousness (the consciousness is regarded as a cognitive process, or as unity of knowledge, effect and will). Researchers abroad regard consciousness as psychological process of perceiving perception, imagination, memory, thinking, and so on. Hirst and Farber definition of consciousness on the first level is broadly consistent, while a higher level of consciousness does not only passively react to this kind of psychological process (perception or awareness), but also includes an active role of these mental processes; that is, the role to control or regulate.
2. Researchers at home defined the scope of consciousness, in addition to cognition, also affect and will (although some scholars do not agree with this view, but it is not the mainstream vies). Definition of consciousness by foreign researchers (including the definition of the second level) involves only cognitive category.

Through comparison of domestic and international definition of consciousness above, one can see that the foreign definitions have the advantages that a clear distinction is made between consciousness and object of consciousness. The advantages of definitions at home are that the connotation of consciousness is more comprehensive, and that consciousness is the unity of knowledge, affect, and will; at the same time with emphasis on thinking and language as the core of consciousness. We think that the object of mental operation or psychological processing is the key to grasp the definition of consciousness. The cognitive process is the core of consciousness, rather than definitions by foreign researchers, listing of things, such as perception, representation, perception, memory, attention, and so on. Therefore, the experience summarized and absorbed from domestic and foreign researchers can help put forward a more scientific definition as follows:

> Consciousness refers to the awareness, regulation or control of mental processes such as cognition, affect and will.

Among them, cognitive processes, including attention, perception, memory, imagination, analysis, synthesis, abstraction, generalization, judgment, reasoning

and other mental processes, are actually what Chap. 2 discussed "spatial-structural thinking and temporal-structural thinking". In this way, we can transform the above definition of consciousness into a more explicit form below:

> In a narrow sense, consciousness refers to awareness, regulation or control, by the brain, of spatial-structural thinking, including imagery thinking and intuitive thinking and logical thinking; in a broad sense, the objects of awareness, regulation or control also include psychological processes of affect and will.

The main feature of this definition is:

1. To grasp the core of the consciousness: the cognitive process is thinking process;
2. To emphasize on thinking includes not only temporal-logical but also spatial-structural thinking (rather than the current understanding of many scholars in the field of philosophy and psychology);
3. To make a clear distinction between consciousness and thinking and not to confuse the two (otherwise it will equate or confuse "consciousness" and "the object of consciousness", thus making the concept of consciousness lose the value of existence.

We believe that these three points are the essence of the definition of consciousness, and also the essence of consciousness. In the next section, we shall further elucidate the essence of consciousness and with no inevitable relation with the left and right brain lateralization.

Throughout the ages, many philosophers and scholars, psychologists explored the essence of consciousness countless times, but never left a satisfactory answer; in contrast, marked with various mysteries, or wrapping the concept of consciousness in heavy fog. Now is the time to clear the fog and mysteries, regaining plain truth to consciousness.

3.3.2 The Distinction Between Conscious and Subconscious Thinking—The Contents of Working Memory

Having understood the nature of consciousness, one can easily understand what is the conscious mind and subconscious mind on this basis.

As mentioned above, in a narrow sense, consciousness is the awareness, regulation or control of the human thinking on temporal-logical and spatial-structural (including imagery thinking and intuitive thinking). Any thinking process, whether the thought process or other forms, is inseparable from the four elements: the object of thinking process (i.e., materials of thinking); means or methods of processing (such as analysis, synthesis, abstraction and generalization, judgment, reasoning and imagination); thinking processing buffer (also called working memory for temporary storage of the object of thinking and results of thinking); and thinking processing mechanism. In other words, as long as any one of the elements is

lacking, the process of thinking will be impossible to carry out and cannot be perceived. Therefore, only to discriminate if conscious or unconscious is there, that is, only limited to the thinking process of awareness, the problem is much simpler. Because we are to be aware of the kind of thinking process, and do not need to carefully analyze each of the four elements. All we need to do is to grasp the most simple and directly related element, and this element is working memory (the cache area of thinking process). This is because working memory is different from long-term memory, in that the contents of working memory is not reserved for a long time; it only takes buffer memory effect—in the thought processes for storage of object of processing and results of processing; after the completion of the processing, the contents will soon disappear. So we do not have to consider the process of thinking mode and mechanism, and we do not need to care about thinking process as well. It is enough to just consider the contents in working memory (having contents or not having contents, no need to care about what kind of contents), and the length of time working memory continues to detect whether there is a thinking process or not.

Over the years, especially the progress of research in brain science in recent decades, it has been found that thinking process involves two different types of working memory[23]: one for storage of verbal material (concept) by language coding; the other a class for storing visual and spatial material (imagery) by graphic coding. Further research shows that not only the concept and the imagery have different working memory, but also the imagery itself has two different working memories.[24] This is because, as previously discussed in 2.4 Chap. 2, imagery of things are of two types: one is to represent basic attributes of things, for imagery recognition of things, generally known as attributes imagery or object imagery; another is used to reflect the space-structural relationship of things (visual positioning), commonly known as spatial imagery, or relation imagery. Spatial imagery does not contain the information of the object contents, and only contains the information of attributes that is needed to determine spatial position of the object or spatial-structural relations. In this way, we have three different types of working memory:

The working memory (verbal working memory) of stored speech materials is suitable for temporal-logical thinking;

Working memory that stores object imagery (attribute imagery) referred to object working memory; suitable for object imagery (attribute imagery) as processing object spatial structure of thinking, that is often called imagery thinking.

Working memory for storage space imagery (relation imagery) referred to spatial working memory, used in the representation of spatial imagery, processing spatial structure of thinking, known as intuitive thinking.

Research results from contemporary brain science have proved that the three kinds of working memory and their corresponding thinking processing mechanism

[23]Smith and Jonides (1995).

[24]Smith and Jonides (1995).

can be found in the cerebral cortex corresponding to their respective regions (although some locations of working memory is not very accurate).

According to current progress of research of brain science, Blumstein[25] from Brown University, pointed out that speech function is not positioned in a small region (according to the traditional concept, Broca speech function involves only the left side of the brain, Broca and Wernicke areas). But it is widely distributed in around left lateral fissure area, and extending to the front and rear of the frontal lobe, including Broca's area, adjacent the motor cortex to the face of the inferior frontal and left pre-central gyrus (but does not include the frontal pole and occipital pole). The damage to Broca's area will affect the expression production function. Damage in Wernicke areas affects understanding speech. But the processing mechanism of verbal comprehension and expression is not limited to these two areas (more than a century in the field of psychology, the traditional concept believed that the two areas fully determined human speech function). For temporary storage of speech materials and working memory are generally considered to be in the left prefrontal cortex, but specifically in which part of the left prefrontal cortex, has yet to be precisely positioned. According to Petrides[26] it tends to be in the left prefrontal Brodmann Area 6.

Compared with verbal working memory, the positioning of object working memory and spatial working memory is more accurate. In 1993, Jonides et al. from Department of Psychology at Michigan University used the most advanced measurement technology in contemporary brain science research, positron emission tomography (PET), for generation process of object imagery and spatial imagery, obtaining very valuable results of the two imagery formation mechanism and working memory location. Since PET uses the positron emitting isotope as a marker, introduced in the brain of a local area known to be involved in the biochemical metabolism process and computer tomography (CT) technology, markers participation rate of metabolic processes of metabolism in stereo as a form of expression, because this is accurate positioning, no damage to the brain, it is advantageous for testing large number of subjects.

Jonides et al. Test results are as follows[27]:

Production and processing mechanism of object imagery in the left hemisphere inferior temporal gyrus (concentrated on the Brodmann 37 Area, stereotactic coordinates: 48, 58, −11), left hemisphere parietal lobe (focus on the Brodmann Area 40, the stereotactic coordinates of the 35, 42, 34) and right hemisphere of the cingulate gyrus anterior (focus on Brodmann Area 32, the stereotactic coordinates of: 1, 14, 43); object working memory is in the left hemisphere of prefrontal cortex (concentrated on Brodmann Area 6, the stereotactic coordinates: 39.3, 29).

Spatial imagery generation and processing mechanism in the right hemisphere of the brain occipital (concentrated on Brodmann 19 Area, the stereotactic coordinates

[25]Blumstein (1995).

[26]Petrides et al. (1993).

[27]Smith and Jonides (1995).

of the: −30, 76, 31) posterior parietal cortex (focus on Brodmann 40 Area and the stereotactic coordinates: 42, 40, 36) and movement of focus (on Brodmann Area 6, the stereotactic coordinates of the: −34, −1, 45); spatial working memory is in the right hemisphere prefrontal cortex (concentrated on Brodmann on Area 47, stereotactic coordinates: 35, 19, 2).

It should be stated that, in each of the test results, when a hemisphere has a significant activation, the corresponding position of the other hemisphere is activated, but the activation did not reach a statistically significant level.

The above results show that the visual information processing mechanism for object recognition mainly locate in the left hemisphere (only cortex around intraparietal sulcus is not in the left hemisphere), object recognition working memory also in the left hemisphere; and spatial imagery of visual information processing mechanism, including internal spatial working memory, is in the right hemisphere.

It should be pointed out that Jonides et al. used noninvasive brain PET technology; the test object is brain damaged patient but voluntary participants of ordinary college students (space imagery operation 18 people, object recognition imagery operation subjects 12 people). Experimental record includes six kinds of scanning, each scan of 20 times of experiments; each of PET image is converted to a stereotaxic coordinates, the conversion required the average number of subjects under certain conditions, and the data standardized, and then with Bonferroni method in multiple comparison correction of the results. So the test result is scientific and credible.

3.3.3 The Classification Standard Between Conscious and Subconscious Thinking

3.3.3.1 Conscious Thinking and Temporal-logical Thinking

In Chap. 2, it has been pointed out that temporal-logical thinking is based on the sequence of language symbols, so it has the characteristics of sequence and continuity. That is to say, in using language based symbols to judge and infer concepts, one has to operate step by step in accordance with the word symbol sequence, and duration tends to be longer, which is more prominent especially in processing the complex relationship between things. In short, in the case of logical thinking, the duration of their working memory is longer, plus a linear, sequential way of work, each step is very clear and lucid. Therefore, the process of thinking is very easy to detect, and the subject is able to describe the process of thinking in every step of the process, turning implicit mental operation into explicit verbal activity. It is in this sense that temporal-logical thinking is often referred to as conscious thinking. In other words, “conscious thinking” is the thinking process that can be detected and described by words. Otherwise, thinking which can not be detected and described by words all belong to “subconscious thinking”.

The characteristics of spatial-structural thinking are not the same. The materials of spatial-structural thinking is imagery (not words and concepts); as mentioned above, imagery are of two kinds, attribute imagery (object imagery) and spatial imagery (relation imagery), of which the characteristics of processing of the two kinds of imagery are not the same.

3.3.3.2 Conscious as Well as Subconscious Thinking and Imagery Thinking

For the processing of attributes imagery (including the basic attribute of information to distinguish other things), methods are usually analysis and synthesis, abstraction and generalization, imagination (both reproductive imagination and creative imagination). For each method, though specific operation and logical thinking process, which use the concept of words as material of thinking, are different, there are still similarities: they can all be split into explicit steps. But due to the thinking processing unit is a complete imagery in spatial-structural thinking (rather than fragmentary words as a processing unit). As a result, on such occasions, although in the imagery analysis and synthesis, abstraction and generalization, imagination process (as mentioned above, usually this process of thinking processing can also be known as "imagery thinking"), it is a step-by-step operation, due to the small processing unit, the procedure was simple, so working memory duration tend to be short, sometimes completed in an instant analysis on the appearance of things,. Since this thinking can also be divided into psychological operation steps, so it can also be described by words and it has the characteristics of conscious thinking. That is to say, in spatial-structural thinking where attribute imagery is taken as the objects of processing (usually called as the imagery thinking), generally it belongs to conscious thinking. But there are two cases which should be excluded:

1. Working memory lasts too short (such as less than one second), and the central nervous system (CNS) of agents of thinking distributes attention, this very brief thinking process may be undetected, thus becoming subconscious thinking or unconscious thinking.
2. In the gestation period of creative imagination, there is also a period of the subconscious thinking process. Due to the difference between creative imaginations and reproductive imagination, creative imagination has not ready-made imagery to use, to create an unprecedented new imagery, so before the conception of this new imagery; the working memory will be a blank in the working memory. This working memory for the blank time, due to the lack of objects for thinking, generally speaking, the process of thinking will not be carried out, it cannot be detected and cannot be described in words, so this is truly a subconscious thinking process. However, if there is a temporal-logical thinking in this period of time joining in, the thinking process is likely to begin, so that the process of creative imagination can complete. As for the way temporal-logical thinking joining in the creative process of thinking, we will deal with it in the next section, *the interaction mechanism between conscious and unconscious*.

3.3.3.3 Conscious as Well as Subconscious Thinking and Intuitive Thinking

For the processing of spatial imagery (for spatial vision location or judgment of spatial structural relation), compared with the processing of attribute imagery, there are many new features. In addition to using a complete imagery as a thinking processing unit, on this point they share the same features; all other aspects are different from the processing of attribute imagery thinking: usually it has no step-by-step sequential processing on spatial imagery by using methods like analysis, synthesis, abstraction, generalization and imagination, instead, it makes the instant judgment on the spatial location or structural relation between things by grasping the entirety (or overall), intuitive perspective and spatial integration. What it stressed is the relation between things (spatial relationships, or other structural relationship, and not specific properties of things. In short, this is different from the temporal-logical thinking, but a spatial structure of thinking also different from spatial-structural thinking, which draws on the attribute imagery as the object of processing (that is, imagery thinking). It is not a slow processing in linear, sequential manner, but a intuitive judgment quickly made on the basis of overall comprehensiveness, spatial integration and intuitive perspective. Therefore, it has been called intuitive thinking (that is, the thinking of taking spatial-relation imagery as the object of processing).

Intuitive thinking can be further divided into simple intuitive thinking and complex intuitive thinking. The object of processing for simple intuitive thinking (materials of thinking) is "location-relation imagery" which is related to spatial-visual location. The object of processing for complex intuitive thinking is "structural-relation imagery" which is used to describe the spatial-structural relations among things (structural-relation imagery and location-relation imagery are two subclasses of relation imagery or spatial imagery) In the situation of spatial-visual location, that is, in the situation of making sure the spatial-location relation of objects (i.e., simple intuitive thinking), working memory will leave attribute the initial value of object locations, in order to determine the spatial location of the object by processing mechanism based on these feature values. In judging and handling the structural relation between complex things (i.e., complex intuitive thinking), due to the structural relation between things hidden is yet to be discovered, so usually in working memory it will not have the initial value. It's a big difference between the two kinds of intuitive thinking.

By the way, it should be noticed that do not interpret the intuitive thinking as a subjective imagination or as a thinking which is only based on intuition without reason or evidence. On the contrary, we should interpret the intuitive thinking as a quick thinking which is based on the accumulation of theoretical knowledge, rich practical experience, in-depth investigation, sharp observation and generalization. This is because, if you do not have the conditions in the aspects of theory, experience, investigation, observation, and summarization, you will never see complex problems in global nature, or complicated relationship with internal relations between things in a moment, and you will never grasp the key of the matter as well

as make the accurate judgment in quick speed. Of course, intuitive judgment, after all, is without rigorous analysis and logical reasoning and so it is sometimes not comprehensive enough, or even with possible errors, so in full time conditions, it is better to use temporal-logical thinking to verify, and to ensure that there is no danger.

From the above analysis it can be seen that since the characteristic of spatial-structural thinking (i.e., Intuitive thinking), which use spatial imagery (relation imagery) as object of processing is a saltatory, rapid stereoscopic thinking based on integral grasp, intuitive perspective and spatial integration (not linear, sequential, orderly, step-by-step analysis of the slow thinking), the working memory is bound to be short, and the thinking process is more difficult to perceive; the thinking process generally do not have clear steps, it is difficult to describe with words (unless, of course, as discussed in 2.3 Chap. 2, writers convert 3-dimensional spatial-visual imagery into event sequence developed on one dimension time axis, which has the potential to describe with words). In other words, this kind of intuitive thinking is not easy to be perceived if not given attention to, so it is often referred to as subconscious thinking. Especially in complex intuitive thinking, because the implicit intrinsic structural relation between things is difficult to grasp, even after long time thinking about the relations, it cannot be found. Then there will be a phenomenon similar to the process of imagination, there is a period of content blank in working memory. And it differs from creative imagination process only in the fact that creative imagination constructs the imagery of an unprecedented new things, and in complex intuitive thinking, it is to discover some hidden relationship between things that others have never revealed. Complex intuitive thinking and creative imagination are the same. They can all generate subconscious thinking process—even central nervous center give enough prior attention (with expectations), and still not able to be aware of the thinking process, and even unable to describe the process with words.

3.3.4 Unconditional Conscious and Subconscious Thinking

Through the above discussion, the following understanding of the conscious thinking and the subconscious mind can be obtained:

1. Since the thinking process of temporal-logical thinking is easy to detect and can be described by words, so it is a conscious thinking under any circumstances.
2. Spatial-structural of thinking and relationship between the conscious and subconscious, showing a variety of different situations:

   ① When attribute imagery (i.e., Object imagery) as object of processing (i.e., "imagery thinking"), the thinking process, generally speaking, can be sensed and can also be described in words, so it belongs to conscious thinking (the two exception: only working memory particularly short and without attention, or in creative imagination stages);

② When location-relation imagery as object of processing (i.e., In the situation of simple intuitive thinking), the thinking process usually undetectable, and difficult to describe with words, so this should belong to the subconscious mind, but if given prior attention, and try to convert spatial-visual imagery to a event sequence on the time line, this kind of thinking can also be converted to subconscious thinking;
③ When spatial-relation imagery as object of processing (i.e., In the situation of complex intuitive thinking), due to this kind of thinking is hard to detect (even given full attention, still to no avail) nor with verbal description, so it is the subconscious thinking, which can be also called as "unconditional subconscious thinking";
④ In two exceptions of imagery thinking, the first needs certain conditions (i.e., working memory short and give no attention) to become the subconscious thinking, while the second (creative imagination) is unconditional subconscious thinking.

The following conclusions can be drawn for the following situation.

- Temporal-logical thinking is a condition of conscious thinking; imagery thinking is generally a conscious thinking;
- Complex intuitive thinking and the creative imagination are all unconditional unconscious thinking;
- Imagery thinking under certain conditions can be subconscious thinking; simple intuitive thinking under certain conditions can be conscious thinking.

The kind of creative activities like music, painting and literature depends on combination of creative imagination and the temporal-logical thinking, while the discovery of regularity of all movement in nature and human society (that is, the exploration of theory of natural sciences and social sciences) depends mainly on the combination of complex intuitive thinking and temporal-logical thinking, or depends on the combination of creative imagination and temporal-logical thinking, and creative imagination and complex intuitive thinking are all unconditional unconscious thinking and temporal-logical thinking is unconditional conscious thinking. It can be seen that for creative thinking, the significant value are unconditional conscious thinking and unconditional unconscious thinking. So, in the future when we talk about the conscious and subconscious thinking, if no special note, all refer to these two unconditional conditions.

3.4 Unconscious Thinking and Left-Right Brain Laterality

In the second section of this chapter it has been pointed out that the main advantage of the existing various insightful creative thinking models recognize significant interaction of the conscious and subconscious thinking as the key to creative thinking. The main defect lies in the idea that the conscious thinking is simply

attributed to the left brain function and the subconscious mind is simply attributed to right brain function. Then the interaction between conscious thinking and subconscious thinking is reduced to the interaction between the two hemispheres of brain function. We think that the view of simply lateralizing the functions of left and right brain lacks scientific basis, and this view is not consistent with the actual situation. This argument is powerless to clarify the essence of consciousness and subconscious thinking and make it impossible for us to find out the real mechanism of interaction of the two kinds of thinking, and also couldn't figure out the real mechanism of creative thinking, thus misleading the research on creative thinking astray. Over the years, creative thinking, especially closely related subconscious thinking, covered by mist and mystery, truly scientific theory of creative thinking is difficult to begin. This has to do with left-right brain function theory (or laterality). Let's take a look at this point of view.

3.4.1 The Origin of Left-Right Brain Laterality

In a hospital in Los Angeles in 1962, a 48-year-old veteran suffered from severe epilepsy, and the patient did not recovered from a twitch another came. When all other treatments failed, his doctor did a bold operation: to reduce the patient's pain through the incision of the corpus callosum linking left and right brain. They referred to the operation as a cleft brain.[28] Results of the operation was very good, not only reduced the twitch, and even the patients were completely cured. Professor Sperry Roger from California Institute of Technology Sperry and his assistants Gazzaniga and Myers seized this rare opportunity to make a deep study of brain surgery patients. Gazaniga also designed specifically for split-brain instrument testing connection between left and right brain. The results showed that when a bunch of light stimulation only projected onto the patient's left visual field (i.e., only the right eye can see, and left eye cannot see), although patients reacted to the stimulation with left button, he said he saw nothing. The patient confirmed by the left key, showed that his right brain has seen the light stimulation. But the left did not see, so it controls speech center to give a negative answer. This is the process of the first discovery of the two separate consciousness systems of the brain. After Sperry, who went on to make up to 5 years of study on this phenomenon, the results show that the existence of this singular state: after human brain hemispheres are separated, each hemisphere seem to play the function outside the range of the other hemisphere's consciousness, each hemisphere can learn, memorize, express feelings and implement the plan of action.[29] This significant discovery made Sperry the winner of the Nobel Prize in medicine for the year 1981.

[28]Blakeslee (1980).

[29]Gazzaniga (1995).

Unfortunately, this important discovery was later made a very inappropriate publicity, resulting in some adverse effects. Gazzaniga[30] noted that, after it was published in 1970s it was mislead. It was an interesting report in the article about split-brain person showing right-brain processing tends for overall stimulation, and left-brain oriented towards analysis work. This field of research was covered with new mystery. The interesting report Gazanniga mentioned here is referred to the 1972 article by Levy, Trevarthen and Sperry in *Brain*.[31] The basic idea proposed by Levi et al. in this article is: "As for visual recognition, the results of visual coding is dealt with by the right brain according to the overall nature of the external stimulus (not according to the analysis of each feature); yet in the situation where the verbal coding is needed, the results will be dealt with by the left brain, and the visual recognition will be carried on according to the naming feature of stimulus". In short, that is "The right brain tends to process holistic stimulation; the left brain tends to process analytic operations". For the human thinking, there are only two kinds of materials of thinking (i.e., the objects of thinking processing): imagery and the concepts based on verbal symbols. Since the verbal symbols are separated with each other and are presented in succession, the concepts are sequential, linear but not integral; imagery, on the contrary, since it is the impression left by the perception of things happened in the past and it is generally the three-dimensional spatial-visual imagery, it is integral and structural. Therefore, the so-called holistic stimulus, using imagery as the materials of thinking, is actually spatial-structural thinking. As mentioned above, spatial-structural thinking can be further divided into imagery thinking and intuitive thinking according to whether the materials of thinking is "object imagery" (also known as "attribute imagery") which reflects the attributes of things or "spatial imagery" (also known as "relation imagery") which reflects the structural relationship between things. Both imagery thinking and intuitive thinking have the characteristic of holistic processing. However, as mentioned above, Jonides et al., coming from Michigan University, use the evidence[32] collected by PET and MRI to express: the right brain only has advantages in intuitive thinking; the left brain has advantages in imagery thinking (the conclusion, drawn by Levi et al., aims at a small number of split-brain people. That is, the conclusion is not based on the experiment in which normal people use "virtual stimulus" to conduct visual recognition. So, this conclusion's reliability as well as scientificity are not as good as that of Jonides et al's conclusion drawn by using PET and MRI to conduct non-destructive testing to a large number of normal people's brains.). Therefore, the conclusion of Levi et al., the so-called "the right brain tends to process holistic stimulus while the left brain tends to process speech analysis", is not completely correct—it is only true for the intuitive thinking which takes spatial-relation imagery as the objects of processing. However, some scholars, not only indiscriminately imitate the ideas of Levi, but also arbitrarily expand and

[30]Gazzaniga (1995).

[31]Levy et al. (1972).

[32]Smith and Jonides (1995).

develop with their own subjective conjecture or speculation (left and right brain have specific skills) without serious scientific experiments. Eventually, it became laterality theory (the left and right hemispheres of the brain have different ways of thinking processes 0. The typical ideas of this theory can be summarized as:

1. The left hemisphere is in charge of speech, analysis, logic, reasoning, mathematics, order and other aspects of language information processing; the right hemisphere is in charge of rhythm, rhythm, painting, vision, space and other non-verbal information processing.
2. Conscious thinking is in the brain, subconscious mind is in the right brain;
3. Creative thinking starts with the combination of subconscious and conscious mind, and also the combination of the division of labor of left and right brain functions.
4. Traditional schools always pay attention to the left brain education (even left education is overdone), and ignore the right brain education. Therefore, the conclusion is to cultivate creative thinking and creative talents, one must strongly emphasize the development of right brain education.

On the theory of left and right brain specific functioning, many domestic and foreign literature of research[33] can be seen. Although the different forms of expression are not exactly the same, its essence is consistent, basically including the above several layers of meaning. The laterality theory is developed on the basis of the article of Levi et al. The article has scientific basis as well as the signature of Nobel winner: Sperry (as the third author). So the article published with international influence. On the basis of laterality theory, arbitrary extension and expansion widely spread. Since the beginning of 1980s, almost no one has ever doubted the scientific nature of the theory. Not only the majority of the people have long been affected; that is, the view is generally accepted by laypersons and the academic community as well. The main defects embodied in the view of current theoretical model of creative thinking are simple attribution of conscious and subconscious interaction to specific brain function. Until 1995 Gazzaniga and Sperry's found the important fact that split-brain people have two separate consciousness system. Gazzaniga contributed a lot to Sperry's success, who was the first to propose sharp criticism to laterality theory.[34] Sperry believed that the simple division of left-right brain functions "used the experimental fact that we were familiar with to deduce illusory description of left-right hemisphere function". He bluntly pointed out that this theory is untruthful. He also pointed out that new research and observation data put forward a challenge to the cerebral hemisphere function and the simple division of two consciousness systems. We believe that Gazanniga's criticism is correct. Here we shall look at how the new progress in brain science research challenges the above views.

[33]Dryden and Vos (1997).

[34]Gazzaniga (1995).

3.4.2 *Challenges of New Development in Contemporary Brain Science on Brain Laterality*

Laterality theory is based, extended and expanded on the article of Levi et al. So in order to understand the laterality theory, there is a need to first understand the ideas and scientific basis in the article of Levi et al., And then, the inappropriate extension and expansion of Levi's ideas, within the laterality theory, will be found out.

3.4.2.1 The Basic Idea and Scientific Basis of Levy's Views

It was pointed out that Levi et al. basic idea of the article is "the right brain tends to process holistic stimulus while the left brain tends to process speech analysis" This idea has its right side and wrong side, and it needs specific analysis.

1. The right brain tends to process holistic stimulus

As mentioned above, the idea of "the right brain tends to process holistic stimulus" is not completely correct because the holistic stimulus is the situation where the imagery is taken as the materials of thinking, that is, the spatial-structural thinking. And the spatial-structural thinking has two different kinds of holistic processing: intuitive thinking and imagery thinking. The result of Jonides et al.[35] has proven that these two kinds of holistic processing are not all located in the right brain.

2. The left brain tends to process speech analysis

It is also mentioned in the third part of this chapter that Blumstein of Brown University, according to the contemporary neuroscience research, pointed out[36] that the speech function does not like traditional view of more than one hundred years that the function just located in the small Broca's area and Werneke area Both areas are in the left hemisphere. And people always believed that Broca's area supervises verbal expression while Werneke's area supervises speech comprehension. The article of Levi et al., published in 1972, is likely to be based on the traditional view that left brain has the advantage of speech analysis). But speech function is widely distributed in left lateral fissure and its surrounding areas, extending to the anterior and frontal parts of the lobe, including Broca's area, adjacent to the face motor cortex of the inferior frontal and left pre-central gyrus (not including the frontal pole and occipital pole). Verbal working memory for temporary storage of materials is in the left prefrontal lobe.

Currently, localization of speech information processing mechanism in the area of cerebral cortex has not been reported yet, as accurately reported positioning as

[35]Smith and Jonides (1995).

[36]Blumstein (1995).

visual-spatial information processing, only many new speech related function cortical areas were found (far beyond Broca's area and Werneke's area). From majority population (not a few people or individual cases), evidences going against the idea of "the left brain tends to process speech analysis" (i.e., left brain has the advantage of speech analysis) have not been reported yet.

In addition, Karin Stromswold, according to neuroanatomy, provided evidences for "left brain containing speech analysis advantage", by using computed tomography (CT) and magnetic resonance imaging (MRI) on language deficient children.[37]

The language area of the brain is functional and anatomical asymmetry at birth or before birth. In anatomy, analysis of the fetal brain showed that the right hemisphere temporal lobe is bigger than left hemisphere temporal lobe. The development of speech function-related cortical areas on left hemisphere obviously lags behind the same cortical areas in of the right hemisphere. The right temporal lobe appears in the 30th week of pregnancy, and the left temporal lobe appears seven to ten days later. The development of dendrites on Broca area lags behind the same region on the right l. From the history of human species, more advanced organs in body develops later, the same is true with o individual development.

CT and MRI scan show that children with serious speech production and speech comprehension defect, the brain generally does not have normal mode of left temporal lobe being bigger than right temporal lobe.

The use of SPECT (single photon emission computed tomography) in the study of children with normal language and language deficiency found that two speech production damaged children (speech comprehension is still normal), the inferior frontal gyrus in the left hemisphere (including Broca's area) fullness (brain volume in the skull) decreased. Nine out of twelve children with defects both in speech production and comprehension saw a decreased brain volume in the left hemisphere temporal top area and right superior frontal gyrus and frontal gyrus. In addition, Lou and Henriksen et al. also found[38] that children with speech defect, their brain volume in the left temporal area decreased.

The above evidence suggests that "the left brain tends to process speech analysis", that is, "the left brain has the advantage of speech analysis", is valid and credible.

3.4.2.2 Laterality's Inheritance and Expansion of Levi's Theory

Laterality's inheritance and expansion of Levi's theory is demonstrated in the following two aspects:

1. view the right brain's processing advantages of spatial location and spatial relation as the processing advantages of all the visual information.

[37]Stromswold (1995).

[38]Lou et al. (1990).

In psychology, the spatial-visual information includes two types: the visual information (named as visual information of things or objects) which reflects the attributes of things (such as shape, size, color, etc.) and the visual information which reflects the spatial-location relation or spatial-structural relation between things (named as visual information of relations). In the process of thinking processing, the objects of thinking processing for the former is attribute imagery (also called object imagery) and its corresponding process of thinking processing is commonly called imagery thinking; The objects of thinking processing for the latter is spatial-relation imagery (spatial imagery or relation imagery for short) and its corresponding process of thinking processing is commonly called intuitive thinking (simple intuitive thinking—corresponding to spatial-location relation imagery, and complex intuitive thinking—corresponding to the spatial-structural relation imagery). These are very clear known facts, but the scholars who advocated laterality theory confused the one with the other. Those scholars believed that the right brain not only had the advantage of intuitive thinking but also had the advantage of imagery thinking, which inherited Levi's idea of "the right brain tends to process holistic processing". A book, for example, currently in the domestic marketing 500 million copies of *Learning Revolution*[39] holds this view; and in psychology a classic book on theory of multiple intelligence by Howard Gardner,[40] spatial intelligence and visual intelligence was regarded as the same kind of intelligence. In Sect. 3.3 of this chapter, we cited Jonides et al. research, using positron emission tomography (PET) and magnetic resonance imaging (MRI) technology for a large number of tests, showed that data proves that although both object imagery and spatial imagery belonging to visual information, but the nature of these two imagery are different, ways and processes of processing are completely different (the former is imagery thinking, and the latter is intuitive thinking).

As mentioned above, the processing mechanism and working memory, related to visual information of relations which includes spatial-location relations and spatial-structural relations, are all in the right hemisphere. Thus to say right brain having superiority for spatial relation fits the facts; and with the attributes of things related to visual information processing and the corresponding working memory is mostly in the left hemisphere (such as above, PET test in the third section indicates, in object imagery processing and four parts in the process of cerebral cortex were significantly activated, three of which are in the left hemisphere, only one in the right hemisphere). In addition to the research of Jonides et al., which showed this conclusion, Farah[41] also pointed out that a large body of evidence supports has imagery generation mechanism in the back of left hemisphere. Evidently, expanding the right brain's advantage of processing spatial relation to the advantage of processing all visual information is not appropriate, because another kind of visual information, that is, the visual information of objects, which is related to the

[39]Dryden and Vos (1997).

[40]Gardner (1983).

[41]Farah (1995).

attributes of things, is equally important as the visual information of relations, and these kinds of visual information are not mainly processed in the right hemisphere.

This idea, inherited from Levi by those scholars who advocate "laterality", will bring consequences in two aspects.

First, the imagery thinking is mistaken for the dominance of right brain—it has been repeatedly pointed out that the spatial-structural thinking, which takes the attribute imagery (i.e., object imagery) as the objects of thinking processing, is commonly called imagery thinking. Since PET test proved that working memory of object imagery is in the left hemisphere, the processing mechanism mainly located in the left hemisphere, and then naturally imagery thinking advantage should be attributed to the left rather than right brain. But over the years, due to the influence of laterality theory, almost everyone, layperson and expert, believes that imagery thinking is in the right brain, and left brain has nothing to do with it. The left brain can only perform step-by-step analysis and reasoning. "no imagination and creativity in the left brain" becomes definite conclusion. Now it seems that this conclusion is not appropriate and should be corrected. In 1997, at the one of the influential monographs, written by famous experts in education organization, entitled *Right brain development: theory and practice of developing imagery thinking*. This book mainly deals with imagery thinking, also involved intuitive thinking, with emphasis on the need of developing imagery thinking through the development of the right brain. Most of the contents are correct, but if imagery thinking process is not in the right brain, how can you develop imagery thinking through developing the right brain? Such an embarrassing example can be found everywhere. This is the consequence of randomly using imagery thinking advantage (Zhang for Li, or actually left brain for right brain).

Second, the advantages of the fields of arts, music, painting, including carving, etc. placed under the right brain. As is known to all, music, painting, sculpture and other art creative activities are inseparable from the visual and auditory imagery, especially inseparable from visual and auditory imagery based on the creative imagination, and inseparable from spatial-relation imagery (including spatial-location relation imagery and spatial-structural relation imagery), the basis of intuitive thinking. Creative imagination and intuitive thinking are the two wings that artists rely on for inspiration. Since the advocates of laterality theory regards spatial position and structural-relation information and all visual information as right brain advantage, of course, creative imagination and intuitive thinking are all under the charge of the right brain. But as mentioned above, processing object, processing methods, processing mechanism of the two thinking are different. Object of processing for creative imagination is attribute imagery (object imagery), the generation, processing and storage mechanism of this kind of imagery mostly locate in the left brain; and the object of processing of intuitive thinking is spatial imagery (relation imagery), the generation, processing and storage mechanism of imagery locates in the right brain. In other words, the two wings of the artistic creation, one supported by the left and the other supported by the right brain, both are indispensable. The support of these two aspects considered as one aspect is obviously inconsistent with the actual situation.

Here we shall look at the inappropriate expansion of Levi's idea by the advocates of laterality.

1. Speech analysis advantage in the left hemisphere extended to the whole language advantage.

Speech analysis refers to the process of logical analysis using concepts of words. In a broad sense, logic analysis, in addition to analysis, also includes synthesis, abstract, generalization, and this is because the latter three kinds of mental operations are all based on the "analysis" as well as closely related to "analysis" (but logic analysis generally does not include the processes of judgment and reasoning). Levi et al. article affirmed that the left brain advantage only in speech analysis, did not put judgments and reasoning or higher logical thinking processes into the right brain advantage. Laterality theory has not been confirmed by experiment, The extension of left brain advantage may result in the right conclusion and may result in the wrong conclusion. At least some are doubtful. Please look at the following facts:

Counter example [1]: since 1990s neurological experiment testified that reasoning is significantly correlated to the right hemisphere, the most powerful evidence coming from H.A. Whitaker and colleagues in 1991, their conditional reasoning experiment,[42] the experiment of a group of patients with brain injury. Two groups of subjects participated in the study of conditional reasoning. Two groups of patients both had bilateral anterior temporal lobe resection to reduce focal epilepsy. One group of patients had lesions in the right hemisphere, and the other group of patients had lesions in the left hemisphere. The results showed that patients with right hemisphere damage to the wrong premise conditions for reasoning results were worse than the left hemisphere patients with impaired performance. For example, the following conditions are given.

If it rains, the streets will be dry.

Catogorical judgment:

It is raining.

The group of patients with impaired right hemisphere of the brain reached a consensus:

The street will be wet.

Patients with impaired left hemisphere may not reason in the wrong way like this. This shows that patients with right hemisphere damage cannot be divorced from their own understanding of the reality to complete the process of deductive reasoning. Therefore Weiteka thought: the right hemisphere should play an important role in reasoning.

[42]Whitaker et al. (1991).

Counter examples [2]: Brownell et al. conducted neurological research in 1986, examining the possibility of reasoning when the subjects do not rely on visual-spatial thinking,[43] for example, given the following two sentences:

Sally walked to the movie star, pen and paper in hand

She's writing a celebrity talking about nuclear power.

Normal subjects are likely to reason that Sally would like to ask the movie star to talk about the nuclear power. But the Brownell et al. observed in the right hemisphere damaged patient yet reached such conclusion as: Sally wants to ask the movie star's growth history—they were misled by the first sentence, and unable to deduce with the second sentence for related reasoning to correct their own understanding. This shows that the right hemisphere damage will make the patient fail to reason with the relationship between things, so as unable to understand the main purpose of paragraph a text. Brown Neil, who also found that the right hemisphere damage will have barrier understanding of the lexical meaning, and the patient's speech comprehension were affected.

Counter examples [3]: Caramazza et al. in 1976 found right hemisphere damage cannot do deductive reasoning with reversible relation of.[44] For example, it is difficult to solve the following problems:

John is higher than Bill, who is shorter?

Similarly, Read in 1981 also found that compared with normal people, the right hemisphere damaged patients showed obstacle in the following type of problems.[45]

Arthar is higher than Bill, Bill is higher than Charles, who is the shortest?

In the experiments reported in the above counter examples, the subjects are the right brain damaged patients, the results might be true; and the patients are not a few, but many; scholars who published the experimental results is by no means the only ones mentioned above, but because there has not been seen in normal people in the right brain verbal reasoning (left and right brain language advantage with normal people is very difficult to do), so the above reports about brain damaged people are difficult to generalize, and cannot be used as evidence for speech reasoning advantage. However, these counter examples at least proposed some problems worth considering: left brain really has the advantages of all speech function? Where on earth is the advantage of language reasoning, in the left or right brain? What is the neural mechanism of language reasoning? Where in the cerebral cortex is the mechanism located? These questions have yet to be further studied. At present it is too early to expand Levi's point of view that left brain possesses language reasoning dominance (it could be proved in the future that the conclusion is right, but now we have insufficient evidence).

[43]Brownell et al. (1986).

[44]Caramazza et al. (1976).

[45]Read (1981).

In the present this expansion may cause the consequences: strengthening the simplistic view that the division of right and left brain thinking is absolute—that left brain alone is responsible for the processing of verbal information, the right hemisphere is in charge of all kind of non-verbal information processing. How simple, distinct, black and white! This is exactly what the laterality theorists have long coveted. But this is their own subjective conjecture, the actual two hemisphere division of function, in terms of thinking, is much more complicated than they thought. It is often different information processing advantages are mutually interwoven; it can never follow this simple principle: the "speech" and "non-speech" determining characteristics and advantages of the left and right brain information processing. The simple principle of subjective division is the root cause of the problem of laterality theory. This is a fantasy that cannot be realized.

3.4.3 Relativity of Left-Right Brain Laterality

The left-right hemisphere brain division of labor is complicated: left brain has advantages of logic analysis, logical thinking as well as imagery thinking. The right brain has the advantages of spatial, intuitive thinking as well as certain speech function. For the left brain, at least at present, it is sure that it has advantages of speech information processing, and also advantage of non-verbal information processing (attribute imagery). It has yet to be determined whether the right brain has advantages of non-speech information processing. In fact, even if not by simple division of laterality theory, but division by comparison with the actual mechanism, left-right brain advantage is relative. Experiment results showed that for majority of people (right-handed about 70%[46]), the locating of left-right brain function is generally according to this division of labor which is not simple (i.e., the left brain has the advantage of speech analysis and imagery thinking while the right brain has the advantage of the spatial-intuitive thinking); For a small number of people, this division of labor is just the opposite (i.e., some speech analysis and imagery thinking is in the right brain, the advantage of spatial, intuitive thinking is in the left brain). In addition, there are some people whose left-right brain division of labor is roughly balanced (There is no side advantage). For the right-hand people, the rest of people take up about 30%. Thus, although the left-right brain in division of non-simple function does have a certain division of labor (not the kind of simple division of labor by laterality theory), and for each individual case it is not necessarily the same. What is more important is that there is no direct correlation

[46]Blakeslee (1980).

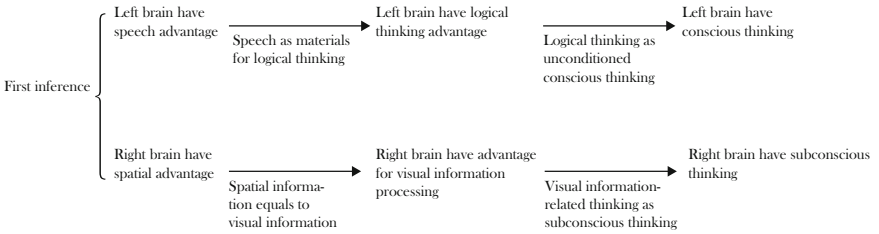

Fig. 3.1 First inference

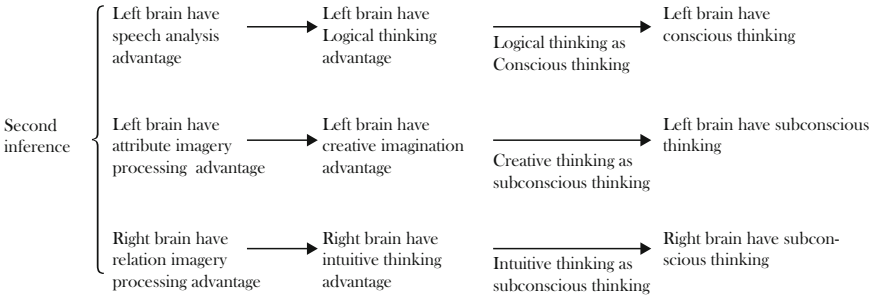

Fig. 3.2 Second inference

between functional division of labor and the conscious thinking and subconscious thinking, which we are most concerned with. This is because:

According to the simple division of labor by laterality theory, the following inference can be made, as shown in Fig. 3.1.

And according to non-simple, near-practical division of labor, another inference can be obtained, as shown in Fig. 3.2.

Since it has been proved that the simple division of the laterality theory is not consistent with the reality of the brain, the first deduction is not possible, while only the second is possible. But at this time, the left brain has conscious and subconscious thinking. Evidently, the original creative thinking theory that as long as it is conscious thinking, it happens in the left brain; as long as it is subconscious thinking, it comes down in the right brain—is groundless. And conscious and subconscious thinking boils down to simple division of left-right brain interaction is also unfounded. It is helpless in the elucidation of the nature of the interaction between the two kinds of thinking, but does not help us reveal mechanism of creative thinking and even lead us astray. So, we must completely abandon laterality theory, and explore different paths for the essence of interaction of the two types of thinking, and on the basis of that, build up a brand new creative thinking theory and model.

3.5 Thinking Process and Features of the Two Kinds of Creative Activities

Human creative activities are usually of two kinds: Arts type (including music, art, literature writing, etc.) and science type (including exploring the theories in the field of natural sciences and social sciences, namely to discover and explain the law of motion of nature and human society in various variation. Thinking process and features of these two types of creative activity are not exactly the same. In order to construct general applicability of the creative thinking theory and model, it should deeply understand, in the first place, the thinking processes of different types of creative activities and their characteristics.

3.5.1 Thinking Process and Features of Artistic Creative Activities

In order to understand creative activity of thinking in artistic activities, the best way is to listen directly to artists, who had their own personal experience and feelings.

Mozart, a master of music, described his thinking process in the creation of music[47]:

> When I feel excellent and in a very good mood, or after I had a good meal for a drive or walk, or find it difficult to sleep at night, thoughts flooded my mind. When and how did they come to my mind, I don't know, and it had nothing to do with me. I kept those thoughts mind, and hummed them in a low voice. At least people had told me that I was doing this. Once I determined the main melody, another melody was, in accordance with the needs of the whole music creation, connected to the main melody; other melodies and each kind of instrument and all melodic fragments came together, and finally a complete works was produced.

The great painting masters Van Gogh described his creative experience like this[48]:

> I rarely see an ideal color effect in Holland painting. Last night I had an unexpected discovery, when I was painting on a slight slope ground in the woods. Around the land was covered with gradually faded leaves of beech. Shining in the sunset, the leaves were stained deep red brown. This kind of color is so gorgeous that you can't imagine the color of any carpet. The problem is how to show this magical color, solid land and great vitality of life—this is a very difficult problem. When I painted down this picture, for the first time I found at dusk the painter should maintain the sunset and rich colors and seize the light.

[47]Blakeslee (1980).

[48]Gardner (1983).

Literary scholar Leo Tolstoy described how he conceived the typical characters of Anna Karenina when he mentioned that the inspiration came from the pattern of his pajamas cuffs. He said[49] that:

> I was sitting in the study and looking at the pattern of the white silk thread on my pajamas. It was very nice-looking. So I think, how can people come up with so many patterns, decoration and embroidery; women interested in sewing, fashion and insights to the whole world. This is how fascinating ah. I understand, women like these things, they will enjoy doing them. Now, of course, I should think about Anna… This pattern inspired me to write a whole chapter.

It is not difficult to see that the thinking process of artistic creativities has the following characteristics, which can be seen from the experience of above artists.

1. Material of thinking (that is, object of thinking processing) mainly reflects the attributes of various kinds of imagery—auditory imagery mainly used by musicians, visual imagery mainly used by painters and writers.
2. Thinking process is mainly subconscious—the climax of the artistic creation (that is, the moment of inspiration) is sudden. As Mozart said, "when are they coming in? I don't know, and I have nothing to do with it. Van Gogh had seen sunset thousands of times, but a true understanding of the setting sun and the color came only from painting in the woods, suddenly flashed. Tolstoy failed to predict in advance that the pattern imagery on pajamas cuffs will to bring their own creative inspiration. The creator cannot be aware of the process in advance, which cannot be described in words, so the birth and development of artistic inspiration is the process of subconscious thinking.
3. Achievement of thought is unprecedented, full of artistic charm, which can give profound beauty of new artistic imagery—crystallization of artistic creative activity. For the composer things are to be embodied in the auditory imagery of things. The painter work reflects visual imagery, and the literary writer uses the imagery of typical characters to reflect thinking products.
4. Thinking process of artistic creation is inseparable from the guidance and control of logical thinking—as discussed above, in the main thinking process of artistic creation the material of thinking is object imagery, which basically belongs to the process of imagery thinking. The climax of art creation activities (inspiration) is an advanced stage of imagery thinking. Although the emergence of inspiration is sudden and accidental, which cannot be detected in advance, but it is not out of thin air. The formation of Mozart's works must first determine a main theme (the theme of the work), the main melody or theme is generally determined through logic analysis and reasoning.

Van Gogh found, in the sunset red leaves and magical color, the great aesthetic value, so as to arouse inspiration, to create immortal paintings, from what common people see in the twilight scene. The reason is because he analyzed and studied the neglect of color in Dutch painting circles. This pertinent analysis and research

[49]Piotrowski (1981).

obviously cannot be separated from deep logical thinking. Tolstoy obtained creative inspiration due to the patterns of the images on the pajamas cuffs, seemingly casual, actually and his mind constantly brewing the image of Anna Karenina and of Anna's personality, life habit.

Writers, who want to shape the typical characters, must understand the personality of their characteristics, their life habits, which cannot be separated from the social environment, background, life experience, education status and many other factors about the characters, through analysis, synthesis, abstraction, generalization; in short, inseparable from logical thinking. Evidently, the thinking process of artistic creation is not only the process of imagery thinking, which must contain logical thinking. Imagery thinking cannot be separated from the guidance and regulation logical thinking; otherwise it will lose direction. Any great works of art are the product of the combination of the highly developed imagery thinking and profound logical thinking.

3.5.2 Thinking Process and Features of Scientific Creative Activities

In order to understand the thinking process of scientific creative activities, the best way is to explore the successful experience of scientists.

It is well known that the discovery of Archimedes's principle is a famous example of the use of intuitive thinking in science history to achieve a breakthrough in the field of science. The Regent of the country, where Archimedes stayed, asked a craftsman to make a gold crown for him, but he doubted it was not made of pure gold, which might be mixed with silver. He asked Archimedes to try to solve the problem.

Archimedes knew, as long as he could measure the volume of the crown, he could decide if it was made of pure gold. The crown volume is very irregular; Archimedes thought for a long time, has not been able to find a feasible method of measurement. One night, when he was in a bath tub to sit down to take a bath, as usual he saw the basin water increased. This kind of phenomenon he had seen a thousand times, which never attracted his attention; and this time, intuition has made him suddenly realize that the water surface elevations is likely to be equal to the volume of his body immersed in water. This is the way to measure the volume of irregular object. It was simple and easy. He was so excited that he immediately jumped out of the tub, and ran down the street shouting: Eureka! Eureka! (I know! I know!)

Archimedes's success lies in the fact that he intuitively found a hidden relationship from two seemingly unrelated things (such as the implicit relationship between the volume and water surface elevation and the volume of body immersed in water).

Newton's discovery of the law of universal gravitation is similar to that of Archimedes'. For hundreds of thousands of years, there had been many people seeing apples falling to the ground and the other similar freely falling body for many times, but never considered the relation of this phenomenon and the rotation of the moon around the earth. Only Newton thought about this problem and keenly discerned implicit relations between these two phenomena—all caused by the gravitational pull of the earth, and on the basis of this, through logical reasoning and rigorous calculation, Newton finally reveals the law of universal gravitation.

As for examples of the use of imagery thinking in science creative activities, the number of these examples is countless. It can be said that any scientific discovery or invention requires having a high degree of imagination, which cannot be separated from association, imagination (especially the creative imagination).

Germany's Wegener had been able to put forward a significant impact on geology (continental drift). Its origin lies in his careful observation of the world map along with imagination. He found forms of South America and Africa on the map so similar that he had a bold imagination: the two parts, was originally a whole, they were split apart later, due to some geological forces. It is based on this kind of imagination, then the use of substantial evidences from fossil glacier, paleoclimate and geology, he finally put forward great innovative theory of continental drift—this is the use of shape similar to start imagination, so as to achieve a breakthrough as a paradigm in the exploration of science.

The sight of the rattle snake is very weak. It cannot see the objects in the distance of less than dozens of centimeters, but in the night it can accurately capture the field mouse from more than ten meters away. Biologists have found that its secret lies in the buccal nest between eyes and nose. This site is infrared sensors in the creature, which can feel a trace of infrared from a distant animal activity and to thermal position the animal. Missile experts in the United States initiated association and then designed the automatic tracking of the target with rattle snake infrared tracking missile—the example of association using biological thermal positioning to develop bionic weapons.

For thinking process of scientists, who creatively discovered essence or nature of things and regularity of human social movement, Albert Einstein, the greatest physicist of the 20th century, had a very insightful discussion about it according to his own experience; this is what he has to say.[50]

"When words and language are written down or spoken, it seems that no effect is on my mind. Those mental entities that seem to be the elements of thought are certain symbols and generally clear imagery, which can be reconstructed and combined at will. Of course, there is a certain connection between the elements of thinking and the corresponding logical concepts. Obviously, the ultimate desire to make the concept of a logically connected is to allow the concept of thinking and

[50]Blakeslee (1980).

the above elements together to play a role on subjective basis. From psychological point of view, this interaction seems to be the nature of thinking—before form any words or other symbols and logical structure take form (these words or symbols can be used to communicate with others).

As far as I am concerned, the above mentioned thinking elements are of visual and muscular type. Only in the second phase, i.e., only when the above mentioned common function has been fully established and can be recycled, it is required to consider how to choose the customary words or other symbols".

Einstein here describes the two stages of science creative thinking process: the first stage refers to the use of vision and muscle type of thinking elements (i.e., visual imagery and kinesthetic imagery as objects of thinking processing) are intuitive thinking and imagery thinking. As mentioned earlier, visual imagery includes spatial-relational imagery (reflecting spatial-positional relation imagery and structural relation imagery) and object imagery (reflecting the attributes of things) and so on. In intuitive thinking which is related to science creative activities, the spatial-relational imagery is mainly used. In imagery thinking which is related to science creative activities, the attribute imagery is mainly used. In the first stage, through imagery thinking and intuitive thinking to grasp essential attributes of things or implicit relations of complex things (namely, the establishment of what Einstein said the idea and the concept of combined action), before moving on to the second stage—selection of the appropriate terms for logical analysis and reasoning, and for demonstration and testing whether the results of imagery thinking and intuitive thinking are correct. In short, What Einstein said the first stage is the stage of intuitive thinking or imagery thinking stage; the second stage is the stage of logical thinking. From the tone of the quote it is not difficult to see that Einstein in science creative activities more stressed is on the first stage, that is, the role of intuitive thinking and imagery thinking. Because of this, so Einstein had expressly declared: "I believe intuition and insight".

It can be seen from the cases of the above scientific discoveries and Einstein's personal experience that science creative thinking process has the following characteristics:

1. Materials of thinking are mainly attribute imagery or spatial-relational imagery—science creative activity is to reveal the essence of things and discover the nature of and movement laws of human society. Nature is the most basic and the most important attribute, laws are internal relations between things (i.e., the structural relations); and the main materials of this kind of creative activity in the thinking process must reflect object attributes of things and reflect the structural-spatial relation imagery (generally referred to as relational imagery for short).
2. Thinking process is largely unconscious process—scientific creation climax (i.e., insights appear instantaneously) is sudden and accidental, such as Archimedes to confirm whether a crown was made of pure gold. He only knew he should try to find the volume of the crown. However, since the shape of the crown is very irregular, there is no ready-made method that can be used for

reference to measure the volume. Archimedes pondered its solution. Just as he got into the tub, suddenly Archimedes found the key to the problem. Newton, through apple falling to the ground, found the law of universal gravitation. This sudden and accidental insight cannot be expected in advance, its forming process cannot be described by the use of words (what can be described is just the results of insight). The development and occurrence of scientific insight is subconscious thinking process.

3. The results of the thought have not been revealed before, scientific value can play a role in promoting new theory and new method—the new theories of human civilization and progress reveal and explain the nature of things and essence of movement of human society; new method is the measure or tip developed to solve the practical problems in related areas, under the guidance of theory (i.e., the understanding of the regularity of the interrelation between things and the nature of things).
4. The whole thinking process of scientific creation is inseparable from the guidance, regulation and validation of logical thinking—as above-mentioned, the main materials of thinking process of science creative activity belong to intuitive thinking and imagery thinking. Scientific creation climax (insight) is the advanced stage of intuitive thinking and imagery thinking —- complex intuitive thinking stage and creative imagination stage. Although insight appeared suddenly and accidentally, it did not come out of thin air. Archimedes' insight came when he went into the bathtub. The reason why he realized the rising of water is the key to him to solve the problem is because he used logical analysis and reasoning beforehand to recognize that any object had density, volume and mass. If it was a crown of pure gold, its density was known, under certain conditions that the volume was fixed, this could be easily computed. So as long as the volume was measured, you can calculate its quality, and also judge whether it is mixed with impurities. So the key to solve the problem was transformed into how to measure the volume of the crown. It is under the guidance of logical thinking, Archimedes focused intuitive thinking on measurement of crown volume. Insight might occur in the process of bath: sudden realization that the relationship between the tub water rising and volume of water with body immersed in. And before this, he was also in the tub for hundreds of times seeing the same water rising, but such insight never happened to him. The reason is that it was without the guidance of logical thinking. In addition, intuitive thinking or imagery thinking led to insight; while making a rapid judgment of things between complex and subtle relationships (implicit), still it could not be guaranteed that such judgments must be correct, and based on intuitive thinking and imagery thinking, making overall comprehensive judgment, and an accurate quantitative analysis of the situation cannot meet the demand. Therefore, for the results of insight, they usually have to be tested through logical thinking. The second stage of creative thinking as Einstein said is to emphasize the important role of logical thinking in this area.

3.5.3 *Relativity of the Division of the Two Kinds of Creative Activities*

In the above we roughly divided the process of thinking into two categories, according to the main characteristics of creative activities, such as arts and sciences. It should be pointed out that this classification is relative. That is to say, creative imagination (higher stage of imagery thinking) is not confined to artistic creative activities only, and without intuitive thinking. Similarly, in science creative activities, intuitive thinking and imagery thinking are not an either-nor situation, but the two are combined.

In fact, there is no lack of intuitive thinking in artistic creative activities. For musicians in the composing process, of course, they mainly use the imagery of things to conduct reproductive imagination and creative imagination (imagery thinking). However, composition must has a main melody (theme). The theme must be determined, as mentioned earlier, through logical analysis and reasoning. There are some musicians who may also use intuition to determine the main melody (how to use the most appropriate music image to express the theme mainly depends on imagination, especially creative imagination). The characters in literary works are lifelike; each character has their own distinct personality, unique ways of using words and manners of behaving. Without mentioning the characters' names, only by words and gestures, readers will be able to judge who the person is. Writers of these typical characters, who want to grasp the characteristics of their words and deeds, need, in addition to logical thinking, sometimes intuitive judgment as well.

In the science creative activities, there are also a lot of examples using intuitive thinking and imagery thinking combined to achieve a breakthrough in creative activities. DNA double helix structure is a shining example of the discovery. The discovery of double helix structure of DNA is one of the greatest achievements of modern science. Because DNA is a biopolymer, ordinary optical microscope cannot see its structure. British biologist Wilkins, who was born in a family of doctors, naturally thought of the use of X rays. In 1945, he first use X-ray diffraction techniques to capture the world's first piece of DNA structure photos, but it is not clear, the photo seemed to be covered with a cloud of the spots, like a spiral, but we cannot be sure of it. In the spring of 1951, Crick, another biologist at the University of Cambridge, used the X ray to take a clear picture of protein, which was a major breakthrough. A young biologist from the United States, Dr. Watson, doing experiments on how DNA influences inheritance, heard the news and came to the Cavendish Laboratory where Crick worked. He and Crick studied together the structure of DNA. This year in May, Watson met Wilkins at an academic conference, and asked for a DNA photo. Wilkins talked about his research without reservation, and suggested that DNA might be the spiral structure as his intuitive conjecture. After returning to the University of Cambridge, Watson and Crick carefully studied the DNA photos. In the process, a three-dimensional image of DNA structure suddenly came to Watson's mind (this is unprecedented creative

imagination). He said to Crick[51]: "I think the shape of DNA structure is likely to be double helix, like an escalator, rotation upward with a handrail on each side". Crick agreed to the idea, but also need to be further confirmed. Subsequently, Watson and Crick repeatedly used optical diffraction technology to take X ray photographs of a variety of virus' DNA. Finally, they found that the basic components of DNA (four kinds of organic base) must follow the law of the structure in a certain pairing relationship, so as to reveal the molecular formula of DNA as a double helix structure. In April 1953, their paper on the DNA structure was published in the British journal *Nature*. This paper has only more than 1000 words, but its weight is enough to compare with Darwin's *Origin of Species*. The structure of DNA brings hope to unlock mystery of inheritance and variation of all creatures (including humans). In 1962, Watson, Crick and Wilkins won the Nobel Prize for medicine due to the discovery of DNA structure. From the situation mentioned before, it is clear that in this process of science discovery, Wilkins' creative imagination on the spiral of double staircase handrails, rotation upward, played the decisive role.

In short, thinking process and characteristics of creative activities was divided as the above, only as a measure in order to facilitate the analysis and research of creative thinking, but the division cannot be absolute. Actual creative activity process is much more complex, can never be so simple and clearly divided. Sometimes like the discovery of DNA structure, two different kinds of thinking are so closely combined that it is hard to distinguish which kind of thinking played a major role. However, generally speaking, in artistic creative activities, imagery thinking (association, imagination, especially creative imagination happens more. Science creative activities require the use of imagery thinking and intuitive thinking at the same time. It should be emphasized that in creative activities, regardless of a major use of imagery thinking or intuitive thinking, or the two combined, the guidance and regulation by logical thinking is indispensable. Simply relying on intuitive thinking and imagery thinking will be difficult to develop into a very valuable inspiration/insight.

3.6 Neural Mechanism of Imagery Thinking and Intuitive Thinking

Through analysis of the characteristics of process of two kinds of different creative activities of thinking and, we know one kind of creative activity is mainly related to imagery thinking; the climax of creative the activity (inspiration) belongs to imagery thinking—at the advanced stage of creative imagination. Another kind of creative activities mainly involves intuitive thinking and imagery thinking; the climax of creative activity (insight) is at the advanced stage of intuitive

[51]Liang (1998).

thinking—complex imagery thinking or creative imagination stage. It can be seen that the key stage of creative thinking is the stage of creative imagination and complex intuitive thinking. Because the two stages depend on the premise general and simple imagery thinking and intuitive thinking, so if you want to clarify creative imagination and complex intuitive thinking and their neural mechanisms, obviously the first thing to do is to understand the neural mechanisms of general imagery thinking and simple and intuitive thinking.

3.6.1 A Model of Imagery Thinking—Based on Psychology and Neurophysiology

As mentioned earlier, the object of imagery thinking (materials of thinking) reflects the attributes of things, so to explore the physiological mechanism of imagery thinking; the first thing to do is to investigate production and processing of object attribute imagery (i.e., object imagery).

For the neuro-mechanism of generation and processing of object imagery, David Lowe proposed a quite good hypothesis.[52] The hypothesis says that visual perceptual processes is a bottom-up process; that is, external objects (object) is seen first. After that feeling registration is seen. Then object as perceptual imagery (i.e., the input information) is fed into the visual temporary buffer. At the same time, this input information will activate the representation system associated with the long-term memory. Often the perceived input is not exactly the same with prototype object (for example, we see a pen, often fail to see the tip of the pen; then it will be difficult to identify it as a pen or a ball pen); so the need of activation, in long-term memory, visual image memory system, comparing current input information with the memory image, extracting the imagery as close as possible and sending it to the working memory. In working memory in the memory image and the input optic perceptual image are compared. If they are matched, the object recognition will be completed; if they are not matched, the information will be sent to "imagery adjustment and integration" in order to adjust, integrate and process this memory imagery according to the contents of visual imagery memory in long-term memory and in order to make them match as far as possible with the current input. Once you reach that goal, the object can be recognized. Clearly, the ability to generate the image should be the basic component of human recognition of the object.[53] This image matching process is realized through feedback, which can be used to fill in the missing part of the input perceptual image, so that the input information is more complete.

[52]Lowe (1985).

[53]Kosslyn and Sussman (1995).

3.6.1.1 Model for Generation and Processing of Object Imagery

According to David Rowe's hypothesis, while considering the suggestion made by Kosslyn that the representational system should distinguish three components including long-term visual memory, mental imagery and visual buffer,[54] and considering Farah's emphasis on the independence[55] in imagery generation,. we believe that a model of object imagery generation and processing can be proposed based on psychology and neurophysiology. The model is as shown in Fig. 3.3 below.

In Fig. 3.3, functions, such as the adjustment and integration of imagery as well as the judgment of whether the imagery is matching, can be represented by a unified function module: imagery generator (as shown in the dotted frame in Fig. 3.3). Is the model shown in Fig. 3.3 a conjecture or a scientific based theory? This is an important issue of concern. Many psychologists and neurophysiologists had experimented on several key links in the model (such as imagery matching, imagery feedback, imagery adjustment and imagery and interaction with perception,), using the method of experimental psychology and neurophysiology careful inspection. The results were confirmed, and showed that the model was reliable.

1. Evidence of imagery matching

Imagery matching is an important part of David Low's model. Do contents of an imagery generator originate from long term memory, whether the imagery is used to match the input imagery for object recognition? Cave and Kosslyn in 1989 studied this kind of problem.[56] They used Low's model for the experiment. They come up with an idea that when the input attributes are not enough to match, people will use memory imagery. They conducted an experiment like this: two objects were presented to the subjects, and one is a diamond shape while the other is a rectangle. An object was marked with coarse black painting and the other drawn out with lighter lines. The two objects were presented one after the other separated by a time interval. The requirement for the subjects is to determine whether the lighter line, a slightly fuzzy object is of the same length. In the experiment, 50% of the lines are the same, and the other 50% are not. Cave and Kosslyn believed that if imagery matching exists, the subject would use the imagery left by the first object imagery (because this is the closest and freshest imagery with imagery presented later). During the experiment, the size of the object is the same in 75%, and the other 25% are different. If the subjects would match the imagery to be presented later, 25% of the subjects need to adjust the imagery domain to meet the input requirements. There are 50% objects of the same type (two times of the diamond) and 50% of the different types in the object that have been presented two times. Obviously, the

[54]Kosslyn (1980).

[55]Farah (1995).

[56]Cave and Kosslyn (1989).

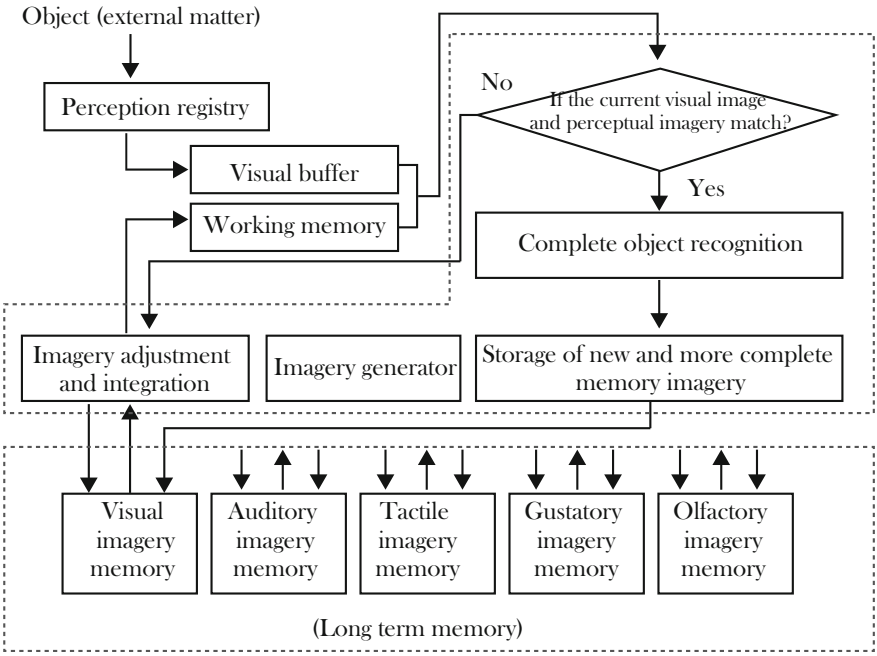

Fig. 3.3 Model for generation and processing of object imagery

subject of the same type of objects, following two times (both were diamond shape), the required response is shorter than the different types of objects following two times.

As expected, when presenting objects and the same type of object appeared, the evaluation time increases linearly as the size between the two kinds of objects; the different size of the evaluation function is very close with the subjects' adjustments of imagery function; on the contrary, when successively presenting the object of different types, the subjects' reaction time prolonged, the difference of evaluation function close to subjects' attention and range of adjustment function. Clearly, the experimental results confirmed that imagery matching existed; i.e., participants actually formed a memory imagery of the first presented object, and used this memory imagery to match and recognize the object presented later.

2. Evidence of imagery feedback

The model of Fig. 3.3 shows that if visual imagery memory system resembles the memory imagery of the current visual perception, and still cannot meet the matching requirements, then the memory imagery will send the feedback to the visual buffer, to supplement the current perceptual imagery. Since the end of the 19th century, it has been thought that visual memory imagery can be fed back to a more advanced visual center. But this conjecture, until 1980s, the end of 20th

century (1989), confirmed by Rockland and Virga.[57] They also pointed out that providing feedback (the outgoing channel) is not exactly the same as the input (the incoming channel); the outgoing channel contains more distributed links than the incoming channel. This discrete nature of the outgoing link means that if the information stored in a more advanced visual center, then the original imagery of the reconstruction will be more valuable. The dispersion of the outgoing channel (i.e., imagery feedback) provides a reliable basis for regulation, processing and reconstruction of the representation.

3. Evidence of imagery adjustment

The matching of memory imagery and the current perceptual imagery is realized by adjusting the size, direction, position and shape of memory imagery. R.N. Shepard in the 70's famous psychological rotation experiment is strong evidence that imagery can be operated and can change direction and position. In 1982, Shepard and Cooper experiments further showed that subjects in the imagination rotating object at greater angles needs more time, whereas the brain does not limit the mental imagery going through certain trajectory. However, when the object is manipulated by hand, the arm has to go through some kind of trajectory, so if people can visualize what they see in the operation, then the object of the imagination will go through that path. Kosslyn et al., tested a brain injury patients,[58] and the patient felt difficult to carry out mental rotation of objects, so during the test, the patient continues moving her hand, as if she is rotating the object. It shows that if someone does a special act, he is thinking about what he sees (mental operation of the imagery).

In 1990, Droulez et al. observed a fact[59]: the fastest speed of rotation of some kind of mental imagery (i.e., memory imagery) a person can do is close to a person's true maximum speed of directional movement. This finding made them believed that mental rotation is calculated based on the simulation of some kind of directional movement, which is the same as the processing used in the real motion.

The above facts show that imagery is not only an objective existence but also can be operated to adjust its size, direction, position and shape.

4. Evidence of the interaction between imagery and perception

Kosslyn et al.[60] pointed out that perception can start imagery, and imagery in turn can start perception. For example, they asked the subjects to check a series of words and calculate the number of vowels in each word, and then imagine lowercase letters vocabulary, and to determine the initial letter and the last letter is of the same height. The subjects in the lexical priming operation showed a shorter completion time than without lexical priming operation, for when they had

[57]Rockland and Virga (1989).

[58]Kosslyn and Sussman (1995).

[59]Droulez and Berthoz (1990).

[60]Kosslyn and Sussman (1995).

previously seen the words in imagination, they can be observed with more priming effect (priming effect refers to the effect of previously learned knowledge on current subconscious memory).

In the process of memory retrieval (such as remembering the number of chairs in your room) or reasoning (for example, the best way to get to the airport from your home), using memory imagery can have a significant priming effect. Then higher-level visual central projection (i.e., feedback) to lower level visual location information start the visual perceptual imagery matching process, reduce the threshold of neurons in the visual buffer, and at the same time discharge pulse to produce stronger perception of the current object.

Imagery can play an integrated role in the process of perception, which can supplement and enrich the current perceptual imagery, and also help people recognize the object, and correct the perception. Meado and colleagues in 1989 did an interesting experiment.[61] They studied three right parietal lesion associated with unilateral neglect patients. The results showed that patients did not see the object of perception in the left, and did not see the object of mental imagery in the left either. The researcher asked a patient to move his head and eyes in order to see the object on the left when recalling the imagery (for example, the left half of a face). After the subjects did so, they found that their ability to look at the left of imagery really greatly improved. Really moving the thing which an individual wants to see or having expectations of the thing, is an effective way to form imagery.

3.6.1.2 Imagery Thinking Model

Through the above four aspects of experimental evidence (including some are psychological experiments, and some other part is neuro-physiological experiments) it can be seen that in Fig. 3.3 model a solid psychological and neuro-physiological basis. It is true that the model is only a model of the object imagery generation and processing, and it cannot cover all the cases of imagery thinking. However, as mentioned earlier, materials of imagery thinking (object of processing) is attribute imagery of things; that is, object imagery. From the psychological point of view, processing method of imagery thinking is analysis, synthesis, abstraction, generalization and imagination and so on, but from the view point of neurophysiology, the processing model and Fig. 3.3 model has no big difference. This is because:

Analysis—is to extract imagery memory from long-term memory of visual imagery and memory system, a process of sending to imagery generator for decomposition into several components (each component is an independent imagery).

[61]Meado et al. (1987).

Synthesis—is to extract a number of similar things in visual imagery, auditory imagery and tactile imagery, etc. from long time memory and other memory systems, a process of sending them to imagery generator, in which to be integrated, so that the process becomes a whole imagery.

Abstraction and generalization—abstraction is to draw out imagery that can reflect the imagery of similar nature, and give up the associated imagery with non-essential attribute imagery; generalization is a psychological process to extend imagery that reflects individual nature to other similar things. To complete this process, one must first extract related imagery from long-term memory system and subsystems to imagery generator, and then in which abstraction or generalization take place.

Since the four processing methods (analysis, synthesis, abstraction, generalization) generally do not involve imagery matching, links of processing will be less than that of object recognition process. Therefore, the processing model can be obtained by simplifying Fig. 3.3 (processing of fewer links may not necessarily be simple, especially imagery generalization is often much more complex than object recognition).

Imagination—is generally divided into three levels: association, reconstruction of imagination and creative imagination. Because of creative imagination involved creative thinking, so it is left to the next section for further discussion. Here we shall make some analysis only of association and reconstruction of imagination.

In 2.5 Chap. 2 it is mentioned that association has several types: similar association, opposite association and related association; namely, association in terms of shapes, functions and basic properties, such as similar, opposite, or logic-related. Therefore, association involves two kinds of imagery; imagery of the original thing and imagery of the association. The former imagery always store temporarily in the visual buffer. The latter imagery (associated imagery) is extracted from the long-term memory related imagery memory subsystem. Associated imagery is extracted and compared with the imagery of original things (but not for matching, but to see whether an imagery is similar, opposite, or related association requirements; i.e., to see whether association imagery and the original imagery is similar or opposite or logically related. If the results do not meet these requirements, the association starts once again until meeting the requirements. Visibly, association process and the object recognition process have many similarities, but a bit simpler (imagery generator only need to extract, from long-term memory, relevant imagery that meets the requirements, without processes of adjustment and reconstruction.

The reproductive imagination is the mental operation process in which imagery that the former or others have described but not been perceived by ourselves will be imagined (that is, the original imagery will be integrated, transformed and recombined) and will form a new imagery of things. In the beginning of imagination process, working memory did not have prototype imagery for comparison or reference (association or recognition has such imagery—original imagery and the current perceptual imagery serves as the reference). So, in this case how to distinguish whether the imagination has reached expected re-construction imagination? In 2.5 Chap. 2, it has pointed out that it has to rely on the regulation and

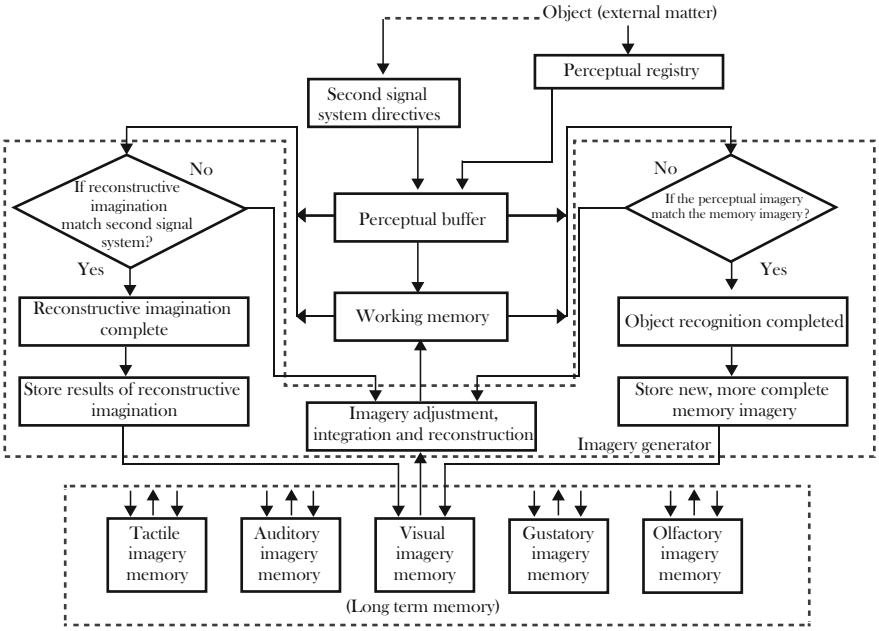

Fig. 3.4 Imagery thinking model based on psychology and neurophysiology

control of the second signal system; that is, the imaginary process depends on the guidance and adjustment of logical thinking based on the speech concepts; finally, whether completed reconstruction of imagination meets the requirements, again it also depends on the results of logic analysis and reasoning to determine.

To sum up, we can get the model of imagery thinking based on psychology and neurophysiology, as shown in Fig. 3.4.

3.6.2 Brain Location of Imagery Thinking

Figure 3.4 shows an imagery thinking model on the basis of psychology and neurophysiology; judgment of whether imagery adjustment and reconstruction match; imagination imagery match (including matching between perceptual imagery and memory image; and matching between imagination imagery and the second signal system instruction) can use a unified function module of "imagery generator" (as shown in the dotted frame in Fig. 3.4). In this way, in the process of imagery thinking, the main parts that relate to cerebral cortex location are four in the long-term memory: visual-imagery memory systems, imagery generator, visual buffer and working memory. The former three is suggested by Collins as three components of distinctive features of representation system.

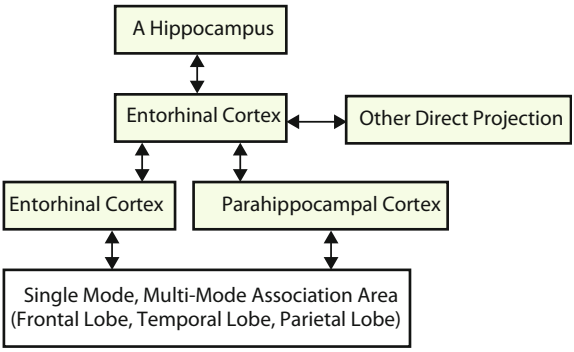

Fig. 3.5 The main structure and relation in support of declarative memory (The shaded part of the structure is temporal lobe, the marginal system)

According to Squire's study,[62] long-term memory can be divided into two categories: declarative and non-declarative memory. Declarative memory (also called explicit memory) is a memory for facts and events; non-declarative memory (also called implicit memory) refers to the memory such as classical conditioned reflex, skills and habits. Long-term memory in imagery thinking apparently refers to the former category (i.e., declarative memory). For the location of this class of long-term memory in cerebral cortices, Mishkin in 1982 and Squire and Zola-Morgan in 1991[63] have made some in-depth study; the conclusion is that the medial temporal lobe is the important area in support of declarative memory. Medial temporal lobe includes hippocampus, entorhinal cortex, parahippocampal cortex and entorhinal cortex, and their relationship with relevant areas is shown in Fig. 3.5 (Shaded areas in the figure denote the structures located in medial temporal lobe. However, amygdale is not included since it does not support declarative memory).

Squires et al. believed that medial temporal lobe is derived from various cortical areas of the brain; i.e., after repeated processing information in the middle of focused point; at the same time, medial temporal lobe projects back to these cortical areas. Hippocampal structure will connect scattered points of memory storage to form the more persistent cortical contact; therefore the system of medial temporal lobe is helpful for combining scattered memories to generate a coherent memory trace, and the trace can then be accessed through a variety of ways.

In 1993, Zola-Morgan et al. confirmed through experiments[64] that diencephalon (including thalamus and hypothalamus) region, which is near the hippocampus, is closely related to declarative memory.

These analyses suggest that the neural mechanism of memory that relates to imagery thinking of long-term memory (declarative memory) distribute in medial temporal lobe and diencephalic regions. These structures belong to medial temporal lobe in the marginal system of the brain, which is not on the left and the right

[62]Squire and Knowlton (1995).

[63]Squire and Zola-Morgan (1991).

[64]Zola-Morgan and Squire (1993).

hemisphere of the brain cortex. As for brain functional localization of object imagery generation and processing beyond long memory, (also the brain functional localization of the process of imagery thinking in addition to long-term memory) it has been mentioned in Sect. 3.3 of this chapter. In 1993, Jonides' research group at Michigan University used an advanced technology, which combined both PET and MRI, found the following results through repeated tests and experiments.

Generation and processing mechanism of object imagery exists in the left hemisphere inferior temporal gyrus (concentrated on the Brodmann 37 Area, positioning coordinates in space: 48, 58, −11), left hemisphere parietal lobe (concentrated on Brodmann Area 40, positioning coordinates in space: 35, 42, 34) and anterior cingulate gyrus (concentrated on Brodmann Area 32, positioning coordinates in space: 1, 14, 43); object working memory is in the left hemisphere of prefrontal cortex (concentrated on Brodmann Area 6, positioning coordinates in space: 39, 3, 29).

In the above functional modules closely related to imagery thinking, a neural mechanism of the long-term memory is in the marginal system in hippocampus and diencephalon area (not in the cortex of the left and right hemispheres). The neural mechanisms of the rest of the functional modules (including functions of imagery's matching, adjustment and reconstruction) are mostly in the left hemisphere while the working memory of the rest of the functional modules are also in the left hemisphere. Thus, the imagery thinking process occurs mainly in the left hemisphere rather than in the right hemisphere of the brain. In the past traditional opinion considered that imagery thinking is mainly in the right side of the brain (or even completely in the right brain), which is lack of scientific basis.

3.6.3 *Intuitive Thinking Model Based on Psychology and Neurophysiology*

Materials of intuitive thinking (object of thinking processing) are spatial position relation imagery (simple intuitive thinking) or spatial structure imagery (complex intuitive thinking). These two kinds of spatial relation imagery, although the same as object imagery belong to the category of spatial visual imagery, their production and processing process, compared with object imagery, have great difference. Smith et al.,[65] hypothesized that generation and processing of space imagery is as follows: when an individual perceives the spatial position of an object, the posterior parietal cortex exists a processing mechanism to calculate the target specific position. The result of the calculation is fed to imagery generating region of the occipital cortex to generate mental imagery (spatial position representation) corresponding to the specific location.

[65]Smith and Jonides (1995).

The position representation similar to the matrix representation, containing all the related location information required, allowing the target object occurs with sequence and structure (i.e., which contains all the information needed. After this spatial imagery is produced, the target object during presentation is responsible for temporary by the right prefrontal cortex; namely the working memory of spatial imagery is in the right prefrontal cortex.

On spatial relations as object of processing, imagery generation and processing (i.e., complex intuitive thinking), compared with spatial position relationship, experiments were much harder to conduct, yet the experimental study and reports rarely found in the literature. However, since both of them belong to spatial relations (one is location relations and the other is structure relations which are more general), there must be commonality in each other. But the structure relation is more complex.

Based on the above two different spatial relation imagery in the production and processing situation, this could be immediately made based on psychology and neurophysiology of intuitive thinking model, but unsatisfactorily, in Smith's hypothesis emphasis is on calculating position by the processing mechanism of the posterior parietal cortex, unrelated to long-term memory. In fact, for any object position determination, in addition to the perception of the position signal, and there is also the need of individual original cognitive structure (the past knowledge and experience), and the judgment of the relationship between the spatial structure is even more so. In the process of dealing with more complex structure relations, it often relies on the guidance, regulation and control of the second signal system (results of logical thinking). Considering these factors, we can obtain an intuitive thinking model based on psychology and neurophysiology as shown in Fig. 3.6.

3.6.4 Brain Location of Intuitive Thinking

Figure 3.6 shows that intuitive thinking model, based on psychology and neurophysiology, is different from imagery thinking in the methods of processing. But its functional structure is similar—including long-term memory, working memory and imagery generator module. Because long-term memory in intuitive thinking process also belongs to the declarative memory, so the module of brain functional localization and imagery thinking is the same (i.e., positioning in the limbic system of the medial temporal lobe and diencephalic regions).

Generation of space position imagery and generation and processing of brain functional location outside long-term memory (i.e., the brain functional location of intuitive thinking process in addition to long-term memory) in the third section of this chapter once mentioned and Jonides' research group at the Michigan University in 1993 by PET and MRI combining technology obtains the following results:

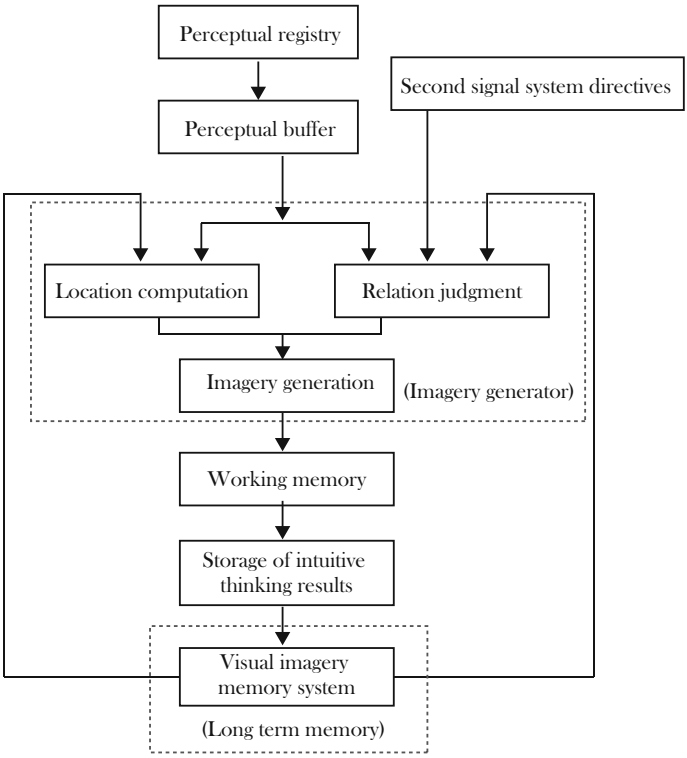

Fig. 3.6 The intuitive thinking model based on psychology and neurophysiology

The production and processing mechanism of space position imagery is in the right hemisphere occipital (concentrated in Brodmann 19 Area, positioning coordinates in space: 30, 76, 31), right hemisphere of the posterior parietal cortex (concentrated in Brodmann Area 40, positioning coordinates in space: 36–42, 40, 36) and right hemisphere of the premotor Area (concentrated in Brodmann Area 6, positioning coordinates in space: 34, 1, 45); spatial working memory is in the right hemisphere prefrontal cortex (concentrated in Brodmann area 47, positioning coordinates in space: 35, 19, 2).

Evidently, in the above function module of simple intuitive thinking, in addition to the long-term neural mechanisms of memory that is in the limbic system (not in the cortex of the left and right hemispheres), the rest are all located in the right hemisphere of the brain. The results of this experiment, though reached just using spatial imagery as object of processing, but due to the space position imagery can be regarded as a sub-class of spatial structure imagery (spatial position relation is a special case of a more general space structure relations). Therefore, we believe that spatial-intuitive thinking mainly occurred in the right brain but not in the left (i.e., right brain mainly in charge of intuitive thinking). This traditional view has a scientific basis.

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Chapter 4
A Model of Creative Thinking

4.1 Interdependence of Temporal-Logical Thinking and Spatial-Structural Thinking

In Chap. 2 we proposed that human thinking has two basic forms: temporal-logical thinking and spatial-structural thinking, according to definition of thinking and inseparability of matter movement in time and space. Since 1980s, a group of scholars, led by Professor Qian Xuesen, supposed that creative thinking is one of the basic forms of human thinking.[1] This academic view is worthy of attention, because It's closely related to training innovative talents. However, we believe that creative thinking and the cultivation of innovative talents, as creative activities, have irreplaceable importance, and it's of a higher level of thinking above temporal-logical thinking and spatial-structural thinking. Creative thinking is not one of the basic forms of thinking as the former two types, nor equivalent, or parallel with the other two types. In order to explain the essential features of creative thinking, we should first of understand the interrelations and features between the first two forms of thinking.

We pointed out earlier that, according to the materials of thinking (i.e., object of processing), spatial-structural thinking can be further divided into two categories: one is *attribute imagery* of basic attribute of things (also known as *object imagery*) known as imagery thinking; another kind is imagery of position relations or spatial/structural relationship (hereinafter referred to as *relation imagery*) known as intuitive thinking. Looking at the issue this way, the basic forms of human thinking usually include three types, i.e. *logical thinking, imagery thinking* and *intuitive thinking*.

According to traditional concepts, the three types of thinking are independent and unrelated of each other. Bias of the sorts often appeared in the past years. They took the form of either one-sided emphasis on logical thinking, ignoring imagery

[1] Yang (1997).

K. He, *A Theory of Creative Thinking*, Lecture Notes
in Educational Technology, DOI 10.1007/978-981-10-5053-4_4

thinking and intuitive thinking. Or the reverse, one-sided emphasis is on the latter and negating the former. As a matter of fact, these two (three kinds) basis forms of thinking, though with difference, are not uncorrelated or mutually exclusive. Instead, they are interrelated, mutually reinforcing. That is obvious to see from philosophical point of view, since the movement of matter is inseparable in time and space, then temporal-logical thinking, which is directly related to time (i.e., directly related to the space, the thinking that makes generalization and indirectly reflects things from the perspective of movement and change, i.e. spatial thinking), and space related spatial-structural thinking, are of course not separable (i.e. from space perspective of movement and change of things make generalization and indirectly reflected things; imagery thinking and intuitive thinking). Recent studies in psychology and neurophysiology also prove this point with more and more facts.

4.1.1 Interdependence of Logical Thinking and Imagery Thinking

4.1.1.1 Logic Thinking Based on Speech Concepts Cannot Be Separated from Imagery of Things

The imagery of things includes visual imagery, auditory imagery, and tactile imagery, olfactory imagery, gustatory imagery, and kinesthetic imagery, representing of senses of sight, hearing, smell, taste and touch; of which the most essential ones are auditory and visual imagery (especially visual imagery). The relation between temporal-logical thinking based on concepts of speech and imagery of things can be explained in the following two aspects.

(1) *If formal structure of language does not link to imagery, it cannot express any idea*

Language changes in phonology, loudness, tempo and length of symbol sequence, but the change is very limited. If not linked with imagery, only dependent changes in language, it would be impossible to set up a complex semantic system. In this respect, language and music has a big gap. Words in a sentence are a simple, linear sequence, while music can be a variety of melodies and various music cooperation and transformation in harmony, duet, trio and organum.

Just as what Arnheim, a famous professor of aesthetics at Harvard University, pointed out: “If we ask the question of whether the ‘form’ in music area can help thinking, what can we answer to this question? I mentioned before that there’s a complex relation among the tones in diatonic scale of western music. A pentatonic scale is divided into five equal distance to imply a relatively simple idea; but even if the so-called primitive music often becomes very complex because of the interaction of various structural changes which have many length, ratio, rhythms of change, varied relations between harmony and melody of tunes, strength of various ranges and levels, and different sounds caused by different instruments. To grasp

these complex patterns, thinking needs to be involved, but the brain needs to work very hard. Musical thinking begins in the form of the media, though the content of musical statement is drawn from life experience beyond the field of music."

Evidently, the structure in the form of music is rich and varied, forms and structures of the music express a variety of complex ideas and inspire a variety of emotions; and yet language merely relies on forms alone cannot make it. The sound of speech may sound wonderful, beautiful, making people resonate, entirely due to the fact that people link it to imagery of things, which gives language concepts specific meaning from the phonetic symbols (or auditory imagery). That is to say, concepts of speech can become essential materials of logical thinking, and it's not the form of language. The biggest advantage of this kind of imagery, especially visual imagery, is that it can provide concrete and visual (three-dimensional) images of objects or events, and it has a clear and stable factual meaning. So language must not be separated from the form; otherwise, language (either verbal or written) would become a pile of meaningless strings of symbols.

(2) *Concepts of abstract language are derived from the concrete images of things*

For example, the word *profound* originally expresses "profound thought" and "profound theory"; yet profound theory and specific depth of wells are described with the same word "深" (*depth* in English), both in Chinese or in English. In English *profundity* is originally from Latin *fundus* (basal, the bottom). The idea "deep" is invisible, intangible, and will not be able to imagine without the aid of visual imagery of physical depth. Arnheim cited many instances: an argument can be said to be *sharp*, various theories can be *harmonious*, or *inconsistent*, a political atmosphere can be *nervous*, a regime can be *corrupt, or* even issued *foul*. In short, people can count on their feelings of all abstract concepts with perceptual equivalents (isomorphism), because these concepts initially come from perceptual experience.

4.1.1.2 Imagery Thinking Based on Attributes Imagery Cannot Be Separated from Speech Concepts

Imagery of things, though has the two advantages (concrete and intuitive imagery and a clear and stable meaning) mentioned above, are not enough to form a truly rigorous scientific thinking. Words and concepts of speech are indispensable as help and support. This is because:

(1) *Speech concepts can provide a clear and definite symbol for each imagery.*

Generally speaking, all things directly obtained from perception are in a continuous, unified and objective world (mainly the visual world), and There's no clear boundary between images. The fuzziness of imagery is detrimental to imagery processing (regardless of analysis, synthesis, abstraction or generalization); rigorous scientific thinking requires clear classification, and concepts based on language just satisfy this requirement—for each icon is provided with a clear and precise symbol. In this occasion words of concepts are like pointers, which point out those meaningful

peaks from the profile of rolling ranges of horizon.[2] Although these pointers are only a number of symbols, They're conducive to the thinking process of imagery distinction and recognition, but also greatly conducive to processing imagery.

(2) *Speech concepts can be used to represent different levels of abstraction for imagery.*

On this issue, Arnheim cited a very vivid example[3]: we can call a creature animal, mammal, cat, a cat or Cat Josie and so on. This level of abstraction is not optional; it depends on the level of abstraction required for a particular situation. For example, if There's a mouse in the house, a cat is needed to catch the mouse; here the cat is not specified which cat, as long as It's a cat. But if it indicates that the old Josie needs to catch that mouse, here it means Josie but not any other cat. This means that the abstraction level of an object has been shown at the time of perception. These different levels of abstraction cannot be distinguished only by images, but can be distinguished by using concepts of speech, thus the contents and results of thinking being accurately expressed.

(3) *Speech concepts are easy to represent relations between things.*

People can form a variety of imagery of different things, but without the help of language, It's difficult to express the relations between various images. For example, we have an image of the lion. There are also concepts of mammals, vertebrate, cat, soft animal images and so on. If you do not use language, you cannot express the existing relations between these images. However, sentences like *The lion is a cat* or *The lion is a mammal of the cat* can help us clearly reveal the relations between them. Also, when it comes to Mr. X and Mr. Y can evoke two images of two persons, the two images are independent of each other; only from the two images one cannot see who they're. But the sentence *Mr. X is the teacher of Mr. Y.* can clearly show the relation between the teacher and the student.

The three facts above show that with attribute imagery as materials of imagery thinking, it cannot be separated from words and concepts for help and support, if one wants to be more precise, more scientific, reflecting the nature of objective things (rather than simple and rough reflection).

4.1.1.3 Mutual Connection and Support Between Logical Thinking and Imagery Thinking

From the above analysis, we can see the two types of thinking (logical and imagery thinking), in a great extent, relate to their objects of processing, i.e. materials of thinking. Logical thinking, based on words and concepts, need images, visual images of things as contents, in order to make the thinking contents alive with flesh

[2]Arnheim (1969).

[3]Arnheim (1969).

and blood, with vitality; and imagery thinking, based on attribute imagery, also relies on words and concepts for help and support, in order to make images with abstraction and generalization, and better reflect the nature of things. Evidently, these two forms of thinking are complementary and inseparable. Ideal logical thinking should have vitality and intuitiveness of rational thinking, which is unlike traditional, pure rational, completely unrelated to specific things. Ideal imagery thinking should also have abstraction and generalization, which can reflect the essential features of things—advanced rational thinking, rather than traditional view of imagery thinking that has only images and intuitiveness (without abstraction and generalization). This type of imagery thinking cannot reflect essential features of things—a low-level perceptual thinking. In other words, logical thinking and imagery thinking can both reflect the nature of things. So both belong to rational thinking (not perceptual thinking), both have no difference as inferior or superior and both relate to each other, with mutual support. The only difference between them is the different materials for thinking. In fact, in real life, apart from the infant, everyone has mastered language with the words and concepts, and not just think in images. With adults, logical thinking and imagery thinking both are often intertwined, very difficult to separate completely. One can only say that one type of thinking plays a relative dominant role, even in the case of professional artists (more of imagery thinking) and of theorists (more of logical thinking).

4.1.2 Interdependence of Logical Thinking and Intuitive Thinking

Materials for intuitive thinking are spatial-relation imagery (including spatial-location relation and structural relation imagery). Both spatial relation imagery and attribute imagery for reflecting basic attributes of things, and for recognition of attribute imagery (also known as object imagery) belong to spatial perception imagery. Therefore, as long as attribute imagery, mentioned in the previous section, expands a little to include spatial relation imagery, then the first argument that imagery of logical thinking is inseparable from imagery of things is still valid. (in fact, in the above argument does not limit what kind of imagery). In addition, intuitive thinking, corresponding to the second argument (imagery thinking based on object attribute imagery is inseparable from the concept of speech), should be intuitive thinking based on spatial-relation imagery and cannot be separated from the concept of speech. Obviously, under the situation of imagery thinking, three arguments were put forward in order to prove the proposition (speech concepts provide clear symbols for imagery, describe different levels of abstraction, and reflect complex relations between images). These arguments are also true for intuitive thinking (by considering object attribute imagery as spatial relation imagery). Especially in the case of spatial complex relations (such as sub-relations of the relationship, or the occasion to consider the occasions of links between different relations), speech concept description plays more important, irreplaceable role.

In the same way, the third argument above (i.e., the mutual connection and mutual support between logical thinking and imagery thinking) also holds true for logical thinking and intuitive thinking. Localization neural mechanism of logical thinking, based on words and speech, has been confirmed mainly in the left hemisphere; the localization neural mechanism of intuitive thinking has been confirmed in the right hemisphere (see Sects. 3.3 and 3.6, Chap. 3). Hence it can be further confirmed with experiment through split brain (the patient, for need of treatment, had corpus callosum incision, so that the connection of two hemispheres is severed, such patient is known as a split brain).

In the experiment, the patient dubbed E.B.,[4] who had a number of tests before surgery, included a metal wire composition test designed specifically for the study of specific right hemisphere phenomena by Milner and Taylor. After target objects were removed, E.B.'s hands can perform composition operation, suggesting that before the surgery on E.B., the intact calluses can, through the right hand, send left brain command to the right hemisphere spatial-relation imagery processing area. But after the operation, E.B. was just like the other split brain, and cannot name the object placed in the left hand. However, more important finding is that E.B. could no longer use two hands to complete the work of the metal line composition. E. B. could complete this operation before the surgery, so it showed that when the left and right hemispheres were connected, he could do it with support and help of speech and concepts of logical thinking. This is another neurophysiologic evidence for the right-brain composition operations (intuitive thinking). Speech concepts facilitate representing and revealing various relations between things (of course including space composition relations).

In addition, an experiment was conducted on a patient of carbon monoxide poisoning causing both sides of the brain occipital lobe damage, which also provided evidence for the above conclusions.[5] In this experiment, the patient's dubbed D.F., and the experiment required D.F. to insert a card into a narrow slot of a cylinder.

The narrow range of groove on the cylinder varies with position of the cylinder (cf. Fig. 4.1). When the groove and position of patient's hand-held card are perpendicular to each other (shows as Fig. 4.1), the patient was in any case not able to put card correctly into the slot—she did not know how to adjust her card in vertical position into a horizontal position slot.

But when D.F. was told how to adjust the card position, the patient could turn the card immediately and insert it correctly without hesitation (see Fig. 4.1b). This experiment clearly shows that the spatial orientation of D.F. is normal; otherwise, no matter what the guidance is, it's not possible to automatically insert the card into the groove of the cylinder. At the beginning, D.F.'s failure was because her brain was damaged, and she lost the ability to use words and concepts to make judgment on the relation between the card and slot location (she did not know in Fig. 4.1a that two positions were perpendicular to each other; namely relations did not match).

[4]Gazzaniga (1995).

[5]Gazzaniga et al. (1998).

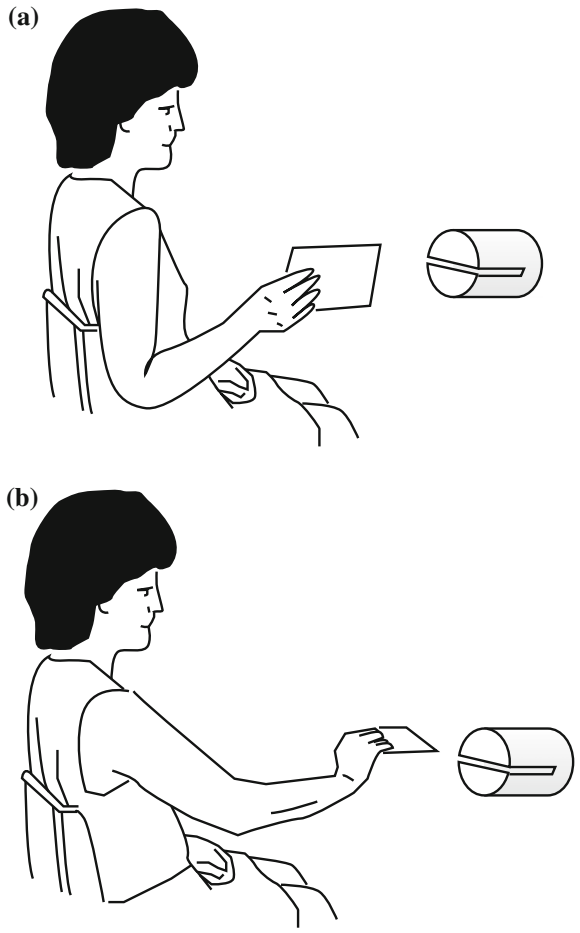

Fig. 4.1 The experiment in which D.F. was required to insert a card into a narrow slot of a cylinder

It's because of this, when the patient once accepted the verbal instructions, she could immediately complete the required work. This is the support of neurophysiologic evidence of logical thinking of spatial-relation operation based on speech concepts (belonging to intuitive thinking).

4.2 Classification and Definition of Creative Thinking

4.2.1 Classification of Creative Thinking

According to the goal of creative thinking, clear or vague, we can divide creative thinking into two categories: *incidental creative thinking* and *intentional creative thinking*.

Incidental creative thinking—the feature of this kind of creative thinking is that there's no very clear goal of creating beforehand, no detailed plans of elaboration about creation, and no steps, and thinking process is quite casual. Results generated by thinking are new, so there's novelty. This kind of thinking results does not necessarily have direct relation and influence for the progress of human civilization, does not necessarily translate into valuable intellectual products or material products, but the thinking may have certain positive significance and value (as a data storage or for its help in the future work).

Examples of incidental creative thinking are such as in painting exercise sometimes creative sketch was made; in daily life or interview process, typical personality traits of distinctive people were discovered accidentally; some innovative ideas temporary germination in experimental designs in the process of scientific experiments, these can be classified as incidental creative thinking.

Intentional creative thinking—is a thinking that has a clear goal; according to the size of the results of creative thinking, it can be divided into general creative thinking and advanced creative thinking.

General creative thinking—the feature of this kind of creative thinking is that there is a clear goal in advance, and in order to achieve this goal there were more careful planning and preparation beforehand; The results generated are unique and unprecedented, and innovative. The outcome of this thinking has certain positive significance for the progress of human civilization, it can be transformed into valuable intellectual products or material products.

The general artistic creation and new product design, common technical innovation and creating a small thing, small inventions, improvement of some theory and method, and so on, as long as the result of thinking is indeed unique and unprecedented—all can be included in general creative thinking category.

Advanced creative thinking—the feature is basically the same as general creative thinking; only the processing mechanism is more complex and the result has greater (or major) importance for the progress of human civilization, which is likely to translate into a larger (or major) value of intellectual products or material products. In advanced creative thinking, there are some results that are new, unprecedented, and some of them are discovery of the nature of things or internal relations between things which the predecessors have never revealed. This kind of creative thinking is of great significance to human civilization and progress, and the results can be translated into intellectual products or material products of momentous value.

Artists (in fields of music, painting, sculpture, and literature) created immortal masterpieces and scientists explored the nature of things and found various principles, laws—all of which can be classified as advanced creative thinking.

Advanced creative thinking is most valuable and most important creative thinking, but this thinking is not out of the air but developed on the basis of incidental creative thinking. In-depth analysis of the processing mechanism of different creative thinking and relations between them has a vital significance to cultivate a large number of advanced creative thinkers. In a word, the division of creative thinking is by no means subjective conjecture, but objective needs of

training innovative talents. Conventionally, if only had a general concept of creative thinking without further analysis as well as research, we cannot understand the basis of advanced creative thinking, cannot make known processing mechanism of creative thinking and mental model, and will never get rid of the blind state in cultivation of innovative talents.

4.2.2 Definition of Creative Thinking

As mentioned in Chap. 2, thinking is defined by the current psychology and philosophy as: the generalization and indirect reflection of the nature of objective world and inherent relation between them by the human brain. Strictly speaking, such a definition does not seem to reflect full range of meaning of thinking, because such a definition, though it covers general human thinking forms, yet it fails to cover creative thinking. As is known to all, the purpose of creative thinking is to create unprecedented, valuable intellectual or material products. Since they're unprecedented, new things or new discoveries, it's impossible to limit to generalization and indirect reflection of the nature of things and inherent relations between them by the human brain. In other words, in addition to generalization and indirect reflection, it should also add a sort of initiative reflection, in order to meet the requirements of creative thinking.

This initiative feature of thinking should not be limited to the original things, and merely a passive reflection of physical world, but should be active reaction to imagery of things; thinking can happen, through imagery operation by integration, transformation and reconstruction, to create new attribute imagery or relation imagery; on the basis of the operation unprecedented intellectual or material products can be created. Therefore, if creative thinking is taken into account, we believe that thinking should be defined as: the human brain's generalization, indirect and active reflection on the nature of physical world and internal relations between things. How can we make this initiative reflection? To answer this question we need to analyze the processing mechanism and psychological model of creative thinking.

4.3 Processing Mode and Mental Operation Model of Incidental Creative Thinking

4.3.1 Processing Mode of Incidental Creative Thinking

The feature of incidental creative thinking is incidental; i.e. there's no clear goal, also it does not need elaboration on the process beforehand, nor plans or steps; the creativity in the results of incidental creative thinking is not high, and the practical

significance and value is relatively small; sometimes the results are very similar to, or even indistinguishable from that of reconstructive imagination. The only difference between the two is that reproductive imaginative thinking has been described and recognized by others or predecessors while incidental creative thinking is novel and unique. The method of processing is approximately the same; both are realized on the basis of divergent thinking and associative thinking with intrepid imagination.

Divergent thinking is also called multi-directional thinking, or reverse thinking. It's not a basic form of thinking, because it does not involve materials of thinking and the process of thinking; its features are only based on "pointing" to the targets (centralized or decentralized, a single target or multiple targets, considering positive side or negative side, convergent or divergent). The purpose is to open up the ways of thinking, expand people's vision, and not to be restricted by traditional ideas, concepts or theories.

Associative thinking, under the guidance of certain thinking objective, through similar forms, opposite forms (such as various forms of association), fully mobilizes thinking participants' original cognitive structure and current thought related to the theme (knowledge and experience and the variety of images stored in the long-term memory), for provision of rich materials as much as possible for reproductive imagination and creative, imaginative thinking process.

In short, incidental creative thinking and reproductive imagination, depending on divergent thinking to expand the field of vision, to open up ways of thought and to provide rich materials for processing by association, finally use bold and reasonable imagination (i.e. using various images from association for further restructuring, integration, transformation and re-construction) to develop new imagery. If this new imagery reflects novel, unique things, then the thinking process is incidental creative thinking; on the contrary, if the new imagery reflects the things that others or predecessor have been recognized and described, then the thinking process is the process of reproductive imagination. Due to the results of this thinking depends alone on three simple processes (cf. Fig. 4.2a): divergence,

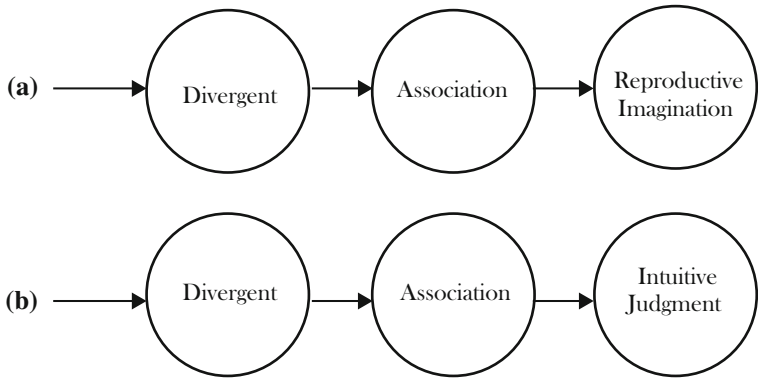

Fig. 4.2 Two ways of processing modes of incidental creative thinking

association and imagination (referring to reproductive imagination), even for incidental creative thinking, it is impossible to have great significance and achievements for human civilization and progress; it cannot be scientific discovery, only has a certain value to the participant of thinking.

There's also other type of incidental creative thinking, the results of which does not reflect the nature of new things, i.e. attribute/object imagery, but to reflect the inherent relation between things, i.e. spatial-relational imagery. At this time the process of incidental creative thinking processing also consists of three links, but the third link is not reproductive imagination but intuitive judgment as shown in Fig. 4.2b.

There is one thing which need to be pointed out. Although logical thinking is not in Fig. 4.2, it doesn't mean that logical thinking has no impact on the process of incidental creative thinking. In fact, as previously mentioned, any imagery thinking or intuitive thinking is interdependent and inseparable from temporal-logical thinking. (cf. Sect. 4.1, Chap. 4). That is, the association and reproductive imagination in Fig. 4.2a as well as the association and intuitive judgment in Fig. 4.2b are definitely under the guidance of logical thinking and the restriction of speech concepts. The effect of logical thinking is weak since the thinking in this situation is optional and without clear creative goals. Therefore, the logical thinking is not clearly indicated in Fig. 4.2. However, association, imagination or intuition is always supported by logical thinking, which must be noticed and remembered.

4.3.2 Mental Operation Model of Incidental Creative Thinking

By Fig. 4.2a, b one can see, the two processing modes of incidental creative thinking are serial, linear processing; in fact, this is not true. Figure 4.2a, b is just a simplified schematic presentation, which fails to reflect specific thinking process. For example, in the link of associative thinking, when we associate with a familiar object, the imagery of object was related to multiple attributes often appearing at the same time; on the screen of the brains, one only sees the shape and size of the object, also see its color and motion state. In addition to these visual imagery, and sometimes related to auditory imagery (such as the roar of an animal, or someone's laughter), gustatory image (such as the thought of arbutus) also appears. These images, which reflect different attributes of the same object, are presented at the same time, but not in sequence. In other words, in the association link, actually there are numerous coexisting perception channels processing at the same time (concurrent processing); here we use the term concurrent processing, not commonly referred parallel processing, in order to include the interaction between processing pathways (see Sect. 5.2, Chap. 5). In reproductive imagination link we use the same term—because the two steps involved in the processing and the association link is the same, reflecting different attributes of things, i.e. attribute imagery, and only the

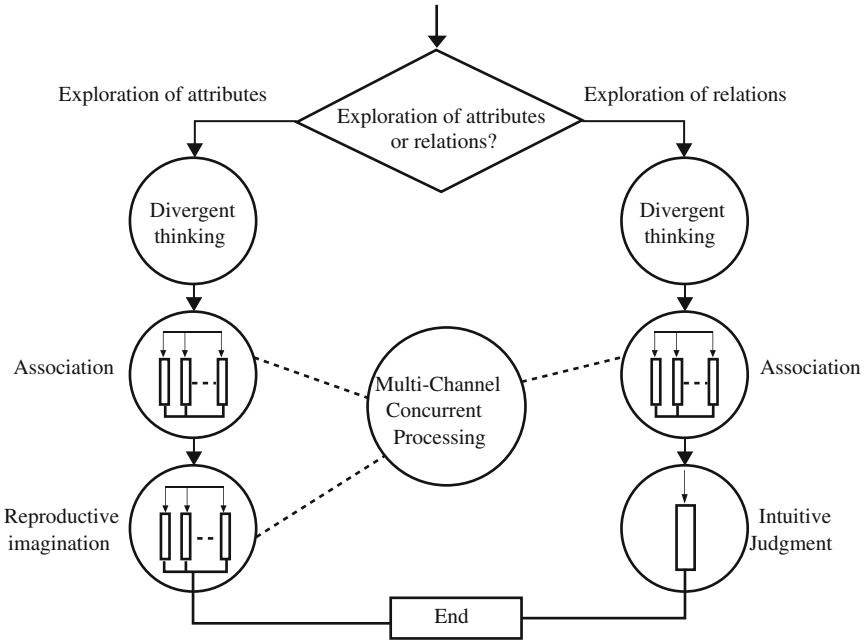

Fig. 4.3 Mental model of incidental creative thinking

two processing modes are different. However, in "intuitive judgment link", it will be different—since the material used by intuitive thinking is spatial-relation imagery ("relation imagery" for short), as mentioned before, relation imagery belongs to spatial-visual imagery. In other words, relation imagery only involves visual channel. Therefore, for the intuitive judgment link, generally, varieties of perception channel are not involved. This indicates that the two processing modes, shown in Fig. 4.2a, b, are actually coexistent, linear processing: between the three links it's serial processing while in association and imagination it's coexistent processing. On the basis of this, we can get a mental operation model of incidental creative thinking based on linear processing, as shown in Fig. 4.3.

From the above analysis, it can be seen that incidental creative thinking is the lowest and simplest level of creative thinking; essentially, it's not much of difference from reproductive imagination (but the depth and results of processing are different). Therefore, we can ask: *Does this kind of thinking have any value? And is it worth seriously study?* We believe that it's the characteristic of incidental creative thinking that we should pay enough attention. This is because:

First, it offers us with a bridge which ensures the smooth transition from general imagery thinking (reproductive imagination) to creative thinking, so that we see clearly natural connection of creative thinking and imagery thinking, thus helping getting rid of the mystery over creative thinking, and establishing a belief that common people can develop and enhance creative thinking abilities.

Second, the processing mechanism of incidental creation thinking can help basic education (especially primary school education) to find a way to cultivate effectively creative thinking in the early elementary school in different grades. Figure 4.3 shows two groups of linear processing links. Figure 4.3 is a diagram of thinking mechanism of incidental creative thinking, and it's also a specific instruction and the operation process of cultivating creative thinking ability: three links, a ring links the other rings, each link has its irreplaceable, specific function in creative thinking; all three are indispensable to each other.

Third, incidental creative thinking is the basis of advanced creative thinking (latter part of this section will demonstrate this in detail). Without this foundation, cultivation of advanced creative thinking will become the castle in the air. As long as our principals and teachers realize the importance of this foundation and ways of cultivation, the foundation is not difficult to lay, because as mentioned above, the method and way to cultivate incidental creative thinking are simple and clear, as long as we follow two processing mechanisms and firmly grasp the three links, in a coexistent, linear processes. Unfortunately, over the years in the education sector, there are at least two faults over this.

One is to pay no attention to the cultivation of young incidental creative thinking. It is generally believed that creative thinking is advanced and complex, which makes people feel unattainable. Principals and teachers do not know where to start; do not know how to enable students to gradually master the ability.

The second is to take an isolated and fragmented attitude to the research into mental processing mechanism of incidental creative thinking. In Fig. 4.2 the three links have been studied over the years, with many of the research (countless books) resulted. In these books one generally finds two shortcomings: first, not treating the three links as an indivisible unity but take the attitude of isolation, and fragmentation. Some researchers were biased and exaggerated the role of divergent thinking as if divergent thinking is creative thinking, or divergent thinking is equivalent to solution of all problems of creative thinking. The representative of this view is the Guilford's. This one-sidedness is obvious; divergent thinking is indeed very important for creative activities. But it's, after all, an issue of orientation, without involvement of processes. Therefore, we must pay full attention to divergent thinking, but not to exaggerate its roles. Some others emphasized and exaggerated the role of association, or put aside divergence and association and or simply over-stressed and embellished the role of imagination. Although these views have their reasonable side, they're one-sided, so it's difficult to achieve the desired results. They do not realize that only by combination of the indivisible three mental processing links can they effectively cultivate incidental creative thinking. Second, they confuse intuitive thinking and imagery thinking, and cannot recognize that they're of two different processing mechanism. In fact, as mentioned earlier, intuitive thinking and imagery thinking, whether object of processing (i.e. materials of thinking) or methods of processing, are not the same. The actual effect of the confusion is to cancel off the study of intuitive thinking, not to mention the

conscious cultivation of intuitive thinking. Due to the presence of the above two disadvantages, how can we expect our schools effectively cultivate a large number of talents with creative thinking?

4.4 Processing Mode and Mental Operation Model of Intentional Creative Thinking

4.4.1 Processing Mode of Intentional Creative Thinking

As mentioned above, intentional creative thinking includes general creative thinking and advanced creative thinking; there's no essential difference in their processing mechanisms, except for a difference in depth of processing, and therefore these two kinds of thinking can be discussed together.

There are two big differences between incidental creative thinking and intentional creative thinking. Firstly, intentional creative thinking, with a creative clear goal, has more thorough planning and preparation beforehand. The reason to formulate clear goals are generally because of the greater difficulty, requiring long deliberation, preparation and accumulation, and achieved not by accident, or chance; secondly, creative thinking results have higher value, and need to be completed through complex psychological processing. It's due to the above two reasons, intentional creative thinking cannot follow coexistent, simple, linear processing mechanism as incidental creative thinking and must find other path.

In Chap. 2 it's pointed out that the means and methods of imagery thinking include analysis, synthesis, abstraction, generalization and association, reconstruction, imagination, and reproductive imagination and creative imagination and so on. These processing methods involve imagery decomposition, abstraction, integration, transformation and reconstruction. The analysis, abstraction and association mainly involve imagery decomposition and extraction (imagery in the processing process remains unchanged in composition and structure); integration and summarization mainly involve imagery reorganization and integration; reproductive imagination and creative imagination (without relation to imagery recombination and integration), and also include imagery transformation and reconstruction (imagery in the restructuring, integration, transformation or reconstruction processes may change in composition and structure). Although several latter processing methods can lead to changes in imagery composition and structure, in addition to creative imagination, all other processing results are recognized and described by predecessors or others, which cannot meet the standards of initiative reflection for creative thinking, only the results of creative imagination can find or create unique and unprecedented imagery. In this sense, we believe that creative imagination is one of the key links in creative thinking.

Creative activity is not only reflected in the creation of new things, but also reflected in inherent relations between things. As mentioned earlier, understanding

and grasp of spatial- structural relations between things usually complete the mastery of complex intuitive thinking. This is because the thinking material for imagery thinking is attribute imagery, rather than spatial-structural relation, so imagery thinking cannot complete such tasks. Thinking materials used in temporal-logical thinking are based on concepts of speech, which also contain structural relations between things, which supposedly can discover laws of internal relation between things. But unfortunately, as mentioned earlier, the essence of logical thinking is one-dimensional time axis linear processing, through step-by-step analytical reasoning by concepts of known things to problem-solving. For the relations between the unknown, there's no reflection of concepts of things and no concepts of links; therefore no logical analysis and reasoning can be done. In other words, temporal-logical thinking can only be used to analyze and deal with the relation between what is known and the nature of what is known, which can apply existing knowledge to solution to practical problems, and it's not possible to directly use temporal-logical thinking to find implicit relation between unknown things and essential attributes of things we did not yet know. It's for this reason that we believe that complex intuitive thinking is another essential part of creative thinking.

Evidently, in order to realize creative thinking, two key links are needed: *creative imagination* and *complex intuitive thinking*. The former is used to create imagery of unprecedented new things, or is used to find attributes of new things; the latter is used to find regularities of inherent relations between unknown things. Having these two key links is not enough. As described in Sect. 4.1, Chap. 4, logical thinking and spatial thinking (i.e. between the temporal-logical thinking and imagery thinking, intuitive thinking) are mutually support each other and interdependent, and without the support from the one, the other cannot exist. Creative imaginative thinking and complex intuitive thinking are advanced stages of imagery thinking and intuitive thinking, so the two stages of temporal-logical thinking should meet requirement of mutual support and mutual dependence, as long as imagery thinking and intuitive thinking (whether It's the primary or advanced stage) cannot do without logical-thinking from the help of concepts of speech in three aspects (verbal concepts provide a clear symbol of images; describe different levels of abstraction; and reflect complex relations between all kinds of images); similarly, when using language concepts to describe spatial relations or describe the complex structure of creative imagination, temporal-logical thinking cannot do without spatial-relation imagery of related things and without strong support of attribute imagery (i.e., support of imagery thinking and intuitive thinking). Due to the fact that these three kinds of thinking mutually support and help one another, it indicates that psychological processing mechanism of incidental creative thinking should be circular nonlinear structure which is shown in Fig. 4.4 (not the linear structure shown in Fig. 4.3). Therefore, intentional creative thinking process is much more complex than incidental creative thinking process. Incidental creative thinking through simple linear processing, sometimes produce different and fresh thinking results, mainly due to the fact that the thinker usually has abundant and profound knowledge and experience accumulated, and often triggered by some

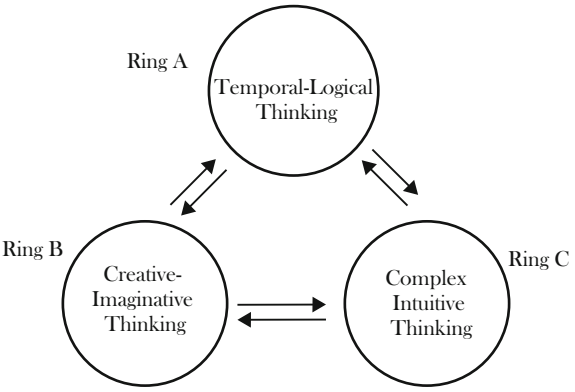

Fig. 4.4 Processing modes of intentional creative thinking

external stimulus, inadvertently reconstruct a new imagery of things (for example, cited earlier in painting practice creative sketch suddenly germinate, or some new experimental design in experiments). In this kind of thinking results, though with certain novelty and without long simmering and deep thinking, the degree of creativity is relatively low, which cannot compare with intentional creative thinking with clear goals.

In circular nonlinear structure which is shown in Fig. 4.4, arrows between Ring A and B as well as arrows between Ring A and C actually have a double meaning: one is the embodiment of mutual support and interdependence between temporal-logical thinking and imagery thinking, and temporal-logical thinking and intuitive thinking; the second meaning indicates the guidance, regulation and checking functions of temporal-logical thinking to the direction and process of creative imagination and complex intuitive thinking, and at the same time reasoning and checking the results of creative imagination and intuitive thinking. On the first meaning, a detailed proof has been given in Sect. 4.1, Chap. 4 and there is no need to reiterate it here. On the second meaning it needs two points of explanation: one, logical thinking has the function of guiding, regulating and controlling imagery thinking (including creative imagination); this is the view of many psychologists and thinking experts.[6,7] The current psychology and thinking science community always confuse imagery thinking and intuitive thinking, supposing they're of the same kind, without distinction. A typical misnomer: imagery named intuitive thinking or imagery named perceptive thinking reflect this view. So when they say logical thinking has a guiding, adjusting and controlling effect on imagery thinking, they actually include creative imagination but also intuitive thinking. We do not agree with the confusion of imagery thinking and intuitive thinking, and advocate a clear distinction between the two, and it's correct for them to have the role of guidance, regulation and control of logical thinking to imagery thinking and

[6]Zhu and Lin (1991).

[7]Liu (1986).

intuitive thinking. This derives from years of observation with scientific basis, and we should adhere to it. Second, the so-called logical thinking has the role of guidance, regulation and control over imagery thinking and complex intuitive thinking results (results of this way of thinking is commonly referred to as inspiration or insight), with reasoning and checking; this is the personal experience of many famous scientists, including Einstein and Qian (see Blakeslee 1980[8]; Qian 1986[9]), so there's no doubt about it. The above analysis of Fig. 4.4 shows that the interaction between Ring A and Ring B and Ring A and Ring C is quite stable. The remaining question to conform is why the interaction also exists between Ring B and Ring C?

As we have mentioned earlier, creative imaginative thinking is used to create imagery of unprecedented new things or is used to find essential attributes of new things. Complex intuitive thinking is used to find intrinsic relations between things unknown. This is generally the case, and in certain circumstances it may also be the opposite; that is, creative imagination is more convenient to find intrinsic links between things. Complex intuitive thinking is more convenient create brand new imagery, or find essential attributes of new things. That is, in terms of creative activities, these two kinds of thinking are needed; they should be combined in order to flexibly choose according to the actual situation. In order to further illustrate the necessity and possibility of this combination, we will look at two typical examples of scientific discoveries.

Instance 1

In Sect. 3.5 (Chap. 3), we have cited the example of the *Archimedes principle*. In this case, It's required to identify whether the crown is made of silver or not. This was supposed to find the new nature of gold—gold density is known and crown quality at that time was not difficult to determine. Therefore, as long as the volume properties of the crown were calculated accurately, the above identification could be made. But because the volume of the crown is very irregular, it's a big problem to directly determine the essential attribute of the crown at that time. Could the measurement problem of irregular volume be converted to the regular volume to be measured? As long as they could find the equivalent of the crown volume, this problem would be smoothly or easily solved. Hence, measuring (or finding) crown volumetric attributes is converted into to finding the equivalent volume of the crown; that is to find equivalent relation between irregular volume and regular volume. It's under the guidance of this idea, when Archimedes settled himself in the bathtub, he found this equivalent relation, so that the problem was solved smoothly. We have mentioned earlier that this is an example of the use of intuitive thinking of scientific discovery. Obviously, this is also to convert the essential attributes of things (content of creative imagination) to finding the equivalence relation between

[8]Blakeslee (1980).

[9]Qian (1986).

things (complex intuitive thinking). This is a good example of the conversion made the problem easier to solve.

Instance 2

In contrast to Instance 1 (namely, the conversion of complex intuitive thinking to creative imaginative thinking), this is an typical example of discovery of the law of electromagnetic induction; in which Faraday found the law of electromagnetic induction. Faraday had long been able to guess the magnetic field that can generate electricity, and there was interaction between the electromagnetic. But it took eleven years to prove that it was a law of science. At first, he had been trying to find out how to generate electricity, and how to interact with the law of the magnetic field, and tested many programs, and the results were all failures.

Finally, he took another way, to do in-depth analysis through attributes and rules of the electric wire, magnetic field, and the basic properties of generation of electricity from the electrified wire. Faraday's observation, analysis of the many and the nature of the experimental phenomena made him most inspired and found the right-hand rule, because it not only revealed that electricity could be generated by the basic properties of the magnetic, but also could reveal that the relation of direction of the current on the wire and the direction of the magnetic force. Which made him realize that if the wire is coiled into a solenoid form but is not energized, and let the bar magnet in the solenoid to move to change magnetic field, it should be able to make solenoid wires produce current—such is the discovery of the law of electromagnetic induction. Faraday's original goal was to explore how the magnetic generates electricity, trying to discover the rules of magnetic and electrical interaction; it would have been typical of intuitive thinking content and the relation between magnetic field and electrical exploration. But he went along the direction for ten years without success.

Later, he, in turn, studied basic properties of electrical conductor (this is typical content of the imagery thinking). Due to the fact that prevailing understanding of the science community on the electrical properties was deeper than understanding of magnetic (right hand rule is the basic characteristics of electric wire through the accurate and intuitive generalization), which could achieve a breakthrough. This is the discovery of the intrinsic link between things (complex intuitive thinking contents) converting into an exploration of attributes of things (contents of creative imagination), which led to success.

It's based on the above two aspects of the facts, we think that in Fig. 4.4, Ring C and Ring B have interaction, which is factual and not fictional.

4.4.2 Mental Operation Model of Intentional Creative Thinking

Below we make a concrete analysis of the model shown in Fig. 4.4: processing methods and process of operation.

(1) By the use of temporal-logical thinking on the goal of current incidental creative thinking, one or several key problems, which should be solved to achieve the creative goal, will be obtained. Each of the key problems is named as a theme, and these themes will be represented as T1, T2, … and Tn. These topics will be stored in the theme list (which can be assumed that the theme list is stored in the first in first out sequence). Remove the top one from the theme list (T1) as the current topic, and then turn to step 2.
(2) The current theme as a processing instruction sending into Ring B or Ring C; if the current theme and exploration is of the essential attributes of new things, then turn to creative imaginative thinking of Ring B, namely to Step 3; if the current theme is to find intrinsic links between things, go into complex intuitive thinking of Ring C, namely to Step 4.
(3) This step is mainly in Ring B: the creative imaginative thinking activities and its processing method is shown in Fig. 4.5.

Processing directives from Ring A feeds into Ring B. First of all, let's consider that whether it's straightforward to achieve the requirements of the current directives

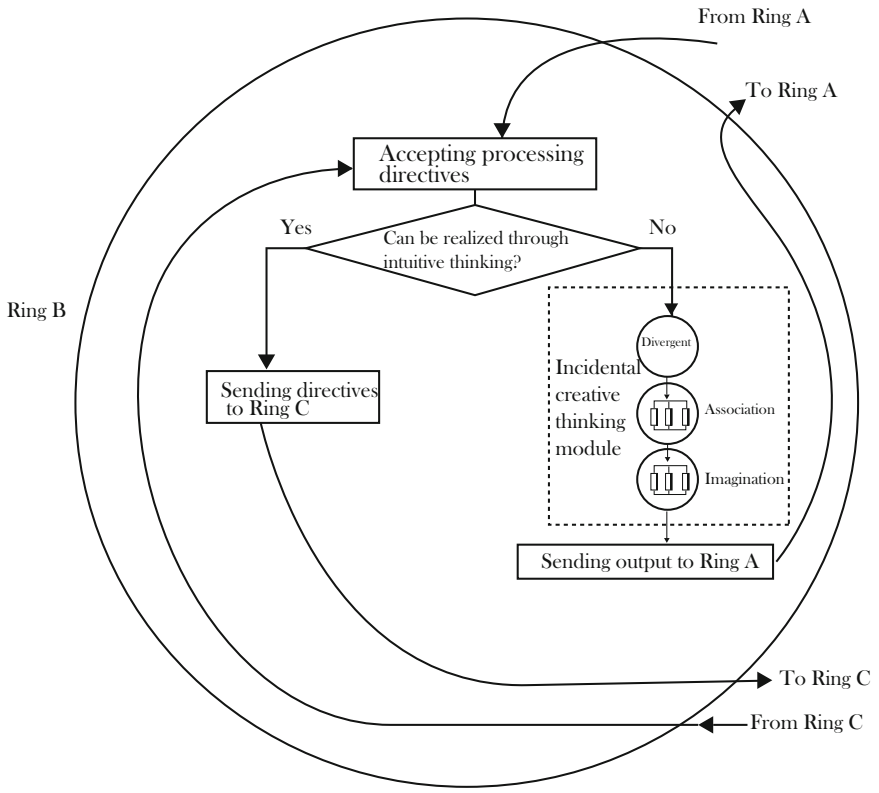

Fig. 4.5 Processing modes of Ring B

through intuitive thinking. If it's possible, the directives are forwarded to Ring C, which is equivalent to Step 4. Otherwise, it's dealt with by Ring B, then transferred to incidental creative thinking module; that is, going through divergence—association—imagination and other rings, according to current directive requirements for serial and concurrent linear processing. Due to the current directive guidance, regulation and control from Ring A (the directive reflects a theme in Ring A), this process, though following the processing method of incidental creative thinking, is not really incidental but with a clear purpose which is embodied in the directives. It's this kind of control of intentional or commanding control that plays an important role in the process of creative imagination. This is because the current goal is to create something new (or to find essential attributes of new things), and the materials used through association are imagery of what is known already, there will be nothing new about images (i.e. imagery reflecting attributes of new things). It's plain that only through simple reorganization or integration of the original known ideas, it will be very hard to achieve the requirements of creating something new; yet through transformation or reconstruction of the original imagery, it's possible to achieve the requirements. So, how should the original imagery be reformed and reconstructed? The directives from Ring A play a critical role in the transformation and reconstruction of the goal, thus reducing the blindness of processing. Nevertheless, due to the fact that creation of new things is not always easy, especially when things are of higher complexity level (the next section will go further dealing with the issue of complexity level), the difficulty will be greater. That is to say, in the beginning stages of processing, this situation often appears: After the processing directives are issued, because association ring cannot work out the imagery as the materials of integration, transformation and recombination to fit the requirements, incidental creative thinking module will not be able to process to fit the requirements (or close to the requirements). At this time the working memory area is in imagery thinking (object working memory mentioned earlier), and there will be blank phenomenon with no contents in memory store. In Sect. 3.3 (Chap. 3) it has been pointed out that the thinking process has four elements (*materials for thinking, methods of processing, processing buffer*, i.e. memory and *thinking processing mechanism*); as long as one of the elements is missing, the thinking process will be difficult to sustain. Due to the fact that working memory not only provides the cache for the imagery extracted by "associative" link from imagery subsystem in long-term memory, but also, for "reproductive imagination", provides cache of processing results for the procedure of integrating, transforming and recombining imagery. It's evident that when working memory is blank, either associative ring is not able to extract appropriate images, or processing mechanism will be able to produce results consistent with the requirements from the directives. In short, at this time there will be no information feedback to Ring A, the thinking process has been interrupted, or at this period of time, the thinking process will not be aware of any directive feedback. This is the so-called subconscious state. The reason to call this as subconscious state rather than unconscious is that at this time in Ring A (i.e. logical thinking), working memory is not blank, and it still maintains the goal of a theme related to creative thinking, i.e., still related to the current processing directives. The instruction is continuously

acting on the input end of Ring B (or C), thereby continuously stimulating the incidental creative module in Ring B. Every excitation caused by a divergent thinking, associative thinking and reconstructive imagination (according to the requirements of the processing directives, which were working towards achieving the objectives of exploration), but at the moment, association cannot work out imagery that fit the needs, or the follow-up imagery processing does not work out imagery that fit the requirement (at the end of the processing of working memory is still blank), Ring B has nothing coming back to output to Ring A. Evidently, the essence of subconscious thinking is interaction between Ring A and Ring B of *serial and concurrent linear processing* of one-way function, the interruption of interaction between two kinds of thinking (logical thinking and imagery thinking), or imagery thinking process interrupts (imagination cannot be completed), rather than aborting the whole process of thinking.

It's because that working memory in Ring A (working memory with temporal-logical thinking) does not show blankness, the input end of Ring B has a constant incentive, and it makes the subconscious mind continue to work for an indefinite period. As mentioned above, every input stimulus causes an exploration: divergent thinking—associative thinking—reproductive imagination (the exploration is carried out in the unconsciousness; so it's known as unconscious exploration). This kind of subconscious exploration often fails in the beginning—through association, one cannot come out with a suitable image, or images; and requirements are far too different, so that reformation and reconstruction of imagery processing cannot be completed. However, with the increase in numbers of exploration, divergent thinking is getting more and more wide; through similar association, opposite association, and a variety of associative thinking, images are also getting more and more comprehensive and rich, these images and correlation with the themes are also getting nearer… Therefore, in the future a failure of certain subconscious exploration may be a success through transformation and reconstruction of some of the original imagery, and create something new in line with the requirements of the current theme of the imagery. This new imagery, completed in "imagination", is naturally kept in the working memory (the working memory is no longer empty) of imagery thinking, and is sent back to Ring A. Due to Ring A, for a long period of time before that, does not receive output feedback information from Ring B, Ring A repeatedly issues directives (that repeatedly stimulate the unconscious exploration) without response; the issue remains long unresolved. Now suddenly this information that fits the content requirement is received, the problem is solved smoothly or straightforwardly. It seems like finding a person in the dim lights upon suddenly looking back. This is generally called inspiration or insight. Through the above analysis, inspiration/insight is not out of thin air, or being mysterious things, but is the inevitable result of many times unconscious exploration (numerous in search of her thousands of times). The subconscious exploration, unlike unconscious theory, is elusive, or unutterable, but it can be used to train step-by-step psychological operation process through three components: divergence—association—imagination, with coexistent, linear processing.

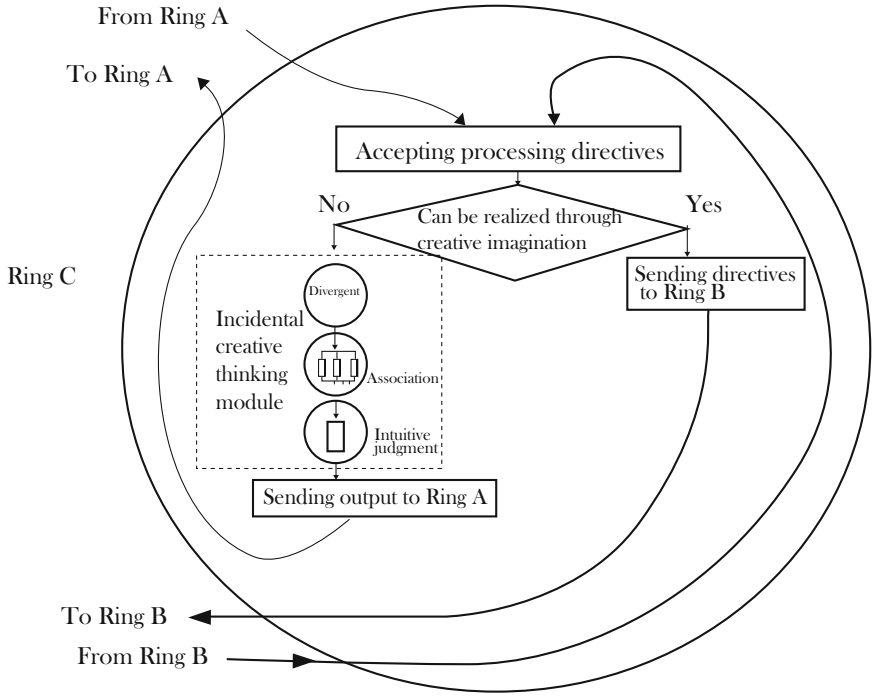

Fig. 4.6 Processing modes of Ring C

After insight comes to the current theme, Step 3 is completed. The following steps should turn to Step 4.

(4) This step happens mainly in Ring C, complex intuitive thinking activities, and its processing is shown in Fig. 4.6.

It can be seen from Fig. 4.6 that the process is essentially the same as in Step 3. The processing directives from Ring A into Ring C, in the input component, judgment is done to see whether it's more convenient to achieve the requirements of the directives through imagery thinking (creative imagination). If it's possible, send directives to Ring B, which is equivalent to steering to Step 3 to do further processing. Otherwise, enter into creative thinking module; that is, through divergence—association—intuitive judgment and so on, according to current requirements of serial and concurrent linear processing. Due to directive guidance, regulation and control from Ring A, this process, though following incidental creative thinking path of processing, is not incidental, but with a clear purpose.

The purpose of creative thinking is to discover the laws of internal relation between things; i.e. the predecessors did not know and had never described before. Reflecting the spatial-structural imagery of the unknown, generally, it will not be difficult to directly find it through associative thinking in long-term memory of

imagery subsystem. At this time there will be a period of time as Step 3, so that the working memory area is blank; that is, there will be a subconscious thinking state and subconscious exploration process. The current exploration of the subconscious is inspired by the processing directives from Ring A, but its processing mode is composed of three links, divergent thinking—associative thinking—intuitive judgment. From long-term memory of spatial relation imagery subsystem, associate, as far as possible, with the theme required or seemed similar with imagery. In the beginning, this effort is often difficult to be effective; i.e. it could not find a proper relation image, or find an image denied by intuitive judgment (intuitive judgment refers to making quick judgment through intuitive perspective and synthesis on spatial relations). This judgment has the main features of, in the first place, consider problems from globally and comprehensively, and is not by a step-by-step analysis and inference; second, grasp the relation between things, but not specific attributes and details, so working memory has no thinking results that can be fed to Ring A. Until unconscious exploration for many times, understanding internal connections and regularities between things are getting closer and closer to the objective reality, suddenly inspiration/insight showed up.

After the realization of the current theme of insight, Step 4 is completed. The following step should be Step 5.

(5) In Ring A, the results of inspiration/insight is logically analyzed and reasoned—by Step 3 or Step 4. If the test is passed, the results are transferred to Step 6; otherwise it returns to Step 3 or Step 4, according to the requirements of the original theme, for further subconscious exploration of re-creating new things or to discover laws of the unknown.
(6) From the theme list move to the next theme (at the same time, the original theme is cancelled), if the next theme is empty, which shows that incidental creative thinking process has been completed, then transfer to Step 7; otherwise, turning to Step 2 to continue processing the next topic.
(7) End.

It should be noted that when the theme, required by achieving intentional creative thinking target, is more than just one (i.e., the key problems to be solved), each theme's completion (i.e., each of the key problem solved) corresponds to a smaller inspiration or insight, and the whole theme corresponds to all the inspirations or insights.

From the above analysis it can be seen that Steps 1, 2, 5, 6 and other psychological operations are of temporal-logical thinking in the scope of Ring A; Step 3 is in Ring B; Step 4 is in Ring C. Thus, by steps 1, 2, 5, 6 one can obtain a flow block of the processing for Ring A in the whole process of intentional creative thinking shown in Fig. 4.7.

On this basis, the use of Figs. 4.3, 4.4, 4.5, 4.6 and 4.7, one can draw a detailed diagram of the mental operation model of intentional creative thinking as shown in Fig. 4.8.

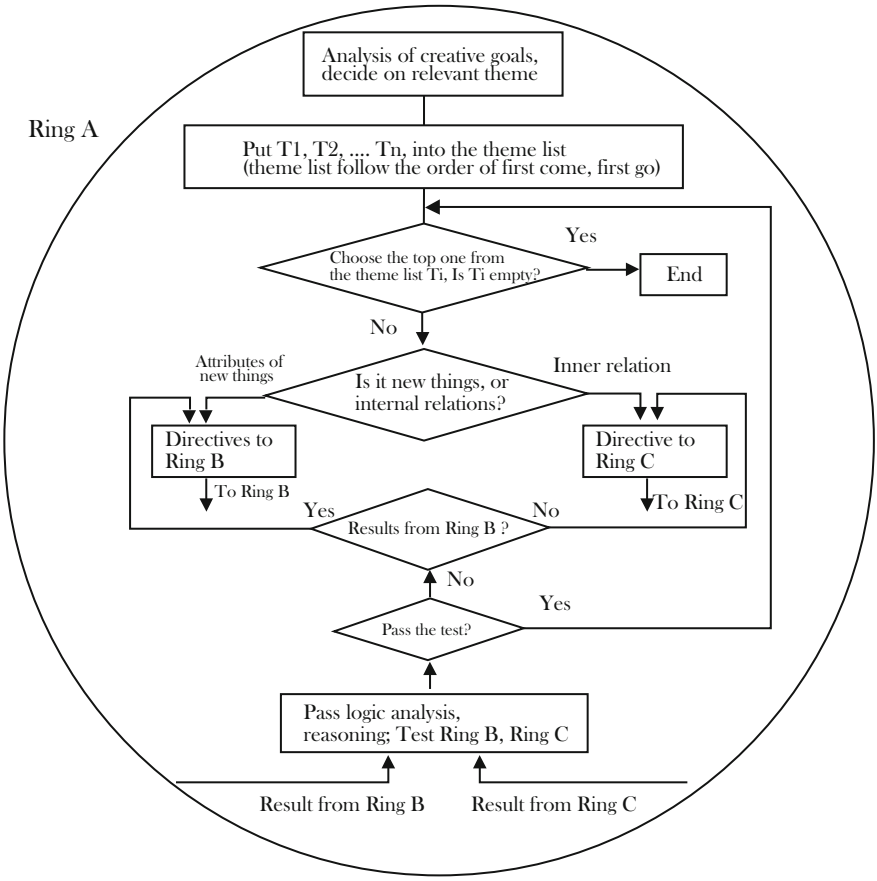

Fig. 4.7 Processing modes of Ring A

4.5 Subconscious Exploration and Complexity Theory

4.5.1 Main Elements of Subconscious Exploration

In the previous section, we discussed, in detail, the operation model and the processing method of incidental creative thinking, which can be summed up with one phrase: "*looped, non-linear interaction*". This way of processing involves Ring A, Ring B and Ring C in the interaction between the three forms of thinking, the process is quite complex, but also one can use one phrase to summarize: "*subconscious exploration*", which formed inspiration or insight; i.e. the goal and core of intentional creative thinking. To get rid of the mystery over inspiration or insight, so that inspiration or insight becomes the ability that everyone can cultivate through

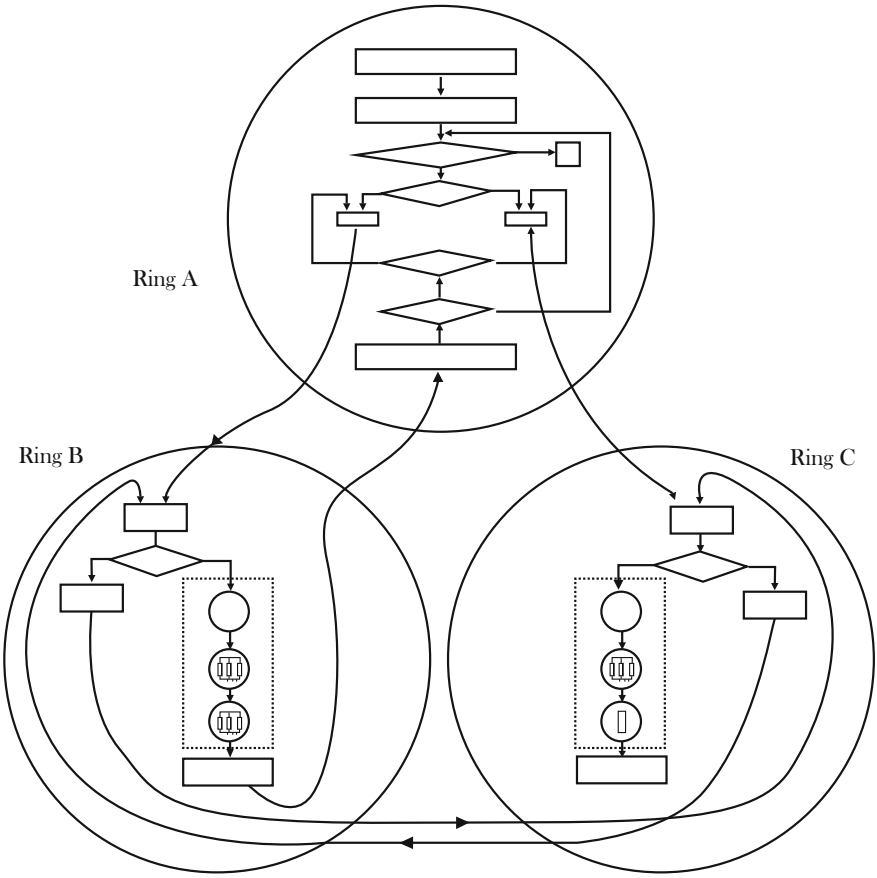

Fig. 4.8 Mental operation model of intentional creative thinking

creative thinking training. Only the mechanism of unconscious mind is understood through in-depth study, the above problem can be solved smoothly.

It can be seen from the section on the loop-shaped, nonlinear interaction process and the operation process, incidental creative thinking process include five links; namely, "*conscious motivation*" (send processing directives reflecting creative goals to Ring B or Ring C), "*divergent thinking*", "*associative thinking*", "*creative imagination*" (or "intuitive judgment"), "*reasoning and testing*". Among these, "creative imagination" link and "intuitive judgment" link belong to the subconscious exploration (the rest of two links belong to conscious thinking).

Then, the most important linking in intentional creative thinking process—"creative imagination" or "intuitive judgment" will be further analyzed.

From the mere process of mental processing, the "imagination" link in Fig. 4.5 *subconscious exploration* or the "intuitive judgment" link in Fig. 4.6 *subconscious exploration* is indistinguishable from the reconstructive imagination or intuitive

judgment in Fig. 4.2 *processing modes of incidental creative thinking*. However, this is the case only from the static graph, and from the dynamic process of actual processing, these two kinds of thinking are essentially different. This is to be expressed in the following three aspects.

In the first place, the purpose of conscious and subconscious thinking is different. The imaginative or intuitive thinking in Fig. 4.2 is incidental. Although this kind of thinking, to some extent, will be guided by logical thinking as well as restricted by speech concepts, it has no clear goal of creation. That is to say,, the starting point of this kind of thinking is not necessarily to create. This kind of thinking is the incidental spark of wisdom or insight (of course, this kind of incidental creation relies on thinker's accumulated, rich knowledge and experience), and the results of it mostly were unexpected beforehand. *Imagination* in Fig. 4.5 and *intuition* in Fig. 4.6 are not incidental and they have a strong purpose, a clear goal to create. This goal is reflected in the current processing directives given. The whole imaginative or intuitive thinking process (including divergent thinking and associative thinking before this) is subject to the guidance, regulation and control of the directives. In other words, the imaginative or intuitive thinking is not roam aimlessly, but to be constrained by directives; the focus of imaginative or intuitive thinking of targets in alignment with key problems to be solved. As a result of a strong purpose, generally the efficiency of this kind of creative thinking is relatively high, which can solve more important, lingering problems. The results of thinking are expected, determined by the creative goals laid down in advance.

Secondly, the processing mode of conscious and subconscious thinking is different. In Fig. 4.2, imaginative or intuitive thinking is usually serial and concurrent processing, linear, one-way one-time processing activities. Because any imagery thinking and intuitive thinking are subject to the guidance and regulation of logical thinking (or restricted by language concepts) in order to make imaginative or intuitive thinking go quickly to find the idea and plan to the problems encountered (which is the theme mentioned in the previous section). Before imaginative or intuitive thinking stages, generally one need to go through divergence and association stages, so in Fig. 4.2 imaginative or intuitive thinking always follows along the guide of logical thinking: divergent thinking setting the direction; association providing materials, imagination (or intuition) producing thinking results. This serial and concurrent, linear, one-way processing is often one-off; this is because since the thinking is incidental, without expected goals, then the results of thinking processing, regardless of the degree of creativity (or even getting thinking results or not) are not as a sign of this thought process—as long as a serial and concurrent, linear, one-way processing ends, you may consider this imaginative or intuitive thinking has been completed, and you can leave the content of the current of thinking to consider other problems.

Imagination in Fig. 4.5 or intuitive thinking in Fig. 4.6 is different due to the predetermined clear goals (presented as current processing directives). If the goal is not reached, then the thinking task is not completed. And the thinking process will not stop the directives which represent the goal as well as come from Ring A. Then, directives from Ring A will often act on Ring B (as processing in Fig. 4.5) or

Ring C (as processing in Fig. 4.6), and continue to encourage the process of processing (logical thinking; divergent thinking setting the direction; association providing materials; imagination/intuition producing thinking results). From the local point of view in Ring B (or Ring C), the process is still a serial and concurrent, linear and unidirectional processing; every time this kind of processing is carried out, its thinking results may be blankness (the previous section refers to this situation as the subconscious exploration) or immature semi-finished products which is far from the target., Whether it's empty or half finished product, the result causes Ring A, over a period of time, to send processing directives again to the input end of Ring B (Ring C), so as to stimulate Ring B (or Ring C) for the next round of serial and concurrent linear processing (output end of Ring B or Ring C is blank or with semi-finished products to Ring A, to which the role has no difference, but for consciousness it makes a difference. As mentioned in Chap. 3, consciousness is the awareness, regulation and control of the process of thinking. When the output of Ring B or Ring C is vacant; i.e. working memory area is blank, the thinking process has no contents to be aware of, which is called the subconscious state; when the output for the semi-finished product, the working memory is not blank, except for the contents having not met the goals and requirements, and then the thinking process at this can have some contents to be aware of, which thus belongs to conscious state of mind)… And so it goes on, the results of every cycle of thinking make imagination in Ring B (or intuition in Ring C) closer to the target requirements, until eventually inspiration/insight reaches the requirements of the target; at the start, the output sends nothing, so it's blank, gradually forming a half-finished product, finally from semi-finished products develops into finished products (of course, There're often cases of jumping directly from the blank state to the finished product without going through the semi-finished product stage). This processing method is shown in Fig. 4.5: from A → B → A or A → B → C → A. In accordance with the processing method of Fig. 4.6, the process is A → C → A or A → C → B → A. The process goes through multiple cycles, continuous interactions, and to the final completion. So imaginative thinking in Fig. 4.5 or intuitive thinking in Fig. 4.6 is processed in line with looped, nonlinear, interactive mode (as subconscious exploration stimulating many times).

Finally, the complexity of the object of conscious and subconscious thinking is different. In Fig. 4.2, it shows that under the incidental creative thinking, though creative thinking results can also be created, the level of complexity is generally low for three reasons: no clear goal of creation before and during the thinking process; no long deliberation as well as preparation to solve problems; it is a one-time processing. Of course, in the actual incidental creative thinking, objects of thinking, which have high level of complexity, will certainly be encountered. However, only two possible results from the situation at the moment: one possible result is to avoid this type of problem and turn to other problems because incidental creative thinking has no predetermined creative goals; that is, it does not have to solve the problems, so when in the one-time processing with on results, it may no longer continue to consider the problem; the other possible result is that after incidental creative thinking turns to intentional creative thinking, if the problem is

unresolved and the thinker is interested in the problem (do not want to give up), then the thinker will process the problem again; if the problem is still unsolved, he will be aware that this is a complicated problem, which needs adequate and necessary accumulation, and practical plan to solve. If he believes that the project has important significance and still maintain a strong interest, he will take the project as his current or future goal, striving to find ways to solve it. This makes the original incidental creative thinking change into intentional creative thinking. This indicates that if incidental creative thinking produces innovative results, the level of thinking complexity must be relatively low. In other words, only in the case of intentional creative thinking, the thinking objects will have higher levels of complexity.

We believe that it's because intentional creative thinking has high level of complexity that leads to the emergence of subconscious exploration. In other words, in the above three aspects of differences between incidental and intentional creative thinking (the level of complexity of the thinking object) the third difference is of more essential and more important significance. Here we shall analyze the complexity of the object of thinking and related theories, as well as the treatment of high-level, complex problems.

4.5.2 Complexity Analysis and Complexity Theory for Objects of Thinking

4.5.2.1 Defects in the Existing Complexity Theory

On the complexity of the object of thinking, little research has been done in the psychological community. A research, by which the issue is explored theoretically and achieved certain results are achieved, is the work of N. Robin et al. study group,[10] Department of psychology, Los Angeles, California University. In the second section of Chap. 3, we have introduced the complexity theory by Robin et al. According to this theory, the reflection of human thinking on attributes of things and the intrinsic relations between things can actually be seen as a reflection of the various relations that exist between things. According to the expression of predicate logic in mathematical logic, the essential attribute of thing itself can be regarded as a kind of relation—unitary relation. And the relation between things can be regarded as the N element relations. N is the dimension of the relations, the greater the N, the more complex the relation is. Therefore, according to the size of the value of N one can define the level of complexity of relationships.

Level 1—one dimensional function, describing things have some kind of attribute;

Level 2—two dimensional function of the relation between the two things describing the relation between two things;

[10]Robin and Holyoak (1995).

Level 3—the relation between three dimensional function, describing the relation between the three things or tertiary relations;

Level 4—the function relation of 4 or above dimensions, describing the multiple relations between four things.

Robin et al. believed that all human knowledge used to solve practical problems is nothing more than two categories: explicit knowledge and implicit knowledge. Explicit relation knowledge is based on conscious thinking, by a step-by- step logic reasoning; implicit relation knowledge is based on fast intuitive subconscious thinking. The relational complexity theory, which is based on predicate logic, is a set of knowledge representation system, which is used to represent the explicit relation knowledge. By using this system, we can easily determine the complexity level of knowledge of current processing (i.e., object of thinking processing), from the simplest to the most complex, divided into four grades, 1, 2, 3, and 4.

From the above introduction, it's known that complexity theory of Robin et al. in is established on the basis of first order predicate logic relations; relations are determined by the number of elements (also called element of relation); such as binary relations, the level of complexity is 2.

Although this kind of complexity theory has certain practical significance, there's a big flaw in that it fails to grasp the key to the complexity of thinking about an object, so its practical role is not great.

As mentioned above, human thinking reflects the essential attributes of things and the regularity of relations between things: the thing itself has essential attributes, which is a unitary relation, and the relation between things is n-nary relations. The greater the n, the more things are involved, the more complex the relation is; so the value of n is defined as the level of complexity is reasonable. However, this is only one aspect of the problem, and yet It's not the most important aspect of the problem. What is the more important aspect? We think that it's in the composite function, which should combine n (i.e. element) dimensions. In multiplicity function m (i.e. order in predicate logic) should combine n, namely $m \times n$ to represent the complexity of the object of thinking, which is consistent with the objective reality as a better guide. In fact, in the process of creative thinking, for the complexity of the representation of the object of thinking, the role of m is much larger than n. To illustrate the problem, we might as well look back at the history of major scientific and technological inventions.

4.5.2.2 The Invention of Electronic Computer and Its Complexity Analysis

(1) *Development of invention of the electronic computer*

The electronic computer is the greatest invention of the 20th century, it also involved the invention of the most complex object of thinking; this invention is used as a window to study the thinking object of the theory of complexity, and has typical significance.

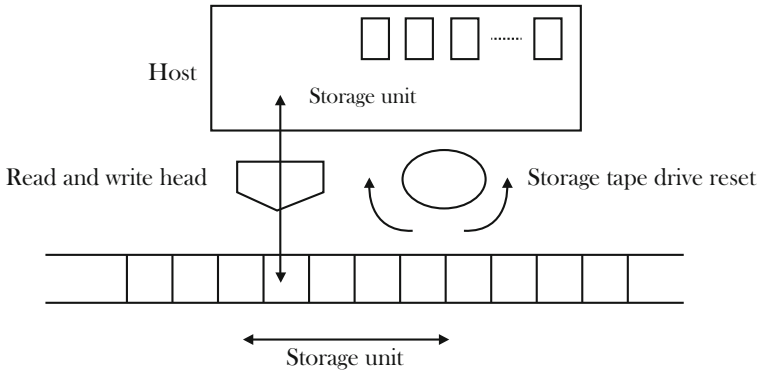

Fig. 4.9 Turing machine

As is known to all, the world's first complete computer was successfully developed in the late 1940s by Americans Echoviruses, and von Neumann et al., but the first computer design technology in 1941 had been basically completed in the world. In fact, initiation of the original idea of the invention of electronic computers begun in the early 30's, the desire to change the traditional calculator. From the initial thought to form a complete design of electronic computer, it took five or six years, culminated in the birth of a relatively perfect computer took longer time, and after many people relay struggle, it was able to complete.[11,12,13]

In 1936, Turing, a mathematician at the University of Cambridge, UK, in order to prove the existence of a function that its function does not have an algorithm to compute, proposed the calculation model, shown in Fig. 4.9, which is the so-called Turing machine. He used reduction to absurdity that any computable function whose value is the corresponding Turing machine; on the contrary, There's no corresponding Turing machine function that doesn't have the function to calculate the values of the function algorithm. Turing machine has the host, read/write head, tape storage and storage belt and driving device and other parts. Host and storage zones are divided into one unit, each time only one symbol can be deposited in; read/write head at any time is aligned storage with one unit, every read/write only one symbol at a time; storage with driving device takes the command from the host storage with left/right movement to one or plural units. In operation, the system is first set to the initial state, and then the host gives commands to the storage with the driver and read/write head. Once the operation is over, the machine will be turned down.

Turing machine is a hypothetical model of a computer, not an actual machine. From the above introduction, It's evident that its structure and operation is very

[11]Liang (1998).
[12]Wu (1997).
[13]Fang (1999).

simple. However, It's such a simple structure that contains the basic working principle of modern electronic computer: for dealing with symbols in serial operation, for storage mode in linear processing.

Almost and at the same time when Turing proposed the basic computational model, J.V. Atanasoff, Professor of mathematics and physics, at Iowa State University, always wanted an invention a faster computing tool in order to solve a variety of complex computing tasks, He analyzed in depth operation principles of the then popular variety of calculators (including mechanical, electric, simulation, etc.), he draw a conclusion that in order to carry on the calculator revolution, the key is to find a high-speed operation component. Under the guidance of this idea, just at the time the Turing model of computation was published, and then the research and application of electronic devices has been made great progress (prior to this, in 1904 invention of vacuum diode, in 1906 invention of triode vacuum tube, in 1919 invention of two triode tube bistable trigger circuit, and after 1930 invention of vacuum tube counting circuit). So it makes Atanasoff produce a bold vision that using electronic vacuum tube produced by the trigger circuit to replace the traditional mechanical calculator.

On this basis, he designed the world's first the structure of the computer circuit with electronic devices. While the structure diagram of the circuit was designed, Atanasoff could not put it to use, because it still lacked a key part of coordinated control. Until 1940, the controller was finally design, which is known as the key components, and the machine design technology was also completed, and on January 15, in 1941, *de Monnes Tribune* for the published the reported.[14,15] If the electronic computer developed, it can be a solution of a simultaneous equation with 30 unknowns; so it caused no small sensation. But unfortunately, shortly thereafter, the Pacific War broke out, the Japanese attacked Pearl Harbor, Atanasoff put on the uniform and joined the army. The research and development interrupted.

At about the same time, Dr. Russell Mulcahy, worked as a teacher in Exinnuo and Pennsylvania, Moore School of physics (he had developed a computer simulation) and produced electronic vacuum tube, having the idea for high-speed arithmetic unit, and was distressed for not having the ideal design. He was very excited when saw the photos of controller design on *de Monnes Tribune.* In June, 1941, he made a special trip to rush to Iowa to see Atanasoff, who enthusiastically received him, without reservation, and lent him his precious design manuscript.[16]

Russell Mulcahy and his assistant Eckert obtained the manuscript as a treasure; they soon improved Atanasoff's design, and with the support of the huge military's funds, in the spring of 1943, they established a computer development group. After two years' effort, finally, at the end of 1945, they developed a machine called the electronic numerical integrator computer (ENIAC), but the machine has one big

[14]Liang (1998).
[15]Fang (1999).
[16]Wu (1997).

disadvantage—calculation program is extrapolation,[17] which needed to spend a lot of time to prepare for the program, and in addition, it used decimal system[18]; components rate has not been brought into full play, and the computing speed was very limited.

In 1946, the mathematician von Neumann put forward a improvement scheme for the shortcoming of ENIAC from three aspects: one, to replace the decimal system with binary system, in order to give full play to the potential of electronic components in terms of rate; two, to set up a program counter to save the address to change the execution; extrapolation calculation procedure to intrapolation calculation, which makes the whole process completely by computer automatic control, and effectively improves the speed of operation; three, according to the Turing model, it is believed that the computer system structure has five parts of by the units of operator, controller, memory, input and output; the program and data units are placed in memory, and for the first time put forward the concepts of central processor unit (CPU) and CPU is composed of operator, controller and program counter, and this is the famous von Neumann architecture.

The improvements in the above three aspects were finally completed in 1949 at the University of Cambridge in the United Kingdom. International computer industry, generally, believed that the proposition of von Neumann architecture and its implementation were an important symbol of sound modern electronic computer.

(2) *The complexity analysis and complexity theory in computer invention*

From the above historical overview, it's evident that the invention of the electronic computer experienced 10 years of ups and downs, and not by a single person, but was done by groups of mathematicians, physicists, electronic experts and engineering and technical personnel. The persons who played a main role include Turing, Atanasoff, von Neumann, Echoviruses and Eckert et al. The invention of the electronic computer is in such a difficult situation, it's a reflection of the high complexity thinking involved in this kind of creative activity. This complexity is mainly manifested in the following multiple composite function.

The first level—to improve creative goals of operation speed, selection of system (such as decimal, octal, binary), which can be be expressed as: g = f1 (x1, Y1, z1);

The second level—to achieve a numeration system (decimal) automatic operation and mode of operation (such as electric, mechanical, electronic digital, analog), the function can be expressed as: x1 = f2 (X2, Y2, Z2, U2);

Third level—to implement electronic digital automatic operation and system architecture (such as input, computing, storage, control, output), the function can be expressed as: z2 = f3 (X3, Y3, Z3, U3, V3);

The fourth level—each module in the architecture has their own different factors, for example: memory module with linear or nonlinear mode; the function can be

[17]Wu (1997).

[18]Wu (1997).

expressed as: z3 = f4 (x4, Y4); operation modules adopts serial or concurrent mode; the function can be expressed as: y3 = f ′4 (x 4, y′4);

Fifth levels—related to linear or nonlinear memory storage and serial, concurrent computing and other factors; the function can be expressed as: x4, Y4 (or X′4, y′4), which can also be expressed as a function of other variables…

Evidently, in the variable x4, Y4 x (or ′4, y 4) relates to the initial of target improving the speed of computation; the composite function can be expressed as the following: g = f1 (f2 (x2, y2, f3 (x3, y3, f4 (x4, y4), u3, v3), u2), y1, z1);or g = f1(f2 (x2, y2, f3 (x3, f′4 (x′4, y′4), z3, u3, v3), u2), y1, z1).

Due to the x4, Y4 x (or ′4, y4) also can be expressed as other function of other variables, the composite function is at least 4 times over the compound function; namely, *m* is larger than or equal to 4; i.e. m $\geq$ 4.

Next we shall have a look at several features in the process of the invention of the electronic computer, played a major role (Turing, Atanasoff, von Neumann, Echoviruses, and Eckert) in solving the complexity issues related to the invention, and their contribution respectively, and how people evaluated them.

Turing proposed a scheme of serial operation, linear storage in symbol processing, albeit an abstract theoretical model, and not to be implemented; however, because It's made a correct abstraction in the fourth level of compound multiplicity *m* = 3. So, they solved the complexity in the process of the invention of the computer of great difficulty (*m* value is larger), which has a high theoretical value, and It's still the bases of modern electronic computer (including personal computer, microcomputer, mainframes and supercomputers). People call Turing as a founder of computer theory and the name of Turing was used as the highest award in the field of computer science; this is a great honor for him.

Atanasoff's contribution is mainly reflected on the first, second and third levels. The level of complexity though lower than Turing's work, but he under the enlightenment of Turing's model, he, in 1941, completed the earliest design in the world of electronic vacuum tube as arithmetic unit of computer technology (division particularly solves the designing problem of a key component—"controller"), which laid a solid foundation for the design implementation for ENIAC computer. It's for these contributions, after nearly a decade of patent litigation, that Atanasoff finally in 1973 won right of invention of the first computer, ruled by Minnesota District Court, the United States, (at the same time, announced the original patent granted to Moakley and Eckert's invalid). Therefore, the invention in October 1990 obtained the national technology medal awarded by the then President of the United States George W. Bush. Atanasoff, obscured many years after, was recognized as the inventor of electronic computer, which he was fully deserved. The reason for Atanasoff's success was that he could solve the first and second levels of complexity to the problem, and used Turing theoretical result and tried to implement it. Obviously, It's not possible to take the lead to design the first electronic computer in 1941, if only all by his own creativity. Von Neumann improve the numerical integral computer on ENIAC from three aspects: first, an improvement on the first level of decimal instead of binary system. Second, improvement is at the bottom level of linear storage through further analysis of the results he found that if viewed

from the storage content (and is unlike it was originally to consider only storage), it can be divided into file storage, data, chart storage, program (instruction), storage and so on, among which, the first three kinds (file storage, data, chart storage), according to their common attributes, can be integrated as data storage. So in order to enable the computer to do a unified treatment of data and program (instruction), von Neumann proposed that program counter should be added to preserve instruction address to be executed (like data storage to store the instructional address), which makes the original extrapolation type of calculation program inserted as built-in.

This improvement is so important that, since then, the program counter has become the core component of the modern electronic computer. This improvement is achieved by extending the complex function to the depth (making compound multiplicity 1 more). The third improvement is to put forward the concept of central processor (CPU) and the whole architecture of modern electronic computer. This is based on the theoretical model of Turing, and further abstract and generalizes from the third level complexity for its completion. From the above three aspects of improvement, the related complexity level is relatively high, especially the second and third improvements), which also is a very big contribution to the future development of the computer. So von Neumann was considered as the father of computer in the world. This argument, though not entirely consistent with the actual (he cannot be regarded as the earliest founder of the computer), but this is not without basis.

As for Echoviruses and Eckert, in all fairness, they also made an indelible contribution to the birth of computer (improved and developed Atanasoff's design scheme and produced a great influence of ENIAC), but from the point of view of theory and creative thinking, the two of them did not leave innovative ideas in the five levels; in the process of computer invention, they solved the complexity problems, compared with the previous three persons, was the lowest. It's even more regrettable that Moakley, in spite of conscience and morality of a scientist, deliberately concealed the fact that Atanasoff retained nothing to help him (including providing him with the initial design scheme), and finally he ended up to be revoked the patent. What an embarrassing fate!

4.6 Processing of High-Level Complex Problems

4.6.1 High-Level Complex Problems and Subconscious Exploration

From the analysis of the previous section it can be seen that the electronic computer is the most significant scientific and technological invention in the twentieth century. The reason for a longer incubation process is not accidental. In order to achieve the creative goal of great improvement in the computing speed, which

involving many factors; these factors are not of paralleled, and coordinate multi-relationship, and often there are layers of nested (i.e. the value of *m* higher) multiple complex function relations. The multiple parallel and coordinate relations has a certain complexity, but generally through simple analysis, synthesis, or association (including association of different types, similarity association, opposite association, relation association) to determine; in the composite functions of high *m* value, due to the masking effect, having nested in different levels of the factors. As for if there's a relation between them and what kind of relation exists, It's difficult to determine through simple analysis, synthesis, or through a comprehensive way of association; this is the cause for a sharp rise in the level of complexity of thinking object, in general, is the fundamental reason that creative imagination (or complex intuition) for a period of time in the process, was unable to work out the result (the working memory area is blank)..In other words, the high *m* value composite function between multiple composites caused by the high level complexity (rather than parallel, coordinate multiple relations caused by general levels of complexity) is the reason for the subconscious state to appear and for the unconscious exploration to be excited. It's very important to have found this reason; even though we cannot know the reason, you cannot prevent subconscious state in the process of creative thinking from appearing or subconscious exploration from appearing. However, knowing the reason can enable us to use appropriate mental processing strategies to effectively reduce the unconscious exploration in a number of times, which effectively reduces the duration of unconscious state, which undoubtedly is very meaningful.

4.6.2 Philosophical Guides for Subconscious Exploration—Dialectical Thinking

Dialectical thinking (that is, dialectical-logical thinking) refers to the use of dialectical-materialist point of view to observe, analyze things—respecting objective laws, paying attention to investigation and to study everything from reality, and seeking truth from facts, which can look at things from viewpoint of unity of opposites, to see both opposition and also unity between things; to see different things in certain conditions that can be transformed into each other; namely to see things in a positive, and also reverse side, seeing unfavorable factors from favorable factors, and also think about favorable factors from unfavorable factors. All in all, it's a two-point theory not one-point theory.

Wheather we can use the dialectical-materialist point of view to observe, analyze things, i.e. Whether we have self-conscious dialectical thinking, is a basic assurance which makes our understanding of objects is comprehensive, profound and insightful and a weapon which carries out subconscious exploration.

In China's ancient outstanding cultural heritage, the use of dialectical thinking can be found ubiquitously, and some have been widely known, deeply rooted in the

hearts of the people. Such as *Chef Ding Butchers Cattle, Cao Gui on Warfare, Cao Chong Weighing the Elephant, King of Qi accepted Zou Ji's advice* and in Liu Yuxi's poem, and so on. All contained profound dialectical- logical thinking. Most of them have been enrolled in primary and secondary school language or history textbooks, if these materials can be used well, they will play an important role in the cultivation of creative thinking of the young. Take *Cao Chong weighing elephants* for example, it's a excellent example for the young to carry out dialectical thinking.

The story *Cao Chong weighing elephants* is a very familiar story for all. The plot of the story is that one day, Cao Cao got a possession of an elephant and he wanted to weigh the monster. He asked his ministers to look for ideas (1800 years ago, in the era of the Three Kingdoms, this was a great problem). A minister said that he could cut down a tree to make a large scale, Cao Cao shook his head; even if we could build a big scale that can bear the weight of an elephant, who can lift him? Another minister said we could kill the elephant, cut into pieces, and then it was easy to weigh. Cao Cao did not agree with the idea, for he would like to see the elephant alive. At this time, seven-year-old Cao Chong rushed out of with a good idea: pull the elephant onto a boat, remember the waterline on the boat, then lead the elephant out of the boat, and replace the space with rocks fitted up the boat, when the rocks reach the waterline, then unload the rocks, weigh the rocks, adding them up and we get the weight of an elephant.

Whether Cao Chong at the age of seven had such wisdom, it's difficult to confirm (perhaps the wisdom of the author of the story); yet this is not important. What is important is the dialectical-logical thinking in this story: to absorb the reasonable factors from the wrong opinions. The first minister of idea seems impractical, because no one could lift so heavy a scale, but it contained a reasonable factors needing a big scale to be able to withstand the weight of an elephant in order to solve the problem; the second minister's idea was absurd, how could we kill the living elephant in order to get its weight? But in this seemingly absurd opinion contained a very valuable thought: breaking up the whole into parts. Cao Chong properly absorbed the reasonable factors of the wrong views of the two ministers, trying to find a scale that could withstand the elephant weight without manpower to provide a large scale; according to everyday experience, the boat could meet the requirements; and then he thought of the use of stones instead of an elephant can achieve the result of breaking up into pieces. It's this dialectical thinking combined with the accumulation of life experience and keen observation, so that Cao Chong, in the end, creatively solved the problem that ordinary people of his time could not solve.

4.6.3 Mental Processing Strategies of Subconscious Exploration—Horizontal-Vertical Thinking

According to the complexity theory mentioned above, we can put forward a psychological processing strategy (horizontal-vertical thinking), which can be

effectively applied in the exploration of the subconscious mind. In order to solve complex problem of $m \times n$, which could solve complex problem and, at the same, parallel and coordinate relations and at different levels due to the masking effect of multiple complex function, nested layers of complexity (represented by the values of the parameter m). We need to consciously apply the philosophy of dialectical materialism as a guide besides in the macro scale, in the microscopic scale we should also explore the subconscious in the key stage of creative imagination stage (or complex intuitive thinking stage) by the use of the strategy of horizontal-vertical thinking processing strategy. Here in the following sections is an introduction to the mental operation of this strategy and the relation between horizontal-vertical thinking and creative imagination (or complex intuitive thinking).

4.6.3.1 Lateral Thinking

Carrying out lateral thinking, first of all, is to determine the various factors, which are in the same level with parallel, coordinate relations,, by the divergent thinking and associative thinking, and try not to have omission (also known as horizontal search). For the creative goals, the factors in the same level and its role are not the same: some factors is elective, we only need to select the most appropriate one, such as in the invention of the computer case, factors in the first, second and fourth level are all elective; some are co-occurrence. Each factor should appear at the same time, each with a specific purpose; one factor less the function of the whole system is not perfect, such as the invention of the computer on the third level of various factors. Therefore, for the lateral thinking, after the end of the horizontal search (that is, as far as possible the relevant factors are not missing), there are two kinds of thinking processing which need to be carried out: “choose” and “determine”.

The first kind is to choose based on analysis and comparison: the choice of the various factors of the known attributes—analysis, comparison (or through intuitive judgment) from which choose one of the factors most suitable for the current requirements of creative objectives.

The second kind is to dertermine based on analysis and synthesis: the known properties of co-occurrence factors were analyzed, on the basis of synthesis, seeing whether they can meet the requirements of all aspects of the creative goals, and determining whether There are missing factors (if goals are still unable to be fully satisfy, there must have a missing factor).

4.6.3.2 Vertical Thinking

Vertical thinking refers to the mining through the vertical, trying to break through the multiple complex function of the layer of nested masking. Two directions of digging are included: downward and upward.

Dig down: Striving to use divergent thinking and associate thinking, people analyze and synthesize certain key factors on certain key levels according to new

ideas, perspectives and directions in order to discover new attributes related to these factors and then discover (i.e. digging out) new functional relationships (for the initial creative objectives of the first level, the compounding of functions enters into a deeper layer). In the example of the invention of electronic computers, von Neumann put forward the innovative thought of program counter, which is the linear storage on the fourth level of the factors. The breakthrough of the traditional concept of storage partitioning, and from the new angle of storage contents to analyze, so we can draw a conclusion the new classification of storage memory, based on re-synthesis of data storage and program (instruction) storage. In this way, a new kind of functional relation was found under the linear storage (i.e., mining a new functional relation). Meanwhile, the function of the compound also entered into a deeper layer.

Dig up: According to new ideas, perspectives and directions, people abstract and generalize known attributes of several co-occurrence factors on certain level in order to discover (i.e. digging out) new functional relationships (for the initial objectives of the first level, the compounding of functions comes back to the former level) related to these co-occurrence factors. Von Neumann proposed the central processor (CPU), an innovative concept (CPU is the heart of a computer). This is new abstraction of attributes, on the third level, of a counting unit, a memory unit and a control unit; and a new generalization from the new perspective of the whole system of operation and control (rather than sticking to the original operation, control, storage of pure functional modules), and he found (digging out) that, in addition to the counting unit and control unit, originally belonged to the program counting unit in the memory, which also has close relationship with the control and operation of the whole system. So on this basis, he boldly made a new generalization: the program counter moving out from memory to combine and the counting unit, control unit, forming a new module; namely, the central processor (CPU), and between CPU and counting unit, control unit, and the program counter are formed a new function (for the initial target, function of the composite exits to a previous level; that is the meaning of digging up).

4.6.3.3 Horizontal-Vertical Thinking and Creative Imagination

Creative imagination is the advanced stage of imagery thinking, which have similar processing methods with the general imagination (reproductive imagination); and which relates to the imagery reorganization and integration, and also includes imagery transformation and reconstruction. It's through this kind of transformation and reconstructions that complete imagery of new things is formed. The difference between creative imagination and reconstructive imagination only lies in the different results of thinking: the former achievements of creative thinking is a unique, unprecedented, and new imagery of things; while the imagery of things, for the latter, have been described by predecessors, or has been recognized by others.

Since there are similarities between creative imagination and reproductive imagination, we know that thinking processing of creative imagination should also

involve imagery reorganization and imagery integration, and processing methods for imagery reorganization and integration include analysis, synthesis, abstraction and generalization. In other words, in the imagery analysis, synthesis, abstraction and generalization also contains the basic way of thinking—creative imagination. As the results of the two process of thinking are different, we think that the processes of creative imagination and general imagination must be different, and must be a big difference. But where does the difference lie? Psychology books so far have not provided us with a clear answer; all psychologists have told us that no matter art or science is not separable from creative imagination and intuitive thinking. However, the answer to the questions like *how should we use these two kinds of thinking* and *creative imagination mental processing strategies and reproductive imagination strategies of mental processing* are completely avoided.

We believe that the difference between these two imaginations lies in the point that creative imagination uses the above horizontal-vertical thinking. The basic thinking methods of horizontal-vertical thinking (including analysis, synthesis, abstraction and generalization, etc.) are based on the implementation of three links at a higher level: divergent thinking, associative thinking, and creative imagination in Ring B, through serial and concurrent linear processing. In the horizontal-vertical thinking process, around what goals to diverge, in what direction to associate, all have clear requirements. The contents of lateral thinking and vertical thinking also have specific instructions, especially vertical processing, its purpose being mining and finding the new properties previously unknown; the method used is through divergent and associative thinking (also can be combined with intuitive judgment), for a key factor on a certain level analysis and synthesis in accordance with new ideas, new perspective or a new direction, to discover new properties; i.e. forming new function relations (for the initial creative goals, this is the equivalent of finding the composite function of a deeper level), and this is the key to the realization of creative goals. Thus it can be seen that the process of horizontal-vertical processing is the process of creative imagination, and the mental processing strategy used in the horizontal-vertical thinking is the mental processing strategy needed by creative imagination.

4.6.3.4 Horizontal-Vertical Thinking and Complex Intuitive Thinking

The previous section has pointed out that intuitive thinking makes a quick decision for spatial-structural relation, through intuitive perspective and synthesis. Its characteristics are of two: first, intuitive thinking is performed from the overall rapid comprehensive consideration of the problem rather than step-by-step analysis and reasoning; second, intuitive thinking is carried out through grasping the relation between things and regardless specific attributes and details. In fact, intuitive thinking and imagery thinking, especially creative imagination, are often blended and difficult to split apart. For example, in the example of the invention of electronic computer, the related factors in the first level are numeration system, and the number of systems that improve operation speed. The questions can be answered by

association of lateral thinking to determine (horizontal search). After association comes up with some factors, which helps make choices (such as decimal or binary), on the basis of analysis of imagery thinking and logical thinking, and comparison (generally, imagery thinking and logical thinking are mingled together and inseparable) can also be judged by intuitive judgment. This intuitive judgment sometimes may not necessarily be right, but in many cases are correct and fast (knowledge and experience of thinker are richer, observation more sensitive, more attention to investigation and study, this intuitive judgment more accurate), and will not lose the opportunity. This is the advantage the other thinking modes could not compare. On the invention of computer case, von Neumann, in the first level of choosing binary system, and the selection of electronic digital type by Atanasoff in the second level, all made first through intuitive judgment, and then through using logical thinking to confirm or inspection. This shows that lateral thinking process and complex intuitive thinking complement each other; i.e. lateral thinking relies on intuitive judgment to make a choice; on the other hand, intuitive judgment relies on lateral thinking to provide the necessary materials of thinking, which can really play a role (lack of necessary materials, intuitive judgment will lose the basis).

In horizontal-vertical thinking, vertical mining has most decisive significance. And the key of vertical mining is to analyze and synthesize key factors of a certain level according to new ideas, new angles or new directions, so as to dig out new attributes related to the factors. But as to what kind of new ideas or new perspective, new direction to analyze and synthesize, it's necessary to rely on intuitive judgment, because the attributes now face is related to previously unknown, so logic reasoning, based on known words and concepts, is needed to make such judgments; otherwise It's impossible. To use of imagination, i.e. imagery thinking is also quite difficult, because since It's the imagery of the unknown, of course It's not able to directly extracted from long-term memory in relation to attribute imagery as the material of imagery thinking. It can be seen that on this occasion, using intuitive thinking is the most appropriate choice. This shows that vertical mining provides ample scope for complex intuitive thinking: for divergence and association in vertical digging process, providing more sufficient materials for intuitive thinking; and on the other hand, processing requirements of vertically mining provide specific objectives and contents for intuitive thinking.

In summary, the above analysis shows that the horizontal-vertical thinking process also inevitably contains complex intuitive thinking process; and mental processing strategy used by horizontal-vertical thinking is the mental processing strategy needed when effectively carrying out the complex intuitive thinking.

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Chapter 5
Theoretical Basis of Creative Thinking Model

In Chap. 4, we analyzed two different types of creative thinking, through examination of processing methods and mental processes, and put forward a mental operation model of incidental creative thinking and intentional creative thinking. Due to the fact that basic human creative activities (be it artistic or science) are the achievements of intentional creative thinking, mental operation model of intentional creative thinking is more direct as an central guide for cultivating creative thinking and innovation talents (generally, the mental operation model of intentional creative thinking is called "creative thinking mental operation model" or "creative thinking mental model"). The processing mode of intentional creative thinking has the feature of *jointly non-linear processing*. Since the model in education (especially in elementary and middle levels of school education) is of more than general importance, we hope that it will be built on a more solid scientific model, which will stand the test of practice (rather than a model out of a subjective fantasy). To this end, we intend to discuss the theoretical basis of the model from two aspects: psychology and neurophysiology. The underlying psychological theory of intentional creative thinking has already explained in fine details in the previous chapter, so this section will focus on relevant neuropsychological aspects, to further summarize, consolidate, and supplement the discussion of psychological aspects.

5.1 Psychological Foundation of Intentional Creative Thinking Model

From the point of view of psychology, the model of intentional creative thinking is supported by the following four assumptions.

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5.1.1 Interdependence Theory of Two Kinds of Thinking

The mutual support and interdependence of the two brands of thinking refers to mutual support and interdependence between temporal-logical thinking and spatial-structural thinking. Spatial-structural thinking can be divided into two sub-types: imagery thinking and intuitive thinking, according to different materials of thinking, so the mutual support and interdependence between the two forms of thinking can be extended to mutual support and interdependence of:

Logical thinking and imagery thinking.
Logical thinking and intuitive thinking.

The mutual support and interdependence of the above forms of thinking has been discussed in Sect. 4.1 (Chap. 4), so we do not need to go into fine details. Here what needs to be stressed is that interdependence of two forms of thinking, logical thinking and imagery/intuitive thinking, which supports intentional creative thinking, differs from traditional psychological views in three essential aspects.

(1) The traditional view regards both imagery thinking and intuitive/perceptive thinking as the same without any distinction; psychology and thinking science community have two accepted, interchangeable terms for it: imagery thinking and perceptive thinking, which reflects the view. And we classify both in the same type under the heading spatial-structural thinking, according to common features of the two (imagery rather than speech concepts as thinking materials); and on the basis of these two brands of thinking (thinking materials are of different imagery), i.e. attribute imagery/object imagery as thinking materials for intuitive thinking, which are clearly the dividing feature of the two different modes of thinking. In other words, we believe that the use of the terms imagery, intuitive/perceptive thinking are not accurate, we use them in this section differently from the traditional use of the terms.
(2) The traditional view sees differences between logical thinking and imagery/intuitive thinking but fails to see the common aspects; therefore, it's difficult for the traditional view to illuminate both the mental model and the processing of creative thinking. We reverse the idea to see both the differences (Since the materials of thinking, that is, the objects of thinking processing, are different, and the thinking process as well as the methods of thinking processing are different, too. These differences will lead to opposition.), and common aspects of the two forms of thinking (mutual support and interdependence). And it's this unity that plays an important role in the process of creative thinking (without mutual support and interdependence between the two, it would not be possible to build an intentional creative thinking model). We emphasize the unity between the two forms of thinking, not in order to deny the difference between them. The difference between them is so obvious that everyone can note without a doubt. The current problem is that many people (including some in the psychological field) do not see the mutual support and interdependence of these two forms of thinking. So now we purposely stress the

unity of the two forms of thinking and made a big blow on the traditional view as a "hypercorrection", which is necessary and beneficial.

(3) The traditional view exaggerates the role of logical thinking and degrades imagery/intuitive thinking, even to the extreme that only logical thinking reflects the essential attributes of things and internal relation between things; thus it's a rational thinking, and advanced thinking. While imagery/intuitive thinking only stays in the perceptual stage of cognition, which does not reflect the nature of things; thus it's emotional thinking and low-level thinking. However, we believe that both brands of thinking have features of abstractness and generalizability, which can reflect internal relation between things and nature of things, so both are advanced and rational thinking. Between them there's no higher or lower division. And we also think that, in the actual process of thinking, these two brands are often interwoven and interdependent. As described in the previous chapter, without support of images, thinking will become meaningless and symbolic game of weak text. On the contrary, if imagery thinking lacks of the guide and regulation on the basis of speech and concepts, it loses directions. As an inevitable result, thinking gets half results with double effort, and even unsuccessful.

5.1.2 Interaction Theory of Two Kinds of Consciousness

The two brands of consciousness refer to the consciousness and subconsciousness. Earlier it has been pointed out that in intentional creative thinking process, the consciousness refers to temporal-logical thinking (because thinking process, all the way through, can be aware of, and the thinker can use words to describe the process. The subconsciousness refers to imagery and intuitive thinking in the advanced stage—creative imagination stage and complex intuitive thinking stage. In Sect. 4.6, Chap. 4, it was pointed out that high m value composite function between multiple composites causes high-level complexity, which is at the root of for two stages of the subconscious state.

The interaction of the two brands of consciousness in the model of intentional creative thinking includes the following three steps (see Fig. 4.8, Chap. 4).

Step 1: conscious stimulus

Through temporal-logical thinking's (in Ring A) analysis of creative goal, some key problems are established, predetermined by the goal, i.e. theme, then the theme as the current processing instruction to inspire subconscious thinking (in Ring B or Ring C).

Step 2: the subconscious exploration

The subconscious exploration operates in the stage of creative imagination or complex intuitive thinking. The subconscious exploration adopted horizontal-

vertical thinking as processing strategy (horizontal search, choose and determine, mining vertically); especially by downward or upward exploration of new attributes of things or new intrinsic rules between things can be discovered. In order to achieve this goal, subconscious exploration should be repeated many times, each time the conscious is significantly stimulated by Ring A, and multiple cycles are repeated in the subconscious. During the subconscious processing, Ring B (or Ring C) has no thinking results sending out (in thinking processing, working memory area is blank), so Ring A judges that the processing instruction has not yet reached, and no knowledge of the contents of Ring B (or Ring C) in the subconsciousness; therefore, Ring A repeat the same processing instructions to stimulate the subconscious exploration (i.e., each issue of instruction is not modified), so once Ring B (or Ring C) has thinking results sending out (whether be it finished or semi-finished products), this round of subconscious exploration comes to an end, and turn to the next step. When that happens, the thinker has inspiration/insight.

Step 3: consciousness test

Conscious thinking in Ring A further confirms and tests inspiration. If it passes the test, intentional creative thinking process is completed; otherwise, the creative goal has not been met and should propose new explicit requirements according to the intended creative thinking goal and check the degree of deviation from the goal (i.e., modify the current processing instructions), and then, turn to Step 1, and repeat the operation.

From the above analysis, it is evident that in intentional creative thinking model, the interaction of the conscious and subconscious includes both internal and external circles: inner circle happens only in between the first two steps, then the conscious instruction in Ring A, though frequently issued, but does not modify; external circle operates between three steps, Ring A issued processing instruction with modification. It should be pointed out that every processing instruction without modification is the essential feature of the inner circle, and essential characteristic of the subconscious state. This is because, if in Ring A, the conscious modifies the current processing instruction according to the processing results of Ring B or Ring C, which means that the thinking results of Ring B or Ring C can be perceived, and can modify the current processing instruction, and regulate and control the perceived thinking activity—this is the feature of conscious thinking, and this feature is in contradiction with the subconscious thinking assumed in Ring B or Ring C in Step 2. Evidently, instruction in inner circle will not be modified, only in the conscious state of outer circle (Step 3), because then Step 2 of the subconscious state has ended, thinking results in Ring B or Ring C can be perceived, so that the processing instruction can possibly be modified according to this awareness (and compared with the targets) and to regulate and control the thought processes of Ring B or Ring C.

On interaction theory of the conscious and subconscious, it should be noted that it is not entirely a new theory, as early as Wallas' four-stage creative thinking

model[1] has implied the idea, and in Liu's unconscious inference model, the interaction consciousness and sub-consciousness is more explicit. We believe that the general direction of this theory is correct, but at present the scholars in support of this theory with different understanding of the conscious and subconscious, and of interaction mechanism of the conscious and subconscious, some of which is really hardly convincing. To this end, we have made great changes and supplements to the theory in constructing the model of intentional creative thinking, which is mainly shown in the following three aspects:

5.1.2.1 Understanding and Definition of the Consciousness and Subconsciousness

As mentioned in Chap. 3, understanding of consciousness (the conscious) is various in the current domestic and foreign research. Corresponding understanding to the subconscious is not consistent either. But, at present domestic and international psychological circle and thinking science community, subconscious issues have not been studied intensely and at a lower theoretical level, of which more prominent researcher would be Liu's unconscious inference model.[2] Therefore, we may wish to use Liu's theory as a representative, to compare the views we held in the intentional creative thinking model.

Liu believed[3] that the one that can drive the limbs and accept information of each part of a human body is conscious; generally speaking, the one that cannot drive limbs but can indirectly accept the information of other part of the body is the subconscious.

In Chap. 3, we defined consciousness (conscious) as, in a narrow sense, awareness, regulation or control of the brain on spatial-structural and logical-thinking; in a broad sense, as awareness, regulation or control of objects also including mental processes of emotion and volition. From the research of creative thinking, consciousness is awareness, adjustment and control of the process of thinking. As can be seen from the above definitions, Liu actually defined consciousness as nervous system and perceptual system in charge of limb movement; the subconscious defined as nervous system, in addition to the competent body movement, all other sense perception system. In other words, Liu's consciousness system is equivalent to a perception system, the conscious mind in charge of the perception system of the body movement; the subconscious is, in addition to physical movement, all the other sensory perception systems. This definition of the conscious and subconscious is unconvincing, driving body and directly receiving information of each part of a human body is awareness or conscious, then all cognitive processes, because they would not drive limbs, will be excluded from

[1]Blakeslee (1980).
[2]Liu (1986).
[3]Liu (1986).

consciousness (conscious) category, which is obviously not appropriate. One that cannot drive body but as long as one can indirectly accept information from each part of a human body is the subconscious, then as "indirectly" is difficult to define, and any expansion of the term is possible, and then the category of the subconscious is difficult to define.

According to our definition from the above, one can include cognitive process, and also the emotional, volition and other psychological activities. And according to the ability to "perceive", a simple and clear standard, it is easy to distinguish the conscious and sub-conscious. As mentioned earlier, specific to the occasions of intentional creative thinking, conscious thinking refers to temporal-logical thinking, while the subconscious refers to a special thinking stage, where creative imagination or complex intuitive thinking temporarily produce no thinking results (working memory area is temporarily blank).

Thus, though in an intentional creative thinking model the concepts of conscious and subconscious are used, our understanding and definition of the conscious and subconscious is essentially different.

5.1.2.2 Views of Interaction Mechanism Between Consciousness and Subconsciousness

In the literature,[4] Liu described the interaction mechanism of the conscious and subconscious as, first of all, a conscious request for directive information which deliver to the subconscious. This is the premise of inspiration; the subconscious inference is around this main line of thinking, i.e. directive information. This directive information, be it in the form of a photon, molecule, acoustic velocity, pressure and temperature, or imagery, language, and emergence of a concept, shall be piled up into a signal as a biological current pulse, transmitted to the brain through the nerve fibers. Generally speaking, the conscious issues directive information that passes to the subconscious, requirements of self consciousness, formed by electric pulse signal of spatial-temporal distribution, often show the 'bright' information, and prompted structural activities of a new sensory input information in the company of existing perceptual experience information to accelerate, the right brain neural network reorganization construction with additional understanding, so as to obtain subconscious inference of 'new' or 'good graphics'. The result of this integrative feedback will be sent back to consciousness, which analyze feedback information often in the form of abstraction, imagery thinking and other forms of synthesis. If identification finds that such feedback information does not meet the requirements, the new directive information will be sent to the subconscious, so repeatedly many times; once the inference comes close to the required goal and flocks to the conscious, inspiration bursts.

[4]Liu (1986).

And our understanding of the interaction mechanism between the conscious and subconscious shows in the internal and external cycles in three steps: conscious stimulation—exploration of the subconscious—confirmation of the consciousness. As mentioned above, in the inner loop process, the instruction or directive information is not modified and the instruction/directive is modified in the outer loop. The Liu's model contains only one cycle, at the end of each cycle, there is new information or good graphics after subconscious inference, sending feedback to the conscious; and during each cycle instructions are modified (delivered to the subconscious as new directive information). Since at the end of each loop with feedback information from the subconscious, and each cycle can send new directives to regulate the unconscious process. This clearly shows that from beginning to end, this so-called subconscious inference activities, can be sensed, regulated and controlled; therefore, thinking activity is simply not a subconscious activity, but a genuine conscious thinking. Evidently, in Liu's subconscious inference model, the interaction of the conscious and subconscious is not true interaction (still the interaction between the conscious), which is different from what we proposed in the intentional creative model of thinking through dual-track of inner and outside circles, which are true interaction between the conscious and subconscious.

5.1.2.3 Understanding of the Relation Between Consciousness/Subconsciousness and Left/Right Brain

The traditional interaction theory of the conscious and subconscious believes that the conscious mainly locates in the left brain, the subconscious mainly in the right brain.[5] On this basis, they also directly attributed complex interactions between many kinds of thinking to the conscious or subconscious. Obviously, this is a simplistic view. In fact, as we have stated in the model of intentional creative thinking, the state of the subconscious can be both in the creative imagination stage and also in complex intuitive thinking stage. As in the early 1990s, PET and MRI techniques have proven (see Smith and Jonides 1995[6]), imagery thinking mainly occurred in the left brain; intuitive thinking mainly occurred on the right side of the brain; namely, the subconscious state can occur on the right side of the brain and can also occur in the left hemisphere. Therefore, we believe that to take the interaction of the conscious and subconscious as the interaction of left and right brain (i.e., interactions between the conscious in the left hemisphere and the subconscious in the right brain) lacks scientific basis.

[5]Liu (1986).

[6]Smith and Jonides (1995).

5.1.3 Two-Dimensional Complexity Theory

About complexity of objects of thinking, traditional theory considers only one dimension; namely, first-order multiple predicates, i.e. multivariate relationships between factors of parallel, and coordinate relationship; the level of complexity relationship between "dimension" as n (also called element). Because the n reflects the complexity of parallel and coordinate factors, it is also called horizontal complexity level. As mentioned earlier, the size of value of n can only reflect the general level of complexity of objects of thinking, which does not reflect higher level of complexity objects of thinking, nor the root cause that the subconscious state and subconscious exploration happen. The intentional creative thinking model adopts complexity theory as two-dimensional, i.e. not only considering multivariate relationships between factors of parallel relationship of first-order multiple predicates (when levels of complexity between the element shown as n), but also considering the above second order multiple predicate (the composite function) in multiple order of factors, when the level of complexity with higher-order predicate order (i.e., multiplex composite function of multiplicity) shown as m. As mentioned before, the size of m value can reflect high level of complexity of object of thinking, and can also be used to explain the reason why the subconscious state and subconscious exploration occur. Because m is related to multiplicity of the composite function, it is also labeled the vertical complexity level. It is evident that intentional creative thinking model of complexity theory takes into account both horizontal complexity n, and considering vertical complexity m (and in intentional creative thinking model, we attach more importance to m), which is shown as $m \times n$ representative of object complexity (and not only n or m), so it is called two-dimensional complexity theory.

In addition, we also use two-dimensional complexity theory for systematic analysis to higher level complexity problem-solving, and in order to solve this problem proposed feasible processing strategy: "horizontal-vertical thinking" processing strategy. Horizontal-vertical thinking is composed of "horizontal search", "choose and determine", "vertical mining" and other processing strategies; these two processing strategies can better explain inspiration/insight, and can give a practical and direct guide for the intentional creative thinking (see Sect. 4.6, Chap. 4). Therefore, intentional creative thinking model is based on two-dimensional complexity theory, which is an important feature of the model.

5.1.4 Dual-Track Processing Theory

Dual-track processing theory is the main theoretical base of intentional creative thinking model; it is the theory for the process of creative thinking that provides most appropriate way of mental processing. On the whole, this process has the characteristics of *jointly non-linear processing*.

The so-called ***jointly*** refers to intentional creative thinking involving three kinds of thinking modes (i.e. temporal-logical thinking, creative imagination and complex intuitive thinking, as shown in Sects. 4.4 and 4.8 (Chap. 4) respectively by Ring A, Ring B and Ring C), their mutual interaction is circular. In most cases, jointly rings refers to a closed loop between Ring A and Ring B (or Ring A and Ring C), in some cases it can also be the closed loop between Ring A, Ring B and Ring C.

The so-called ***non-linear*** which refers to the processing path in the closed loop is not only A to B to A type (or from A to B to C to A), but there are a variety of possible options.

A → B → A
A → C → A
A → B… Enter the subconscious state
A → C… Enter the subconscious state
A → B → C → A
A → C → B → A
A → B → C… Enter the subconscious state
A → C → B… Enter the subconscious state.

Pointed lines in the formula (…) indicate that the thinking process in Ring B or Ring C fails to produce the expected result of thinking (the working memory area in the process of thinking is blank), so there is no output information to return to Ring A. In other words, this time Ring B or Ring C in the process of thinking will break; this is the so-called subconscious state. Every A, B… (or A to C…, or A → B → C…, or A → C → B…) cycle completes, a subconscious exploration concludes (that is, the interaction of the conscious and subconscious, in the process of interaction Step 2). Because the process is not only one or two single direction of linear path, but a variety of possible directions of path, which are available to be used; so it is a non-linear processing.

It should be explained that, in the case of emergence of subconscious exploration, as a result of Ring C or Ring B with no output information to feedback to Ring A, and thus does not constitute a closed loop. Unconscious exploration process can be constantly excited (until inspiration/insight shows up), which is a conscious initiative of Ring A as mentioned above; Ring A represents temporal-logical module; i.e. conscious thinking. This means that the mode, process and results of this thinking can be perceived, and can be adjusted and controlled; i.e. the monitoring of the thinking process itself at any time. So when Ring A sends out processing instruction, after a period of time, consciousness in Ring A will take the initiative to check; if no feedback information is found from Ring B or Ring C, Ring A will once again issued the same processing instruction (like the first one that has not been modified instructions) to inspire the next subconscious exploration; then, after a period of time (the length of time depends on the degree of thinker's concern for the theme; this period of time is relatively short, when concern is high; it will be relatively long when concern lows) conscious in Ring A and will take the initiative to check, if there is no feedback information, it will issue the same

processing instruction again to inspire subconscious exploration. And so it went on, until Ring B or Ring C has finished or semi-finished products of thinking results sending to Ring A (at the same time, this round of the unconscious exploration is at the end, it will shift to interaction of the conscious and subconscious Step 3 to continue processing).

The so-called ***interaction*** refers to the interaction between the conscious and subconscious in intentional creative thinking, as mentioned above, this interaction is achieved through internal and external dual loops and three steps.

From the overall perspective (viewing from the interaction of three ways of thinking), the mode of processing of intentional creative thinking is *jointly non-linear processing*, but if viewed from the local perspective, such as only from the point of view of the link of Ring B or Ring C, it is serial and concurrent linear processing (cf. Figs. 4.5 and 4.6, Chap. 4). The processing mode of Ring B (or Ring C) shown in Fig. 4.5 can be seen in the process of serial and concurrent linear processing. As for *concurrent*, it refers to the concurrent processing, at the same time, of varieties of perception channels in "association" link or "imagination" link (see Fig. 4.3).

The above holistic and local aspects of processing mode are combined, known as dual-track processing; the theory of this processing method is dual-track processing theory.

From the above analysis it can be seen that dual-track processing theory determines the mode of processing for intentional creative thinking process: regulation. Intentional creative thinking is realized through three basic forms of processing: temporal-logical thinking, creative imagination thinking and intuitive thinking. In the process of creative thinking, between the three forms of thinking, what exactly is the relation of the three? How does interaction of opposition and unity between them reflect? "Interdependence of two kinds of thinking" theory is to give a clear answer to these questions. The interaction theory of the conscious and subconscious is based on dual-track processing theory and interdependence theory; and intentional creative thinking, the formation process of which is the formation of inspiration/insight. To make a scientific elaboration can unravel centuries of mystery shrouded over inspiration. The two-dimensional complexity theory further analyzes the processing of inspiration, which is the key to the process of higher level complexity, providing feasible solutions, so that everyone, through training to acquire the ability of thinking, is possible to form inspiration/insight.

The goal of creative thinking is to reveal the essence of things or to find intrinsic relation between things, and to achieve the goal of creative inspiration/insight. Therefore, to elucidate inspiration/insight formation process, the theory of interaction between the conscious and subconscious is the core theory in support of incidental creative thinking model. As mentioned above, the core theory involves complex interaction of the conscious and subconscious and through implementation both inside and outside double loops and three steps; so we can also call intentional creative thinking as *Inside and Outside Circulation Model* (Double Circulation model, or the DC model). This is from the formation of inspiration/insight, namely, from the point of view of how to make a creative break-through, we should consider

interaction theory of the conscious and subconscious as the core theory of the DC model. However, if it is considered from the processing mechanism of creative thinking, then interaction between the conscious and subconscious and analysis and treatment of high *m* value complexity problem (i.e. using two-dimensional complexity theory) to rely on dual-track processing; therefore, dual processing theory should be considered as the basis of theoretical support for DC model.

In short, these four aspects of the theory have different roles and focus, they are integrated together to form relatively comprehensive theoretical basis for intentional creative thinking model in psychology.

5.2 Neurophysiological Basis of Intentional Creative Thinking Model

In the previous section we have clarified the processing mechanism of intentional creative thinking model (the DC model), which is mainly based on dual-track processing theory, and dual-track processing is referred to as *Serial and Concurrent Processing* and *Jointly Non-Linear Processing* in intentional creative thinking. Below we argue respectively the basis of neurophysiology of the two processing, as much as possible according to the latest progress achieved in 1990s.

5.2.1 Neurophysiological Basis of Serial and Concurrent Linear Processing

As mentioned earlier, the *serial and concurrent linear processing* refers to the processing mechanism used in the process of intentional creative thinking, Ring B or Ring C. Intentional creative thinking happens via conscious logical thinking (in Fig. 4.8, Chap. 4 shown with Ring A); realized through interaction of subconscious incidental creative imaginative thinking (Ring B) or complex intuitive thinking (Ring C). Ring B in creative imagination is the stage of high level of thinking in imagery and Ring C complex intuitive thinking is the advanced stage of intuitive thinking. Imagery and intuitive thinking (whether they are in the advanced or primary stage) are mainly used for spatial-visual imagery.

Admittedly, the materials these two brands of thinking used involved other images, such as auditory imagery, olfactory imagery, gustatory image, but the main (and in most cases) are visual spatial imagery-auditory imagery (as American experimental psychologist Treicher experiments show: human access to sources of information 83% through visual, 11% through the sense of hearing, several other sensory channels to obtain information add up to 6%). Therefore, in the following argument, we present neural physiological basis of *serial and concurrent linear processing*, and we can use visual channel as an example for the analysis.

5.2.1.1 The Meaning of Serial and Concurrent Processing

Monkeys and apes belong to primates and their brain systems are very similar, in order to facilitate the study of the cerebral cortex structure and function through neurophysiologic and anatomical methods, at present mostly macaques and rhesus monkeys were used as a neurophysiologic measurement or anatomical objects. The results of these measurements or anatomical findings suggest that primate visual processing involves several sub-cortical centers as well as dozens of different cortical areas. These structures are arranged in a hierarchical way, and there exist *serial and concurrent processing* at each level.

As Van Essen[7] pointed out that we use the term *concurrent processing* but not commonly used term *parallel processing*. This is because we want to be able to include possible interaction between processing pathways. Essen believed that there are three types of *serial and concurrent processing*: the first is complete separation of each processing pathway, independent of each other, which is general *serial and concurrent processing* (Fig. 5.1a); the second is that there is interaction between processing pathways and between a level or more than one level (Fig. 5.1b); the third is more complex interaction between the processing pathways, which may appear convergent and dispersive, with some processing path merging or splitting (Fig. 5.1c).

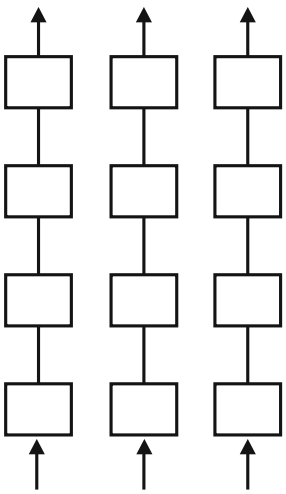
It should be noted that, under the second and third conditions, though interaction between the processing pathways exists, information flow remains in the same path; namely it remains serial between various levels. Figure 5.1c is a typical *serial and concurrent processing*, and generally series-parallel processing can be seen as a special case of *serial and concurrent processing* (Fig. 5.1a). As a matter of fact, in *serial and concurrent processing*, in addition to Essen's three cases, and there is a more complex case: not only the existence of interaction between processing pathways (lateral interaction), there are still interaction between different levels of interaction (longitudinal interaction), as shown in the dotted lines in Fig. 5.1d. This longitudinal interaction means connection between different levels of signals, not only from lower level to higher level projection (forward projection), also from higher to lower level projection (back projection). That is two-way interactive projection.

5.2.1.2 The Neural Mechanism of *Serial and Concurrent Processing*

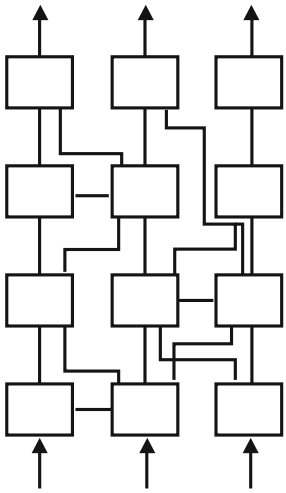
(1) The formation of lower level sensory information and visual perception

Human perception of an object is a lower level of a variety of sensory information (including spectral components, binocular parallax, speed, orientation, etc.),

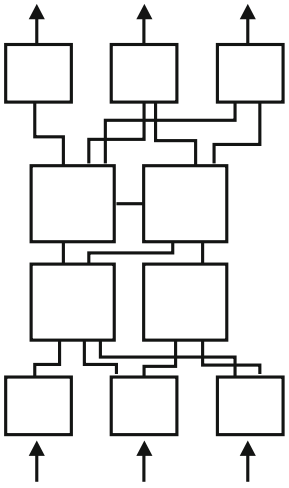
[7]Van Essen and Deyoe (1995).



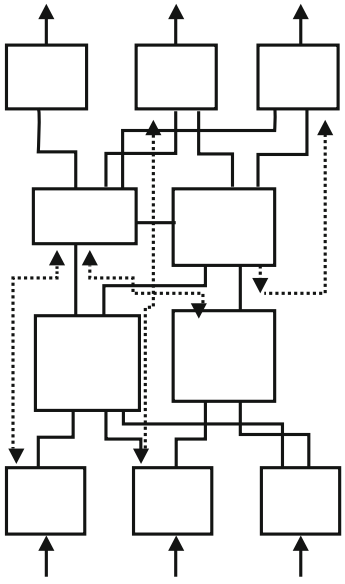
(a) Parallel Processing of Completely Separated Strands (Concurrent Processing of Common Strands)



(b) Parallel Processing of Horizon - tally Interrelated Strands



(c) Parallel Processing of Horizontally Gathered and Scattered Strands



(d) Parallel Processing of Horizontally and Vertically Interrelated Strands

Fig. 5.1 The sketch map of serial and concurrent processing

gradually forms through a multi-level processing. Lower level sensory information refers to the information that's extracted from the retina corresponding to early processing of visual perception. Sensory information contributes to visual perception: spectral components are involved in the perception of color formation, the range information involved in shape perception formation, binocular parallax involved in the formation of depth perception, and velocity information involved in the formation of motion perception, as shown in Fig. 5.2.

This simple mapping means that visual perception is processed by independent concurrent channels shown in Fig. 5.1a. But neurophysiologic experimental evidence[8,9] shows that, each a lower-level sensory information is involved in the formation of multiple perception. For example, the speed information involved not only in the formation of motion perception, and the movement process structure in shape perception formation, but also uses the motion parallax processing in depth perception formation (as shown in Fig. 5.3a).

Similarly, binocular parallax in formation of depth perception, is also involved in forming shape and motion perception (Fig. 5.3b); range information in addition to directly participate in forming shape and depth perception, but also indirectly involved in the perception of motion formation, as shown in the dotted line in the Fig. 5.3c; spectral components, in addition to participate directly in the color perception formation, but also indirectly involved in the movement, shape and depth perception formation (Fig. 5.3d).

Figure 5.3 shows that different processing paths are dependent of each other, related to each other, and interaction exists; in other words, perception is formed by concurrent processing.

(2) The neural mechanism of visual perceptual *serial and concurrent processing*

Van Essen et al. after many years of research found that retina acquires the lowest level of sensory information, to final completion of the process of visual perception; that is, the formation of visual spatial imagery (including attribute imagery/object imagery that reflects what properties can be used for recognition of objective things, and imagery reflects spatial-structural relations), going through a number of levels, with convergence of information and dispersed on *concurrent linear processing*. The specific experience of the level of processing and process is shown in Fig. 5.4.[10]

Figure 5.4 shows that the lowest level of the hierarchy refers to the retina, lateral geniculate nucleus (lateral geniculate of nucleus (LGN, also known as lateral geniculate) sends small cells (P) and large cell (M), they pass the second and third level of cortical processing, showing a selective cell projecting patterns. In Fig. 5.4 the higher level, the connection displays these pathways to participate in intermediate visual tasks, then comes to poly cortex to the temporal gyrus region and the

[8]De Yoe and Van Essen (1988a).

[9]Stoner and Albright (1993).

[10]Van Essen and Deyoe (1995).

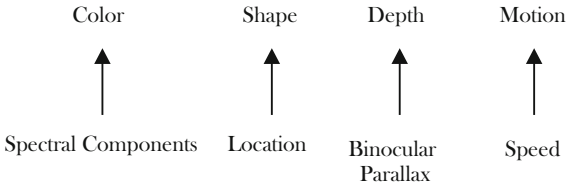


Fig. 5.2 The formation of lower level sensory information and visual perception

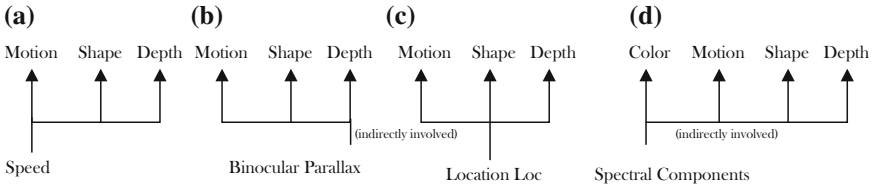


Fig. 5.3 Each a lower-level sensory information is involved in the formation of multiple perception

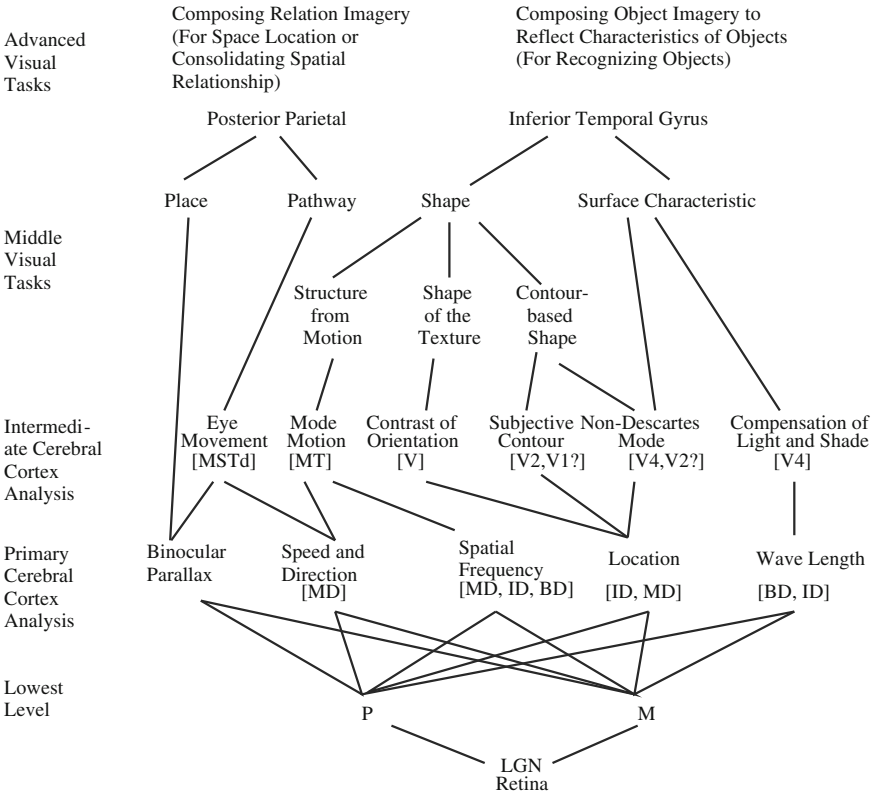


Fig. 5.4 Serial and concurrent processing of visual imagery (from Van Essen and Deyoe 1995, 59)

posterior parietal, characterizing two different visual perceptual tasks. Figure 5.4 clearly shows that inferior temporal gyrus is the main area in generation of object imagery, posterior parietal cortex is the main area in generation of relation imagery). Here we illustrate neural mechanisms at each processing level in Fig. 5.4.

① *Neural mechanism of the lowest level of processing*

All visual information gets input through the eye. Eyes are like a camera, which can be used to adjust the focal length of the lens, can change the size of the pupil, and can accept the focus image of the retina and other three major parts. The retina is composed of several layers of cells: the outermost is photoreceptors (responding to the incident photon) cell layer; according to its shape divided into rod cells and optic cone cells. In each eye, the rods are more than one billion, and they respond to the faint light. The number of cones is only about 7 millions, and they are responsive to light. The innermost layer of the retina is the ganglion cells, whose function is to transfer the signal from the input to cerebral cortex. The input to the eye is the light of the incident eye, and the output is the release of the ganglion cells (i.e., the electrical pulse signal emitted by the light quantum).

For primates, there are two major categories of ganglion cells: M cells and P cells. M refers to Magno, its meaning is big; P refers to Parvo, meaning small. Any point in the retina, M cells are larger than P cells, and have thick axons; therefore, faster signal transmission speed; and M cells have larger sensilla, and the intensity distribution of micro difference sensitive, so it can effectively deal with very low contrast, but at a high ratio of projecting rate to reach saturation with low spatial resolution and color insensitive. P cells, on the other hand, can effectively deal with high degree contrast, the relationship between input and output is close to linear, and have high spatial resolution, color sensitive, but the signal transmission speed is slow, the number is far more than M cells (P cells account for about 80% ganglion cells, M cells account for only 10%, and another 10% or so for other cells).

Light quantum electrical pulse signal, mainly composed of M cells and P cells of the ganglion cells, through the axon, will be transmitted to lateral-geniculate (LGN), and then transmitted to the cerebral cortex by LGN.

Lateral geniculate of the primate has 6 layers, as shown in Fig. 5.5[11]; the two layers of which is composed of large cells, receiving input from the right eye or left eye, and input enters the M cells mainly from retina. P cells on the retina are projected onto the other 4 layers (from the left and right eyes, but each layer can only get input from one eye). Physiological experiments showed that the layer of small cells in the LGN neurons mainly carry on color, texture, shape, parallax information, large cell layer of neurons mainly carries color, texture, movement and target scintillation related information.[12]

[11]Crick (1994).

[12]Schiller and Logothetis (1990).

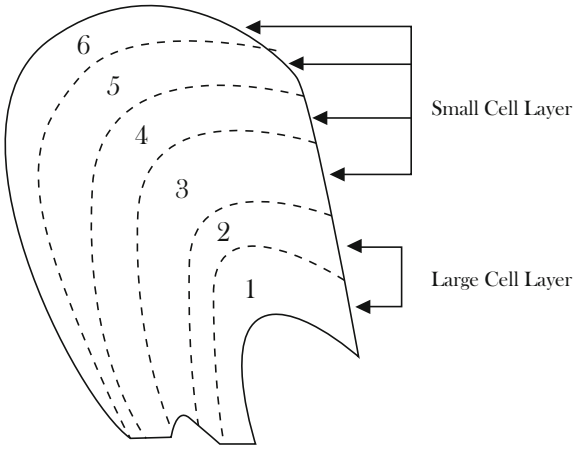


Fig. 5.5 Six layers of primate's lateral geniculate

② *The neural mechanism of primary visual cortex processing*

The structure of cerebral cortex is also layered, and is (which is) generally divided into 6 layers; in fact, some layers is also divided several sub-layer, as shown in Fig. 5.6.

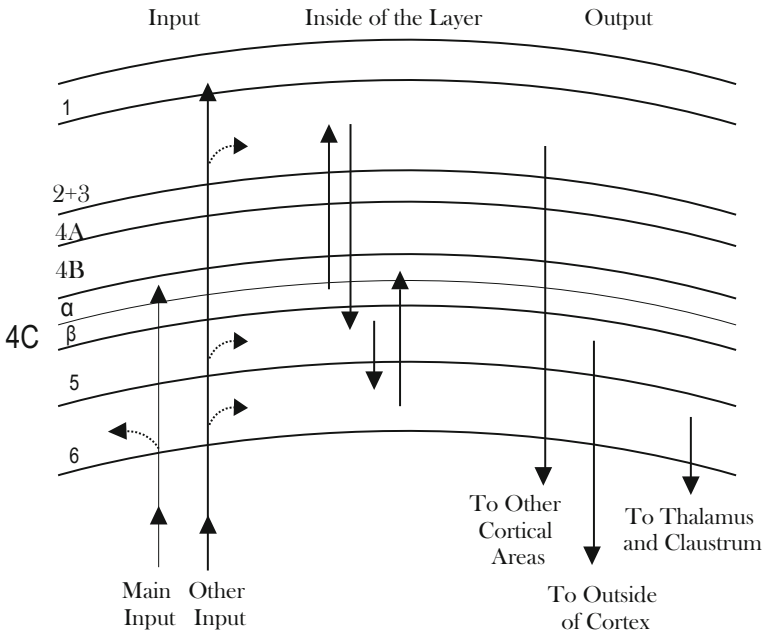


Fig. 5.6 Hierarchical structure and input/output channels of cerebral cortex (from Crick)

The above layer is the first layer, which has only a small number of cell body, mainly composed of the following layer of the pyramidal cells to extend upwards to form dendritic terminals and peripheral connections between axons. There are second and third layers below it, and there are a number of pyramidal cells in the two layers. These three layers are usually referred to as the upper layer of cortex. The fourth layer is composed of many excitatory spiny stellate cells, and almost no pyramidal cells (pyramidal cells because of glutamic acid and its analogs have high affinity and ability to assimilate, and form excitatory synapses. So it is considered to be exciting neurons, spiny stellate cell is exciting, but smooth stellate cells belongs to inhibiting type); Layer 4 containing 4A, 4B, 4C, three sub-layers; 4C can also be further divided into alpha and beta two sub-layers. The fifth, sixth layers are called the lower layers of cerebral cortex, which contain a number of pyramidal cells, some of which can be extended to the first layer on the top.

The second and third layers of cells are only related to other cortical areas, although some of them can be connected with the other hemisphere of the brain through the corpus callosum, but they are not projected beyond the cortical area. Layer 6 in some neurons via lateral axon is connected with Layer 4, but the principal neurons of the layer are of reverse projection to the thalamus or claustrum (located in the cortex and attached to the cortical nuclei. It leads to the middle of brain). Layer 5 is a special level, only the layer of neurons completely project to outside of cortex, in a sense, it can be said that Layer 5 sends processed information to other parts of the brain in the cortical and spinal cord.

Livingstone and Hubel using electrophysiological and cytochrome oxidase staining techniques, made a series of in-depth study the macaque cerebral cortex Area 17 (also called V1) and Area 18 (also called V2), based on the study they proposed shape, color, and the depth of visual information in V1, V2, i.e. the primary visual cortex, were serial and concurrent linear processing model[13,14] as shown in Fig. 5.7.

In Fig. 5.7, VIP—abdominal parietal area; MST—medial temporal region; IT—temporal region; MT—rolantic; 7a—cortical area 7, a sub region; TH—temporal H area (redrawn by Shou Tiande from Livingstone and Hubel 1987[15]; Deyoe and Van Essen 1988b[16]; Zeki 1992[17]).

Lateral geniculate nucleus (LGN) neurons in large cell layer directly project onto cell layer of 4Cα layer within V1 cortex, then turn to project onto 4B layer cells, forming retinal M cells (M cells represented by black dots in Fig. 5.7) → LGN → 4Cα → 4B pathway; in addition, the cells in the spot on the 2 + 3 layer are also likely to receive input from 4C layer of LGN large cell. So spots within cells and intercellular between dots exercise different but complementary functions; most spots within cells

[13]Livingstone and Hubel (1987).

[14]Shou (1997).

[15]Livingstone and Hubel (1987).

[16]De Yoe and Van Essen (1988b).

[17]Zeki (1992).

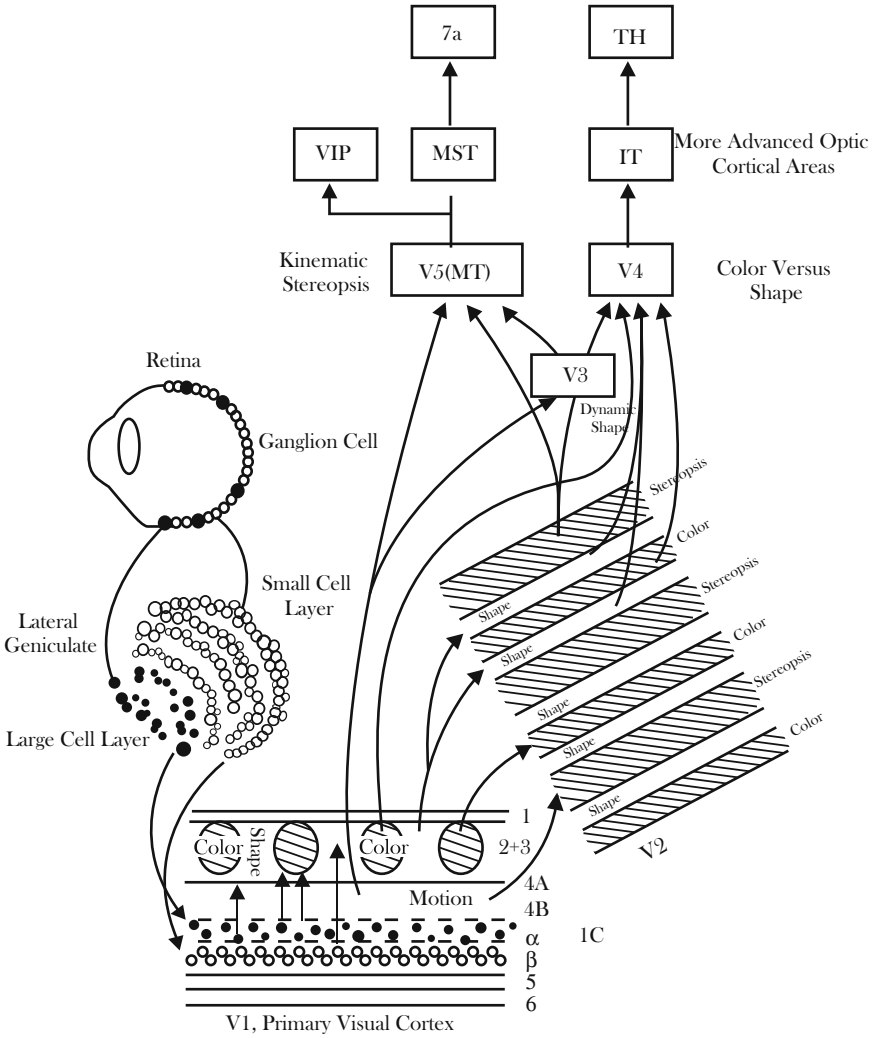


Fig. 5.7 Shape, color, motion and depth information in primary visual cortex in serial and concurrent processing

have obvious color coding, excited by the spectra of certain wavelengths of light stimulation, and on another wavelength segment light stimulation produced inhibition, no choice of the position. In the other part of the spot, the cell is a broad band cell, which has no selectivity to wavelength, but is sensitive to brightness and contrast. Most cells are of no color selection; reaction to a specific range line or border, and regardless of color; spots between cells, although certain spots between cells are of no obvious color selection, but still can accept color coded small LGN cell layer neuron input and still respond to the color. In view of this, through the processing of V1

produced two separate cell populations; one group with no color selection but there are obvious color coding (i.e., with obvious color selection) and another group without obvious color selectivity but the orientation selective.

In the V2 region, the cortical cells of the dark narrow stripes accept the projection of the 2 + 3 layer of V1 layer in the area of the cells. They have no orientation selectivity, and about half of the cells are color coded. The V2 region dark wide stripes within the cells accept projection of V1 4B cell layer, they have no color selectivity, but the vast majority show orientation selectivity. Their most important properties are stereo depth selectivity; namely reaction to monocular stimulation is very weak, and response to the stimulus to both eyes is strong; to change stimulated in the horizontal position of the eyes (retinal disparity) is very sensitive. In area V2 of the bright band of cortex cells accepted projection of dot layer between the cells in the V1 2 + 3, they have the orientation selectivity, but not direction selectivity; bright band of cortex cells and V1 spots between cells are similar, there is no obvious color coding, but response to the color contrast boundary.

From the above analysis, in the primary visual cortex V1, V2, through Serial and Concurrent Processing, color, shape, depth of different visual information has begun to separate. The following will find V2 or above in mid high-level visual cortex and the tendency of separation will be more obvious.

③ *Neural mechanisms in the processing of middle and advanced visual cortex*

According to the research achievements of Livingstone, Huber and Essen et al., intermediate neural mechanisms of visual cortex in primate can use four relatively independent subsystems to illustrate[18]: one involves motion; one relates to color; and two involve shape (Fig. 5.7).

The kinematic subsystem in primary visual cortex locates outside the central area V5 (also known as MT). The input pathway is from the retinal M cells → LGN cell layer → in area V1 of 4Cα → 4B and 4B directly again projects to the V5 (or indirectly by V2 dark wide stripe area).

Color subsystem in primary visual cortex is outside central nervous system V4 Area. The input pathway is from small retinal P cells → LGN cells layer, in area V1 of 4Cβ → 2 + 3 layer spots within cells, and then directly (or indirectly by V2 dark narrow stripe region) projecting to the V4.

One of the shape subsystems is based on V4 area, which is associated with color. Its input pathway is from the retina of the P cells → the LGN small cell layer t → 4C region of 4Cβ → 2 + 3, 2 + 3 layer of the spotted area → the bright band V2 → V4 layer of the cell; another shape subsystem is based on the V3 area (19 area), which focuses on dynamic shape; that is, the shape of object in motion. Its input pathway is from M cells → LGN large cell layer → V1 region of 4Cα → 4B, and then 4B directly (or indirectly through the V2 dark wide striped area) project to V3.

[18]Edinger et al. (1975).

So far, we only discussed forward projection (or positive projection) from the primary visual cortex V1 and V2 regions to the more advanced optic cortical areas (such as V3, V4, V5). Yet is there a reverse projection in more advanced visual cortex to V1 and V2? According to Essen et al., a large number of neurophysiologic experiments on the macaque monkey brain showed that the back projection not only exists, and almost all of them are round-trip with a few notable exceptions, and are generally two-way interactive projections, i.e. reverse projection and forward projection. Such as V1 and V2, V3, V4, V5 (MT) is a two-way interactive projection; V5 at least has reciprocal projections with seven determined visual cortical areas: MST (medial temporal area), VIP (internal parietal area), VP (posterior abdominal), V4, V3, V2 and V1, which MST and VIP belong to higher visual areas.

Although in anatomy there is a large body of evidence for reverse projection, the significance and role of reverse projection from advanced visual cortex to lower visual cortex (information from the top to the lower layer feedback input) are not known enough. It is worth noting[19] that the lower visual cortex of V1 and V2 areas of each sub-layer of the division of the cell is relatively clear, and from the more advanced visual cortex to return to V1 and V2 projection is diffuse. Taking the 4B layer of V1 as an example, the 4B cells not only project to V5 but also project to V3 and the V2 of the cytochrome oxidase staining of the broad striped areas, where V5 can return to the V1 area of the 4B sub-layer and V3 and V2 wide striped area, so that 4B-V5 (in charge of movement information) and V3 (in charge of the shape information) integrated. Similarly, V5 reverse projection to V3 and forward projection V3 V4 affect V2 narrow striped region; and V4 (color in charge of information processing), through reverse projection to V3, as well as V3 reverse projection of V2 wide stripe region, can also affect the movement and dynamic shape information processing. It is evident that the returning of the feedback information pathway not only helps to return to the original visual input neurons, where the sub-layers locate, but also link the primary visual area, the color, shape and motion information together, playing a role of integration.

The above analysis shows that formation of actual visual perception is processed by *serial and concurrent processing* as shown in Fig. 5.1d.

5.2.2 *Neurophysiological Basis of Jointly Non-linear Interaction Processing*

As mentioned earlier, *jointly non-linear interaction processing* refers to the formation of the process of creative thinking (i.e. inspiration/insight), through the interaction of a number of inner loops and the outer loop between logical thinking (Ring A) and subconscious imagination thinking (Ring B) or complex intuitive

[19]Shou (1997).

thinking (Ring C). Here the *jointly* is the inner loop and the outer loop between Ring A and Ring B (or Ring A and Ring C); *interaction* refers to repeatedly executing the mental operation process of inner and outer loop, such as "conscious motivation—subconscious exploration—conscious inspection", to make the repeated interaction between consciousness and subconsciousness come true; *non-linear* refers to the paths to inner loop and outer loop are more than one, but a variety of possible choices (see Sect. 5.1). So the above three aspects are different sides of the same theme, which is through the interaction between the conscious and subconscious thinking, form inspiration/insight. *Jointly* and *non-linear* are methods, the path of mental processing, demonstrating this theme; *interaction* explains from the psychological processing of the specific content. In fact, serial and concurrent linear processing is the same, when the theme is through the interaction of different levels of visual processing to form spatial-visual imagery (i.e., completing the processing of imagery thinking and intuitive thinking); in this occasion, *serial* and *linear* are methods, path of mental processing; *concurrent processing* (as mentioned above, concurrent processing includes the interaction between different paths and between different levels) involves the specific content of mental processing. So in the following, we shall analyze the neurophysiologic basis of *jointly non-linear processing* around the conscious and subconscious interaction (i.e. interaction between temporal-logical thinking and imagery thinking or temporal-logic and intuitive thinking). Because the subconscious thinking only occurs in Ring B or Ring C, and Ring B or Ring C on both neural-physiological basis of serial and concurrent processing mechanism has been discussed in the previous section in details. Ring A is conscious temporal-logical thinking; therefore, to explain neural-physiological basis of jointly non-linear processing between consciousness and sub-consciousness is in order. We only need to further solve the following three problems: neural mechanism of Ring A thinking process; neural mechanism of Ring B (or Ring C) outputting to Ring A and neural mechanisms of Ring A outputting to Ring B (or Ring C). In the following the three questions will be examined one by one.

5.2.2.1 Neural Mechanism of Thinking Processing in Ring A

The processing flowchart in Ring A shown in Fig. 4.7 (Chap. 4) is evident that it is serial, linear sequential processing. In order to accomplish the processing, the brain should provide physiological support for two functions. First, processing mechanism of logical thinking (to determine plan, order, logical analysis, judgment, reasoning for the thinking process, and the monitoring and regulation of the process of realization of the goal); Second, logical thinking processing buffer (also called speech working memory, for temporary storage of processing object, of intermediate results, or final results of logical thinking). On the localization of these two functions in the brain, it is at present not yet very precise. (Jonides et al. made a thorough study of imagery thinking and intuitive thinking about working memory

and processing mechanism, using PET and MRI technology, but did not specifically study logical thinking); however, there are many researchers, who explore carefully in this regard. The following discussion is based on worldwide research progress in this field since 1990s.

(1) Processing mechanism of logical thinking

There are numerous views about localization of cerebral cortex in the processing mechanism of logical thinking:

① *The view from* Robin et al.

Nina Robin et al. believed that[20] human knowledge of problems solving is nothing but two categories: explicit relation knowledge and implicit relation knowledge. Explicit relation knowledge is based on consciousness, but a step-by-step logical reasoning; implicit knowledge is based on the process of subconscious, rapid and intuitive thinking. Robin et al, through cranial nerve anatomical and electrophysiological measurements, confirmed that the main function of the prefrontal cortex is to acquire and use explicit relation knowledge, and is responsible for the distribution of attention, behavior planning, supervision and regulation, and the control of activity of the time sequence. In other words, the prefrontal cortex is the basis of logical analysis and reasoning.

Robin et al. also pointed out that the prefrontal cortex includes three component parts: principal sulcus and prefrontal dorsolateral cortex, arcuate sulcus and surrounding areas and the orbitofrontal cortex; each part has the function of analysis and understanding of attributes and complex relations between things; i.e. to satisfy the requirements of logical thinking.

The dorsal part of the principal sulcus—is responsible for controlling attention and working memory, making plan, has some influence on the learning of stimulus response of accidental events.

Arcuate sulcus and surrounding areas—plays decisive role on the learning of stimulus-response conditional accidental events, especially on emergency response and treatment.

Orbitofrontal cortex—is responsible for selective psychological processing and emotional control.

② *The view from* Knight et al.

Human thinking activities usually include three levels: the first level is the perception, the second level is the executive function, and the third level (the highest level) is awareness and self-awareness. R.T. Knight et al. believed[21] that in addition to the first level, the remaining two levels of function (also the key functions of human cognition) are dependent on the dorso-prefrontal cortex.

[20]Robin and Holyoak (1995).

[21]Knight and Grabowecky (1995).

Knight et al. also pointed out that consciousness on the third level contains four sub-components: awareness of sensation, conscious behavior monitoring, planning for the future of internal simulation (i.e. expectations and evaluation of the results of future activities), and continuous behavior monitoring (to ensure integrity, coherence and consistency at different time). As a result of the second and three level functions are dependent on the dorso-prefrontal cortex, so Knight et al. believed that the prefrontal planning to achieve the goal, making decisions to problems, monitoring and adjustment and control, plays a decisive role to the time sequenced tasks.

Knight et al. identified the prefrontal cortex as, 8, 9, 10, 44, 45, and 46 regions of the cerebral cortex in Brodmann Area 6.

③ *Gazanniga's view*

Gazzaniga[22] et al. believed that the brain is organized in modules of subsystems by the nervous system at various levels of activities; each subsystem is responsible for the behavior occurrence, control of mood and cognitive processes. But all of these subsystems are integrated and monitored in order to be coordinated and must be subject to a specific system called interpreter. Gazzaniga believed that the interpreter should be located in the left hemisphere of the cerebral cortex, which is the most important system of the human brain. It gives us the ability to reason, so that we do not make simple responses to a variety of stimuli in daily life; it makes us form belief and psychological structure, so that a variety of psychological activities can be carried out. Therefore, Gazzaniga said the interpreter is actually the processing mechanism of logical thinking. But it is a pity that he only affirmed that the interpreter is in the left hemisphere of the brain, but failed to point out which part of the left hemisphere of the cortex it should be specifically located.

Considering the three points above, we believe that logical thinking processing mechanism positioning identified in Knight et al., prefrontal cortex dorso-latero part is more credible. The reason for believing so is:

First, Knight et al. said of prefrontal cortex dorso-latero part and Robin et al. identified in the prefrontal cortex of three composition parts in the first part (main groove and around prefrontal cortex dorso-latero part) is basically the same. And Robin et al. said two other components, although having some relations with logical thinking, did not play the main role (especially orbito-frontal, which relates more closely with emotion control).

Second, Knight et al. defined functions of prefrontal cortex dors-latero part (including planning for realization of the goal, decision making, monitoring and regulation of problems and behaviors, and control of sequential tasks) which coincide with the goals of logical thinking.

Third, Knight et al. provided localization of prefrontal cortex dorso-latero part, which is, comparison with cerebral cortex, more accurate; Brodmann areas 6, 8, 9, 10, 44, 45 and 46.

[22]Gazzaniga (1995).

(2) Working memory area (logical thinking processing cache area)

At present, there are some views about processing buffer area (i.e. speech working memory area) of logical thinking in cerebral cortex.

① Petrides et al.[23] believed that working memory and verbal materials is in Brodmann Area 6.

② According to Knight et al. (see footnote[24]), the location of dorso-lateral prefrontal cortex is in cerebral cortex refers to all areas related to logical thinking (i.e. with Knight et al. said the second and third levels on the entire regions); that is to say, a verbal working memory area should also be included within the seven Brodmann Areas (6, 8, 9, 10, 44, 45 and 46). Combined with Petrides' opinion, we have reason to believe that Knight et al. of verbal working memory of cerebral cortical location should also be in Brodmann Area 6.

③ Martinez and Jonides et al. in the use of PET and MRI techniques accurately positioned object working memory zone in the left prefrontal cortex (concentrated on Brodmann Area 6, positioning coordinates in space: 39, 3, 29), and then made additional experiments specifically for Petrides' view.

On the results of the experiments, Martinez[25] described: People think that this part relates activation and use of speech materials and working memory; imagine naming geometric shapes and replicating the names, and then our experimental data showed that the activation and use of language processing are consistent. The meaning of this paragraph is that in the object recognition experiments of Martinez et al. (the object is geometric shapes), if adding geometric shape naming and duplication in the experiment (i.e., increased with the concept of speech materials as logical thinking experiment content), is seen that the original n location in the cerebral cortex and activated position are consistent. This is to say that the experiment confirmed Petrides' view, and also confirmed neurophysiologic argument in the first section of this chapter that temporal-logical thinking and spatial-structural thinking are interdependent (especially the argument that concepts on the establishment of speech symbols must be combined with relevant imagery; otherwise words and concepts will become meaningless).

According to the above three views, especially Jonides et al's experimental results in complement of Petrides' view, we can conclude that in the case involving imagery thinking, verbal working memory in logical thinking and imagery thinking should be object working memory (the two coincide), which should be on the left prefrontal cortex (focus on Brodmann 6 Area, space positioning coordinates: 39, 3, 29); and in the case involving intuitive thinking, though Jonides et al. did not conduct similar experiments, considering that the speech concepts has anaclisis for

[23]Petrides et al. (1993).

[24]Knight and Grabowecky (1995).

[25]Smith and Jonides (1995).

object imagery (whether attribute imagery or relation imagery)—concepts will become the meaningless symbols without the imagery, therefore, we have reason to believe that, when the intuitive thinking is involved, logical thinking and verbal working memory areas should also be the same area for spatial working memory of intuitive thinking, which should be in the right prefrontal cortex (concentrated in the location Brodmann Area 47, space positioning coordinates: −35, 19, −2).

5.2.2.2 Neural Mechanism of Output of Ring B (or Ring C) to Ring A

The output of Ring B refers to the output generated when creative imagination takes place, because at this time thinking results are saved in imagery thinking processing buffer zone; namely, object working memory area, so the output of Ring B refers to the object processing buffer zone; output of the Ring C is the output generated when complex intuitive thinking takes place, because at this time thinking results are kept in intuitive thinking in the cache zone; namely spatial working memory area; so output of Ring C refers to output in spatial working memory area. But in the above discussion about logical thinking processing buffer (i.e., speech working memory area), we have proved, through Martinez et al. experiments and interdependence theory, that under the condition of imagery thinking, speech working memory area and object working memory area coincide; under the condition of intuitive thinking, speech working memory area coincides with spatial working memory area. Speech working memory area is logical thinking for temporary storage of objects of processing (including the initial input directives and intermediate results of thinking and final results of thinking. Figure 4.7 shows Ring A at the bottom of the flowchart: logical analysis and reasoning test Ring B (or Ring C) for insight; its operation is carried out in this buffer area. Because imagery and logical thinking (or between intuitive thinking and logic thinking) is working on serial-linear processing, so that shared memory area no harm, and save storage space and improve efficiency of thinking. This clearly shows that coincides with the natural temporal-logical and imagery thinking (or temporal-logical and intuitive thinking) this two brands of thinking form memory area, and the two forms of thinking in a serial, linear processing (only in imagery and intuitive thinking process, namely inside of Ring B or Ring C concurrent processing); this is the neural mechanism of cerebral cortex, which transmits the output information of Ring B (or Ring C) to the input end of Ring A.

Obviously, we should not consider the above input of Ring B (or Ring C) as the main path (not the only access) of input information to Ring A in any case. In fact, the above input (that is, from Ring B or Ring C input information), only in intentional creative thinking process that Ring A is the main input pathway under working the condition of the DC model; while in general thinking process (i.e. not in the DC model) Ring A can also have many other input pathways.[26] As Robin

[26]Robin and Holyoak (1995).

et al. pointed out that between prefrontal dorsal cortex and cortex posterior has many links, through which the back side (i.e., location of the processing mechanism of logical thinking) can receive visual, auditory and other somatic sensory information. In short, prefrontal cortex and other cortical areas and sub-cortical structures (including almost all parts of central nervous system) have extensive interaction relations, and play the role of integration and coordination in behavior control.

5.2.2.3 Neural Mechanism of Output of Ring A to Ring B (or Ring C)

The neural and physiological evidence on Ring A, which can send output information to the input end of Ring B (or Ring C); i.e., logical thinking can guide, regulate and control imagery or intuitive thinking, which has the following aspects.

(1) The paragraph just cited from Robin et al. showed that There are extensive interactive relations among dorso-lateral prefrontal cortex (i.e. location of logical thinking processing mechanism), cerebral cortex posterior and cortex structure (including almost all parts of the central nervous system). Because of this connection, it can get information from a variety of sensory channels (visual, auditory, and other somatic sensory channels), and also in turn affect these channels. This is because a large number of neurophysiologic measurement results and primate brain cortex anatomy have proved that cerebral cortex between various parts of information transfer (in neurophysiology, it is called projection) has two tenets.[27,28]

First, interactivity—generally, apart from few exceptions, projections between cortexes are interactive, i.e. if ascending projections from V1 to V2 or MT (also known as positive projection), then there will be descending projection from V2 or MT to V1 of the (also known as reverse projection).

Second, asymmetry—though projections between two cortexes are interactive, but not along the same path; in the forward projection, projection cells (hair discharge pulse signal of cells) come most from the shallow layer cortex (see Fig. 5.7), only about 10–15% of the few projecting cells come from the deep layer of cortex, but all came to an end in Layer 4 of the cortex; and in the back projection, projecting cells come from both shallow and deep layers, but are projected onto the other levels beyond Layer 4, such as Layer 1 and Layer 6. In other words, the forward projection is mainly terminated in Layer 4, and the reverse projection is mainly terminated in Layer 1 and Layer 6; thus it is not symmetrical.

It is due to the interaction between cortical projection and in dorso-prefrontal cortex (logical thinking processing mechanism location) that through multiple sensory channels to obtain various sensory information at the same time, exerting

[27]Van Essen and Deyoe (1995).

[28]Shou (1997).

influence on these channels. Due to the formation and processing of these sensory channels closely related to various kinds of imagery (processing of imagery thinking and intuitive thinking is closely related); therefore, logical thinking plays a role of guidance, regulation and control to imagery thinking and intuitive thinking.

(2) Van Essen et al. used pathway-tracing techniques in a large number of brain physiology experiments, and found that there're a lot of cortical connections within the visual cortex, 305 connections having been found (up to now accounted for only about 1/3 of 35 visual cortex areas have been found), these connections form net hierarchy, as shown in Fig. 5.8. From V1 to the topmost visual cortex (36, 46, TF, TH) consists of 10 levels, also along the bottom of retina and LGN two sub-cortical levels, and on the top has also two levels of the limbic system (ER—entorhinal cortex, HC—the hippocampus).

Figure 5.8 shows that the highest level includes dorso-prefrontal cortex, Brodmann Area 46. Area 46 and intermediate levels exist many areas (such as V4 and MT) directly projecting reciprocally, and at low levels of V1, V2, though there's no direct connection, but due to V1, V2 and V4 and MT intermediate levels have a direct interactive projection. Therefore, through the intermediary role of V4 and MT areas, Area 46 still exerts influence on primary visual cortex.

In other words, Area 46 (a part of logical thinking processing mechanism) can exert direct or indirect effect on visual cortex (whether it is in high level, middle level and low level) and also on the visual-perceptual channel. As visual-perceptual channel is the main channel for processing object imagery and relation imagery (i.e., the main processing channel for imagery thinking and intuitive thinking) and so the cortex shown in Fig. 5.8, cortical connections to net hierarchy should be the major neural mechanism for guidance and regulation of implementing imagery/intuitive thinking in logical thinking. Considering Fig. 5.8 is just about hierarchical graph of visual perception channels in cortex (cortical connection network); in auditory channel it should also have corresponding hierarchical net graph; namely, the dorso-lateral prefrontal cortex (part of the processing mechanism of logic thinking). In auditory channel, olfactory channel, gustatory channel, kinesthetic channel, except for Area 46, other areas should also, through different net structure, exert influence to corresponding perceptual channels of the whole processes (from low level, intermediate level to a higher level).

(3) Edinger and Skinner et al pointed out[29,30] that prefrontal cortex has a network to suppressive output to cortex and other cortical areas. Skinner et al. also studied prefrontal thalamic gating mechanism[31] and found that gating mechanism will send to the primary cortical areas to convert sensory input modality of inhibitive specificity; and if blocking prefrontal thalamic gating mechanism, it can result in primary sensory cortex to increase stimuli-response amplitude,

[29]Edinger et al. (1975).

[30]Skinner and Yingling (1977).

[31]Skinner and Yingling (1977).

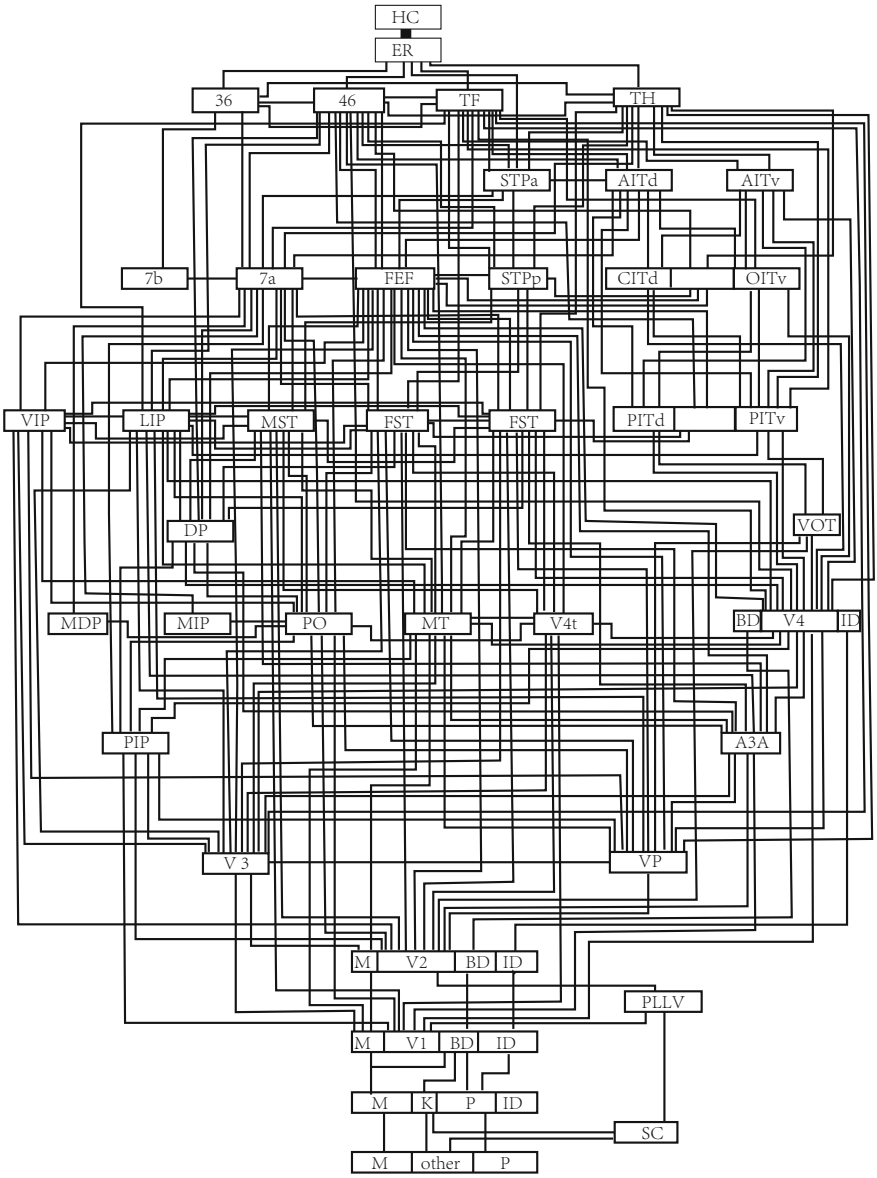


Fig. 5.8 Primate visual cortex—cortex network (from Van Essen and Deyoe 1995)

otherwise response amplitude will decrease. Visual, auditory, olfactory, and kinesthetic and various sensory information lead to cerebral cortex pathway, must go through the transfer station—part of the lateral-geniculate nucleus (LGN) of thalamus, so LGN is actually main exit of a variety of sensory

channels into cerebral cortex. It is evident that prefrontal lobe of thalamus gate mechanism is Ring A, which can affect Ring B (or Ring C) input, so as to become another neural mechanism for regulatio

(4) As "transfer station" of varieties of sensory channels or main input port LGN, through which input information enter into cerebral cortex; yet it is not the only source where external direct perception come into (For visual channel, the input information from sense organs comes from retinal ganglion cells M cells or P cells, which provide electric pulse signal through conversion of light quantum). As mentioned above, Robin et al.[32] pointed out that dorso-lateral prefrontal cortex and other cortical areas and sub-cortical structures (including almost all parts of the central nervous system) have extensive interactive relations. Therefore, LGN can also back-project, through dorso-prefrontal cortex on the layer of skin structure to obtain feedback input from dorsal part.[33] As Chinese neurophysiologists Shou Tiande pointed out that even thalamus lateral-geniculate also accepts a lot of corticofugal projections. In the total input of cat lateral-geniculate, cortical projection fibers presumably are over 50%; in the total input of primate lateral-geniculate, from prefrontal dorso-lateral cortex (i.e. from the processing mechanism of logical thinking, or from Ring A) of projection generated by feedback input (i.e. reverse projection), specific percentage of which at present has not been reported in research literature, but presumably account for a large proportion (as it is speculated to be more than 50% of the cat). As mentioned above, logical processing buffer (i.e., speech working memory area is the buffer of results of logical thinking) is also in the dorso-prefrontal cortex, so it can also, through reverse projection to the LGN, generate feedback input. Due to the fact that speech working memory stores the results of logical thinking, LGN is the main entry of all sensory channels into cerebral cortex (i.e. main entry of imagery thinking and intuitive thinking), which is equivalent to directly add output of logical thinking (i.e., output of Ring A) to the input end of imagery thinking and intuitive thinking (i.e., the input end of Ring B (Ring C)). Evidently, LGN can directly accept the reverse projection from prefrontal cortex, and it is proved that this reverse projection is indeed another neural mechanism of Ring A to Ring B (or Ring C).

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[32]Robin and Holyoak (1995).

[33]Edinger et al. (1975).

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Chapter 6
Cultivation of Creative Thinking

In Chap. 4, we proposed an intentional creative thinking model: *Inside and Outside Circulation Model* (double circulation model or the DC model for short) after making an in-depth analysis of intentional creative thinking process. In the beginning of Chap. 5, we pointed out that the mental model of intentional creative thinking is what we usually called creative thinking mental model (or "creative thinking model" for short). In other words, the creative thinking model is "inner and outer circulation" (i.e. DC model). In Chap. 5, we also argued deductively, from the psychology and neurophysiology of two different angles of the DC model, that the model does have a solid theoretical basis. Because the model can clearly elucidate psychological process and processing mechanism of intentional creative thinking; therefore, it may be used for the training of creative thinking, so as to promote the growth of a consignment of creative talents. To this end, we should further develop a set of guiding strategies and methods, which can be applied to the practical teaching and training of creative thinking with the DC model. The purpose of this chapter is dealing with this issue.

As mentioned before, the core of the DC model is continual interaction between internal and external cycles. The inner loop is the circulation between the two mental operations: conscious stimulus and subconscious exploration. The role of inner loop is to make a creative breakthrough in creative goals around consciousness (directives from Ring A) in order to generate inspiration/insight. The role of external circulation consists of three mental operation cycles: in conscious stimulus and subconscious exploration and conscious check-up and others. The role of this loop is to test the thinking results from the inner loop (i.e. the inspiration/insight): if it fails to pass the test, modify Ring A directives, according to the gap between current achievements and creative thinking goals; and then return to inside cycle to explore a new round of the subconscious; if it passed the test, it shows that the original creative goals have been achieved, and that brings to the end of the process

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of creative thinking. It's evident that in internal and external cycles, for creative breakthroughs, the key is to rely on the inner loop. Internal circulation is related to both conscious thinking (by consciousness stimulus, guidance and regulation) and the subconscious, and creative breakthrough happens mainly in the subconscious. The outside circle includes inner circle. From the global point of view, it's related to the subconscious mind, but if the inner circle is considered as an independent entity, the outer loop (after removal of the contents from the inner circle) relates to the conscious mind (i.e. temporal-logical thinking). This shows that we should firmly grasp the key (the inner circle) to the development of creative thinking in the young people; at the same time, we should take into account the external cycle.

In Chap. 4, Fig. 4.8 shows the DC model and Figs. 4.5 and 4.6 show processing closely related with internal circulation. It's evident that inner circle mainly involves the following thinking processes: temporal-logical thinking, divergent thinking, imagery thinking (including the object attribute images: association, imagination, analysis, synthesis, abstraction, generalization and other mental operations); intuitive thinking (attribute imagery of overall pictures, intuitive perspective and fast comprehensive judgment); and the inner circulation of the subconscious exploration stage also considers specifically designed complex problems-solving of high *m* value; i.e. to realize the creative breakthrough of psychological processing strategy—horizontal-vertical thinking (see Sect. 4.6, Chap. 4).

In the outer loop, it mainly involves temporal-logical thinking. In addition, in order to make the process thinking more depth and insight and in order to make inspiration/insight generate along the right direction and goals as soon as possible, as described in Chap. 4, using the philosophy of dialectical materialism to guide the whole process of thinking is crucial; in other words, without dialectical-logical thinking (dialectical thinking for short), creation can not be achieved. In this way, there are six kinds of thinking forms in the process of creative thinking; namely, divergent thinking, imagery thinking, intuitive thinking, temporal-logical thinking, dialectical thinking and horizontal-vertical thinking. The following is a discussion about the different roles and relations of these six kinds of thinking as well as their training strategies and methods.

6.1 Six Elements of Creative Thinking

According to the double circulation model (the DC model) of creative thinking, we already know that the process of creative thinking is supposed to be composed of six elements: divergent thinking, imagery thinking, intuitive thinking, temporal-logical thinking, dialectical thinking and vertical-horizontal thinking. The six factors are not unrelated, isolated, parallel, but play primary or secondary roles, in accordance with division of labor, and complement each other. For creative breakthroughs, some elements play a greater role (even a key role), and some elements relatively smaller role, but each of the elements are essential, and irreplaceable, so as to form an

organic whole in the creative thinking structure. In the following, we shall analyze the role and characteristics of each element in the structure.

6.1.1 Divergent Thinking—A Sign of Thinking Direction

According to the direction, thinking can be divided into two types: convergent thinking and divergent thinking. Convergent thinking is also known as concentrated thinking; divergent thinking is also called reverse thinking or multi-directional thinking. Convergent thinking stresses the only correct goal, which requires thinking contents and results of creative thinking be concentrated on and unified to traditional concepts or the original concept; otherwise everything else is regarded as an error or deviation; and divergent thinking stresses that the contents and results of thinking be different from the traditional or original concepts; or even on the contrary, the goal of thinking cannot be determined in advance, and the goal can be one, or multiple.

Divergent and convergent thinking have no specific materials for thinking and no specific means and methods of processing (temporal-logical thinking, imagery thinking and intuitive thinking have specific thinking materials and specific processing means and methods). So divergent and convergent thinking are not considered basic forms of human thinking; it just guides the human thinking in terms of thinking goals.

The guidance can be used for logical thinking, but also can be used for imagery, and intuitive thinking. In short, divergent thinking only explains the direction of thinking (where to proceed thinking), but not to solve the specific problem of how to think. In spite of this, in creative thinking activities, divergent thinking still has value, which should not be underestimated. This is because we must first determine the direction and goal before we do things; if the direction is mistaken, it's futile to spend more energy, for it's not your destination, and it may be poles apart. So it's true with creative thinking activities.

Convergent thinking, due to the requirement of content of thinking, thinking results should be centralized and unified to traditional or original concepts, so the advantage is that it's conducive to knowledge teaching and learning, and conducive to the mastery of previous knowledge and experience; its malpractice is that it's easy to cause students to trust books, teachers, and the authorities; whatever teachers say is the truth, students are unable to show the slightest doubt. So if we just care about convergent thinking, our understanding will always stay in the previous level, which of course cannot produce a new theory, or new ideas. In order to innovate, divergent thinking must be stressed. If there's no divergent thinking (divergent thinking, reverse thinking or multi-directional thinking), it would be unable to have any starting point for creation nor any creative achievements. It can be said that all creation originated from divergent thinking. Numerous examples of this can be cited.

6.1.1.1 Faraday's Discovery of the Law of Electromagnetic Induction

In 1820, H.C. Oersted, a Danish, found that electrified wires could make magnetic needle nearby deflect (electric can produce magnetic). The same year, A.M. Ampere of France also found the interaction between two electrified wires. When the two electric currents are in the same direction, they will repel each other. When the two electric currents are in the opposite direction, they will attract each other. M. Faraday, who got to know the news, immediately thought that since electricity can produce magnetic, then in turn, the magnetic should also be able to generate electricity. This is reverse thinking, divergent thinking; it's under the guidance of this thinking that Faraday, after 11 years of efforts, finally confirmed the hypothesis by experiments, and found that the size of electromotive force and the variation rate of magnetic flux is proportional to the law of electromagnetic induction.

Not only the sprout of this creation, but also the creative achievements relied on reverse/divergent thinking. Although Faraday firmly believed that the magnetic field can generate electricity, he did not succeed in proving it after hundreds of experiments since he did the experiments along traditional ideas: current always ran along a straight line, so experiment always led magnetic field to a straight wire (convergent thinking), and then to observe whether the wires had current running but results always turned out in failure. Until then he realized that current could run along an arbitrary direction, as current-carrier wire could also be arbitrary shape, so he put wire bent into a circle (divergent thinking), and solenoid form, and permanent magnet is inserted into and then pull out (to change the magnetic flux), and this time he succeeded. It's the experimental basis of the law of electromagnetic induction.

6.1.1.2 De Broglie's Wave Theory of Microscopic Particle

In 1905, Einstein has theoretically proved the particle-like nature of microscopic particle (such as photon) and proved that each photon (also called optical quantum) with speed and quality (photon rest mass is zero). Soon after, Compton also confirmed the particles through experiments (Compton Effect). So at the beginning of twentieth century, there was no doubt that the microscopic particle has the particle-like nature, and almost no one doubted about it. Only de Broglie took the opposite direction, using reverse thinking he put forward that the microscopic particles could also have particle-like nature as well as volatility (volatility and particle-like nature are completely opposite) and under the guidance of this idea in 1924 the wave theory, three years later, was indeed confirmed by Davidson's electron diffraction experiments (that interference and diffraction phenomena are

essential characteristics of volatility). This is famous physical theory wave-particle dualism—making significant revision and development to Einstein's authoritative conclusion.

6.1.1.3 Bill Gates and Personal Computer Revolution

In January 1975, Bill Gates was still a sophomore student in the Law Department of Harvard University. One day he saw photos that showed MITS Company's first personal computer on *Electronics Popular* cover. The computer used Intel 8080CPU chip (8 bit machine), he immediately recognized that the machine was of small volume, low price, which could easily enter the family, be owned by each person, and might cause a profound revolution—not only in the field of computer, and it was the revolution of human society in life style and work style. He realized that it was a golden opportunity; he determined to seize the opportunity.

The idea of Bill Gates was unusual at that time, contrary to the dominant idea of the computer world. At that time, the view of computer kingdom of IBM was that miniature personal computer was a gadget that could only play games, a simple application of low taste; the role of trend-leading computer could only rely on large, giant types. It is Bill Gates' peculiar divergent/reverse thinking, and the spirit to challenge the tradition and authority that led to his great success. He said to himself that it was necessary to seize the most valuable opportunities in life; he said so and did so. He offered to write to the boss of MIT, to volunteer interpretation program with BASIC for personal computers (knowing that without easy-to-use computer programming language, personal computer was difficult to multiply). With the help of his friend P. Allen, they finally accomplish the task in five weeks, which made a great contribution to the popularization of personal computer. Then he dropped out from Harvard midway and together with Alan founded his own company Microsoft, a well-known company now.

In addition, the invention of helicopter (start from the divergent thinking about propeller installation: the position of propeller installation changed from the front of fuselage to the top of fuselage), the creation of aircraft carrier (originated from the whimsical divergent thinking that the concrete runway could flexibly move), the invention of a new generation of cancer drugs (originated from reverse thinking which is the complete opposite of the traditional concept: trying to convert cancer cells to normal cells with the idea of converting enemies into friends instead of killing cancer cells by using radiation or resisting the invasion of cancer cells by using drugs) as well as the creation of other things all have the help of divergence thinking (divergent/reverse thinking, multi-directional thinking), which shined with brilliance. Evidently, divergent thinking, though it involves only the direction of thinking (and does not involve specific how to think), but in creative activities it can often play a decisive role.

6.1.2 *Imagery Thinking, Intuitive Thinking and Temporal-Logical Thinking—Core of Creative Thinking*

As described in Chap. 2, according to the philosophical view of time and space: inseparability of moving matters and space and time, human thinking in its basic form, as generalization and indirect reflection of movement of objects, has only two types: temporal-logical thinking and spatial-structural thinking. The material of temporal-logical thinking (thinking objects) is a concept based on language. For the material of temporal-logical thinking, the main methods of thinking processing are analyzing, synthesizing, abstracting, generalizing, judging and reasoning by the use of concept; the materials for spatial-structural thinking are mainly visual-spatial imagery, which reflect attributes of things (termed attribute imagery or object imagery) and reflect relation between things (called relation imagery or spatial imagery). Because of relation and object imagery have great differences in processing methods (corresponding brain physiological mechanism is not the same either), it's usual that spatial-structural thinking is further divided into two subclasses: imagery thinking, imagery as material of thinking, and its methods of processing are mainly by analysis, synthesis, abstraction, generalization and association, imagination (representative thinking and creative thinking); intuitive thinking is the thinking which takes the relation imagery as thinking materials and its methods of processing are mainly by overall grasp of imagery, directly through visual perspectives and rapid and comprehensive judgment. It can be seen that temporal-logical thinking, imagery thinking and intuitive thinking are the three basic forms of human thinking.

But in the traditional school teaching, only temporal-logical thinking is stressed, but not the other two: intuitive thinking and imagery thinking.

Up to now in textbooks compiled and published by the state order (the former Chinese State Education Commission) for institutions of higher learning, the dominant view in philosophy and psychology is that only logical thinking can reveal the nature of things and intrinsic relation between things; so the view comes down to rational thinking, advanced thinking, and other forms of thinking, such as the imagery thinking and intuitive thinking cannot reveal the nature of things and relation between things, which can only obtain perceptual knowledge of things, thus non-rational thinking (the implication is that it's lower-level thinking). In fact, there are only three forms of basic modes of human thinking, which are different only in methods and means of processing, without distinction of higher and lower ranking. And from the perspective of exploring the nature, the patterns of new things, i.e. from the perspective of creative activities, imagery thinking and intuitive thinking are often more suitable than logical thinking for the needs of exploration and innovation because of their integrity and unconventionality (instead of the linearity and sequentiality owned by logical thinking). In fact, the key breakthrough in creative activities (i.e. creation of inspiration/insight) can only be dependent on imagery thinking (especially creative imagination) or intuitive thinking, and rather

than reliance on logical thinking. This breakthrough can not be made without logical thinking's guidance and adjustment of the former two thinking.

6.1.2.1 The Formation of Inspiration/Insight and Imagery Thinking

At this point we shall look at some cases of imagery thinking engendering inspiration/insight.

Case 1: *The Proposing of Continental Drift theory*[1]

At the beginning of the 20th century, some geologists and meteorologists (such as American Taylor and Baker and German Wegener et al.) found that the external contour of South America was so similar to that of Africa when reading the world map. Hence they produced a fantastic imagination: billion years before, the two pieces, originally was a whole, due to the change of geological structure later gradually split apart. Under the guidance of the imagination, Wegner did a large number of geological survey and ancient fossils study. Finally, he proposed continental drift hypothesis, with the support of climate, glacial and geological structures on both sides of the ocean and matched rock composition. This hypothesis of continental drift had significant influence on geology (until the 1950s the hypothesis was further confirmed by the British physicist geomagnetic measurements). Evidently, the proposition of the continental drift hypothesis cannot be separated from the above wonderful imagination.

Case 2: *Invention of infrared tracking technology*

Biologists know that eyesight of rattlesnake is very poor; nearly tens of centimeters things are not able to see, but in the night they can accurately capture voles 10 m away. The secret lies in buccal nest between the eyes. This part is a biological infrared sensor, which can feel animal activities in the distance, due to the heat generated by micro infrared, so as to achieve thermal localization. From this case, American missile experts started to think: if an electronic device similar to rattlesnake's biological infrared sensor were manufactured (electronic infrared sensitive device) for the acceptance of radiation of infrared generated by engine heat during aircraft flight, this would be used to realize automatic tracking of a target by thermal localization. The so-called infrared tracking of Rattlesnake Missile is designed on the basis of this association.

Case 3: *Establishment of cone-cutting theory*

In imagery thinking, inspiration/insight can be generated, as in the above two examples, through association and imagination, and can also be generated by object imagery through analysis, synthesis, abstraction and generalization. The process of establishment of cone cutting theory is a good example. As early as in the Aristotle

[1]Hui (1994).

era, people had geometry concepts like circle, elliptic and hyperbolic, but then these concepts were isolated from each other, and were not related to each other. Kepler, Desargues and Poncelet, through analyzing and synthesizing the various shapes (object imagery) of cross sections of cutting cone, found that these cross-sectional shapes were of only three types: circle, ellipse and hyperbola; on the basis of further abstraction and generalization, three imagery of common features cut by a cone were obtained, the only difference between them lies in different ways of cutting (plain cutting—circular; vertical cutting—hyperbolic; Oblique cutting—ellipse). In this way, the original three geometric patterns which are not related to each other are linked together by cone cutting theory, which forms a geometric system with tight structure.

6.1.2.2 The Creation of Inspiration/Insight and the Intuitive Thinking

We shall look at the following examples that intuitive thinking generates inspiration/insight. However, it's necessary to make some explanations of the concept of *intuition* and *intuitive thinking* before discussing the examples.

Intuitive thinking is not yet profoundly investigated in the field of psychology, so it's not very clear on the nature of the process and features. Because of this, the general public, and even among some academics also hold the view of a popular saying: intuition is the sixth sense. What is the sixth sense? It's an imprecise, inexplicable feeling. Intuition for many people seems to come out of the blue with a groundless subjective conjecture. This understanding of intuition is false, but intuitive thinking is a basic form of human thinking (it's indispensable with other two forms of thinking, namely, imagery thinking and temporal-logical thinking); it's not the sixth sense. Intuitive thinking has at least three features in mental processing (actually, it is the specific feature of the thinking processing method when the "relation imagery" is the material of thinking).

First, grasp the broad picture—put aside minutiae, think from macroscopic point of view.

Second, integration of intuitive perspective and space—for intuitive thinking, grasping the overall picture refers to the overall grasping of relation between things; namely, intuitive thinking considers only relation between things, and does not consider specific attributes of things (analysis, synthesis, abstraction and generalization of specific attributes is the task of logical-thinking and imagery thinking, not of intuitive thinking). From the overall grasp of relation between things, intuitive thinking uses the methods of intuitive perspective and spatial integration, rather than rely on logical analysis and synthesis.

Third, rapid judgment—intuitive thinking requires rapid judgment of spatial-structural relation, so it's a fast, three-dimensional thinking, in a jumpy fashion (and logical thinking is a slow, linear, sequential thinking, along one-dimensional time axis).

As far as intuitive thinking is concerned, we should make a note of two issues: one, in the three aspects of intuitive thinking the most important and most essential feature is the relation between things (that is, the inner connection), it's decided by the intuitive thinking materials (relation imagery); second, intuitive thinking requires instant judgments, but not out of thin air from groundless subjective conjecture, but on the basis of rich practical experience and wide range of accumulated knowledge, using the methods intuitive perspective and space integration. Although we cannot guarantee intuitive judgment absolutely reliable (if the situation is not very urgent, i.e., time allowed, after intuitionist judgment is made, it's best to use logical analysis and reasoning to test it), generally speaking, there's always some basis for intuitive judgment. The more practical experience a person has, the wider the knowledge, the more reliable, and the more accurate it will be.

From intuitive thinking to inspiration/insight, a famous example was the discovery introduced in Sect. 3.5, Chap. 3, the Archimedes principle. This led to a breakthrough in the field of scientific theory. Through intuitive thinking, Archimedes, sitting in the bathtub, suddenly realized that the surface of tub water elevation is likely to equal to the volume of the body immersed in water. That is, the volume of the water surface elevation is the volume of body immersed in water. On the surface the two things looked irrelevant, but Archimedes through the grasp of the overall picture and intuitive perspective discovered the inner link between the two: equal volume (or implicit relation). Without intuitive thinking, Newton could not found the law of universal gravitation when seeing the apple falling to the ground: The fall of an apple and the moon rotating around the earth, in the eyes of ordinary people, are irrelevant. However, from this case, Newton realized the reason why the apple fell to the ground instead of rising up into the sky and the reason why the moon always went around the earth instead of turning away from the earth as well as solar system to the depths of the universe is because of the force of gravity. That is, he found the relations (implicit relations) between the two facts which seemed to be unrelated. This is a highly developed intuitive thinking ability. If you want to be able to see the invisible relations that an average person cannot see, you must rely on this ability.

6.1.2.3 The Accomplishment of Creative Goals and the Guidance as Well as Adjustment of Temporal-Logical Thinking

Because processing features of temporal-logical thinking is linear, sequential, along one-dimension time axis, based on the concept of the original knowledge step-by-step slow rhythmic logical analysis and reasoning, and the thinking process cannot achieve leap or mutation, the logical thinking may not resemble imagery thinking and intuitive thinking that directly lead to inspiration/insight. However, in the process of thinking, temporal-logical and creative thinking are indispensable elements; regardless of imagery and intuitive thinking, the creative goals are

ultimately inseparable from the guidance, regulation and control of temporal-logical thinking. Such as the above mentioned *Continental Drift Theory*, though it was originated from the observation and imagination on the map of the world, in the early part of the 20th century, people who had this observation and imagination were not only a German Wegner, when American Taylor and Baker, who also had the same observation and imagination and idea that continent may drift, but ultimately they failed to develop the complete theory like Wegener.

The reason is that his new viewpoint had been strongly opposed by traditional fixists (the scholars who held the view that land was fixed in relative position). Since the lack of support by the faith based on logical analysis, Taylor, Beck and others did not dare to continue to explore in this direction. So they finally stuck in the original level of imagination. Only Wegner, using the knowledge of meteorology, analyzed the phenomena of ancient climate and ancient glacial, and the results of the logical analysis made him still believe in his original idea. And under the guidance and control of analysis, with bulky research of geological and paleontological fossils on both sides of the ocean, he finally published the famous book *The origin of continents and oceans* and put forward complete *Continental Drift Theory* with a lot of evidence in 1915.

For another example, Archimedes in the bathtub found the implicit relationship between the water rising and volume immersed with his partial body. Of course, this finding was due to intuitive thinking (to grasp the relationship between things) that led to insight; but this kind of insight was not out of thin air. As Sect. 3.5, Chap. 3 points out, before the discovery Archimedes analyzed and reasoned that if it was a crown of pure gold, given its density is known, the volume of its weight was easily computed, and then compared with the crown of the actual weight, he could determine whether a crown was made of gold. In other words, as long as volume is known, the measurement of weight could be calculated; from here it could be determined whether the crown was impure or mixed, so the key to the problem was transformed into how to measure the volume of irregular crown. It was under the guidance of logical thinking, Archimedes focused intuitive thinking on measurement related to crown volume, and then insight occurred in the process of bath. And before this, though Archimedes, in the bathtub, saw the same phenomenon a thousand times, similar insight never occurred—this is due to the lack of guidance from logical thinking.

These facts indicate that logical thinking, though at the time, did not directly generate inspiration/insight (inspiration/insight always come in the form of imagery and intuition thinking), creative goals had the guiding and regulatory role, chance upon imagery and intuitive thinking; without the role of logical thinking, creative activity is impossible. Taylor and Baker et al, though once had the same observation and imagination as Wegener (i.e. had the same inspiration/insight), still can not make theoretical innovation in the end; the reason for this was again the lack of guidance from logical thinking.

6.1.3 *Dialectical and Horizontal-Vertical Thinking—The Guide and Strategy to Complex Problem-Solving*

Dialectical thinking and horizontal-vertical thinking have their own specific processing methods but do not have their own specific materials for thinking, so they're not basic forms of human thinking, but in creative activities, especially in solving difficult, (i.e. high m value) complex problems in the processing, each of them has unique role—providing important ideological and philosophical guide for human, mental processing strategy.

Humans face a variety of problems, some complexity level is lower ($m = 1$), which can be solved by ordinary processing methods and strategies with the above three basic forms of thinking (imagery, intuitive and logical thinking); but if thinking complexity level is high (high m value), the use of general methods and strategies will not work. Even if it works, efficiency is very low with subconscious exploration cycle (i.e. inner cycle). And it will take longer time. If dialectical thinking and vertical-horizontal thinking are used, this can effectively solve the problem; namely, it can shorten unconscious exploration cycle, relatively rapid formation of inspiration/insight.

6.1.3.1 Dialectical Thinking

In Sect. 4.6, Chap. 4, it has pointed out that dialectical thinking (i.e. dialectical-logical thinking) refers to the use of dialectical-materialist point of view to observe, analyze things, respecting objective laws, paying attention to investigation and to study everything from reality, and seeking truth from facts, which can look at things from viewpoint of unity of opposites, to see both opposition and also unity between things; to see different things in certain conditions that can be transformed into each other; namely to see things in a positive, and also reverse side, seeing unfavorable factors from favorable factors, and also think about favorable factors from unfavorable factors. All in all, it's a two-point theory not one-point theory.

Evidently, dialectical thinking provides guidance to complex problem solving from philosophical point of view. Effectiveness of the ideology in ancient China shows vividly in many ancient allusions, idioms and literary works; in contemporary world, where sharp and complex political struggle, social problems and increasingly grave global crisis exist, there are countless examples in which the use of dialectical logical thinking can change the dangerous situation into safety and turn the tide to obtain creative breakthrough. Throughout ages countless facts proved that dialectical-materialistic philosophy as a guide to thinking is the fundamental guarantee of profound and insightful thinking, and is a sharp weapon for solving any complex problem.

6.1.3.2 Horizontal-Vertical Thinking

Horizontal-vertical thinking consists of two aspects; that is, horizontal search and vertical mining.

(1) *Lateral search*

Lateral search for solving horizontal complexity (characterized by n); namely, to make a correct choice, among parallel factors and in parallel relations, based on comprehensive search, according to one of the following two kinds of circumstances: determine whether there's a missing factor in co-occurrence relationship; choose a most appropriate factor in alternative relationship. Among parallel factors, and in parallel relations, the comprehensive search is realized through divergent thinking and associative thinking in co-occurrence relationship factors (to determine whether there's an omission of factors), through analysis, synthesis; of alternative factors such as relationship between choices, select the most appropriate factors).

(2) *Vertical mining*

Vertical mining is used to solve vertical complexity (represented by m); that is, the complexity of multiple complex functions caused by the nested masking. The vertical mining can be achieved by digging up and down.

Digging down—to analyze and syntheses a key factor of multiple complex function in a certain level with new ideas, new perspective and new direction to discover new attributes of related factors (namely, digging out); the key factors and properties of a new function relationship (for the first level of initial creative goals, function of the composite goes down into a deeper layer). The methods for downward mining are usually divergence, association, imagination and analysis, synthesis. If conditions allow, new function could also be obtained directly through intuitive thinking.

Digging up—to abstract and generalize multiple complex function in a hierarchy of several co-occurrence factors of known properties, according to new ideas, new perspective and new direction to find (i.e. digging out) through these co-occurrence factors in new ways of generalizing a new function relations (for the first level of initial creative goals, function of the composite exit to a upper level). Upward mining method is usually divergence, association, imagination, plus abstraction and generalization (In order to summarize, we must first abstract). If conditions allow, the required new function can also be directly obtained through intuitive thinking.

Thus, dialectical thinking is to solve problems of high difficulty (high m value) from the height of cosmology as well as methodology to provide philosophy guiding ideology, horizontal-vertical thinking from a psychological point of view to solve complex problems of high m values to provide specific operational strategies. One is macro philosophy guiding ideology; the other is micro psychological processing strategy. The two complement each other.

6.2 Cultivation of Divergent Thinking

The cultivation of divergent thinking is not only an issue of methods, but also of ideological understanding. So in order to effectively teach the youth divergent thinking, we should follow three steps: first, to change the traditional education ideas and concepts; secondly, to correctly understand the nature and function of divergent thinking; and then, on this basis to consider appropriate tasks.

6.2.1 Change the Traditional Thoughts and Ideas in Education

Traditional education only emphasizes convergent thinking (concentrated thinking, thinking to seek common ground), which has deep educational, ideological roots, without speaking of divergent thinking (divergent thinking, reverse thinking, multi-directional thinking). The traditional teaching mode is teacher-centered, emphasizing unidirectional teaching, transmitting knowledge from the teacher to students, the students being knowledge-receivers. The goal of teaching is to nurture students to be good at understanding, digesting and applying the past knowledge and experience (but not good at creating new theory, new knowledge). From knowledge-transmission point of view, traditional education does not have any advantage (though looking at examinations, student achievements are generally higher than that in the western countries). The main disadvantage of traditional education is that it cannot cultivate a large number of creative talents, because the goal of education is not to cultivate innovation ability nor regard students as cognitive subjects who have subjective initiative or creativity. Instead, the goal of traditional education is to instill knowledge into students and to regard students as the receptor of external stimulation or the memorizer of predecessor's knowledge and experience.

Under the guidance of this educational thought, the basic theory and concept of understanding and digesting the subject, to understand and digest the content of the teacher's teaching is the premier requirement and uppermost goal of teaching. The ideas of students and their understanding of all issues must be integrated to basic concepts and theoretical system of the school subjects. Students of all words and deeds must be consistent with requirements of the teacher and traditional norms. This is the goal of convergent thinking (concentrated thinking, thinking to seek common ground).

It can be seen that whether or not to cultivate divergent thinking is not just an issue of method of thinking, which involves fundamental issues of educational ideas, concepts and teaching models. If traditional thoughts, ideas continue to dominate education, teacher-centered classroom continues to be the central mode, we cannot get rid of the restraint of convergent thinking and cannot begin to talk about active and conscious cultivation of divergent thinking.

So, to cultivate divergent thinking, we must first deepen education reform, change traditional education thoughts, ideas, reform teacher-centered teaching mode, and construct new teaching modes—fully reflecting students' cognitive function. On this basis, it's possible to talk about how to cultivate divergent thinking; otherwise, everything is impossible. In order to confirm this, we might as well look at an example of intelligence test.

There are many different scales for children's intelligence test. One of them is an influential Wechsler scale (WISC).[2] This scale has 12 kinds of tests; the first 6 categories belong to verbal tests, 2 of the 6 categories are classificatory tests, based on similarity between things to distinguish between the 17 groups, children match up pairs of words, which are similar. For example, it's supposed to point out that orange and banana are fruit; wood and alcohol are organic matter and so on. It's clear that this scale is presumably in accordance with the standards of cultivating convergent thinking, which uses book knowledge as standards, uses the teachers' requirements for the design. In accordance with the requirements of this intelligence scale, even if one can get a full mark, it does not necessarily mean that children have creative thinking ability, and it may be likely that they have a high score and low abilities as the result of rote learning. For the discrimination tests of wood and alcohol, as Arnheim[3] pointed out: students will get zero if they answer that the similarity is knocking down people (make people fainted). In fact, this answer is not wrong, but shows that the testees have agile mind. They could find, in an instant, the place where two were very different things on surface. This is the comprehensive embodiment of excellent ability of divergent thinking and intuitive thinking. But under traditional educational thoughts and ideas, creative thinking was not encouraged, but was excluded and attacked (to get a zero is regarded as mentally retarded). The first 6 of verbal tests in Wechsler scale basically stifles creative thoughts.

In fact, not only intelligence tests, it's true with various tests at all levels in schools at present (ranging from usual subject tests to final exam, quizzes and even national college entrance examination); only requiring to rote-learn book knowledge, not allowing to have the slightest imagination and association. For example, in the Chinese test, the question is transforming "holding the same idea and working together" into an idiom. The model answer is "consensus and synergy", and if the students' answer is "make concerted effort", they will have no scores on this question; the question is transforming "depict vividly" into an idiom. The model answer is "absolutely lifelike", and if the students' answer is "true to life", they will have no scores on this question. This kind of practice is actually coerced convergent thinking (thinking, convergent thinking, positive thinking), to the exclusion of divergent thinking (concentrated thinking, thinking to seek common ground, forward thinking), and actually stifle creativity. It's not surprising that intelligence tests and school tests are so similar because they are rooted in the same educational ideas, concepts, and teaching models. Evidently, if not to change

[2]Yan (1997a).

[3]Arnheim (1969).

traditional educational ideas and concepts first, the training of divergent thinking cannot be implemented, students spontaneously formed divergent thinking and creativity will be destroyed.

6.2.2 *Correct Understanding of the Nature and Function of Divergent Thinking*

The concept of divergent thinking, as early as in 1918, was put forward by psychologist Woodwarth.[4] And then there are some psychologists used the term, but the term did not call people's attention. Until 1967 American psychologist Guilford based aptitude research on the proposed three-dimensional structure of intellect model[5,6] which considered divergent thinking as one of the main factors of the structure of intelligence, and prepared a series of training of divergent thinking materials, and formulated specific methods for corresponding training programs and tests of divergent thinking ability. For a time, the United States, Japan and some other countries started an upsurge of divergent thinking. With Guilford's advocating, many researchers even think, divergent thinking is actually equivalent to creative thinking.[7] In this way, the influence of divergent thinking has become more and more blown up.

Under the guidance of Guilford's view and of assistants Torrance et al. the role of divergent thinking was exaggerated (the divergent thinking is even regarded as creative thinking); they made further analysis about divergent thinking and believed that divergent thinking contains four basic properties[8]: Fluency, flexibility, originality and delicacy, and that the training of divergent thinking should work closely around the four basic properties. These four properties are:

Fluency—refers to the number of points of view and ideas expressed in a short time;
Flexibility—refers to the multi-directions, multi-perspective of thinking;
Originality—refers to the ability to produce distinctive new ideas;
Delicate—refers to the detailed and accurate description of things.

Guilford and his colleagues at the University of Southern California developed a test (also known as the Guildford creativity test), which was used for measurement of the four properties of divergent thinking. This test was originally used for measurement of divergent thinking, and later dubbed creativity test; however, Guilford et al.'s guiding ideology was to consider divergent thinking as being

[4]Yan (1997b).
[5]Bai (1997).
[6]Zhu et al. (1991).
[7]Dong (1993).
[8]Lin and Xin (1996).

comparable of creative thinking, even equated creativity. We contend that according to this guiding ideology we cannot truly cultivate divergent thinking ability, or the ability so cultivated is unlikely to be divergent thinking ability, but the ability of verbal communication ability. This is because fluency and flexibility indicate productive language ability, having nothing to do with divergent thinking; originality is the goal that divergent thinking pursues, but not basic attributes of divergent thinking or key elements (because you cannot expect every instance of divergent thinking is a unique). In these four properties, only the second property—multi-direction, multi-perspective of thinking flexibility—really relates to the nature of divergent thinking, because this is undoubtedly one of the major features of divergent thinking. Unfortunately, flexibility used by Guilford et al. was not accurate and easily misunderstood. Clearly, with the above four properties to define divergent thinking (consider divergent thinking is composed of the above four elements) is not scientific, and misunderstanding of the nature of divergent thinking, which should be undoubtedly rejected.

A proper definition of divergent thinking, to our mind, should be:

"Divergent thinking (also known as reverse thinking, multi-directional thinking) is one element in creative thinking structure, but not a basic form of human thinking; its role or function is just to specify direction of creative thinking activities, which requires thinking toward opposite direction (one or multiple) from traditional thoughts or ideas." From this definition, it can be seen that the essence of divergent thinking is to break through the shackles of traditional ideas, concepts and theories.

According to the above definition, we may establish the following basic understanding of divergent thinking:

(1) Divergent thinking is one of the elements in the structure of creative thinking, and it's an indispensable part of the six elements. But it's not the whole of creative thinking.
(2) Divergent thinking points direction or sets the goal in creative thinking (i.e., determine the direction of thinking). This role of direction, in creative thinking activities, is of decisive significance; so the role of divergent thinking must not be underestimated, but also not at liberty to boast that it can solve all the problems of creative thinking activities.
(3) Divergent thinking has no specific thinking materials of its own, nor specific means or method of processing, so it's not the basic form of human thinking. It's not possible for it to become the main part of creative thinking (i.e., the main process of creative thinking); it only has the role of directing thinking. The main process of creative thinking can only be achieved by the other three forms of thinking (imagery thinking, intuitive thinking, and temporal-logical thinking). Divergent thinking should not take over other's job. Since the four basic properties, regulated by Guilford et al., failed to truly reflect the essence of divergent thinking, developing divergent thinking according to requirements of the four properties is bound to lead us astray, which cultivate other ability rather than divergent thinking ability.

6.2.3 Methods of Cultivating Divergent Thinking

Based on the reform of traditional, educational ideas and correct understanding of divergent thinking, we think that the training of divergent thinking can be carried out under the guidance of the three principles. These three principles are:

First, to seek differences on common ground—get rid of common mindset and traditional concepts, and put forward completely different views, with supporting reasons.

Second, to seek the right side from the reverse—not blindly believing in authority, dare to challenge traditionally correct concepts, theoretical system or scientific concepts, and put forward new theories, or new concepts.

Third, multi-direction radiation—analyze complex problem (or key points) from a variety of angles, multiple directions, so as to draw up a variety of possible solutions.

The three principles are essential, the cultivation of divergent thinking strictly abiding by the three principles (rather than focus on concepts like fluency and elaboration) can give full play of divergent thinking in creative thinking activities; it's possible to cultivate truly divergent thinking, not bad, out-of-shape divergent thinking. With these three principles, we can create a variety of practical, effective training methods for divergent thinking, and we can also directly use other methods. For example, the well-known brainstorming as long as a little supplement, modification can become an effective way of training of divergent thinking.

Brainstorming is a very effective creative thinking technique proposed by Osborn from the United States in 1953, and it can be used as a reference for the training of divergent thinking. This approach may be applied to a class or a small group; no matter what kind of occasion, there need a moderator (usually a teacher). In order to effectively implement this method, both the participants and moderator are required to be acting on certain requirements. Each participant should think about four points:

(1) No criticism (no criticism of others' opinion);
(2) Free play (to be bold and imaginative, free to speak; the freer and more unrestrained, more novel the better);
(3) To speak enthusiastically (the less sticking to formalities the better);
(4) Draw upon all useful opinions (to learn, to benefit by mutual discussion and to put forward newer and better ideas on the basis of the opinions of others).

The moderator in the brainstorming activity are supposed to beware two principles:

(1) Delayed judgment—that is not to make premature conclusions, so as not to bind the imagination of the participants, and even put out the spark of the participants divergent thinking;

(2) Quantity breads quality—Osborn believed that in the process of creative solutions to the problem, the initial idea is often not too mature, but later the idea became more and more perfect in the future, more profound. Therefore, the moderator should encourage and inspire the participants to express their views as much as possible.

Here it should be noted that participants or the moderator will remember the three guidelines (seeking differences on common ground, seeking the right side from the reverse, multi-direction radiation). In other words, the free play of participants is not a play without goal; the inspiration as well as guidance of moderator are not aimless, but strictly follow the obligations of the three principles. Only in this way can the brain-storming method better serve the training of divergent thinking. This is somewhat different from Osborne's original intent; Osborne's sense of freedom of imagination was not subject to any constraints, and while the training of divergent thinking requires participants to follow the direction of the three principles of free imagination.

There are a variety of ways to cultivate divergent thinking, modified brain-storming is one of them. As a matter of fact, it's beneficial to use any methods that can cultivate free association, free imagination and free elaboration, plus the three principles mentioned above in application of the training of divergent thinking. But here it must be stressed that there must be three principles; otherwise, free association and free imagination will become free imagery thinking, and not divergent thinking; likewise, free elaboration is a free logical thinking, not divergent thinking. This is because without the three principles, free imagination and elaboration will not necessarily be able to achieve target of divergent thinking—to break through the shackles of traditional ideas, concepts and theories, and realization of the unique and unprecedented innovation.

6.3 Cultivation of Imagery, Intuitive and Temporal-Logical Thinking

6.3.1 Misconceptions of Basic Forms of Human Thinking

Imagery thinking, intuitive thinking and temporal-logical thinking are basic forms of human thinking and in the six key elements of creative thinking structure; these three forms of thinking also play the main role in creative thinking process, and the relationship among these three elements is also very close, so on the cultivation of creative thinking, we put these three elements as an indivisible whole in the discussion.

At present in all types and levels of educational system (especially in the field of basic education), since various misunderstandings of the three forms of thinking exist, it is unable to find a more effective method to comprehensively train adolescents in imagery thinking, intuitive thinking and temporal-logical thinking, thus

affecting the growth of large number of creative talents. In a variety of misunderstanding about the three basic forms of thinking, the chief ones (related directly to the training of three forms of thinking ability) are the following three kinds.

(1) Confusion of the distinction between intuitive thinking and imagery thinking

Some of research literature labelled intuitive thinking also as perceptual thinking and equate it with imagery thinking, regarding them as the same kind of thinking.[9] Some believed that intuition is observation ability in imagery thinking,[10] namely intuition as an attribute of imagery thinking. All in all, they denied that intuitive thinking is an independent form of thinking, and it's not the basic human thinking mode. The consequences of this has weakened or even abolished the training of intuitive thinking in the young.

(2) Putting logical and imagery thinking (or logical and intuitive thinking) in opposition

Only see the difference or opposite side of the two forms of thinking, without seeing mutual support and interdependence between the two forms of thinking; as a result, always looking at these three forms of thinking in isolation and fragmentation (between logical and imagery thinking or logical and intuitive thinking). The results must be that for every form of thinking correct training methods could not be set up; in other words, the young people could not be most effectively trained in the three forms of thinking.

(3) Improperly dividing high and low levels among the three basic forms of thinking

Originally, imagery, intuitive and temporal-logical thinking are the basic forms of human thinking; their materials for thinking and methods of mental processing are the only difference between them. There's no high or low rank between them. But for a long time, in circles of philosophy and psychology, many textbooks and works have been promoting such a view, i.e. only logical thinking can reveal the laws of internal relations between things, which can enable us to understand objective things by enhancing perceptual thinking to rational thinking, so it's advanced thinking; and imagery thinking and intuitive thinking can only enable us to get an intuitive understanding of objective things, it's difficult to reveal the nature and law of the things, which implies that it's relatively a lower level of thinking. Under the guidance of this kind of thoughts, it's necessary to attach importance to logical thinking and despise imagery and intuitive thinking. Because these three forms of thinking in fact relate with mutual support and interdependence (see Sect. 4.4, Chap. 4), one-sided emphasis on logical thinking weaken greatly imagery thinking and intuitive thinking, also logical thinking suffers as well.

[9]Qian (1984).

[10]Wen and Lian (1997).

The above three misunderstandings are one reason that our education for many years trained a large number of practical personnel, but rarely trained creative talents (another underlying reason is that the teacher-centered educational thought and teaching mode long ruled schools at all levels of classrooms). In fact, misunderstanding about the three forms of thinking comes from a philosophical point of view: metaphysics. Seeing commonality between intuitive and imagery thinking, but fail to see the difference and particularity between them—this is the first mistake. Only seeing the difference or opposite side of the two forms of thinking (or logical and intuitive thinking) without seeing mutual support and interdependence between the two forms of thinking—this is a second mistake. Looking at issues from the surface, unable to make a concrete analysis of concrete problems, believing that materials of logical thinking are abstract language symbols, thus it is believed that the inference that only logical thinking has features of abstraction and generality and only logical thinking are able to reveal the nature and laws of things; however, this view fails to see that abstraction and generality are the common attributes for all three basic forms of thinking (see Chap. 2 for the argument), and thus they all can reveal the nature and laws of things; or just view things in a one-sided way, and only see the fact that it is possible for imagery thinking and logical thinking to engender inspiration as well as insight without seeing the fact that the forming process of inspiration and insight is based on the guidance as well as adjustment of logical thinking, which is the error of the third view.

6.3.2 *Experimental Research on Cultivation of Imagery and Logical Thinking*

Since the mid-1980s, some experts and scholars from psychology and education circles began to gradually realize the existence of problems 2 and 3 mentioned above, and realized that these two problems would exert great negative impact on cultivation of creative thinking in teenagers. And from the late 1980s, articles and works emphasizing the combination of imagery thinking and logical thinking was on the rise, and some experts, together with teachers from primary and secondary schools, explored in-depth experimental teaching reform, by combining imagery thinking and logical thinking, in order to develop teenager's creative thinking. An influential achievement is a key project of Eighth-Five-Year Plan, Beijing Philosophy and Social Science—Right Brain Development: development of imagery thinking in teaching experiment and research. The project was chaired by Wen, Lian and others. The project group composed of teachers and experts from universities, secondary schools, primary schools, kindergartens and Department of Teaching and Research, adding up to 75 people; 15 experimental subjects, including kindergarten arts, music, mathematics; primary school Chinese, mathematics, arts, music; high school language, mathematics, history, geography, physics, chemistry, physical education; and university of engineering graphics; time ranged from 1992 to the second half of November, 1995, lasted for more than three years. The final

results of the project presented in the form of a published monograph (see Wen and Lian 1997[11]). It should be said that this is a larger scale of exploration of imagery thinking in the country, playing a role in promoting cultivation of creative thinking in the young, and providing a lot of useful experience. But it should be noted that due to the weak theoretical foundations (mainly relying on simple division of labor theory of the brain: the outdated foreign research so-called left brain tendency toward thinking, the right hemisphere tendency toward imagery thinking. And at the time there was a lack of own research on creative thinking theory, model and structure), which brought about inherent deficiency in guiding ideology of experimental design. Therefore, though the experimental scale was large, adequate input of manpower, material resources, but the experimental research results had certain limitations. This is mainly manifested in three aspects:

6.3.2.1 Play Down Intuitive Thinking by Believing that Intuition Is just an Ability of Observation

Wen et al.,[12] on page 81 of their book, pointed out that what is intuition? When people observed something deeply for many times and accumulated very rich representation and experience. When he is in a situation which is new and changed and observe again, he can immediately make discrimination. This is intuition. So intuition is a sort of observation ability, it's a type of thinking ability to identify and judge things, and it's a kind of imagery thinking. Evidently, Wen et al.[13] believed that intuition is attributable to observation ability of imagery thinking, namely regarding intuition as an element or attribute of imagery thinking, which denied that intuition is a type of independent form of thinking; of course, not to say a basic form of human thinking. As mentioned above, under the guidance of this thought, it necessarily leads to great weakening or even eliminating completely the cultivation and training of intuitive thinking in the teaching process.

6.3.2.2 Simplistic Division of Left-Right Brain Function as Theoretical Base of Experimental Research

In Sect. 3.4, Chap. 3, we have discussed simplistic division of left-right brain function (believing that left brain is in charge of logical thinking, the right brain is in charge of imagery thinking), which lacks scientific basis, and an outdated theory. In *The theory and practice of developing imagery thinking—development of the right brain,* Wen et al.[14] copied the theory intact, and in experiments of every school

[11]Wen and Lian (1997).
[12]Wen and Lian (1997).
[13]Wen and Lian (1997).
[14]Wen and Lian (1997).

subject began repeatedly stressing that to this theory has the scientific evidence. As noted in Page 138 of Wen and Lian (1997),[15] this theory provides a scientific basis for our research. A major breakthrough in the two hemispheres of brain function research uncovered mysteries of the brain, so that we recognized that right brain has great potential, which we need to develop. How to develop the right brain, we think that the key lies in the development of imagery thinking. As provided in Chap. 3, since 1990s the brain physiology experiments have shown that imagery thinking processing mechanism and processing buffer (object working memory area), mainly locates in the left brain, but not on the right side of the brain; then what the meaning of developing imagery thinking is? This means that the whole issue of scientific basis for the study (that is, the theoretical basis) was built on the beach.

6.3.2.3 One-Sided Understanding of Creative Thinking Structure

Since the research group of Wen et al.[16] has not made the theoretical model of creative, the understanding of the structure of creative thinking is not comprehensive; that is, as long as imagery and logical thinking can be combined (hereinafter referred to as the combination of two types of thinking)—that is creative thinking. As described in Sect. 6.2 of this chapter, creative thinking structure is of six components, which imagery, intuitive and temporal-logical thinking constitute the main part of creative thinking, but, after all, this does not equal to the entire contents of creative thinking. The direction-guiding role of divergent thinking and the role of dialectical and horizontal-vertical thinking in creative thinking activities on the breakthrough of the key issues cannot be ignored. Wen and Lian (1997)[17] only considered two forms of thinking combined (not including intuitive thinking) as an equivalent to creative thinking. In other words, in the six elements only two elements were considered. This is obviously one-sided interpretation of the structure of creative thinking, so it will backfire.

Wen et al., who studied the issue, though weak in theoretical foundation, flawed in guiding ideology, in terms of experimental research, the research achievements were still worth affirmation. Especially the research always emphasized the idea that imagery and logical thinking must be combined, and under the guidance of this idea carried out a more in-depth exploration. This is commendable, for the study of creative thinking promoted Chinese research in the field; at the same time, they combined two types of thinking to provide useful experience of imagery and logical thinking of the students in high, middle and primary schools and kindergartens in 15 school subjects. If you do not consider the whole structure of creative thinking, but only focus on two elements: imagery thinking and logical thinking, then it should be said that these experiences are very meaningful. So in the following

[15]Wen and Lian (1997).

[16]Wen and Lian (1997).

[17]Wen and Lian (1997).

discussion on how to foster imagery, intuitive and logical thinking (especially the combination of imagery thinking and temporal-logical thinking), we will cite references of the research results in this area, acknowledging these researchers.

6.3.3 Cultivation of Imagery Thinking, Intuitive Thinking and Temporal-Logical Thinking

In order to cultivate and train the young in imagery, intuitive and temporal-logical thinking, we must clarify the following three guiding principles.

First, intuition is not one of the basic forms of human thinking—intuitive thinking cannot be confused with or attached to imagery thinking.

Second, the three basic forms of thinking are equally important without distinction of higher or lower ranking. Imagery thinking, intuitive thinking and temporal-logical thinking are crucial forms of human thinking. The three forms of thinking can process through abstraction, generalization to rational understanding. Among the three forms of thinking, the differences only lie in their materials of thinking (object of processing), processing methods, thinking processing buffer (working memory) and mental processing mechanisms, without distinction of more advanced or lower stage of thinking.

Third, the three basic forms should combine with each other instead of being fragmented and contradictory—like time and space are inseparable, and temporal-logical and visual-spatial thinking (imagery and intuitive thinking) are inseparable. That is to say, imagery thinking and temporal-logical thinking (as well as intuitive and temporal-logical thinking) always support each other, mutually depend on each other, and combine together. In actual thinking process this is so, and in training thinking in the teaching process this should also be the case. In short, in order to help cultivating and developing of the three forms of thinking ability, we should try to make them mutually dependent and combined with each other, and not to separate them.

Aware of the three principles, school teachers at all levels can follow a saying "like the Eight Immortals crossing the sea, each one shows his/her special prowess" to create varied and colorful methods on these three forms of thinking in the training program. In order to facilitate teachers to understand and master the principles, in order to create a more suitable, practical and more effective training methods, we have listed below, some disciplines, some example use of the principles (especially combined-not-fragmented principle) with children or adolescents in intuitive thinking, imagery thinking and temporal-logical thinking for the teachers in real teaching as a reference. For the sake of conciseness, in the following discussion, when a project involves the blending of ***imagery thinking and logical thinking***, the short form X-L training will be used. When a project involves the blending of ***intuitive thinking and logical thinking training***, the short form Z-L training will be used.

6.3.3.1 Thinking Training in Chinese Language Teaching (X-L Training)

Chinese language teaching can effectively develop students' imagery thinking; in the process of implementation, we ought to be cautious about the following four steps: enlarge imagery repertoire, developing the ability to observe, developing imagination and paying attention to X-L training.

1. To enlarge imagery repertoire

Li Jianming, a teacher in Beijing Sanlihe Primary School, on how to increase students' imagery buildup, summarized the following 5 skills.[18]

Organizing observation before class

When the students read a text, with no text-related images in the mind, it would be difficult to process the text. In order to make up for the lack of related imagery, it's necessary to organize observation ahead of class. Like the text *Fair*, before the lesson, the teacher asked the students to take a stroll to the morning and night market, observing carefully the prosperous market scenes, and eavesdropping sale-bargains. Through reconstruction of imagination to understand the text, Due to personally experience of buzzing market scene, the students read the text, as if they were in the market, and felt dramatic.

Providing background materials

Some contents in textbooks are far from the students' life, they lack corresponding imagery set, so it's difficult to imagine the situation described in the text; and difficult to understand the author's thoughts and sentiments. For these kinds of texts, collecting relevant materials through a variety of ways or providing background materials through the internet can greatly increase students' text-related imagery.

Creating teaching situations

According to teaching contents, preparing PowerPoint slides, audio-visual materials and or multimedia courseware to create a specific situation effectively help reproduce imagination with desired imagery.

Use of figurative language

The more vivid and more colorful language the teacher uses, the more it can activate relevant imagery of cognitive structure of the students to partake current cognitive activities.

[18]Wen and Lian (1997).

Reading aloud with feelings

The teacher (or students) read with sentiments, which can reproduce the author's thoughts and moods and can enable students to form a colorful picture in mind. Therefore, students can be moved emotionally and enlightened with reason. Students will have the full experience of the author's feelings; at the same time, the idea has become richer, fuller and clearer.

2. To cultivate the ability to observe

Li deemed that to cultivate students' ability to observe, we must, in the first place, consider students' interest in observation, and secondly attend to methods to guide the observation.[19]

Interest of observation can be nurtured through the following activities.

To guide students to observe their most familiar, favorite people and things

To create a teaching-related situation with purpose and plan, and guide students to observe

To lead students to the natural environment to observe and experience

To carry out a variety of extracurricular activities, guide students to observe real life.

In these activities, it's necessary to guide students to listen carefully, look carefully, and come into contact with all sorts of things, as much as possible, to understand, identify things, with all the senses and guide them to observe, based on careful thought, help them comprehend things gradually from perceptual to rational understanding.

To cultivate observation, methods ought to be taken care of, consider the following aspects:

To observe in a certain order

To observe in an orderly way is an easy way for not to miss anything. To observe structure of things, one ought to consider logical order (from the whole to the part, or from part to the whole, from top to bottom, from outside to inside, and so on); to observe sceneries, one may beware spatial order (from near to the distant, from front and rear), or to observe events, one should be cautious about sequence (time, place, person, cause, process, effect); to observe activities, one should attend to time sequence (such as before rain, during rain, after rain, or in the morning, at noon, in the evening and at night) and so on.

To observe with focus

Grasp the key to a problem, instead of attending to grapple big and small matters all at once. For example, at a class conference, the teacher and students might discuss many issues, or many speeches, and debates, too many things at a time. Though many things can be observed, many things can be recorded, however the

[19]Wen and Lian (1997).

central theme of the meeting is the key issue, as well as points around the issue that caused the debate, the main argument on both sides of the debate, and the final decision. Other irrelevant problems are minor; the observation of class activities must be around the key issues so as to seize the core of the problem and it's the key to success.

To pay attention to the main features of things

In order to identify things, it's necessary to seize features of things, not just skim over the surface. Such as wolves and dogs, on the surface, they're very similar, but if you look with care you can find different features: the tails—the dog's tail sticks upwards, the wolf's tail droops down. After seizing this feature it's not difficult to make a distinction between the two.

To guide students to observe and think

We should guide students from the current observation of things to think about the past similar things, to supplement imagery from the past, to enrich and deepen the appreciation of the present observation.

3. To develop imagination

Through Chinese language teaching, we may develop students' imagination. Usually, there are several ways which can be used.

Stimulate emotion

The process of reading texts is a process of re-creation imagination; that is, the process of imagery thinking. Imagery thinking is a kind of emotion inspired activity and strengthened by understanding.[20] Evidently, to expand imagination one must have plenty of emotion, so emotion is the prerequisites for developing imagination. Liao Changyan, a teacher from Experimental High School attached to Beijing Normal University, used such an example.[21]

Zhu Ziqing's *Viewed From Behind* is a text whose material is commonplace, language is simple and plot is not lively or interesting. In the past, students could not comprehend the text and have resonance while learning the text. Later, he changed his teaching methods. He let the students watch the film adapted from the text where the actors read the text with strong feeling; the author's love for the father was showed incisively and vividly in the reading, which was very moving and immediately put the students into a specific atmosphere. In this atmosphere, their emotional experience and rich imagination were aroused, and students are reminded of their feelings with parents. At this time, the students began to see affectionate descriptions behind seemingly dull words, as if they had witnessed the author's father struggling to climb up and down the platform to buy the author oranges; the fine details help the students feel the deep, sincere love of a son to a father.

[20]14 Institutes and Universities (1981).

[21]Wen and Lian (1997).

Imagine with pictures

To guide students to observe and imagine with text illustrations is one of the effective ways to cultivate students' imagination (It's even better to demonstrate with multimedia courseware). For example, *My Comrade Qiu Shaoyun* is a lesson with one illustration. On the picture, Qiu Shaoyun laid still on fire. The teacher may require students to thoughtfully observe the illustration, combined with relevant contents in the text, to write a passage, through association and imagination. In order to stir the imagination of students, the teacher can put forward some questions for students to think: what kind of environment Qiu Shaoyun was in? How Qiu Shaoyun reacted (looked, acted) on fire? What Qiu Shaoyun might think at the moment? Let the students look at the picture while thinking, then put them into discussion groups, and finally write down what has been talked in the discussion. This experiment showed that imagination with pictures (or multimedia association) can usually obtain better results.

Plot supplement

Some text passages in textbooks end with unexpressed, implied meanings. The teacher can ask the students to imagine, extend and complement the plot of the story. Other texts, in order to express the theme, the main plot is described in fine detail, while some secondary contents are touched on slightly. In teaching, the teacher can ask students to expand the text into a fuller plot, according to the theme of the text and specific circumstances.

Students' self-made fairy tale

For example, after learning the text *Excursion of the Animals*, students will be allowed to choose one or several animals, such as bees, fish, and birds, as the main character of their self-made fairy tales. The students have a high interest in doing this; they can narrate an interesting story and also in every fairy tale entails some implied truth.

Imagine the future

In a composition class, the teacher can ask the students to talk about projected ideals, or describe a better future. Every student has their own ambition, like to imagine how to achieve their goals, and cherish a vision of a different future. Through free imagination, the students, integrating and processing the imagery in their minds, are often able to write new ideas with individual features of personality. This imaginary composition, not only foster the students' ability of imagination, but is also beneficial to establishing correct ideals and enlighten sentiment.

4. To pay attention to X-L training

With blended imagery and temporal-logical thinking students can practice two forms of thinking simultaneously; and the interaction and mutual support of the two promotes both; and also gets efficient development results of both thinking. In fact, any thinking training methods are often not focused purely on one particular way of

thinking, but involve other forms of thinking as well, such as in the development of imagery thinking illustrated above (increasing imagery accumulation method). Through coherent, convincing documents the teacher provides background materials, and read the text with sensitivity resulting in logical thinking, and producing more outstanding, a representative results, so in the process of using background materials and reading text, we enrich students' imagery and demonstrate what would be correct logical thinking. Another example, in the cultivation of observation, the teacher is supposed to highlight main features and key points for observation. However, what are the main features and focal points, which are not usually determined by imagery thinking, but relying on logic analysis; so determination of focus with main features is a process for training logical thinking. As for the development of imagination, it became more closely linked with logical thinking—even in the situation such as "stimulating emotion" (without any psychological preparation beforehand, students' feelings are only stirred up by the sight), it is not the pure imagery thinking. This is because, even in the same situation, not only the strength of each student's feeling is different, the content of the feeling (happiness? Sorrow? Love? Hate?) is different, too. Just as Chairman Mao pointed out in *On Practice*: "What we feel can not be understood by ourselves immediately; only those things which are understood can be deeply felt." This shows that "sight" (feel the external objects) and "engendering feelings" (i.e. carrying out logical analysis, judging and reasoning) are inseparable. That is to say, "stimulating emotion" is inseparable from logical thinking.

Since the rest four links of "developing the ability of imaginary thinking" training (reading pictures with imagination, supplementing the plot, self-made fairy tale and imagination of the future) all involve language expression process, the logical thinking is even more indispensable. We can not be able to imagine or express vividly and smoothly, make fairy tales, supplement the plot, or portray the dreamed future without considering through logical thinking. For example, the theme extraction, material selection, deliberation of layout and words, all these rely on logical thinking. Therefore, in the above processes of developing imagination, imagery thinking is also a process of cultivating rigorous logical thinking, which should be clearly understood by teachers who are the culturist of teenagers' creative thinking.

In addition, X-L training in Chinese language teaching, that is, realizing the combination of imagery and temporal-logical thinking, other methods can be used as well in the following ways.

Writing observation diary

Writing this type of diary needs to observe, imagine and analyze and think, so it's a good way for achieving X-L training. The length of diary is not essential, but writing every day is the key. Students are required to record what they have seen and heard with deepest impression (i.e. form a clear and complete imagery), also required to analyze carefully and think, on the basis of this, make some statements about it or make a proper evaluation as far as possible, so as to raise the ability to observe, and also improve the ability to analyze.

Analyzing psychological states of characters in the work

Language teaching texts consist of a large number of materials from literature. For junior high school and senior high school students, it's one of the most effective approaches to combine the two kinds of thinking; students analyze the psychological activities of the characters according to the description in the works. For example, a junior middle school language lesson is Anton Chekhov's novel *The Frail*, which portrays a weak female teacher, under the employer's unreasonable exploitation and humiliation without resistance. When people felt anger about her encounter and asked why she was so weak, she just smiled. The work described here has a profound connotation of smiling, which hides behind the female teacher much bitterness and frustration. The teacher from Experimental High School Attached to Beijing Normal University, Liao Changyan, when teaching this part, firmly grasped the image of the moment, let the students imagine and analyze the mood of the teacher at the moment, and interior monologue of psychological activities of the character portrayed. To do this, the students must read with great care the text and find out mood and emotion of the character in the novel and carefully analyze the characters, so this is a close combination of an imagery thinking and logical thinking.

Using games and role play

Based on the features of teaching contents, the teacher can use simulation games, or role-playing to guide students to write, adapt, act and self-evaluate. This can activate classroom atmosphere, cultivate students' imagination, and also in the process of compilation, performance, assessment, students effectively exercise language ability of expression and analysis, evaluation, thus development of imagery and logical thinking.

6.3.3.2 Thinking Training in Mathematics Class (Z-L Training)

Mathematics deals with the relation between spatial structure and quantity of objective things. There are only two kinds of concepts in mathematics: one, involving spatial-structural relations between things; another, involving relations of numbers. Mathematical theorem can usually be divided into two types: one, numbers as known conditions, and spatial-structural relations (mostly positional relations) as a conclusion; another, spatial-structural relations as known condition, and numbers as a conclusion. Quantity relationship usually depends on temporal-logical thinking using numbers or symbols through step-by-step analysis, reasoning and computing; spatial-structural relation is most suitably determined through intuitive thinking; this is because materials of intuitive thinking (object of processing) reflect spatial-structural relation (relation imagery); features of mental processing is to grasp overall pictures, intuitive perspective, spatial integration and quick judgment. It can be seen that the nature of mathematics itself decides that the teaching process must be closely mixed of the two types: intuitive and

temporal-logical thinking; that is, the method Z-L training should adopt. Regrettably, mathematics teaching for many years has completely ignored intuitive thinking, almost turned it into a pure use of logical thinking, which was an important reason for many students feel that mathematics is abstract and difficult, boring, and forbidding. In order to change this situation, and realize the goal of mathematics teaching reform, one should strictly follow the preceding three guiding principles. First of all, it's necessary to correctly appreciate intuitive thinking, do not consider intuitive thinking as imagery thinking, and do not deny its existence; but instead, consider imagery thinking, temporal-logical thinking as equally important. These three are basic forms of thinking. At the same time, it's necessary to seriously link intuitive and logic thinking; that is, Z-L training method in mathematics teaching (including sub-branch as geometry, algebra, triangle, calculus, etc.). With many years of experiments carried out in China and other countries, effective methods of implementation of Z-L are *Geometer's Sketchpad* (i.e. using the software *Geometer's Sketchpad* assisted teaching method), *Shatalov Method* and *Ma Chengrui Method* and others. One of the most significant effects is most popular method *Geometric Sketchpad*. Here we briefly introduce these methods (teachers can create more methods and better Z-L training in their own teaching practice under the guidance of the above three principles).

(1) Geometer's Sketchpad Method

Geometer's Sketchpad is excellent teaching software, introduced by People's Education Publishing House and with Primary and Secondary Research Center for Computer Education (hereinafter referred to as the center) in 1995, from abroad. The software function is powerful; its biggest characteristic is to be able to easily use the dynamic way to show the spatial-structural relation of objects, so it's an ideal tool for Z-L training. Using this platform, the teachers can prepare and develop courseware according to their own teaching needs, and students can take the initiative to explore. Since 1996 the center developed the Chinese version of Geometer's Sketchpad, which was quickly well received by mathematics teachers, after the center in recent years held period Geometer's Sketchpad application training and test by some schools, the use of the Geometer's Sketchpad produced good results, mathematics teaching reform ideas have begun and accepted by the teachers, and has been gradually applied and popularized in many middle schools across China.

Geometers Sketchpad can create situations and encourage students to actively engage in learning, so it can effectively stimulate the interest of students in learning, the abstract and boring mathematical concepts become intuitive, imagery; thus changed the students from fear and loathing mathematics into love of mathematics and willing to learn. The fact that students doing mathematical experiment to take the initiative to discover and to explore, realizing the integration of intuitive and logical thinking led to better development of students' logical thinking, spatial imagination and mathematical operation. And it also cultivated the ability of divergent thinking and creative thinking, which develops students' creative thinking

well. In order to understand how to use the Geometer's Sketchpad to Z-L training, we shall turn to the following two examples.

Example 1[22] Using the Geometer's Sketchpad teaching abstract mathematical concepts

Du Liping, a teacher, from Beijing Zhichunlin Middle School, teaches the concept of axis of symmetry like this: Du first uses Geometer's Sketchpad to make a flying butterfly, the butterfly just flies in the screen, immediately attracted all students' attention; some of them who used to detest math became active at the time. The students watched the movement of two wings of the butterfly, constantly flapping, they soon understand the concept of axis symmetry, and inspired by this phenomenon they could cite many other examples of symmetry axis. Then on the screen two symmetrical triangles were shown; then with the help of animation and certain hidden features on Geometer's Sketchpad and, sometimes two symmetrical triangles move, so different symmetry appeared (such as symmetrical on both sides of the axis, two cross graphs or symmetrical points on an axis); some of the segments and extended lines are sometimes invisible or visible. In this vivid situational teaching, no students felt bored at all, instead under the teacher's guidance and inspiration they were at all times engaged in earnest observations, active thinking, and one by one to find out the relations between the point symmetry and symmetry lines and symmetry axis, then the students naturally found three basic properties of symmetry axis and understood the corresponding theorem, so as to realize the organic combination of intuitive and logical thinking, and realized the active construction of new knowledge.

Example 2[23] Using Geometer's Sketchpad to do mathematics experiment

Sketchpad provides an ideal environment for mathematics experiment. With the Sketchpad, it will take a few minutes to achieve animation effects, also dynamically measure line length and angle size. By dragging the mouse one can easily change graphic shapes, thus can fully use drawing board for students to do mathematics experiments. So, it can replace teachers-teaching-writing mode with the new teaching mode. Since the main teaching process is letting students to do experiments by themselves, so the teacher, when preparing lessons, considers not what to talk about, nor what and how to speak, but how to create situations that conforms to the requirements of teaching contents, how to guide the students to do experiments, and how to organize the students in collaborative learning and communication. In this way, teachers will be transformed from roles of masters of the classroom, and knowledge transmitter into organizer of teaching activities, creator of learning situations, guide of students in the experimental process and helper in meaning construction.

[22]National primary and secondary school computer education research center and Beijing Tianyi Company jointly prepared (1998).

[23]National primary and secondary school computer education research center and Beijing Tianyi Company jointly prepared (1998).

Mathematics teaching in the past often emphasized the theorem proving (logical thinking process, and do not consider students direct experience of sensibility and intuitive thinking, which makes it difficult for students to understand the concepts in geometry and geometric logic. Geometer's Sketchpad can help students observe, explore and discover dynamically the changes in quantity relations and spatial structures, which can act as an effective tool for mathematical experiments to help students, through the computer, shift from listening to mathematics into dong mathematics. For example, in order to help students understand two right angled triangles congruent condition more profoundly, the teacher can use Geometer's Sketchpad to show such mathematical experiment. In the experiment, students can make any changes to length of line segments and drag mouse from endpoint to observe changes of two triangular shapes, students can be intuitive and natural to generalize the right angled triangle congruent; judging axiom does not need teachers like in the traditional teaching, and students' understanding of theorems and mastery much better than traditional teaching.

(2) Shatalov Method (*Outline Signal Method*)[24]

Shatalov was a middle school mathematics teacher in Donetsk, Ukraine, of the pre-Soviet Union. In the late 1960s he created a new teaching method, *Outline Signal Method* as the core. The so-called outline signal graph is composed of letters, numbers, words, graphics, tables, etc. with intuitive and images of as teaching aids. Outline signals (that is, able to reveal things between spatial structures and relations to signal). Graphs can be shown with a variety of colors or chart presented visually, using different colors and fonts to highlight or emphasize relations for more important knowledge points or things. This outline signal chart both help students to grasp things between spatial structures (that is conducive to cultivate intuitive thinking), and help students understand and memorize concepts of abstract mathematical analysis, (i.e. conducive to development of logical thinking), so it's also a tool for implementation of Z-L training. Outline signal chart design is simple to make, the effect is obvious. Places and school districts, where the computer has not been accessible, and no conditions for the use of Geometer's Sketchpad software tools, the ideas of this method can still be applied. The core of Shatalov method is to design and produce outline signal chart, so the method are also known as *Outline Signal Method*.

(3) Ma Chengrui's Method

Ma Chengrui, a teacher from the Experimental High School Attached to Beijing Normal University, summed up a set of innovative principles,[25] according to years of teaching experience, on how to actualize the combination of intuitive and logical thinking in mathematics teaching, namely of Z-L training.

[24]Hu (1994).

[25]Wen and Lian (1997).

The principle of Z-L training in geometry teaching

To begin analogy learning, first learn drawing, and emphasis the combination of five aspects:

- Number and graph combination (graph is not isolated number, and number from graph);
- Dynamic and static combination (trace equation and its parameters);
- Special and general combination (standard equation and general equation);
- Intuitive judgment and logical reasoning (problem based on graph, graph on theory);
- Combination of theory and Practice (various types of applications).

The principles of Z-L training in algebra teaching

In set learning, it's to emphasize the use of block diagram; in mapping, it's to use tree diagram; in function, it's to highlight images and stress a functional point of view to study inequality, series; arrangement, combination, binomial theorem as far as possible "visualized".

Take the application of inequality as an example, in teaching the teacher selected two examples questions, the students think about the questions before class as an assignment; in class the teacher organized students to discuss with brainstorming technique. The teacher designed 6 slides, through projection, explaining briefly, with static and dynamic combination, mathematical thinking, showing vividly and intuitively, effect of each solution parameter change and restriction of equation; this is conducive to the students with number-shape combination and understanding concept of function.

6.3.3.3 Thinking Training in the Teaching of History (X-L Training)

History is a descriptive discipline; it has to be through the process of vivid historical figures and historical events to illustrate the law of historical development and motivation for pushing forward the advancement of history and to enable students to truly recognize who is the creator of history. Therefore, the study of history naturally requires the combination of imagery and temporal-logical thinking; that is, history teaching should adopt the X-L training method. According to features of historical subjects, we should consider the five essentials; namely, emotional stimulation, indirect perception, reasonable imagination, comparative analysis and role play in the history teaching.

(1) Emotional motivation

As mentioned above, to arouse emotion is the prerequisite of developing imagination. And vivid and specific historical figures are most likely to arouse the students' emotional resonance, so that history teaching has unique conditions for emotional incentives, we must tightly hold this condition, make sure that history

teaching better developing imagery thinking and implement quality education. As Zhao Henglie, a teacher from Beijing Institute of Education, once commented that he should owe much to history teaching, emotional motivation is to have a broad vision, leading students to concern about society, about the rise and fall of civilization and a nation, the social advance and retreat, the national humiliation and glory of the country. This kind of emotion is the individual's responsibility to the society. Teachers should use the spirit of people as the creator of history to care the younger generation. Zhao considered that emotional incentives can be done in a variety of ways.

First, use role model as incentives. The power of example is infinite. The heroes who save the country in peril; the national revolutionaries, who raised the standard fighting a just war; enterprising social reformer, and scientists who made major discoveries are all examples for teenagers.

Second, use honor and disgrace as incentive. The nation is prosperous, entrepreneurs illuminate for century; a national is humiliated, traitors scorned by the people. The future of the state, the fate of the nation is tied to every citizen. Young people need to know that devoting themselves to the national minorities is an honor and damaging the interests of the nation is a shame.

Third, use achievement as motivation. The Chinese nation is renowned for the diligence and wisdom. Chinese have universally acknowledged achievements which have made tremendous contributions to the civilization and progress of mankind. To encourage young people to carry forward the fine tradition of the Chinese nation, and strive to learn, grow in wisdom, for the country to achieve a spectacular success for the cause of mankind.

Fourth, use intellect as motivation. China has a history of 5000 years; there's a wealth of cultural books, a brilliant intellectual civilization. Mencius' words: in the world today I shall shoulder the responsibility, Qu Yuan's words: even though I die nine times, I will not regret devoting myself; Zhang Zai's words: for eternal peace, breadth of mind. These are the precious intellectual wealth to cultivate the noble character of the young people.

(2) Indirect perception

The existence of things can be directly perceived; history cannot be repeated, so cannot be directly observed and perceived; it can be indirectly perceived through historical heritage, historical relics passing down from history. Zhang Guifang, a teacher from Beijing Department of Teaching and Research, described the experience[26] that when teaching unit of the Peking man. If the direct use of abstract concepts, then in the students' opinion it would be that the Peking man is composed of a just series of few words and sentences; and words and sentences are boring. If you change a way, first of all, put the bust of the Peking Man on the podium, told students that this is the Peking Man who lived 700 thousands of years to 200 thousand years ago; the Peking Man looked like this. How will the class react?

[26]Wen and Lian (1997).

First, it's a bust that looked like an ape and a statue of a man. It makes students feel curious. 'Is it a man?' 'Why is he so ugly?' Students' attention and interest are stimulated, and with the new, exciting new materials classroom atmosphere will immediately be lively. Practice shows that the students' excitement at this time has always focused on their visual object, the bust of the Peking Man, and the difference with the modern people. Second, the appearance of Peking Man is different from that of modern people, which will also causes the students' desire to explore: compared with the modern people, where are the Peking Man's facial special features? Why is Peking Man called a man, not an ape? After arousing the students' strong desire to learn, and guide the students to find head features of the people in Beijing, to imagine the social life of the people in Beijing; finally, make an inductive conclusion about the understanding of the Peking Man, which will achieve a better teaching effect. Since this kind of teaching method, discovering the head features of Peking Man as well as summing up the understanding of Peking Man, is based on the imaginative thinking of indirect perception, it is an example of carrying out X-L training by the use of indirect perception.

(3) Reasonable imagination

Imagination historical facts should be logical and historical, rather than subjective conjecture. For example, in discussing the text *Li Bing Built Dujiangyan Dam*, in order to help students understand the text better, Zhang Guifang introduced this kind of processing method[27]: to hang out Dujiangyan Dam blueprint,used concise and vivid language to lay out local situation before the construction of Dujiangyan Dam, and asked the students: if you were Li Bing, standing in front of the Yulei Mountains, looking at the surging river flooding, thinking of the other side had a large areas of farmland needing irrigation, what plan would you design to control the flood? Some of the students could answer: to slash the mountain to distract the water, flood diversion and irrigation—shooting two birds with one arrow. The teacher inspired students through analysis of the terrain and reasonable imagination embankment scheme to propose for themselves, and asked again: because of terrain and water shortage, it was difficult to achieve the above purpose, what to do? Under the inspiration and guidance of the teacher, the students, through discussion, analysis and imagination, finally formed an assumption to control through the embankment on both sides of the water flow. In this way, the students stood in Li Bing's position, designed construction of the main part of a bottle-shaped-vase watercourse, Jingang embankment, Feisha Dam and Dujiangyan Dam. By means of logical analysis and reasonable imagination, the communication between ancient and modern over time and space had been achieved. The interest and attention of students have reached a high degree of concentration and achieved good results.

[27]Wen and Lian (1997).

(4) Comparative analysis

Tian Jingsheng and Qi Yuhua, teachers from Beijing Xicheng District Education Bureau, in teaching why the civil war broke out in the United State,[28] suggested that to enable students to better understand the cause of the outbreak of the American Civil War, they used two pieces of wall charts of the Greek slave market and auction slave, guiding students to observe and compare. Students came to the preliminary conclusion: one, the two pictures reflected the sale of slaves, that slave was brutally oppressed by slave owners, they had no social status, and no personal freedom; two, two pictures were a reflection of the slave owners using violence to maintain this bloody business; slaves were not willing to be oppressed, continued to struggle. Then the teacher further inspired students: the above conclusions were two pairs of the same picture; was there any difference? Students, by further comparative analysis, realized that a marked difference between the two was that Greek slave market reflected the prosperity of the 5th century BC Greek slave society, and auction slave reflected slavery in the middle of the 19th century in the American South. Both were slave trade, but the difference is the gap between the two—2000 odd years between. In nineteenth century, capitalism was booming. There was still a backward, brutal slave system, which was clearly not in line with the law of historical development. Therefore, sutdents could trully understand the reasons for the civil war in the United States.

(5) Role play

The two teachers, Tian Jingsheng and Qi Yuhua, pointed out that role play for X-L training requires teachers to be very serious about teaching design: creating a classroom atmosphere of the history, guiding students to be empathetic, so as to achieve the experience and appreciative understanding of history. There are many examples such as leading students to do research in the oracle site of Yin as archaeological lovers; letting the students play the role of Li Chuang Wang's military officer to give advice and suggestions on peasant uprising; organizing students to argue about sea defense and port defense in late Qing Dynasty palace. Role playing can exercise aspects of imagery thinking and temporal-logical thinking. Thus, either in the teaching of history or Chinese, role-play is a good approach of X-L training.

6.3.3.4 Thinking Training in the Teaching of Geography (Z-L Training)

Geography is a subject that studies the relationship between geographical environment, human activities and geographical environment. Its main research object is spatial concepts. Various geographical elements form their own spatial

[28]Wen and Lian (1997).

distribution on the surface of the earth. The results of these elements' interaction cause natural environment and human activities in various regions to have obvious regional features and comprehensiveness. In the course of teaching, we should introduce the geographical elements, spatial location, spatial distribution and various kinds of spatial relations between them. Understanding the features of geographical elements and their spatial structure (including spatial position, spatial distribution, and spatial relations) is a kind of instinctive thinking; summary of evolution of geographical phenomena, mutual influence and the genesis and distribution belong to logical thinking. Obviously, the nature of geography itself decides that the teaching process must combine intuitive thinking and temporal-logical thinking; that is, the Z-L training method should be adopted both. According to the experience of Yin Peihong, a teacher from Beijing Hui Wen secondary school summed up some methods teaching geography, which the Z-L training methods are proved effective.[29]

(1) Training of map-reading, map-using

Geographical elements and geographical phenomena must be expressed by maps, graphs or images. On the map or chart one can grasp the complicated spatial-structural relations, also analysis and multi-factors of nature and economic geography phenomenon, which is the goal that intuitive and temporal-logical thinking expect to achieve. Therefore, reading maps and using maps are the primary means of intuitive thinking and training in geography teaching, as well as the main content of Z-L training. Map-reading and map-using training usually includes two aspects.

(1) Through guiding students to observe, analyze maps or charts, inspire students to think of the problem, analyze the problem, sum up the features and rules of geographical phenomena.
(2) To cultivate students' ability of decomposition and combination of geographical images, and promote the understanding and memory of geographical knowledge by the way of filling in and drawing blank distribution maps, and so on. For example in high school geography teaching, a hundred of place names, such as the distribution of China's major mineral resources, the distribution of industrial cities and the production base of agricultural products, will be told. In the past the ways of teaching these used to be boring, students felt headache. In order to overcome difficulties of the teaching plan, the teacher made full use of the blank map in the teaching. In order to determine the location, students must cautiously observe geographical features of rivers, borders and boundaries. This trained map-reading ability enabled students to master related knowledge of geography. Students could also use different symbols or colors to represent the functions of different cities, or the distribution of different minerals. So in one picture with

[29]Wen and Lian (1997).

different colors, students can understand and summarize geographical distributions, and geographical imagery of decomposition. Combination training greatly reduced the amount of memory to geographical knowledge.

(2) Experiment demonstration

Experiment demonstration is an effective way to cultivate concepts of dynamic space, and if schematic diagram is used in conjunction, it can cultivate a strong spatial intuitive judgment of students; i.e. upon seeing plain plans one will be able to imagine a three-dimensional shape, from static images to imagine dynamic characteristics. For example, the movement of the earth, frontal formation and many other contents can be learned through experiment demonstration. In addition, experimental demonstrations are also helpful in understanding principles and concepts of abstraction.

(3) Production of geographic models

Give students design task and make geographical models can deepen the understanding of spatial and geographical phenomena and laws of the movement, and promote formation and development of spatial-intuitive judgment. However, this method is more time-consuming and can only be used as a supplement to classroom teaching.

In the teaching of topographic map, the key is to show the three-dimensional terrain with plane and to require students to imagine the undulating terrain condition upon seeing the plane map, which is a thorny point in teaching. In order to break through this difficult point, Yin Peihong organized the students in extracurricular activity groups, and took the following steps to make contour map model.

First of all, produce a hierarchical color contour map;

A few pieces of glass were used to describe the contour lines of various heights;

And then put topography, glass plate in order, which complete the production of contour map model.

At this time, look from top down, the terrain undulating, real and vivid. The team members participated in the task immediately understood and mastered the basic knowledge of topographic map, and used this model to help other students to solve difficult problems in this area.

(4) The creation of learning situation

Learning situation creation refers to the use of a variety of means, including slide projector, PowerPoint slides, video recording, realia, specimens, charts and multimedia courseware to create a geographic learning context, so that students can observe and experience. Because the geographical study objects spread everywhere, with strong regional and timely features, these objects cannot all be done through field trip; more is done with indirect perception. Creating a geographic learning environment can show in front of students through the various means the different geographical phenomena, so as to promote forming and developing geographical imagery and enhancing spatial imagination and intuitive judgment.

6.3.3.5 Thinking Training in the Teaching of Physics and Chemistry

Physics and chemistry are two basic subjects, which study physical and chemical changes of matters. They are based on observation and experiment, so the two share common features. Observation is most commonly used scientific research method in natural science. Observation can be done under natural conditions and as well as experimental conditions; experiment is developed from observation—the extension and expansion of observation. In teaching physics and chemistry, the teacher should guide students to observe and experiment, and also to inspire students, according to the results of observation and experiment, to associate and imagine; and on this basis, further analysis and thinking, so that through exploration of numerous phenomena to discover the essence of things and laws of internal relation between things.

Observation, association and imagination belong to the category of imagery thinking; the revealing essential attributes of things usually relies on imagery thinking (especially creative imagination) and blended with temporal-logical thinking for problem-solving. To discover internal relation between things (i.e., spatial-structural relations) one often has to rely on intuitive and logical thinking combined. Evidently, physical and chemical features of the disciplines decide that the teaching process must mix together imagery, intuitive and logical thinking, which should adopt X-L training and Z-L training methods; otherwise training will get twice effort, half results and difficult to obtain good teaching effect.

According to the experience of Zhang Lixiong and Zhou Jing, teachers from the Experimental Middle School affiliated to Beijing Normal University, suggested that for physical and chemical teaching in the implementation of the X-L training or Z-L training, a better model can follow six steps.[30]

(1) To put forward a new problem for students to analyze and think (logical thinking) according to the existing knowledge background of the students;
(2) In order to solve a problem, the teacher requires students to design an experiment; encourage the students to first imagine or think out an experimental framework, by intuitive conjecture, and as far as possible imagine what may happen in this experiment process, such as a state, color, sound, smell all sorts of changes (intuitive and imagery thinking).
(3) After completing the general framework of the experiment, in order to implement, students should also be required to use the existing knowledge and experience to solve some technical problems, and to develop a specific implementation steps (logical thinking);
(4) Students work on the experiment, and observe in the experimental process carefully, record experimental phenomena and results to form experiment related, various imageries; i.e. mainly visual imagery (including attribute and relation imagery), in some physical and chemical experiments, auditory imagery, or olfactory imagery may occur (imagery and intuitive thinking).

[30]Wen and Lian (1997).

(5) Analyzed experimental phenomena and results, the integration process of the new imagery and cognitive structure with the original imagery, form a re-creative imagination or intuition and the resulting conclusions are expressed with charts or language (imagery and intuitive thinking);
(6) The use of the knowledge and experience of the above, which was produced by intuition or imagination, verified the conclusion to see whether attributes of things or internal relations (logic) have been found.

In this kind of teaching mode, imagery, intuitive and temporal-logical thinking can get better trained and it's conducive to the combination of imagery and logical (or intuitive and logical thinking); and in the process, middle school students are no longer passive recipients of knowledge from external stimuli, but active knowledge explorer, discoverer. Therefore, it's conducive to the growth of creative talents.

As for this mode of teaching, there's again a question about how to apply to specific training of imaginative and intuitive thinking, through observation, experiment, imagination, analysis, verification. Since this question is similar to the previous discussion in other disciplines, it will not be repeated here.

6.4 Cultivation of Dialectical Thinking

Dialectical thinking can be a sharp, ideological weapon as vertical-horizontal thinking for the breakthrough to creative thinking, and also can have an important guiding role in the whole process of creative thinking activities (from the beginning to the end).

As mentioned before, dialectical thinking (that is, dialectical-logical thinking) refers to the use of materialist dialectic methods to observe and analyze things. In order to cultivate and develop students' dialectical thinking ability, the teacher should pay attention to guide and help students to solve the following two aspects of problems.

6.4.1 Dialectical Thinking Training—Setting up Three Points of View

6.4.1.1 Materialist Point of View

Dialectical thinking emphasizes materialist dialectics (and not Hegel's idealist dialectics). This dialectics and materialism are highly unified, indivisible, which is one of the most salient features of Marxist philosophy.[31] To use materialist point of

[31]Li et al. (1995).

view is to respect the objective facts, to start everything from reality, to pay attention to investigation and study, to collect facts and information as much as possible for the problems faced, and to draw conclusions from facts and to avoid subjective bias with first impressions.

6.4.1.2 Unity of Opposites

By the use of dichotomy, not only the opposition between things should be seen, but also the unity between things need to be seen. Different things, under certain conditions, can be transformed into each other, which need to be seen. That is not only to see the positive things, but also the opposite side of things; i.e. from favorable factors to see negative factors, and also to see favorable factors from adverse factors. In short, it's two-point theory, not one-point theory. Lenin[32] made it clear that the unity of things is divided into two parts as well as understanding its contradiction; this is the essence of dialectics. And he also thought that dialectics can be briefly defined as the theory of the unity of opposites. This will grasp the core of dialectics. Obviously, Lenin believed that the law of the unity of opposites is the essence and core of materialist dialectics. Why did Lenin make such a claim? As Li et al.[33] said that this is because materialist dialectics is a theory of universal connection and eternal development. The law of unity of opposites reveals most common, most essential relation of things; that is, connection of two sides: mutual distinction, mutual antagonism, and mutual contradiction. And the theory reveals that an internal contradiction of things is the source and motive force of development, which fundamentally shows the essence of universal connection and eternal development of the objective world.

This is the focus of struggle between materialist dialectics and the two kinds of world outlook, which is the fundamental difference between them. Since the law of unity of opposites reveals the most profound essence of connections and development, it should also run through the other laws and categories of dialectics. In fact, the other laws and categories of materialist dialectics are to reveal the unity of opposites from different sides. For example, revealing that the law of mutual change of quality and quantity is the relation of unity of opposites between quality and quantity, the quantitative change and qualitative change; the law of negation of negation reveals the affirmation and negation, inheritance and development, reply and forward relation of unity of opposites. The various categories of dialectics, in essence, are the unity of opposites. Therefore, the law of the unity of opposites links other dialectical laws into an organic unified system.

In the process of cultivating dialectical thinking, we must firmly grasp the most central view that unity of opposites.

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[32]Lennin (2014).

[33]Li et al. (1995).

6.4.1.3 Connection and Development Perspective

Everything in the universe has universal connection and everything in the universe is of eternal development.

(1) On connectionist point of view

As far as connectionist point of view is concerned, one should grasp the point of this[34]

Pay attention to relations between the whole and the part

The whole is made up of parts, without understanding the part one cannot grasp the whole. Therefore, the extracted single thing from universal relation is absolutely necessary for study, but materialist dialectics stresses the study of individual or a part of things, and see its connections in the whole and the parts in the overall picture. Any simple things can not be seen clearly if the connection is cut off; the various parts of the whole can not be understood if the whole is put aside.

"Conditions" to consider

Everything is in general connection, but any specific connection depends on certain conditions. As conditions change, the nature of things and connections between things will change; this is conditional connection. And the conditions are specific and various: necessary and unnecessary conditions, decisive and non-decisive conditions, favorable and unfavorable conditions, subjective and objective conditions and so on. Specific, comprehensive analysis of various conditions, clarifying connections of natural things—these are the premise to solving various contradictions. It has the decisive significance for dong all the work well—all depending on time, place and conditions. Leaving the conditions, nothing can exist, and can be understood. In this sense, the general connection theory of materialist dialectics is the theory of condition.

Notice "Intermediary"

It's necessary to understand the concept of *intermediary* in order to understand how each of these things relates to other things. Intermediary refers to intermediate links between two things; no matter there are how much difference, you can communicate through the middle of the link. As Lenin[35] said that everything is one identity through the intermediaries, through the transition and connection. Everything is a ring in the universal relation, so everything can become the medium of other things, everything and other things are connected through the intermediary and into a whole; the difference is the intermediary connection between two things may be more or less (known as a multi-agency). When the two things are not connected with each other through an intermediary, it's called direct connection;

[34]Li et al. (1995).

[35]Lennin (2014).

when two things are connected through an intermediary or multiple intermediaries, it's called indirect connection.

Establishment of connectionist point of view on how to carry out scientific exploration has important guiding significance. In fact, the so-called scientific discovery is to reveal the laws of internal relations, which have not yet been recognized. The element periodic law reveals the connection between chemical properties of elements with atomic number; the law of electromagnetic induction reveals the link between electricity and magnetism; the law of universal gravitation reveals the contact between two moving objects. Analysis of contradiction with condition theory provides guidance and direction for uncovering the laws of internal relations between things; intermediary in connection indicates the complexity of e relationship between things, providing philosophical foundation for complexity theory as we pointed out in Sect. 4.5, Chap. 4. Here the multiple intermediaries is what we mentioned earlier "multiple complex function", intermediary composite multiplicity (that is, the vertical complexity, expressed by *m* value). This shows that the theory of horizontal-vertical thinking is specially used to solve complex problems, which not only has the foundation of psychology but also philosophical foundation.

(2) On developmental view

As far as developmental view is concerned, one should take hold of three aspects.[36]

Multi-directions of development of things

The development and change of things is multi-directional not single-directional, i.e. three directions. One, the horizontal direction movement, that is, change along the same level. For example, in the mode of production and social relations; second, descending motion, that is, from advanced to lower forms, change from order to disorder, such as in compounds and organisms, life, death; in mechanics, optical, electromagnetic; in chemistry, transformation of life motion to thermal motion; third, ascending motion, namely from lower to higher level, such as change from disorderly to orderly.

General trend of development of things

Since metabolism is the general and eternal rule in universe, we must recognize the basic direction of the development of things (i.e. general trend): forward motion and upward motion; but this does not mean that there's no retreat, decline and twists and turns. The trend of forward and upward direction of movement is in general bigger than backward, descent direction movement, but any forward, upward motion must be accompanied by a backward and downward motion, as any evolution contains degradation, backward, decreased, which is a necessary condition of forward, rise of movement.

[36]Li et al. (1995).

New things are invincible

The development of any new things undergoes a process from small to large, from imperfection to perfection. New things in infancy are always weak, and it's inevitable that there's a flaw, and the old things are often more powerful. Because of the conflict between the old and new things, the suppression and resistance of the old things to new things, the growth of new things is bound to go through a tortuous process. However, new things are invincible, temporarily weak, regardless of many difficult setbacks, will eventually overcome the seemingly strong of old things.

To establish a developmental view in scientific exploration, it's a strong moral support to correctly treat difficulties, setbacks, and even failure, and always keep strong confidence to win. Any scientific exploration is a new thing; the growth process is bound to encounter the repulsion, repression of old forces and is inevitably accompanied by the movement of recession and decline. But new things are eventually invincible; to establish the view of development is to build confidence in new things to win, and to love, support and nurture all new things. It's to be noted here that difference between the old and new things are not determined by time sequence, and by unconventional form, but to see who can really be consistent with the inevitable trend of historical development.

6.4.2 Dialectical Thinking Through the Whole Process of Creative Thinking

Dialectical thinking, from philosophical point, provides ideas and strategies to solve problems of creative thinking activities, so it has a vital significance in the breakthrough in creative thinking activities, and also a guiding role in the whole process of creative thinking. For example, on the initial stage of creative thinking, as mentioned before, it relies on divergent thinking with the role goal orientation, in order to direct thinking. Divergent thinking provides three guidelines for thinking process, keeping it in the right direction; i.e. commonality in difference, positive in negative, multi-direction radiation. It's not difficult to see that in these three guidelines, each shines with the beauty of unity of opposites (commonality-difference, positive-negative are the two sides of contradictions and multi-directional radiation constitutes relations of unity of opposites with centralized thinking of one-way convergence). These guidelines are concrete manifestations of dialectical thinking. Therefore, divergent thinking can actually be regarded as a form of dialectical thinking in the starting phase of creative thinking.

Imagery, intuitive and temporal-logical thinking, being basic forms of human thinking, certainly cannot resemble divergent thinking; in essence, they're equivalent to dialectical thinking. However, the purpose of thinking is to make a general reflection of nature of things or internal relations between things (i.e. things between spatial structures); there's an issue of how to make such reflection more effectively. As is known to all, materialist dialectics as a Marx's philosophy, its

views and methodology are universal, which is the fundamental guarantee for the comprehensive, deep and insightful of human thinking. Therefore, in the whole process of thinking, the use of materialist dialectics as a guide is possible to make basic human thinking forms (no matter what form) meet the requirements of the above thinking most effectively.

In short, we should regard dialectical thinking throughout the whole process of creative thinking, so as to make the contents and results of thinking more comprehensive, profound and insightful, and make it possible to accomplish creative breakthrough.

6.5 Cultivation of Horizontal-Vertical Thinking

The horizontal-vertical thinking is a new element in our definition of creative thinking structure, and it is a psychological processing strategy raised to solve complex and difficult problems (i.e. to achieve key breakthroughs in creative activities)—the psychological processing strategies include two aspects: horizontal search and vertical mining.

Because it's a new psychological processing strategy, so it has no very mature training methods and even the effectiveness of this processing strategy is to be proved by more facts.

In Sects. 4.5 and 4.6 of Chap. 4, we proposed horizontal-vertical thinking theory, on the basis of in-depth analysis of the complexity process of the invention of electronic computer, and the key technological breakthroughs involved in electronic computer invention process. We analyzed specific mental operation of horizontal search and vertical mining, their contents and implementation steps. Readers from this paradigm can get a glimpse of horizontal-vertical thinking, and learn how to master the method as a psychological processing strategy. The examples help readers understand more deeply the meaning and substance of horizontal-vertical thinking and specific role in creative thinking activities. Here, a few more examples, in which the author solve complex and difficult problems by using processing strategies of horizontal-vertical thinking, will be served as references for readers.

In the process of writing this book, the author has encountered many difficult problems, and has long been haunted by them. The vast majority are the ones that have not yet been studied in depth by the current academic community; so in the existing literature one cannot find answers to the questions. Later, due to the use of horizontal-vertical thinking, the author finally resolved these problems within a short time. The following are four illustrative examples. Although the four examples came just from the author's personal experience, the problems, involved in the four examples(i.e. tries to handle), are not common. Instead, these are the challenging problems which have not yet been resolved in the field of psychology and thinking science or have great controversy. Therefore, the author thinks that, with these examples, the majority of readers will find their referential value.

Example 1 Definition of imagery and intuitive thinking (horizontal search Case 1)

In psychology and thinking science, it's generally recognized that imagery thinking and intuitive thinking have a key role in the formation of inspiration/insight. But there's no scientific definition or statement of what is intuitive thinking in the current work of psychology and thinking science. Many scholars confuse it with imagery thinking, or take it as a feature or attribute of imagery thinking. How do we define imagery thinking and intuitive thinking? Is there really a difference between these two kinds of thinking? This problem has long haunted the mind of the author without solution. And in all the existing works of psychology or thinking science, the answer to this problem can not be found. Later the author used horizontal-vertical thinking with horizontal search strategies, which included the connotation of imagery thinking and intuitive thinking factors, through comprehensive search, found that regardless of imagery thinking, intuitive thinking or temporal-logical thinking all have four parallel factors: thinking materials (i.e. the object of thinking process), thinking processes, thinking processing buffer (also called working memory) and thinking processing mechanism. On the basis of different thinking forms, the author compared the four factors one by one, and finally found the four factors: imagery thinking, intuitive thinking and temporal-logical thinking are not the same (in order to confirm the latter two factors are differences, namely working memory and thinking processing mechanism in the cerebral cortex region with different orientation, the author took more than half a year time to access to a large number of foreign literature since the 1990's, in the neural physiological literature), and then scientifically defined the connotation of the two concepts of imagery thinking and intuitive thinking; that is, materials of imagery thinking reflect attributes of things (attribute imagery), intuitive thinking is a reflection of the relationship between the material of things (relation imagery), processing methods of these two kinds of thinking in working memory and mental processing mechanism are also different (see Chaps. 2 and 3). In this way, the vague, or even mysterious idea of intuitive thinking, which had been existing in academic circle for many years, was clarified. Moreover, we will be clear that the relation and difference between imagery thinking and intuitive thinking are spatial-visual instead of verbal imagery concepts. And the mainly materials of these two thinking are spatial-visual and non-verbal imagery concepts, so both belong to spatial-structural thinking (this is the very reason why the two are often confused); but imagery thinking materials are attribute imagery, and intuitive thinking materials are relational imagery. And processing methods and working memory and processing mechanism of the two are not the same, so the two cannot be confused. The above shows that the scientific definition of intuitive and imagery thinking is inseparable from the finding of four elements' association as well as difference among three thinking, by using "horizontal research" strategy in horizontal-vertical thinking for a comprehensive search of factors included in various thinking.

Example 2 Division of basic forms of human thinking (upward "vertical mining" case)

In current academic circles, there is no unified opinion about the question that how many basic forms (or basic types) the human thinking has. Most scholars think

there are two, namely, logical thinking and imagery thinking. Some scholars think there are three, namely, logical thinking and imagery thinking, plus inspiration thinking,[37] or creative thinking.[38] But whether it's two o or three kinds of basic forms of thinking as scholars claimed, we need to clarify the problem from theory: why only two or three, why not other forms of basic forms human thinking. So it makes one feel that this division is purely subjective, speculative, lack of scientific basis, and it's difficult to be convinced.

In order to solve this problem, the author took another way to use horizontal - vertical thinking: vertical excavation in the sense of digging-up strategy, abandoned only from the point of view of psychology, but considered the traditional concept of human thinking, from a new view point—philosophy of human thinking process—to abstract and generalize. Since human thinking process is the reflection of laws of internal relation between objective things, and essential attributes of things, from which people make generalizations, and Marxist philosophy tells us that movement is the essence of things, and the movement is in certain space and time. The movement of matter cannot be separated from time and space, so it's necessary that thinking form reflects material movement reflects also related to time and space. Through analysis of logic thinking material (consisting of a sequence of words and concepts) and processing method, it shows that mental operation of logical thinking has the feature of one dimensional time sequence, which coincided with the material movement in time and corresponding with its characteristics; and materials of imagery thinking and intuitive thinking of thinking, as mentioned above, respectively are the imagery of things (mainly spatial-visual imagery) and relation imagery (which also belongs to spatial-visual imagery); and the processing method of the two kinds of thinking, though different, has unity (i.e., three-dimensional) and high-speed characteristics corresponding to the spatial characteristics of motion of matter. So if from the point of view of philosophy, one would, starting from a new angle of temporal and spatial characteristics of human thinking process, abstract and generalize that imagery thinking and intuitive thinking as a new thinking that reflects the spatial characteristics of motion of matter, spatial-structural thinking. This is a new functional relationship through the use of "dig up"; that is, the composition of functional relationship K = f (x, Z), made up by the spatial structure of thinking (K) and imagery thinking (x) and intuitive thinking (z). At the same time, logical thinking can be specifically designed to reflect time characteristics of the motion of matter. It was the reason why we rename logical thinking as temporal-logical thinking. In this way, we have made a more convincing and scientific explanation of the division of the three basic forms (or basic types) of human thinking. From the above analysis, it can be concluded that this kind of scientific explanation and is not separable from the use of horizontal-vertical thinking with digging-up strategy.

[37]Qian (1986).

[38]Yang (1997).

Example 3 Divergent thinking and the training methods (horizontal search: Case 2)

Since the American Guildford in the sixties of the 20th century put forward Three Dimensional Structure of Intellect Model, divergent thinking is listed as one independent factors, divergent thinking has been considered to constitute one of the important factors of creative thinking. After Guilford and colleague Torrance advocated divergent thinking; the preparation of textbooks and test scales, and experiments were carried out in some schools to further expand the influence of divergent thinking, and even made many people (including the academia) mistakenly believed that creative thinking is mainly dependent on divergent thinking, even some people simply deemed divergent thinking as creative thinking. Guilford et al. gave divergent thinking a classical definition and the training of divergent thinking, based on the requirements of the four basic properties of divergent thinking (fluency, flexibility, originality, elaboration) has become the golden rule of divergent thinking. However, the author of this book, made a comprehensive search, from the study of the goal of divergent thinking (in order to break the shackles of traditional ideas, theories and methods), function of divergent thinking (for creative thinking points in the right direction), using horizontal-vertical thinking search strategy, found that in the four properties required Guilford et al., at least two (fluency and exquisite) were completely inconsistent with the purpose of divergent thinking, and the other two elements cannot accurately reflect the divergent thinking connotation, which prompted the authors to make a new interpretation for the definition and connotation of divergent thinking (see Sect. 6.2, this chapter), and on the basis of this interpretation and the factors of horizontal search set a guideline for training of divergent thinking, which is completely different from Guildford's (difference in unity, positive in negative, and multi-directional radiation). This new concept about the connotation of divergent thinking and its training methods, obviously, are due to the use of strategy horizontal search in horizontal-vertical thinking.

Example 4 Inspiration/insight formation mechanism (downward vertical mining case)

How inspiration/insight forms has always been a mystery. In the field of psychology or thinking science, there's not an article or a book that can really make the problem clear. The consensus made so far is roughly that inspiration/insight formation is due to significant interaction of the conscious and the unconscious. Consciousness is generally recognized as logical thinking, but in the end what the subconscious refers to is of different opinions. It's not clear how conscious interacts with the subconscious mind. A very influential view of inspiration[39] considered that the so-called inspiration is part of the human brain re-processed information, but the person was not aware of the fact, this is known abroad as multi-selves, i.e. not only one self, but several self; one was aware of itself, and the other were not. But the self which has not been realized also worked there. So, suppose a very difficult problem, in the subconscious processing, the mind processed it many times, and finally got the results, then it may communicate with the conscious mind, and then

[39]Qian (1984).

got the answer. We may not know the whole process. This is called inspiration. This paragraph talked about the subconscious and conscious processing. However, there is still no explanation about questions like: how to process?; how does the subconscious communicate with the conscious?

Liu really did a lot of study on these problems and can explain it with the theory. In *New exploration of inspiration*, he put forward the theory of subconscious inference,[40] and made a concrete analysis of the process of inspiration, based on the theory. But, as we have pointed out earlier, there's still a big flaw in this theory, and it has not clarified the true process of inspiration.

The author of this book, using horizontal-vertical thinking of vertical mining of digging down strategy, analyzes and syntheses the key factors of creative imagination, with the new theoretical view. Then, the author finds out that the key of forming creative imagination (i.e. Making inspiration/insight happen) is to solve the complexity of horizontal-vertical dimensions. In horizontal complexity level expressed with n, longitudinal direction with m. For creative breakthroughs, the most difficult thing is the vertical complexity of the higher m value (as mentioned earlier, this complexity is the root cause of why the subconscious search process will happen.) So in creative imagination (assumed expressed by the letter C) between the horizontal complexity (n) and vertical complexity (m) formed a function relation $C = \Psi(n, m)$. This is what we found, through digging down, the new function relations (the function relations between the key factors and their attributes). On the basis of this, we carefully analyzed and studied this new function, finally we found it more effective to use the horizontal search processing strategy to solve horizontal complexity; and found that it's relatively more effective to use vertical mining processing strategy to solve longitudinal complexity. And the two mental processing strategies are the combination of horizontal and vertical thinking. In other words, the new horizontal-vertical processing strategies also rely on the strategies "vertical mining" in the "digging down".

In the same way, the key factors in the process of intuitive thinking can be similar to the downward vertical mining, which can be similar to the above imagery thinking process.

With the principles provided by dialectical thinking from the level of philosophy as well as the specific strategies provided by horizontal-vertical thinking from the aspect of mental processing, the period of subconscious exploration will be greatly shortened, which provides advantages for the achieving of creative breakthrough (i.e. the forming of inspiration/insight). This is our basic view about how inspiration/insight forms. As mentioned above, this view is based on the theory of horizontal-vertical thinking. In other words, the forming process of inspiration/insight is not the sudden "communication" between consciousness and subconsciousness, but a process which can be formed gradually through horizontal

[40]Liu (1986).

research or vertical mining. The four examples given above not only reflect the specific process of achieving breakthroughs by using horizontal-vertical thinking, but also show real examples of promoting and accelerating the formation of inspiration (or insight) by using horizontal-vertical thinking. Of course, since the horizontal-vertical thinking is only a mental processing strategy, it can not replace the arduous exploration during the process of scientific discovery. However, with this strategy we can specify the direction and goals of exploration and efforts, which can shorten the process of exploration.

The four given examples, which solve difficult problems and achieve creative breakthroughs by the use of horizontal-vertical thinking, are just the experience of the author and are not confirmed by others. However, the horizontal-vertical thinking itself is summed up by the analysis of the complex invention process of computer. Besides, the horizontal-vertical thinking has been proved by the practices of solving creative problems during the process of writing this book. So we trust that vertical-horizontal thinking, as a new strategy of psychological processing, accelerates the formation of inspiration/insight; i.e., it will help the realization of key breakthroughs in creative thinking activities.

In other words, horizontal-vertical thinking is a key element in the makeup of creative thinking. I hope that the experts, scholars and young people who aspire to invention may wish to try to use horizontal-vertical thinking. The horizontal-vertical thinking will give you a helping hand.

6.6 Questions Need to Be Noticed During the Cultivation of Creative Thinking

From the the narration of each section, it can be seen that among the six elements of creative thinking, divergent thinking is mainly to solve the issue of goal-directedness, i.e. direction of thinking; dialectical thinking and vertical-horizontal thinking are mainly to solve complicated problem by providing effective guidance and processing strategies; imagery thinking, intuitive thinking and logical thinking are three basic forms of human thinking, but they are also the main process for realization of creative thinking (main body). In other words, among the six elements, one is used for direction of thinking (guiding direction) and two for providing a highly complex problem-solving with guidance and strategy, and the other three constitute the main body of the process of creative thinking. As shown below:

A pointer (divergent thinking)—to be responsible for direction of thinking;
Two strategies (dialectical thinking, horizontal-vertical thinking)—to provide macro philosophical guidance and micro-psychological processing strategy;
Three forms of thinking (imagery thinking, intuitive thinking, and temporal-logical thinking)—consist of the main body of creative thinking.

These are different roles of the six elements in creative thinking and relationship between them. The so-called creative thinking structure is composed of the above six elements according to the above relationship. To understand the structure of creative thinking is to get the key to creative thinking and to the training of teenagers in creative thinking and to get the key to the blueprint of training program. Therefore, we must have a comprehensive and correct understanding of the structure and functions and properties of various elements. In view of the reality of the situation on current theory of creative thinking it's still relatively vague (and even some confused), we think. To better understand the structure of creative thinking, we should first clarify the following five aspects.

First, the six elements of the structure of creative thinking are of organic unity of the whole, which cannot be separated.

For the six elements, at any time, will not be allowed to stand alone, one or a few isolated from others, or to be stressed individually; otherwise it will produce one-sidedness. For example, there's a very popular view in currency, in China: when speaking about creative thinking, just talk about divergent thinking and believe that divergent thinking is equal to creative thinking. Now on the market there are a quite influential university entrance exam review guide series, the titles were: *Divergent thinking of mathematics, Physics divergent thinking, Chemistry divergent thinking, The language of divergent thinking* and so on. It's a typical reflection of this view. In fact, this is American psychologist Guilford's basic views in the 1960s and 1970s, now the view is outdated, and many of us still hold this distorted view as a fashion spread everywhere. In addition, some people when speaking of creative thinking, only mention imagery thinking and without talking about logical thinking, divergent thinking; or on the other hand, only emphasize logical thinking, ignoring imagery, intuitive and divergent thinking. All of this is one-sided view, and lacks a rational understanding of the structure of creative thinking.

Second, one should not confuse intuitive thinking with imagery thinking.

In the structure of creative thinking, intuitive thinking and imagery thinking are two elements that are both interrelated and independent of each other. They are related because both of their thinking materials are mainly visual-spatial imagery and then they all belong to spatial-structural thinking; but the two are independent of one another because each of them has its particularity; imagery thinking materials reflect attributes of things, while intuitive thinking materials reflect relations between things; their localization of mental processing mechanisms and working memory area in cerebral cortex are also completely different: processing mechanism of imagery thinking and working memory area mainly are in the left hemisphere, mental processing mechanism of intuitive thinking and working memory area are on the right side of the brain. So, the two of them should not be confused. The scientific community of psychology and thinking science often use the term imagery/perceptual thinking or imagery/intuitive thinking; we think this is a misnomer, which causes concept confusion.

Third, the main features of logical thinking are not abstract, but linear and sequential.

At present, in the field of psychology and philosophy, there is a very popular saying: abstract logical thinking, which means that only logical thinking is abstract, general and other basic forms of thinking, such as imagery and intuitive thinking do not have abstract feature and generality. In fact, abstraction and generality are common attributes of all three basic forms of thinking, and it's not unique to logical thinking. The true logic thinking has the unique feature, which is one-dimensional time axis, linear and sequential. This is because of the object of logical thinking is based on language symbol sequences. Therefore, we should change abstract logical thinking to temporal-logical thinking to be truly worthy of the name (The book follows this consideration, so the whole text adheres to the latter naming).

Fourth, one should not set temporal-logical thinking against imagery and intuitive thinking.

At present, a bias exists in the field of psychology and philosophy: some scholars emphasize logical thinking while often belittling imagery and intuitive thinking; and some other scholars emphasize imagery and intuitive thinking to another extreme. In fact, these three basic forms of thinking are mutually supportive and interdependent, which can be demonstrated from psychology, and also from neuro-physiology (for example, from cerebral cortex function localization) evidence can be found, such as temporal-logical buffer (speech working memory area) in Chap. 5 in the process of imagery thinking comes logical thinking, which is completely overlapped with imagery thinking buffer (object working memory area).

Fifth, more attention should be paid to the study of dialectical-logical thinking.

Dialectical-logical thinking is one of the elements in the structure of creative thinking, but one finds it rare to read papers and treatises on dialectical thinking in psychology circles at home and abroad; it's even more difficult to see careful studies in the literature. It seems that dialectical thinking is purely philosophical, and only philosophers should study it (the current study of dialectical-logical thinking can only be found in philosophical works). We judge this view to be biased, and will not be conducive to the development of creative thinking research; so I hope that psychologists pay serious attention to the study in this area.

All in all, we need to seriously rectify the five erroneous tendencies and try to lead people's understanding of creative thinking on the right track by using the scientific theory. It is especially important to regard the creative thinking structure as an organic whole and see the cultivation of creative thinking, comprehensively and systematically, rather than only regarding one or a few elements in isolated and split way (we should not only emphasize one or a few elements). Otherwise, we will behave like the blind, touching the thigh of an elephant and regarding it as the pillar; touching the belly and regarding it as the wall. At present, in educational, psychological or noetic science circles, there are so many scholars who are just like that. We need to learn a lesson and dance to another tune, otherwise, our descendants will be delayed.

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