# Visualizing Creativity:

An analysis of the relationship between creativity and visualization through an overview of theories of creativity visualization technologies

Richard Li

MCT

2010

# Visualizing Creativity:

An analysis of the relationship between creativity and visualization through an overview of theories of creativity visualization technologies

Richard Li

A thesis submitted to

Auckland University of Technology

in partial fulfilment of the requirements for the degree

of

Master of Creative Technology (MCT)

2010

Faculty of Design and Creative Technology

Primary Supervisor: Charles Walker

## Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Richard Li

Acknowledgements

I would like to thank my supervisor Associate Professor Charles Walker for his invaluable contributions

## Abstract

The broad purpose of this thesis is to present an interdisciplinary analysis of the relationship between creativity and visualization. More specifically, the research engages with artistic, cultural, technical and scientific modes of recognizing and evaluating creativity. The thesis explores the potential for new visualization technologies to represent, communicate or interactively engage with theories of creativity in order to extend our understanding of creativity and its application across differing domains. The research has been developed from two parallel but previously under-related discourses. The first informs a discussion of general problems in the study of creativity across different domains, while the second focuses more on studies of artistic creativity using computer technologies.

The thesis gives an overview of various creative theories and the neuroscience approach to creativity. It demonstrates that most studies on creativity focus on the process of creativity and measuring creativity. The process of creativity includes where the creative thought is produced which involves consideration of individual, social and environmental factors. The measurement of creativity focuses on evaluating the individual ability of creativity. The subject of much study on creativity is human and other elements related to the human ability of creativity. Analyses of artistic creativity engaging with computer technologies in the form of case studies raise questions on how to understand the “machine’s creativity” and what is the role of the “machine as creator” in the study of creativity. This investigation of art practice engaging with technology indicates a contribution of the “machine as creator” to a new knowledge of creativity.

The above analysis of the various definitions, theories and concepts of

creativity and visualization indicates that there is a gap in a creative technology-based approach to creativity. The subsequent investigation of visualization technology indicates that the technology itself plays a key role in transforming or interpreting data into visual media for scientific findings.

The result of the study also indicates some future directions for research in this emerging interdisciplinary field.

Table of Contents

# Introduction

This thesis is the result of an interdisciplinary investigation of potential relationships between two different domains: *Creativity* and *Visualization*.

Creativity is understood here as a fundamental concept that involves a mental process of producing new ideas and products. Since there is a wide range of different disciplinary perspectives on creativity and different understandings of creativity at the different times, there are thus many different concepts on creativity. For example, in many arts related fields, creativity is often regarded as mysterious; learned or developed tacitly and evaluated through interpretive methods such as reviewing and critique. In the more technical fields such as engineering and robotics, however, it is often regarded as akin to problem solving and capable of being subjected to a few of well defined methods for developing and quantitatively evaluating creativity. In psychology, creativity refers to "solving problems, communicating with others, and entertaining ourselves and others" by using to generate ideas, alternatives, or possibilities (Franken 2001, p.394). In the field of cognitive science, research on creativity has been related to brain function and the development of computational models. In addition, different cultures have exhibited the different understandings of the concept of creativity. From a Western perspective, creativity can be defined as the capacity to produce work that must be novel and appropriate (Barron 1988). However, in Eastern cultures, the concept of creativity emphasizes personal attachment a primordial realm or a personal expression of an inner essence (Kuo 1996). Nevertheless, in many fields, any understanding of creativity remains limited.

For this thesis, visualization can be considered as a process of the transformation, translation or interpretation of certain forms of information into another (visual) form. For the scientist, visualization is an important tool for observing, understanding or representing complex scientific data. During these interactive processes, the techniques of visualization and the manipulations of data play a key role in discovering and communicating knowledge or findings. However, the translation and interpretation of complex mathematical data into visual media is often limited by both technical and perceptual issues. For example, many scientists may have a limited engagement with visual communication techniques and designers often lack understanding of scientific forms of information. In this regard, both hardware – in the form of machines or devices – and software as programmes and codes – become highly significant. These relationships will be explored further in this research.

As well as for scientific purpose, visualization also plays an important role in a modern society in which large quantities and diverse forms of information have become an integral part of people's life and culture. However, scientific visualizations, which emphasis quantitative interpretations of scientific data, can be monotonous and unsatisfactory to post-industrial society. Therefore, how to effectively represent data or information in clearly understood visual form has become an important issue for both scientists and designers.

The thesis aims to explore how to broaden and link differing understandings of creativity and how technology may contribute to applications of creativity across differing fields. The thesis thus explores two fundamental questions: What *modes* of creative expression can help to understanding and visualize data in order to effectively communication of data? What visualization technologies can best represent and communicate for the understanding of creativity and its applications?

In the first Chapter, the thesis introduces the different definitions and criteria for creativity and examines how those different concepts contribute to the understanding of the topic. Chapter Two provides an overview of studies of creativity. It outlines a number of different approaches to creativity from earliest Mystical Approaches to Psychometric Approaches, from Social-personality Approaches to Neuroscientific Approaches. Those studies attempt to explore a range of possible explanations of creativity from a number of different angles, including that of McLaren (1999) who addresses the “dark side” of the human misuse of the gift of creativity. Attempts to measure creativity are also discussed through overviews of some major tests developed for measuring the human’s ability for creativity, such as the well known Torrance Tests of Creativity Thinking (TTCT) developed by E. Paul Torrance in 1966. This chapter also examines how different cultures might influence creativity. It develops a discussion of concepts of creativity and creative process in Western and Eastern cultures. It is apparent that both concepts and creative processes of creativity are different in these two cultural spheres. While Western culture focuses on innovative products and problem solving, Eastern culture emphasizes on how the “new” is recreated from the “old” and how creativity growing from the “old” is regarded as having greater “value”. However, according to the research from Kim(2009), Eastern culture (at least in term of Confucianism) is “negatively related” to creativity and studies that have suggested that people from East Asian societies tend to be “less creative” than people from the more individualistic Western societies (Kim 2009).

In the last decade, studies of creativity have also focused on studies on working memory and the cerebellum, and the role of the function of the brain on artistic creativity. Scientists believe that the ideas of creativity might be the result of brain mechanisms. In Chapter Three, two important theoretical approaches will be examined: Working Memory and the Cerebellum, and Neuroesthetics. The theory of Working Memory and the Cerebellum mainly discusses the purpose or objectives of creativity in general, while Neuroesthetics theories are more focused on how the study of visual brain applies to or explains what we might recognize as "artistic" creativity. In the newly emerging field of Neuroesthetics, Zeki's theories and Ramachandran's "visual laws" will be examined.

Chapter Four, examines the relationship between artistic creativity and technologies. In this study, art will refer to visual art such as paintings, sculptures and media art, but not music or writing. The chapter argues that art creativity often engages with new technologies *through*- or frequently *as*- new media, hence the focus here on artists' engagement with emerging computing technologies in the processes of modern art. This creative engagement with computing techniques is divided into three parts: computer as a tool, computer as a creator and other computing applications. From its earliest period, the computer has often been used as tool to explore creativity, albeit initially often by mimicking the work of established artist. With the fast grow of both computing hardware and software in the more recently decade, computer as a tool has also been widely used in generation of 3D animations, images and even internet-based art. To achieve those special artistic effects, new complex computing techniques and hardware devices have been put to use in the name of art creativity. From the other side also, some artists have been interested in designing and developing machines for visualization, in which machine can make a drawing or painting with or without human's instructions. Here the thesis raises the question of what role of "machine as creator" plays in the process of creativity?

Towards the end of this chapter, the thesis outlines a new approach to data visualization that is here named “artistic data visualization”. The work of artistic data visualization might not accurately represent scientific data and might not be a tool to translate or communicate data to any scientific sense. Artistic representations of data are intentional and intended to communicate but may not necessarily communicate nor be tightly connected to scientific data.

In the current studies on creativity, most theories of creativity are framed by human products or perceptions. However, there are very few theories concerned with the creativity of machines. This chapter asks how can we understand the notion of an autonomous mechanism of presenting creativity?

After Frank Popper (1993), Ingram is suggesting that as art creativity increasingly engages with new techniques, the role of the computer in art has gone beyond its function as a tool or a medium.

Building on Popper’s notion of the computer “operating rather as a purveyor of information and as an intellectual instrument” (Popper 1993, p179), Chapter Five, investigates a number of different technologies of visualization. After a short statement on the definition of visualization, visualization technology is discussed in two basic respects: hardware and software. The two respects are interdependent and hardware devices are clearly supporting and supported by related software. For a computer hardware, it refers to computer input and output devices and for software, it refers to programming languages, operation systems, programming applications and computer algorithms. Some recent visualization technologies and techniques such as Illustrative visualization, information visualization and virtual reality are also examined.

It is apparent that there is a gap in the study of the kinds of creativity that engages with computing techniques and a deficiency in explanations of the role of technology in the mental activity of creativity. This thesis examines this gap in terms of what role we can say the machine’s “creativity” plays and whether that may also be indicative of a new concept of “creator”? It is predicted that the study on “machine creativity” indicates a new approach of creativity.

## Chapter One: The Definitions of Creativity

When talking about creativity, people normally believe art, music or novels belong to the category of creativity. However, inventions such as airplanes, engines, furniture are also products of creativity. While the work of such as artists, musician or novelist are often unquestioningly accepted as creative, so also might an innovative business plan be. Even, a new idea for planting in the garden may be creative. The concept of creativity might be applied to many different fields or subjects. However, people might ask on what creativity is indeed? How can we identify a product that is creative? Can we measure creativity? Why this person has more creative ability than others? To answer those questions is not easy. At the first, we need to define the creativity. However, most researchers believe defining creativity is difficult, as the "understanding of creativity is changing throughout the history and creative ideas usually appear unexpectedly, with little conscious awareness of how they arose on the part of the people who have the ideas" (Niu and Sternberg 2001). While some scientists and researchers have attempted to seek a definition which can cover all expressions of creativity, it also seems that are many ways to define creativity and many versions of creativity have been proposed and discussed. According to *Webster's Ninth New Collegiate Dictionary* (Mish, Morse et al. 1990), creativity is "an ability to create, and the verb 'to create' refers 'to bring into being', such as 'God created the heaven and the earth'. Earlier definitions of creativity in psychology have focused on the novel characteristic of creative production" (Niu and Sternberg 2001). In his theory of the "Structure of Intellect", Guilford (1956, 1986) believes that creativity is kind of divergent thinking, "in which the quantity (fluency) and quality (flexibility and originality) of information people generated from given information has been used to represent people's divergent thinking" (Niu and Sternberg 2001). However, researchers such as Amabile (1996) and Sternberg & Lubard (1995) argue that the actual processes of creativity are much more complex than the processes of just generating information and the more important thing is that people must accept the products of creativity as valuable or useful. A widely accepted definition of creativity is proposed as one's ability that can generate ideas or products that need to be judged by a group of people to be new and useful (Sternberg and Lubart 1999).

Many researchers investigate creativity through different approaches and different theories. For instance, J.P. Guilford and E. Paul Torrance, who are pioneers in recognizing that creativity can be understood by scientific means, were "both basically psychometric theorists and conceived of and attempted to measure creativity from a psychometric standpoint" (Sternberg and Lubart 1999). Psychometric theories mainly are the study of psychological measurement which involves the tests such as questionnaires on the measurement of personality traits, ability and knowledge. They concentrated on divergent thinking as the basis of creativity and devised tests that emphasized the assessment of divergent thinking. However, Kaufman (2005) and Sternberg (2006) chose to use a confluence approach as a basis for their work on creativity. The concept of divergent thinking which was developed by J. P. Guilford is a thought process that aims to generate many different ideas around a topic. It is often used joint with convergent thinking, which follows a particular set of logical steps to arrive at one "correct" solution. Divergent thinking, which is often used in arts and humanities related fields, normally occurs in "a spontaneous, free-flowing manner" that most ideas are generated in a "random, unorganized fashion". Then many possible solutions are explored in short time and “unexpected connections are drawn”, by using divergent thinking, ideas and information are “organized and structured” (Retrieved 2010-02-09). Confluence approach, similar with convergent thinking, is just opposite of divergent thinking. It emphasizes to bring many facts to answering a question that often used in scientific or technology related fields.

Creativity is not only a modern concern, Plato had discussed society’s need for creative people and suggested ways of fostering their development (Cropley 1999). Traditionally, creativity is a patent for painters, sculptors, poets, writers, and other people in the creative arts field and they have often discussed creativity in relation to their works. As an artist, creativity is one of the most important criteria by which to judge whether works are successful or unsuccessful. From ancient Greece until the Renaissance, it was widely believed that all desirable innovations were inspired by the divinity (depending on the creator’s religious orientation). But since the Renaissance, this viewpoint began to give way to the idea that creativity is a “matter of genetic inheritance” (Dacey 1999, p.310). In $19^{th}$ century, there was a theory wildly accepted that creativity was closely aligned to madness (Cropley 1999). At the beginning of $20^{th}$ century, “the debate turned to an argument over the relative contributions of nature versus nurture” (Dacey 1999, p.310). However, shortly after the Second World War, researchers began to explore creativity in mathematics, the natural sciences and in professions such as architecture in which creativity have “strong aesthetic connotations, and was largely seen as a medium for beautifying the environment, a form of self-expression and communication, or a way of understanding, opening up or coping with the previously unknown” (Cropley 1999, p.512). Furthermore, in recent years, there has been growing acceptance of biopsychosocial theories, that is, the belief that all creative acts are "born of a complex interaction of biological, psychological, and social forces" (Dacey 1999, p.310).

As well as in psychology, social culture, art, and music, creativity has been studied in the field of business with an overwhelming emphasis on meeting competition, and for markets and acquiring market shares. More recently, there has been considerable emphasis on creative management, especially in creative leadership, innovation, and the management of innovation, with research focusing on productivity, effectiveness, and the like (Cropley 1999). According to the research by A. J. Cropley (1999), creativity is defined as "a social phenomenon that is facilitated by some social factors, and inhibited by others" (p.511). Cropley points out a work place is an important social background "where an interaction between the person and the environment affects the process of innovation" (p.511).

In his book *"Human Motivation",* R. E. Franken (2001) defines creativity as "the tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others" (p.394). He believes that the reasons for the people are motivated to be creative is a kind of need of new, different and complex stimulation, communication of ideas, value, and problem solving (Franken 2001). To be creativity, Franken argues that people need to seeing things in "new ways or from a different perspective and need to generate new possibilities or new alternatives" (p.394). He also believes that tests of measuring creativity should measure both the number and uniqueness of alternatives that people can generate and "the ability to generate alternatives or to see things uniquely does not occur by chance" (p.394). And such tests of creativity is "linked to other, more fundamental qualities of thinking, such as flexibility, tolerance of ambiguity or unpredictability, and the enjoyment of things heretofore unknown" (p.394).

Weisberg (1993) in his book *"Creativity – Beyond the Myth of Genius"* argues that "...'creative' refers to novel products of value, as in 'The airplane was a creative invention.' Creative also refers to the 'person who produces the work, as in, Picasso was creative.' 'Creativity,' then refers both to the capacity to produce such works, as in 'How can we foster our employees' creativity?' and to the activity of generating such products, as in 'Creativity requires hard work'" (p.4).

All people who study creativity agree that not only novel is important to creativity, but also believe that creativity must have value or be suitable to the cognitive demands of the situation (Weisberg 1993). In a word, creativity contains the idea of *novelty*. Whether it relates to discovery or an emphasis on meeting competition, the idea of novelty is central (although not necessarily sufficient) and novelty must be the production of relevance, effectiveness and ethicality as well and the different understanding of novelty causes the distinction between creativity in the sublime and in the everyday sense (Cropley 1999). By considering personal element, creativity is defined as "an aspect of thinking, as a personality constellation, and as an interaction between thinking, personal properties, and motivation. This interaction involves a number of paradoxes, in that apparently contradictory elements have to coexist for creativity to emerge" (Cropley 1999, p.511).

Sternberg & Lubart(1999) defines that "creativity is the ability to produce work that is both novel (i.e. original, unexpected) and appropriate (i.e. useful, adaptive concerning task constraints)" (p.3). They believe that creativity is important to “both individual and societal levels for a wide range of task domains” (p.3). Creativity is relevant at an individual level, however, at a societal level, all new scientific findings, new movements in art, new inventions are also results of creativity. In the business area, creativity generates the new products and services for the maximum profits and more jobs (Sternberg and Lubart 1999).

Rob Pope (2005) examined the definition of creativity theoretically. In his book “*Creativity: Theory, History, Practice*”, he explores, in detail, single words, combinations of words and sentence that have been used to define creativity. Pope discusses the different aspects of creativity in terms of “ ‘..extra/ordinary’; original and fitting; full-filling; in(ter)ventive; co-operative; un/conscious; fe<>male; re…creation” (p.52).

The consensus on any standard definition of creativity from most researchers tends to turn on a conception of creativity as something “new and valuable” or “novel and appropriate”. “‘Original and appropriate’…; ‘something new that people find significant…;’ ‘novel and adaptive solutions to problems’ … (Pope 2005, p.57). Different cultures have different definitions on the creativity. For example, a Western viewpoint on creativity is very different from the one held by an Eastern culture. From a Western viewpoint, creativity can be defined as the ability of produce works that are novel and appropriate (Pope 2005). The conceptions of Eastern creativity believe that “re-creation” of the “the old” is valued or “novel” and must be based on “previous one/the old” (Pope 2005). This suggests that Eastern conceptions of creativity may be similar to “neo-Classicism” or other kinds of traditionalism in the West (Pope 2005). At the same time, Margaret Boden (1996) argues that “novelty may be defined with reference either to the individual concerned or to the whole of human history”(p.351). Boden’s P-creativity and H-creativity are two sensors of creativity which P-creativity is that which makes a discovery or experiences a personal break-through and H-creativity is what is known already or had been known before (Pope 2005). Furthermore, by adding from “a Western modern point of view” to Lubart’s definition and adding “new to the person or new to history in some context of ex/change” to Boden’s definition of creativity, Pope (2005) argued that it is absolutely necessary as “it is the very project of modernity … that by definition promotes ‘the new’ as modern and downgrades ‘the old’ as ancient; and because precisely what is judged ‘value’ depends upon a complex, often contentious sense of changing ‘values’ and variable rates of exchange” (p.57). Therefore, Pope believes that defining creativity is “couched more circumspectly, in terms of what is ‘original and fitting’, with several different senses in play” (p.57). Based on “original and fitting” terms, Pope defines a conception of creativity that is adaptable and may formulate as following:

> *Creativity may be ‘original’ in the sense both of drawing on ancient origins and of originating something in its own right; either way, the overall aim or end is a ‘fitting’ – an active exploration of the changing proportions, measure, ratios-between older modes of understanding and newer ones. (Pope 2005, p.59)*

Sometimes people can have their own “original and fitting” terms. Derek Attridge (2004), for example, adapts and develops Kant’s “exemplary originality” to appoint “a particular kind of difference from what goes before, one that changes the field in question for later practitioners" (Attridge 2004, p.36) and furthermore believes that a true originality is not just imitate others but helps prompt originality. In addition to, Pope(2005) introduced a conception called *"re…creation"*, and he believes that the *re…creation* is like a kind of "the ongoing of making afresh" (p.84). The prefix "*re…"* can mean "afresh" as well as "again", and denotes repetition with variation, not just duplication. The concept of "*…creation*" is considering as reviewing of many different meaning of the "creativity" that includes such God as Creator, "'the creative artist' and the various 'creatures' of the imagination, along with such processes as 'creative evolution' and 'heterogenesis' … they range over everything that creativity is or may yet be – from 'extra/ordinary' to 'fe<>male' and beyond. We are in part of that 'beyond' now…" (Pope 2005, p.84). Pope explained the "suspension dots" in the word "*re…creation*" as a considered device which "invites us, then, not only to 'mind the gap'… but to also "pause and reflect upon the potential meanings and inter-relations that are in play, and, each in our own way, to 'jump' and thereby 'bridge' it" (Pope 2005, p.85). The concept of '*re…creation*' "invites us to see through the exiting possibilities to words beyond as well as between; and it encourage a view of 'difference' that is genuinely otherwise… it is an invitation to keep on jumping or bridging the gap…" (Pope 2005, p.88).

Pope argues that instead of that provided by "standard definition of creativity in the specialist literature, the concept '*re…creation*' is more responsive and responsible in defining creativity. Because '*re…creation*' leaves more room for conserving and sustaining as well as recasting and refreshment, while resisting conservative, reactionary impulses of an unthinking and merely reflexive kind" (Pope 2005, p.88). Pope also mentions the “next step” of the creativity and social self-creation which are both known and unknown events. He believes that to take “next step” and process the “next work”, “we must move beyond the terms *create*, *creative* and even *re…creation*; for it will be abundantly clear by now that, however we define it, creativity will always be ‘something more and something different’… ” (Pope 2005, p.88). Furthermore, Pope argues that the concept of creativity needs to continue to be reinterpreted and rewritten in current terms.

In conclusion, the understanding of creativity has never stopped at a point that makes defining creativity easy. It reminds hard and difficult. Such an understanding involves many personal and environment elements such as social context, culture as well as different perspectives on the relationship between “old” and “new”. This chapter has given an overview of the different definitions or criteria of creativity and those outstanding theories emphasize on a “new” or “original” and “valuable” as a basic of creativity. Creative thought might happen through divergent thinking with a complex process and under some certain kinds of conditions such as cultural, social, competition elements. In addition, creativity might necessitate meeting competition, solving problems and addressing social phenomena. However, Pope proposes a new and different concept of creativity, “re…creation” that goes beyond the conventional concept of creativity. Because a better understanding of creativity is a long-term, challenging task and this new concept avoids rigid definitions and posits a continual re-explanation of creativity in the future.

# Chapter Two: Creativity Studies: An Overview

Creativity is a fundamental concept involving new ideas and new products. People are always interested in questions on creativity, such as; why does this person have more creative ability than others? Why is culture an important element in considering creativity? Where do the creative ideas come from? How can we measure the creativity? This chapter provides an overview of diverse theories of creativity.

At the first, creativity is a topic of broad scope that is important at both the individual and societal levels for a wide range of task domain (Sternberg and Lubart 1999). When considered at an individual level, it relates to the solving problems on the job. At a societal level, it can “lead to new scientific findings, new movements in art, new inventions, and new social programs” (Sternberg and Lubart 1999, p.3). Creativity has been studied from wide range of different disciplinary perspectives, such as behavioral psychology, social psychology, psychometrics, cognitive science, artificial intelligence, philosophy, history, economics, design research, business and management, neurobiology, among others.

Creativity in many arts-related fields is often regarded as mysterious; it is learned or developed tacitly and evaluated through interpretive methods such as reviewing and critique. In fields like Engineering and Robotics, creativity is often regarded as akin to problem solving, with a number of well defined methods for developing and quantitatively evaluating creativity. In the fields of cognitive science much research has been related to brain function and the development of computational models that can only represent certain dimensions of these complex processes.

In this chapter, I outline some key approaches, or paradigms, that have been used to understand creativity: mystical, psychoanalytic, pragmatic, psychometric, cognitive, confluence, and social-personality.

## 2.1 Mystical Approaches

Mystical beliefs have always been important in association with the study of creativity. People in early times believed divine intervention cause the creativity. According to this approach, a creative person “was seen as an empty vessel that a divine being would fill with inspiration and then he would pour out the inspired ideas, forming an otherworldly product” (Sternberg and Lubart 1999, p.5).

Plato believed that divinity such as Muse dictates the people to create the art works. He argued that the finest of all lyrical poems…an Invention of the Muses (Rothenberg and Hausman 1976). Until now, people sometimes still “refer to their own Muse as a source of inspiration” (Sternberg and Lubart 1999, p.5). In addition, it believes that mystical sources come from the creators’ introspective reports (Ghiselin 1985). For instance, Rudyard Kipling (1985) believes the “Daemon” lives in the writer’s pen, therefore, “My Daemon was with me in the Jungle Books, Kim, and both Puck books, and good care I took to walk delicately, lest he should withdraw. When your Daemon is change, do not think consciously. Drift, wait, and obey” (p.162).

## 2.2 Pragmatic Approaches

Pragmatic approaches mainly focus on developing creativity; here, how to understand the creativity is not the first concern. One of the most significant thinkers in the pragmatic tradition is Edward De Bono. De Bono’s work was successful in business fields and arguably more concerned with practice than theory (Sternberg and Lubart 1999). For instance, De Bono suggests using a tool to concentrate on all aspects of an idea that are pluses, minuses, and interesting (Bono 1971). His “Thinking hats” is a tool for stimulating creativity where individuals metaphorically wear different hats, such as a white hat for data-based thinking, a red hat for intuitive thinking, a black hat for critical thinking, and a green hat for generative thinking, in order to “stimulate seeing things from different points of view” (Sternberg and Lubart 1999, p.5). Osborn (1953) developed the technique of “brainstorming” to encourage people to solve problems creatively by seeking many possible solutions, instead using critical but using constructive (Osborn 1953). Gordon (1961) attempted to stimulate creative thinking by a method called synectics that primarily involves analogies recognizing and creating analogies.

Other researchers such as Adams (1986) and von Oech (1983) argue that people can foster creative ability by identifying and reducing or removing the things that interfere with creative functioning, such as sometimes people used to construct a series of false beliefs and often believe there is only one right answer and must escape from ambiguity at any time. Therefore, Von Oech (1986) suggests that to be more creative, people should assume all kinds of different roles such as artist, judge and warrior.

However, Sternberg and Lubart (1999) argues that pragmatic approaches lack “any basis in serious psychological theory” or any “serious empirical attempts to validate them...” (p.6). It is also criticized that the results of such approaches are less serious endeavor on psychological study rather associating with commercialization (Sternberg and Lubart 1999).

## 2.3 Psychodynamic Approaches

Psychoanalysis provides the first major theoretical foundation for the study of creativity in the twentieth-century. This theory posits that creativity rises from the tension between conscious reality and unconscious drives (Sternberg and Lubart 1999). Freud (1959) argued that the secret of the artist's power over his audience was "the ability to disguise and then portray the forbidden themes which all men have repressed into their unconscious" (Sternberg and Lubart 1999, p.6). He suggested that through "a publicly acceptable fashion" to generate creative works is a way or method that artists and writers "express their unconscious wishes" (Freud 1908). For Vernon (1970), such unconscious wishes involve power, riches, fame, or love.

The key theoretical concepts in psychoanalytic approaches are the two concepts of *adaptive regression* and *elaboration*. Adaptive regression refers to the intrusion of "unmodulated thoughts in consciousness". Unmodulated thoughts can occur during active problem solving, but often occur during sleep, intoxication from drugs, fantasies or daydreaming, or psychoses (Sternberg and Lubart 1999). The second process, elaboration, refers to the "reworking and transformation of primary process materials through reality-oriented, ego-controlled thinking" (Sternberg and Lubart 1999, p.6). Other theorists such as Kubie (1958) proposed that "preconscious, which is between conscious reality and the encrypted unconscious, is the true source of creativity because thoughts are loose and vague but interpretable" (Sternberg and Lubart 1999, p.6). Comparing with Freud, Kubie (1958) believes that because of leading to fixed and iterative thoughts, unconscious conflicts are negative to creativity.

However, Sternberg and Lubart argue that psychoanalytic theory, although it offered some insights into creativity, is not longer at the centre of the emerging scientific psychology. In addition, psychoanalytic theory relies almost exclusively on case studies of “eminent creators” such as Michelangelo or Einstein. The methodology of psychoanalytic theory has been criticized because of the difficulty of measuring proposed theoretical constructs (such as primary process though) and the amount of selection and interpretation that can occur in a case study (Sternberg and Lubart 1999).

### 2.4 Psychometric Approaches

As it is very difficult to study eminent artists such as Michelangelo or Einstein, Guilford(1950) proposed a new theory in his APA (American Psychological Association) address. He suggested that the study of creativity should focused on everyday subjects with a psychometric approach by using paper-and-pencil tasks, such as the Unusual User Test, “in which an examinee thinks of as many uses for a common object (such as a brick) as possible” (Sternberg and Lubart 1999, p.7) That is well known theory “divergent thinking” model which had became the main instruments for measuring creative thinking quickly. It was a convenient way to test people on a “standard” creative scale (Sternberg and Lubart 1999). Further discussion on the divergent thinking will be in measuring creativity.

Building on Guilford’s work, Torrance(1974) developed the well-known the Torrance Tests of Creativity Thinking(TTCT) which consist of several relatively simple verbal and figural tasks that involve “divergent thinking plus other problem-solving skills” (Sternberg and Lubart 1999, p.7). The TTCT test can be scored from four aspects: “fluency (total number of relevant responses), flexibility (number of different categories of relevant responses), originality (the statistical rarity of the responses), and elaboration (amount of details in the responses)" (Sternberg and Lubart 1999, p.7).

Sternberg (1999) discussed how the psychometric revolution of measuring creativity had both positive and negative effects on the field. On the positive side, Sternberg believed that the tests facilitated research by providing a brief, easy-to-administer, objectively scorable assessment device and the tests could be applied to everyday people (i.e. noneminent samples). However, such simple paper-on-pencil tests are not sufficient to measure creativity (Sternberg and Lubart 1999). Amabile (1983) critiqued that fluency, flexibility, originality, and elaboration scores failed to capture the concepts of creativity. As the definition and criteria for creativity are "a matter of ongoing debates", and relying on the "objectively defined statistical rarity of a response with regard to all the responses of a subject population is only one of many options". Other possibilities include using "a consensus of judges regarding a product's creativity" (Sternberg and Lubart 1999, p.7). Some other researchers disagreed with the assumption that "noneminent samples could shed light on eminent levels of creativity, which was "the ultimate goal of many studies of creativity" (Sternberg and Lubart 1999, p.7).

## 2.5 Cognitive Approaches

The cognitive approach to the study of creativity seeks to understand the "mental representations" and "processes underlying creative thought" (Sternberg and Lubart 1999, p.7). The human subjects and computer simulations of creative thought are two different approaches which have been studied with cognitive theory. For the human subjects approach, Finke (1995) proposed what they called "Geneplore" model (see *Figure 1*). Under the Geneplore model, creativity through is broken down into two distinct phases: a generative phase and an exploratory phase (Retrieved 2010-01-15). In the generative phase, “preinventive structures” is mental representations of individual and its properties can promote creative discoveries. In the exploratory phase, there are some mental processes involved into the generation of those creative ideas that are generated by those properties. Those mental processes include the processes of “retrieval, association, synthesis, transformation, analogical transfer, and categorical reduction (i.e. mentally reducing objects or elements to more primitive categorical descriptions)” (Sternberg and Lubart 1999, p.7). In a practical test designed from this model, participators have been asked to imagine combining three parts, which are parts of objects such as a circle, a cube or a cylinder, to present a practical object such as a tool or a weapon. Then those composed objects will be scored by judge based on their practicality and originality (Sternberg and Lubart 1999, p.8).

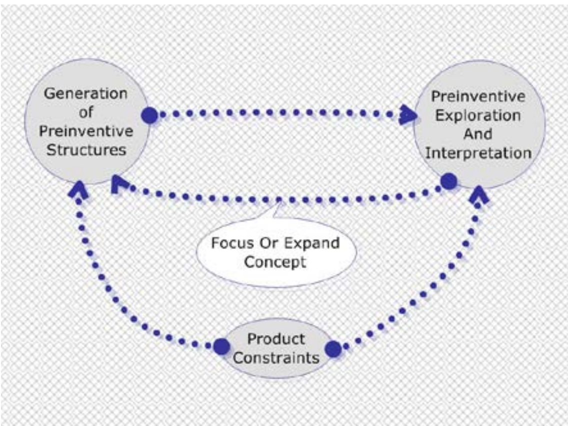


*Figure 1*

*(from http://www.redchurch.com/quantum/2006/10/24/the-geneplore-model)*

Through the study of eminent creators and laboratory research, Weisberg

(1993, as cited in Sternberg and Lubart 1999) believes that creativity "involves essentially ordinary cognitive processes yielding extraordinary products" (p.8). He aims to demonstrate that insights decided by participators who are used to using conventional cognitive processes applied to knowledge that are already stored in memory. For example, in the classic Duncker's candle box experiment, participators are given a candle, a box of thumbtacks and a book of matches. They were been asked to attach the candle to the wall and it can not drop onto the table. The result of the experiment shows that most participators try to attach the candle directly to the wall with thumbtacks or stick it to the wall by melting it. Only a few of participators were using the box as a candle holder to tacking it to the wall. The experiment shows a concept of functional fixedness that participators have the use of the familiar objects in an unfamiliar context (Retrieved 2010-09-10). .

Boden (1994) reports that the computer simulation approaches explored the creative thought by using a computer program to simulate people activities. Some scientists such as Langley, Simon, Bradshaw, and Zytkow have developed some computational models that depend on "heuristics-problem-solving guidelines – for searching a data set or conceptual space and finding hidden relationships between input variables" to rediscover basic scientific laws (Sternberg and Lubart 1999, p.8). The computing program BACON uses heuristics to search data for pattern, for example, it needs to consider the radio if "the value of two numerical terms increase together". And for the further programs, it involves the research heuristics, "the ability to transform data sets, and the ability to reason with qualitative data and scientific concepts" (Sternberg and Lubart 1999, p.8).

In addition, concerning an artistic domain, Johnson-Laird (1988) develops “a jazz improvisation program” to guide the novel deviations by harmonic constraints and random selections if it exits a few allowable directions of improvisation (Sternberg and Lubart 1999).

## 2.6 Social-personality Approaches

Social-personality approaches focus on “personality variables, motivational variable, and the sociocultural environment” that lead to creativity occur (Sternberg and Lubart 1999, p.9). Some researchers such as Ambile (1983), Barron (1968, 1969), Eysenck (1993), and Gough (1979) believe that people who have creative ability possess certain individual potentially relevant traits that have been identified through correlational studies and contrasting between high creativity and low creativity samples which are at both eminent and everyday levels (Barron and Harrington 1981). These traits include independence of judgment, self-confidence, and attraction to complexity, aesthetic orientation, and risk taking (Sternberg and Lubart 1999). According to Maslow (1968), those traits can also be boldness, courage, freedom, spontaneity, self-acceptance, and other traits lead a person to realize his or her full potential. Rogers (1954) describes the tendency toward self-actualization as having motivational force and being promoted by a supportive, evaluation-free environment. Some theorists such as Amabile (1983), Crutchfield (1962) have hypothesized the relevance of intrinsic motivation need for order (Barron 1963), need for achievement (McClelland, Atkinson, Clark, & Lowell 1953) and other motives. Researchers believe that creativity may not only need motivation, but also need to generate it. It has shown that when creative students are taught and their achievements are then assessed in a way that values their creative abilities, their academic performance improves.

The studies on the societal environment have been conducted by researchers such as Simonton (1994b) in order to identify the various environment elements may influence creativity. In Simonton's study, he links eminent creativity through different cultures over a long time period to environmental variables such as "cultural diversity", financial support, competitors in the domain (Sternberg and Lubart 1999, p.9). By comparing different cultures, it is apparent that different cultures have different expression of creativity. The creativity across the cultures will be discussed further in the next section.

However, Sternberg and Lubart (1999) concludes that the cognitive and social-personality approaches are "mutual repulsion" each other. For example, the cognitive approaches of creativity attempt to ignore or downplay the elements of personality and society while the social-personality approaches try to avoid the talk about "the mental representations and processes underlying creativity" (Sternberg and Lubart 1999, p.9).

## 2.7 Confluence Approaches

Confluence theory hypothesizes that to promote the occurrence of creativity, multiple components must converge (Csikszentmihalyi 1988). According to Sternberg (1985b) examines two concepts of the creative person: one is from normal people's implicit concept that contains a "combination of cognitive and personality elements such as "connects ideas", "sees similarities and difference", "has flexibility", "has aesthetic taste", "is unorthodox", "is motivated", "is inquisitive", and "questions societal norms" (Sternberg and Lubart 1999, p.10). Another is explicit theory from experts which some theorists gave different “system” approaches. For example, research by Ambile (1983, as cited in Sternberg & Lubart 1999) describes creativity as the “confluence of intrinsic motivation, domain-relevant knowledge and abilities, and creativity-relevant skills” (Sternberg and Lubart 1999, p.10). The skills strong connections with creativity suggest a cognitive style that “involves coping with complexities” that can break people’s mental set in a process of problem solving. The creativity related skills are also including knowledge of heuristics that could generate new ideas and a work style depicted by “concentrated effort, an ability to set aside problems, and high energy” (Sternberg and Lubart 1999, p.10).

For a better understanding of creativity, Gruber and Davis (1988) proposed a model called the developmental evolving-system model. According to the theory, the people’s purpose and knowledge can “amplify deviations that an individual encounters, and lead to creative products” (Sternberg and Lubart 1999, p.10). Charles Darwin’s evolutionism has been cited to demonstrate a developmental change in the knowledge system. The purpose refers to develop and guide an individual behaviour (Sternberg and Lubart 1999). Csikszentmihalyi (1996) proposes a different approach that focuses on the interaction among the individual, domain, and field. In this approach, an individual transforms or extends the information available in a domain through cognitive processes, personality traits, and motivation. The domain which is a “culturally defined symbol system” transmits creative products to other people and next generations. Some of people such as art critics control or influence a domain make up a field. And novel ideas or products are evaluated and selected from such people (Sternberg and Lubart 1999).

Sternberg and Lubart (1996) proposed a confluence theory named "investment theory of creativity". According to this theory, creative people are those who are prefer and able to "buy low and sell high" in the realm of ideas. Buying low means pursuing ideas that are unknown or out of favor but that have growth potential. When those ideas are first presented, they encounter resistance. The creative individual persists in the face of this resistance and eventually sells high, moving on to the next new or unpopular idea (Sternberg and Lubart 1999).

In addition, Sternberg & Lubart point out the environmental importance in the supporting and rewarding of creative ideas. They believe that one can have "all of the internal resources needed in order to think creatively", thus the results of creativity may not be known by the public if there is a lack of some environment support. For example, a forum is good place to proposing those ideas (Sternberg and Lubart 1999).

Confluence theories are believed that provide the possibility of accounting for some different aspects of creativity (Sternberg and Lubart 1999). Sternberg and Lubart explain that by an example of the analyses of scientific and artistic achievements, which suggest that "the median creativity of work in a domain tends to fall toward the lower end of the distribution and that the upper (high-creativity) tail extends quite far" (Sternberg and Lubart 1999, p.12).

## 2.8 Neurobiology Approaches

Creativity has been studied in not only conventional disciplines such as psychology, artistic, and cognitive science etc, but also in terms of brain functions such as research on the cerebral cortex. For example, Colin Martindale (1999) proposed a model that creativity thought arises from cortical arousal. Because creativity is thought to be the result of representing a form of cognition (Mumford and Gustafson 1988), therefore, the nature and origins of creative though have attracted researcher's interesting. For years, researchers have proposed a number of different models to approach how the brain function works to problem solving (Mumford and Caughron 2007).

Historically, ancient philosophers such as Aristotle, Pliny the Elder, Alberti and Leonardo explored art or artistic creativity by through something akin to neuroscientific studies (Onians 2007). Aristotle realized that "in our mental activity we often seem to be working with images of things we cannot see, as when we remember or think about something", and he asserted people can not think without "a mental image (phantasma)", because "those images exist independently of visual experience" (Onians 2007, p.22). Aristotle deduced that there were two ways to seeing: one is perceptive (aisthetikon) and the other is imagination (phantastikon). Other scientists such as Freud realized that the knowledge of the brain's structure is a key to the understanding of thinking or seeing (Onians 2007). Heilman, Nadeau and Beversdorf (2003) wrote that "creative innovation might require coactivation and communication between regions of the brain that ordinarily are not strongly connected." (Heilman, Nadeau et al. 2003). Flaherty (2005) presented a three-factor model of human idea generation and creative drive. Drawing from the evidence of the brain imaging, drug studies and lesion analysis, she described that creative drive focuses on "interactions between the temporal lobes, frontal lobes, and limbic system" (Flaherty 2005).

Highly creative people have three key elements which are different from others. They must have a high level of specialized knowledge, be capable of divergent thinking mediated by frontal lobe and be able to modulate neurotransmitters such as norepinephrine in their frontal lobe. Therefore, the frontal lobe appears to be the part of the cortex that is most important for creativity (Heilman, Nadeau et al. 2003). Flaherty (2005) also believes that the frontal lobes can be seen as responsible for idea generation, and the temporal lobes for idea editing and evaluation. If the frontal lobe has abnormalities such as depression or anxiety, it normally decrease creativity, however, it often increases creativity if abnormalities in the temporal lobe. She also believes that high activity in the temporal lobe normal inhibits activity in the frontal lobe, and vice versa. And high dopamine levels increase general arousal and goal directed behaviors and reduce latent inhibition, and all “three effects increase the drive to generate ideas” (Flaherty 2005).

The modern neuroscientist Semir Zeki is applying that knowledge of the brain’s structure and how its functions affect human’s behavior to the understanding of art. Zeki seeks to explain art creativity and how it leads to acquisition of knowledge by through the “infinite creative variability” that allows different artists to creative radically different styles “arises out of common neurobiological processes” (Zeki 1998).

### 2.9 Measuring Creativity

Measuring creativity is an important part for the understanding of creativity. What the things or qualities are that can be thought of as “Creativity” and how to measure those have been a major research questions in this field. There have been some approaches to find tools to measure creativity. The “Creativity Quotient” (CQ) has been developed to complement the Intelligence Quotient (IQ), However, these attempts have been unsuccessful. Kenneth M Heilman (2005) gave an example about the intelligence test which was Lewis Terman’s

(1954) IQ test. The test collected a group of children who scored very high on IQ tests, and when they grow up as adults, Terman found that most of them turned out to be very successful. However, few people of the group proved to be extremely creativity. Interestingly, one child who was identified as low IQ score won the Nobel Prize in physics when he grew up. The boy was William Shockley, who invented the transistor. Therefore, it is clear that people who have very high IQ scores do extremely well in school and be very successful in life, however, they are not very creative people. People who are extremely creative people may not have very high IQ scores (Heilman 2005).

The Guilford group developed some tests to measure creativity in 1967. The tests included “Plot Titles” test that asks participants to write original titles by through the given the plot of a story; “Quick Responses” is a test scored for uncommonness with word associated; “Figure Concepts” test that asks participants to find out qualities or features that are common by two or more drawings through the given simple drawings of objects or individuals and then; “Unusual Uses” test is finding unusual uses for common everyday objects such as bricks; “Remove Associations” test that asks participants to find a word between two given words; “Remove Consequences” test that asks participants to generate a list of consequences of unexpected events (Guilford 1967). The well known the Torrance Tests of Creative Thinking (TTCT), developed by Torrance, was based on Guildford’s tests. TTCT test scores at four criteria: Fluency, Flexibility, Originality and Elaboration that have been discussed in section of Psychometric Approaches.

The Creative Achievement Questionnaire (CAQ) is a new measurement of creative achievement based on self-report. The questionnaire focuses on “assess achievement across ten domains of creativity” that is designed for the “objective, empirically valid, and easy to administer and score” (Carson, Peterson et al. 2005). The CAQ is shown to be reliable and valid when compared to other measures of creativity and to independent evaluation of creative output.

However, most current measuring-oriented tests of creativity are too simple and a lack of considering or engaging with the difference of the disciplinary and subject. A test might facilitate to one subject but might not facilitate to another one. A key issue of the tests for measuring creativity is how to design a method or test to not only facilitate to the “old” definition of creativity but also facilitate to new understanding of creativity. Like the ongoing understanding of creativity, the methods of measuring creativity are also need be redesigned.

## 2.10 Creativity in the Different Cultures

This part will compare ideas around the concepts of creativity and the creative process in Western and Eastern cultures, and how the different cultures influence the creativity. The influence and impact of socio-cultural environment on creativity has become an important field of study. Creativity, as a scientific concept, is normally rooted within psychology, intelligence, neurobiology or medicine. However, creativity is also an aspect of human endeavor that is largely influenced by culture. The economic, social, political and cultural aspects of the environment can influence substantially on both creative potential and evaluations (Kharkhurin and Motalleebi 2008).

According to study from Triandis (1996, as cited by Sternberg and Lubart 1999), culture refers to “a shared system of cognitions, behaviors, customs, values, rules, and symbols concerning the manner” in which people can interact with social and physical environment and culture can be educated and transmitted to the future generation (p.339).

### 2.10.1 The Difference Concepts of Creativity

From the Western perspective, creativity can be defined as “the ability to produce work that is novel and appropriate” (Barron 1988). This novel work should be original, not predicted, and distinct from the previous work. Work that is appropriate, “satisfies the problem constraints, is useful, or fulfills a need” (Sternberg and Lubart 1999). In addition, creativity can occur “at all domains, including visual arts, literature, science, business, and everyday life” (Sternberg and Lubart 1999). Ambile (1983) proposes that the creativity of a product is, to large extent, a social judgment; assessed by group of judges, including peers or experts (Sternberg and Lubart 1999). In addition, the Torrance Tests of Creativity Thinking test demonstrates the product-oriented, originality-based definition of creativity (Sternberg and Lubart 1999).

Compared with the Western concept of creativity, the Eastern concept of creativity seems less interest on novel products. However, the Eastern concept of creativity emphasis on a state of personal achievement or the personal expression of an inner essence (Kuo 1996). In Hinduism, creativity is seen as spiritual or religious expression rather than as an innovative solution to a problem (Lubart 1999). In Hindu cosmology, time and history are seen as cyclical. As research from Paul O Kristeller (1983, as cited by Lubart 1999) indicates that in Eastern view, creativity is considered as involving the “reinterpretation of traditional ideas” – finding a new point of view – whereas in the Western approach, creativity involves “a break with tradition” (Lubart 1999, p.340).

.

### 2.10.2 The Difference of Creative Process

It is widely cited that Western description of the creative process includes four stages: “preparation, incubation, illumination, and verification” (Lubart 1999, p.341). In where preparation consists of preliminary analysis of a problem and initial conscious work on the task; Incubation follows and may involves active unconscious work on the problem, automatic spreading of activation in memory, associative play, or simple forgetting unimportant problem details and resting mentally. Illumination occurs if a promising idea suddenly becomes consciously available (Lubart 1999). However, Lubart believes that the most important feature of the Western process model is its “cognitive problem-solving orientation”, which fits well with a product-oriented definition of creativity (Lubart 1999).

For the Eastern culture the process of creativity will be different, for example, Lubart gives an example from Maduro’s (1976) study of traditional Indian painters. A four-stage model based on the Yoga Sutras was described as “preparation, achievement, insight, and verification”. Preparatory, as the first stage but the difference from the Western model, As stated by R. Maduro (1976, as cited in Lubart 1999) is “the artist attempts to contact by self-will and ceaseless effort the subjective region of his mind…The artist remove himself symbolically from the normal world by burning incense…to deities [and] … prays for inspiration from Vishvakarma [the patron of creativity]” (Lubart 1999, p.342). The second stage is “achievement of an internal identification” with the subject matter of the painting. As stated by R. Maduro (1976, as cited in Lubart 1999) “Only after becoming the deity in his feelings can the artist paint creatively…” (Lubart 1999, p.342). The third stage of the model, as similar to illumination, insight seems to be more “personal- than product- or subject-oriented”. The last stage is similar with Western verification with “social communication of personal realizations” (Lubart 1999, p.342).

### 2.10.3 The Influences of Culture on Creativity

Lubart (1999) analyses four ways that cultural influence might affect creativity: (a) People from different cultures may have different concepts of creativity; (b) people from different cultures may use different psychological processes when they engage in creative endeavors; (c) language may influence the development of creativity; and (d) environment can either promote or reduce people’s creativity. Creativity is a “very complex interaction” between a person, a field, and a culture. The ability of native creativity varies from person to person. However, other elements - like education, culture, and environment - could also affect people’s creativity. Culture is one of most important factors which could influence people’s creativity capability, behavior, and production. From Kim HK, East Asian cultures are based upon the principals of Confucianism (Kim 2009). Kim studied the relationship between East Asian culture Confucianism and creativity, by comparing Korean educators scores using a measure of Confucianism (Eastern-Western Perspective Scale) with their scores on a measure of creativity (Torrance Tests of Creativity Thinking-Figural). The results indicate that Confucianism is negatively related to creativity. Specially, some elements of Confucianism, "Unconditional Obedience, Gender Inequality, Gender Role Expectations, and Suppression of Expression", may present "cultural blocks to creativity." (Kim 2009). Many similar studies have found that people from East Asian societies tend to be less creative than people from the more individualistic Western societies. Thus, "something in East Asian culture may present blocks to creativity" (Kim 2009).

In summary, and as Lubart (1999) points out that the Western understanding of creativity can be defined as "a product-oriented, originality-based phenomenon" that can be compared with an Eastern concept of creativity as "a phenomenon of expressing an inner truth in a new way or of self-growth" (p.347).

**2.11 Genius and Creativity**

Creativity sometimes aligns closely with genius. When a person who is very creative, and well recognized for his or her creativity, the person can be called a genius (Heilman 2005). However, genius itself has many different definitions. Samuel Johnson defines the genius as "a mind of large general powers" (Heilman 2005). Webster's defines genius as "someone who has exceptional intellectual ability and originality" (http://www.websters-online-dictionary.org).

Scientists have designed many tests for measuring of genius and creativity, such as IQ tests or other intelligence tests. If the person has more than 130 or 140 scores on IQ test, they can be called genius. The Wechsler Adult Intelligence Scale assesses domains such as language, visual-spatial skills and working memory. There are examples of high-functioning autistic people ("savants") who have much better working memories than do normal people, but have low IQs because they perform poorly on other parts of this test. To be creative, a person has to have skills and knowledge in the domain in which the person is creative, but in other domains the person skills may be average or below average. However, Heilman (2004) argues that people with those special skills or talents might not use such skills to their creative activity. Therefore, those intelligence tests might not be enough to judge human creative ability. Creativity might be affected by many factors such as environment, education, endurance, culture etc. But a chance for them to display their creative product is also very important for a successful creativity. It would appear that creativity is synthesizing outcome engage with many different activities, those activities mainly involve mental struggles.

**2.12 Creativity and Intelligence**

The discussion of the relationship between creativity and intelligence bring up two different viewpoints. The debate has been focused on whether intelligence and creativity are part of the same process (the conjoint hypothesis) or represent distinct mental processes (the disjoint hypothesis) (Retrieved 2009-10-10). Some scientists believe that creativity is the outcome of the same cognitive processes as intelligence, and it is only judged as creativity in terms of its consequences (Sternberg and Lubart 1999).

However, Torrance proposed a popular model "the threshold hypothesis". The model holds that a high degree of intelligence appears to be a necessary but not sufficient condition for high creativity (Guilford 1967). The model shows a "positive correlation" between creativity and intelligence. This correlation will be found if not only a sample of the most highly intelligent people is assessed

(Retrieved 2009-10-10). However, the result of the research on the threshold hypothesis "produced mixed ranged from enthusiastic support to refutation and rejection" (Retrieved 2009-10-10).

### 2.13 "The Dark Side" of Creativity

Although the benefits of creativity to the society have been noted, there is clearly a dark side to creativity. McLaren (1999) believes that the problem of creativity "lies not alone in the fields of endeavor where it is enlisted (art, science, technology etc), but within the creative impulse itself, its narcissistic temptations, and our ways of responding to its urging." (McLaren 1999). It recognizes that creativity has its dark side hiding deeply inside human nature. To explain the dark side of creativity, McLaren gives some examples: such as the bloody spectacles of the Coliseum of Rome, or the artistic innovation that was exercised by the ancient Assyrians to decorate their homes with the peeled and painted skins of their fallen enemies (McLaren 1999). Although art has been employed to celebrate faith, beauty, nobility and love, the Nazis used "artistic creativity" to fashion lampshades of the skins of holocaust victims. McLaren also notes that creativity also encompasses a wide array of practice; from inspiring oratorios to sheer pornography, the "hideously clever" torture devices of the Spanish Inquisition, the sweatshops and mines of the industrial Revolution, and the gas furnaces of Auschwitz and the invention of the nuclear technology threatens the global security if the technology is been abused (McLaren 1999). For McLaren, the moral crises of the dark side of creativity arise within from humankind itself; "as pride and conceit underlay their misuse of the gift of creativity, and this ultimately led to humankind's mutual estrangement" (McLaren 1999).

## Chapter Three: Scientific Studies on Brain and Creativity

Recent studies on the brain and creativity have been largely focused on studies of working memory and the cerebellum, and the function of the brain on art creativity. In this chapter, I will examine two important theoretical approaches to the function of brain and creativity: Working Memory and the Cerebellum, and Neuroesthetics. The theories on Working Memory and the Cerebellum seek to the nature of general creativity derived from the studies of the brain. Working Memory and the Cerebellum is mainly concerned with the objectives or general purpose of creativity, while emerging Neuroesthetics theories are more focused on how the study of the visual brain explains the artistic creativity.

### 3.1 Working Memory and the Cerebellum

Different with memory, working memory is a place where thinking, problem solving, daydream, expert and exceptional performance occur. According to Vandervert et al. (2007), working memory consists a “collection of cognitive functions” that is engaged people’s thinking and “both simple and complex everyday cognitive tasks” (Vandervert, Schimpf et al. 2007). For example, when reading a story in the newspaper, image the rearranging the furniture in a living room, or give directions to shops, working memory is been used for those tasks (Miyake and Shah 1999). In Miyake and Shah’s book “*Models of working memory: Mechanisms of active maintenance and executive control*”, Cowan (1999) provides a definition of working memory as following:

> *Working memory is those mechanisms or processes that are*

> *involved in the control, regulation, and active maintenance of Working memory refers to cognitive processes that retain information in an unusually accessible state, suitable for carrying out any task with a mental component. The task may be language comprehension or production, problem solving, decision making, or other thought (p. 62).*

Miyake and Shah (1999) believe that to understand the cognitive processes of working memory, it has to retain information from memory stores (short-term memory and long-term memory) within a mentally apprehensibility during the process of thought (Miyake and Shah 1999). Accomplishing this maintenance task, the working memory components includes a "central executive function and two slave functions: a visuospatial sketchpad and a speed loop" (Vandervert, Schimpf et al. 2007). Vandervert (2007) explains how the working memory is operated by giving an example of reading newspapers. He believes that the "working memory's central executive functions" operates the "attentional control" in actions such as reading and thinking newspaper articles. The attentional functions of the central executive "supervise, schedule and integrate information from different sources" (Vandervert, Schimpf et al. 2007). The two functions of working memory: visuospatial sketchpad and the speed loop are "manipulation and rehearsal processes". The processes retain related visuospatial images and speech information that are needed for "the on-line comprehension, decision making, and thinking" about the contents of the newspaper articles (Vandervert, Schimpf et al. 2007). To complete those mental tasks, the central executive applies the visuospatial sketchpad and the speech loop in "a continual process of *repetitive manipulation, rehearsal and* *updating*” (Vandervert, Schimpf et al. 2007). The studies on Neuroimaging have confirmed those working memory processes can be associated with various areas of both the cerebral cortex and the cerebellum (Chein, Ravizza et al. 2003). Therefore, Vandervert et al (2007) argue that working memory must be collaborated with the cerebellum as long as working memory executed (Vandervert, Schimpf et al. 2007).

Vandervert (2007) proposes that the brain’s frontal lobes and cognitive functions of the cerebellum “collaborate” to generate creativity and innovation (Vandervert, Schimpf et al. 2007). *Figure 2* shows that lateral view of the human brain (right side). As the cerebellum contains about 100 billion neurons which more than the rest of the entire nervous system, all processes of working memory (responsible for processing all thought) are “adaptively modeled by the cerebellum” (Schmahmann 2004).

Vandervert believes that creativity and innovation are “the result of continuously repetitive processes of working memory that are learned as cognitive control models in the cerebellum”. Within the MOdular Selection and Identification for Control (MOSAIC) and hierarchical MOSAIC (HMOSAIC) cerebellar architectures, those cerebellar control models are made up by multiple-paired predictor models. To explore and test the problem-solving requirements, forward predictor models need to feed forward to more efficiently control the operations of working memory that lead to creative and innovative problem-solving occur which include “the experience of insight and intuition” (Vandervert, Schimpf et al. 2007).

According to the research by Vandervert et al. (2007), the details of creative adaptation begin in ‘’forward’’ cerebellar models which are anticipatory/exploratory controls for movement and thought. These cerebellar processing and control architectures have been termed Hierarchical Modular Selection and Identification for Control (HMOSAIC). Since the “cerebellum adaptively models all movement and all levels of thought and emotion”, research from Vandervert et al (2007) could explain creativity and innovation in many fields such as art, music, sport, business, design of computer game, mathematics and thought in general (Vandervert, Schimpf et al. 2007).

The research by Vandervert et al. (2007) is attempted to propose a new theoretical model of creativity and innovation through the substantial research from the neurophysiology of working memory and the cognitive functions of the cerebellum (Vandervert, Schimpf et al. 2007). In addition, they applied those theories to an analysis of autobiographical accounting for creativity and innovation. The value of an analysis of autobiographical accounts of working memory is map the “certain categories of the phenomenal imagery of creativity and innovation” to the particular components of working memory. A theoretical model can be provided by the modularity inside of the cerebellum that can suggest where the activity of creativity and innovation might occur in the brain. The research could benefit to design future experiments purposed at “locating creativity and innovation, in vivo, in specific complexes of cerebro-cerebellar circuitry” (Vandervert, Schimpf et al. 2007).

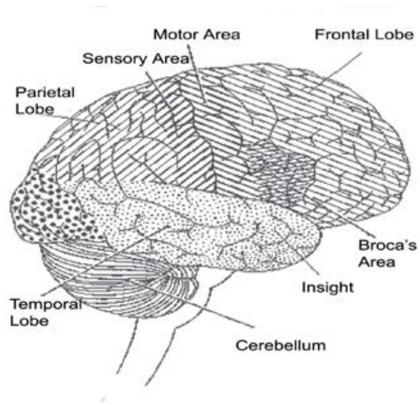


*Figure 2*

**3.2 Critiques on the Working Memory and the Cerebellum**

However, there are some researchers who are not in agreement with Vandervert et al.'s postulate. Miller (2007) argues that Vandervert et al.'s model lacks on application although the model has value on "the theoretical side of cognitive scientific models of the mind" (Miller 2007). In the example of Einstein's autobiographical accounts of creative discovery, Miller (2007) believes that Vandervert et al.'s theory notes visual imagery in Einstein's creative thinking, but not mention *thought experiments* and new concepts of *symmetry*. Because all of the three were driven by Einstein's realization that the key problems were based on clashes with physics as it was understood at that time. In addition, Miller also argues that Vandervert et al.'s model is unclear and broad in scope that "it pertains to all visual thinking and problem solving" (Miller 2007). Miller disagrees that the model can actually be programmed to solve "real" problem and that the methodology lacks collaboration with historians and some knowledge of what happened in the physics of 1950s.

In addition, Miller (2007) put forward his model of creative thinking which he called as "*network thinking*". He believes that the *network thinking* is closer to what helped Einstein's discovery of relativity in 1905 that "was that the *thought experiments* concerning the process called *electromagnetic induction* was the 'illumination' - the result of unconscious thought – which surfaced into his conscious thought" (Miller 2007). Therefore, in Miller's opinion, Vandervert et al.'s model not only has problems on application but also that his own "*network thinking*" bears a closer relation to the way scientists actually work than the one proposed by Vandervert et al. (Miller 2007).

Mumford and Caughron (2007) also critique Vandervert et al.'s model of the neurological mechanisms, which give rise to creative thought. Mumford & Caughron question the role of visual images and basic cognitive images of Vandervert et al.'s model. They believe that Vandervert et al.'s model of creative thought focuses only on the visual aspect of creative thought, but not across all domains, such as linguistic concept on creative thoughts. They also disagree that the basis of creative thought lies in the "formation of new attributes, or logical connections, to account for multiple images generated by prediction, or forecasting, models" (Mumford and Caughron 2007). Because they believe that creative thought relies on not only on "the production of new declarative knowledge" but also demands "strategies, or heuristics, for working with information" (Scott, Lonergan et al. 2005). Unfortunately, the role of the cerebellum in identifying and applying these strategies is not discussed in the model proposed by Vandervert et al. (Mumford and Caughron 2007). Mumford & Caughron believe that the model proposed by Vandervert et al. is not entirely or necessarily offers a fully adequate description of creative thought.

### 3.3 Directions of Future Research

Vandervert et al.'s model suggests a potential direction of future research which is the requirement of neuroimaging studies that offer "data monitoring cerebellum activity in the course of creative thought – studies" that will, it is hoped, that "examine a range of tasks both visual and verbal" (Mumford and Caughron 2007). It also suggests four other phenomena: errors, forecasting, action orientation and mental models (Mumford and Caughron 2007). In the model of creative thought proposed by Vandervert et al., "errors" refer to "undesirable attributes of ideas" with those errors "evaluations leading to acceptance or rejection of ideas emerging from the activation of multiple predictive models" (Mumford and Caughron 2007). However, Mumford & Caughron (2007) argue that it is still not clear what kind of errors will lead people to reject new ideas. Moreover, the difference of individuals in their sensitivity may play a critical role in accounting for individual differences in creative achievement. Therefore, they believe that research on examining people's sensibility for errors in certain aspects of new ideas could have "substantial value" with regard to enhancing the understanding of creative thought.

For the creative thought, it is very important to require the "generation of predictions about the future status of the world and possible impact on ideas and actions based on the ideas" (Mumford and Caughron 2007). Mumford & Caughron (2007) believe that it is little "*attention*" of the way for creative people generate and integrate "*forecasts*" in the literature with experience (Mumford and Caughron 2007). Therefore, they suggest that forecasting needs more attention in studies of creative thought, in particular studies "indicating the nature and structure of forecasts derived from the forward models that appear to contribute to creative thought" (Mumford and Caughron 2007). In additional, for general understanding of creative thought, it is valuable to studies examining how these forecasts are revised and reorganized with feedback. Mumford & Caughron also give suggestions on action-oriental and mental models. They believe that testing of number implications is useful in enhancing the understanding of creative thought. These testing include the direct effects on creative thought by perceptions of the feasibility and/or exercise influence; manipulable aspects of the environment may directed on creative thought; creativity with high levels may be associated with "the identification of concepts, or techniques, that increase the feasibility of action within a given domain" (Mumford and Caughron 2007). Finally, Mumford & Caughron believe that it is possible that "certain unique characteristics of the mental models" bring to problems may serve to "stimulate creative thought" (Mumford and Caughron 2007).

In addition, Brandoni and Anderson (2009) propose a new neurocognitive model for assessing *divergent thinking* (or known as divergent production). The model includes a two-dimensional matrix which based on neuroscience literature that could be helpful in research and practical applications in education field. The model underlying this is two dimensional: neurocognitive theory and cognitive theory. Neurocognitive theory examines the relationship between the structure and function of the brain and in more recently, the neurocognitive theory has extended to examination of normal human cognitive (Brandoni and Anderson 2009). In neurocognitive field, there is a constructivist theory which relates to how humans learn meaning material and provides "a neurocognitive basis for constructivism" in education field (Brandoni and Anderson 2009). The brain generates multiple representations of sensation, entailing divergent production, as the experience of construction and reconstruction. Therefore, constructivist theory provides a useful conceptual framework for building a neurocogntive model of divergent thought (Brandoni and Anderson 2009). However, Brandoni and Anderson argue that many evidence indicate that structure-function based theories are not “insufficient to explain the role of active learners as posited in modern theories” (Brandoni and Anderson 2009). The new model is based on the integration of diverse functional areas which is a key theoretical premise. The second dimension of the model that the first level encompassed directly observed and concrete responses focuses on how information was processed largely from a cognitive perspective. The first level of the cognitive dimension emphasizes recognizing and discovering. However, higher levels involve more abstract representations which are “integrating direct observations with semantic and episodic memory” (Brandoni and Anderson 2009). The fourth level is use the independently generated data to arrive at a new perspective on a problem or given topic. The results of the new model suggest that the model categories may capture aspects of divergent thought production that makes individuals different with a novel method, which is different with traditional ways (Brandoni and Anderson 2009).However, the matrix model still has not fully categorized one person’s complex thinking. Brandoni & Anderson imply that the results can be a “stepping stone for future research” in more fundamental scientific based teaching and learning (Brandoni and Anderson 2009).

### 3.4 Neuroesthetics

Neuroscience-based research on creativity is a relatively new study field. It is believed that the ideas of creativity might be the result of brain mechanisms. Scientists are interested in the nature and the origins of the creative thought. As one of the important areas in neuroscience-based research into artistic creativity, Nueroesthetics sheds light on why art has been so prevalent and valued over the course of human history and raises questions concerning the nature and future of art (Drichard 2009). For this thesis, it is also important to note that it uses neuroimaging technology to develop a scientific understanding on how the brain encounters and creates art.

The main studies on Neuroesthetics concern Zeki's theories about how to make an explanation on artistic creativity by a study on the function of the brain, e.g. from a scientific research view point to explain art. Those studies could help people to understand the reasons such as why people have large potential abilities on creativity. For example, Zeki (2001) believes that artists "unconsciously use techniques to create visual art to study the brain" (Zeki 1999). Zeki's theories attempt to explain the basic human perceptive on the art creativity.

One of the most intriguing conclusions from Zeki's theories is his proposition that "…the artist is in a sense, a neuroscientist, exploring the potentials and capacities of the brain, though with different tools. How such creations can arouse aesthetic experiences can only be fully understood in neural terms…" (Zeki 1999). The explanation is that artists and neurologists have both studied the perceptual commonality that underlies visual aesthetics. He gives an example of Mondrian to support his conclusion (*see Figure 3*). There are cells in the brain that respond selectively to straight lines and are widely thought to be the neural "building blocks" of form perception. The cells are called "orientation-selective cells". However, before the discovery of those cells, Mondrian has settled on the straight lines as the main feature of the composition of his "cold" abstract paintings. Therefore, Zeki(2001) suggests that those compositions "were thus admirably suited for simulating the cells in V5 and anticipated artistically the physiological properties of motion-selective cells" (Zeki 2001).

For Zeki, visual art obeys the laws of the visual brain. He proposed two supreme laws of the visual brain: constancy and abstraction. The constancy means that "the function of the visual brain is to seek knowledge of the constant and essential properties of objects and surfaces", because the information - such as distance, the view point, illumination conditions - is changing all the time (Zeki 1998). What the brain does is to remove those changes and reclassify phenomena as an object. Therefore, when perceive a visual stimuli, the brain has a special capacity to hold the knowledge of constant and basic properties of an object and remove irrelevant dynamic properties. An art work, for example, could also be considered to captures the essence of an object. Therefore, Zeki (2001) asserts that "Monet could paint landscape without knowing anything about the objects for capture their essential form". And that the primordial function of the visual brain is "the acquisition of knowledge and ….also the primordial function of art" (Zeki 2001).

From the Zeki's theory, we learn that an abstraction law refers to that process in which "the particular is subordinated to the general, so that what is represented is applicable to many particulars" (Zeki 2001). Abstraction is a critical step in the efficient acquisition of knowledge. The artist forms abstractions in a process similar to the brain's one; in which cells in the brain are able to recognize objects in a view-invariant manner after brief exposure to several distinct views, which they obviously synthesize (Zeki 2001). Zeki points out that as a key feature of an efficient knowledge-acquiring system, abstraction may be a refuge for art and the abstract “ideal” synthesized by the brain from many particulars can “lead to a deep dissatisfaction” (Zeki 2001).

In addition, Zeki (2001) gives an example of Michelangelo in order to express his Neuroesthetics- based explanation to the master’s art works (*see Figure 4*). As artist Michelangelo has left many of his sculptures unfinished, according to institutional critics, spectators can finish Michelangelo’s unfinished works and satisfy the ideals of their brain and that unfinished works can be interpreted in different ways. However, Zeki (2001) argues that because Michelangelo realized that was hopeless to translate the synthetics ideas formed in his brain into a single work or a series of sculptures (Zeki 2001).

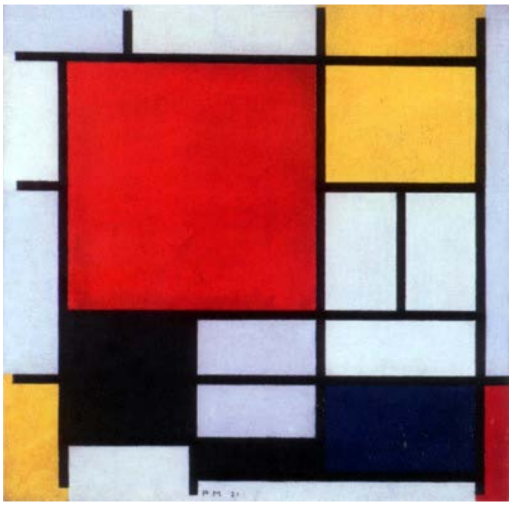

*Figure 3 Composition with red, yellow blue and black, Piet Mondrian*

*Figure 4 The Rondanini Pieta, Michelangelo Buonarroti*

According to the discussion above, Zeki (2001) concludes that art has been a creative refuge for other unsatisfied ideals created by the brain through its abstractive process, thus hastening our cultural evolution. All human activities are ultimately the product of the organization of our brain, and subject to their laws. The function of art is an extension of the function of brain because both the functions of art and brain are the acquisition of knowledge about the world. The characteristic of an efficient knowledge acquisition system "… is its capacity to abstract, to emphasize the general at the expense of the particular" (Zeki 1998). Then he affirms "this remarkable capacity is reflected in art, for all art is abstraction" (Zeki 1998). Zike (1998) concludes that the consequence of the abstractive process is "the creation of concepts and ideals. The translation of these brain-formed ideals onto canvas constitutes art" (Zeki 1998).

Zeki (2001) proposes that the infinite creative variability allows different artists to create radically different styles. According to Charles Darwin's *The Origin of Species*, the variability is greatest in structures that evolve fastest. Zeki claims that the art is one expression of this variability. The variability is regarded as "a key factor in the further evolution of human societies" (Zeki 2001). Although the variability is often "cause of serious injustice and marginalizes from society those whose conduct or inclinations are judged to be deviant from the norm", it benefits art and contribute to cultural evolution (Zeki 2001).

An important theory on human artistic experience and the neural mechanisms is Vilayanur Ramachandran's *Eight Laws of Artistic Experience*. The Laws are the "set of heuristics that artists either consciously or unconsciously utilize to optimally stimulate the visual areas of the brain" (Retrieved 2010-05-27). The Eight Laws include Peak Shift Principle, Isolation, Grouping, Contrast，Perceptual Problem Solving, The Generic Viewpoint, Visual Metaphors, and Symmetry. The first Law, Peak Shift Principle, explains a wide variety of art from abstract expressionist painting to ancient religious sculptures. The artistic process is defined by a "deliberate" hyperbole that can be found in all those creations (Lehrer 2009). Isolation Law attempts to answer a question of "why an outline drawing has more aesthetically pleasing than a color photography", that because before the appearance is amplified, the desired visual from is required to isolated. Grouping is perceptual to delineate a figure from the background and the source of pleasure might come as the evolutionary necessity that "gives organisms an incentive to uncover objects" (Retrieved 2010-05-27). Contrast Law involves "eliminating redundant information and focusing attention". Perceptual problem solving Law refers to the discovery of an object after a struggle. The discovery is more desire than an obvious one. The mechanism of Law assures that “the struggle is reinforcing so that the viewer continues to look until the discovery” (Retrieved 2010-05-27). The Generic Viewpoint Law refers to “the visual system” that accepts the visual interpretation for “an infinite set of viewpoints that could produce the class of retinal images” but not rely on a certain vantage point (Retrieved 2010-05-27). Ramachandran (1999) defines “a metaphor as a mental tunnel between two concepts that appear grossly dissimilar on the surface, but instead share a deeper connection” (Ramachandran and Hirstein 1999). According to Ramachandran (1999), the “aesthetic appeal of *symmetry”* is important during the detection of a predator, location of prey to display symmetry in nature (Ramachandran and Hirstein 1999).

**3.5 Criticism on Neuroesthetics**

There are some different opinions to disagree with the researchers who attempt to reduce aesthetic experience to a set of physical or neurological laws. It might be questionable whether such theories can “capture the evocativeness or originality of individual works of art” (Ramachandran and Hirstein 1999).

Bardin (2007) disagrees with above theories and he emphasizes the context-specific reaction effect by “understand art by understanding brain” or vice versa. He argues that the whole process of “explaining art” with neuroscience “fundamentally attempts to fit a square peg-the objective understanding of neuronal relationships –into a round hole – the subjective world of art appreciation” (Bardin 2007). Regarding Zeki’s theory on “abstraction and concept formation”, Bardin argues “… that is the greatest weakness in neuroesthetics' current form, and that perceptually unambiguous art forms such as photorealism can be equally successful as artistic paradigms partaking in the process of concept formation that Zeki describes" (Bardin 2007). And then he gives an example, Italian artist Maurizio Cattelan's *La Nona Ora (The Ninth Hour)*, to explain his viewpoint on cognition conflict as the brain's visual processing areas easily identify both the pope - especially given the singular "pope staff"… and the meteor (Bardin 2007).

Lehrer (2009) wrote "Unlocking the Mysteries of the Artistic Mind", an article about mysteries of the artistic mind on Psychology Today (Lehrer 2009). He used a "peak-shift effect" to explain the distortion on the art work, like Picasso's cubism. He wrote that "the fusiform gyrus, an area of the brain involved in facial recognition, responds more eagerly to caricatures than real faces … the abstractions are like a peak-shift effect , turning the work of art or the political cartoon into a 'super-stimulus'" (Lehrer 2009).

Ramachandran (1999) argues that "the peak-shift effect explains a wide variety of art from abstract expressionist painting to ancient religious sculptures such as a 12$^{th}$ century Indian sculpture of the goddess Parvathi with exaggerated feminine features. There creations are all examples of the 'deliberate' hyperbole that defines the artistic process" (Lehrer 2009). Experiments performed may not account for these theories directly. Also, current experimentation measures a person's verbal response to how they feel about art which is often selectively filtered. Ramachandran (1999) suggests the use of galvanic skin response to quantify the judgment associated with viewing aesthetics. Overall, it can be argued that there is a lack of proportion between the narrow approach to art taken by researchers versus the grand claims they make for their theories (Freeman 1999).

### 3.6 Other Approaches on Brain and Creativity

As well as studying in the function of brain, scientists are also very interested in the phenomenon or results generated from the function of the brain such as memory, sleep or dream. The research shows that the REM sleep (dreaming sleep) might enhance on the creative solving problem. According to research by Wagner et al. (2004), creativity involves “the forming of associative elements into new combinations that are useful or meet some requirement” and “sleep aids this process” (Retrieved 2009-10-10). Cai et al (2009) suggests that during REM sleep, the changes in cholinergic and noradrenergic neuromodulation can occur. According to research by Hasselmo (1999), during the REM sleep, “higher levels of acetylcholine in the hippocampus suppress feedback from the hippocampus to the neocortex, and lower levels of acetylcholine and norepinephrine in the neocortex encourage the spread of associational activity within neocortical areas without control from the hippocampus”, because the “higher levels of norepinephrine and acetylcholine inhibit recurrent connections in the neocortex” (Cai, Mednick et al. 2009). Cai et al. (2009) proposes that REM sleep would add creativity by allowing "neocortical structures to reorganize associative hierarchies, in which information from the hippocampus would be reinterpreted in relation to previous semantic representations or nodes." (Cai, Mednick et al. 2009).

# Chapter Four: Artistic Based Studies on Creativity and Technology

What we might understand as “modern technology” has been applied to the creation of art works at least since the Industrial Revolution. From the late nineteenth century into the early twenty century, the modern art movement had pushed the traditional art to its end through probing of the whole concept of what constitutes “art” through an engagement with new technology and new medium. Art was also addressing and encountering developments in modern scientific and the related changing of the society. Since then, the concept and understanding of art had been continually reinterpreted and has produced many art movements. A key change in understanding art creativity was in bringing the new technologies into artist’s process of creation. Artist such as Eadweard Muybridge used photographic techniques to capture the actual sequence of movement on his animal locomotion (*see Figure 5*). In the postmodern period, art creativity largely involves how artists use new computing technologies - including computing software and hardware system, internet, video, photography, and multimedia technologies – in the creation of art works. For example, art based in notions of “interaction” allows the spectator “participate” in a “communication” between art works and spectator themselves. That is “a process that becomes possible only through the new technological devices that create a situation in which questions by the user/spectator are effectively answered by the art work itself” (Popper 1993, p.8). In such art works, technique plays a key role in the process of art creativity. That focuses on various different scientific and computing techniques and analysis the relationship between the technology and aesthetics under different technologies. Such “technological art”, particularly in forms like in Kinetic and Lumino-kinetic art, have been “the most important sources … related to the new interpretation and use of light and motion …” (Popper 1993, p.12).

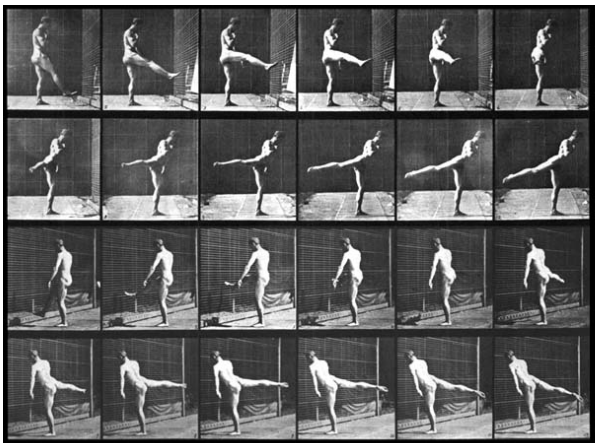

*Figure 5 Animal Locomotion Plate 99*

*(from http://www.acmi.net.au/AIC/MUYBRIDGE_BIO.html)*

According to the research by Popper (1993), “technological art” has about five categories: Laser and Holographic Art, Video Art, Computer Art, Communication Art and Installation, demonstration and performance Art. In this study, the focuses will be on the discussion on computer art. How such artists carry on the art creativity by engaging with computing techniques may determine the future direction of art development. Because the computing techniques have spread to every corner of the society and effect people’s life and culture, especially in the last decade, the computing techniques such as internet has become an inseparable part of both individuals and societies experience of art. The revolutionary changes of the computing age have also changed the modes of artistic creativity. As those computing techniques are applied to other art fields such as laser, video, film and installation art, computing-based creativity has become a critical important artistic movement. While they rely heavily on the both computer software and hardware and the visual effects themselves, depend on the various techniques of computing, the artists also use new techniques to link artistic creativity with cultural discourse.

Such art works can be an image, sound, animation, video, CD-ROM, DVD-ROM, videogame, web site, algorithm, performance or gallery installation. Many traditional disciplines are now integrating digital technologies and, as a result, the lines between traditional works of art and new media works created using computers has been blurred. For instance, an artist may combine traditional painting with algorithm art and other digital techniques and then either display the images by a computer monitor or just print out on paper or canvas. A computer can be a tool for the artistic creativity. Some artists might believe that computer is a means of fabrication. Other artists might believe that computer "possesses capabilities analogous to human intellectual processes and may even be considered as a creative entity in its own right" (Popper 1993, p.78).

The first computer art was established in about 1950 with Ben Laposky's oscilloscope images with a supporting thesis entitled "Oscillons: Electronic Abstractions" (*see Figure 6, 7*). He generated the images with analogue electronics and then recorded onto high speed file. From Laposky's works, we find that the computer-based art has now come to be popularly identified as a "digital art" (Popper 1993). As one of the earliest pioneers, Michael Noll used the computer technology to create patterns and animations as artistic creativity. In 1962, Noll created his first computer art at Bell Labs. As the simple, unmatured computing technology at the early of computing age, those art works created by computer present very simple shape or form with no color. However, they still present a new exploration of art creativity to the public.

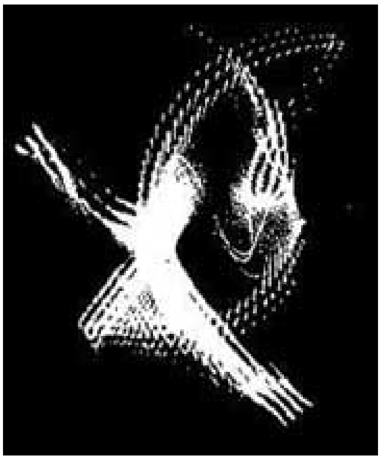

*Figure 6 (from Noll's website)*

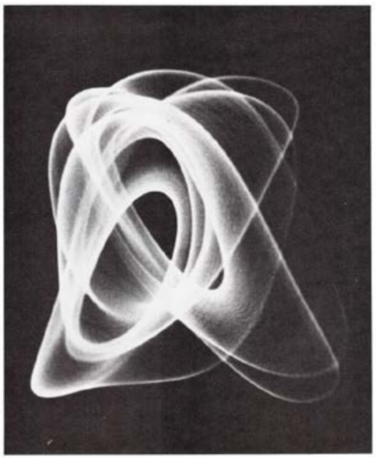

*Figure 7 (from Noll's website)*

The work "Computer Composition with Lines" was created in 1964 (*see Figure 8*). "The work closely mimics the painting 'Composition with Lines' by Piet Mondrian. When reproductions of both works were shown to 100 people, the majority preferred the computer version and believed it was done by Mondrian. This early investigation of the aesthetics of computer art has become a classic and is described in the published paper by A. Michael Noll, 'Human or Machine: A Subjective Comparison of Piet Mondrian's 'Composition with Lines' and a Computer–Generated Picture'" (Noll 1964). In the early 1960s, Noll created a work named "Ninety Parallel Sinusoids With Linearly Increasing Period" (*see Figure 9*). In the work, the top sinusoid was expressed mathematically and then repeated again and again. The result closely approximates the op-art painting 'Current' by Bridget Riley (Noll Retrieved 2010-02-16).

*Figure 8 (from Noll's website)*

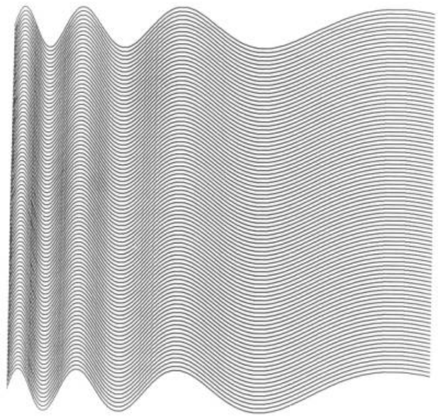

*Figure 9 (from Noll's website)*

It is clear that the most of early computer generated art works kind of mimic human's traditional paintings, especially in abstract style paintings. The mimic presents a simple geometry shape objects or lines or embodies abstract aesthetics that represented traditional paintings in a way of engaging techniques and machines. Such computer art in the early time actually is in many ways similar to, a scientific experiment, examining how a new computing technology might be applied to creativity, or create a new digital aesthetics.

In general, there are about three main categories of the computer art creativity engaging with computer techniques. One is the notion of "computer as tool", one is "computer as creator" and the third might be defined as any other areas of art creativity using computer techniques but not included in first or second categories.

### 4.1 Computer as A Tool for Art Creativity

Artists use computer software and hardware system as a design tool to generate complex images which normally is difficultly draw by hands or impossible to achieve by hands. For example, Photoshop, Illustrator, and Painter are common software used by artists to manipulate with images. Artists use those computer programming applications to create realistic or abstract images that may normally be hard to draw by human hands with traditional methods and tools. For example, artist David Em and Charles Csuri are artists who use computer as a design tool to generate art works. As early as 1980's, Em created a group of digital landscapes inspired by methods of topographical illustration (Popper 1993). He was one of the first artists to "make art with pixels" (Perry and Wallich 1985). In 1975, Em used a computer system called "SuperPaint" to create digital paintings (*see Figure 10*). And his "cosmic fantasies epitomize the aesthetics and subject matter of computer-generated imagery" (Popper 1993, p.80). Although Em used new computing techniques to implement his works, he still believed in art works in a traditional sense.

*Figure 10 (from David Em's website)*

Artist Charles Csuri uses computer as an assist tool to his art creativity.

According to his statement, his interest is in “mixing the qualities of drawing and painting”, and by playing with light on the lines, the things created “looks like eyes and nose from Nefertiti’s headdress” (Csuri Retrieved 2010-07-09). The artist sought a way to “soften the harsh surface qualities of the solid representation” … As an animation, it looks like used some atmosphere and “watching those forms move through space is intriguing” (Csuri Retrieved 2010-07-09) (*see Figure 11*).

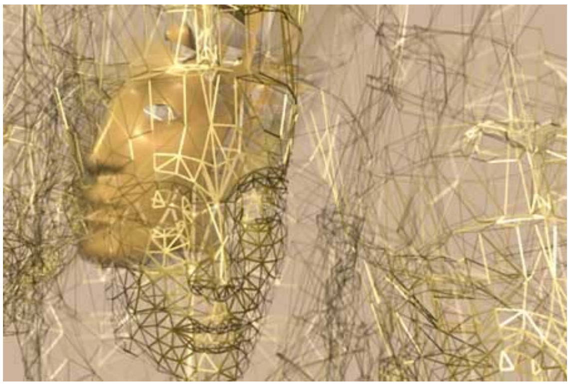

*Figure 11 Lines in space (from Charles Csuri’s website)*

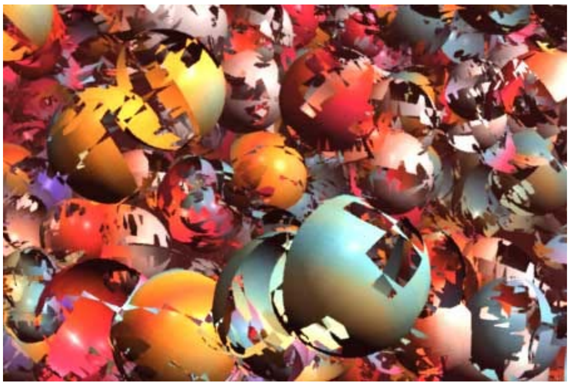

*Figure 12 Instancing (from Charles Csuri’s website)*

The work instancing “places objects onto the vertices of invisible objects. The shape and scale of the invisible objects determine the positions of the instanced objects” (Csuri Retrieved 2010-07-09). This painting is part of an animation that all the objects are moving slows in a 60 inch TV display (*see Figure 12*). Both David Em and Charles Csuri are using the computer programming as tool to assist them on art creativity. Their creative ideas might be same as traditional but use some new technology or medium. However, the common points from both of their art creativity are impossible present the art works by through a traditional technology. For example, a traditional hand based painting can not present a 3D animation, or even a “perfect” shape, line, color and circle. In addition, both artists are using existing computer software application such as “SuperPaint” software system was using by David Em.

Some other artists are using their own codes to their art practice. Those who use their own codes are called Algorithmic artist (or algorists) and those art works are called Algorithmic art. Algorithmic art, also known as algorithm art, is generated by an algorithm. Georg Nees and Frieder Nake created the earliest algorithmic art works in the early 1960s. They use a plotter controlled by a computer to create those works that process involves writing programming and the performance of the plotter (Retrieved 2009-07-10). In 1970s and 1980s, artists such as Yoshiyuke Abe, Yoichiro Kawaguichi create and present their works by their own computer algorithm. For example, Yoshiyuke Abe is writing his own code to working in a color palette that is almost extra-terrestrial in its electronically hyperbole (*see Figure 10, 11*).

*Figure 10 (from Yoshiyuke Abe website)*

*Figure 11 (from Yoshiyuke Abe website)*

Yoichiro Kawaguichi is an artist well known on his "GROWTH model" (*see Figure 12, 13*). The “GROWTH model” is “a self-organizing method to give form to one's rich imagination or to develop one's formative algorithm of a complex life form” (Retrieved 2009-08-09). In this case, art creativity is a result of an application of algorithmic process that often uses “a random or pseudo-random process to produce variability” (Retrieved 2009-07-10). Because the art sequence, a computer program generates a form that is “allowed to grow systematically according to a set formula”. However, this "GROWTH Model" is not based on a static process that allows constructive mathematics to take its course (Retrieved 2009-08-09).

The iteration for simple form of inner mathematical principles is deduced by through the observation of eddies and spirals. The images of the "GROWTH Model" are similar with complex view of living creatures and put subtle form like a conch shell as a starting point, the shapes of ammonite, nautilus, tentacles, plant vines and coral…(Retrieved 2009-08-09). According to Kawaguichi, the "recursive structure" is the most important concept of the

“GROWTH Model”. The concept is a repetition of simple rules within complexity. The computer is repeatedly to create growing images with maximized memory space through running a genetic program implemented with the structure.

Because the program starts from an initial shape to the final image unpredicted emerges, the "GROTH Model" is considered as an unforeseen form to the progress of time (Retrieved 2009-08-09). The "GROTH Model" intends to generate a new bionomic pictorial space. In the most of Kawaguichi’s works, there is some kind of creatures presented in the images. Such creatures have a self-organizing form. The creatures that “sensually moans and squirms” and may exists “in the evolutionary past or that may appear in the distant future”. The model is defined as “a life form of probability” (Retrieved 2009-08-09).

*Figure 12 (from Ohio State U website)*

*Figure 13 (from Ohio State U website)*

As an algorithm art, an algorithm must be designed as a part of process during the process of creativity. According to the explanation of algorithm art, an algorithm is “a detailed recipe for the design” and “possibly execution of an artwork”. Depend on which one finally determines the form the art, it may include computer code, functions, expressions, or other input. Those different inputs of an algorithm refer to “mathematical, computational, or generative in nature”. As results always in the process of identical artworks, some random elements is usually introduced although algorithm attempts to be deterministic (Retrieved 2009-07-10). If the algorithm is executed by a computer, this can be “the use of a pseudo-random number generator”. Some artists are working with gestural input that modified by an algorithm such as organically based gestural input (Retrieved 2009-07-10). In the following, I will give an example of the algorithm art --- Fractal Art.

### 4.1.1 The Fractal Art

The fractal art refers to a process of creativity on images, animations, or other media that are calculated the fractal objects and representing the result of the calculation. It is based on new kind of mathematics called fractal geometry. Fractal geometry was developed by French mathematician Benoit Mandelbrot in the 1970s and 1980s. The basic principle of fractal art is repeating simple patterns billions and trillions of times (*see Figure 14, 15*). According to Mandelbrot (1982), fractal is from “the Latin adjective fractus” and “the corresponding Latin verb frangere means ‘to break:’ to create irregular fragments”, and also, he believes that fractus means “irregular” on both “meanings being preserved in fragment” (Mandelbrot 1982, p.4). According to Kenneth Falconer (2003), a fractal usually has some features and a fine structure at arbitrarily small scales. It has an important property that called “self-similarity”. By the assistance of fractal-generating software, fractal art is created iterating through three steps: setting parameters for selected fractal software, executing the possibly lengthy calculation and evaluating the product.

Because fractals appear similar at all levels of magnification, they are considered to be infinitely complex. Natural objects that are approximated by fractals to a degree include clouds, mountain ranges, lightning bolts, coastlines, snow flakes, various vegetables (cauliflower and broccoli), and animal coloration patterns. However, it is not all self-similar objects are fractals. For example, the real line is formally self-similar but fails to have other fractal characteristics. A famous example of a fractal is called the “Mandelbrot set” that is a set of points in the complex plane, the boundary of which forms a fractal. “The Mandelbrot set is a mathematical set, a collection of numbers” (Dewey Retrieved 2010-03-27).

Those nice and perfect presented images or animations really look like beautiful crafts created by computing technique and mathematics functions. Rather than saying it is called art, fractal art is a way of the artists exploring mathematics knowledge involving mathematical algorithm visualization.

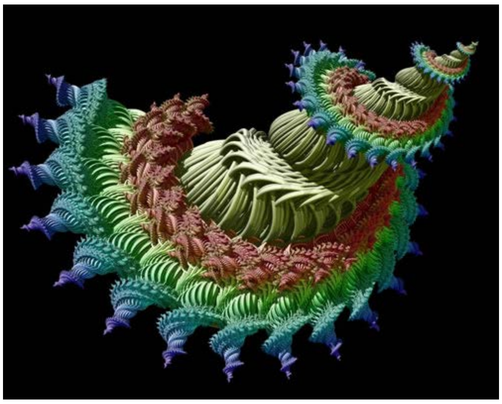

*Figure14 (fromhttp://msenright.blogspot.com)*

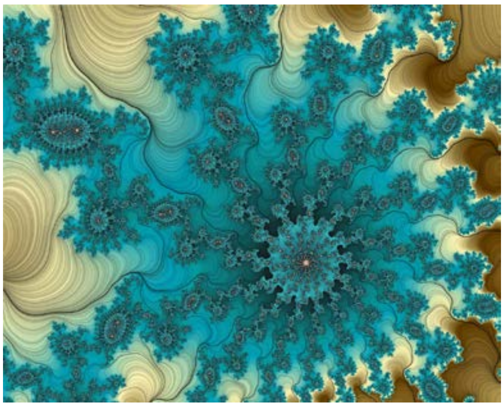

*Figure15 (fromhttp://msenright.blogspot.com)*

### 4.2 Computer as A Creator for Art Creativity

Using computer as a creator means that artists develop a computer controlled drawing machine by using computing Artificial Intelligence technique. The special drawing machine can create an art work such as painting or drawing without any human interruption or ideas, the use of the computer technology “changes the strategy of image-making” and raise questions of “which the computer actually creates art itself” (Popper 1993, p.80). Therefore, we really can not just classify computer as a tool but something like “a creator” or “a simulator of memory, of reasoning and of the brain itself” (Popper 1993).

The first artist who explored in this area is Harold Cohen who develops an Artificial Intelligence program called AARON, which is a computer system that can actually make a drawing (*see Figure 16, 17*). It takes more than 30 years to develop the drawing system to become a “creator” of computer art. From early of 1970’s to now, AARON has been developed its painting technology from simple sharps to color, from abstract to realistic figurer through its robotic arm. The art works that created by AARON more and more like paintings drawn by human. How the AARON makes a painting is decided by computer programe implemented in its “brain”. AARON has been programmed with two types of knowledge. The first type of knowledge in AARON is coded the all kinds of different sharps about the world in it’s programming such as how is make up the human body and what is the shape of a simple tree. The programming of the knowledge about the world is a little similar with human memory where the information is stored. This part is called “declarative knowledge”. The second type of knowledge in AARON programming is called “procedural knowledge” that allows it move from a start to an end by through a series of inter-connected steps during the process of making a painting. Those two types of knowledge in AARON programming is a soul of this computer art creator. The artist’s aim of AARON is “shaped by the historically long-standing dream of a ‘thinking machine’ and he looks forward to a time when computers will be able to surprise him, not only by drawing something he did not anticipate but by producing a drawing only possible through the computer’s own modification of the programme” (Popper 1993, p.80). The *Figure 18* and *19* are paintings created by AARON.

However, there is still having many limitations on AARON. It is believed that AARON’s creativity is not enough that means it needs to examine the process of the understanding of creativity although computing technology can bring a new platform in which artists have a new way to understanding of creativity.

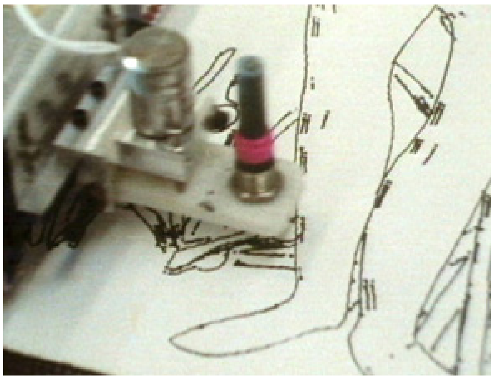

*Figure 16 (from the Age of Intelligence Machines)*

*Figure 17 (from Harold Cohen's website)*

*Figure18 (from Harold Cohen's website)*

*Figure 19 (from Harold Cohen's website)*

Artists Roman Verostko and Simon Ingram are also using computer as creator. Roman Verostko, for example, interested in pure visual form as “the life of forms” in his art creativity (*see Figure 20, 21*). The theories and practice of Mondrian, Kandinsky had inspired him on the process of his art practice. The artist has engaged “both arbitrary and constructive procedures experimenting with ‘visual form’” and later on “sought to original forms that are unique realities without reference to other objects or images” (Verostko Retrieved 2009-10-20).

*Figure 20 (from Roman Verostko’s website)*

*Figure 21 (from Roman Verostko’s website)*

The artist describes that these visual forms are “visual celebrations of information processing procedures embedded in today's culture” and the works are “visual analogues of the coded procedures” through their growing. The works of art “serve as icons illuminating the mysterious nature of code, the procedures underlying the shape of our evolving selves” (Verostko Retrieved 2009-10-20). The technology used in the process of art creativity is a kind of drawing machine. Different with Harold Cohen's AARON, Verostko uses ink pens than mounted on the drawing machine (*see Figure 22, 23*). The controlling algorithms for all procedures named as "Hodos" by the artist. The machine is HI 7000 with DOS operation on PC by using BASIC programming with DMPL.

*Figure 22 (from Roman Verostko's website)* *Figure 23 (from Roman Verostko's website)*

Artist Simon Ingram's art works explore on the reciprocal between artist and computer. Art works can be "created by 'hand' (artist himself) according to simple sets of machines like rules i.e. 'Artist as machine'" (Retrieved 2009-07-21) (*see Figure 24, 25*). Beside the art works are self-making painting machines, Ingram's works is considered as the "machine as artist". Those works "interprets the modernist practice of the autonomous, self-made artwork in relation to painting as a constructional and computationally based self-organising system" (Retrieved 2009-07-21). There have three distinct lines of art works created by the machine, which includes "machines made from Logo robotics" and "generic constructional materials that paint autonomously in oil paint with brush" and "painting made by the artist that uses artificial life systems as a method machines". By drawing on divergent strands of knowledge such as artificial life, painting, critical theory, software, the work “re-stage and reinvents painting as a critical, contemporary project that explores painting’s conceptual signification while remaining resolutely fabricational” (Retrieved 2009-07-21).

*Figure 24 (from Gow Langsford Gallery’s website)*

*Figure 25 (from Gow Langsford Gallery’s wesite)*

In describing his works, Ingram states that “so systemics are only interesting to the extent that they are disassembled by painting to become something else … I'm not making painting machines in the sense of a device whose configuration insists on its separability from the drawing/painting it produces as an output ... this situation is closer to thinking than it would be were separability available. The work that I'm doing incorporates a machine in painting, so the painting is the machine, not an outcome of the machine" (Smith 2004).

**4.3 Other Computing Techniques Applied on Art Creativity**

In this category, artist is given as an example to discuss on computing techniques on art creativity. Artist Vera Molnar who is one of pioneer in computer art believes that computer servers about four purposes. At the first, computer techniques offer a possibility of its infinite array of forms and colors and the development of space. The second she believes that the computing technology avoid the traditional restriction to "satisfy the desire for artistic innovation" and an aesthetic shock could be created by the unforeseen destructive and break "the systematic and the symmetrical" (Popper 1993, p.80). At the third, a new computing technology can inspire people to think at a new way that might be increase the ability of creativity. At the last, artist believes that the computing technology helps to "measuring the physiological reactions of the audience" and brings closer to the creativity (Popper 1993, p.80).

For example, Molnar's work transformations (*see Figure 26*), there are many simple geometric elements such as squares were arranged because of her aesthetic preference as well as creative are works in a way of "much more consciously controlled and systematic" (Popper 1993, p.81).

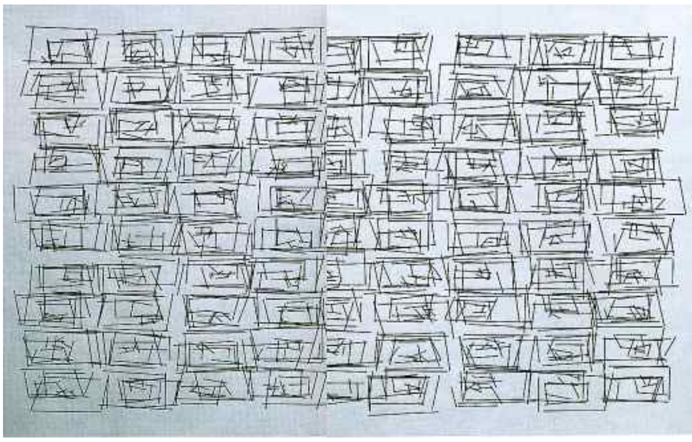

*Figure 26 (from personal.stecens.edu website)*

Other artists who are using computing technology to their art creativity may include Manfred Mohr, Rebecca Allen, and Hans Dehlinger etc. For example, Manfred Mohr focuses his works on “the interface between mathematical logic and aesthetics” (*see Figure 27, 28*). By separate from materiality, artist develop “the utopian dimension” of a calculated world between “configuration and disintegration”, between “construction and deconstruction” (Mengden 2007). Manfred Mohr’s works have been influenced by German philosophy *Max Bense*’s writing on the notion of information aesthetics. His work focuses on the notion of a new art in the technological era, and the concept of an art based on the emotions, but not rationally (Mengden 2007). As same as other computer artists, Mohr creates his art works by developing his algorithm. The machine can be defined an extension of human intelligence, as “visual high-speed thinking" and as "a heightening of our intellectual” and as “visual experiences”, Mohr’s works demonstrate the large potential of the machine (Mengden 2007).

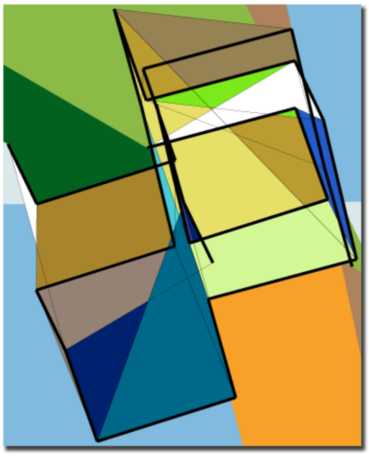

*Figure 27 (from Manfred Mohr's website)*

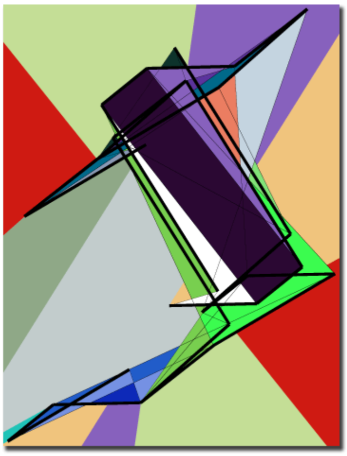

*Figure 28 (from Manfred Mohr's website)*

Rebecca Allen's works focus on a range of different new technological forms of expression such as 3D animation, music videos, large-scale performance works, interactive art installations etc. According to artist's statements, Allen is not "interested in a technology for its sake…", but in a techno-culture which "humanizes technology towards it… or perhaps one can even say that it is her critical approach towards technology that helps humanize it" (Allen Retrieved 2009-07-20).

Artist proves this critical approach with artistic quality and "the conceptual integrity of her work" that focuses on the effect of the viewer's intelligence. However, her main concern is to investigate the viewer's "perceptual and cognitive processes" (Allen Retrieved 2009-07-20).

*Figure 29 (from Rebecca Allen's website)*

*Figure 29* shows an interactive art installation created by Allan in 1997. The installation examines "the role of human presence in a world of artificial life", for example, the soul of a person enters a virtual world such as a virtual bush and is alive and responsive. By defining the behaviors and desires, all inhabitants are brought to life (Allen Retrieved 2009-07-20).

Artist Hans Dehlinger is interested in enchantment of the pen guided by machine, monochrome line and the code for programming (*see Figure 30*).

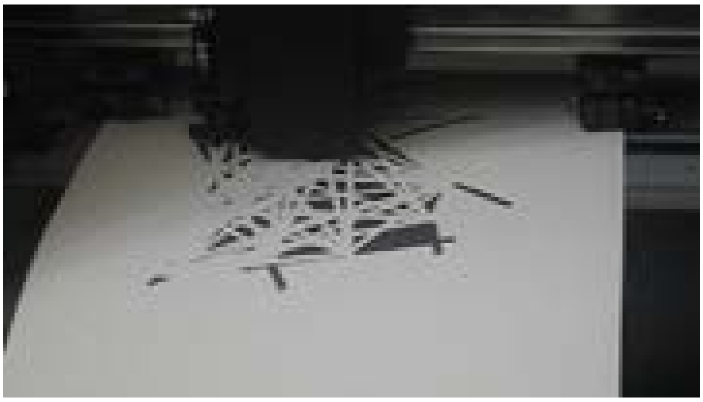

*Figure 30 (from Hans Dehlinger's website)*

The artist's works are obviously different with other artists. Dehlinger's works (*see Figure 31,31,32*) present monochrome drawings that compose a enormously rich domain of art (Dehlinger Retrieved 2009-08-10). According to artist's statements, it is a metaphor that "the moving pen in the grip of a plotter in action resembles relatively closely the process of the hand engaged in drawing". However, interesting result from those works is that a universe is "complemented by an equally rich universe of machine-generated drawings, also a universe in its own right" (Dehlinger Retrieved 2009-08-10).

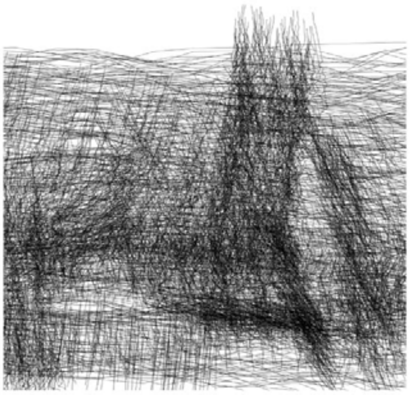

*Figure 31 (from Hans Dehlinger's website)*

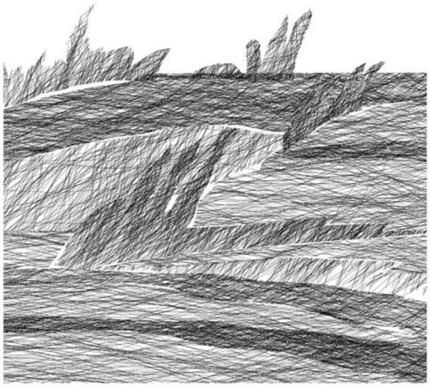

*Figure 32 (from Hans Dehlinger's website)*

In summery, all above computer-related art works share one character that focus on autonomous and mechanism of presenting art works. According to Weisberg's definition of creativity, creative refers to novel products of value such as "the airplane was a creative invention". Therefore, any painting machines produced by artists can be referred as the result or product of creativity. One of the advantages of computer technology is that computer system can generate "perfect" sharp form, straight line and standard circular type that compose into either abstract or realistic images embody certain aesthetic. However, how to understanding of the paintings were created by the machines might rise the different arguments. Some artist such as Ingram believes that the paintings from the machine are not the outcome of the machine but the machine. And other art related people such as art historian, critic may questionable on new computer art (or digital art) and might not recognize the works produced by a machine are same as one created by human hands. The computer-based art works might satisfy with many different creativity theories.

### 4.4 Artistic Data Visualization

Creative visualization is modeling on novel, varied and complex stimulation, to communicate ideas and values and need to solve problems, to the knowledge acquisition. It includes the aesthetic display of the visualization, invention of new visualization techniques (e.g. hardware and software), artistic visual representation etc.

Because of the big improvement of the computer techniques on both computer hardware and software, people could use computer techniques to create visual data representation, even in personal computer. At the present, people do need requirement of knowledge of C/C++ to write code in order to create data visualization. Instead of using some special designed software for artist/designer such as Processing (www.proceesing.com), Flash (www.adobe.com), artists could use their own algorithm to achieve the data visualization.

It is clear that artistic data visualization is different with normal data visualization that has more focused on data. Artistic data visualization can be define as “visualizations of data done by artists with the intent of making art”

(Viegas and Wattenberg 2007). According to Viegas & Wattenberg (2007), artistic data visualization must have two basic properties. The first, actual data is basic for the art works that include “the metaphors or surface appearance of visualization” (Viegas and Wattenberg 2007). The second is that artistic data visualization might not as beautiful as people’s expectation. Because aesthetic is not about beautiful and art works might not be nice or beautiful presented. For example, the scientific experiment’s microscope photography obviously is not artistic visualization, as that scientific photography mere presents scientific reality or findings. Although some scientific visualization presented as beautiful images, they lack intent of art creativity. The difference of both artistic visualization and scientific visualization largely focuses on how to explain or explore the data with the certain ways. In another word, the way to seeing the data makes the difference of artistic and scientific visualization. Scientific visualization presents a highly data-accurate and artistic visualization needs a free creativity with a less representative of data (Lau and Moere 2007).

Artists and designers have taken “matters into their own hands and expanded the conceptual horizon of infovis as artistic practice” (Viegas and Wattenberg 2007). There are an increased number of artists who are working in the art practice based on data visualization. Following are some examples of those art works and to examine “how artists appropriate and repurpose ‘scientific’ techniques to create pieces that actively guide analytical reasoning and encourage a contextualized reading of their subject matter” (Viegas and Wattenberg 2007).

### 4.4.1 Examples of Artistic Data Visualization

***- Jason Salavon and the Power of Colored Pixels***

Salavon's art works encounter the spectators with "inescapable, pervasive pattern" in normal people's life. The subject of his works cover from "innocuous mementos such as high-school year books to racy centerfolds of adult magazines" (Viegas and Wattenberg 2007). His work "*The class of 1988*" (*see Figure 43,44*) are created by computing techniques that takes the mean averaging color of every photo, pixel by pixel and then represented those photo as totally different new images. Salavon attempts to focus on "the collective aggregation of human experience" through the process of blue individuals (Viegas and Wattenberg 2007).

*Figure 43 (from (Lau and Moere 2007))*

*Figure 44 (from (Lau and Moere 2007))*

Salavon's other works use the same averaging technique to "*Homes for Sale"* (*see Figure 45, 46*). The work visually represents "a series of realtor photos of single-family home" for sale across the US. The purpose of the images is visually representing the median price range of a collection of home in a given metro region (Viegas and Wattenberg 2007).

*Figure 45 (from (Lau and Moere 2007))*  *Figure 46 (from (Lau and Moere 2007))*

By through the arrangement of colored pixels in an image, the concept of narrative also has been expanded by the artist (Viegas and Wattenberg 2007). The artist explores this concept of narrative by his art work "*The Top Grossing Film of All Time*" (*see Figure 47*). In this work, the movie *Titanic* is visual represented through digitized entirely and extracted individual frames in which every frame is "averaged to a single color that best representative of that image", thus, the narrative is presented in color through reading from left-right and top-bottom (Viegas and Wattenberg 2007). For example, the golden tones illustrate the luxurious interior of the ship half-way across the movie. And also in near to the end, highly "pixilated" band of color is presented that indicates the climatic point where the ship sinks… At the bottom of the work, deep blue that dominates the whole tone suggests a freezing and tragic scene where passengers were floating in the ocean and waiting for rescue (Viegas and Wattenberg 2007).

*Figure 47 (from (Lau and Moere 2007))*

### *- Golan Levin and the Power of Numbers*

The work of “*The secret lives of number*” (*see Figure 48*) presents an interactive system that the spectators can explore “how the usage patterns of numbers reflect culture, history, and biology”. The data in the work was collected from a popular web search engine in a certain period of time and the data “represents the “popularity” of every integer between 0 and 100000”. The result of this data visualization is telling us a true that people do love some numbers and dislike some others (Viegas and Wattenberg 2007).

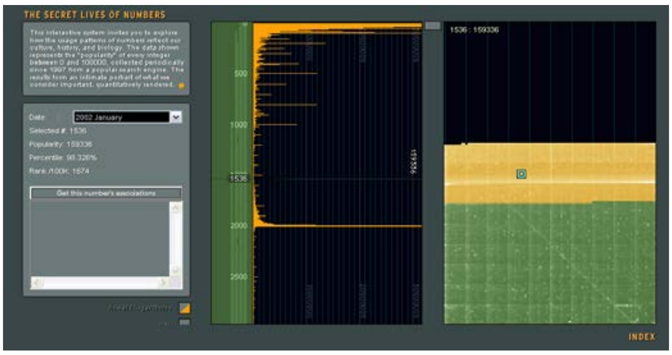


*Figure 48 (from (Lau and Moere 2007))*

***- Last Clock and Jussi Angesleva & Ross Cooper***

Artist recognizes the widespread presence of surveillance cameras in cities, and “has experimenting with ways to capture some of the most evocative aspects of the medium”(Viegas and Wattenberg 2007).

In the “Last Clock” (*see Figure 49*), artist uses video footage to record time to generate the images. Those images similar as an analogue clock which has second hand, a minute hand and an hour hand. The images show the clock presenting as a unique emblem of its surroundings after few hours running. “Not useful for either surveillance or video watching, the visualization succeeds in creating a powerful record of time and place” (Viegas and Wattenberg 2007).

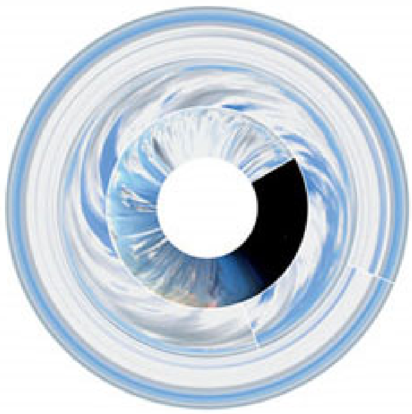

*Figure 49 South Kensington,London (from (Lau and Moere 2007))*

Those examples have a same common ground that makes them different from traditional visualization tools. Each of them embodies “a forceful point of view” (Viegas and Wattenberg 2007). Viegas and Wattenberg (2007) argue that “the artworks derive their power from the fact that the artists are committing various sins of visual analytics" (Viegas and Wattenberg 2007). In addition, another key point is they all have distortions from the original data. However, those distortions are not "mistakes on the part of artists". The value of the artworks "rests on the fact that their creators recognize the power of visualization to express a point of view". However, the traditional visualization have "sought to minimize distortions", because the distortions might interfere with dispassionate analysis of data (Viegas and Wattenberg 2007).

Viegas and Wattenberg (2007) conclude that because visualization community has a tradition of interdisciplinary, it needs to be learned from the current artistic explorations and suggest the solutions might hide in "the artistic use of a particular point of view or persuasive goal" (Viegas and Wattenberg 2007).

***-- Lucas Maassen and Dries Verbruggen and Brain Wave Sofa which knows what you are thinking***

A Dutch industrial designer Lucas Maassen designed a special sofa to visualizing EEG data cooperate with Belgian designer Dries Verbruggen (*see Figure 50*). Through visualizing an electroencephalogram (EEG) signal, This project allowed audiences to interactive with the data. The physical shape of the sofa is made of foam. The data collected from the participant by using a set of electrodes connected to the head. The data represent a 3D data landscape by a computer application for visualizing neuro-feedback: the depth is the frequency of the brain-activity in hertz; the height is the strength of the signal; the length is the timescale. Based on this 3D-EEG data, the file got directly milled in foam by a 3D CNC milling machine and then upholstered in felt by hand (Baudisch and Rosenholtz 2003; 2009). When the participant closes the eyes, it shows the 3 seconds Alpha wave. Because Alpha activity is peculiar: when one closes the eyes the Alpha activity strengthens and other brain activity dims. The Alpha activity is actually to prepare the large input of signals when one opens the eyes. Every time, an EEG data creates a 3D landscape of the brain wave, which looks different.

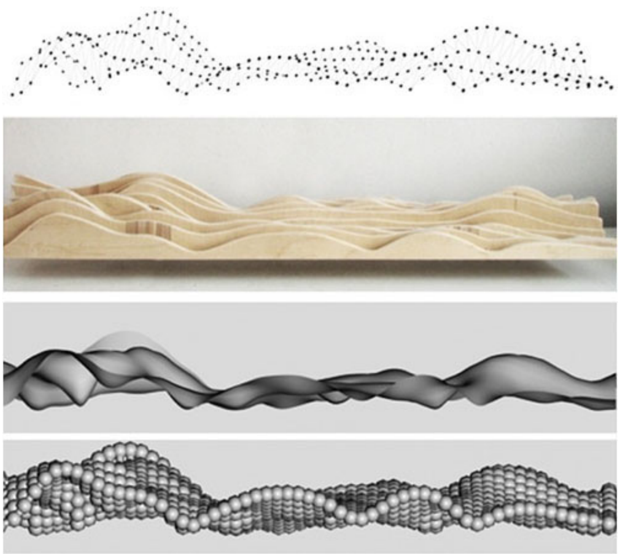

*Figure 50 (from http://infosthetics.com/archives/2009/10/brain_wave_sofa.html)*

This physical shape 3D visualization has presented non-conventional scientific data visualization and it beyond scientific visual analysis to a new level. The different with conventional visualization is that creative visualization more tend to express designer own ideas rather than rigorous scientific data analysis. The result shows that a tight connection with data will limit an artist creative input (Lau and Moere 2007).

## Chapter Five: The Effect of Technology on Studies of Visualization

In the twenty-first century, people live in a society surrounded by large amounts of data and information. In a fast-paced society, for instance, people often need to comprehend or understand the meaning or implications of data or information in a very short time. However, how to efficiently present data or information to the people is a key issue in achieving this comprehension. Generally speaking, it is much easier for humans to recognize or understand image than numbers, symbols or letters. Scientists believe that the visual brain has developed more than the linguistic brain during the evolutionary process. Therefore, for most humans, visual presentation is much easy to understanding than numerical presentation. The basic function of visualization is transform the data or information into “a visual model capable of revealing its essence” which people can easy understand (Wildbur and Burke 1998).

Visualization presents some kinds of visual information in visual form, such as maps, paintings, movies, photos, charts and diagrams. In fact, “visualized information” exists everywhere in our society such as TV weather report, product manuals and transport timetables. There is a long history of people using visualization to represent data or information from different fields. For example, Ptolemy’s Geographic ($2^{nd}$ Century AD) (*see Figure 33*) presents the utility of a map; Da Vinci’s illustrated notebooks convey the salient details of complex processes; Minard’s (1861) diagrammatic map representing Napoleon’s invasion of Russia.

Another aim of visualization is that the result of the visualization itself might contribute to scientific findings. Scientists are seeking for the truth from the complex data through the efficient visualizing data. Not only does it allow scientists to recognize the information behind the data but the process also contributes to a better understanding of data itself. Scientists may wish to “engage the reader or spectator in a wonderful journey of imaginative visualization”, after analysis, they wish to “communicate an interpretation that embodies testable content in an unambiguous way” (Valle 2008). However, visualization from artists is almost always using ambiguous and interpretative methods to facilitate an expression of hidden information behind the data.

Visualization has three basic elements: data, methods and the technologies. The technology plays a most important role in the process of visualization, in as much that it both captures and represents phenomena; and then to large extent determines whether or not it successfully transforms the data into certain visual forms that reflects the scientists or designer’s purpose. It focuses on capturing and creating images that “convey salient information about underlying data and process” (Hansen and Johnson 2005). The visualizing images include pictures, diagrams, 2D or 3d images, animations and films. Before the invention of computing technology, most visualization works were finished by hands and the common technique was illustration or drawing by using traditional tools such as paper, ink, pen and brush etc. Since the fast development of computing technologies, visualization has seen unprecedented growth in the last decade. By using those computing technologies, visualization can present comprehend large and complex data in two, three, or even more dimensions. Computing technologies consist of hardware and software. Computing hardware refers to physical devices such as CPU (Central Processing Unit), memory for store data, input and output equipment such as monitor, keyboard and mouse, and some other equipment for 3D Virtual Reality which include head-mounted displays, headphones, and motion-sensing gloves. Computing software refers to computing programming, which is the "soul" of the whole visualization. Computer software includes applications (e.g. Photoshop, Illustration, and Painter), programming languages (e.g. C/C++, Java), operation system (e.g. Windows, Linux). The biggest difference between computer hardware and software is that hardware is visible and software is invisible.

The visualization is applied to a wide range of fields such as engineering, medical, biological, science, education, statistics, chemical processes etc. In this part, I will discuss the definition of the visualization and overview the key technologies of data visualization.

*Figure 33 The Ptolemy world map, reconstituted from Ptolemy's Geographia*

### 5.1 Defining Visualization

According to the description in the 1987 National Science Foundation's Visualization in Scientific Computing Workshop report, the visualization can be explained as flowing:

> *Visualization is a method of computing. It transforms the*

> *symbolic into the geometric, enabling researchers to observe their simulations and computations. Visualization offers a method for seeing the unseen. It enriches the process of scientific discovery and fosters profound and unexpected insights. In many fields it is already revolutionizing the way scientists do science … The goal of visualization is to leverage existing scientific methods by providing new scientific insight through visual methods.*

Visualization normally request data and information. In the IT industry, data is raw, undigested stuff of acquired numbers and letters. For example, data might include stock market, weather measurement, survey response, and website metrics. Information comes from the processing of the data to derive something useful, so weather data can be processed into synoptic chart for making a weather forecast, survey results can show the public's response to a marketing campaign, and so on.

Traditionally, the data visualization has roots in computer science which uses technologies such as interactive, sensory representations of the abstract data to enhance cognition, hypothesis building and reasoning. Hamming (1973) believed that the purpose of visualization is "insight" and not "pictures". The main goals of this insight are discovery, decision making, and explanation.

## 5.2 The Hardware of Visualization Technology

The hardware provides a platform for the possibility of the many different performances of visualization, such as 3D, animation and interactive. The hardware refers all physical devices for present the data or information dividing as input and output devices. The input device includes keyboard, mouse, touch pad, graphical tablet with stylus and a modified mouse and the output includes monitor display, printer equipment, and speaker etc (*see Figure 34*). The hardware also includes the equipments for 3D Virtual Reality such as head-mounted displays, headphones, and motion-sensing gloves.

Before the advent of computing age, the common hardware for the illustrative visualization were traditional drawing tools such as brush, pen, paper, ink, all sort of color. The evolution of such hardware was reasonable slowly and it had often been “modified or created by the people intimately connected with the technology being superseded” (Wildbur and Burke 1998, p.7). The changing of technology may change the role of people working in those fields. For example, Wildbur & Burke (1998) give an example of transformation in typesetting device. It is fast changing from a mental type of typesetting to film setting and even to the early digital typesetting. The actual setting skills “remained in the hands of trained ‘compositors’, craftsmen who served a long trade apprenticeship and who acted as intermediaries between designer and machines” (Wildbur and Burke 1998, p.8). In addition, the printing industry involved other specialists such as proof readers, photographic retouchers and art workers etc. However, the invention of computer technology changes the situation of printing industry, such as desktop publishing that has a total control on the process of the printing as one in a relatively short time (Wildbur and Burke 1998).


*Figure 34 (from the website http://www.3dmultimedia.com/help/windows/intro_eng.htm)*

As one of the latest technique, an interactive technique has been recognized and applied at many different visualization fields. The interactive technique requires a device for a communication or operation with the data, such as a joystick might be very useful for exploring data.

Some of hardware device are designed for obtaining data and then transform into computer-readable images such as scanner, digital camera, Computerized Tomography (CT). At the present, most complex scanning devices are focused on medical science field such as CT has widely used in medical field for the study and diagnose of the brain diseases. By the definition of Merriam-Webster's online dictionary, CT (*see Figure 35*) refers to a "radiography in which a three-dimensional image of a body structure is constructed by computer from a series of plane cross-sectional images made along an axis" (Retrieved 2010-03-02). It is a non-invaded method to obtain imagining data from the human body. Digital geometry processing is used to generate a three-dimensional image of the inside of an object from a large series of two-dimensional X-ray images taken around a single axis of rotation (Herman 1980).

Brain images can be generated by "means of computerizes axial tomography (CT) and magnetic resource imaging (MRI)" (Wildbur and Burke 1998, p.167). CT generates a volume of data which can be manipulated through a process called "windowing", which in order to demonstrate various bodily structures based on their ability to block the X-ray beam. Although the traditional images were generated through in "the axial or transverse plane, orthogonal to the long axis of the body", the modern scanners have functions to allow "this volume of data to be reformatted in various planes or even as volumetric (3D) representations of structures" (Retrieved 2010-03-02). CT is not only used in medical field but also used in other fields such as nondestructive materials testing.

*Figure 35*

*(from http://www.wired.com/*

*gadgets/miscellaneous/news/2008/04/Toshiba_CTScanner)*

In the traditional way to capture the body images has some limitations such as the machine only can rotate simple tube at about 40 degrees angle. However, in modern CT technique, the source/detector makes a complete 360-degree rotation about the subject obtaining a complete set of data (Retrieved 2010-03-02).

The MRI (magnetic resonance imaging) is the latest technique for the visualization of detailed internal structure. It provides much more contrast between the different soft tissues of the body (*see Figure 36*). The difference between CT and MRI is that a CT scanner uses X-rays, which is type of ionizing radiation to get the images, while a MRI scanner uses non-ionizing radiation radio frequency signals to get images. The CT techniques are good for examining tissue composed of elements with a higher atomic number. However, MRI is the best for non-calcified tissue (Wu, Chesler et al. 1999).

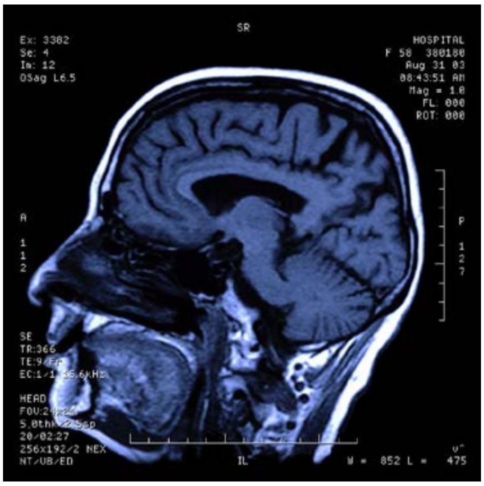


*Figure 36 (from http://precisionimag.com/mri)*

The hardware of the Virtual Reality (VR) includes manipulation and control of devices, stereo vision, and head-mounted display. The ability to manipulate and control device is the most important part of Virtual Reality, because virtual world needs interactive experience between users and the system. A conventional mouse, trackball or joystick is the simplest control hardware. As well as traditional two dimensional devices, a number of new three and six dimensional mice, trackball or joystick devices are available. The extra added buttons and wheels can control not just the XY translation of a cursor, but its Z dimension and rotations in all three directions such as the Global Devices 6D Controller is a 6D joystick that looks like “a racket ball mounted on a short stick” (Retrieved 2010-05-09). The ball of the new joystick can be pull and twist as well as control the left and right or forward and back of a normal joystick. A 3D and 6D mice, joystick and force balls will become a key trend of the hardware technology. In a virtual environment, an instrumented glove is a necessary tool that has a number of different types of sensors that can be used. Other devices have been developed such as the body suit (Retrieved 2010-05-09).

The sensors of the tracking system, which is an important part on the Virtual Reality environment, can be used to tract positions. A new sensor device called ultrasonic sensors which have two key components: emitters and receivers. The emitters of ultrasonic sensors are pulsed in sequence and the time lag to each receiver, while triangulation gives the position. Obstacles are low resolution and long lag times to ultrasonic, even the environment intervenes those obstacles such as echoes and noises (Retrieved 2010-05-09). Stereo vision is accomplished by generating two different images of the world for each eye. There have many technologies for display the images that are computed with “the viewpoints offset by the equivalent distance between the eyes” and the images can be designed with corresponding polarized filters placed in front of the eyes for the users (Retrieved 2010-05-09).

## 5.3 The Software of Visualization Technology

Like an engine needs petrol, a computer hardware system needs software to support. Without corresponding software, hardware is nothing. In this study, software refers to computer software that is a general title for the different kinds of computer programming. Computer software receives the command from the computer users and passes the instructions to the hardware for executing the tasks. Software is contrast to the hardware which means physical devices such as monitors, keyboard, CPU, memory, hard disk etc. Comparing with hardware, software is intangible, invisible. It includes application software, programming languages, operating system etc. Operating system is basic software for the hardware, such as Mircosoft Windows, Linux, DOS. Programming languages defines the syntax and semantics of the programs, such as C/C++, BASIC, Java, Processing etc. Application software is software that computer user to communicate or operate with the computer in order to achieve certain tasks, for example, word processors, games, online chat tools, internet explorer etc.

The design and development of computing software is the most important part of visualization that directly impacts the effect of the visualization. The process of designing computer software usually involves design, write, implement, test, debug and maintain the source code of the programming. Algorithm is key step in the process of software design and how to implement the most efficient algorithm is big concerned in academic computing programming.

In this study, I will outline some common used and important mathematic algorithms for visualization. The most common used in the visualization techniques are ranged from volume visualization to isocontouring, from vector field streamlines or scalar, vector and tensor topology to functions on surfaces. There are a wide variety of techniques have been developed for the visualization of scalar, vector and tensor field data. The algorithms that transform data are the heart of data visualization. It can be categorized by the *structure* and *type* of the transformation (Schroeder and Martin 2005). The *structure* means “the effects that transformation has on the topology and geometry of the dataset” (Schroeder and Martin 2005, p.3). The *type* means “the type of dataset that the algorithm operates on”, such as Scalars or Vectors (Schroeder and Martin 2005, p.4). Structural transformation can be classified in four ways: Geometry transformations, Topological transformations, Attribute transformations, and Dataset transformations. Type transformation includes Scalar algorithms, Vector algorithms, Tensor algorithms, and Modeling algorithms.

Scalar algorithms operate on scalar data which are single data values associated with each point and/or cell of a dataset. For example, the generation of contour line of temperature on a weather map. Vectors algorithms operate on vector data. For example, vector visualization can be showing oriented arrows of airflows (direction and magnitude). Tensor algorithms operate on tensor matrices. For example, a tensor algorithm shows the “components of stress or strain in a material using oriented icons”. Modeling algorithms generate dataset topology or geometry, or surface normal or texture data. It tends to be the multi-algorithms for the algorithms that do not fit neatly into any single category mentioned above (Schroeder and Martin 2005).

The Color Mapping, Contouring, and Scalar Generation are common and important techniques. For example, color mapping can apply to transform color on the final image colors. Two examples of algorithm for the visualization are given as following:

### 5.3.1 Color Mapping

The implement of scalar mapping involves a color "lookup table" in where scalar values are indices. An array of colors such as red, green and blue are held inside of lookup table associated with a minimum and maximum scalar range. If the scalar values are "greater than the maximum range", values are "clamped to the maximum color" and if the scalar values are "less than the minimum range", values are "clamped to the minimum color value" (Schroeder and Martin 2005, p.5).

Color mapping is usually used to map 2D or 3D objects that it maps a piece of information (a scalar value) into a color specification. It is important to select the look up table carefully for color mapping of scalar visualization. *Figure 37* shows that Flow density colored with the different look up tables. However, in the practice, tables need "accentuate important features while minimizing less important or extraneous details" (Schroeder and Martin 2005, p7).

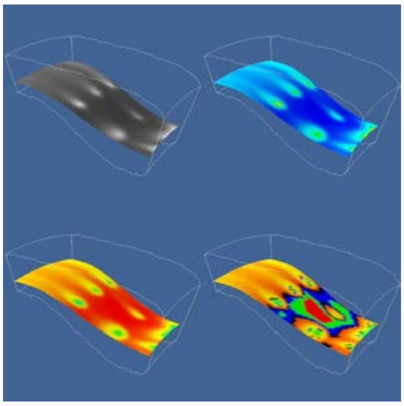

*Figure 37 (from Visualization Handbook)*

### 5.3.2 Tree-Maps

Tree-maps is a space-constrained visualization of hierarchical structures (*see Figure 38*). It is very effective way to showing attributes of leaf nodes by using size and color coding. The technique enables users to compare nodes and sub-trees even at varying depth in the tree, and help to “spot patterns and exceptions” (Johnson and Shneiderman 1999, p.149). It is also an interactive visualization method which can presents a large set of data. The method maps hierarchical information into a 2D display in a space-filling manner and both structural information and content information could be presented through an interactive control (Johnson and Shneiderman 1999).

Figure 38 shows a traditional approach to present tree structures such as normally “the root node at the top and the children notes below parent node” (Shneiderman 1991).

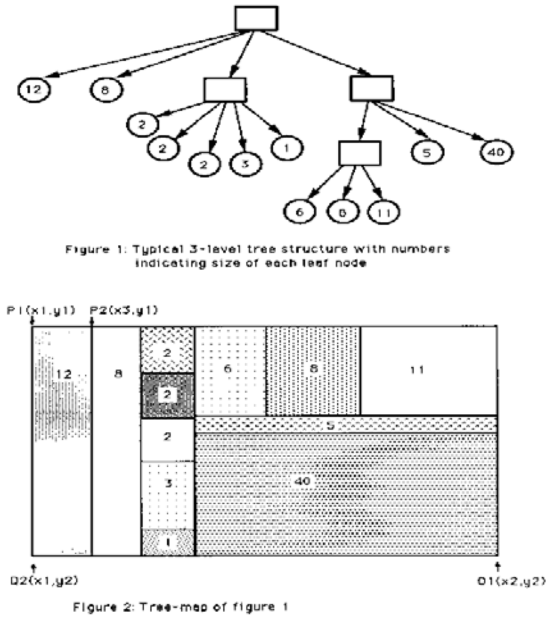


*Figure 38 (from http://hcil.cs.umd.edu/trs/91-03/91-03.html)*

### 5.4 Illustrative Visualization

Illustrative visualization refers to a kind of visualization that can be defines as “a computer supported interactive and expressive visual abstraction motivated by traditional illustrations” (Rautek, Bruckner et al. 2008). Traditional illustration includes drawing, painting, photography, which stresses on the subject.

The most important model of the illustrative visualization is called “*non-photorealistic rendering*” (NPR) which were adopted and used in visualization techniques, because the photo-based realism often fails to depict the basic features of interest (Rautek, Bruckner et al. 2008). The NPR techniques do not focus on “a realistic depiction of scenes and objects”. It attempts to “express features that cannot be shown using physically correct light transport” (Rautek, Bruckner et al. 2008).

Rautek et al.,(2008) believe that in order to using artistic freedom to depict features in scientific visualization through an expressive way meanwhile proving insight into the data, abstraction plays a key role to achieve this purpose. According to research by Rautek et al., (2008), abstraction can make rendering techniques to “correct interpretation of the phenomena” (Rautek, Bruckner et al. 2008). Therefore, the technique like *focus+content* has been used in data visualization rather than by using photorealistic techniques. In the more recently, some other techniques such as Flow visualization and volume visualization are used to explore the illustrative techniques.

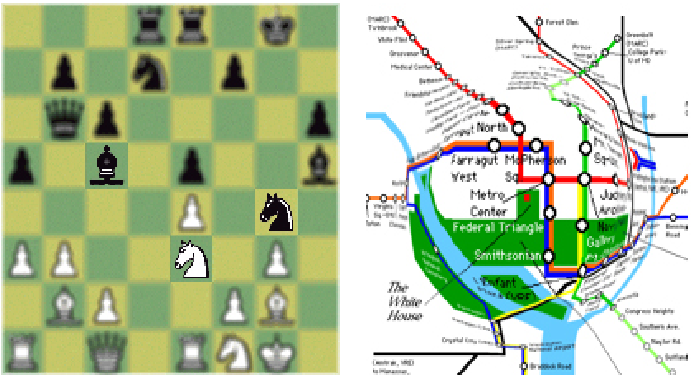


*Figure 39 (from (Rautek, Bruckner et al. 2008))*

In illustrative techniques, visual abstraction is a key component and the *focus+context* technique has been used in visual abstraction. *Figure 39* is an example of *focus+context* technique. On the left image, it shows a semantic depth of field example; on the right image, it shows a non-linear magnification transformation of a subway map. The primary focus of the NPR approach is Low-Level visual abstractions (*see Figure 39*). In *Figure 40*, the left image shows an “important-driven cutaway rendering” and the right image shows an exploded view (Rautek, Bruckner et al. 2008). The *focus+context* technique can integrate local details and global context with "geometrically distorted views" (Chen 2004, p.118). This technique has to prioritize what should be shown and what is not when users need access into local details of the focal objects and global information as well. However, *focus+context* technique has weakness that may "lose the sense of continuity" when the focal points are changed intensely (Chen 2004, p.118).

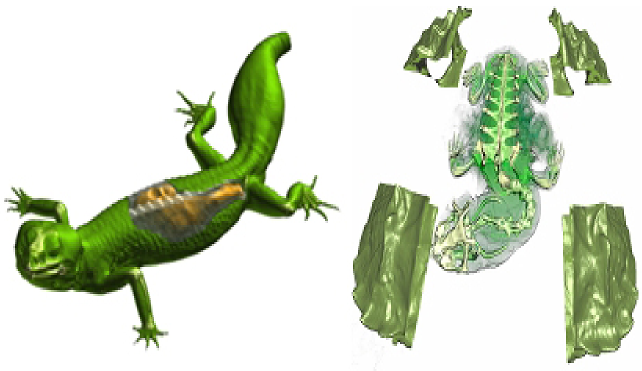

*Figure 40 (from (Rautek, Bruckner et al. 2008))*

Meister Eduard Groller (2008) predicts that all visualization will be illustrative visualization in the future. At the moment, illustrative visualization is a tool for effectively communicate of knowledge and only be used for presenting scientific "knowledge gain and knowledge communication" pipeline (Rautek, Bruckner et al. 2008). Rautek et al. (2008) argue that by using knowledge assisted methods, illustrative visualization will be "integrated into all stages of the scientific pipeline" that achieve a paradigm shift of visualization. They also believe that the future direction of the development on the illustrative visualization will focus on “the seamless integration of visualization software into the workflow of illustrators” and illustrative visualization methods need apply at the early stages of “the knowledge gain pipeline” (Rautek, Bruckner et al. 2008). Therefore, it is clear that the new technology integrated illustrative visualization enhances the communication between different disciplines. Rautek et al. (2008) conclude that integrated illustrative visualization offers a platform for extracting patterns and automating complex processes, because it offers customized interfaces that both knowledgeable domain experts and the scientific illustrators (Rautek, Bruckner et al. 2008).

## 5.5 Information Visualization

A result of information visualization could be present as art pieces or useful analysis tools. It is not only accurately represents scientific data as an information transmitter but also presents as a visual image embody aesthetics perceptive. Information visualization has become a popular topic that has been presented with different techniques at 2D, 3D, animation and interactive ways.

In the process of information visualization, mapping techniques “draw from visual cognition research in order to maximize the effectiveness and efficiency of the user’s ability to detect data patterns” (Lau and Moere 2007). However, the techniques are designing to use more interpretive mapping if the information visualization is targeted on non-expert of general users. Because visual appeal engages with a means of attracting and maintaining user, information visualization usually used as commercial tool as its popularity (Lau and Moere 2007).

As part of visualization, Information visualization is different with data visualization, although they are very similar. The difference mainly focuses on how to distinguishing and representing data and information. According to Ackoff's definitions, data is raw that simply exists and it has no significance beyond its existence. Data can exist in any form, usable or not. It does not have meaning of itself. In computer parlance, a spreadsheet generally starts out by holding data. Information refers to data that has been given meaning by the way if relational connection that meaning can be useful, but does not have to be. In computer parlance, a relational database makes information from the data stored within it (Card, Mackinlay et al. 1999). According to Card and Mackinlay et al. (1999), data refers to an independent fact or statement of event. In contrast, information refers to understand a relationship of some sort, possibly cause and effect. For example, that "it is raining" is data, but that "the temporary dropped 15 degrees and then it started raining" is information. In another word, information visualization is a process of interpret raw data into information. It is clear that information visualization is representing data into meaning form that normal people can understand easily. However, as a tool for scientific findings, data visualization emphasizes on accurately representing data.

### 5.5.1 Type of Data

To classifying data is closed to classifying knowledge, Bertin (1977) suggests that there are two fundamental forms of data: data values and data structures. The data can be divided into entities and relationships. Entities refer to the objects of interest such as people, hurricanes and buildings can be entities, a school of fish can also be considered as a single entity as a group of things (Ware 2004). Entities are “the objects for the visualization and the relations define the structures and patterns that relate entities to one another” that forms the structures that relate entities. Relationships consist “the structures” that relate entities, for example, a wheel can be a “part-of relationships” to a car (Ware 2004, p. 29). However, in computer programming, data type is a kind of classification identifying many different types of data, such as integer, floating, boolean. For example, integer number includes natural number such as -3, -2, -1, 0, 1, 2, 3 without a decimal component.

### 5.5.2 Mapping Data to Visual Form

To describe the process of mapping raw data to visualization, a diagram will be used to discuss information visualization systems and to compare and to contrast them. *Figure 41* presents a completed process of data transformation from raw data into the visual form which human can easy to understand. This diagram shows that the arrow flow at the right to the right (human) through a series of transformations and arrow flow from the human into transformations that indicate “the adjustment of these transformations” controlled by the user (Card, Mackinlay et al. 1999, p.17). The whole process is Data Transformations map Raw Data into Data Tables, Visual Mappings transform Data Tables into Visual Structures, at last, View Transformations “create Views of the Visual Structures” through “parameters such as position, scaling, and clipping” (Card, Mackinlay et al. 1999, p.17).

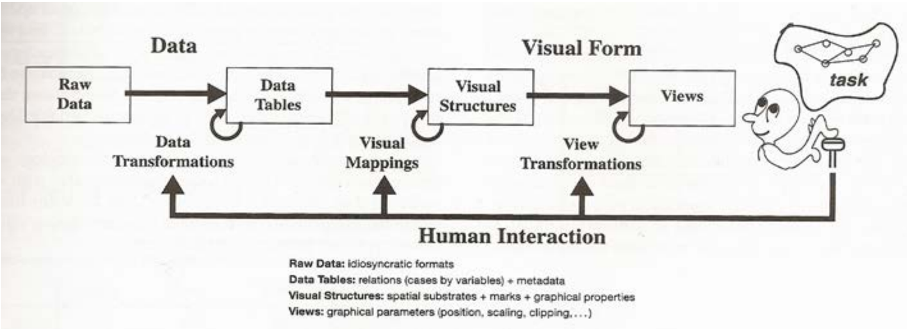


*Figure 41 (Card, Mackinlay et al. 1999)*

.

### 5.5.3 Future Development

There are several directions for the future development of information visualization. The first of all, information visualization will become the mainstream of visualization. The key performance relies on the rapidly hardware improvement and software development. The second is focusing on application as the new techniques are usually created by the particular applications that a way of establishing the value of the techniques. The third is that individual visualizations need to form integrated package. The fourth is networks, which are emerging as an important delivery means. Some information visualization can be done across the network that is used as data. The last one is educational infrastructure, which emerge as a topic for the courses (Card, Mackinlay et al. 1999).

According to Card et al (1999), there are still some key issues need to be solved in the future. The first, it needs a “new metaphors/new visualization”. The new techniques need to found to sort out the stock of visualization because they are easy to invent. The second is to bring the science to the craft and the cyberspace may become one huge net where hold most information. Visualization needs a problem oriented process. The process of information visualization needs integrating into its large context (Card, Mackinlay et al. 1999).

### 5.6 Virtual Environment Visualization

A special visualization called Virtual Reality (VR) that is one of the most "frequently and innovatively" using 3-D visualization technologies. The aim of a VR is immersive environment in which users can interactive with the system in a real experience of perceptive through the related technologies that include a head-mounted display, a instrumented gloves etc (Lee 2009). According to the explanation from Reheingold (1991), Virtual Reality can be defined as an experience of user who enters into a three-dimensional computer-generated representation. User can move around in the virtual world to reach into it, grab and reshape it (Rheingold 1991). A Virtual Reality environment mainly displays by monitors or special stereoscopic displays and some additional systems such as speakers or headphones even haptic systems. Steuer (1999) believes that Virtual Reality has been classified as a medium same as television or telephone, and it is typically "defined in terms of a particular collection of technological hardware, including computers, head-mounted displays, headphones, and motion-sensing gloves" (Steuer 1999, p.35).

Virtual Reality integrates many different techniques on both hardware and software that associated with immersive, 3D environments and graphic hardware acceleration etc (*see Figure 42*). Heim(1993) identifies seven different concepts of Virtual Reality: simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and network communication (Heim 1993). The technologies of Virtual Reality make it possible to recreate many different sites extremely accurately. For example, recreation of a history heritage, the recreation can be presented in the different media. Although original sites might not available to the public or even not exist, the Virtual Reality technology can be used to “develop virtual replicas of caves, natural environment, old towns, monuments, sculptures and archaeological elements” and by using simulate light and materials of the historic site, people could have a better understanding of history (Lee 2009).

At the early period of the Virtual Reality, its application had limited to a few areas such as computer games. However, at the moment, the techniques of Virtual Reality have been extensively used on many domains. For example, in the medical field, the bio-medical images have been used for many medical practices such as diagnosis, treatment planning, rehabilitation therapy etc (Lee 2009). The 3D visualization techniques also are been used in education and the academic fields. Lee (2009) believes that a powerful virtual reality can be used in “enhance a person’s comprehension by allowing him or her to see and control virtual objects and experience the learning environment multidimensionally as in a real environment” such as a virtual environment-generating program called Second Life is used in education field (Lee 2009). The difference is that the program allows the people to design their own virtual environment and interactive with the system.

The programming languages used for the implementation of the virtual reality environment may include C/C++, Perl, Java and Python etc. The most popular computer graphics languages are OpenGL, Dirct3D, Java3D and VRML.

There have two different relations: VR world to user and user on the VR world. For the VR environment, user is interactive with VR and decides when turning head and moving the direction of viewing. To change point of the view of the same object, the viewer position has to be changed; therefore user has to "move". The position of the user in the VR environment could be either without any representation, or presented as a special observatory object of the world (Lee 2009).

*Figure 42*

*(from http://electronics.howstuffworks.com /gadgets/other-gadgets/virtual-reality.htm and http://pieterpelt.com/)*

### 5.6.1 CAVE (Cave Automatic Virtual Environment)

A classic example for an immersive Virtual Reality environment is called the CAVE (Cave Automatic Virtual Environment). The name of CAVE comes from "The smile of the Cave" in Plato's Public in which the allegory of a philosopher discusses perception, reality and illusion from shadows in the cave wall. It is "a multi-person, room-sized, high-resolution, 3D video and audio environment" (Retrieved 2010-04-01). The first CAVE was developed by the Electronic

Visualization Laboratory and demonstrated at the 1992 SIGGRAPH. The initial CAVE was developed in response to a challenge of scientists to create and exhibit a one-to-many visualization tool that utilized large projection screens (Retrieved 2010-04-21).

In side of the CAVE, it is surrounded by walls that compose by the project screens. The user needs to wear some special equipment for entry to the virtual world. The basic equipment is the 3D glasses, which allow user to see “real world” such as objects float in the air, and user has real feeling to enter the space. Other equipment includes glove, speaker or headphone etc. Under the current system settings, the graphics are rear projected in stereo onto two walls and the floor and people view them with stereo glasses. When people move around, it updates the correct perspective and stereo projections of the environment (Retrieved 2010-04-01).

In conclusion, traditional visualization techniques such as brush, pen or traditional typesetting device have been replaced by the more advanced and complex computer technologies such as high resolution monitors, joystick, mouse and keyboard. The new technology of visualization engaging with computer has been proved as an effective technology for visualization that consists of hardware and software. Hardware and software are inter-related constrains that directly affect the effect of visualization. Comparing to software, visualization hardware has got greatly increased in the past decade. From the earliest black and white small computer monitor to large size of LCD display, from the simple keyboard and mouse to complex 3D head-mounted displays and gloves, the physical devices play key role to enhance the effect of visualization. Software is designed to associated development of the hardware. In the basic, software is developed in programming languages. The development of hardware with related software not only provides scientific research with visualization tools for scientific findings, communications but also uses to educational, cultural and entertained services. It is clear that computing technologies has largely improves the effect of visualization and could help to understand complex scientific data.

## Conclusion

The study has presented an analysis of the relationship between creativity and visualization through discussion that draws together previously disconnected theoretical research in disparate domains of creativity and the technologies of visualization.

From the foregoing discussions and investigations, it has been found that the understanding of creativity depends on two basic key points: novelty and value. Typically, concepts of “novelty” are described by comparison to the “old”. The “value” of creativity is usually interpreted as useful or defined as appropriate in relation to some domain-specific goals. However, in practice, the thing that we recognize as creativity has been found to emerge as the result of a much more complex process of interaction between psychological, environmental, social and biological actions and criteria.

Moreover, while differing understandings of creativity have been resulted in different definitions of creativity in different fields and at different times, the thesis accepts and builds on Pope’s (2005) concept of “re-creation” to suggest that creativity indicates a requirement for an ongoing understanding of creativity as a quality that changes or develops along with the evolution of societies or fields. In order to develop this hypothesis, the thesis explored some implications of current scientific theories which suggest that it is the structure and activity of the human brain that generates creative ideas.

The result of this study shows that there is an obvious insufficiency in the study of creativity, specifically in the area of its engagement with the technologies designed to facilitate discovery and representation of those neural structures. At the moment, while most of the theories on creativity do acknowledge approaches from human perceptive, psychological, cultural, neuro-scientific, social domains, there are few approaches to creativity that are mediated through technology; partly because the fast development of technology is changing our understanding of the world and consequently, changing our understanding of creativity.

In addition, most current tests for measuring creativity are based on paper-and-paper tasks such as using questionnaires or brainstorming. The advantage of those question-orientated tests such as the Torrance Tests of Creativity Thinking (TTCT) is that they are fast, brief, easy-to-administer, objectively scorable assessment models. However, those tests have been showed to have limitations in measuring or determining the individual creative ability. In here, it is apparent that we lack a technology-orientated test for measuring creativity. In the technological society, most creative products or ideas are not only the result of thinking or imagination, but also are the results of collaboration of thinking and technology. The actual creative ideas are normally realized by using related technology as an associated tool. All of this suggests not only that we require knowledge of any specific technology but also knowledge of the methods of using technology to facilitate or measure the process of creativity.

Therefore, it is suggested that a new test involved technology needs to be designed for the measuring creativity. For example, a computer game can be designed to test individual ability of creativity; a test on how to create different solutions by using different techniques might be more helpful to measuring individual ability of creativity; a Virtual Reality might be used to create immersive an environment for the measuring spatial creativity in problem solving.

Both of scientists and artists represent data as a visual form. However, the difference between two of them is that scientists tend to visualizing data in an unambiguous way in order to communicate with an interpretation, while artists always using ambiguous and interpretation way for an expression of artist's intentions, for example, artistic data visualization attempts to express artist's intentions by using ambiguous ways.

This study investigates the visualization technology at its two components: visualization hardware and visualization software. The investigation shows that visualization software plays a key role as an interpreter between user and hardware devices. Software receives the command from the user and then it interprets human instructions into machine's instructions and passes the instructions to the hardware to executive the tasks. In such different software, algorithm is the most important part of software. With different algorithm, it generates the different effect to represent data or information. Most of visualization integrates many different techniques both on hardware and software such as Virtual Reality is typical application by using different techniques to present immersive, 3D environments.

In relation to computer-based art creativity, we are faced with two key questions: is the computer-based art work, in itself, a "new" form of creativity? How can we to evaluate the novel role or value of the "autonomous, mechanism" or "thinking machine" model of production offered by computing technology, in terms of creativity? The research suggests that computer-generated art work is a "new" form of creativity if only because those "assisted" or "created" paintings or drawings have an obviously autonomous or mechanism character that distinguish them from the traditional hand-on works. In addition, artists in traditional art creativity often directly perceptive art works and thinking each step throughout the whole process of art creativity.

However, it is also evident that role of computer as a machine in the process of creativity has been largely expanded and goes beyond a role of a tool or a medium to a new concept of “creator”. The new concept of machine indicates a new approach on the creativity in the future. To evaluate the autonomous quality or contribution of technology, we need to set up a theoretical model based on an understanding of our human relationship to these “creative technologies”. It is apparent that these is a gap on the study of the creativity engaging with computing techniques and a deficiency in understanding the active role of technology in the process of creativity.

In conclusion, the problems of how to understand the concepts and manifestations of creativity are of critical importance in many fields. One of the key functions of visualization is effective and efficient to transformation, translation or interpretation of data into visual medium. This study on theoretical models of creativity and their application contributes knowledge about the relationship between and effect of expression on visualization. It has been shown that the model of an approach to creative expression involving new technology is effective in discovering, understanding and representing the value of ideas and/or data across scientific and artistic fields. Creative visualization has significance for scientists, as it seeks new creative models of expression and uses creative technologies to translate and interpret data into visual form in order to facilitate understanding of often complex concepts. On the other hand, his research has significance in the evaluation of creativity or creative practices. For example, artistic data visualization has been defined as an example on analysis of relationship between creativity and visualization. At the first, artistic data visualization is emphasis on “artistic” (creative) concept other than conventional visualization model that represents data with the limited, unchanged, unambiguous techniques and methods. It represents data in an ambiguous, different, intentional visual form. In the second, the new “creative” (artistic) concept not only improves the effect of visualization but also examines the new creative practices in order to explore the understanding of creativity.

Clearly, the limitations of this study cannot cover all the fields in studies of creativity and visualization technologies. Furthermore, what must be emphasized here is that the understanding of creativity is an ongoing process of the new interpretations and exploration. However, there are a number of issues that need to be addressed in future research: A purely technology-based study on creativity is insufficient; the understanding of what is artistic should include the concept of design and craft; developing technological methods to foster the individual creative productivity on visualizing representation of scientific data. The issues of a technology-based approach to creativity will need to include a higher knowledge level of related technology, as well as a focus on defining problems-orientation, and the changing role of technology in the process of creativity.

For the future study, this researcher will continue to investigate the relationship between creativity and visualization by using creative practice-based methods to investigate a specific area of data visualization including the examination of specific data visualization technologies, the development of a model of a visualization technology-mediated approach to creativity, and a practical work of data visualization.

## References

(Retrieved January 13, 2010). "Visualization (computer graphics)." from http://en.wikipedia.org/wiki/Visualization_%28computer_graphics%29.

(2009). "Brainwave Sofa: sitting in your brainwave EEG data." from http://infosthetics.com/archives/2009/10/brain_wave_sofa.html.

(Retrieved 2009-07-10). "Algorithmic art." from http://en.academic.ru/dic.nsf/enwiki/2402695.

(Retrieved 2009-07-21). from http://www.gowlangsfordgallery.co.nz/exhibitions/pastexhibitions/simoningram.asp.

(Retrieved 2009-08-09). "CG Artist." from http://individuals.iii.u-tokyo.ac.jp/~yoichiro/profile/profie.html.

(Retrieved 2009-10-10). "Creativity." from http://en.wikipedia.org/wiki/Creativity.

(Retrieved 2010-01-15). "The Geneplore Model ", from http://www.redchurch.com/quantum/2006/10/24/the-geneplore-model/.

(Retrieved 2010-02-09). "Divergent Thinking." from http://faculty.washington.edu/ezent/imdt.htm.

(Retrieved 2010-03-02). "Computed Tomography." from http://www.merriam-webster.com/dictionary/computed+tomography.

(Retrieved 2010-04-01). "CAVE Automatic Virtual Environment." from http://www.evl.uic.edu/pape/CAVE/oldCAVE/CAVE.overview.html.

(Retrieved 2010-04-21). "Cave Automatic Virtual Environment." from http://en.wikipedia.org/wiki/Cave_Automatic_Virtual_Environment.

(Retrieved 2010-05-09). "VR Hardware." from http://vr.isdale.com/WhatIsVR/noframes/WhatIsVR4.1-Types.html.

(Retrieved 2010-05-27). "Neuroesthetics." from http://en.wikipedia.org/wiki/Neuroesthetics.

(Retrieved 2010-09-10). "Research Methods of Problem Sovling ", from http://dshw.nenu.edu.cn/Courseware/%E5%AE%9E%E9%AA%8C%E5%BF%83%E7%90%86%E5%AD%A6/chapter13/13-1-1.htm.

Allen, R. (Retrieved 2009-07-20). "About the Artist." from http://rebeccaallen.com/.

Attridge, D. (2004). the singularity of literature. Oxon, UK, Routledge.

Bardin, J. (2007). "Neuroesthetics, Part 2." from http://thethirdculture.wordpress.com/2007/07/06/neuroesthics-part-2/.

Barron, F. (1988). Putting creativity to work. The Nature of Creativity. R. J. Sternberg. New York, NY, Cambridge University Press.

Barron, F. and D. M. Harrington (1981). "Creativity, Intellience, and Personlity." Annual Review of Psychology **32**(439-476).

Baudisch, P. and R. Rosenholtz (2003). Halo: a technique for visualizing off-screen objects. Human Factors in Computing Systems
Proceedings of the SIGCHI conference on Human factors in computing systems. Florida, USA

Boden, M. A. (1996). Dimensions of Creativity. Dimensions of Creativity. M. A. Boden, MIT Press.

Bono, E. D. (1971). Laternal Thinking for Managment. New York, McGraw-Hill.

Brandoni, C. and O. R. Anderson (2009). "A New Neurocognitive Model for Assessing Divergent Thinking: Applicability, Evidence of Reliability, and Implications for Educational Theory and Practice." Creativity Research Jounal **21**(4): 326-337.

Cai, D. J., S. A. Mednick, et al. (2009). "REM, not incubation, improves creativity by priming asociative networks." PNAS.

Card, S. K., J. D. Mackinlay, et al. (1999). Readings in Information Visualization using vision to think. San Diego, CA, Academic Press.

Carson, S., J. B. Peterson, et al. (2005). "Reliablity, validity, and factor structure of the creative achievement questionnaire." Creativity Research Jounal **17**(1): 37-50.

Chein, J. M., S. M. Ravizza, et al. (2003). "Using neuroimaging to evaluate models of working memory and their implications for language processing." Journal of Neurolinguistics **16**(4-5): 315-339.

Chen, C. (2004). Information Visualization: beyond the horizon London,UK, Springer-Verlag London

Limited.

Cropley, A. J. (1999). Definitions of Creativity. Encyclopedia of Creativity, Academic Press.

Csikszentmihalyi, M. (1988). Society, culture, and person: A systems view of creativity. The nature of creativity: Contemporary psychological perspectives. R. J. Sternberg. New York, NY, Cambridge University Press**:** 325-339.

Csuri, C. (Retrieved 2010-07-09).

Dacey, J. (1999). Concepts of Creativity: A History. Encyclopedia of Creativity, Academic Press.

Dehlinger, H. (Retrieved 2009-08-10). from http://www.generativeart.de/main/01_plotter_eng.php?lang=en&t=main.

Dewey, D. (Retrieved 2010-03-27). "Introduction to the Mandelbrot Set." from http://www.ddewey.net/mandelbrot/.

Drichard. (2009). "Neuroesthetics: An Exploration of Aesthetic Appraisal in the Human Brain." from http://serendip.brynmawr.edu/exchange/node/4177.

Flaherty, A. W. (2005). "Frontotemporal and dopaminergic control of idea generation and creative drive." Journal of Comparative Neurology **493**(1): 147-153.

Franken, R. E. (2001). Human Motivation, Wadsworth Publishing.

Freeman, A. (1999). Signs of the Times: Cracking the Code of Art's Allure. T. U. Courier, The Unesco Courier.

Freud, S. (1908). "The Relation of the Poet to Daydreaming." Collected papers **4**: 173-183.

Ghiselin, B. (1985). The Creative Process: A Symposium. Berkeley, University of Carlifornia Press.

Guilford, J. P. (1967). The Nature of Human Intelligence. New York, NY, McGraw-Hill.

Hansen, C. D. and C. R. Johnson (2005). The Visualization Handbook. Oxford, UK, Elsevier Inc.

Heilman, K., S. Nadeau, et al. (2003). "Creative innovation: possible brain mechanisms." from http://www.ncbi.nlm.nih.gov/pubmed/14972752.

Heilman, K. M. (2005). Creativity and the Brain. New York and Hove, Psychology Press.

Heilman, K. M., S. E. Nadeau, et al. (2003). "Creative Innovation: Possible Brain Mechanisms." Neurocase **9**(5): 369-379.

Heim, M. (1993). The Metaphysics of Virtual Reality, Oxford University Press.

Herman, G. T. (1980). Fundamentals of Computerized Tomography: Image reconstruction from projection, Springer.

Johnson, B. and B. Shneiderman (1999). Tree-Maps: a space-filling approach to the visualization of hierarchical information structures. Readings in Information Visualization using vision to think. S. K. Card, J. D. Mackinlay and B. Shneiderman. San Francisco,CA, Academic Press.

Kharkhurin, A. V. and S. N. S. Motalleebi (2008). "The Impact of Culture on the Creative Potential of American, Russian, and Iranian College Students." Creativity Research Journal **20**(4): 404-411.

Kim, K. H. (2009). "Cultural Influence on Creativity: The Relationship between Asian Culture(Confucianism) and Creativity among Korean Educators " Journal of Creativity Behavior **43**(2): 73-93.

Kipling, R. (1937/1985). Working Tools. The Creative Precess: A Symposium. B. Ghiselin. Berkeley, University of California Press.

Kuo, Y.-Y. (1996). "Taoistic Psychology of Creativity." Journal of Creative Behavior **30**(3): 197-212.

Lau, A. and A. V. Moere (2007). Towards a Model of Information Aesthetics in Information Visualization. Information Vizualization (IV), 2007 International Conference Zurich,Switzerland

Lee, S. (2009). "The development of 3-D visualization technology: the
potential impact on interior design and its consumers." International Journal of Consumer Studies.

Lehrer, J. (2009) Unlocking the Mysteries of the Artistic Mind. Psychology Today **Volume**, DOI:

Lubart, T. I. (1999). Creativtiy Across Cultures. Handbook of Creativity. R. J. Sternberg. Cambridge, UK, Cambridge University Press.

Mandelbrot, B. B. (1982). The Fractal Geometry of Nature. New York, NY, W.H. Freeman and

Company.

McLaren, R. B. (1999). Dark Side of Creativity. Encyclopedia of Creativity. M. A. Runco and S. R. Pritzker, Academic Press.

Mengden, L. v. (2007). "Manfred Mohr - Research in the Aesthetic Universe of the Cube." from http://www.emohr.com/ww2_out.html.

Miller, A. I. (2007). "Unconscious Thought, Intuition, and Visual Imagery - A Critique of "Working Memory, Cerebellum, and Creativity"." Creativity Research Jounal **19**(1): 47-48.

Mish, E. C. F., J. M. Morse, et al. (1990). Webster's Ninth New Collegiate Dictionary. Springfield,MA, Merriam-Webster.

Miyake, A. and P. Shah (1999). Models of working memory: Mechanisms of active maintenance and executive control. Cambridge, UK, Cambridge University Press.

Mumford, M. D. and J. J. Caughron (2007). "Neurology and Creativity Thought: Some Thoughts About Working Memory, the Cerebellum, and Creativity." Creativity Research Jounal **19**(1): 49-54.

Mumford, M. D. and S. B. Gustafson (1988). "Creativity syndrome: Integration, application, and innovation." Psychological Bulletin **103**(1): 27-43.

Niu, W. and R. J. Sternberg (2001). "Cultural influences on artistic creativity and its evaluation." International Journal of Psychology **36**(4): 225-241.

Noll, A. M. (1964). "Computer Compostion with Lines." from http://stage.itp.nyu.edu/history/timeline/lines.html.

Noll, A. M. (Retrieved 2010-02-16). "Examples of Early Computer Art." from http://www.citi.columbia.edu/amnoll/CompArtExamples.html.

Onians, J. (2007). Neuroarthistory: from Aristotle and Pliny to Baxandall and Zeki. New Haven and London, Yale University Press.

Osborn, A. F. (1953). Applied Imagination New York, Scribner.

Perry, T. and P. Wallich (1985). "Inside the PARC: The Information Architects." IEEE Spectrum: 68-69.

Pope, R. (2005). Creativity: Theory, History, Practice. Oxon, UK, Routledge.

Popper, F. (1993). Art of The Electronic Age, Thames and Hudson Ltd.

Ramachandran, V. S. and W. Hirstein (1999). "The Science of Art: A Neurological Theory of Aesthetics Experience." Journal of Consciousness Studies **6**(6-7): 15-51.

Rautek, P., S. Bruckner, et al. (2008). "Illustrative Visualization-New Technology or Useless Tautology?", from http://www.siggraph.org/publications/newsletter/volume-42-number-3/illustrative-visualization-2013-new-technology-or-useless-tautology

Rheingold, H. (1991). Virtual Reality. New York, Summit.

Rothenberg, A. and C. R. Hausman (1976). The Creativity Question. Durham, NC, Duke University Press.

Schmahmann, J. D. (2004). "Disorders of the Cerebellum: Ataxia, Dysmetria of Thought, and the Cerebellar Cognitive Affective Syndrome " Journal of Neuropsychiatric and Clinical Neuroscience **16**: 367-378.

Schroeder, W. J. and K. M. Martin (2005). Overview of Visualization. The Visualization Handbook. C. D. Hansen and C. R. Johnson. Oxford, UK, Elsevier Butterworth-Heinemann.

Scott, G. M., D. C. Lonergan, et al. (2005). "Conceptual Combination: Alternative Knowledge Structures, Alternative Heuristics." Creativity Research Jounal **17**(1): 79-98.

Shneiderman, B. (1991). "Tree Visualization with Tree-maps: a 2D space-filling approach." from http://hcil.cs.umd.edu/trs/91-03/91-03.html.

Smith, A. (2004). Simon Ingram: towards a painting that thinks. Manukau City, New Zealand, ArtSchool Press.

Sternberg, R. J. and T. I. Lubart (1999). The Concept of Creativity: Prospects and Paradigms Handbook of Creativity. R. J. Sternberg. Cambridge, UK, Cambridge University Press.

Sternberg, R. J. and T. I. Lubart (1999). The Concept of Creativity: Prospects and Paradigms. Handbook of Creativity. R. J. Sternberg. Cambridge, UK, Cambridge University Press.

Steuer, J. (1999). Defining Virtual Reality: Dimensions Determining Telepresence. Communication in the Age of Virtual Reality. F. Biocca and M. R. Levy. Hillsdale, New Jersey, Lawrence Erlbaum Associates.

Valle, M. (2008). "Visualiztion and Art." from http://personal.cscs.ch/~mvalle/visualization/VizArt.html.

Vandervert, L. R., P. H. Schimpf, et al. (2007). "How Working Memory and the Cerebellum Collaborate to Produce Creativity and Innovation." Creativity Research Jounal **19**(1): 1-18.

Verostko, R. (Retrieved 2009-10-20). "Imaging the Unseen." from http://www.verostko.com/archive/statements/statement-recent.html.

Viegas, F. B. and M. Wattenberg. (2007). "Artistic Data Visualization: Beyond Visual Analytics." from http://whitepapers.techrepublic.com.com/abstract.aspx?docid=293874.

Ware, C. (2004). Information Visualizatgion perception for design. San Francisco, CA, Elsevier Inc; Morgan Kaufmann Publishers.

Weisberg, R. W. (1993). Creativity - Beyond the Myth of Genius, W.H. Freeman & Company.

Wildbur, P. and M. Burke (1998). Information Graphics: Innovative Solutions in Contemporary Design. London, Thames and Hudson.

Wu, Y., D. A. Chesler, et al. (1999). "Multinuclear solid-state three-dimensional MRI of bone and synthetic calcium phosphates " Proceedings of the National Academy of Sciences of the United States of America **96**(4): 1574-1578.

Zeki, S. (1998). "Art and Brain."

Zeki, S. (1999). Inner Vision. New York, NY, Oxford University Press.

Zeki, S. (2001). "Artistic Creativity and the Brain." Science **293**(5527): 51-52.