# THIRTEEN WAYS OF LOOKING
# A Theoretical Inquiry in Computational Creative Thinking

*Thoughts as Shapes, Ideas as Spatial Relations,*
*And*
*Creative Thinking as Shape Grammar*

*by*
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Submitted to the Department of Architecture and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees

Of

**Master of Science in Architecture Studies and**
**Master of Science in Electrical Engineering and Computer Science at the**
**Massachusetts Institute of Technology**
**September, 2017**



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**‘If we understood something one way, we would not understand it at all’**

*- M. Minsky*

# Thirteen Ways of Looking

by

Dishita G. Turakhia

Submitted to the Department of Architecture and
the Department of Electrical Engineering and Computer Science
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ABSTRACT

The vision of this research is to propose a novel computational framework to study *Creative Thinking*. If we are to embed machines with creative thinking abilities, then we first need to study the evanescent nature of human creative thinking. Creative thinking is neither entirely random nor strictly logical, making it difficult to fit its computation into structured logical models of thinking. Given this conundrum, *how can we computationally study the process of thinking creatively?*

In this research, I first present the current scientific definitions of creative thinking. Through literary survey of cognitive, computational and design thinking frameworks, I identify the missing links between human creativity and AI models of creative thinking. I assert that creative thinking is result of two features of human intelligence, *cognitive diversity* and *social interaction*. Cognitive diversity or the ability to parse knowledge in different ways is a crucial aspect of creative thinking. Furthermore, social interaction between cognitively diverse individuals results in restructuring of thoughts leading to creativity and epiphanies (the aha moments). I posit that Shape Grammar, with its ability to fluidly restructure computation, can be used to study and demonstrate cognitive diversity and interaction. If we conceive thoughts as shapes and ideas as configurations of those shapes, then cognitive diversity can be described as rule-based computation on shapes to generate those configurations; and interaction as the exchange of rules between cognitive diverse entities (humans or machines).

The contributions of this research are threefold. First, I present a literature review of current frameworks, and identify the two gaps between machine and human creativity. Secondly, I demonstrate how shape grammar can fill those gaps of cognitive diversity and interaction. Thirdly, I propose thought-shape framework that adapts principles of shape grammar for computational creative thinking.

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## Acknowledgements

I take this opportunity to express my deepest gratitude to my mentor and advisor Prof. George Stiny, for his patience, encouragement and ceaseless inspiration. Without the stimulating discourses during seminars, this thesis would not have been conceived. I want to especially thank him for allowing me to take risks and as he called it, *be brave.*

I thank my biggest source of inspiration at MIT, Prof. Winston for all his time to advise and encourage me, but more importantly, for being open to unconventional ideas. Prof. Winston's classes, and teachings have been a source of constant motivation for me over the last two years at MIT.

I am very thankful to Prof. Terry Knight for for offering her support and help, not just for academically, but also during my personal struggles. Prof. Knight's feedback has been the most valuable in my growth during the course.

I also extend my gratitude to the entire Computation and Design group, the faculty and the administrative staff, especially Andreaa and Cynthia for their unconditional support.

I acknowledge the great impact the SMArchS Computation Group had on my journey and want to thank Ege, Oscar, Scott, Hunmin, Jonathan and Yasaman for the stimulating discussions about design, research, life and everything else under the sun. I thank all my other friends and professors at MIT who have influenced my life and my thinking in significant way. I also thank all my friends back home in Mumbai and everywhere else who have been my strength before MIT and through my life here.

I thank my best friend Stawan, without whom I would not have been part of the great MIT community. Thank you for being my rock.

Last, but not the least, I thank my wonderful, supportive parents and the best brother in the world, Yatish who make me smile every single day. I am forever indebted to my wonderful parents and my brilliant brother.

## Dedication

*This work is dedicated to Mom, Dad and my brother, Yatish,*

*and*

*to my new home, MIT*

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**‘Creativity is piercing the mundane to find the marvelous’**

- *B. Moyers*

# Chapter 1

# Introduction

### Foreword

*Can machines think?* In 1950, Alan Turing[1] re-framed this question to what we term as Turing test: *Can machines do what we (as thinking entities) can do, well enough that a judge cannot tell the difference?* By segmenting the abstract and intangible aspects of thinking into observable behaviors, Turing re-articulated the quest of building thinking machines as a computational inquiry. This seminal inquiry in theory of computation led to the formalization of field of Artificial Intelligence at the Dartmouth conference in 1956.[2] This set stage for research on the computations of human mind that lead to intelligent behavior and outcomes, so that we can build machines capable of exhibiting similar intelligence.

Over half century later, machine intelligence has become ubiquitous in our lives. Owing to vast bits of training data and fast processing capacity, these machines have the capacity to translate that data into (seemingly sensible) information. As efficient solution space searchers or logical problem solvers or statistically driven (supervised and unsupervised) learners, the machine learning algorithms have exhibited a sophisticated capacity to recognize patterns in noisy data. However, some aspects of human intelligence, such as creative thinking, which does not follow specific patterns are hard problems in AI.[3] Machine learning algorithms also fail to transfer knowledge across diverse domains and in unrelated

[1] Turing, Alan M. "Computing machinery and intelligence." Mind 59, no. 236 (1950): 433-460.

[2] Moor, James. "The Dartmouth College artificial intelligence conference: The next fifty years." Ai Magazine 27, no. 4 (2006): 87.

[3] Wiggins, Geraint A. "Searching for computational creativity." New Generation Computing 24, no. 3 (2006): 209-222.

contexts to device creative solutions.[4] In short, machines are currently incapable of creative thinking or be partners to humans in creative thinking.

Today, as AI researchers[5] aim to achieve the next milestone of machine creativity, I hope to highlight the challenges and possible solutions for achieving this goal in this research. My vision is to present a computational framework that can be used to study and illustrate human creative thinking and then apply in the design of creative machines. The goal is to build creative machines that can perform the role of being creative partners to human designers.

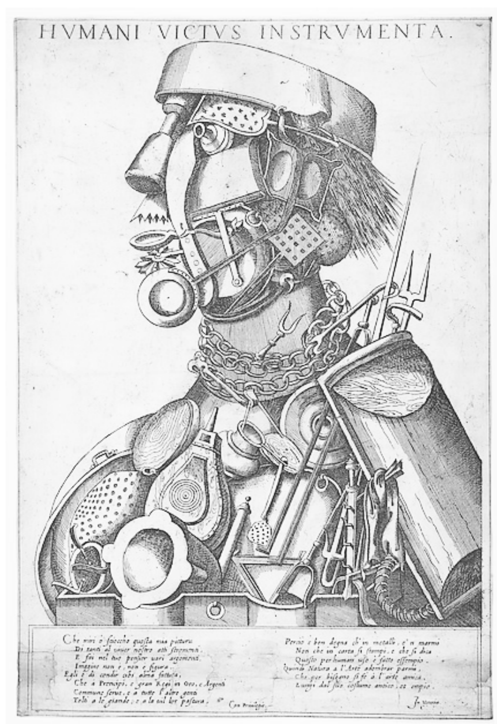



Figure 1.1: Humani Victus Instrumenta (1569)
[6]

*The image[7] above is a sixteenth century engraving of an artist's vision of a human like machine, designed to have the versatile abilities - both mechanical and creative.*

[4]Colton, Simon. "Creativity Versus the Perception of Creativity in Computational Systems." In AAAI spring symposium: creative intelligent systems, vol. 8. 2008.

[5]Colton, Simon, and Geraint A. Wiggins. "Computational creativity: The final frontier?." In Proceedings of the 20th European conference on artificial intelligence, pp. 21-26. IOS Press, 2012.

[7]Image Reference: http://www.metmuseum.org/art/collection/search/367504

## 1.1 Motivation: *Machines as Creative Partners*

Today, the community of AI stands divided[8] on the topic of creativity in context of machine intelligence. Researchers[9] of computational creativity acknowledge the limitations of statistically driven learning methods to produce meaningful creative solutions. But AI enthusiasts, however predict that statistical[10] models of learning might soon become creative partners by learning to create under the supervision of human designer. The motivation of this inquiry is to critically examine "what makes humans such good creative partners?" and how can machines exhibit same characteristics. In short, this project is a theoretical investigation into the potential of machines to be creative partners. My expectation from this inquiry is that by bringing together knowledge of creative thinking from sciences of cognition, computation and design, we can redefine the goals of creative machines. In doing so, we would also reassess the use of current methods of machine intelligence and invent new ways of looking at the challenge of computational creative thinking.

Lickliders vision of man-machine symbiotic enterprise[11] has inspired numerous devices and interfaces[12] that augment our ability to create through human-computer interaction. However, these tools still rely on human creativity to make the outcomes valuable. I argue that these machines cannot replace human designers or behave as creative partners. For example, machines cannot provide insights, inspirations or engage in a creative conversation in ways a fellow-designer can. Also, because most machines or programs behave the way they are expected to, they fail in inspiring their human counterparts the way other humans can.[13] These machines may present foresight or predictions for problems based on memorized or training data, but this form of machine intelligence does not provide an "insight" - the integral feature of creativity. *So what makes humans better creative partners?*

Reflecting on my personal experience of creative problem solving in the field of design, I often managed to escape my cognitive fixation on a certain solution by inviting others perspectives to the problem. And frequently, their diverse perspectives led to creative solutions. As more researchers delve into deciphering the mystery of human creativity and how to build machines to enhance it, this experience made me understand the impact of cognitive diversity and interaction on creativity.

[8] Rowe, Jon, and Derek Partridge. "Creativity: A survey of AI approaches." Artificial Intelligence Review 7, no. 1 (1993): 43-70.

[9] Gero, John S. "Computational models of creative design processes." In Artificial Intelligence and creativity, pp. 269-281. Springer Netherlands, 1994.

[10] Licata, Ignazio, and Gianfranco Minati. "Creativity as Cognitive design: The case of mesoscopic variables in Meta-Structures." In Creativity: Fostering, Measuring and Contexts (F. Columbus, ed). Nova Publisher, 2009.

[11] Licklider, Joseph CR. "Man-computer symbiosis." IRE transactions on human factors in electronics 1 (1960): 4-11.

[12] Jacko, Julie A., ed. Human computer interaction handbook: Fundamentals, evolving technologies, and emerging applications. CRC press, 2012.

[13] Consider for example, a creative team of architects designing a structure within the constraints and contexts provided by the client. Human designers are very efficient in providing feedback or inspiration through a meaningful dialogue. Even with sophisticated programs and chatbots, that might pass the turing test, no program can have a sustained, meaningful dialogue with another human in context of creative thinking

I posit that our creativity stems from our two extraordinary abilities  cognitive diversity and social interaction. Cognitive diversity is the ability to parse the worldly knowledge in diverse ways. The second ability of social interaction is the capacity to communicate our diverse perspectives to each other. As cognitively diverse individuals, our experiences and memories enable us to build models of the world in different ways and thus develop diverse perspectives. And as we interact/converse, we exchange our perspectives with each other and restructure these mental models.

In short, to build machines with creative abilities, we need to first build computational systems that can be "cognitively diverse" or be able to generate multiple perspectives of a given problem. Further, these machines need to have the ability to "explain" [14] their diverse perspectives and interact with humans (either through language or visuals).

[14] through conversation, and not just communication

## 1.2 Vision: *Computational Framework of Human Creative Thinking*

The objective of this inquiry is to propose a computational framework that satisfies the conditions required to study and illustrate the ephemeral nature of human thinking. Our thoughts are dynamically generated, structured and re-structured based on our experiences, interactions and memories leading to new ideas of connections across diverse domains. This behavior can be illustrated computationally, only if the framework is dynamic and fluid enough to accommodate multiple (and possibly infinite) representations of a single entity. Also, to illustrate our ability to connect diverse representations of not just single but also different entities requires working within a flexible paradigm. The rules for generating representations and making connections (between seemingly unrelated concepts in creative way) need to be changeable at any given instant, so that outcomes can be novel yet sensible. In order to explain the meaning in the connections, the framework needs to first find sense in those connections and then be able to communicate the rules. To this achieve this computationally is challenging, but also imperative because this ability represents the core of human creative thinking.

Current statistical methods of machine intelligence do not provide the flexibility essential for such creative processes because of heavy dependence on training data. The objective of this research is to address these computationally hard problems by firstly identifying the specific aspects of creative thinking that lead to diverse representations of single entity, making connections and communicating the rules of those connections. Secondly, by using shape grammar to demonstrate how knowledge can be parsed differently, I propose that we can build cognitively diverse computational systems. The fluid nature of shape grammarian framework also provides the opportunity for emergent ideas through interaction between cognitively diverse systems. The unique method proposed in shape grammar called the *decompose, fuse and embed* cycle (detailed in chapter 4) gives a formal rule based method to generate complex ideas, connect multiple ideas and find new ideas in existing ones.

The broader vision of this research is to contribute towards design of systems that are capable of challenging a designers ways of seeing a problem, and not just solving it or predicting outcomes. By finding the missing link between sentient cognitive models of human intelligence and statistical predictive models of machine intelligence, the proposed computational framework will take the designer on a journey from *foresight* to *insight.* as illustrated in the following figure.

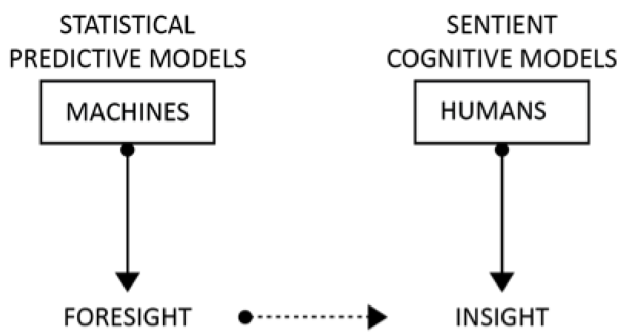



Figure 1.2: Missing Link between Machine Intelligence and Human Intelligence

## 1.3 Hypothesis

In this theoretical inquiry, I posit three arguments.

- Firstly, I present a comprehensive definition of creative thinking that extends the currently restrictive descriptions. I use cognitive, computational and design thinking frameworks to study current literature on creative thinking. The goal of this literature review is to identify which aspects of human creative thinking are not captured in these frameworks.
- Secondly, I provide literary evidence on how two features of human intelligence, namely cognitive diversity and interaction are crucial for creative thinking. I argue that current computational systems are too static and statistically driven to embrace dynamic characteristics of cognitive diversity and interaction; and thus cannot be creative.
- Thirdly, I propose using Shape Grammar framework to embed cognitive diversity (the ability to parse the world using different rules) and interaction (ability to communicate the sequence of rules) in computational systems.

In principle, if we recognize thoughts in terms of shapes and ideas in terms of spatial relations between those shapes, then both attributes of creative thinking namely cognitive diversity and social interaction can be explained computationally using Shape Grammar. In addition to providing a formal framework to study creative thinking, shape grammar also provides a framework to explicitly compute the implicit processes of creative thinking. The rules of shape manipulation, for example, provide a formal mechanism to operate with abstract concepts and convert them into meaningful ideas.

***What do you see?***

## 1.4 Problem Setting: ***Thirteen Ways of Looking***

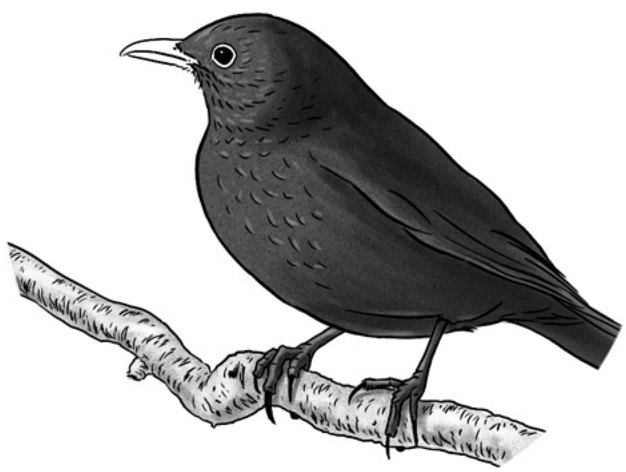


Figure 1.3: Is it a black bird?

*Well, look again...*

***What did poet Wallace Stevens*[15] *see?***

[15]Wallace Stevens is one of America's most respected poets. He was a master stylist, employing an extraordinary vocabulary and a rigorous precision in crafting his poems. But he was also a philosopher of aesthetics, vigorously exploring the notion of poetry as the supreme fusion of the creative imagination and objective reality.
https://www.poetryfoundation.org/poems-and-poets/poets/detail/wallace-stevens

**Thirteen Ways Of Looking**

I
Among twenty snowy mountains,
The only moving thing
Was the eye of the blackbird.

II
I was of three minds,
Like a tree
In which there are three blackbirds.

III
The blackbird whirled in the
autumn winds.
It was a small part of the panto-
mime.

IV
A man and a woman
Are one.
A man and a woman and a black-
bird
Are one.

V
I do not know which to prefer,
The beauty of inflections
Or the beauty of innuendoes,
The blackbird whistling
Or just after.

VI
Icicles filled the long window
With barbaric glass.
The shadow of the blackbird
Crossed it, to and fro.
The mood
Traced in the shadow
An indecipherable cause.

VII
O thin men of Haddam,
Why do you imagine golden birds?
Do you not see how the blackbird
Walks around the feet
Of the women about you?

VIII
I know noble accents
And lucid, inescapable rhythms;
But I know, too,
That the blackbird is involved
In what I know.

IX
When the blackbird flew out of
sight,
It marked the edge
Of one of many circles.

X
At the sight of blackbirds
Flying in a green light,
Even the bawds of euphony
Would cry out sharply.

XI
He rode over Connecticut
In a glass coach.
Once, a fear pierced him,
In that he mistook
The shadow of his equipage
For blackbirds.

XII
The river is moving.
The blackbird must be flying.

XIII
It was evening all afternoon.
It was snowing
And it was going to snow.
The blackbird sat
In the cedar-limbs.

Poem: 13 ways of Looking at a Black Bird [16]

[16] Keast, W. R. "Wallace Steven's "Thirteen Ways of Looking at a Blackbird"" Chicago Review 8, no. 1 (1954): 48-63.

***What did artist Michael Spafford[17] see in Wallace Steven's poem?***

[17] http://www.woodsidebrasethgallery.com/artists/michael-spafford/

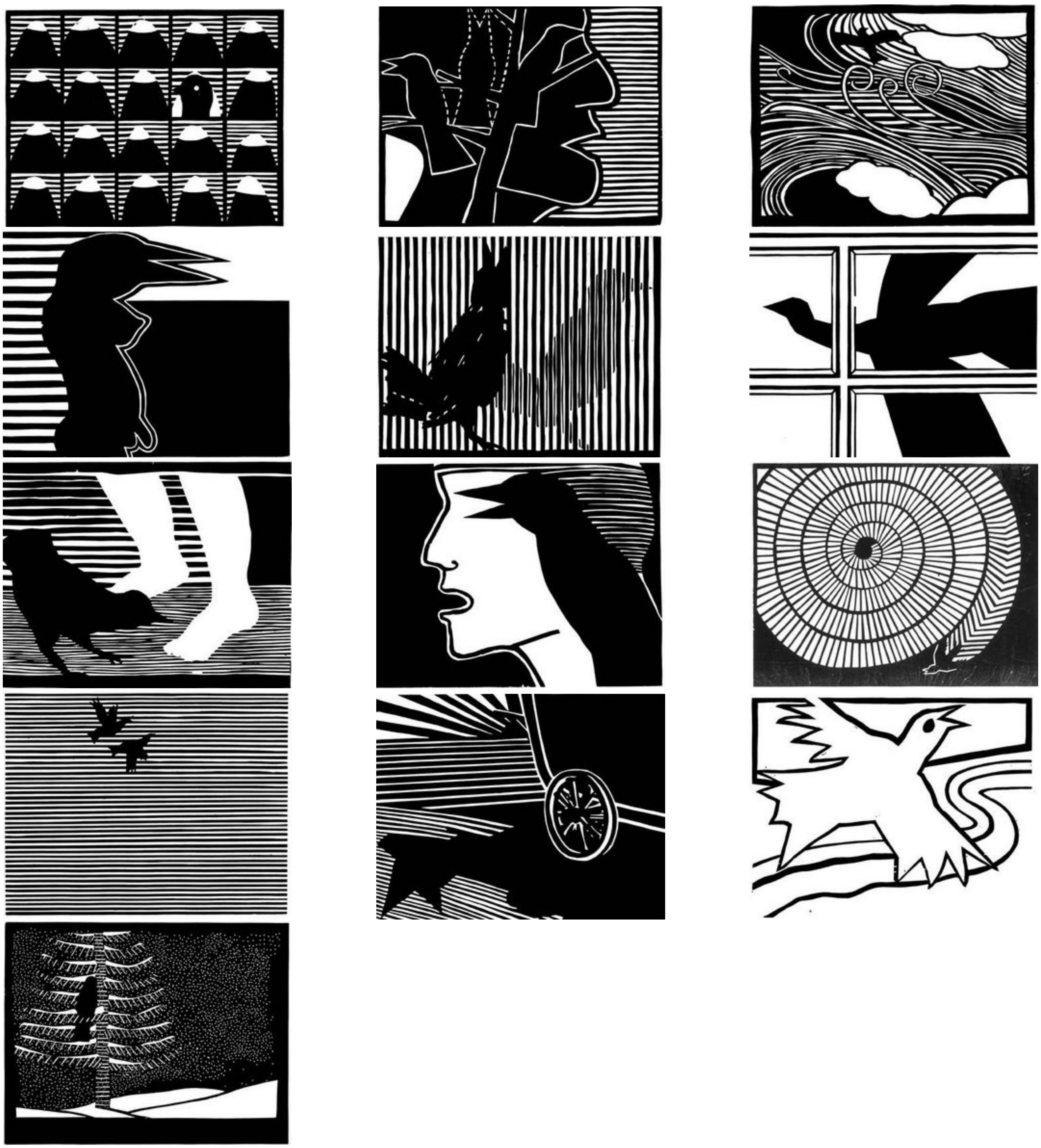


Figure 1.4: Michael Spafford's Interpretation of Wallace's Poem - Thirteen ways of looking

In 1975, Spafford produced Thirteen Ways of Looking at a Blackbird, based on the Wallace Stevens poem of that title. The work consisted of 13 panels, one per stanza.[18]

[18]Image Source: $http://www.artsjournal.com/anotherbb/2009/04/wallace_stevensmichael_spaffor.html$

***And, he looked again*[19]*...***

[19]In 1985, ie. ten years after his first creation, Spafford re-created, and re-produced the 13 panels that were based on Stevens poem

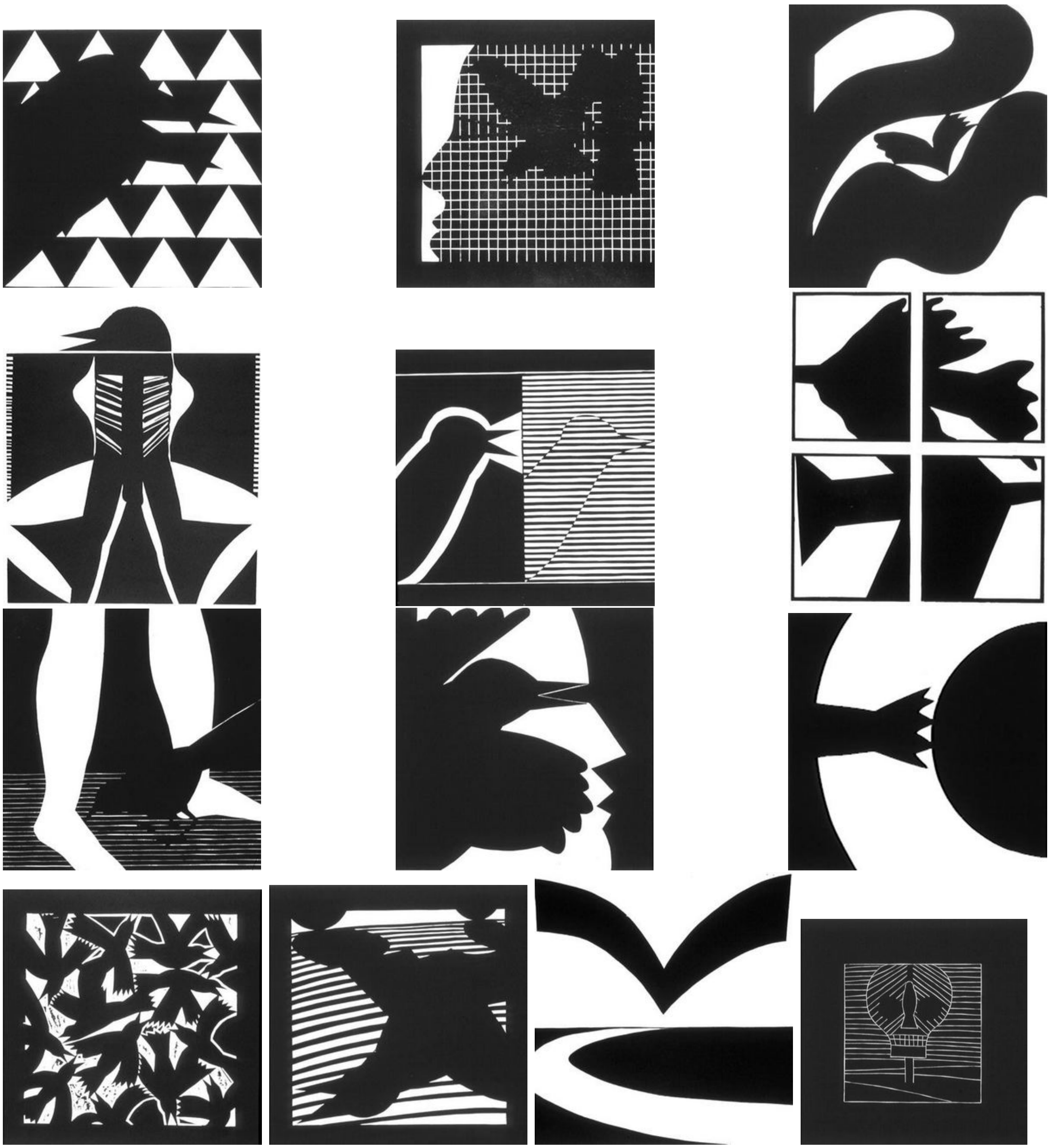


Figure 1.5: Michael Spafford's Re-interpretation of Wallace's Poem - Thirteen ways of looking

Image Source[20]

[20]Image Source: *http://www.artsjournal.com/anotherbb/2009/04/wallace_stevensmichael_spaffor.html*

The value of creative mediums such as poetry, fiction, art, architecture and others emerges from the ability to produce something new but meaningful. The outcomes can be either expression of creative thoughts or creative solutions to constraints or problems. In both creative solutions and art media, the creativity emerges from seeing some meaning that was commonly unnoticed or unknown.

These creative pieces highlight principle question addressed in this research  Where does creativity emerge from? How did Stephen Wallace come about writing this piece of poetic art? And how did his expression lead Michael Spafford to create this visual art? His piece "13 ways of looking at a black bird", presents novel ways of looking at something ordinary and often viewed as insignificant, such as a blackbird. The manner in which he embeds meanings in a blackbird and connects it to seemingly unrelated entities (for example a river) is unarguably creative.

Through his poem, Stephen Wallaces communicates the cognitively diverse ways he used to look at the blackbird which differ from the rest of his audience. As his audience, while trying to extract meaning from his expressions we try to first break his creative connections into components and then reconnect them, so that we might align our way of looking with his. This process of decomposing, fusing and embedding meaning leads to our new way of looking. For example, Michael Spafford formed his own unique way of looking that he expressed in visual art. And as we try to understand his way of looking by decomposing our own, fusing thoughts and re-embedding new meaning, the cascading creative thinking process continues in our minds.

How can/will machines acquire the ability to generate such meaningful creative operations? However, before we can build machines capable of such processes, we need a computational framework to understand dynamic and ambiguous nature of these creative processes. The problem addressed in this research is - how can we computationally talk about these implicit processes of looking at something, embedding meaning and communicate our ways of seeing with each other?

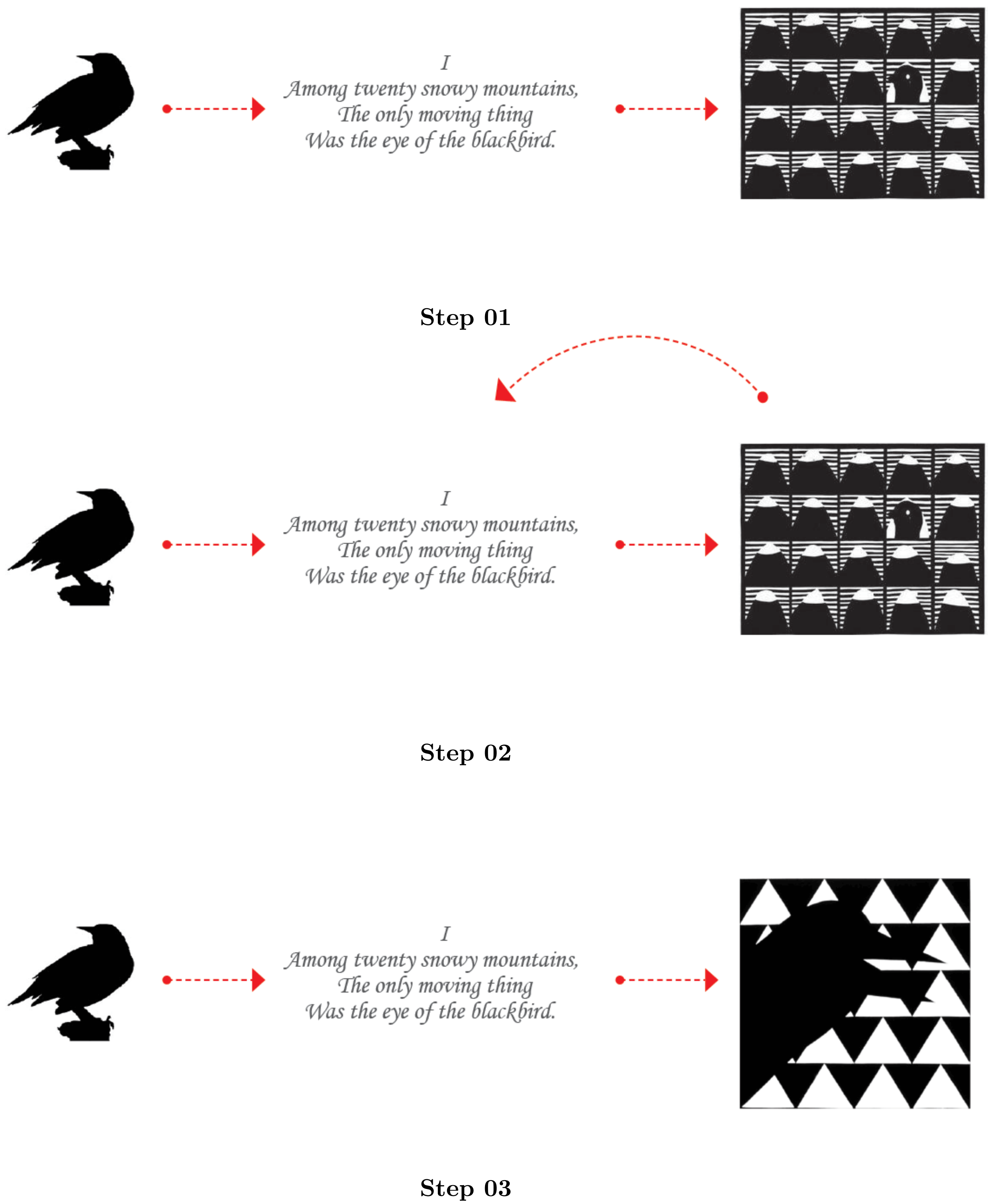



Figure 1.6: Iterative cycle of Human Creative Thinking that can transfer concepts from one medium to another

## 1.5 Methodology and Steps:

The goal of this inquiry is to propose a theoretical model that provides a way to not only study human creative thinking computationally, but also deploy this dynamic process in machines. This inquiry develops in the following stages:

- **Redefining Creative Thinking through literary survey:** I first provide a brief survey of the different scientific definitions of Creativity and Creative Thinking. I primarily use cognitive scientist Boden's definitions of computational creativity. At the end of the section, I highlight the missing aspects of the definition and provide an alternate way of defining creative thinking.
- **Comparative analysis of cognitive frameworks:** In order to study how these definitions of creative thinking can be represented into structured frameworks of cognition, I present a comparative analysis two prevalent ways of understanding thinking within cognitive science. In this analysis, I mainly compare two different ways of representing thoughts - one way represents thoughts as abstract fixed concepts and other way represents thoughts as metaphors and mental states.
- **Comparative analysis of computational systems:** I then extend the comparative analysis to existing computational frameworks of thinking. The goal of this comparative analysis is to highlight the rigidity of existing computational frameworks making it difficult to accommodate the dynamic nature of human thinking within these frameworks.
- **Shape Grammar Framework:** In this inquiry, I present the characteristics of Shape Grammar Framework and how this framework can be used to represent our dynamic thoughts and study creative thinking. I demonstrate how this framework can be used to represent cognitive diversity and social interaction - which I argue the two essential aspects of human creativity.
- **Proposal of Thought-Shape framework:** In conclusion, I present a new approach to understand the evanescent nature of our creative thinking based on shape grammar framework. In this framework, I propose that in principle, if we suppose thoughts as shapes and ideas as spatial relations, we can computationally represent our thinking using shape grammar rules.

## 1.6 Anticipated Contributions: *Thought-Shape Framework*

Through this research, I anticipate to contribute to the field of design theory and artificial intelligence in the following ways:

- Present a comprehensive definition of creativity and what creative thinking entails
- Study literature from cognitive, computational sciences and design thinking
- Highlight the inflexibilities of current frameworks in explaining dynamic creative thinking
- Identify the components of human creative thinking that are missing in current machine intelligence systems
- Demonstrate how cognitive diversity and interaction are two essential features of creative thinking
- Build a formal computational framework to explain cognitive diversity and social interaction in context of creative thinking
- Propose ways of implementing this framework for building applications for computational creative thinking

**‘To define is to limit’**

- *O. Wilde*

# Chapter 2

# Literary Overview

**Foreword to Chapter**

To study creative thinking in terms of computations of mind requires use of diverse frameworks. The goal of this literature review is to survey the different approaches proposed in the fields of cognitive science, computer science and design to explain creative abilities in humans.

In order to understand models of thinking, we need to first understand what are the units of thoughts, how these units are structured to form comprehensive thoughts and how do our interactions enable re-structuring of these thoughts. Furthermore, we need to understand how this re-structuring leads to emergence of new thoughts. I present a comparative analysis between two main cognitive science frameworks of explaining these key questions. The first framework explains thoughts as symbolic representations of knowledge and thinking as a process of symbolic manipulation of thoughts. The second framework explains the process of thinking as drawing connections between similar concepts through structural mapping, as though these concepts were metaphors of each other.

This dichotomy of approaches for understanding the nature of our thinking is also evident in the computational frameworks of thinking. In this literary review, I analyze the two distinctive architectures of mind, one using symbolic hierarchical structure of knowledge and the other using a metaphorical structural mapping of metaphors.

## 2.1 Creative Thinking: *Unpacking the suitcase term "Creativity"?*

Key Questions:

- *What are the definitions of Creativity?*

- *What are the processes of Creative Thinking?*

- *What are the assumptions of these definitions and processes?*

In general, creative thinking can be defined and a mental process involving generation of new ideas or concepts, or new associations of the mind between existing ideas and concepts.

Given this definition, can computers be creative? Ada, Lady Lovelace was the first to express the opinion on how computers and creativity lie on the opposite end of the philosophical spectrum. Her observation of Babbage's 'Analytical Engine' was that the creativity involved in any elaborate piece of music emanating from the Analytical engine would have to be credited not to the engine, but to the engineer. Her remark mainly means that a computer can do only what its program enables it to do.

Cognitive scientist and AI researcher Margaret Boden, however, presents a different view of understanding computational creativity. She breaks the inquiry on computer related creativity into four questions: (i) whether computational concepts can help us understand how human creativity is possible; (ii) whether computers (now or in future) could ever do things which at least appear to be creative; (iii) whether a computer could ever appear to recognize creativity - in poems written by human poets, or in its own ideas about science or mathematics; and (iv) whether computers themselves could ever really be creative (as opposed to merely producing apparently creative performance whose originality is wholly due to human programmer)[1] In her opinion, the fourth question is less significant, but because the answers to the first three is yes, she insists there is value in studying computational creativity.

Boden argues there are principally three modes of creative thinking  combinatorial, exploratory, and transformational. According to Boden, "The combinatorial mode of creativity involves novel combinations of existing old ideas, where the surprise caused by a creative idea is due to the improbability of the combination. The novel combinations have to be valuable in some way, because to call an idea creative is to say that it not only new, but also creative" This generation of new ideas can either be a

[1] Boden, Margaret. "Creativity and knowledge." Creativity in education (2001): 95-102.

deliberate process or a subconscious act. In other words, it involves creation of a new solution space or design space to search. The exploratory creativity involves exploration of design space or as Boden terms it "concept space" to find a new thought that has been previously not discovered, but existed within the landscape. Transformational creativity, involves changing the landscape of design space to generate novel ideas.

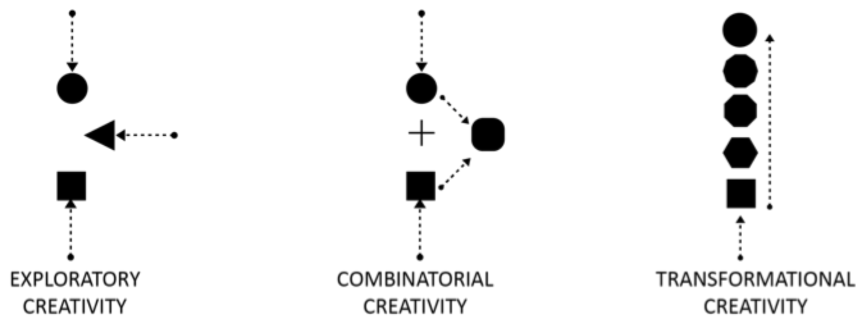



Figure 2.1: Interpretation of Types of Creativity

Boden further emphasizes on elements of surprise and novelty as essential characteristics of a creative idea. An idea might be valuable, but if it has been previously thought or if not surprising, in general it might not be deemed as creative.

These definitions, I argue are restrictive because they encompass only the individual creative thinking. And it assumes that a creative idea is mostly a *new* idea generated from existing ones in different ways. It limits creative thinking to seeing connections in different things  making it a generative or transformational process. I argue that creativity also involves seeing the same thing differently  making it an emergent/decomposition process. This new way of seeing might have connections to preexisting ideas (like metaphors) or might be completely unrelated. This ability to see the same thing differently is also termed as cognitive diversity, explained further in following sections.

Within the scope of this research, creative thinking is the mental process that leads to creative outcomes. In other words, it is the act that involves both seeing connections in different things, but also seeing the same thing in a different way.

In this context, the creative thinking processes are considered analogous to search processes. The underlying assumption is that the design space embodies all the possible solutions and creative thinking merely requires navigating this design space that could be small, astronomically large or infinite.

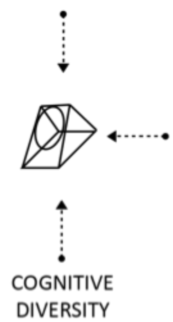



Figure 2.2: Representation of Cognitive Diversity

This assumption implies that the process of creative thinking can be computationally hacked by improving searches within these design spaces. I argue, however, that if creativity was merely searching/exploring/navigating within design spaces, statistically driven machine learning algorithms (that are now capable of large computations), should have been able to generate some form of creative outcomes.

In contrast, human creativity is swift, intuitive and full of *aha* moments. While the processes to reach to those moments are laborious and critical to the creative outcomes, often lead to cognitive fixity. So how do we come up with new ways of seeing? How do we generate new meaningful thoughts in those evanescent moments of epiphany?

## 2.2 Cognitive Frameworks: *What is (creative) thinking?*

Key Questions:

- *What is the basic unit of thought?*

- *What is the structure of thought?*

- *How does social interaction transform this structure of thoughts leading to emergence of new thoughts?*

**Summary:**

In order to understand how we create meanings, generate new ideas and converse about conceptions of our minds, it is first essential to understand what the units of these thoughts are. In general, there is a wide consensus among cognitive scientists and linguists on accepting that concepts form the basis of all our mental activity - although there is difference in definition of concept itself. Also the question of how these concepts are represented in our minds remains unresolved in spite of receiving tremendous research attention. There are multiple views on how we might generate and store concepts in our minds and I provide features of the main theories in this section. In particular, I compare the two diverse views on structure of thoughts - the conceptual semantic framework and the conceptual metaphor framework. One theorizes that we perceive the world in preset or new conceptual frames while other proposes that we acquire new knowledge through frames of existing concepts. Studying the structure of concepts is essential in order to understand how new concepts/ideas can emerge/be formed computationally by changing this structure.

**Concepts**

Concepts[2] are the building blocks of cognition, or in words of cognitive scientist Jesse Prinz - "the basic timber of our mental lives"[3]. It embodies our knowledge about the category and its members. Concepts do not necessarily represent what objects, people, or situations are really like; but they represent what we believe them to be like. Psychologists also use more general terms like mental representations, knowledge structures and schemas to describe concepts more generally. Some terms like prototypes and frames contain specific assumptions about the nature of representation.

Without concepts, our world would make little sense. We would not be able to extract meaning from a huge amount of information that surrounds us, unable to generalize from one experience to another, and unable to effectively communicate with each other. The crucial functions of concepts include classification, inferring additional attributes, guiding attention and interpretation, communication and reasoning.

In contemporary philosophy, there are two prevailing ways of understanding concepts:

- Mental Objects: Concepts as mental representations, where concepts are entities that exist in the brain.
- Mental States: Concepts as abilities, where concepts are abilities peculiar to cognitive agents.

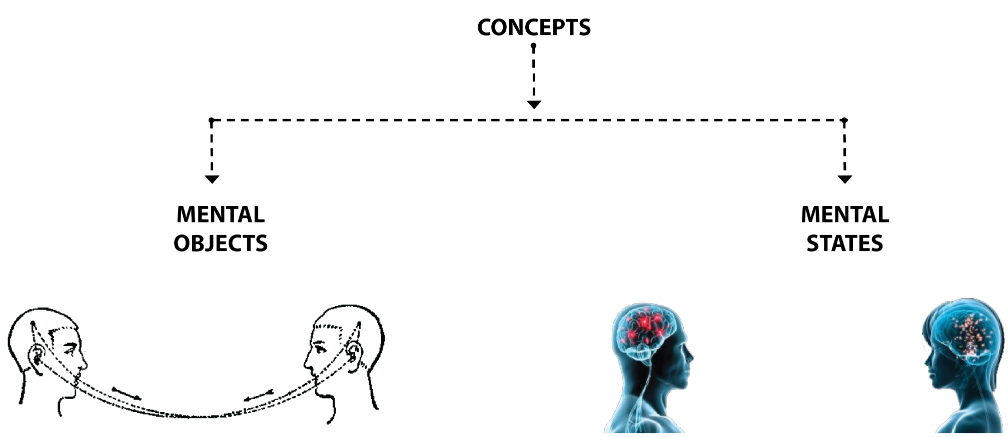



Figure 2.3: Types of Concepts

[2]Kunda, Ziva. Social cognition: making sense of people. Cambridge (Mass.): The MIT Press, 2002.
[3]Prinz, Jesse J. Furnishing the mind: concepts and their perceptual basis. Cambridge, MA: MIT Press, 2004.

| Concepts as Mental Objects | Concepts as Mental States |
|---|---|
| - Disembodied | - Sensorial |
| - Symbolic | - Brain States |
| - Abstract Representations | - Unique to Individuals |

Table 2.1: Properties of Concepts as Mental Objects v/s Mental States

### Structure of Concepts[4]

The classical view of structure of concepts adopted by most philosophers, linguists and psychologists is centered around the assumption that concepts may be defined by a set of necessary and sufficient attributes. However, the inability to come up with a fixed set of attributes or features to define a concept across diverse contexts highlights that this classical view of structure of concepts is inefficient. This classical view[5] where concepts are abstract, disembodied symbols also assumes that the representational format of a concept is qualitatively different from sensory experiences concepts relate to. This general perspective assumes that concepts are ultimately abstracted from brain states that give rise to them, with distinction between conception and perception. Representatives of this symbolic approach include Dennett[6], Jackendoff [7], Newell and Simon[8].

The other emergent perspective on structure of concepts blurs the distinction between perception and cognition. This view assumes that concepts arise directly from brain states. As we perceive and interact with objects of the world, we extract the perceptual and functional attributes of those objects and store the brain states it in our memory. As we imagine that object again at a later time, we simulate our experience with that object, replay those brain states and recall the attributes(similar to Minskys K-line). Different people would have different attributes assigned to the same object based on their experience and interaction. Further, we use these attributes to connect dissimilar objects in the world. We might also use these attributes to understand new objects in the world by connecting its attributes to familiar objects we already know of.

### Symbolic Structure of Concepts

According to Cariani[9], a primitive is an indivisible, unitary entity, atom, or element in a system that has

[4]Kunda, Ziva. Social cognition: making sense of people. Cambridge (Mass.): The MIT Press, 2002.

[5]Margolis, Eric, and Stephen Laurence. The conceptual mind: new directions in the study of concepts. Cambridge, MA: MIT Press, 2015.

[6]Dennett, D. C. 1993. Content and consciousness. n.p.: London ; New York : Routledge, [1993], 1993.

[7]Jackendoff, Ray. 1983. Semantics and cognition. n.p.: Cambridge, Mass. : MIT Press, c1983., 1983.

[8]Newell, Allen, and Herbert A. Simon. Human problem solving. n.p.: Englewood Cliffs, N.J., Prentice-Hall [1972], 1972.

[9]Cariani, Peter. "Creating new informational primitives in minds and machines." In Computers and Creativity, pp.

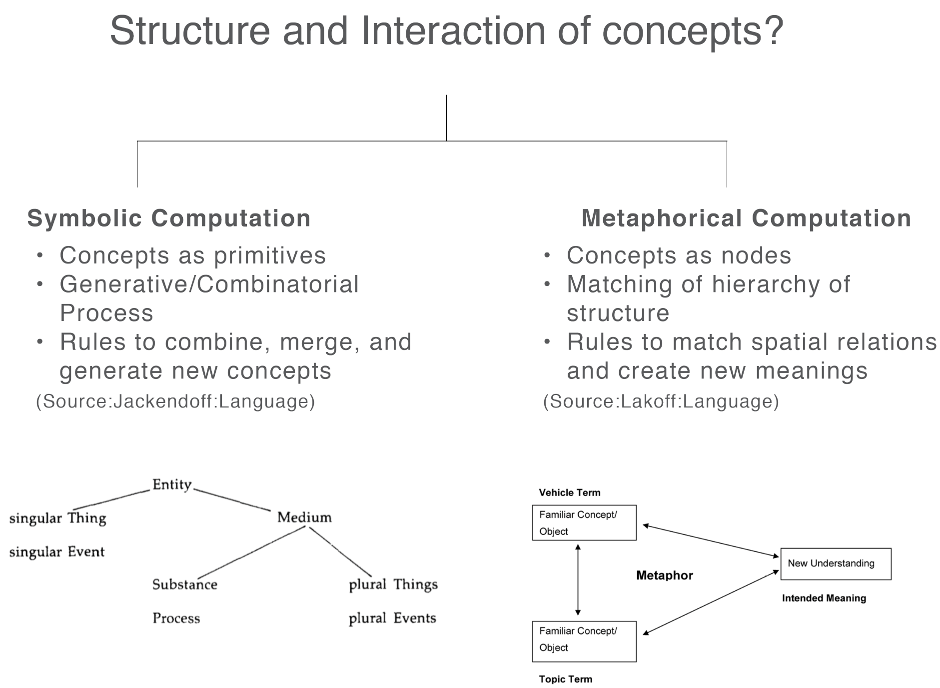



Figure 2.4: Structure of Concepts

| **Symbolic Structure** | **Metaphorical Structure** |
|---|---|
| - Concepts defined as primitive symbols | - Concepts defined as entities on hierarchical structure |
| - New ideas result of symbolic manipulation - Generative and Combinatorial in nature | - New ideas derived by matching nodes and entity properties within hierarchical structure |
| - Computation → Rules of symbolic combination | - Computation → Rules of matching spatial relation |

Table 2.2: Structure of Concepts

no internal parts or structure of its own in terms of its functional role in a particular system. Individual symbols are the primitives of symbol string systems, binary distinctions are the primitives of flip-flop-based digital computers, and machine states are the primitives of finite state automata. Combinatorial creativity then entails either the appearance of new combinations of previously existing primitives or the formation of entirely new ones. The primitives in question depend upon the discourse; they can

383-417. Springer Berlin Heidelberg, 2012.

be structural, material "atoms"; they can be formal "symbols" or "states"; they can be functionalities or operations; they can be primitive assumptions of a theory; they can be primitive sensations and/or ideas; they can be the basic parts of an observers model.

**Metaphorical Structure of Concepts**

According to Lakoff[10], our conceptual system is largely metaphorical, and the way we think, we experience and what we do every day is a very much a matter of metaphor. One way to assess this hypothesis is by looking at language. According to lakoff's metaphor theory, since communication is based on the same conceptual system that we use in thinking and acting, language is an important source of evidence for what that system is like. By giving examples of frequently used linguistic phrases like "your claims are indefensible", "he shot down all his arguments", he claims that we grasp the concept of argument in terms of matching it with the attributes of war. This framework implies that we understand and discover new concepts and ideas by superimposing and matching its attributes with the attributes of existing concepts.

**Social Cognition, Interaction and Restructuring of Thoughts**

Human thinking is deeply connected to our social interaction with each other. We learn not only from direct interactions but also from our observations of each other. Albert Bandura talks about the interdependency of personal agency and social structure. In these agentic transactions, people are producers as well as products of social structures. He further points out that knowledge structures are formed from the styles of thinking and behavior. The knowledge structures are modeled from the outcomes of explanatory activities, verbal instruction, and innovative cognitive syntheses of acquired knowledge, (in short communication and conversations). In other words, he highlights how conversations lead to new knowledge structures being formed  a process significantly different from knowledge acquisition. He also refutes the prevalent psychological theories that have focused almost exclusively on learning through the effects of one's actions (meaning people learn by performing actions and noticing the effects they produce) - sort of like testing hypothesis.

In short, this theory of social interaction implies that the structure of our thoughts and concepts (or, our mental objects and mental states) alter by our social environments (and not just by our disembodied individual thoughts).

[10] Lakoff, George, and Mark Johnson. Metaphors we live by. University of Chicago press, 2008.

But how does interaction lead to restructuring of our thinking? Zawidzki fragments the process social interaction in 4 stages that lead to thought transformation:

- **Mindreading:** It refers to a phenomenon also called $'mentalizing'$ or exercising one's $'theory of mind.'$ Mindreading is the ability to understand each others goals, desires and objectives. Basically the theory implies that we succeed in cooperating with each other in a dramatically wider variety of endeavors, of dramatically wider complexity, involving far greater numbers of interactions than any other primates because we are far better mind readers and far better at anticipating each others behavior.

- **Mindshaping:** Shaping each others minds is one of other cognitive behaviors we engage in at a subconscious level ceaselessly. We either are influenced by someones ideas or try to influence them. The ideas can be perceived to exist at two statuses and mindshaping theorizes that if one of the two people has a higher status, then he/she changes the mind of the other lower status.

- **Pervasive Cooperation:** In this stage, once, two (or more individuals) have shaped each others minds, the next stage is pervasive cooperation when there is sync in understanding and similarity in mental states.

- **Symbolic Communication:** While language is of course the best example of symbolic communication, other forms include music, ritual, art and dance. Human communication stands out from other species that communicate because it marries extremely complex structure with extremely flexible use. There is a finite set of rules for pairing semantics with expressions, allowing for the well-ordered construction of an infinite variety of messages.

In conclusion, I argue that while communication enables creation of new ideas and thoughts, there are also cognitive stages prior to communication which lead to reshaping of our thoughts and are instrumental in our creative abilities.

## 2.3 Computational Frameworks: *Can we computationally replicate (creative) thinking?*

Key Questions:

- *What are computational frameworks of creative thinking/problem solving?*

- *Can these frameworks be dynamic to accommodate interactive creative problem solving/ What are the CSC (Computational Social Creativity) models?*

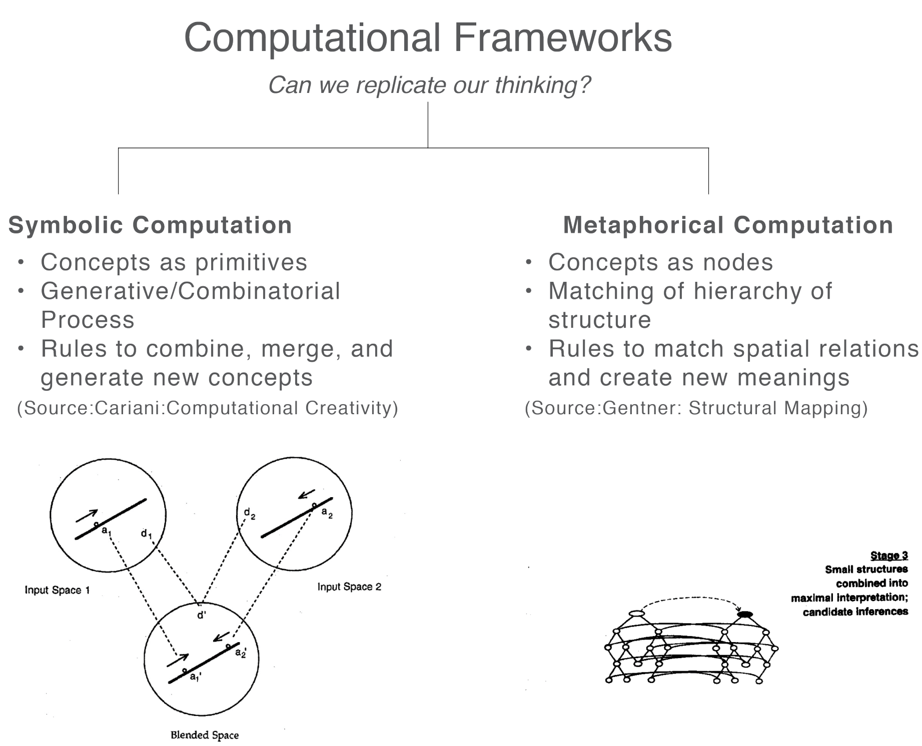



Figure 2.5: Computational Framework of Concepts

**Summary:**

When this difference in understanding of concept is extended to computational frameworks, the resultant models exhibit rigidity, especially in context of creative thinking. - Symbolic - In the symbolic approach, concepts are fixed symbols results as a combinatorial process, where algorithm searches the

solution space for all possible combinations.
- Metaphorical - In the metaphorical approach, connections are formed through analogies, ie. by matching new structures with previously learned, existing ones. [11].

However, in both these frameworks, primitives get predefined, attributes get pre-assigned and once meaning embedded, it does not allow multiple representations. These frameworks cannot explain our cognitively diverse views and how social interaction restructures our thoughts. In short, thinking becomes an iterative algorithm.

Our thinking is ephemeral - one moment we might understand something one way, another moment completely differently. We dynamically decompose our thoughts, fuse them and embed thoughts. Units of thoughts are evanescent in nature. They serve the purpose of explaining the meaning only momentarily and then next moment, disappear, or reappear to make new meanings.

[11] Gentner, Dedre, and Arthur B. Markman. "Structure mapping in analogy and similarity." American psychologist 52, no. 1 (1997): 45.

## 2.4 Critique on literature: *What is missing?*

Creative thinking is not just an iterative process - it is an interactively process - where meanings are constantly created and redefined. Thus it involves generation and decomposition. It is dynamic in the sense that new goals are created while trying to achieve existing ones. I claim that creative thinking is not an iterative puzzle-solving process where one finds missing parts and connects them but it is the process of generating new meanings and images from existing puzzle pieces.

In cognitive frameworks, because we have already embedded meanings in concepts (the basic unit of thoughts), we can engage in generative creative thoughts where we create new meanings by combining two or more existing ones, or connect two or more ideas, but we do not change the meaning of existing concepts. This partially static nature is evident even in the computational frameworks which is basically symbol manipulation, or generation of new symbols, but there is no way to change the meanings of existing symbols. An effect of this framework can also be explained in design thinking frameworks where ideas are defined as merge-create exercises. While there might be generation of creative ideas, it is limited.

**'A designer sees, moves, and sees again.'**

- *D. Schon*

# Chapter 3

# Domain of Inquiry: *Design*

If creative thinking is the process that leads to solutions, then design is the way of externalizing the implicit process of creative thinking. Creative thinking is a dominant component of the process of designing, and thus design is a good medium to study how we think creatively. Design processes can be documented, and analyzed and computationally represented. If we can study and represent the dynamic aspects of design, we can, by analogy extend the computational framework to creative thinking.

*What is design?* Stiny[1] describes design as being neither a process, nor a product(Or solution). Computationally speaking, design is neither an algorithm that produces an output, nor the output itself. Stiny defines designs as useful tools to describe things for making and showing how they work. In other words, designs function as descriptions that communicate ideas, knowledge, and creations in a definitive way. These descriptions could be in the form of drawings, text, graphs, numbers, mathematical expressions, models, etc. These designs can be partial *descriptions* like construction drawings or multifaceted with connected descriptions across different mediums. These descriptions could also vary from person to person.

[1] Stiny, George. "What is a design?." Environment and Planning B: Planning and Design 17, no. 1 (1990): 97-103.

> "Designs follow from a confluence of considerations, some dealing with form, and others dealing with aesthetics, function, material, construction, and so on. The impetus for practice comes from multiple perspectives that may each be dominant at different times. These perspectives make their separate contributions but are connected, allowing for diverse interests and goals to interact and to influence one another mutually. Designs are complicated and multifaceted; they are the very stuff of relations, algebras, and computations."

Now suppose if we use algebraic methods to describe designs. We can now computationally understand designs as set of transformation rules (schemas) and relations between the elements transformed. The grammar that emerges from describing designs as set of rules and relations can be used to describe same thing differently by different people or can be used to describe different things in similar way. (Each design description can be considered as a unique perspective.) This flexibility provides an opportunity to draw connections between elements and entities across domains and thus engage in creative thinking. It also allows for specialists to communicate across domains and contribute by examining designs from different perspectives. This computational framework also provides means of communication with machines through programs.

Based on the properties of the elements, this computational framework can be used to study and describe designs in art, architecture, poetry, literature etc. More importantly, we can study the diverse perspectives of looking, creating, understanding various designs. The focus of this research is to study these diverse perspectives in relation to design. How do diverse perspectives affect design, and how do designs enable communication across diverse domains?

In the following sections, I will detail the terms cognitive diversity and interaction and further detail how these aspects can be used algebraically to describe designs and creative thinking in general.

## 3.1 Cognitive Diversity: *Looking at same thing, seeing differently*

Figure 3.1: What do you see?

Consider the figure above as an example, and describe what you see? Whether you see the figure being a vase, or two faces or both or something entirely different, you would be correct in your observation. As long as you can embed a meaningful relation between its entities, explain how you embedded that meaning using that relation, you would have a correct interpretation of the figure, irrespective of what the creator of the figure intended.

This ambiguity and open-endedness is a valuable component of creative thinking. It allows for creation of meanings in different forms, across different domains just by changing our ways of looking at the problem. We practice this open-ended way of looking at things in most fields, but particularly more often in creative fields. Artists and designers often leverage this ability of seeing different ways for designing creative solutions. This ability is termed as cognitive diversity and I will present how cognitive diversity is the key to our creative thinking.

In general, cognitive diversity can be defined as different ways in which people construe the world. Neuroscientist Laura Otis[2] emphasizes the importance of cognitive diversity in her book, Rethinking Thought that features interviews with 34 creative professionals (scientists, engineers, web and game designers, novelists, poets, painters, photographers, lawyers, teachers, and flamenco dancer). Otis describes how different experts are cognitively diverse - for example a mathematician can "see" the math in objects and a dancer who can calculate the structure of dance in steps as if formulating an

[2]Otis, Laura. Rethinking Thought: Inside the Minds of Creative Scientists and Artists. Oxford University Press, 2015.

algorithm. She further points out that *creativity often occurs at the intersection of diverse perspectives - while shifting from one way of seeing, thinking and analyzing to another way.*

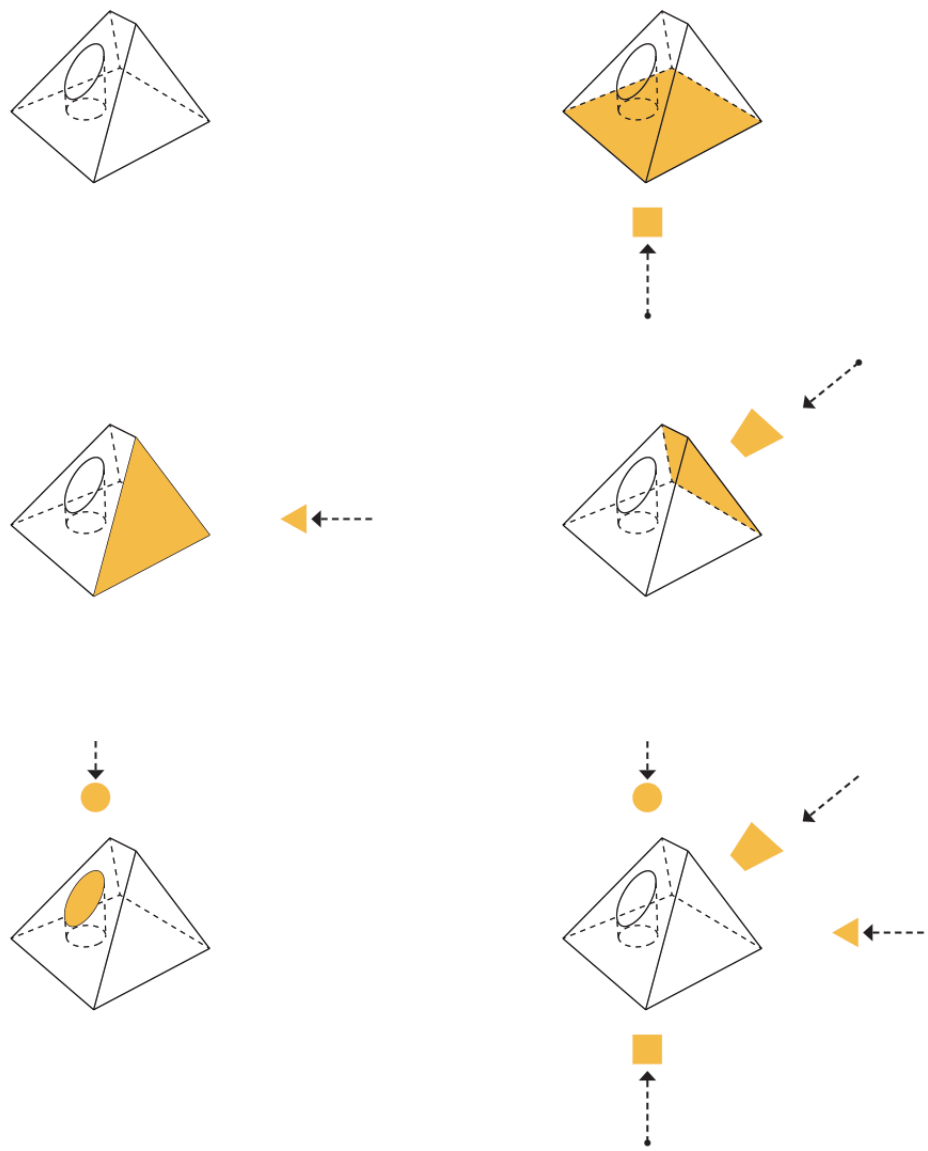


Figure 3.2: Cognitive Diversity: Different Rules of Parsing the World

As described in the foreword of this chapter, using algebraic methods of describing designs gives us a computational way of communicating our perspectives. For example, consider the following figure how might we describe this design algebraically?

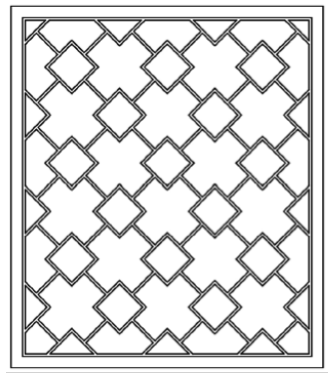


Figure 3.3: Design of lattice

Based on personal preferences, we might formulate multiple interpretations of the given figure and generate multiple (possibly infinite) ways of designing it, parsing it. If you look at the figure as a series of crosses arranged diagonally, you would generate a rule to design the figure using crosses. Or, if you look at the figure as a series of squares and lines, you will use squares and lines to generate the design. In general, the rules we use to parse the information explain the way we look and interpret a given entity, in this case the geometric design. This aspect of knowledge parsing is particularly significant, because depending on diversity or similarity of our rules of parsing and interpreting a given entity, we can construct models of our cognition.

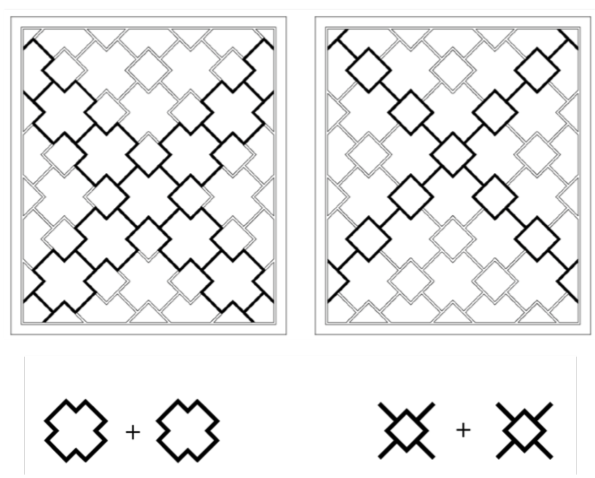


Figure 3.4: Cognitive Diversity: Different perspectives of seeing the same thing

Changing the ways of seeing to find new design possibilities is valuable because it opens a plethora of possible outcomes. This process is different from random generative algorithmic approach to design generation because unlike a generative process, which aims to only produce multiple options without any intended meanings, this approach has meaning embedded in the outcome. Meaning embedded in each output is a result of specific set of rules and specific grammar and vice versa. Further, this process is also significantly different from a mere design-space search algorithm. Changing the way of seeing changes the design-space landscape, and thus the characteristics of design previously unknown get revealed. From a computational standpoint, this means encoding the same information differently, using different rules. Thus rule based grammar is a powerful tool to study cognitive diversity of people.

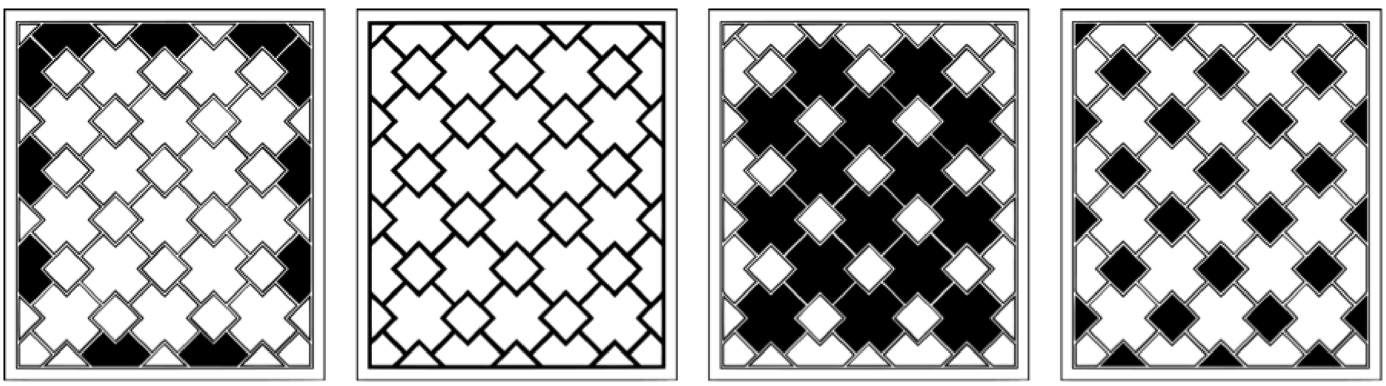


Figure 3.5: Possibility of outcomes based on cognitive diverse perspectives

The distinctive feature of cognitive diversity from a design space search is that changing the way of seeing changes the design space landscape, and thus the characteristics of design previously unknown get revealed. Thus, the same design can be viewed differently from cognitively diverse perspectives. From a computational standpoint, this means encoding the same information differently like in the following example. Based on how you parse the image into elements, the meaning you embed in the image changes.

Figure 3.6: What do you see?

For a given entity, in this case an image, how do we parse or decompose a given entity into its components? Is the process deliberate and conscious or cognitively sub-conscious? Stiny uses the following illustration example of Albertis landscape from "Hypnerotomachia Poliphili"[3] where the character Poliphilo ("Friend of Many Things", from Greek Polloi "Many" + Philos "Friend"), wanders in the woods. This illustration is particularly captivating because of how the shape of the character emerges, or "jumps at you" after seeing at it for a few moments longer.

This illustration is from *Hypnerotomachia Poliphili* by Francesco Colonna
Translated by Joscelyn Godwin Published by Thames & Hudson ISBN 0500 019428

Figure 3.7: Alberti's Landscapes

Are these the tricks of the eyes or our imagination? Shakespeare connects the experience of emergent figuration with emotional state of mind.

*Or in the night, imagining some fear,*
*How easy is a bush supposed a bear!*

If creative thinking is dependent on the ability of seeing differently, it is imperative to understand how do we see differently. Surely, our sensory and perceptive apparatus plays a vital role in how we make sense of the chaotic world. This principle explains the Gestalt behavior and theory using shape forms. But do we also rely on our sensory perception to make sense of the non-visual entities? Consider the

[3] Image Source:http://special.lib.gla.ac.uk/exhibns/month/feb2004.html

following poem by Jorie Graham on "The Way Things Work", where she explains that to understand the forces of the physical world is by just opening them, not resisting, having faith that the objects will reveal their ways of behaving. She talks about parsing the world constantly in different ways, and believing that eventually, the way will emerge.

***The Way Things Work***

*The way things work*
*is by admitting*
*or opening away.*
*This is the simplest form*
*of current: Blue*
*moving through blue;*
*blue through purple;*
*the objects of desire*
*opening upon themselves*
*without us; the objects of faith.*
*The way things work*
*is by solution,*
*resistance lessened or*
*increased and taken*
*advantage of.*
*The way things work*
*is that we finally believe*
*they are there,*
*common and able*
*to illustrate themselves.*
*Wheel, kinetic flow,*
*rising and falling water,*
*ingots, levers and keys,*
*I believe in you,*
*cylinder lock, pulley,*

*lifting tackle and*
*crane lift your small head*
*I believe in you*
*your head is the horizon to*
*my hand. I believe*
*forever in the hooks.*
***The way things work***
***is that eventually***
***something catches.***

In a way, Jorie Graham talks about the phenomenon of "Interaction → Epiphany". She encourages us to keep interacting with the objects of the world until an insightful discovery takes place. This process of interaction that leads to epiphany is described by Donald Schon[4] When he talks about design as a reflective practice.

> *"A designer sees, moves, and sees again. Working in some visual medium–drawing, the designer sees what is 'there' in some representation of a site, draws in relation to it, and sees what he or she has drawn, thereby informing further designing."... In all this "seeing," the designer not only visually registers information but also constructs its meaning–identifies patterns and gives them meanings beyond themselves. Words like "recognize," "detect," "discover," and "appreciate" denote variants of seeing, as do such terms as ' seeing that, "seeing as" and "seeing in." This process of seeing-drawing-seeing is one kind of example of what I mean by designing as a reflective conversation with the materials of a situation."*

But is this process entirely dependent on our perceptive and sensory apparatus? Can seeing new things be a systematic process that does not entirely depend on serendipitous moments of epiphany? Or can we engage in a systematic process of interaction and discovery without falling in the trap of cognitive fixity? In the following section, I present a framework by mathematician and social scientist Scott Page to understand cognitive diversity of different people.

[4] Schon, Donald A. The reflective practitioner: How professionals think in action. Vol. 5126. Basic books, 1984.

## 3.2 How to study Cognitive Diversity?

Mathematician and social scientist Scott Page in his book, The Difference[5] explains how cognitive diversity contributes towards creative thinking. He argues that the process of innovation may depend a lot less on intelligence of lone thinkers but more on diverse people working together through capitalizing on their individuality. He makes a case for how diversity trumps ability. The cognitive diversity of an individual can be encoded in four variables  perspectives (ways of representing the world), heuristics (techniques and tools for making improvements), interpretations (ways of creating categories) and predictions (inferences about correlation and cause and effect). If two individuals differ in ways of encoding knowledge in any of these variables, they are cognitively diverse and vice versa.

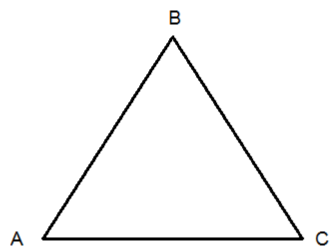
**Perspectives:** A perspective is a map from reality to an integral language such that distinct object, situation, problem or event gets mapped to a unique word. Each frame of perspective embeds an intelligence based on training and experience. When we say that two people have different perspectives, we could mean one of the two things. We could mean that they map reality differently into the same internal language or that they map reality into different internal languages.

An internal language can be written in words, in numbers or symbols or in abstract shapes and forms. Internal language is different from spoken or written language and is where the flexibility arises from because same object or thing can be encoded to different words internally. For example, Lets say we represent a triangle in the form of its angle and adjacent sides. Given the figure(1), the same object can be encoded in multiple ways even using same internal language of angles and adjacent sides  As AngleA, SideAC and Side AB; or Angle B, SideBA and Side BC. Conversely, we can also use different languages to describe the following figure, which can be encoded as a square or 4 perpendicular lines and both perspectives would be correct.

New perspectives can be built by changing existing ones. As we will observe in following sections, Shape Grammar uses this flexibility of perspectives to devise multiple ways of looking at a design and how creativity emerges from this flexibility. This is not to say that all diverse perspectives are helpful and valuable, but diversity of perspectives is certainly valuable in escaping cognitive fixity.

**Heuristics:** A heuristic is a rule applied to an existing solution represented in a perspective that

[5] Page, Scott E. The difference: How the power of diversity creates better groups, firms, schools, and societies. Princeton University Press, 2008.




generates a new (and hopefully better) solution or a new set of possible solutions. In general, heuristics are used to search for optimal solutions, but can also be used to simply explore the solution space or the design space. Diversity of heuristics not only helps in generating different solutions, it can also help in switching between different perspectives. While applying new heuristics, we might realize that the same way of solving might be more effective for a different context, thus giving an opportunity to connect between different concepts and ideas. New heuristics also create unexpected movements within a certain framework, revealing a certain dimension previously unseen by others. Within academic fields, the construction of new heuristics is a constant enterprise  in short, making new ways of solving problems, new ways of designing, new ways of making etc.

Heuristics and Perspectives are highly related and often deployed in different contexts for creative thinking and problem solving. Diversity of perspectives and heuristics together can lead to diverse new outcomes. But creativity also arises from changing the landscape of the design space itself. By this, I mean that by not only seeing something in a different way, but also interpreting the same thing in new way, we can generate new meanings from existing entities.

**Interpretation:** If perspectives are mappings from reality to a unique word in the internal language, interpretation is mapping from categories of things, situations, events and objects to words. In an interpretation, one word can represent many objects. In some sense, this is a higher level of parsing of the world. These interpretations help us with knowledge acquisition by interpreting this new knowledge using existing categories within our knowledge. We often do not assign each situation, event or outcome its own name, but use categories to lump similar events together and describe them. Interpretations are valuable in creative thinking because a given thing can be interpreted in multiple ways and lead us to draw diverse inferences and insights into the given thing.

**Predictive Models:** If interpretations help us in revealing insights, predictive models help in foresight.

We can create hypothesis, judgments, and predictions using computational models. These predictive models enable us to navigate the solution search space and propose optimized solutions.

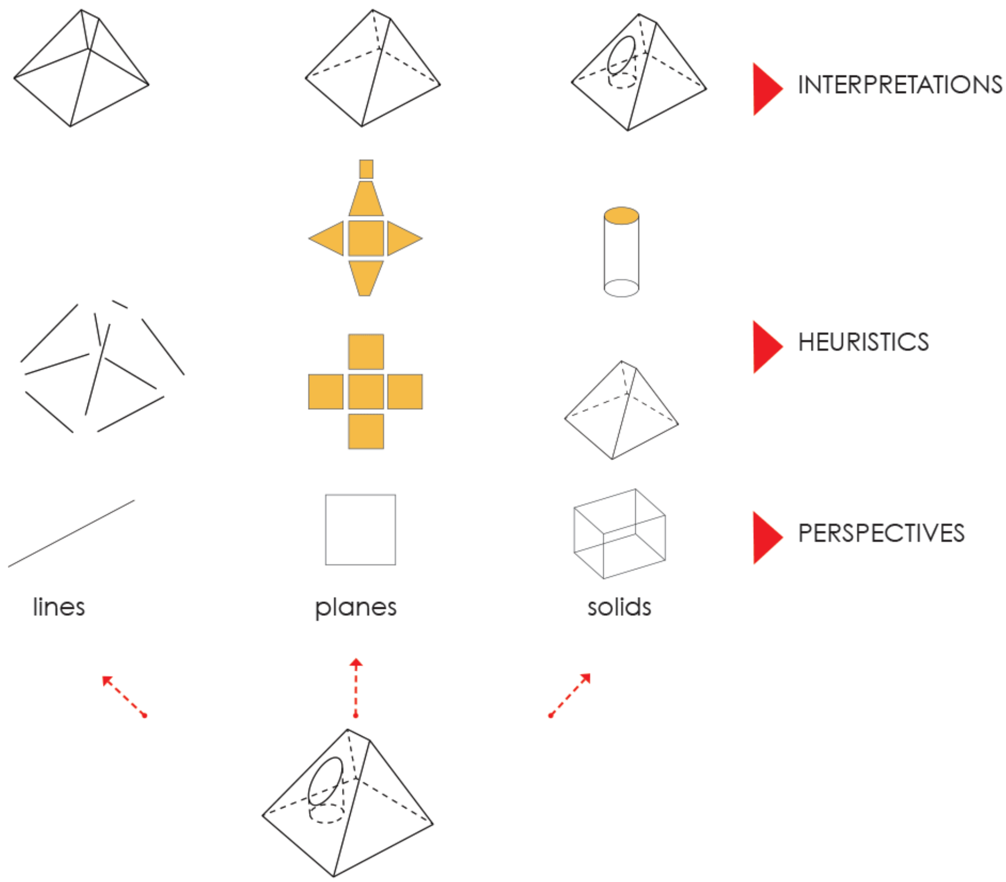



Figure 3.8: Using cognitive diversity toolbox - perspectives, heuristics, interpretations and predictions

Using this toolbox of our intelligence, which consists of perspectives, heuristics, interpretations and predictions, we can now understand our cognitive diversity more scientifically. Also, we can now break the process of creative thinking into more structured computational components. In the following chapter, I present how Shape Grammar framework provides opportunity to construct the cognitive diversity toolbox computationally. However, before we understand how cognitive diversity can be structured computationally, I will first explain the role of interaction between cognitively diverse people for creative thinking.

## 3.3 Role of Interaction

If we all were cognitively diverse and not able to interact, there would be little value in having that diversity in the population. It is also imperative to be able to exchange the information and knowledge of different perspectives, heuristics, interpretations and predictions between diverse people. As mentioned earlier, neuroscientist Otis suggests that creativity often occurs while switching between one way of seeing to another. I argue that interaction is one way of triggering that switch, by exchanging ways in which we parse the world.

Interaction, in the scope of this thesis is defined as the method of communicating each others perspectives, heuristics, interpretations and predictions. In other words, it is exchange of each others rules of parsing knowledge. I argue that in spite of having infinite possibilities of generating creative ideas, we tend to be fixated on our ways of seeing/solving/understanding a certain thing. However, our interactions with our environments help us escape this cognitive fixity because we are offered new ways of looking/solving/understanding that thing. In short, interaction is exchange of our rules of parsing knowledge. Learning these new rules of decomposing and embedding boosts our creativity.

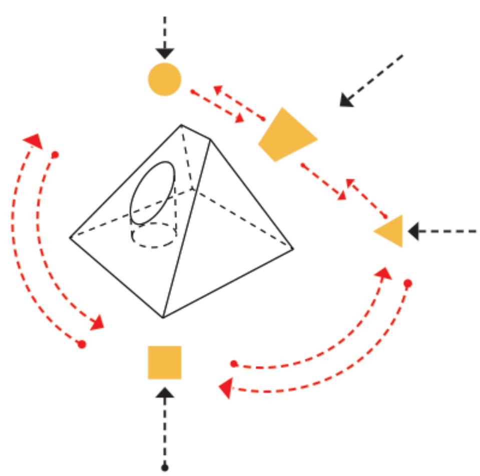


Figure 3.9: Role of Interaction in Creative Thinking: Exchange of Rules of Parsing

**What is Missing?**

In this section, I first explained the value of looking at the same thing but seeing different things using examples from literary and visual art. I then provided a framework that can be used to study peoples cognitively diverse outlooks. I also explained how interaction between diverse people is essential to creative thinking.

But can this aspect of cognitive diversity be computationally embedded in machines? Circling back to the overarching vision of this thesis of building machines/computational systems capable of being creative partners, I reiterate that we need to embed cognitive diversity and interactive capabilities in these systems. The process of going from interaction to epiphany moment is a dynamic one. In order to accommodate multiple perspectives, heuristics and interpretations that lead to diverse predictive models, the computational framework needs to be flexible. By flexible, I mean that for example for the following figure, the framework should be able to accept the definition being 2 squares, or 1 rectangle + 1 line, or 5 lines, or 7 lines. The framework also needs to be flexible enough to switch between these multiple perspectives at any given point of time.

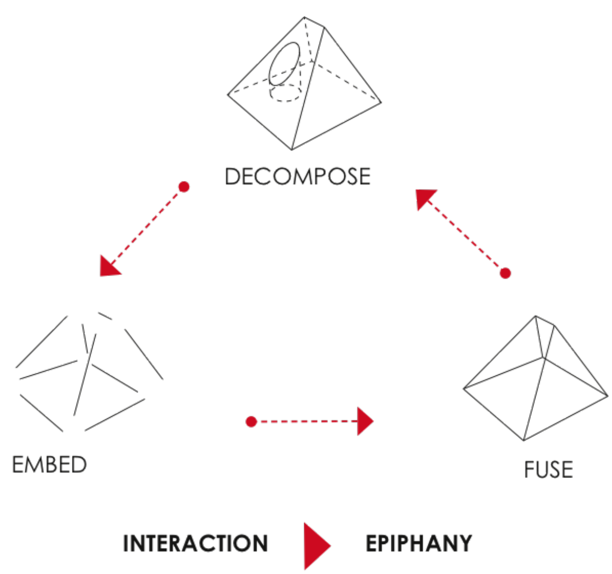



Figure 3.10: The dynamic cycle of interaction to epiphany

In general, computational frameworks do not have the flexibility of recoding given information and restructuring it over in new ways or formats. For example, if a figure is constructed out of lines, the decomposition of that figure will always be in into those same lines. However, Shape Grammar is unique because it provides a computational framework that allows dynamic restructuring and revision of how the information is encoded and decoded.

**'Designing is a practical way of thinking (reasoning) in which seeing is key, but its thinking all the same.'**[6]

- *G. Stiny*

[6] Stiny, George. Shape: talking about seeing and doing. MIt Press, 2006.

# Chapter 4

# Shape Grammar Dynamism

**Foreword to Chapter**

Shape grammar is a formal system to understand and create design drawings through a systematic algebraic (rule-based) computation of shapes. However, the basic unit of shapes is not fixed and can be changed at any point. In short, the computation does not need to have memory and previous representations can be overwritten. This allows for restructuring of rule-sets, re-framing of methods and reformulation of goals anytime during the process of computation. This feature of accommodating fluidity of representation is vital for emergence of novel forms from point of view of creativity. Gips[1] states that one of the wonders of application of shape grammars to solve specific design problems is the potential of surprises and emergent behavior. (In other words, the epiphany or aha moment.)

In this section I describe Shape Grammar  definitions of shapes, value of using algebraic rules and grammar for spatial relations and how this grammar can exhibit dynamism. I further explain how Shape Grammar eloquently explains cognitive diversity and interaction - the two aspects that are focus of this thesis.I lay the groundwork for proposal of the main contribution of this thesis  the Thought-Shape Framework, where thoughts can be described in terms of shapes and subsequently creative thinking can be explained by Shape Grammar.

In the following sections, I give a background to Shape Grammar and connect the concepts of shapes, spatial relations, shape computing and grammar with the process of creative thinking.

[1]Gips, James. "Computer implementation of shape grammars." In NSF/MIT workshop on shape computation, vol. 55, p. 56. Cambridge, MA: Massachusetts Institute of Technology, 1999.

## 4.1 Shapes, Rules and Grammar

In general, shapes can be defined as the external form or appearance characteristic of someone or something; the outline of an area or figure; or the particular condition or state of someone or something. In short, shapes are ambiguous forms that are visible, describable in terms of its components, but not definite. In the context of Shape Grammar, Stiny[2] describes Shapes as follows:

> *"Shapes are formed when basic elements of a given kind are combined, and their properties follow once the embedding relation is extended to define their parts. Shapes can be made of points, lines, planes or other shapes. Every shape is defined crudely with discrete elements that are numerically distinct, but with no implied granularity or structure."*

Shapes are thus characterized by the properties of its components, but not limited by it. This means that shapes are not only formations of its components, but also subshapes that were not necessarily used to create the shape. For example, the following shape can be 2 squares that were used to generate the shape, or even 4 triangles or 8 lines or even 12 smaller lines.

> *"This sub-shape relation allows for shapes to be decomposed in any way whatsoever. Reciprocally, shapes are composed by combining them in sum and differences. Shapes are defined in different algebras, compared to numbers."*

According to Stiny[3], the three substantial advantages of using shape grammar properties for computation in exploring designs are: novel representation of drawing process without definite assignment of units and features in the beginning; use of dynamically changeable rule set and transformations in the design process; and possibility of new rule emergence at any time during computation. He also stresses the structure of rules is evanescent and need not be remembered as the computation moves forward.

A computation in a shape grammar is a series of labeled shapes produced by following rules:

- Rules of generation
- Rules of decomposition

[2]Stiny, George. Shape: talking about seeing and doing. MIt Press, 2006.

[3]Stiny, George. "A note on the description of designs." Environment and Planning B: Planning and Design 8, no. 3 (1981): 257-267.

Creative thinking emerging from Cognitive Diversity can be defined as a cyclical or iterative process involving rules of decomposition - where existing objects are decomposed using shape rules. As we decompose a shape into its entities, we embed meaning to the shapes based on its spatial relations. The next stage of this process involves rules of fusing, which can also be extended to rules of generation.

Shapes and arrangement are different because one is ambiguous, other is clear. Shape is indefinite and dynamic where is arrangement is definite and static in that moment. A shape can divided further in sub-parts and becomes an arrangement of those sub-parts. Thus shapes are cognitive and visible, but are ambiguous until the meaning is embed or reified by explaining through spatial relations. Shapes come first, and arrangements/spatial relations or sets are ideas and can be clear.

*"A shape grammarian exploits the ambiguity in art and design. Ambiguity is something to use. Many things alter freely the way shapes do when you look at them second time."*[4]

4

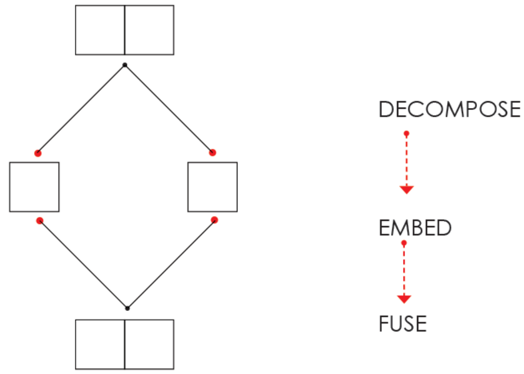



Figure 4.1: Shape Grammar Framework: decompose-embed-fuse cycle

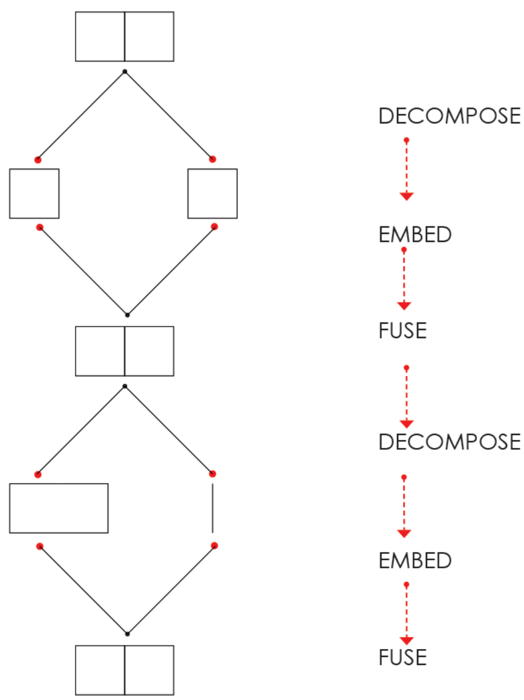



Figure 4.2: Shape Grammar Framework: Parsing information differently everytime the decompose-embed-fuse cycle runs

## 4.2 Shape Grammar Dynamism: *Seeing and Doing*

The main takeaway of the shape grammar framework, besides computing and creating with shapes, is the dynamic process of restructuring. Stiny describes the process of restructuring information as a 3-step cycle of decomposition, fusion and embedding. Shape grammarians have shown theoretically, mathematically and computationally how shape manipulation (often practiced in design for drawings) through rule based grammar can demonstrate all forms of creative processes. Stiny describes how lines (drawings) can do surprising things in combination to confuse the eye and to excite the imagination: they divide and fuse in unexpected ways to offer new opportunities for change. In this section, I present the shape grammarian features that are valuable in illustrating how cognitive diversity and interaction between cognitively diverse individuals can be computational.

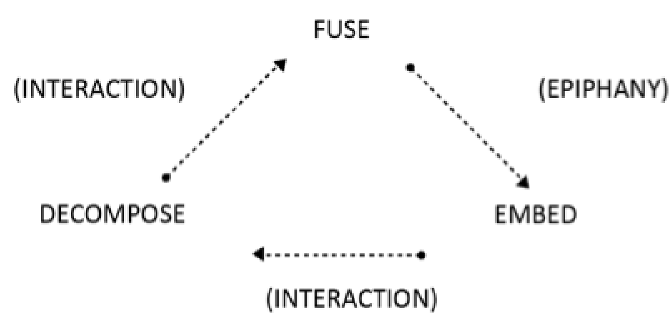



Figure 4.3: Seeing and Doing represents the Decompose-Embed-Fuse cycle

## 4.3 Shape Grammar in Design

According to Stiny and Gips[5], designs are neither products nor processes but rather are descriptions of making things and descriptions to show how the things work. Because designs are descriptions, they are complicated and multifaceted. In general, designs are described as drawings, diagrams and illustrations. These drawings may be single descriptions or multi-faceted, for example plan and elevation together describe the design of a three-dimensional object. However, drawings are not the only form of descriptions, sometimes designs are described in the form of 3-dimensional geometries (CAD models in Computers) or physical models supplemented with additional instructions and commentary. Because many devices connect to make designs, they are described as n-dimensional relation among drawings, other kinds of descriptions, and correlated devices.

The value in defining designs as description is that these descriptions can be formulated in terms of algebras of shapes. These algebras describe relations between shapes and provide procedure to generate designs. Additionally, these algebras also help in discovering different ways of generating same design using same or different shapes. This feature of shape grammars is highly appreciated because now we have a computational method of describing designs. It is a framework to not only generate designs, but also study existing designs by decomposing it into algebraic rules.

According to Stiny[6], "designs follow from a confluence of considerations, some dealing with form, and others dealing with aesthetics, function, material ,construction, and so on. The impetus for practice comes from multiple perspectives that may each be dominant at different times. These perspectives make their separate contributions but are connected, allowing for diverse interests and goals to interact and to influence one another mutually. Designs are complicated and multifaceted, and composed of relations, algebras and computations."

In addition to providing a computational framework, the value of Shape Grammars is in how it combines computation with human cognition. It takes into account how artists and designers engage in creative thinking by cognitively (talk about how designers embed meanings and how algebras embed relation of sub-shapes etc

[5] Stiny, George, and Lionel March. "Design machines." Environment and Planning B: Planning and Design 8, no. 3 (1981): 245-255.

[6] Stiny, George. "What is a design?." Environment and Planning B: Planning and Design 17, no. 1 (1990): 97-103.

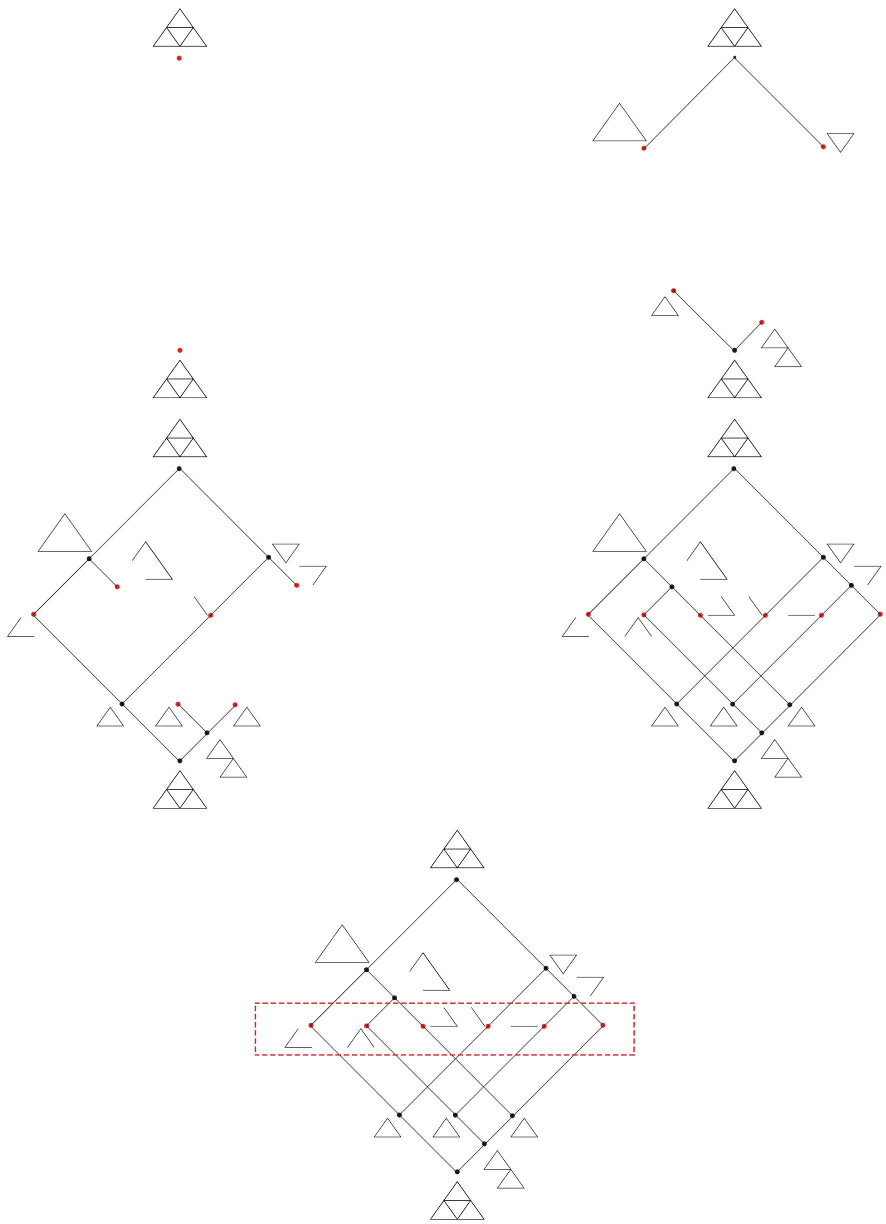
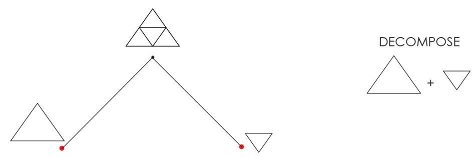


Figure 4.4: Cognitive Diversity explained in terms of Shape Grammar Framework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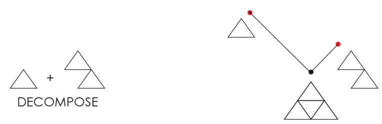
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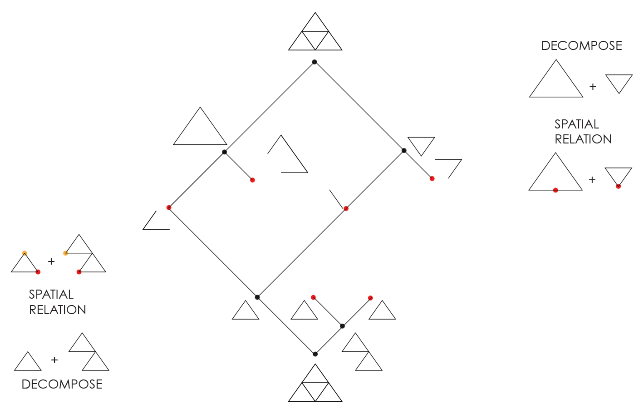
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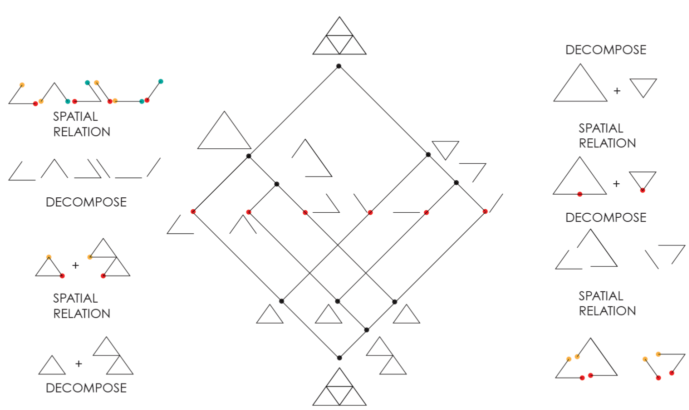
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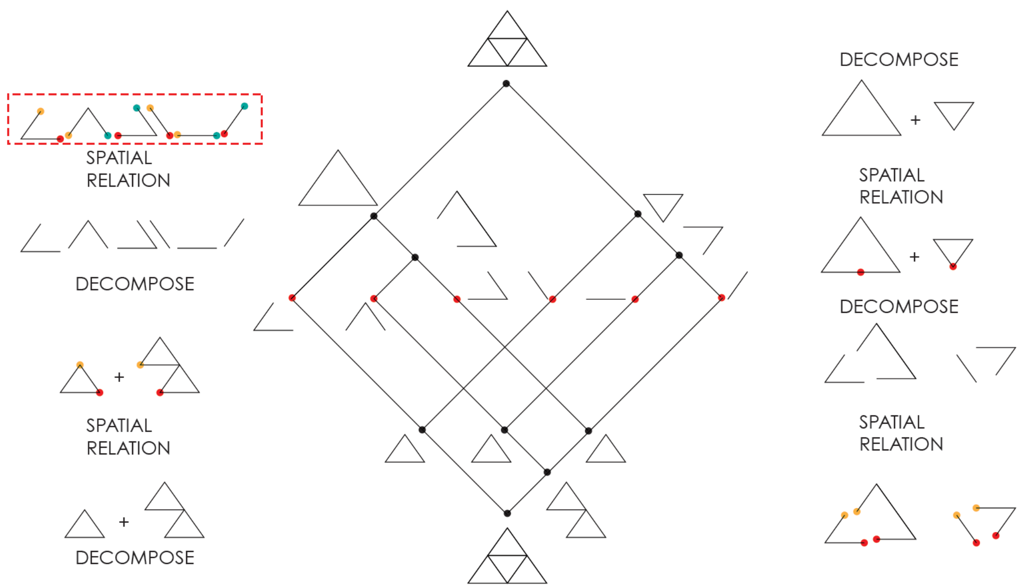


Figure 4.5: Design as Spatial Relations - using Rule based Grammar/Computation

## 4.4 Shape Grammar Programs

Based on the given descriptions of rules of design generation and decomposition described in the earlier section, we can now build computational programs for design. Gips[7] suggests that shape grammar programs can be of three types interpreter, parsing, inference.

In an interpreter kind of program, one (user/designer) enters shape grammar (shapes + rules) into the program and the interpreter generates the outcomes. Thus, this is a generative program. A parsing program is given a shape grammar and a shape, and the program, determines if the shape is in the language generated by the grammar. If the result is a positive, then the program gives the sequence that would generate the shape input based on the input grammar. This is an analytical program. In the inference program, the input is a set of shapes and the program is expected to generate the grammar to make those input shapes.

The workings of shape grammar can be explained best as following. Imagine two light sources that pass the light through a series of frame with cutout shapes projecting at a screen. An interpreter is light source 1 where the cutout frames and its sequence are given and the task of the program is to generate the subsequent shapes. A parser is the source 2 where cutout frames are given, and the program needs to figure out the sequence of arrangement of the cutout frames in order to get the shape projected on the screen. An inference program can only see the projector screen and needs to figure out which shapes and what sequences would generate the shape on screen. The third kind of program is hardest to design because of the infinite design space. But this concept is similar to Minskys concept of frames and his discussion on cognitive diversity.

The Shape Grammar formalism, and these programs can be extended to thinking. Stiny and Gips use Craiks schemas[8] to connect design with thought processes. According to Craik, thought involves three processes:

- Translation of external processes into words, numbers or symbols
- Arrival at other symbols by reasoning, deduction, inference etc

[7] Gips, James. "Computer implementation of shape grammars." In NSF/MIT workshop on shape computation, vol. 55, p. 56. Cambridge, MA: Massachusetts Institute of Technology, 1999.

[8] Stiny, George, and Lionel March. "Design machines." Environment and Planning B: Planning and Design 8, no. 3 (1981): 245-255.

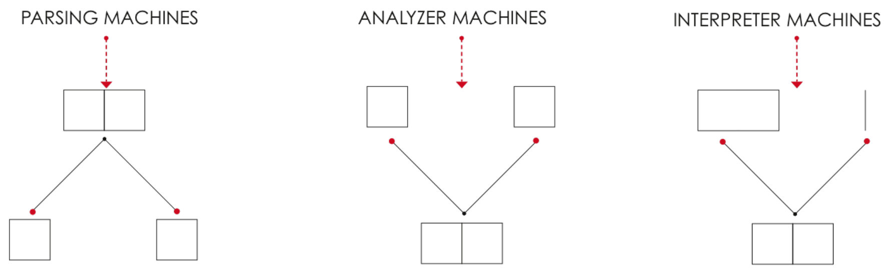


Figure 4.6: Types of Shape Grammar Programs

- Retranslation of these symbols into external processes

Reasoning is the crucial aspect because it is the mediating part the thinking part and the part that interacts with the external world. In some sense, it gathers information from the external world, parses it in a particular way, fuses it again to embed meaning and then communicates back to the external world.

## 4.5 Cognitive Diversity and Interaction Through Shape Grammar

I will use the analogy of light sources and frames to describe relation between shape grammar and cognitive diversity. Cognitive diversity is essentially the different frames and the sequences used to create the same on the projector screen. In Scott Pages terms, the frames are the diverse perspectives, the sequence is the different heuristic, interpretation is the final projected screen and the prediction is the confidence levels in knowing what image will be projected on the screen. When two light sources use different set of frames or different sequence to make the same image, they demonstrate cognitive diversity.

Now if these sets of frames and sequences were exchanged between these light sources, this interaction would lead to escaping the cognitive fixity of these light sources. Not only are these light sources now equipped to diverse knowledge, but also possibility of generating new shapes, sequences and configurations.

Now replace the cutout frames as thoughts, the configurations as ideas, what we have achieved is a creative thinking process between cognitively diverse individuals. If we replace one light source with a human and another with a machine, we can achieve a human-machine symbiotic creative thinking enterprise. In the next section, I explain how we can adapt shape grammar framework for creative thinking.

# Chapter 5

# Thought-Shape Framework

**Foreword to Chapter**

In order to use the Shape Grammar framework to explain thoughts, ways of thinking and how to change those ways of thinking, we need to understand how thoughts can be explained in the Shape Grammar framework.

I propose that instead of understanding thoughts in terms of static units of concepts as abstract objects or metaphors, we can understand them in terms of dynamic shapes. If thoughts are assigned properties similar to shapes, in principle we can consider ideas analogous to spatial relations between shapes. Ideas can be considered as unique spatial relations where meanings emerge out of random, ambiguous collection of thoughts. By thinking of thoughts as shapes and ideas as spatial relations, we can now consider creative thinking as a computational process that can be studied, represented and computed in shape grammar formalism. In this chapter, I present how this approach can lead to development of thought machines capable of creative thinking.

## 5.1 Thoughts as Shapes

Thoughts and shapes share many similarities. Thoughts are connected, disconnected, continuous, discrete, linear, cyclical, hierarchical, overlapping, illusion, broken, whole, partial, complete, abstract, meaningful, meaningless, and much more. While thoughts are not physical entities, they have properties that we intuitively know exist. Shapes on the other hand have the same properties and behavior. Shapes also have the characteristics of similarities, differences, and ambiguity and can be used to explain metaphors, analogies and other frames of references. Shapes, I argue can be perfect conduits for externalizing the internal thoughts.

Shapes are somewhat measurable, with characteristics that are describable. This is why shapes can be a valuable medium for communication, interaction, between different entities/systems/individuals. The advantage of shapes is that we can compute and calculate with them. If creative thinking is computation of thoughts and concepts, then visual computing is a perfect framework to understand computational aspects of creative thinking.

## 5.2 Ideas as spatial relations

A diagram is generally a collection of shapes arranged specifically in ways to generate meaningful representation of something. Similarly, ideas are thoughts and concepts arranged in ways that generate meanings. The value of this comparison goes beyond mere analogy because now we can apply computation to decompose ideas into thoughts in same way as we can deploy visual computing on shapes. With handful rules, complex ideas can be generated from thoughts and ideas decomposed into simple thoughts. This computation of generation and decomposition provides tools for the exchange of ideas between two entities. Spatial relations between thoughts explain how the thoughts relate with each other to generate meaning. When two people are talking about the same thing, they might not necessarily mean the same thing  thus exhibiting cognitive diversity of thinking. This element of human intelligence is significant towards creative thinking. This is where creativity emerges from, because two people are using diverse paradigms for understanding the same thing  we term as perspectives. But because ideas can be explained by decomposing them into spatial relations between thoughts, we have a method for exchanging rules.

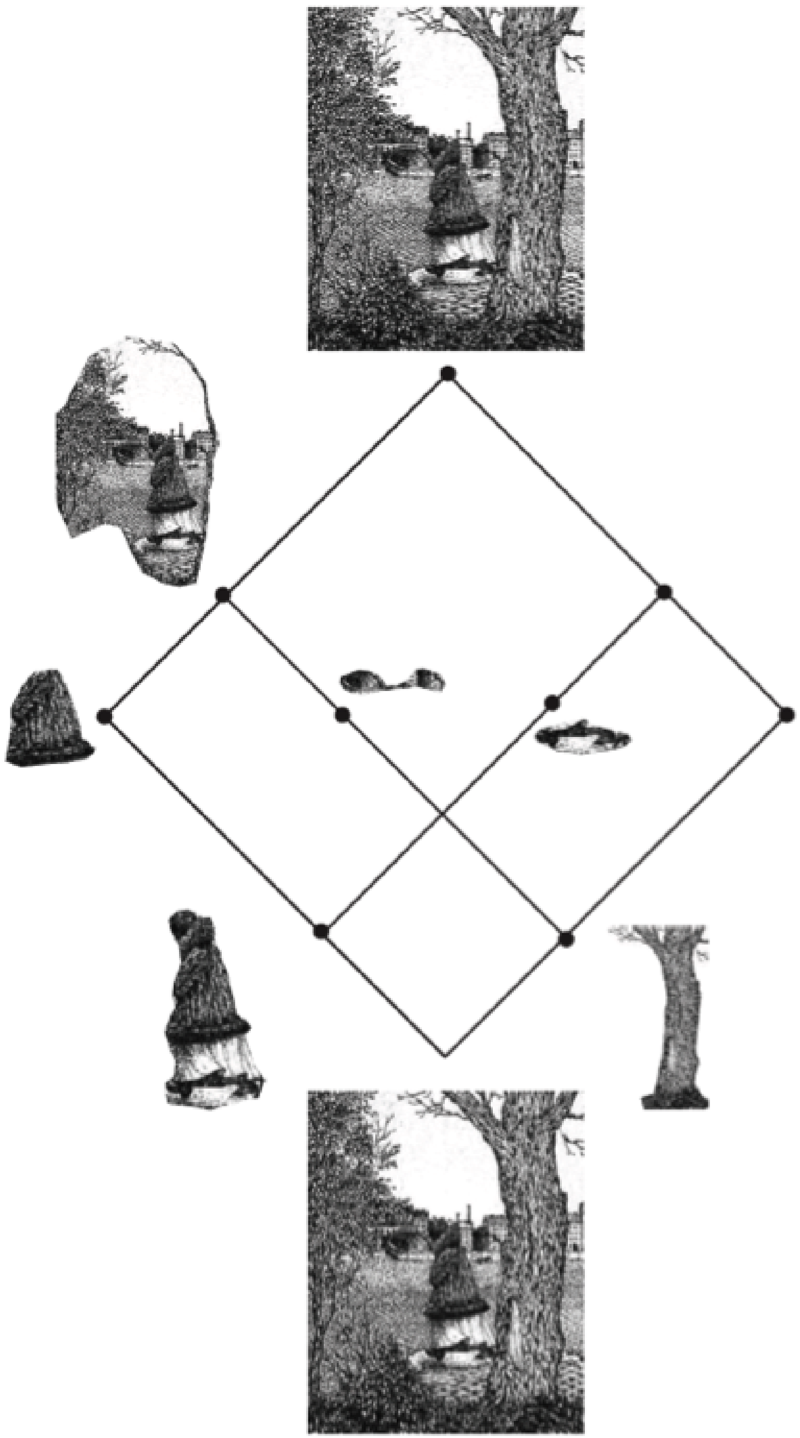

Figure 5.1: Cognitive Diversity: Different ways of parsing information

## 5.3 Computational Creative Thinking as Shape Grammar

We now have a formal way to study our thinking be decomposing ideas into thoughts and spatial relations. How can we use this thought-shape framework to study creative thinking? (Especially from the two core aspects focused on, in this paper  cognitive diversity and interaction between diverse people). Coming back to the first argument I posited in this paper about the definition of creativity, I reiterate that creativity is not just in creating new ideas from existing ones, but also seeing existing things in new ways. While the first is a generative process, the latter requires decomposition with different rules and relations. When people interact and exchange their rules of generation and decomposition, they expand each others ways of thinking. While this observation might seem obvious, this claim is significant from artificial intelligence point of view, because now we can computationally generate meanings and decompose complex ideas and possibly use the framework for creative machines. Conventionally followed theories in AI of hierarchical thoughts, metaphorical thoughts that have problems of combinatorial explosion are no longer required to get machines to generate thoughts and ideas. It is essential to note however, that a significant aspect of this process is linked with innate ability in humans to embed meanings in thoughts. Even if we equip machines and algorithms with ability to generate thoughts and link them to create seemingly different meaningful ideas, how creative can these ideas really be? While this is a valid criticism, the goal of this research is not to design creative machines, but creative partners  meaning machines that have the ability to show a different way of thinking/seeing/doing something other than the what the designer is following. Computers have access to large amount of information, but no way to make sense of that information (wait, can ML be counter argument to this?) But studying designers way of thinking, decomposing it , deciphering the rules, machines can offer different ways of relating these ideas and seeing the problem in new ways. If there is value or not in computationally diverse outlook offered is debatable, but there certainly is value in escaping ones cognitive fixity from purely the standpoint of expanding ones knowledge.

As discussed earlier, shape grammar formalism allows for three kinds of programs to be developed - the parser programs, the analyzer programs and the interpreter programs.

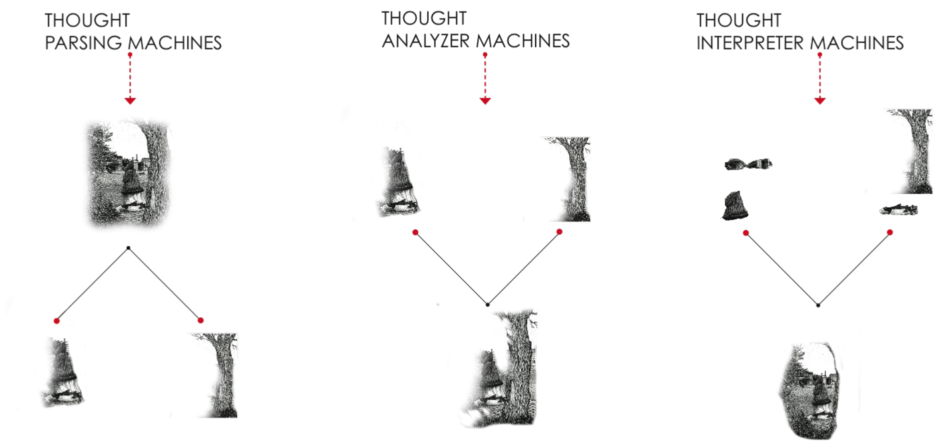


Figure 5.2: Types of Thought-Shape Programs

**‘Creativity involves breaking out of established patterns in order to *look* at things in a different way.’**

- *E. Bono*

# Chapter 6

# Contributions

The goal of this theoretical inquiry is to demonstrate how cognitive diversity (diverse parsing of the world) and social interaction (exchange of the rules of parsing) can be represented using Shape Grammar Formalism. Because shape grammar is a dynamic framework, it accommodates for the evanescent nature of our creative thinking. The major contributions of this research can be listed as follows:

- Literature Review: In the literature review section, I have provided a brief overview of the different cognitive and computational frameworks of creative thinking and identified the two missing aspects crucial to human creativity - cognitive diversity and social interaction.
  - I have provided a brief overview of the different definitions of creativity within the domain of computational thinking.
  - I present a different way of understanding and defining creative thinking using cognitive diversity.
  - I present a brief comparative analysis of symbolic v/s metaphorical cognitive and computational frameworks used to study and represent human thinking.
  - I argued how these frameworks cannot represent the dynamic nature of human creative thinking.
- Thought as Shape Framework: I argue how shape grammar formalism can provide a computational method to encode cognitive diversity and interaction, and thus provide a way to study our

creative thinking. In this section,

- I demonstrated how shape grammar rules can be used to represent cognitive diversity - or different ways of parsing the information of the world
- I present a new approach, called thought-shape framework where if we consider thoughts as shapes (in principle), ideas as spatial relations, then thinking can be captured using shape grammar.
- I propose how this framework can be used to develop computational systems and programs that can engage in a creative thinking process with human designers.

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