Generative Design: 
Rule-Based Reasoning in Design Process

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Alteration, movement without rest,
Flowing through the six empty places,
Rising and sinking without fixed law,
...
It is only change that is at work here.
from “Yi Jing” (Book of Change)

Life is no thing or state of a thing, but a continuous movement of Change.
S. Radhafrishnan

Introduction

As emphasized by Professor Soddu’s series of pioneer works on generative design, the fundamental theoretical base can be generally considered as a design process that generates design by the initiation, developing and manipulation with designers’ objectives as well as their associated set of rules. This process is, in a broad sense, a reasoning process that follows the rules being set forth. In many cases, the rules are common logic that governs our reasoning, while in others they are more special rules that restrict the generating process to a confined space. Computer assisted generative design has made impressive progress over the past decade, along with the rapid growing capacity and speed of computers as well as development and discovery of rules, rule setting and effective manipulating schemes and algorithms. After many impressive progress and remarkable results has demonstrated from time to time, however, theoretical foundation of such design approach, or the significance of awareness of such approach has not been thoroughly treated, recognized and discussed, not to mention clearly understood.

There are also confusions and misconceptions, or sometimes simply misuse and misinterpretation of technical terminologies, such as “rule-based”, “automation” “CAD” … which could refer to very different design and operational schemes in the realms of artificial intelligence or presentation/reproduction tools. The following two examples illustrate some of the differences.

In the first design example (Opus Building, Seoul, Korea) shown in figure below, the angled planes of the building is the result of response to the daylight envelope rule set by the city regulations, while maintaining a goal of making the most use of its limited site space. This is good example of generative design with rule based reasoning process, even though computer technology was not responsible for generating the original design.

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In the second example shown in the figure below, computing technology was the vital and enabling element that is responsible for being able to reproduce and represent the original design made with cardboard model into design drawings. Although heavily relying on computing technology and automation, the basic design approach is not the same as that of generative design based on the process of reasoning with rules.

This paper dedicates its focus to the discussion of some fundamental and important issues of the generative design approach and rule based design reasoning.

**Generative Design**

Generative design approach is a design approach that generates design concepts and/or artifacts based on a set of rules governing a process of manipulation of original ideas or requirements to satisfy a set of goals.

Design is an activity with purposes, so is generative design. Although the purposes or goals may change over time during the process, purposes do exist and are to be met or strived to be met. In a similar but different paradigm, generative art using fractal technique is an example where complex images are generated as art forms with computers based on some algorithms. The complexity and some times beauty of the forms generated are truly remarkable, and the algorithms used for the generation are often astonishingly simple.

The images shown in the following figure are some example fractals belongs to a class of fractals called standard Julia sets that is generated by an extremely simple function, \( z^2 + c \). They were produced automatically by a computer program that searches the mathematical plane of complex number (as the value for the term \( c \) in the function) for interesting cases, where \( c \) is given by \( c = -2 + p / 21845 + i q / 43691 \) with \( p \) and \( q \) being two four-digit hexadecimal numbers. The image plots cover the range \( z = (-0.02, 0.02) + (-0.02, 0.02) i \). The seed, or “genetic code” of the seed, that shaped the difference among the images is nothing but the values of the pair of number \( p \) and \( q \) used in the function. (The values shown with each image are expressed as hexadecimal format.)

\[ p=c340, q=5247 \]
\[ p=af20, q=6d1a \]
Issues of Design Reasoning, Processes and Rules

Processing Rules versus Solution Rules

Rules can be recipe like that specifies solution remedies of given situations. Such rules could be called solution rules. There is another type of rules, namely processing rules. These rules do not specify any specific remedies as resolution of specific situations. Instead, they specify the rule of reasoning or processing. In other words, they specify the rules of game. A cooking recipe is a typical example of the solution rules, while the rule of chess game is a typical example of the processing rules.

Expert system paradigm in the real of artificial intelligence is essentially based on a rich set of solution rules, although innovative design is likely to benefit more from processing rules due to the innovative nature of design tasks. The recipe type of solution rules tends to effectively provide known solutions, or in other word, reproduce know solutions when situation repeats. They do tends to be effective and efficient when it come to using known solution to address know situations based on experiences.

On the contrary, the fractal image example is an extreme example of using processing rule. In fact, it is so extreme that the relationship between the rule and the solutions is so remote and unpredictable, which is very much responsible for the surprising factor or “innovation” in the solution.

Less extremely, the Opus building design example presented previously is probably a more typical example of using processing rules. Although the daylight envelope rule does not specify any particular design remedy, it does have clear restricting effect on the design solution. However, such restriction by no means dictates a know solution or limits innovation in the solution, it rather channels the search for solutions towards certain directions that leads to feasible solutions.

Crisp, Vague and Fuzzy Rules

Rules can be crisply clear and definitive such as mathematical algorithms. Rules can also be vague such as certain laws and regulations are some times subject to interpretations. Another type of rules is fuzzy rule. The theory of fuzzy reasoning and fuzzy logic based evaluation belong to this category.

Design as a Wicked Problem

Although rule based processing rules are extremely useful in design reasoning process, one must not forget that design problems are wicked problems. The choice or decision about the solution is subjective by nature and there is no absolutely objective criterion, although objective measures can be utilized to assist the evaluation process.

The nature of design, as a wicked problem, determines that it does not have an objectively persistent goal. Although the design process is a reasoning process of searching for solutions to meet given goals, the goals are evolving as the solutions are. It is not uncommon for designers to find themselves in a situation of a negotiation between goals and solutions and making changes to each site in order to meet the other.

Due to such wicked nature, a design process does not have an objective criterion for ending. The decision of ending the process is more of a subjective matter than objective, since the process of mutual evolving and mutual matching between the solution and the goal can continue forever in theory. In practice, a design process has to be completed within a reasonable amount of time and a solution, as well as the corresponding goal met, be adopted as final result. Although objective measures and criteria are often used as an excuse for the way out to conclude a design process, the decision is ultimately subjective and in a sense arbitrary.

Eastern Dialectics
Yi-Jing: Rules of Change

The oriental philosophy of change and its deep-rooted idea of dialectics is another interesting type of rules that can be very powerful in design reasoning and processes. Since three thousand years ago when Yi Jing[^1] (易经, also known as Book of Change) was written, Chinese scholars (and designers of all sorts) have understood and emphasized the importance of the continuous movement of change rather than the accumulation of artifacts or products.

Seemingly casual, circumstantial, episodical and even sporadic cognitive processes of design reasoning could become quite systematic and methodical in the realm of eastern dialectic. The Chinese theory of FengShui (风水), a methodology applied to site planning, architectural design, landscape design and interior design, is a good example which in fact was originally derived from the theory of YiJing. Another good example is the methodology of diagnostics and prescription in Chinese medicine. The key essence of it is referred to by a Chinese word “BinZheng” (辨证) which means dialectics and happens to be pronounced the same as the Chinese word for diagnostics (辨症). The theory of such ancient eastern dialectics has been studied, interpreted and developed by many modern scholars. The theory of Contradictions and Balances is one of the mainstream interpretation and development of such theory.

Contradictions and Balances

The theory of contradiction and balance is also called the law of contradiction or the law of the unity of opposites. A contradiction is defined as two opposite aspects coexist in a thing as a unity. According to the theory, contradiction is universal that it exists in all things. The theory also states that contradiction is particular that every thing has its particular contradictions. It is the difference of such contradictions determines the difference of the nature of different things. The theory further states that in every thing there is a principal contradiction that is dominant, and that in every contradiction there is a principal aspect that is dominant. The dynamic change and movement of any thing can be explained as the change and movement of the contradictions in the thing, which are driven and governed by three dynamic changes: the transformation of principal contradiction and secondary contradictions, the transformation of the principal aspect and the secondary aspect, and the affection of contradictions on each other’s transformation.

The theory also teaches that the process of problem resolution is the process of contradiction resolution. The best approach of such contradiction resolution is: first identify the principal contradiction and the principal aspect of the principal contradiction, and then to resolve the principal contradiction by causing the principal and secondary aspects of it to transform to the desired direction. Once the principal contradiction is resolved, the situation will change with one of the secondary contradiction rise to become the principal contradiction. The continuously iterative application of above describe procedures will result in resolving contradictions one after another and thus causing the situation (the thing) to continuously transform to the desired direction.

The Process of Design Reasoning seen through Eastern Dialectics

Design process is a process of dynamic movement and change or transformation of design concept or artifact. All design issues are contradictions exist in the design.

To improve the design (or make it work) is to address the issues, or to resolve the contradictions by causing contradictions to transform towards the desired directions. Addressing a predominant issue is to resolve the principal contradiction.

Design process studies have found that design processes progress in identifiable episodes. In the view of eastern dialectics, an episode is characterized by the state of contradictions. In other words, the resolution, or transformation between the principal aspect and secondary aspect, of the principal contradiction of the design at the time determines the transition from one episode to another. During this transition, the previously identified principal contradiction transforms into a secondary contradictions while another secondary contradiction is identified as risen to become principal contradiction. The subsequent episode would be the process of resolving the new principal contradiction or addressing the new predominant major issue.

The most effective approach of design process is to address the predominant issue first. In other words, grasp the principal contradiction and focus on resolving the principal contradiction first. Then derive a solution to influence and cause the principal contradiction to transform towards the desired direction, or resolve the dominant issue to achieve a more satisfactory state such that the issue is no more predominant concern in the design. The success of such resolution terminates an episode of the design, and the next episode of the design begins with identifying the next principal contradiction, or the new predominant issue.

Within the eastern dialectics framework, the wicked problem characteristics of the design can also be interpreted as such that:

- Contradiction always exists and cannot be eliminated. Resolving a contradiction is to find a way to cause it to transform and reach a new more desirable balance.
- A design concept or artifact as a temporal state during an evolving process is a temporal state of particular balances of contradictions. It is the result of a change (resolving and transforming of contradictions) as well as the starting point of a new change
- A design process has no natural end. The end of each episode of design process is a temporal state in a flowing river of events of changes. The “final” design is only a designer’s subjective choice of a snapshot of the flowing river of changes.

[^1]: Yi Jing (易经)
Viewing the design process through eastern dialectics as briefly describe above agrees very well with observations established in modern design studies that focused on various aspects of design such as process, cognition and reasoning, etc. The benefit of eastern dialectic view is that it offers a more systematic framework for analyzing design process and reasoning as well as a pragmatic guideline in practices.

Pragmatically, perhaps some useful guiding principals can be derived from the eastern dialectics view of design as following:

- Design is a series of episodes of evaluation and composition.
  - The evaluation phase of an episode needs to not only evaluate whether design can be stopped as satisfactory but also identify the dominant issue as the objective for the next episode to resolve
  - The composition phase of an episode needs to concentrate on resolving the dominant issue(s) identified in the previous evaluation phase
- Skills for effective design reasoning has multiple aspects
  - The “science”:
    - scientific and technical knowledge and innovation
  - The “art”:
    - Knowing the dominant issues at different stage
    - Knowing the proper balance of the contradictions
    - Knowing the effect of changing balance of one issue to other issues

Examples of Generative Design

A Student Project

A student in the generative design class (Spring, 2002, Polytechnic Institute of Milan) once showed me her project in which she has created a design and the retroactively defined a set of rules that would lead to the design. With my strong encouragement, she reworked on her design by following the rules that she has defined, she came up with two more somewhat different designs. However, when she gave the set of rules to her sister as an experiment, her sister came up with a very different design by following the rules. To her astonishment, she likes her sister’s design better than her own. This seemingly trivial incident is in fact a powerful example that illustrates the capacity of innovation within the generative design approach based on reasoning rules.

A Modular Housing Design

This example illustrates a quite old concept and practice of rule based design. Yet it is a typical and simple generative design approach. The overall design is to be accomplished by composition of a set of subcomponent modules. Restriction rules are defined to insure validity of compositions while allowing rich enough variations for different purposes such as performance optimization and innovative alternatives.

There is no fundamental difference in theory whether the composition is performed manually (with drawing board or scale model) or by computers with special modeling, although the efficiency and productivity difference can be crucial in practice.

An Campus Complex Plan

In this example of rule based design as generative design approach, the rules are significantly more complex than the previous example. However, the fundamental ideas and the essence of the processes are the same.
A Concert Hall Design

The following figures illustrate the design of a Concert Hall, Denver Center for Performing Arts, that was built in 1980. (Architect: HHPA, Acoustics: C. Jaffe).

For acoustic performance requirement of avoiding any specific resonant frequency that would negatively affect acoustic fidelity, it is desire that the columns in the concert hall be positioned randomly. The more random, the merrier. However, the design and construction practices dictates that the position of every column can be easily located both in drawings and on the construction site. Such pragmatic restrictions require a simple positioning scheme be devised to locate the columns. In this case, the architect and acoustic designer have worked out a simple geometric rule system, as shown in the drawing below, such that the locations of columns can be easily pin pointed both in the drawings and on site. The rules are simply specified with lines of sight, angles between the lines and distances measured along the lines. Simple and regular as the rules are, the resulted distribution of column positions is remarkably random (considered nearly infinitely complex).
A Byzantine Church Design

Byzantine church, lines of sight. (Kalligas, 1948) and a church generated by computer with parametric rules. (Potamianos, et al. 1995).
A Train Station Design

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Yi Jing has been translated into English as I-Ching.

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