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QUANTUM ARCHITECTURE

An indeterministic and interactive computational design system

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Abstract. The evolution of computational design technique from mere substitution of hand drawing to customised design algorithms exhibiting a certain degree of intelligence, naturally opens up a new research frontier that studies the relationship between designers and customized design algorithms. Most of current customised architecture design algorithm adopts a deterministic paradigm to raise their design questions, that is to say, given the explicit rules and parameters, only one solution is allowed at each discrete computation step. Due to this deterministic nature, an intuitive and efficient communication between design algorithm and designer is hard to achieve, as there is almost no space for designer to step into the running generative process. This lack of progressive communication channels and the inefficiency of translating perceptual judgment into computer language directly results in the unconscious rejection of non-parameterisable design factors like intuition, aesthetic judgment and associational reasoning that are essential to any design activity. This paper introduces the quantum design paradigm as alternative computation paradigm for constructing an interactive and intuitive design system. An algorithm prototype, probability field, will be introduced to illustrate the logic and possible application of the proposed quantum design paradigm.

Keywords. Quantum design paradigm; intuition; algorithm prototype; interactivity; probability field.

1. Interactive design computation

The evolution of computational design technique from mere substitution of hand drawing to customised design algorithms exhibiting a certain degree of intelligence, naturally opens up a new research frontier that studies the relationship between designers and customised design algorithms. As shown in figure 1, this relationship can be mapped as a rigid master/slave model which is deeply rooted in the early day's 'batch' mechanism. This relationship can however be set up as an interactive[1] process, for which designer not only program the design algorithm, but also actively communicate with design algorithm to bring in a set of non-parameterisable design factors, such as intuition, aesthetics judgment and associational reasoning[2] that are essential to any design activity.

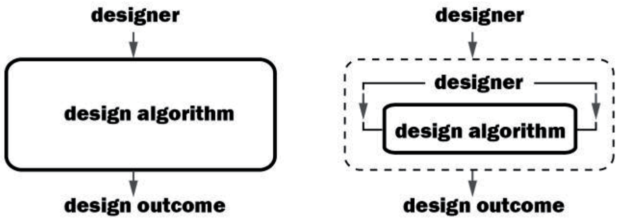

Figure 1. Designer and design algorithm relationship.

This inquiry into the conversational designer/design algorithm relationship has profound impact on the design of a new kind of design algorithm which challenges the binary nature of current design computation philosophy. This paper presents the probability field algorithm prototype[3] as one possible way to construct such an indeterministic and interactive design computation system. A brief examination on the limitation of deterministic algorithm structure will be provided at first to reveal the necessity for introducing an indeterministic and interactive design paradigm namely the quantum design paradigm.

2. The limitation of deterministic algorithm structure

According to Wikipedia, as for mathematic and computing, *an algorithm is defined as a sequence of finite instructions. It is formally a type of effective method in which a list of well-defined instructions for completing a task will, when given an initial state, proceed through a well-defined series of successive states, eventually terminating in an end-state.*

In light of this definition, most of current customised architecture design algorithms are constructed as a series of computation instructions that are organised by a predefined structure, while the transition between different instructions are rigidly regulated by *if, then* logic. For such algorithms, given explicit rules and parameters, only one solution is allowed at each discrete computation step, i.e., the computation question is always formulated to expect only one rational answer. This algorithm structure may work independently with strictly defined design problem solving and optimisation, but due to its deterministic nature, an intuitive and efficient communication between design algorithm and designer is very hard to achieve, as there is almost no space left for the designer to step into the running computation process, and no reason for the independent design algorithms to provide feedback to the designer except for an error print. This lack of communication and the inefficiency of translating perceptual judgment into computer language directly results in the unconscious rejection of non-parameterisable design factors and reduces the customised algorithm to mere design problem solving machine instead of a design partner to its full potential.

This deterministic algorithm structure may very well be addressed to the Newtonian philosophy that advocates the clockwork paradigm while minimising human impact to preserve the rigor of the perfect machine. In order to open up the design computation process to personalised design considerations from designer, it becomes important to search for an alternative computational design paradigm for novel conceptual framework and methodology.

3. Quantum design paradigm

Many, if not all, of our computation methods are actually originated from scientific observation and abstraction of physical reality, e.g., genetic algorithm, neural network, fractal geometry and swarm logic. Quantum theory, as the most successful explanation of the particle world, has not only triggered tremendous technical improvement but also an emerging scientific worldview: Quantum paradigm. Quantum paradigm advocates an interactive relationship between human being and their physical environment, thus put into question the deterministic worldview as stated by Newtonian physic. Its implications in different social and technical aspects are profound. In order to better discuss the relevance of quantum paradigm to design computation system setup, a brief introduction to quantum paradigm in general will be necessary.

3.1. A BRIEF INTRODUCTION ON QUANTUM PARADIGM

Quantum paradigm is constructed by a set of correlated philosophical reflections on the nature of the universe and our relation to it. As stated by the Wave-particle duality[4] and Heisenberg uncertainty principle, the observed reality is a statistical representation of a relative reality that has its uncertain principle derived from the irreducible fuzziness of its basic building blocks, particles. As for quantum paradigm; nothing can be said for certain about a physical system other than a probability wave function that can only be described with statistics. While any attempt to probe the configuration of a quantum system will definitely collapse its wave function. This is to say that the very act of observation is actually an interaction between the observer and observed system that not only yields a reading of the current configuration but also reconfigures the system itself. Thus the objective belief of an absolute and deterministic reality is put into question, and replaced with a relative reality that potentially includes consciousness as a part of it.

Besides the concept of absolute reality, the principle of locality has also been violated by quantum theory. Derived from Eisenstein's relativity theory, the principle of locality states that physical processes occurring at one place should have no immediate effect on the elements of reality at another location. As proven by a series of experiments, the opposite of this principle is apparently well demonstrated. The violation of the principle of locality promotes new ideas of understanding the universe with more than 3 dimensions which were further developed into many-world interpretations and the super string theory that, among many others, are both very important explanations of the quantum reality.

3.2. KEY CONCEPTS FROM QUANTUM DESIGN PARADIGM

The study on quantum design paradigm yields a set of interrelated concepts for setting up such an interactive computation system. This paper will discuss two key concepts that have been tested with the probability field algorithm prototype.

3.2.1. Probabilistic description method

For quantum physics, probability is a definable indeterministic function based on the assumption of the system's elements. Due to the internal fuzziness and correlated event potentiality of any quantum system, it becomes necessary to introduce a probabilistic description method to depict the state of tendency for a quantum system with incomplete information. An illustration of the probabilistic description method can be found in figure 2, which is a sequence in increasing time after the launch of two wave packets in a weak random potential landscape that is outlined by dark high potential barriers. In this artwork, instead of a definite indication of the exact position in time, the colour temperature of the 2D space represents the possibility for the electrons to be at that particular spot at a particular point of time,

By introducing the concept of computational probability and probabilistic description method into computation system setup, we have the tool to construct and communicate with an indeterminisitic system built with multiple possible configurations. Thus, on top of the classical description vocabulary composed of position, velocity and other affirmative object properties, we could add one more dimension to describe the system potentiality. This naturally legitimates open-ended computational design questions with a set of simultaneously rational solutions.

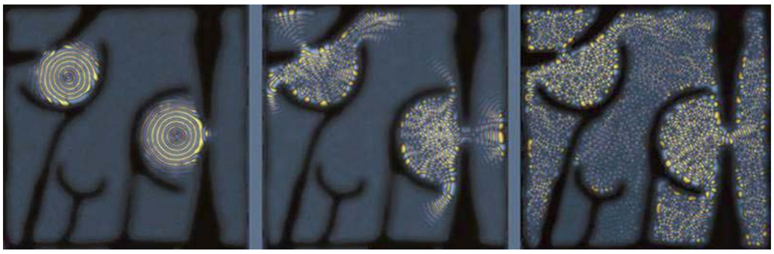

Figure 2. Resonator Triptych by Eric J. Heller (2004).

3.2.2. Non-local information sharing

In quantum physics, the violence of locality has been accepted as a given fact of particle universe. As for the computational design system setup, the concept of non-local information sharing indicates a condition that information within a computation system can be communicated and shared remotely. This leads to a new attitude towards the bottom-up computation system, for which local connectivity won't be the obstacle for direct communication of certain kind of information that are necessary to be grasped by the whole community of actors. This understanding naturally paves the way for introducing global constant as a common design constraint, which is currently treated as a taboo in the field of complex adaptive system research, while actually can be crucial for certain architecture design scenario that requires particular overall system summation to be constant, e.g., the general construction cost and overall construction area should be controllable to ensure realistic design proposals.

4. Probability field algorithm prototype

The probability field algorithm prototype is based on the synthesis of non-local information sharing concept and probabilistic description method. Its algorithmic principles can be summarised as following:

- The probability field is constructed with homogeneous, non sub-divisible units, which are identifiable by unique states.
- The units from different states have different impact on their neighbor units, measured by the intensity of its influence field.
- Unless sufficient local and global information is obtained, a single unit is always in a quantum state, which is a collection of all possible states. For these elements, a probabilistic ranking between all possible states can be calculated and communicated.

- The order of the probabilistic ranking can be altered by the designer to introduce personal design considerations.
- The global criteria must be always fulfilled by means of automatic system examination and update mechanism.

4.1. PROBABILITY FIELD ALGORITHM STRUCTURE

The probability field algorithm structure is constructed by grafting the reasoning tree structure on top of a bottom up computation grid, as shown in figure 3. Global constant parameter is also introduced as an overall computation criterion to regulate the evolution of system solution space.

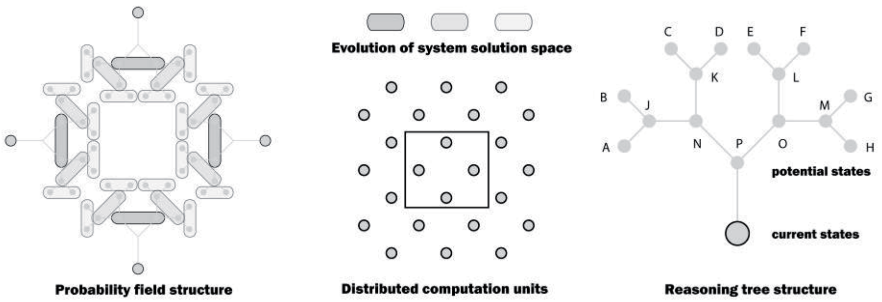

Figure 3. Reasoning tree structure and bottom up system.

The reasoning tree structure allows multiple computational solutions to be simultaneously rational at each decision making node. Similar to the traditional branching design decision making process, the reasoning tree structure here also allows the interactive design system to jump back to a previous decision making node to choose another path while keeping the reasoning trajectory before that node untouched. The bottom up computation grid provides a set of distributed computation units to handle massive design information. By manipulating node state of the reasoning tree structure of each distributed computation unit, designer can affect the computational decision making process on the basic computation unite level.

As shown in figure 4, the evolvement of the probability field algorithm prototype is triggered by the interaction between the human designer and the design algorithm. At each computation step, the design algorithm will examine the general system condition and suggest a list of rational states that the designer can assign to the particular computation unit that is of concern for this step. All of these rational states will be further evaluated on their different level of recommendation according to the built-in evaluation criteria, while the result of this evaluation will be presented to the designer as visual feed back, as indicated by the gradient colour in this diagram.

The human designer is free to choose any rational states that are allowed but not best recommended by the algorithm to manifest his/her particular design consideration that overweighs the generated ranking. Thus the evolution of this computation design process will no longer be confined to predefined mathematical formulas, but open to personalised aesthetic and intuitive judgment from human designers. General checking will be carried out automatically after each decision making step, for any unit, if there is a conflict[5] between its current state and its local condition, the system will automatically fix it and update the entire system accordingly.

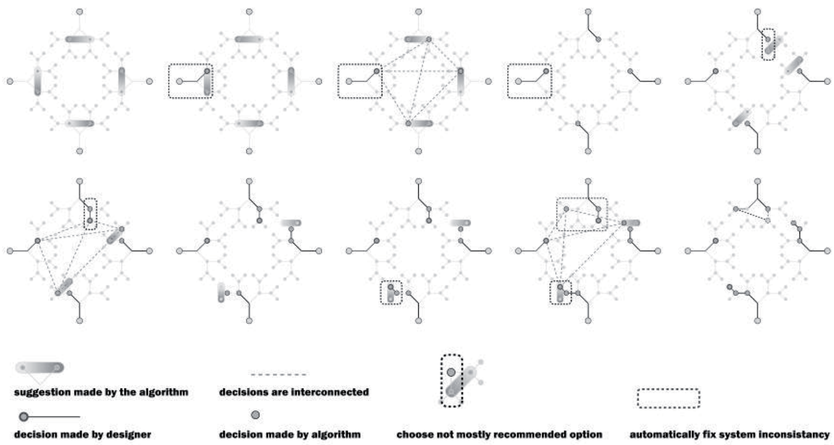

Figure 4. Computation system evolution.

4.2. MINESWEEPER DESIGN GAME

The probability field algorithm prototype has been implemented with an interactive design system, the minesweeper design game, figure 5. This design game reverses the mine discovering process of the classic minesweeper game into a design process that requires the designer to define the location of mine cells by assigning local connectivity figures to the undetermined cells within a definite 2D matrix. By assigning a local connectivity figure N to any undetermined cell, say with 8 neighbors, the designer is actually telling the algorithm that there will be N mine cells located beside this particular cell, thus the local probability parameter for all adjacent cells to be a mine cell will increase by N/8 according to this newly registered information. There is also a global constant of the total amount of mine cells, which introduces a global probability parameter for each undetermined cell. The overall probability parameters will be constantly updated after each new design decision and visualised with the gradient color to inform the designer about current system condition.

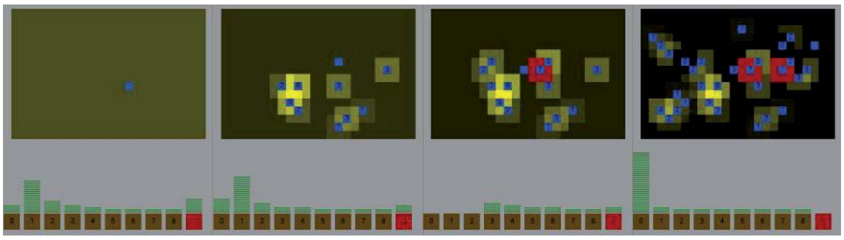

Figure 5. Screen shots from Minesweeper design game.

For any undetermined cell picked by the designer, the minesweeper design algorithm will suggest a list of ranked possible figures that can be assigned to this cell. The action of assigning one particular figure will trigger a checking process through out the entire matrix, which will locate and fix any system inconsistency. Thus, this design algorithm actually acts more like a supportive design partner who not only provides suggestions, but also makes necessary corrections on designer's decisions.

4.3. APPLICATION SKETCH

The logic of probability field algorithm can be applied in various design scenarios that involve both massive computation and personalised design judgment. As for complex design task, different design considerations can be mapped onto different probability field layers and added up together later to reduce scripting complexity. As in the urban development game sketch, figure 6, the probability field table A controls the amount of extrusion of individual units, while table B distorts the control grid surface.

The surface population tool sketch, figure 7, aims at integrating parametric modeling, building performance evaluation and personalised selection within one interactive design computation procedure. Realtime data exchange between different software platforms is being developed at this moment to

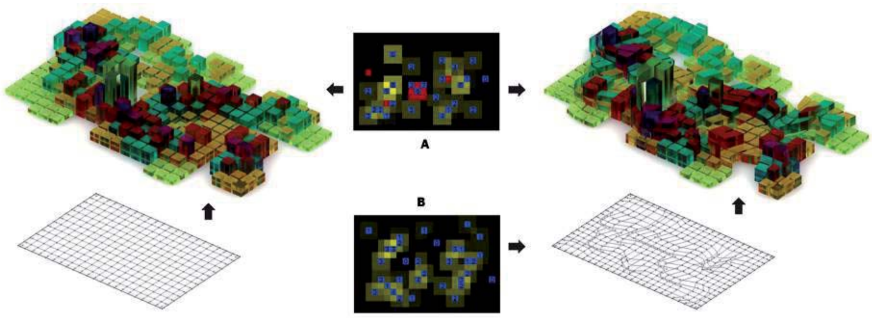

Figure 6. Urban development game.

update the originally iterative design-evaluation-selection workflow with a new progressive workflow that incorporates different design considerations all at the same time.

Figure 7. Surface population tool.

5. Conclusion

Quantum design paradigm, as discussed in this paper, provides novel concepts and methods for setting up an indeterministic and interactive design computation system. The switching mentality of creating design algorithm as design partner instead of design tool, naturally requires design algorithms to handle computation questions with multiple rational solutions. The selection of the 'best' solution in this case involves both the objective evaluation carried out by design algorithm and subjective evaluation derived from the sensibility of designer. Operate in a progressive manner, as discussed in the surface population tool sketch, these two types of evaluation are not separated as independent functions, but constantly negotiating with each other to balance different design impetus and promote the general evolution of design.

Although promising potentials can be clearly envisioned, the research on designer/design algorithm interaction and probability filed algorithm prototype also exposed a great need for the support from a branch of parallel research. Some of the expected research may come from the design cognitive point of view about how human designer adapts his/her design habit to the interactive design environment, some from the computer science point of view about how to make algorithm smarter to understand, remember and even predict the design preferences of different designers, some may also come from the interface design point of view about how to balance the level of representational complexity from both sides to facilitate efficient communication. All of these interdependent research trends could be very well concluded under the general research direction of interactive design computation, which could be a new challenging and promising frontier for the current exploration of digital architecture.

Endnotes

1 As for this paper, interactive refers to a circled communication process that involves mutual understanding and unexpected stimulation, which should be carefully distinguished from the concept of reactive. A rigourous terminology for conversation, interaction, environment and participation can be found from Gordon Pask's conversation theory.

2 Oppose to causal reasoning which has been commonly deployed by computer programming, associational reasoning refers to the faculty of human mind to bridge one idea with another in consciousness, if they were associated by principles like similarity, contiguity and contrast.

3 Algorithm prototype refers to an abstract machine exhibiting particular computation structure and logic, e.g., cellular automata and genetic algorithm. It mainly concerns with typological computation principle and is open to further specific implementation.

4 Wave–particle duality is the concept that all matter and energy exhibits both wave-like and particle-like properties. A central concept of quantum mechanics, duality addresses the inadequacy of classical concepts like "particle" and "wave" in fully describing the behaviour of small-scale objects. http://en.wikipedia.org/wiki/Wave-particle_duality

5 As concrete prediction on designer's future decision is impossible, the conflict between current rational suggestion and certain possible future system states is inevitable. Instead of making the effort to model an over-simplified decision making strategy of designer, this research adopts the checking function to achieve maximum robustness and tolerance that are essential to human-machine interaction.

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