Computational Design Emergence by Complexity and Morphogenesis *(Paper)*

Topic: Design

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Abstract

Emergence is the form or behavior of natural or artificial systems, which materializes due to the system components' interactions with each other and their environment. Emergent properties are a result of processes of self-organization of complex systems such as swarming behavior of birds, insect colonies, immune systems, cities, the World Wide Web, social interactions, etc., as well as processes of natural morphogenesis that exhibit behavior of growth and adaptation. Emergent systems are also closely related to the field of creative design, where novelty and utility are equally valued. Here, the idea that natural phenomena in nature emerge spontaneously from the interplay of intersity differences is extended to design, wherein design morphogenesis assumes the role of the generative mechanism. The ability of morphogenetic processes to adapt and transform renders the design form dynamic, mutable and evolvable through its transformative interactions. Similar to complex systems, therefore, morphogenetic forms can be said to be emergent. Computational design systems such as agent-based systems, cellular morphologies, branching systems, neural networks, evolutionary algorithms can simulate the mechanisms of emergent systems. Characteristics of such design systems exhibit non-linear bottom-up behavior are accompanied by qualities such as stochastics, spontaneity, unpredictability, irreducibility and innovation instead of typology and standardization. This paper explores the concept of emergence, its implications on and implementation in the creative design field. To this end, we first introduce characteristics of emergent systems in natural and artificial systems as well as design. We then present a design example of a generative system that makes use of diffusion-limited aggregation. Finally, we discuss the potentials and limitations of emergent design systems for both routine and creative design tasks.

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Key words: generative design, complexity, morphogenesis, diffusion-limited aggregation

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Design Emergence by Complexity and Morphogenesis: A Case of Branching Growth

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Abstract
Emergence is the form or behavior of natural or artificial systems that materializes due to their components' interactions with each other and their environment. Emergent properties are a result of processes of self-organization of complex systems such as swarming behavior of birds, insect colonies, immune systems, cities, the World Wide Web, social interactions, etc., as well as processes of natural morphogenesis that exhibit behavior of growth and adaptation. Emergent systems are also closely related to the field of creative design, where novelty and utility are equally valued. Computational design systems such as agent-based systems, cellular morphologies, branching systems, neural networks or evolutionary algorithms can simulate the mechanisms of emergent systems. Characteristics of such design systems exhibit non-linear bottom-up behavior and are accompanied by qualities such as stochastics, spontaneity, unpredictability, irreducibility and innovation, rather than rigid types or standardization. This paper explores the concept of emergence, its implications on and implementation in the creative design field. To this end, we first introduce characteristics of emergent systems in natural and artificial systems as well as design. We then present a computational generative system that makes use of diffusion-limited aggregation to transform 2D images as an example of a design algorithm exhibiting emergent properties. Finally, we discuss the potentials and limitations of emergent design systems for both routine and creative design tasks.

1. Emergence in Complex Systems and Morphogenesis

Emergence is a property of complex systems that are comprised of a heterogeneous network of entities that interact with each other, learn and adapt over time, and eventually give rise to dynamic structures or patterns. Complexity thinking results from the limitations of the positivist paradigm of the scientific method. Instead of trying to understand cause and effect by means of simplifying problems into their most basic elements, complexity sciences support the idea that everything exists in connection with each other, and the total is greater than the sum of its elements. Complex systems are characterized by self-organization, wherein parts communicate with each other to reorganize themselves. Especially open systems that have permeable boundaries can adapt to the changing environmental conditions.

In contrast to the reductionist approach that follow a few guiding rules that control its components in a top-down manner, complex systems are characterized by bottom-up behavior. In systems of high complexity, the resulting behavior of the system is difficult to predict although the behaviors of the individual entities are well-defined and predictable. Here, small deviations in the beginning states or the input can trigger large-scale change in system behavior, known as the avalanche effect. Such sensitivity towards initial conditions is a common characteristic of chaotic systems. Similarly, non-linearity of complex systems point out to the disproportionate scales of system’s input and output. The self-organized order is imposed by the topology of the system, namely its connectivity and interdependence between the elements. Because of its multi-level structure, complex systems propagate the behaviors and actions throughout their topology.

Emergence similarly is associated with natural morphogenesis, which is the formation of complex biological shapes as a result of development. Through a continuous exchange of matter and information with its environment, a biological entity of a complex and heterogeneous nature is formed by time. This conception of morphogenesis together with the principles of biological growth, adaptation and evolution yield in formal differentiation of biological entities. Dissimilarities in morphogenetic rules or the environmental factors can give rise to widely different results. Therefore both complex and morphogenetic systems result in unpredictable end states. This is what brings about a great diversity of patterns, both physical and structural, at various scales and contexts.

Emergence through morphogenetic processes are commonly observed in natural systems. The spider web, for instance, is a behavioral pattern that responds to environmental factors, similar to a complex algorithm. The formal variety of the spiders’ webs is a direct result of this “algorithm” responding to different parameters such as tension of the web, orientation memory, sensory input, integration path etc. An experiment conducted by NASA to test the influence of psychoactive drugs such as caffeine, amphetamine, marihuana, LSD and chloral hydrate on the formation of spider webs. The study concludes that these drugs have a strong effect on the spiders spinning webs and their perception of their environment. A similar and more recent example is Rose Lynn Fisher’s photography work titled The Topography of Tears (Figure 1). Here, a formal variation similar to spider webs materializes due to the differentiation of tears in the micro scale. The formation of tears is a process that is based on the chemical reaction between water, proteins, minerals, hormones and enzymes. The artwork of Fisher samples tears that were gather in moments of “elation to onions, as well as sorrow, frustration, rejection, resolution, laughing, yawning, birth and rebirth” [5]. This differentiation in the initial environmental conditions has a substantial effect on the crystallization process (or the algorithm of morphogenesis) and the eventual visual pattern when magnified under a standard light microscope.

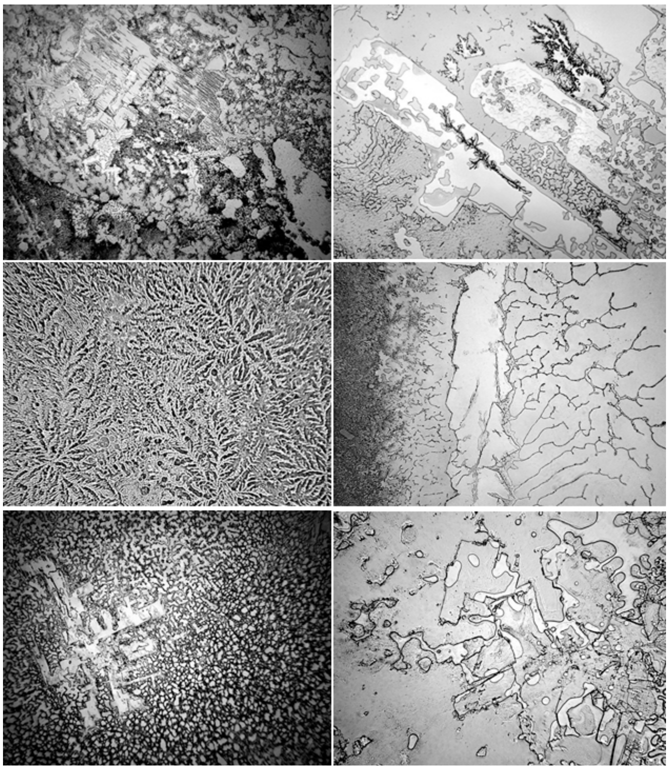


Figure 1. Tears crystallized under different conditions resulting in different formal characteristics in the micro scale, from “The Topography of Tears” by Rose-Lynn Fisher [5]

2. Emergence in Design

The richness of natural systems in the formation processes are exploited in design as well for design processes of creativity and novelty [4]. The study of complexity extends beyond natural systems towards urban studies and architecture. The medieval city is such an artificial system that is built incrementally over long periods of time, wherein transformative interventions in different scales shape the morphology of the city. Armelle Caron [2] demonstrates how bottom-up planning processes contrasts with the formal standardization of top-down formation in New York (Figure 2). The morphological difference and variation in medieval neighborhoods of Istanbul are due to processes of self-organization and an organic, bottom-up urban growth process. The regular rectangular grid of New York, on the other hand, is a result of top-down planning that took place during the Commissioners' Plan of 1811, which was described as a “predilection for control and balance” [1].

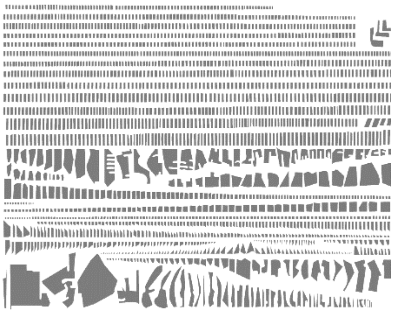
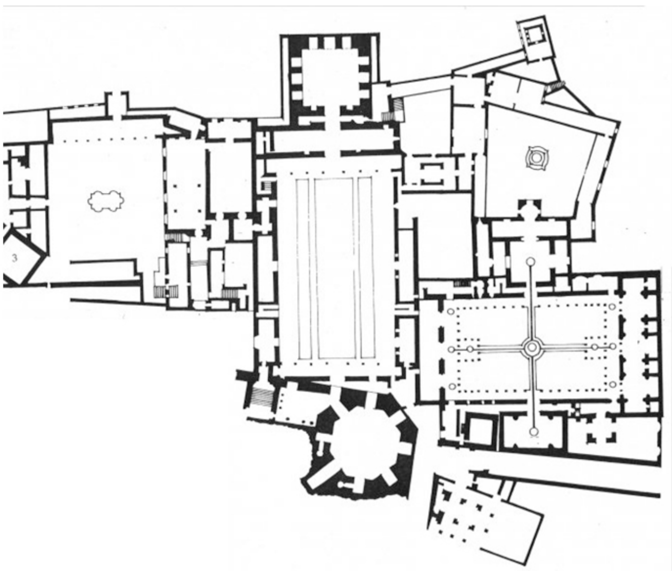


Figure 2. Armelle Caron, Les Villes Rangees (http://www.armellecaron.fr/works/les-villes-rangees)

Morphogenetic approaches have a huge influence on the architectural thought. Both architecture and morphogenesis study the formation processes of forms that exist in a particular context and that engage in non-linear relationships with other entities in time. The main difference between them is, however, that natural morphogenesis occurs spontaneously, while design morphogenesis needs to operationalize synthetic algorithms for designing. In this regard, two opposite architectural instances can be exemplified Alhambra Palace (Spain) and Notre Dame de Paris (France) (Figure 3). Alhambra Palace is located in Granada, and is formed under very different influences including topographical, social, political, military etc. between the 9th and 19th centuries. The palace grew in time and fulfilled various different purposes including being a military area, the residence of royalty, the first palace to the Nasrid kingdom, citadel and houses of noblemen and plebeians. The fragmented morphology of the settlement is also due to the rocky topography that it is located in. As the palace formed in multiple phases, its form is organic, asymmetrical, non-centric and non-hierarchical. In this regard, it can be considered as the "diagram of forces" [12]. Notre-Dame Cathedral, on the other hand, strictly implements the cathedral typology together with the top-down implementation of Gothic architectural principles and elements, together with its rigid and symmetrical architectural form. As such, it contrasts with the formal variety of Alhambra that results from a morphogenetic development process.



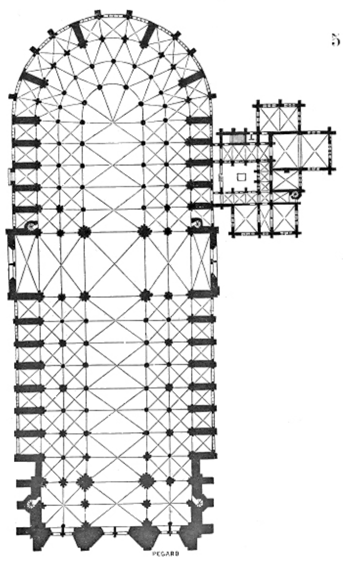


Figure 3. Left: Alhambra Palace, Spain. Right: Notre Dame de Paris Cathedral, France.

In architecture, emergence can purposefully be embedded in design. Cedric Price, in his

Generator project (1976-1979) proposes a reconfigurable and responsive architecture wherein users are actuated as active agents that interact and transform the architectural elements through predetermined guiding principles. In his work, uncertainties are acknowledged and taken into account starting from the conceptual phase of design, and changes in users' behavior are considered as a triggering force for new modes of architectural generation. Price's architecture suggests multiplicity of use, flexibility of architectural solutions and the emergence of design instead of static representations to be able to address future unforeseeable conditions. Cybernetics is used to facilitate change, which allows new architectural elements be added as needed, or modifying and altering the states of the existing elements. As such, it questions the act of design synthesis, authorship, and the degree of designerly control on the environment.

The idea that natural phenomena in nature emerge spontaneously from the interplay of intensity differences [3] can be extended to design, wherein design morphogenesis assumes the role of the generative mechanism. Computational design morphogenesis refers to design processes that guide form development by means of computational processes, or algorithms, from initial generation to its eventual state [7]. Here, due to the design artifact's response and adaptation to external and internal forces, a form in morphogenesis is only temporal; it is only an intermediate state within the process of development. The ability of morphogenetic processes to adapt and transform renders form dynamic, mutable and evolvable through its transformative interactions [8]. Similar to complex systems, therefore, morphogenetic forms can be said to be emergent.

The distinction between the lower-level behavior of elements giving rise to global system behavior calls into question the ways in which the elements can be encoded to interact with each other and share information in architectural settings. New conditions of architectural potentials can emerge by implementing open-ended processes benefiting from the volatile nature of generative multi-agent systems. In this case, design intent can be embodied by the individual agents, as they interact through design rules and give rise to emergent architectural and urban morphologies [11]. This way, emergent design systems assume a certain level of autonomy and actively take part in the design synthesis process.

3. Design of Emergent Systems Exhibiting Branching Growth

An alternative design approach is to operationalize emergent systems to complement 2D visuals towards enriching environmental experiences. We propose that existing visual qualities can be augmented and transformed by means of benefiting from the visual richness and the adaptive qualities of emergent systems. We present the results of generative algorithmic design work, wherein computational methods are used to simulate generative emergent systems. In the particular example, we reinterpret and transform the 2D qualities of images by developing an artificial emergent system that offers alternative ways of perceiving and experiencing images and transforming visual interaction.

In systems that demonstrate growth behavior, visual patterns emerge as a result of biological and physical factors. Branching systems are a common example of morphogenetic structures [6]. Many biological systems such as the bronchial tree of lungs, kidneys, vascular systems or glands, are made up of networks that exchange fluids. Such branched morphologies aim to maximize efficiency by the maximal use of the active surface area and the minimization of transport distances [10]. While branches develop in various ways, they follow similar growth patterns that specify the direction of the branches and their shape. Moreover, branch morphologies are characterized by self-similarity, which is defined by the geometric similarity of the components of the whole that is a result of the repetition of the same pattern. Various computational approaches have been developed that propose an iterative procedure that determines the location of the root, how a branch splits and the location of the branches. An existing approach is Lindenmayer systems (L-systems) that makes use of a set of rewriting rules for defining complex morphologies by the iterative replacement of parts of a simple initial object [9]. The geometric and topological variety of L-systems can further be enhanced by the use of context sensitive production rules or stochastic selection of production rules or other geometric parameters.

An alternative to L-systems is diffusion-limited aggregations (DLA). DLA imitates natural processes such as metal growth that exhibit behaviors of random walks and percolating clusters. Diffusion-limited aggregations can be exemplified by natural phenomena such as growth of coral or bacterial colonies, lightning, coalescing of dust or smoke particles, corrosion of solids and crystal growth. DLA processes can generate large complex structures by the diffusion of seed particles that are traveling within a predefined boundary, while creating fractal self-similar geometries that follow a growth pattern. As such, agents populate and traverse the 2D surface while following simple bottom-level rules of interaction and giving rise to emergent global patterns.

The DLA algorithm starts with a number of seeds that form the aggregate structure, and a number of random walkers that iteratively walk the environment while avoiding collision with itself and the obstacles in the environment (Figure 4). Self-collision is avoided as the walker attaches itself to the existing branch structure when it reaches within a predetermined proximity to it. To avoid collision with obstacles, first the boundary conditions need to be defined. A boundary condition can be the number of allowed particles, maximum distance between the particles, or certain geometries that restraints the actions of particles.

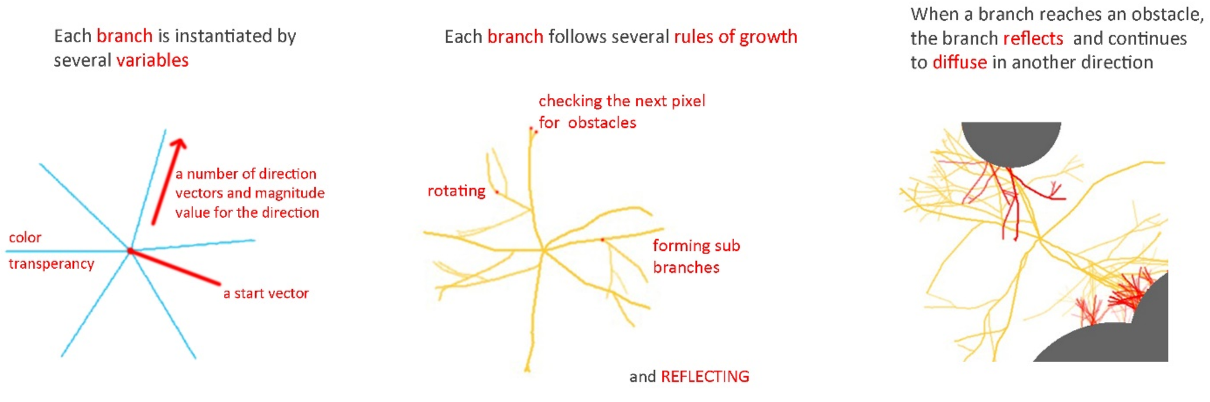


Figure 4. The Diffusion limited aggregation algorithm, rules of growth

A Processing code is developed that algorithmically grows a branching structure on 2D images. The algorithm starts with a 2D image. First, a random number of seeds are placed on the image. After this initial state, the seeds start to grow by branching in multiple directions. Fractal geometries check their growth direction for any available obstacles within the canvas. Obstacles are defined by the difference of contrast between the start and end points of a branch that is to be generated. If the fractal’s direction is free from any obstacles, a random move is generated from a list of predefined actions such as growing in that direction, deviating the direction by a small rotation, or branching an additional self-similar fractal. In the case of a collision with an obstacle, the fractal continues to grow in the reverse direction by reflecting from the obstacle geometry. Moreover, the branches can be of arbitrary colors. As such, stochastic growth in two dimensions is achieved that eventually yields non-linear formation and emergent form. In both projects the resulting structure

displays qualities of structural regularity, self-similarity and random formation at all scales.
Two examples of the algorithm applied on different 2D images can be seen in Figure 5 and Figure 6. In both cases, it can be seen that the branch seeds are initially distributed randomly on the 2D image. Then, they are allowed to traverse this 2D surface while branching out new line segments wherever obstructions allows. Obstructions are defined as the exceeding of the threshold of pixel brightness between the start and end points of each branch. When the critical threshold value is exceeded, the algorithm considers this as an obstruction and does not grow branches in this direction. As a result, new 2D branching patterns can be grown on existing 2D images, transforming the initial image by means of morphogenetic processes that are characterized by stochasticity and non-linearity. Processes of algorithmic iteration and feedback facilitate the formation of complex structures and give rise to the self-organization new design forms.

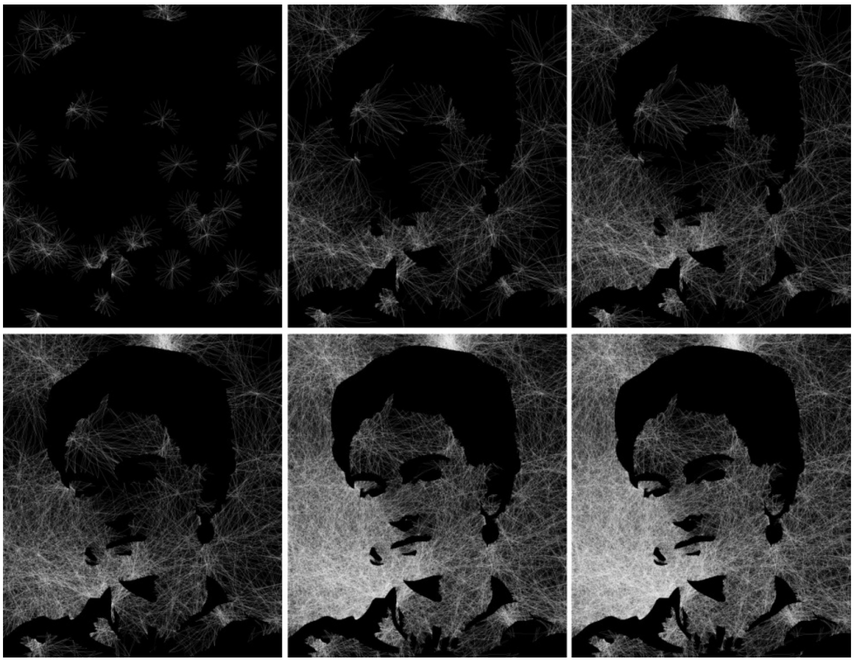


Figure 5. The consecutive phases of the application of the diffusion limited aggregation algorithm on an image of Frida Kahlo

Figure 5. The application of the diffusion limited aggregation algorithm on various image with the use of color

Conclusion

Emergence is a key concept in natural systems as well as artificial systems including design. Concepts of emergence can inform architectural design such that the principles of complexity, biological growth, adaptation and evolution can be operationalized in design synthesis, especially with the support of computation. In synthetic complex systems in design, self-organizing systems can be said to be on the verge of non-design, due to their preference on self-organization and emergence rather than control. On the other hand, the instability of an emergent system has the potential for generative formation. Due to emergent systems' open-ended generative possibilities, they are potent with unforeseeable and creative formations, supporting creative design.

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