Generative design: a paradigm for design research

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Abstract

Generative design offers new modes of aesthetic experience based on the incorporation of system dynamics into the production of artifact and experience. In this paper, we review a number of processes that can be explored by designers and suggest how design as a discipline can benefit from this research. These processes include self-organization, swarm systems and ant colonies, evolution, and generative grammars. We give example applications of these processes to creativity and design.

1. Introduction

Our world is becoming increasingly infiltrated and mediated by electronic systems and devices. The role of design is shifting in response to these changes. In this new role, established design practices may be inadequate or insufficient, particularly if we consider the function of design to extend beyond the simplistic desires of consumerism and the validation of corporate ideologies. A more expanded agenda, such as that proposed by Anthony Dunne, sees design as 'relocating the electronic product beyond a culture of relentless innovation for its own sake, based simply on what is technologically possible and semiologically consumable, to a broader context of critical thinking about its role in everyday life' (Dunne 1999). If design is to have such an expanded agenda, it is important to examine what kind of processes might facilitate this.

Generative systems offer a methodology and philosophy that view the world in terms of dynamic processes and their outcomes. In the terminology of Thomas Kuhn (Kuhn 1996), it offers a paradigm shift for the process of design and the expression of that process. For designers, it involves a reconsideration of the static artefact and the actions that manipulate it. Conceptualisation shifts from the primacy of objects to envisaging interacting components, systems and processes, which in turn generate new artefacts, with special properties (outlined below).

The generative methodology offers an unconventional way of conceptualising and working in design. Research in generative systems is closely tied to the general concept of *synthesis*, most viscerally apparent in nature and natural systems. Nature has devised a specific mechanism for generalised synthesis, using the physical apparatus of DNA, protein synthesis and biochemistry. The diversity and adaptability of life on Earth demonstrates the potential of these mechanisms to overcome problems in design and to generate novelty and diversity from relatively simple units.

1.1 Generative Systems and Design

Generative systems are relevant to contemporary design practice in a variety of ways. Their integration into the design process allows the development of novel design solutions, difficult or impossible to achieve via other methods. *Grammar-based* techniques exploit the principle of *database amplification*, generating complex forms and patterns from simple specifications. *Evolutionary* systems may be used in combination with *aesthetic selection* to breed design solutions under the direction of a designer. Interface design and other sign systems may be defined in terms of *adaptive procedures* to create communication that adapts to its interpretation and use by an audience (Innocent 1999).

The electronic object is becoming ubiquitous. A significant proportion of its content being transmitted through dynamic displays ranging from the miniature screen of the mobile phone, to large, animated billboards in public spaces. Electronic design for the multitude of screens may take advantage of some of the unique properties of the medium. By their nature, electronic media are fluid and mutable with the capacity to change their structure and meaning in response to their environment, user interaction, incoming data or other factors. Generative processes may be used to communicate via elements such as dynamic imagery, animation, textures, form, music and typography.

Finally, generative processes have broad cultural effects. The philosophy and operating principles of these systems may inspire alternative approaches to design in a more general sense. Ideas of evolution, breeding, cross-fertilisation and adaptation may be applied to the design process to generate alternative design practices or applied to non-digital design. In this scenario, generative systems stimulate new possibilities for a single project, or perhaps transform the methodology and culture of a design team.

2. Generative Design Culture

The culture of design has changed significantly in the past decade. First, there has been an increased interest from the design community in collaborative, interdisciplinary approaches to design problems. There is also a more intimate connection between concept and production/realisation in the design process through the flexibility introduced in digital design methodologies. The design process is largely viewed as a collaborative, interdisciplinary activity that is more flexible than some of the approaches that emerged during the 1970s and 1980s.

In this environment, concepts from evolutionary systems and artificial life — indeed biological systems in general — are becoming integrated into the cultural vernacular. Cultural systems can be conceptualised as ecosystems in which various fashions, trends and ideas compete for the attention of an audience (Aunger 2000). Hence, implicitly the role of chance and adaptation is recognised as significant in the design of ideas and products. Successful designs are not necessarily 'made': new functionality may 'evolve' through the use and interpretation of artefacts by an audience. For example, products designed for a niche market develop broad use and popularity while others disappear altogether. More recently, the development of information environments such as the World Wide Web show an accelerated evolution and adaptation when compared to more traditional media such as the printed page. This has arisen in response to the demands of a global audience with instant access to ephemeral electronic media.

3. Properties of Generative Systems

The key properties of generative systems can be summarized as:

• *The ability to generate complexity*, many orders of magnitude greater than their specification. This is commonly referred to as *database amplification*, whereby interacting components of a given complexity generate aggregates of far greater behavioural and/or structural complexity. Such aggregates may in turn generate their own interactions forming new aggregates of even higher sophistication and complexity. This is referred to as a *dynamic hierarchy*. A poignant example being complex multi-cellular organisms, whose hierarchy can be summarized: atom; molecule; organelle; cell; organ; organism; ecosystem.

• *The complex and interconnected relationship between organism and environment*. Organisms not only evolve and adapt to their environment, their presence and number may effect and change the environment itself. Inter- and intra- species dependencies form a complex web of relations (an ecosystem), within which there are often many feedback loops. These systems are typically homeostatic. That is, they actively maintain their state in order to offset environmental changes.

• *The ability to self-maintain and self-repair.* Human-designed structures are typically *brittle* either in a physical or functional sense. As stated above, generative systems may adapt themselves to maintain stable configurations within a changing environment. Swarm systems for example can overcome significant disruption and individual loss, reforming and adapting their behavioural function to survive. They exhibit fault-tolerance and have a high degree of internal redundancy, giving them the ability to overcome changes that would limit a more fragile design.

• *The ability to generate novel structures, behaviours, outcomes or relationships.* Novelty used in this sense means the quality of being new, original and different from anything else before it. There are of course, different degrees of novelty. RNA and DNA were novel in that they introduced a completely new mechanism for replication and encoding of protein synthesis. Artists and designers are always seeking novelty (the opposite of which is mimicry or copying, something depreciated in the art and design world). Artistic novelty may not have such a significant impact as, for example, DNA, but the key concept is that of the *new* — generative systems have the potential to give rise to genuinely new properties. This is why they are often referred to as *emergent* systems. These new properties typically fall outside the designer's expectations or conceptualisations for the design, resulting in functionality or outcomes that were not anticipated. This of course raises the issue of control, a problematic issue for generative design, particularly if the designer is accustomed to organizing outcomes in a predictable way.

4. Methodologies for Generative Design

4.1 Self-organization and self-assembly

Self-assembling systems consist of large numbers of relatively simple, autonomous components that combine to construct large-scale artefacts or may interact with one another to solve problems collectively.

One means of instigating self-assembly involves mimicking the behaviours studied in Chemistry. This entails modelling or constructing a large number of simple elements which may attach themselves to one another in various configurations according to binding sites on their surfaces and according to laws of attraction and repulsion. If the rules for these bindings are well considered by the designer, and the form of the elements is well conceived also, it becomes possible to witness the self-assembly of various structures as a consequence of the rules of interaction of the elements. Such techniques form the basis of supra-molecular chemistry and nano-technology.

In practice, it is very difficult for the designer to specify effective rules for self-assembly of virtual elements. Additionally, the software for modelling such systems may be quite complex and unwieldy. Hence, whilst in biological design self-assembly is commonplace (in fact this is one of its defining characteristics), in human design, we are yet to turn such systems to our advantage. If this means of constructing or designing artefacts can be harnessed, it promises to be perhaps *the* most powerful tool for simultaneous design and manufacture we have yet imagined.

There are self-organizing systems of a kind slightly different to that described above which might be more successfully used for design with current technology. These systems typically consist of *loosely* coupled elements (often labelled *agents*), capable of independent action based on their perception of immediate surroundings (including other elements like themselves). The nest-building behaviour of ants, their efforts to locate food, clear debris or repel predators, provide an interesting example of such 'distributed problem solving'. In these systems, no individual ant has a complete understanding of the nest, its design or maintenance. Nor does any ant direct the other members of its colony. Instead, each ant goes about its daily business and together the colony is able to solve the problems it encounters for survival.

Other biological problems that have been solved by nature in this manner include the coordinated movement of large groups of animals in schools, flocks and herds, the capture of evasive or dangerous prey by packs of weaker animals, the foraging for nectar by colonies of bees, the synchronization of behaviour in fire-fly flashes.

4.2 Evolutionary Systems

Evolutionary systems are based on simulating the process of natural selection and reproduction on a computer. This technique has found wide application in design for computer animation and graphics, but also in architectural, industrial and engineering design (Bentley 1999). The technique depends on the specification of a parameterised model that is general enough to allow a wide variety of possible outcomes of interest to the designer. In cases where a very specific goal is sought, the parameter space must also be sufficiently broad to encapsulate an answer to the problem that meets the specified design constraints.

Initially a 'population' of potential designs is generated with a random set of parameters. This random population may be displayed visually to the designer. The designer's aesthetic sense then determines the 'fittest' designs of those displayed, and these are 'bred' with one another to produce a new population of designs that inherit the traits of their successful parents. This process is akin to selective breeding of apple trees for the taste and colour of their fruit – both subjective qualities assessed by humans (Dorin 2001).

An alternative means of utilizing this evolutionary process exists where a *fitness function* may be explicitly coded by the designer. For example, perhaps a designer seeks the lightest, cheapest set of automobile wheels. This fitness function is coded into the evolutionary system and the computer evolves populations of wheels towards a successful structure independently of further human input. Where creative designs are sought with some aesthetic value, the former technique of interactive evolution is more practical.

This requires constant human interaction, a necessary bottleneck as long as it remains difficult to encode subjective qualities like ‘beauty’, ‘ugliness’ etc. in such a way that a computer can operate with them.

4.3 Generative grammars

Grammar-based approaches involve the specification of a mapping between a *string* of characters and the artefact to be designed (or its components). Characters in the string are taken from an *alphabet* of possible characters. These characters may directly represent elements of the artefact being designed. Alternatively, they may indicate instructions for building the artefact that then need to be executed by a physical machine or by the computer itself.

These systems commence with an initial string of characters, the *axiom*. A set of *production rules* must also be designed. The rules specify how each of the characters in the alphabet is to be individually replaced with another set of characters in discrete time steps. The system begins with the axiom, and replaces each of its characters according to the production rules to produce a new string of characters. Then, each character in the new string is replaced with a successor according to the production rules. This process of *string-rewriting* occurs until a string is located which represents the final structure or instructions for it to be built.

Alternatives to character-based grammatical systems have been devised which involve the replacement of shapes in a structure with further sets of shapes using production rules. *Shape grammars* (Stiny 1975) have found application in architecture and design, as well as in their analysis.

5. Example Applications to Design

In recent years, many artists and designers have turned to generative systems to form their design basis. *Dextro* (www.dextro.org) has developed a diverse range of interactive drawing systems in which simple design elements such as points and lines replicate and self-organise to create illustrations and animations. Digital artists *Meta* use generative processes to create streams of abstract video (www.meta.am), expressive of the multi-layered, fluid mutable nature of electronic space. Jared Tarbell (www.levitated.net) has experimented with the intersection of generative systems, typography and graphic patterns in his experimental web design projects. Software such as *Auto-Illustrator* (www.auto-illustrator.com) and *Autoshop* (www.signwave.co.uk) combine generative systems with the image composition and editing functions of popular computer drawing programs to ‘automatically’ create new designs ready for use in projects. *Groboto* (www.groboto.com), a program that allows users to develop their own systems for growing 3D forms, makes these systems accessible to a wider audience by placing a GUI in front of the lines of code usually required to work with generative systems.

6. Concluding Remarks: the Role of the Designer in Generative Design

In traditional design, the role of the designer is to explore a solution space. Solutions may be aesthetic, semiotic, cultural, dynamic, industrial, corporate, political, or any combination of these and other determinants. The key relationship between designer and artefact is a direct one (even if mediated via some third-party or medium). There is a direct relationship between the designer's intentions and that of the designed artefact. In contrast, design using generative methods involves the creation and modification of rules or systems that interact to generate the finished design autonomously. Hence, the designer does not directly manipulate the produced artefact, rather the rules and systems involved in the artefact's production. The design process becomes one of *meta-design* where a finished design is the result of the *emergent* properties of the interacting system (McCormack & Dorin 2001). The 'art' of designing in this mode is in mastering the relation between process specification, environment, and generated artefact. Since this is an art, there is no formalized or instruction-based method that can be used to guide this relationship. The role of the human designer remains, as with conventional design, central to the design process.

6.1 Originality and Intent

Some unique means of 'applying individuality' are available to a designer working with generative media. Specifically, the designer's role may become one of shaping the constraints on the dynamic process and its behaviour. The designer may seek behaviours in the artefact which are genuinely novel, even to him or herself. In other instances, perhaps a predictable, controllable outcome is sought. There are moral obligations for wishing to impose such constraints on the artefacts one designs.

An additional aspect for the designer to consider is the coherence of the design, regardless of the physical or behavioural transformations it undergoes during its lifetime. Biological organisms often remain unique, identifiable entities, despite the flux of their components, the dynamics of their behaviour or the morphological processes of growth and decay. That is, the lifetime of the organism is determined by the extent to which it may maintain its organization in the face of decay.

As a designer working with generative processes, one may still wish to leave a recognizable mark on a creation. This may be achieved statically using fixed components with a trademark style. A more interesting way to achieve this is to ensure either that the organization of the artefact bears the stamp of its designer, or that its behaviour falls within the gamut of work typically produced by the designer. Of course the designer may not be interested in imposing a recognizable style, however the utilization of generative techniques does not preclude this option. In this sense, generative design still requires the skill and artistry that encompasses any mode of design.

References

Aunger, R. 2000, *Darwinizing Culture : The Status of Memetics as a Science,* Oxford University Press, Oxford ; New York.

Bentley, P.J. 1999, *Evolutionary Design by Computers,* Morgan Kaufmann Publishers, San Francisco, Calif.

Dorin, A. 2001, 'Aesthetic Fitness and Artificial Evolution for the Selection of Imagery from the Mythical Infinite Library' in Kelemen, J. & P. Sosík (eds), *Advances in Artificial Life, Proceedings of the 6th European Conference on Artificial Life*, vol. LNAI2159, Springer-Verlag, Prague, pp. 659-668.

Dunne, A. 1999, *Hertzian Tales: Electronic Products, Aesthetic Experience and Critical Design,* RCA CRD Research Publications, Royal College of Art, London.

Innocent, T. 1999, The Language of Iconica, in Dorin, A. & J. McCormack (eds), *First Iteration: A Conference on Generative Systems in the Electronic Arts*, CEMA, Melbourne. pp. 92-104.

Kuhn, T.S. 1996, *The Structure of Scientific Revolutions,* (Third Edition), University of Chicago Press, Chicago, Ill.

McCormack, J. & A. Dorin 2001, 'Art, Emergence and the Computational Sublime' in Dorin, A. (ed), *Second Iteration: a conference on generative systems in the electronic arts*, CEMA, Melbourne, Australia, pp. 67-81.

Stiny, G. 1975, *Pictorial and Formal Aspects of Shape and Shape Grammars,* ISR, Interdisciplinary Systems Research; 13., Birkhäuser, Basel ; Stuttgart.