Degrees and Switches

Abstract:

In recent years, evolutionary biology has been the focus of post-Darwinist theories superseding the mere notion of variation with a concept called evolutionary development. The theory of evolutionary development, commonly referred to as *evo-devo*, follows a series of observations on the nature of organic developments and natural morphologies. Its main contribution rests on an evolutionary model that considers the similarities of genetic material forming organisms and their differences in morphological development due to switching mechanisms between the assigned genes. As observed by the American biologist Sean Carroll[1], evolution follows regulatory sequences of selector genes that are similar and can be found across various species of insects, plants and animals. This observation represents a counter-proposal to the old-modern evolutionary theories that looked at processes of adaptation as a function of the emergence of new genes. *Evo-devo*, on the contrary, recognizes that morphological differences are triggered by recombinatory switches that re-arrange genes in manifold ways to produce numerous characteristics of adaptation.

From a design point of view, *evo-devo* has tremendous implications because it suggests that generative design protocols may induce sets of similar operations, yet stimulate a wide range of morphologies according to their sequential arrangements and activities. These generative design strategies include, among others, computational methods such as *structural shape annealing* and *object-oriented analysis and design.* While these methods are now integrating computing design practices, it is here proposed to review these two computational design methods in the context of three research projects.

I. Evolutionary development: A model of Recombinatory Architecture

The development and refinement of a *structural shape annealing* protocol has been the focus of a two-year collaborative research between a world renowned engineering office and our laboratory. It has led to the development and implementation of a full scale prototype whose design has been automated in terms of structural efficiency, architectural morphology, construction detailing and manufacturing. Following an initial positioning of structural nodes on the site of Rudolph Schindler's case study house in Los Angeles, the self-similar nodes evolved according to a series of operational switches that activated the formation of an iterated set of possibilities. This method has been reiterated in a large scale interactive installation recently constructed in Hollywood, California. This installation emphasizes the notion of genetic switches by tracking and registering various movements of a grid which represents an n-dimensional data structure.

The concept of data structure, and its related potential to mutate under the influence of operational switches, is emphasized in a recent project for the design of a computationally formed chair. This project is based on *object-oriented analysis and design (OOD)*. The overall principle is to study emergent morphologies of differentiation in terms of form, structure, and function. The fusion of *OOD* and *evo-devo* drives the emergence of performative clusters akin to differentiated internal organs as found in advanced natural organisms. Growth is regulated by the stochastic clustering of related information gradients and a series of transformations including binarization and tropic expansions and contractions. The coupling of these methods offers the possibility to create a stochastic evolutionary process of design iterations, each different in terms of their resulting morphologies yet similar when it comes to their set of generative operations.

While traditional genetic algorithms have recently been the focus of various researches, it is here suggested that the notion of operational switches and its subsequent computational procedures stimulate a perception of reality by *degree.*

II.   Degrees: The N-dimensional Model

Amid a wide range of projects that address the intricate relationship between computational architecture and biologically formed systems, *The Hylomorphic Project* exemplifies the notion of degrees of optimization. The complexity of this project was mitigated through the use of an integrated design process which includes architects, structural engineers, and software developers.
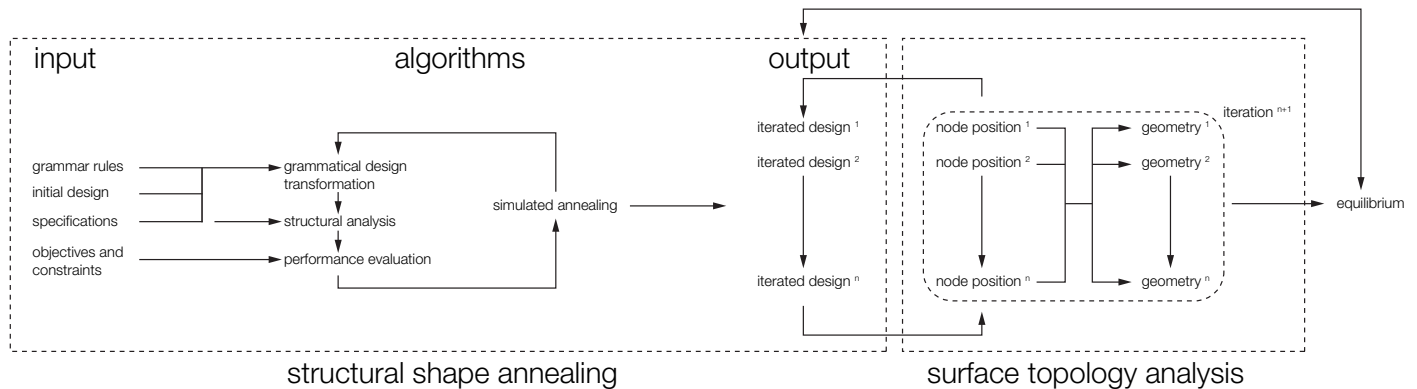
Protocol of The Hylomorphic Project showing the interconnectivity of rule-based operations and geometrical analysis

This research addresses the formation of an assemblage constituted of intricate - yet generalized - components that manage n-degrees of parametric differentiations such as structural forces, geometrical triangulations and material properties. The Hylomorphic Project is based on an evolutionary stochastic algorithm. Reacting to multiple constraints, an iterative optimized solution evolves as a topological condition of form finding. CNC milled manifold connectors negotiate multidirectional movements. Each connector is specialized, yet each follows typological principles of generalization.

Using Rudolph Schindler's Kind Road house in Los Angeles as a test-ground, the hylomorphic procedure uses the modernist structural grid as an initial phase. As in the genomic codification of complex organisms, the computational protocol leads from an idealistic typology, the King Road House structural grid, to a standardized language of adaptive topology, an n-dimensional grid.

A grammar language of shapes is used to identify the connectivity between the design topology and its structural translation. This insures the convergence between form and structure according to a set of logical relations. A formal definition can evolve while remaining consistent with its structural definition. With the addition and removal of structural members, the algorithm produces an infinite set of solutions that we have called *n-degreed formations*.

This algorithm is based on a method called *structural shape annealing*. This method consists of applying two distinct computational procedures to a layout of discrete structures: A grammatical formalism (shape grammars) and a directed stochastic search (simulated annealing). A shape grammar creates a language of discrete structures that specifies spatial transformations according to the relation between

form (e.g. number of structural members and triangulations) and function (e.g. material economy and structural efficiency) in the structure.[2] The structural shape annealing method defines a state space which inherently suggests degrees of optimization. The structural language opens a vast field of optimally directed essays of discrete solutions.[3]

The Hylomorphic Project prototype at Rudolph Schindler House, 2006

The striking feature of the structural shape annealing method rests on its translation of the discrete structure based on global and local design goals. The structural network is evaluated and optimized following behavioral constraints[4] in terms of relations and acceptable levels of system flow. Through a series of transformations, the coupling of topology with shape and sizing optimization makes the design state space multi-dimensional. A second topological state is informed by size while a third topological state is informed by shape. A fourth topological state is created with the transformation of the primary topological state. It is within this new topological state that sizing and shape transformations may occur.[5] Our engineer describes structural shape annealing as "defining the semantic space that describes a set of purposeful designs for a structural design application. The semantic space provides for the interpretation of designs existing in the design state space in terms of the individual goals of the designer (objectives) and the requirements of the design problem (constraints)".[6] The negotiation between design objectives and constraints defines the structure of the semantic space allowing different designs within the same semantic space. This relation between design state space and semantic space opens the possibility for distinctive solutions to be generated from a single initial design problem.[7] By generating one design essay among many, design solutions are optimized.

The Hylomorphic Project prototype at Rudolph Schindler House - Detail

The notion of degree of optimization and its visual cues as offered by the shape annealing method has tremendous consequences with regard to architectural research. An evolutionary model of similar operations stimulates degrees of morphology according to arrangements and activities. The tracking and registration of these degrees of transformation has recently been explored by our research laboratory. *I-grid* is a large scale installation located on Sunset Boulevard in Hollywood, California. Based on a two-dimensional grid, a 50 feet high billboard features the transformation of its original rigid format into a multi-dimensional grid. The project aims at reflecting the manifold movements of the original grid when pressured by the shape annealing method. I-grid registers the multiple movements of spatial coordinates by on a predefined set of operations and a randomized search, The resulting image composite expresses a statistical morphology of the original format. The experiment's set of iterations represents a series of points of bifurcation. These points refer to moments of topological transformation induced by the shape annealing method. They reveal multi-topological degrees of design transformation.

I-grid - Sunset Boulevard, Hollywood, 2007

Considering the notion of n-degrees of evolution, as exposed in the Hylomorphic Project and I-grid, implies that architecture is no longer considered in terms of *form* but of *formation*. Based on interrelated notions of semantic space, design state space. and points of bifurcation, the architectural formation is regulated by multiple computational switches.

III.   Switches: The Differentiated Model

Taking cues from the theory of evolutionary development in biology, our laboratory has produced an evolutionary computational procedure which creates radically different morphologies based on a switch-regulated combination of sub-modules. The algorithm utilizes operational switches which are combined, turned on and off, and follow gradients according to the on-going adaptability of the model. The striking feature of this model is that differentiated organisms, such as hierarchical trees and rhizomic forms as found in nature, may be produced out of self-similar algorithmic operations[8]. The arrangement

and combination of operations and their regulating switches lead to very different morphologies and consequently, to *emergent behaviors.*

Striking similarities between current biology and computer science include switches,[9] modularity,[10] containment, hierarchy, combination, aggregation, encapsulation, inheritance, and polymorphism[11]. Switches can combine independently or hierarchically to activate or repress morphology. They can be present in sufficient or necessary levels. They can act directly or indirectly.[12] The *C-chair* project represents the first phase in the development of an algorithmic framework for the evolution of *differentiated* architectural forms. The C-chair itself can be thought of as a metaphorical artifact of both a biological system and an object-oriented machine. It is composed of two components – a tree and a rhizome. The tree represents the structural support system, and the rhizome acts as the surface. Each component has its own innate "knowledge" concerning its morphology. The rhizome "knows" how to proliferate and grow horizontally along a surface. This is accomplished through a mechanism which can grow homologous, self-replicating strands and roots. The ontological drift of each strand is controlled by rules, and is regulated by design parameters which act as genetic switches for speed and direction of growth and the amount of proliferation. Similarly, the tree "knows" how to proliferate and grow. This knowledge is modified and augmented with the ability to maintain vertical structure. The roots remain, but the strands are replaced by a trunk, branches, and leaves. The more complex organism, the tree, builds upon the established knowledge of the less complex organism, the rhizome.

The functions that are common to both forms are regulated by reused switches, and new switches regulate new functionality. In biological terms, both organisms are made up of cells, and each cell has a cell-membrane. The rhizome's cell-membranes are not structural, thus constraining the rhizome to grow only horizontally. The tree's cell-membranes are structural, allowing for the enhanced performative aspect of vertical growth and structural qualities. A phylogenetic tree[13] can be used to map the specificity and diversity of switches as they evolve to regulate increasing complexity through inherited knowledge and the combination of modules. In OOD, this knowledge is encapsulated in terms of objects and methods. There is an inheritance relationship between the tree object and the rhizome object. Some methods are reused and others are augmented or overridden.
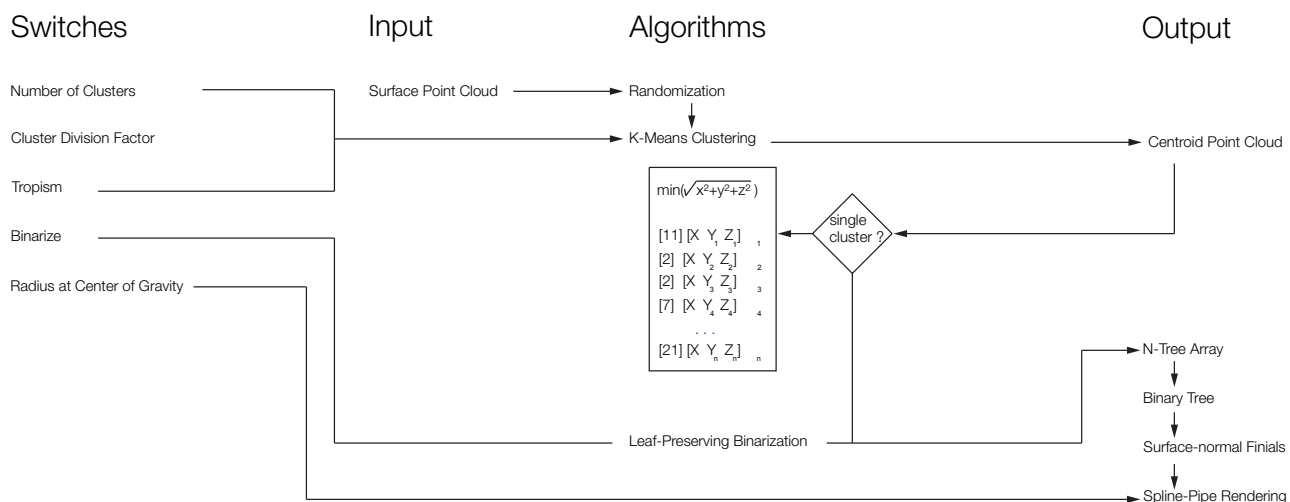
Protocol of The C-chair Project showing the use of OOD, clustering, and binarization techniques

A clustering technique is utilized to generate the C-chair. The chair form negotiates between the upper chair surface and the base surface. Both surfaces become point clouds of density which are randomized so that the emerging clusters are evenly distributed. The density areas define zones where the chair's structural support is required. After randomization, the number of clusters desired is input as a genetic switch. One by one, the points are moved from one cluster to another until the system stabilizes to form

a minimal overall Euclidean distance[14]. This particular method results in a circular morphology. Other distance methods, such as nearest-neighbor, can act as evolutionary regulating mechanisms to create different morphologies. Once the centroid points are established, they are "pulled" in toward the overall center of gravity of the initial point clouds. This effectively creates a natural tropism of eccentricity of the emergent network. This eccentricity can be manipulated by another design switch, *tropism* in order to model external forces on the fabric such as gravity.

Protocol of The C-chair Project showing the use of object-oriented design, clustering, and binarization techniques

In a self-similar fashion, the algorithm proceeds by packing the first generation of centroids into a point cloud which is then recursively fed back as the next point cloud to be clustered. The number of second generation clusters is determined by another switch, the cluster-division-factor. This, in effect, regulates the thickness of the internal branches. For example, if the initial design called for 23 clusters, and the cluster-division-factor was 2.0, the second set would have int(23/2.0) or 11 clusters. The process is repeated until the number of clusters reduces to 1, at which time a set of N-tree data structures is created. 'N' refers to the fact that a typical tree node contains one parent node, and N child nodes. *Leaf-preserving-binarization* is a transformation that is optionally applied to the N-tree in order to produce a binary tree. This transformation is productive in many ways. In terms of a data structure, a binary tree can be traversed and balanced for efficient information management. In terms of a physical structure, it is advantageous for fabrication to constrain the number of branches emerging from each node to 3 or less. Also, material usage is reduced.
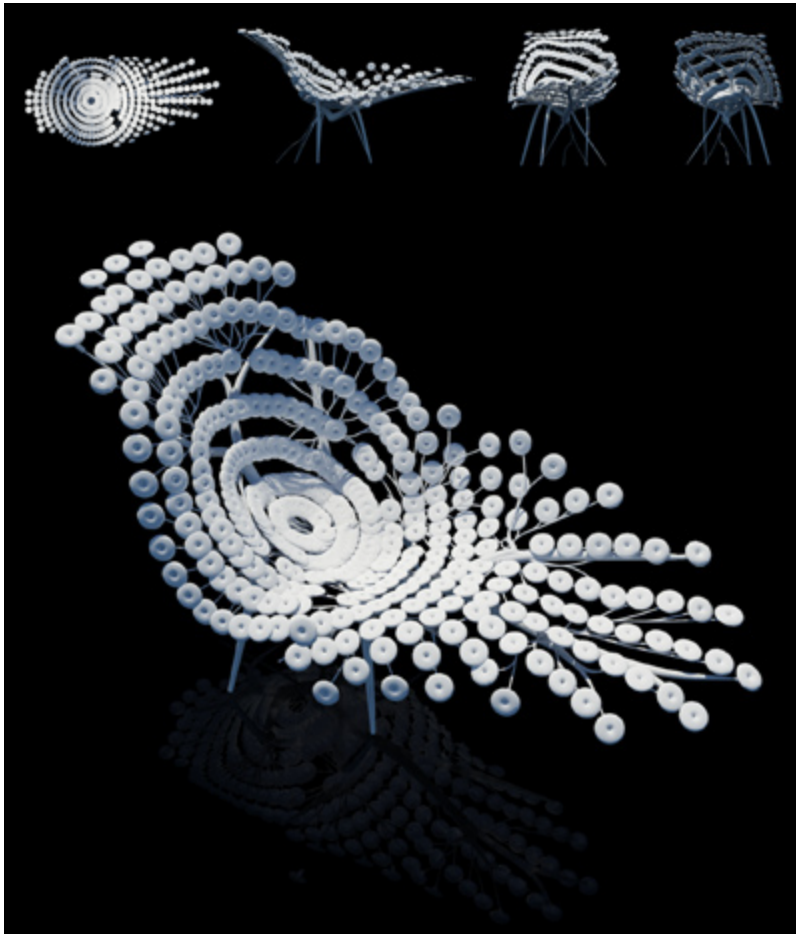
C-chair - rhizomorphic finials based on 9 clusters

Once the tree point cloud is generated, it is rendered in a separate operation. A switch selects from a set of pre-order traversal rendering routines: straight line, spline, and tapered pipes. Other switches, *radius* and *radius-reduction-factor* regulate the morphology of the branches. Once the traversal reaches a leaf, a finial is attached. A geometric form guides the creation of a disk-like pattern. The original surface is used as a guide for the orientation of each finial disk; the disks are all perpendicular (normal) to the initial modeled surface. These disks form the emergent surface of the C-chair.

This technique effectively creates a diagram or a map in which a multiplicity of solutions can be easily generated and formally explored. The technique is extended in order to model the duality of a rhizomorphic structure[15]. By emulating these results digitally, it is possible to cull similar characteristics and to easily generate many permutations of the experiment.

IV. Conclusion

With the increasing interest to relate architectural morphology to models of complexity present in nature, a form of recombinant architecture has emerged in recent years. The modus operandi of such architecture relies on the use of generative design methods such as structural shape annealing and rule-based systems. Complexity is mitigated through the use of object-oriented design. These computational procedures integrate an operational structure which is based on a series of subsystems acting as switches. Inspired by the notion of evolutionary development, switch-regulated combinations of identical subsystems can produce a wide variety of morphologies. As proposed in our recent research on the C-chair, operational switches induce the emergence of recombinant models that evolve according to a principle of selection rather than adaptation. With our research on the Hylomorphic Project and I-grid, the recombinant model offers an architecture that exemplifies a perception on nature in terms of degrees of optimization. Degrees and switches express a reality that is in a state of *becoming* rather than *being*.[16]

Endnotes

1 See Sean Carroll, "Endless Forms Most Beautiful: The New Science of Evo Devo", W. W. Norton Publication, 2005
2 See Kristina Shea, "Essays of Discrete Structures: Purposeful Design of Grammatical Structures by Directed Stochastic Search", A dissertation submitted to the Carnegie Institute of Technology, 1997, p. 1
3 Ibid, p. 3
4 Ibid, p. 3
5 Ibid, p. 4
6 Ibid, p. 6
7 Ibid, p. 6
8 See Sean Carroll, "From DNA To Diversity: Molecular Genetics and the Evolution of Animal Design", Blackwell Publication, 2005, p.10
9 Ibid, p. 59
10 Ibid, p. 96
11 Ibid, p. 230
12 Ibid, p. 59
13 Ibid, p. 242
14 See online Teknomo, Kardi, "K-Means Clustering Tutorials", http:\\people.revoledu.com\kardi\ tutorial\kMean
15 See Gilles Deleuze and Félix Guattari, "A Thousand Plateaus: Capitalism and Schizophrenia", Continuum International Publication, 2004
16 "It is quite remarkable", writes Ilya Prigogine, "that such a transformation exists and that as a result we can now unify dynamics and thermodynamics, the physics of being and the physics of becoming" in Ilya Prigogine, "Order out of Chaos", Shambhala Publications, 1984, p. 277