

## RECAPITULATION IN GENERATING SPATIAL LAYOUTS

### *Representations of Embryogenesis in Evolutionary Design Modelling*

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**Abstract.** The noted 19th century biologist, Ernst Haeckel, put forward the idea that the growth (ontogenesis) of an organism recapitulated the history of its evolutionary development. While this idea is defunct within biology, the idea has been promoted in areas such as education (the idea of an education being the repetition of the civilizations before). In the research presented in this paper, recapitulation is used as a metaphor within computer-aided design as a way of grouping together different generations of spatial layouts. In most CAD programs, a spatial layout is represented as a series of objects (lines, or boundary representations) that stand in as walls. The relationships between spaces are not usually explicitly stated. A representation using Lindenmayer Systems (originally designed for the purpose of modelling plant morphology) is put forward as a way of representing the morphology of a spatial layout. The aim of this research is not just to describe an individual layout, but to find representations that link together lineages of development. This representation can be used in generative design as a way of creating more meaningful layouts which have particular characteristics. The use of genetic operators (mutation and crossover) is also considered, making this representation suitable for use with genetic algorithms.

**Keywords.** Generative Design, Lindenmayer Systems, Spatial Layouts

### 1. Introduction: The Biological Metaphor

D'Arcy Thompson's 1917 work *On Growth and Form*, led the way for research examining the morphogenesis of living creatures and the way in which species related to one another. One of the most famous ideas put forward in his writing comes from the chapter '*The Comparison of Related Forms*' where Thompson shows how simple mathematical transformations could be used to model the way in which species related to each other through their morphology.

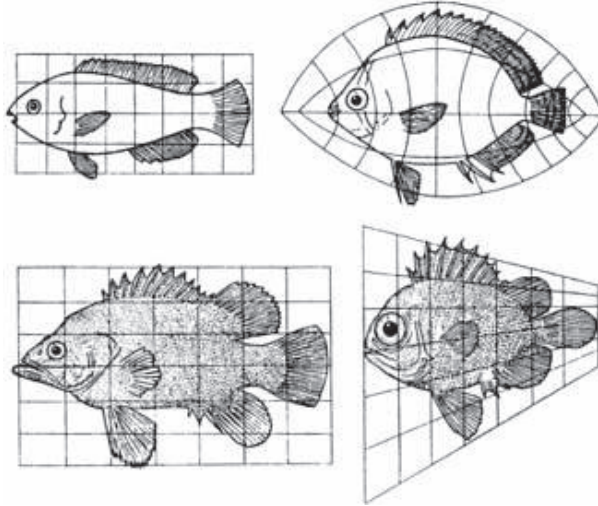
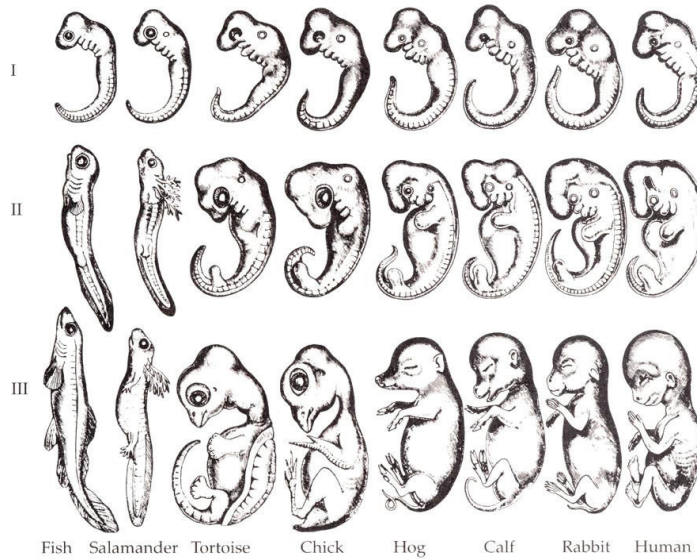


Figure 1. Transformations between species of fish (Thompson, 1917)

Central to this form of modelling is the consideration of topology where the body plan stays fixed but the lengths of parts vary and produce different species. It is not always intuitively easy to see how closely body plans are related to one another in biology. As an example, consider the skeleton of a bird (shown in Figure 2) where the position of the ankle is so high up (compared to a human) that it looks as if it provides the function of a knee. The actual knee (or equivalent feature) is also quite high up and is hidden from view. In a similar fashion, the finger bones of a bat still map to those of a human but their elongated form and webbing between allow them to operate as wings.

This biological metaphor can allow us to group architectural examples, transcending period and style and focusing on their underlying structure. In the study of generative design, the metaphor can be used as the basis for designing representations. In this research, the design of representations

suites for genetic algorithms are explored that have this quality of mapping between instances allowing us to create lineages of designs. Ernst Haeckel made famous the phrase “ontogeny recapitulates phylogeny”. The key idea behind what would get known as ‘Recapitulation theory’ was that the developmental stages of the embryo showed forms influenced by the history of the species.



*Figure 2. Romanes's comparisons of embryo development (columns show species, rows show development stages).*

Drawings by Haeckel and other biologists such as George Romanes (see Figure 2) over-emphasized the similarities and the theory subsequently went out of favor.

**2. GL-Systems for Evolutionary Design Modelling**

L-systems were introduced in 1968 by the Hungarian theoretical biologist Aristid Lindenmayer at the University of Utrecht (Lindenmayer, 1968). another. A machine that is allowed a certain amount of memory (a stack of memory) will now be used. L-systems use a rule-rewrite system which is then interpreted by a reader that reads relative coordinates. This is commonly

called a ‘turtle’ and the drawings it produces are called ‘turtle-graphics’. There are two parts to an L-system: an initial configuration, a rule set that describes the replacement of a symbol by another set. The turtle has a ‘memory stack’ and can remember a position in space and return to this position without drawing. There is a set of symbols that are read by the turtle in an L-System setup. In this section, only a small subset shall be used.

These are:

Table 1 Symbols used in Lindenmayer Systems

F	This the turtle move forward.
+	The Turtle turn right.
-	The Turtle turn left.
	The two symbols which require a memory stack are:
[	instructs the turtle to save its current position on the stack.
]	instructs the turtle to move position on the stack

By replacing the initial symbol according to the rules and having the turtle draw according to the symbols at each iteration, it is possible to model various growth patterns as shown in Figure 4. The importance of this representation is that it can capture recursive motifs in growth in an intuitive an easy to implement manner.

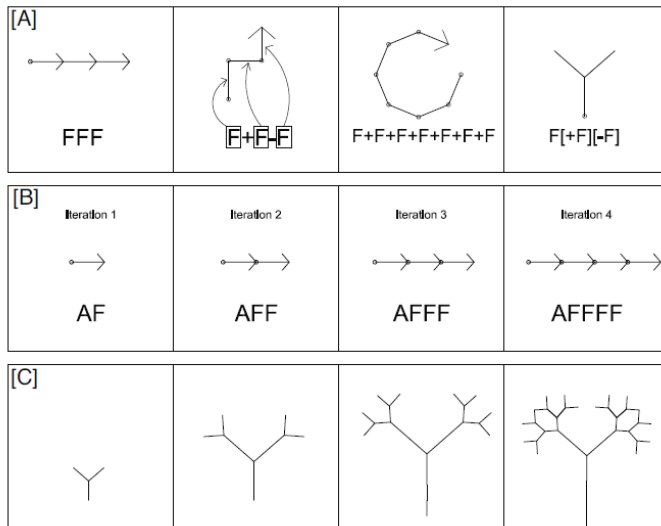


Figure 3. Some L-Systems interpreted at various iterations.

The rule set given below would give the lower set of iterations shown in Figure 3. Note how in the first rule, the symbol 'A' is present in both the left and right hand side. This is what allows recursive behavior when drawing.

A-> BF[+BFA][-BFA]  
 B -> BF

2.1 GL-SYSTEMS

A representation system based on L-Systems is now put forward. These have been named Grid-based Lindenmayer Systems (or GL-Systems). In addition to the commands given in the previous section, the following commands are presented:

Table 2 Commands used in GL-Systems

L	Followed by number - change the distance that the turtle travels with each move.
o	Revert to the original distance that the turtle moves.
s	Follow by an integer, change the 'state'
% and *	Save the position onto the stack when encountering '%' and when encountering '*', draw a rectangle on the grid.

These commands are interpreted by a turtle which is working on a grid of cells, with the commands changing the state of cells. This is a digital representation as a cell can only be whole state. Figure 4 shows a GL-System with a branching structure along two axes.

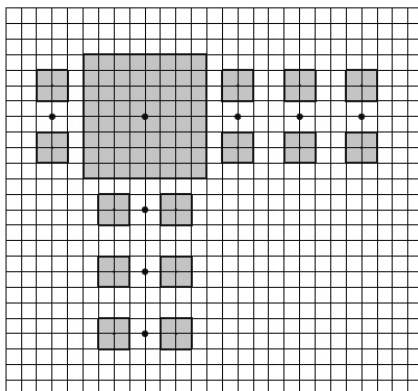


Figure 4. GL-System showing branching along axes.

One of the strengths of this representation is that it captures form as well as compositional motifs such as linear positioning as shown in Figure 5.

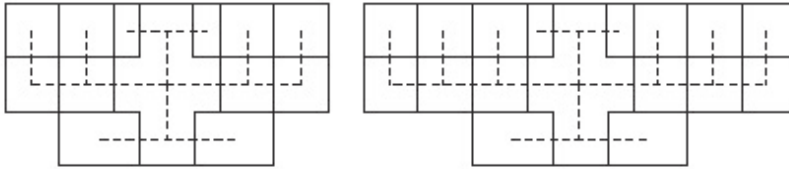


Figure 5. The representation of the villa after 3 and 4 iterations.

### 2.1 GENETIC OPERATORS

The two most important operations in evolutionary systems are crossover and mutation. The most common way to recombine data structures that are tree-like is with Genetic Programming (Koza, 1990). This is in contrast to traditional genetic algorithms which use bit-strings and also tend to have simpler mappings between genotype and phenotype. Figure 6 shows three data-structures that take the form of a tree. The first gives the arithmetic equation “(3+2) \* 4” and the second and third are two forms of the machine instructions in L-Systems structuring the sentence ‘FF[+F][F]’. The second one uses a n-ary tree while the third is a binary tree. It should be noted that many instruction sets can come up with the same form.

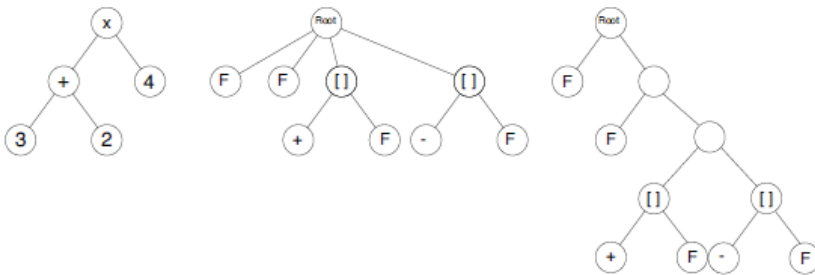


Figure 6. Tree data structures.

Crossover (the joining of two genotypes) can be achieved by grafting the sub-tree of one parent into a node in the other. This ensures that the representation is always ‘correct’ in the sense of matching parentheses and

other symbols that require closing (i.e. the ‘%’ and ‘\*’ command). Mutation can be achieved by moving sub-tree within the GL-System or by changing extensive values such as with the ‘l’ command.

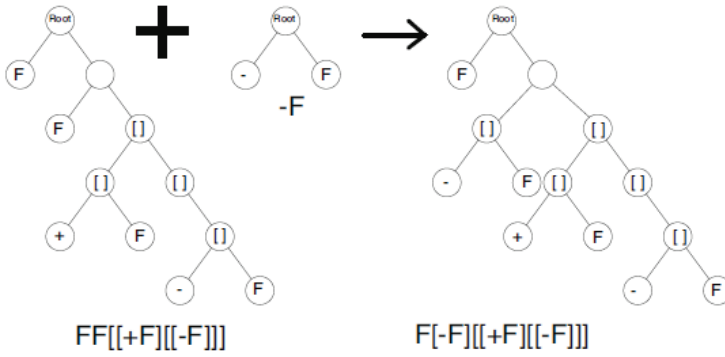


Figure 7. Crossover on two GL-System rule sets.

### 3. Case study: Palladio to Write

As an example, some of the villas of Palladio were chosen for their historical significance both to architecture and Computer-Aided Design research. There is significant writing on representing the concept of a Palladian Villa through shape grammars such as given by Mitchell (1991).

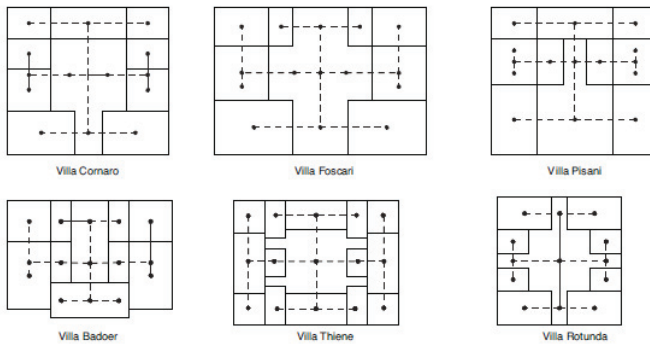
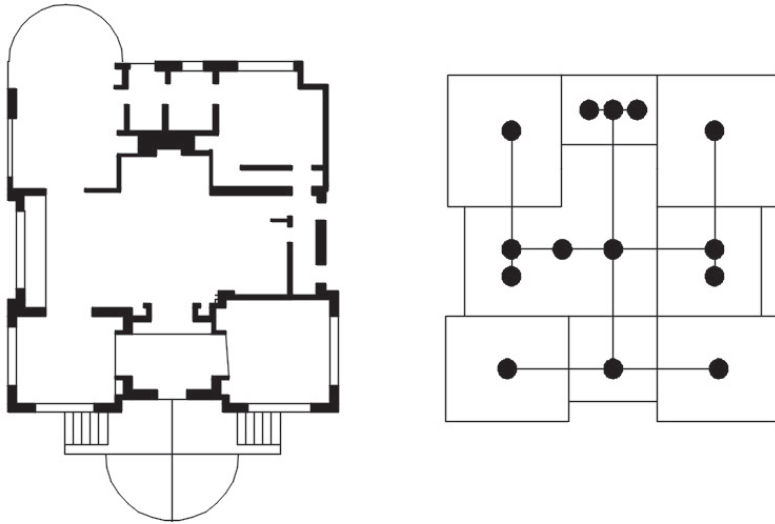


Figure 8. Some Palladian Villas which follow the 3x3 grid.

Through the six villas, their underlying skeleton expressed as a GL-System is given. Using the same skeleton can produce the variety of villa shown and can also be used to make a tracing to a much later architectural work as shown with Frank Lloyd Wright's Blossom house (an example of Jefferson Palladianism).



*Figure 9. Frank Lloyd Wright's Blossom house expressed as a GL-System.*

Note that with the skeletons, there are points which have no effect on the phenology. These exist as vestigial DNA which links the designs together though losing use in later examples. While there are an infinite number of ways that the same phenotype can be represented with different gene sets, some of these genes would be more appropriate for presenting the entire design family and its morphology than others.

#### **4. Conclusion**

While there are many computer representations to that are suited for representing form, it is still a challenge to represent families of designs especially when working within the field of evolutionary design modelling. The biological metaphor of evolution is useful as it provides an intuitive understanding of how change occurs over time as well as how forms are



related to precedents. There is therefore a gap in the research concerning representations suitable for the analysis of designs.

This research adapted Lindenmayer Systems (originally designed for the purpose of modelling plant morphogenesis) to create spatial layouts on a grid of cells. The advantage of this representation is that it can capture both the growth of an individual as well as the evolution of the population. To be relevant to evolutionary design modelling, some notes were given on how genetic operations could be applied to this representation (crossover and mutation).

The case study of Palladio's Villas was examined finding a skeleton (or body plan) that could unify an entire set. In other words, bring them close enough in the genotype, that they could be considered a single genus. To achieve this, vestigial points are present in the representations used, in order to keep the skeletons underlying the body plan as topologically equivalent. An example from several centuries – Blossom House by Frank Lloyd Wright - later was shown with the same skeleton overlaid. The importance of this particular example lies as it being an early starting point for much later creative work with varied floor plans in the Prairie style. A small amount of mutation can account for the differences in topology while changes in extensive genes such as the sizes of rooms accounts for most of the form.

In order to progress with evolutionary modelling, more design lineages need to be explored. It is also important that a systematic analysis of the effects of mutation and crossover are studied in order to control the amount of mutation. Future work in this area could look at progressing to further cases such as the evolution of Wright's style as well as other architects that were inspired by Palladio (for example Le Corbusier's Villa Stein is known to be related to the Villa Malcontenta).

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