A Morphogenetic Design Strategy Using a Composite CA Model

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ABSTRACT

In this paper, we present an exploration of digital morphogenesis in architecture, using a composite Cellular Automata (CA). This model allows us to produce a vast array of different spatial topologies by evolving the boundaries of spatial units. This approach focuses on the formation of spatial patterns, where their characteristics emerge as consequence of the evolution of the system, rather than being prescribed by design. The experiment presented here investigates whether the composite CA is capable of generating aggregate spatial units to match the characteristics of specific spatial configurations.

Categories and Subject Descriptors

I.6 [**Computing Methodologies**]: Simulation and Modeling-cellular automata

Keywords

Cellular automata, digital morphogenesis, evolutionary design, generative design

1. INTRODUCTION

Architectural design can be conceived as a purposeful, constrained, open-ended decision-making process where the aim is to transform an existing situation into a desired one [2]. Observation of design processes generally reveals the use of generative approaches, where design choices are probed and evaluated to identify what Simon [2] refers to as 'satisficing' alternatives.

In this paper, we argue that in order to creatively explore design space a method that allows for the systematic evaluation of spatial structures is required. Drawing on recent theoretical and simulation work examining morphogenesis, we propose a 'generate and explore' process that utilizes a composite CA that includes a combination of 'self-assembly,' 'pattern formation' and 'best variant' selection to generate cross sectional diagrams. We introduce metrics to evaluate the emergent spatial attributes, which allows the designer to interactively identify configurations that may satisfy design requirements in unexpected ways, opening the possibility to represent and understand the design in a novel manner.

The rationale behind our design methodology is to define a way to enable the exploration of design solution space – using low-level design elements – rather than focusing on optimizing a solution based on a fixed set of requirements.

2. MODEL

We introduce a digital morphogenesis technique – a composite CA – to generate diagrammatic cross-sections of architectural form to be used in the early stages of design [1]. Our model consists of multiple, regularly spaced, interleaved 1D CA (Fig 1a) arranged in a horizontal-vertical configuration (Fig 1b).

This composite CA approach provides a mechanism to evolve flexible spatial units, where the 'cells' are not defined as programmatic elements but as 'form-making' elements. This represents a departure from the typical use of CA models in architecture and urban design, by focusing on the ways in which space can be physically reshaped and reconfigured, where its characteristics (such as open/closed, exterior/interior etc.) emerge from the evolution of the system, rather than being prescribed by design.

The configuration of the interleaved 1D CA results in 16 different possible configurations for each of the encapsulated spatial units, three of which are illustrated in Fig 1c.

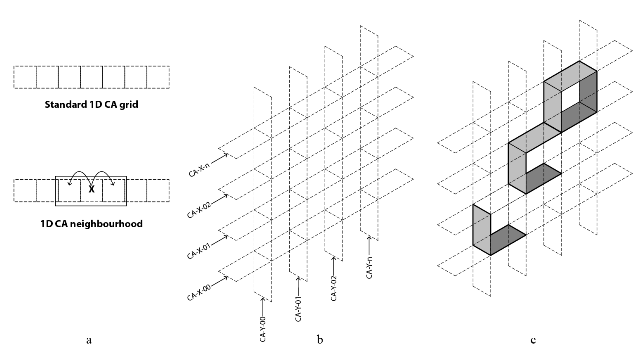

Figure 1: (a) Standard 1D CA. (b) Composite 1D CA consisting of interleaved horizontal and vertical 1D CA. (c) Representative examples of spatial unit configurations, defined by active boundaries.

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From an architectural design perspective, the main difference between a traditional 2D CA and the composite CA model proposed is that in the former, the states of the cells are predefined, whereas in the latter the individual spatial units do not have prior meaning; their characteristics are defined by the configuration of the 1D CA that constitutes their boundaries. The outcome of a time-evolution of the composite CA is essentially a spatial configuration for every time step. Importantly, the composite CA can generate a variety of well-formed morphologies and/or target spatial structures of arbitrary size, which may be coupled together. The designer can interact with the composite CA, and select a topological configuration at a given time step, which can be interpreted as an arrangement of buildings, rooms or other spatial elements, depending on the scale of the model's implementation, in a creative and functionally sensible way.

3. EXPERIMENTS

One of the challenges of designing environments for human inhabitation is that all requirements and desires have to come together as physical form. This is achieved by demarcating, reconfiguring and characterizing 3D space.

One main question guided the experimental design: Does the composite CA allow for the flexibility and fluidity that is required for creative exploration, when used to generate diagrammatic cross-sections of architectural form in early design stages?

3.1 Methodology

We examine whether the composite CA can evolve aggregate spatial units, with specific spatial attributes, corresponding to configurations representing a mix of open and closed spaces. This phase allows us to bring an understanding of the results into the context of architectural design.

3.1.1 Parameters

We set the length of each CA to $L = 10$. We set the local neighbourhood size $n = 3$, and limited the alphabet of cell states to $\Sigma = \{0, 1\}$ (i.e. the cell representing the boundaries of the spatial units are either active or inactive). The state transition rules are drawn from Wolfram's [3] elementary 1D CA rules (as shown in [1]). Each simulation trial was run for 200 time steps, starting from uniformly randomly drawn initial cell states. The entire system is updated simultaneously in discrete time steps.

3.1.2 Analysis

The composite CA time evolution is deterministic (seeded from a random initial condition). The user (designer) can interact with the system, pause a run (based on specific 'performance' metrics, such as degree distribution of nodes, and ratio of open *vs.* closed clusters), 'zoom in' on a particular configuration and explore emergent patterns.

We introduce a phenotypic diversity measure on the space of the composite CA to analyse emergent behaviour. Specifically, we examine the embedded 'connectivity graph' where nodes within the graph correspond to the centre of active adjacent spatial units in the model. The structures of connected nodes – clusters of adjacent spatial units – are defined by active/inactive cells of the composite CA. This graph-based analysis provides a concise way to examine the spontaneous formation of 'motifs' that represent a wide variety of spatial attributes.

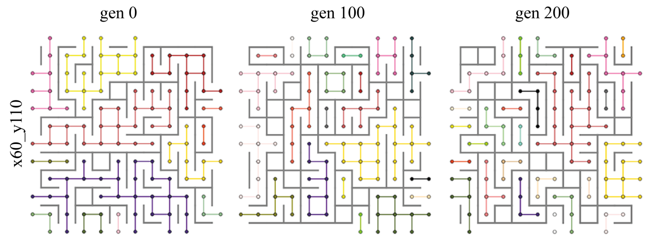

Figure 2: Snap shots of the evolving composite CA. Connectivity graphs at times t=0,t=100 and t=200 for rules 60 (horizontal) and 110 (vertical).

3.2 Results

In Fig 2, we plot snap-shots of the evolving connectivity graphs corresponding to the emergent spatial forms. The emergent spatial structures change shape significantly over the course of the simulated evolutionary time, to a point where there is no apparent relationship between generations evolved using a particular set of rules. These abstract configurations would then be translated into architectural cross sections as part of the early stage of design.

4. DISCUSSION AND CONCLUSION

Our goal was to explore the formation of aggregates or clusters of encapsulated spatial units, in search for 'interesting' spatial organizations with potential to be developed and/or interpreted by a designer at a later stage. Significantly, our model was able to produce clusters of a wide variety of sizes, shapes and with different 'spatial attributes' (regularity, openness, fragmentation, among others).

Our composite CA can be described as a tool that provides designers with a range of alternatives to satisfy given design requirements, rather than acting as a direct design tool for completed design solutions. The introduction of protocols to search for characteristics of the space (e.g. open *vs.* closed space, or mean cluster size) is seen as a strategy that suits the purpose of enabling the emergence of unexpected spatial configurations.

Naturally, beyond the proof-of-concept simulations presented here, a more systematic exploration is needed. Further possible efficacy improvements might come from increasing the number and accuracy of measures used in the analysis of 'spatial attributes' of the model's generated instances, along with the use of much more sophisticated evolutionary algorithms / pattern search algorithms than the very simple interactive model described here.

5. REFERENCES

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