Cognitive Assemblages: Spatial Generation Through Wave Function Collapse and Reinforcement Learning

Alessandro Mintrone
University of Bologna
alessandro.mintrone5@gmail.com

Alessio Erioli
University of Bologna
alessio.erioli@unibo.it

Abstract

This research explores the integration of AI in an iterative decision process for the open-ended procedural generation of architectural spaces. Leveraging on state-of-the-art Deep Reinforcement Learning techniques, an Artificial Neural Network (ANN) is trained to perform local decisions selecting *tiles* in a Wave Function Collapse (WFC) algorithm, assembling discrete elements that build up a complex spatial organization, pursuing selected spatial qualities at the architectural scale.

Introduction

Numerous current applications of AI for spatial generation, aim to generate complete, self-sufficient results, producing images, be they plans or pictures, out of other images or language. These applications leverage on a traditional idea of conception, where the added value of the outcome mostly comes from the human interpretation rather than its intrinsic qualities. Instead, we challenge our way of conceiving instruments and authorship, binding reinforcement learning to a distributed network of decisions.

The act of thinking is here envisioned as diffused, granular and embedded in an ecology of cognitions capable of extending and reshaping our mental territory (Clark 2008). Our approach addresses liberated tools, no longer intended as reflections of their users' minds, nor poised to parrot human thinking (Picon 2016). Entities capable of privileging certain directions while resisting others, developing their own bias and sensibility while controlling articulated and specific spatial conditions that result from an iterative assemblage of 3D, space-containing, parts (Parisi 2014).

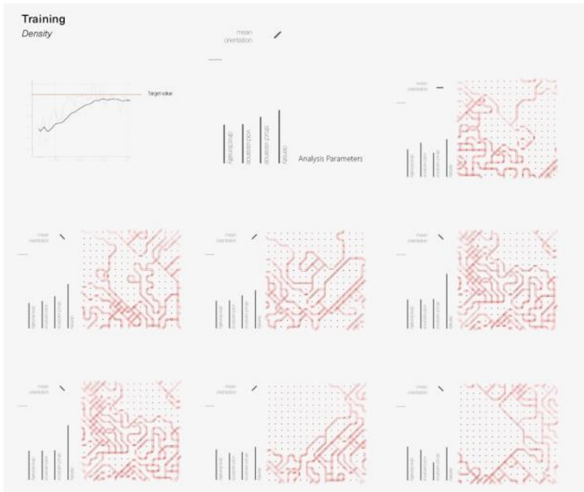

Fig. 1. *Cognitive Assemblages*, 2020, Alessandro Mintrone, 2D training results.

Wave Function Collapse

WFC is a constraint solving algorithm that iteratively places discrete components called *tiles* in a predetermined grid according to their connectivity rules. It is widely employed both in 2D and 3D procedural content generation.

Aiming at the generation of three-dimensional spatial assemblages, given a limited set of parts and their local connectivity rules, this combinatorial process can unravel a vast array of unique, yet similarly structured, spatial patterns (Gumin 2016). Implemented in Unity3D, the algorithm is intended both as a platform for generating and exploring a large field of possible assemblages, and as training environment for the ANN. In fact, its discretized representation of space makes iterative assemblage generation approachable with Machine Learning techniques. Each element, while not constituting a self-contained spatial unit, when combined with other components, defines boundaries and reinforces possible paths, structuring an otherwise amorphous space. It is from the growing network of relationships among elements that a spatial organization emerges, and the assemblage takes on its identifying patterns and structures.

Proximal Policy Optimization

Relying on a Proximal Policy Optimization reinforcement learning algorithm, an ANN is trained to control tile placement at each iteration, replacing the weighted random choice used in the standard WFC algorithm (Schulman *et al.* 2020). The system gains the ability to steer the assemblage, articulating the highly homogenous spaces generated by WFC, by discovering non-linear correlations between its local decision and their outcomes at the global scale. It has proved sufficiently general and capable of operating in both 2D and 3D with different sets of *tiles*, while maintaining the same architecture and hyper-parameters. It shapes its behaviours not by relying on a dataset of examples to imitate, but learning from experience, continuously confronting the environment, and trying to maximize the rewards awarded after its actions (Juliani et. al. 2020). Six quantified descriptors are defined for local and global spatial qualities: density, material distribution, prevalent orientation, structural connectivity, spatial connectivity and planar connectivity. Their use is twofold, they provide continuous feedback characterizing the spatial conditions of the assemblage, while they are employed for assigning the rewards by comparing their values with defined goals.

Exploring different behaviours, the agent hones its own sensibility, developing strategies to generate diversified spatial conditions. Varying the goals and their relative weight, the AI is able to learn generalized internal representation of the possible outcomes. The AI develops an understanding of complex spatial qualities closer to human representation. In this unending dialogue, the designer and the algorithm are connected in a feedback loop, a novel state of engagement in which human and non-human cognitions continuously negotiate both their agency and authorial status, unfolding consequences potentially exceeding human or machinic reach alone.

References

Clark, Andy. 2008. *Supersizing the Mind: Embodiment, Action, and Cognitive Extension.* New York: Oxford University Press.

Gumin, Maxim. 2016. "Bitmap & tilemap generation from a single example by collapsing a wave function." Accessed June 23, 2020. https://github.com/mxgmn/WaveFunctionCollapse.

Juliani, Arthur, Vincent-Pierre Berges, Ervin Teng, Andrew Cohen, Jonathan Harper, Chris Elion, Chris Goy, Yuan Gao et. al. 2020. "Unity: A general platform for intelligent agents." arXiv:1809.02627v2.

Schulman, John, Filip Wolski, Prafulla Dhariwal, Alec Radford, Oleg Klimov. 2017. "Proximal policy optimization algorithms." arXiv:1707.06347v2.

Parisi, Luciana. 2014. "Automated Architecture: Speculative Reason in the Age of the Algorithm." In *#Accelerate#, The Accelerationist Reader*, edited by Robin Mackay and Arnem Avanessian, 401–24. Falmouth: Urbanomic Media Ltd.

Picon, Antoine. 2016. "Free the Robots!" *Log*, no. 36: 146-51.

Biographies

Alessandro Mintrone works with computational design, art, architecture, and engineering, exploring the porous zone between, artificial cognition, simulation and machinic fabrication.

Alessio Erioli is University of Bologna Professore Aggregato (Teaching Professor), co-founder and designer at Co-de-iT. He researches the aesthetics and tectonics that emerge as a consequence of computation (in architecture and related fields), focusing on intelligence in the design process. He is also skilled in computational design, programming & modelling.