Genetic Game of Life

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Abstract

Conway’s Game of Life (GoL) cellular automaton (CA) is extended to allow evolution by the association of genetic information with live cells in the CA. A newly born live cell’s genome is copied (potentially with mutation) from one of the live neighbour cells (there are three in the GoL) and is deleted when the cell dies. We discovered a deterministic and spatially symmetric rule to implement a genetically neutral choice of ancestor, making our model deterministic (like the GoL) in the absence of mutation. Just as biological evolution constantly discovers innovations in the space of chemical and physical functionalities that it controls, we seek to explore how the addition of genetic information to the game of life can display the same type of discovery process, where the genetically controlled innovations are now spatially local modifications to the game of life local dynamical rules. Complex cellular automaton dynamics of the game of life become the default “chemistry and physics”, and local genetic modifications that persist are the innovations discovered by evolution. In the work presented here, systematic genetic variations near to the game of life rule are investigated and found to produce signs of computational complexity with an abundance of glider structures.

# Introduction

Conway’s Game of Life (GoL) [Ref 1,2,3] is a deterministic dynamical system that takes two dimensional spatial patterns of binary states (‘live’ or ‘dead/empty’) to new patterns as time progresses discretely, through the action of a local rule; Each site’s state at time *t+1* is dependent on its state and the states of its nearest neighbours at time *t*. In Golly’s compact notation for life-like 2d cellular automaton rules, The game of life is a totalistic cellular automaton (CA) rule, depending only on the sum of the neighbour states rather than their detailed configuration, and can be denoted by the code S23/B3, meaning that a live cell survives (a “1” at a site at time *t* persists to time *t+1*) if there are either 2 or 3 neighbours alive in the 8 cells surrounding the site (otherwise dying to “0” at time *t+1*), and an empty “0” state cell undergoes birth (transitions to “1”) only if there are exactly 3 neighbours alive. Starting from random initial state patterns on a finite compact domain, it is well known that the GoL almost always settles down to a combination of isolated static and simply periodic structures or gliders which are individually of limited spatial extent [Ref 4,5]. Although specially engineered initial states can have extremely long transients, occupying large regions of space, and indeed the Gol has been shown to support universal computation [Ref 6,7], the absence of complex interconnected pattern persistence starting from random initial conditions means that it is not a good candidate for the emergence of complexity.

However, because of its rich dynamics from special initial conditions, documented in massive catalogue projects [Ref 8,9] and other articles [Ref 10,11,12], it would appear to provide an interesting model of a rich but very simple “physics” or “chemistry” that may be coupled to biological evolution through genetic information. The coupling of GoL to genetic information has already been attempted in various ways, but a systematic investigation of near GoL evolving dynamics is still outstanding. Here, we enhance the deterministic GoL dynamics to create an evolutionary system, by associating a genome with all the live states. Genetic inheritance is ensured by a newly born live cell’s genome being copied (potentially with mutation and recombination) from one or more of the live neighbour cells (there are three in the GoL) and being deleted when the cell dies. In this article we focus on the simplest case of mutation and asexual reproduction without recombination. The

We can examine genetics associated with the unmodified

As we shall see, and in contrast with prior

, and prescribing extra-GoL rules that specify how the genes affect the GoL dynamics and how genetic information is transferred from one time step to the next.

Regarding the transfer of genetic information, a deterministic selection mechanism is realized, so that mutation provides the only source of random variation in the dynamics. Four levels of perturbations on the B3/S23 standard GoL rules are investigated: (0) genetic selection on the GoL, with the genes not influencing the GoL rules (1) genetic selection on GoL-like rules, e.g. S2gb3gB2g3 ∈ {S(2g(b))(3g(b))/B(2g)3(g)}, with conditional rules depending on genes denoted by g and survival rules involving birth overwrites denoted by b (2) genetic modulations of the live neighbour counting process that allow different numbers of live neighbours a) for specific 2nd neighbour ring configurations b) using masks on 1st neighbours encoded by the existing live neighbours c) with the gene specifying the allowed numbers directly (3) limitations of the influence of arbitrary gene encoded rule departures in varying symmetries through the requirement that state changes induced by a non-GoL rule inhibit further rule departures in their neighbourhood until corrected by a regular GoL rule. Whereas many perturbations of the GoL rules either quickly die out or proliferate rapidly to fill space with reproducing structures, a family of interesting dynamical systems is found, and its tendency towards open-ended evolution analysed by means of activity statistics. Note, that while the standard B3/S23 game of life, starting from random patterns of 50% 1s and 0s, in most instances does not produce complex dynamics, the new family does.

Notation: Rule extensions  [Golly](https://en.wikipedia.org/wiki/Golly_(program)) open-source cellular automaton package

# Some text blocks

## Movement vs copying.

Whereas the indistinguishability of GoL “1” states means that it is not possible to distinguish movement from death and rebirth, with genetic information attached to the live states, it would be possible. Is there a meaningful assignment of a subset of GoL birth or survival transitions to movement? It would make a difference if mutation were deemed not to occur for transitions involving movement. Also, it might be appropriate to make the choice of an ancestor sensitive to the interpretation of movement *vs* birth: e.g. to minimize the number of births needed to maintain the dynamics. For example, an isolated rod of three live states is a GoL oscillator between vertical and horizontal configurations. In the deterministic most different ancestor canonical assignment of ancestors from three live neighbours, the central gene is copied to two new sites so that (without mutation) the rod becomes genetically homogeneous in one step. This process is clearly a copy mechanism. On the other hand, in the 0-bit canonical assignment of ancestors, the two peripheral genes circulate anti-clockwise and this is more naturally understood as a process of motion and as such should be carried out without mutation.

## 3D GoL Extension

Carter Bay proposed investigated possible extension of the Game of Life to 3D, finding that amongst the possible totalistic rules with 26 neighbours there were strong constraints for rules that exhibited the central properties of the game of life:

*“Definition 1. A rule ElEuFlFu defines a "Game of Life" if and only if both of the following are true.*

*1. A glider must exist and must occur "naturally" if we apply ElEuFlFu repeatedly to primordial soup configurations.*

*2. All primordial soup configurations, when subjected to ElEuFlFu, must exhibit bounded growth.*

*(Here we define primordial soup as any finite mass of arbitrarily dense randomly dispersed living cells.)”*

In particular, 5≤Fl≤9 are hard constraints to ensure 1. and 2. and Carter focused on the range 4 to 7 as most relevant to GoL likeness for both E and F. He found only two rules 4555 and 5766 to satisfy definition 1, and of these only the rule 5766 supported an extension of many 2D-GoL objects to 3D (by plane duplication). It seems that in 3D, as for 2D, the totalistic rules provide very tight constraints without significant alternatives to the known GoL rules. Bay also discusses possible extensions to rules that distinguish the 26 neighbours into three classes: face-centered (6), edge-centered (12) and corner (8) sites. Given the preferred z-axis of our asymmetric 64xNxN space and the desire to relate 3D rules to 2D rules it makes sense to further distinguish the (xy) in-plane and out-of-plane sites yielding 5 classes with 4,2,4,8,8 members. The number of rules with the total sum in the range 4-7 is then …