

Being a Glider in the Game of Life

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January 24, 2011

Contents

1	Preparations	1
1.1	Autopoiesis as a definition of life	1
1.2	Cellular automata as a model for reality	1
1.2.1	Game of Life from the outside	2
1.2.2	Game of Life from the inside	3
2	Life of a glider	4
2.1	Identity	4
2.1.1	Discerning unity	4
2.1.2	Identity as a network of becoming	5
2.2	Organization and structure	7
2.3	Cognitive domain	8
3	At the end of the day..	9

Abstract

The existence of a glider in Conway's Game of Life is analyzed completely. The glider is identified as an autopoietic entity and its cognitive domain fully mapped. This analysis is put into the context of the perception of an observer and the limitations posed by the vantage point of an observer are discussed. Observation from inside a universe as opposed to an outside perspective is found to differ fundamentally. Through careful distinction between these two perspectives, cellular automata are discovered a model for the physical world, whose exploration in inter-disciplinary research may yield new insights into reality.

1 Preparations

In order to follow the argumentation of this paper and appreciate the full scope of its implications, certain preparations have to be made. Autopoiesis as a definition of life and cellular automata as a model for reality need to be understood. Both require a different view on the world than is common; the reader is encouraged to keep an open mind.

1.1 Autopoiesis as a definition of life

Autopoiesis is a definition of life, conceived of by Maturana and Varela in the late in the late 60s and first published in the 70s [7, 2, 3]; it means *self-producing*. When we can see an entity as composed of other entities, it becomes a system. We can then look at the relations of the components of the system as they develop in time. If we do this for animals, we will find that they are composed of cells. If we do this for cells, we will find that they are composed of molecules and this is where Maturana and Varela started. A cell differs from a rock in that the molecules move a lot, it differs from a river in the way the molecules interact. This particular way that molecules of living things relate to each other is what is understood as the autopoietic organization. They interact in a certain pattern that recursively creates this very pattern. This circularity is continuous, there is no interruption in this pattern, a living thing cannot lose its organization by means other than death and there is no coming back from there. Other than enabling us to tell the living from the dead, the notion of autopoiesis allows us to see life as separate from the actual components of a living system. It does not matter for the autopoietic organization which specific molecule is where, or what the molecules of a cell are made of, as long as they have the necessary characteristics to keep that pattern of life creating itself. It matters for the *structure*, which is the specific realization of an organization; there can well be two different cells, made from different molecules and thus having a different structure, but both are of the same organization, both are living cells. This differentiation also entails that it is possible to create life in computer simulations and has been pursued ever since [6, 4, 5, 7, 1].

1.2 Cellular automata as a model for reality

Maturana, Varela and Uribe demonstrated Autopoiesis using a tessellation automaton which would now be regarded as an artificial chemistry [7] (while the first computer simulation was not fully autopoietic, later implementations

proved the correctness of the model [5]). So life forms (in the sense of being autopoietic) can be manufactured in artificial chemistries, but artificial chemistries work differently from cellular automata. In a cellular automaton (CA), there are no particles that float around, the cells of a CA never change their place, they do not have different properties and they only ever change their own state. How can we compare a CA to an artificial chemistry then, not to speak of real life?

Any particle, be it in an artificial or real chemistry, can only have a certain number of other objects in contact with its surface because its surface area is limited. It can only interact with objects that are in contact with its surface. In a two dimensional CA with neighborhood radius 1, such as the Game of Life is, each cell is connected to 8 other cells with which it can interact. The simplification that is important for the interaction of objects, is that in the Game of Life, any object only ever interacts with 8 other objects at any given time. Thus, all “particles” are of equal size. Now, cells of CA have different states, two in the Game of Life. One of these states (the *off-state*) does not change unless there are cells in the second state (the *on-state*) in direct contact with it. We could view areas of off-cells as “free space”, however, this notion does not correctly reflect the properties of these cell states. Rather, think that there is no free space in the physical world and that you perceive free space as such because you are perceiving the world as part of that world, as opposed to CA where you are outside the world, looking in. I have reached a point where I cannot explain further from the vantage point of the world as we know it. I shall thus call upon your imagination to relocate your existence to inside the Game of Life.

1.2.1 Game of Life from the outside

Conway’s Game of Life or *Life* (capital ‘L’) is a 2 dimensional, binary, outer-totalistic cellular automaton. For the purpose of this paper, boundary conditions are left unspecified, instead a large enough lattice is assumed so that no observation takes place near a boundary. The physical laws of this world are as follows. Each primal unit of space (a *cell*) is in one of two distinct states at any time, which are referred to as “on” and “off”. For each update of the automaton, each cell assumes one of the two states based on the ratio of on- to off-cells in its Moore-Neighborhood and its current state. If this ratio equals $3/5$, the cell will be on in the subsequent time step. If it equals $2/6$, it maintains its current state. Otherwise the cell will assume the off-state. Convention is to just count the on-cells and I will make use of this convention for convenience, however it should be noted that off-cells *do* count. Whenever we count 3 on-cells in any binary Moore-Neighborhood we could just as well count 5 off-cells. The reason for why it is usually the on-cells that are counted becomes apparent from the number of configurations that lead to the two distinct states. More often than not, a configuration leads to the off-state, making it the more prominent of the two. That and the fact that off-cells maintain their state in the absence of on-cells leads to the off-cells constituting a quiescent background on which patterns of on-cells set themselves apart and constitute observable unities.

1.2.2 Game of Life from the inside

The first thing to notice is that cells do not have spatial dimensions in themselves. We assign width and height to them in order to enable us to observe a CA from the outside; If we did not, we would not see it at all. That does not necessarily mean it would not be there (it can still be simulated without being displayed). Now, if space is not an intrinsic property of the cells, what would the Life universe be like from the inside? To understand this, we have to leave our notion of space as we know it behind. Space does not exist in itself, it is but the relation of one thing to another. How long would a meter be, if there was nothing as long as a meter? You might say: "A meter is longer than your arm and shorter than your leg" or define it to be as long as a specific thing (in fact, this is how measures of space were created). However, this measure exists only in relation to another thing. This is not only true for measures. When you look at a flower in the garden, you do not experience a flower, you experience electro-magnetic waves perturbing your retina. If the light was of a different wave length, it might just pass through you without you noticing (like the signal of your cell phone). The perturbations on your retina only manifest because of the relation between the properties of your retina and the electro-magnetic wave that comes into contact with it.

You are now inside the Life universe. You are an entity bigger than anything that can currently be simulated. A much smaller, but still complex entity in Life is a mere photon for you that can perturb your retina. Now, space definitely exists for you, as there is a relation between you and other objects in the universe. The complex photonic entity propagates through the universe, bumps off some other really big entity, say a rock (also way too big to simulate), flies right into your eye and ultimately makes you experience a rock. You see, the world would not necessarily look that different from our physical reality.

What about time? Time is continuous in real life, but in a cellular automaton it is discrete, is it not? Again, time is continuous because you exist within the same reality as time, in truth there is no time, there is only the notion of how one thing changes relative to another. If the whole world stood still, would you notice? Most certainly not, as you would not move, perceive or even change your brain patterns the slightest bit. All clocks would stand still; it would not matter at all if time stood still for millennia because these millennia would not exist in our universe anyway. Inside the Life universe, you experience time exactly like that: how one thing changes in relation to another. It takes a certain amount of "time" for a "photon" in Life to bump off a "rock" before it perturbs your "retina".

Let us look at the limits of space and time in the Game of Life. The lower limit of space-time is not discernible. At some point your act of observation would inevitably influence the outcome of your measurement. You are rightfully reminded of the uncertainty principle. Upper limits? Nothing in Life can propagate faster than one cell per step, this limit is rightfully called "speed of light". There is no unit of time smaller than what it takes to process information from one cell to another. Space obviously depends on the boundary conditions (periodic, always on, always off, infinite), anything is possible, in real life we simply don't know because nobody has ever observed a boundary.

It seems that if the real world as we know it was indeed a cellular automaton, we would not know and it would be impossible to prove. Given the similarity

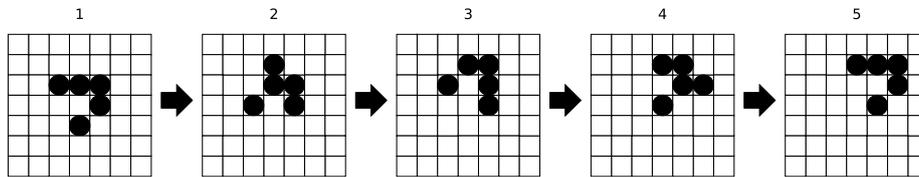


Figure 1: Movement of a glider in Life, creating the same pattern one cell diagonal of its original position in 4 steps. Here and throughout the paper, on-cells contain a black circle, off-cells do not.

of the limits of space-time in the physical world compared to space-time as it would be seen from inside a CA, seeing the physical world as a CA does offer an explanation for scientific observations and should not be dismissed prematurely.

This outlook makes interesting a scientific analysis of cellular automata in order to discover phenomena as they are found in the physical world. One of these phenomena is autopoiesis and it is discussed in the following.

2 Life of a glider

With the above preparations in mind, I now take a more common view on cellular automata, describing them from an outside perspective with space assigned as to match our perception in order to allow for more convenient description. A glider is commonly known as the pattern evolving as depicted in figure 1.

2.1 Identity

What is it that makes a glider a glider? I have identified two pitfalls in the process of identification that both stem from our way of thinking about the world. In a case as simple as a glider in Life, this leads us to create false criteria for identification if we do not look closely enough. In the following, both pitfalls are being described and a measure of identity is established.

2.1.1 Discerning unity

A simple task: Find the glider in figure 1. Our immediate response is to distinguish between the black on-cells and the white off-cells and declare that the 5 on-cells somehow form a moving unity and thus belong to the identity of a glider. But then, how much of a glider would the pattern of on-cells be, if it was located in a background of on-cells? It becomes clear that *some* off-cells have to be part of this configuration.

In order to find out which, we look at the number of neighbors of each cell. The update rule of Life acts upon these numbers to calculate the next state of any given cell. I therefore agree with Beer [1] that the glider configuration is constituted not only by the 5 on-cells, but also by the 17 off-cells that surround them as illustrated in figure 2. These cells differ from the off-cells of the background in their number of neighboring on-cells, which is what sets them apart from the background and gives rise to the unity that is the glider configuration. At the same time though, these cells differ from the rest of the glider in their

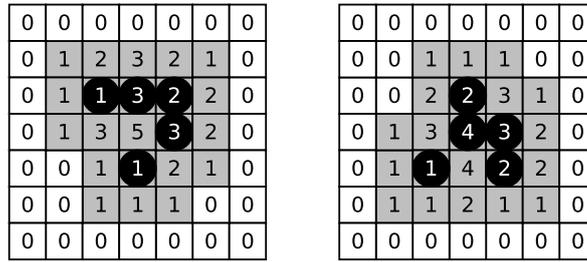


Figure 2: Defining a boundary of a glider in Life. The boundary is composed of off-cells that confine the on-cells of a glider and have a non-zero count of neighboring on-cells. Boundaries are painted in gray.

state. They form a natural boundary that is both part of the glider and part of the background, yet is neither glider nor background. This boundary is the interface between glider and environment. All glider/environment interaction takes place on this boundary alone.

All of the 16 different configurations consisting of 4 directions and 4 phases each (figure 3) are configurations we discern as gliders. These configurations are rotations and reflections of 2 configurations. In the following, the configurations with direction NE and phases 0 and 1, as circled in figure 3, shall be used as representative for all 16 configurations.

2.1.2 Identity as a network of becoming

Much like without time we could not tell the difference between a human being and a dead body, it does not make sense to speak of a glider out of time. How can we discern a static pattern as a glider then, as we just did in the last paragraph? This is because we have knowledge of the physical laws of the Life universe and are therefore able to predict the future state of a configuration. If we did not know the update rule of the cellular automaton in question, we would be unable to tell whether this pattern truly *is* a glider, because it might just not glide. It follows that the identity of a glider must include the process of its becoming in addition to its being. I define the identity of a glider to be the becoming of a glider configuration (as listed in figure 3) from either a glider configuration, in which case the identity is maintained, or a different configuration, in which case the identity has emerged. Obviously, this becoming has to follow from the dynamics of Life rather external forces.

One consequence of Life being a cellular automaton with neighborhood radius 1 is that information cannot propagate faster than 1 cell per time step (commonly called the *speed of light* in cellular automata). If, therefore, in a given time step a glider configuration de-manifests at a location and a glider configuration manifests in a place more than one cell away from that location, I attribute to it a different identity, as the totality of information encoded in the glider could not have traveled this far and these two manifestations are therefore to be seen as at least partially separate.

I formalize identity in Life as follows.

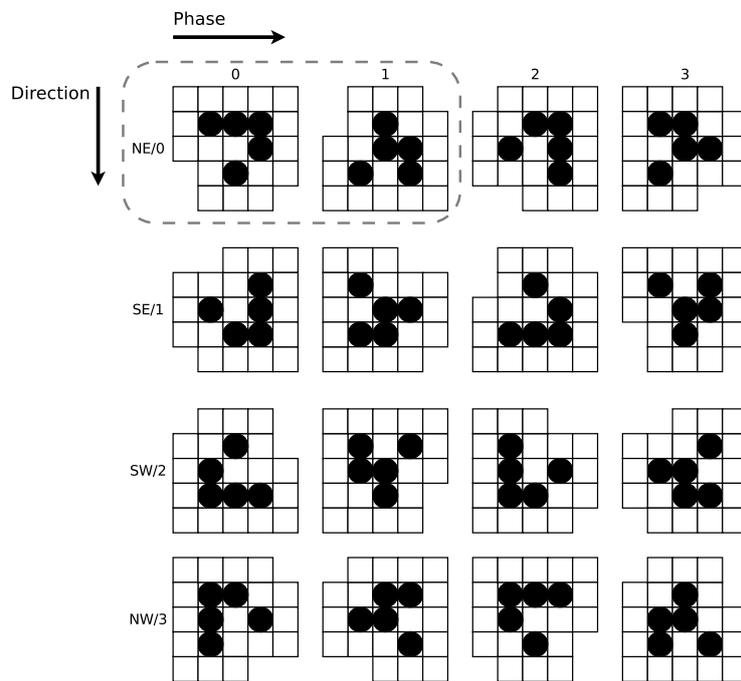


Figure 3: The 16 configurations discerned as glider. Circled: two representationally used states that all other states can be constructed from using rotation and reflection.

Let C be the set of all configurations discerned by an observer as belonging to the same class and $c_1 \in C$ be observed in position p at time step t .

The identity I_t is *maintained (continued)* if, and only if, $c_2 \in C$ has been observed in step $t - 1$ at either p or in the Moore-Neighborhood of p . Otherwise I_t has *manifested (emerged)*.

It is apparent that C is both requirement for and consequence of I_t as the identity constitutes a network of becoming within the domain C . I would like to note that at the fundamental level, there is no identity and no domain of configurations. Any configuration is like the other. It is the observer who, by the nature of his perception, discerns unities and classifies them. At the fundamental level, the task of finding the glider in figure 1 becomes absurd: There is no glider. However, here we are, observers who classify configurations to belong to a glider and give rise to its identity by our very perception. It is for this reason that the above definition does not contain the word “exists” because the existence of a thing can only be ever meaningful when observed. A glider emerges when it is observed for the first time.

2.2 Organization and structure

To determine whether a glider is autopoietic, I shall use the following definition:

The autopoietic organization is defined as a unity by a network of productions of components which (i) participate recursively in the same network of productions of components which produced these components, and (ii) realize the network of productions as a unity in the space in which the components exist. [7]

What are the components of a glider? Certainly not the cells themselves, because as a glider moves, it leaves cells behind while its organization is maintained. Rather it is the *states* of the cells of the glider configuration, as they make possible the continuation of its identity. In each update step, 2 on-cells become off-cells and vice versa; 4 cell states are produced. See figure 4 for illustration. Clearly, the cell-states form a self-producing network in time, the organization of a glider.

The structure of a glider, i.e. the realization of its organization in the space of its components, then, are the concrete cells (i.e. the location in the universe) that the glider organization uses to produce cell-states in order to produce itself. A glider undergoes structural change over the course of its life through its movement. As the glider organization moves in space, it produces its components (cell-states) but in ever different locations (structure). A glider is, therefore, an autopoietic system. It is operationally closed, but structurally open. The organization is circular and self-contained, however the glider’s structure undergoes changes, i.e. it forms a history of structural coupling that, due to the nature of the Life universe, results in locomotion of the glider unity.

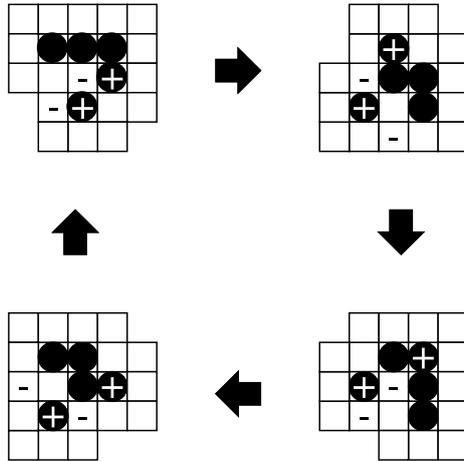


Figure 4: Organization of a glider imposed on its structure. A plus sign indicates the production of an on-cell, a minus sign the production of an off-cell.

2.3 Cognitive domain

How are we to understand the mind of such an entity? Again, Maturana and Varela provide a framework for understanding:

A cognitive system is a system whose organization defines a domain of interactions in which it can act with relevance to the maintenance of itself, and the process of cognition is the actual (inductive) acting or behaving in this domain. [2]

As stated before, all glider/environment interaction takes place at the boundary of the glider. So far, we investigated gliders in a very limited environment where the glider was untouched by external perturbations. This is about to change. For the identity of a glider to be maintained, only a limited set of configurations of on- and off-cells (figure 3) is allowed to be assumed. This constraint, together with the neighborhood radius of 1 of the Life cellular automaton, limits the perturbations that a glider can face, to what I call the *zone of perturbation*, depicted in figure 5. Any of the 2^{24} possible combinations of on- and off-cells in this zone cause perturbations to the glider. Perturbations under which the glider's identity is maintained are part of the cognitive domain of the glider. As Beer [1] suggested for further analysis, I fully mapped the cognitive domain of a glider.

I ran simulations of the two representational configurations of direction NE, phases 0 and 1. These simulations placed a glider in the middle of a 7x7 Life universe and tested for each of the 2^{24} possible perturbations whether its identity is maintained in the following time step. It turns out that of all the 2×2^{24} possible perturbations only 0.14% belong to the cognitive domain of the glider, the rest is lethal. The 45360 non-lethal perturbations fall into only a few behavioral classes as shown in figure 6. With these statistics we can fully map the life of a glider. Whenever a glider manifests, it enters a network of structural coupling. In this network, each node represents one of the configurations $c \in C$. Each arrow depicts a structural change. Arrows that lead from one node to

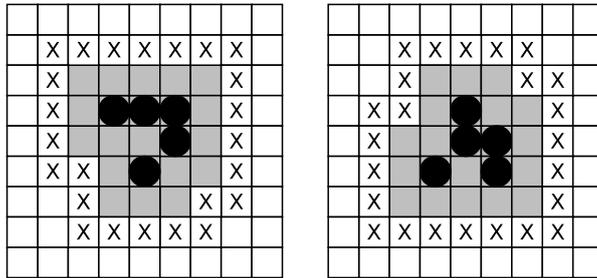


Figure 5: The zone of perturbation of a glider, marked with 'X'. On-cells in this zone cause perturbations in the sum of on-neighbors of boundary-cells without destroying the glider identity.

another depict the continuation of the glider identity, arrows to the outside symbolize perturbations under which a glider configuration manifests or demanifests, depending on the direction of traversal. The life of a glider makes for a pretty diagram, as you can see in figure 7.

There is one problem with this mapping, however, some of the tested perturbations may possibly only occur as *Garden of Eden states*, i.e. configurations that can only occur as initial configurations in a cellular automaton. What is known for sure is that a glider cannot possibly experience anything but what is shown in figure 7. Therefore, this mapping is to be taken as the upper limit of what a glider can experience, whereas what it actually encounters during CA evolution may only be a subset of what has been analyzed here.

3 At the end of the day...

I introduced a way of viewing the world that allows the study of cellular automata to have an impact on scientific disciplines concerning the physical world. From this new vantage point, I confirmed Beer's analysis [1] of a glider in Conway's Game of Life and amended it with a complete mapping of the cognitive domain of a glider. The living seems to be realizable inside cellular automata. Questions arise as to how limited our own cognitive domain is. Since a cellular automaton is deterministic at the fundamental level (yet not necessarily predictable, e.g. Life is not), free will is questioned once again and the fate of the universe might not be decided yet, but will take the course it takes, as do we all.

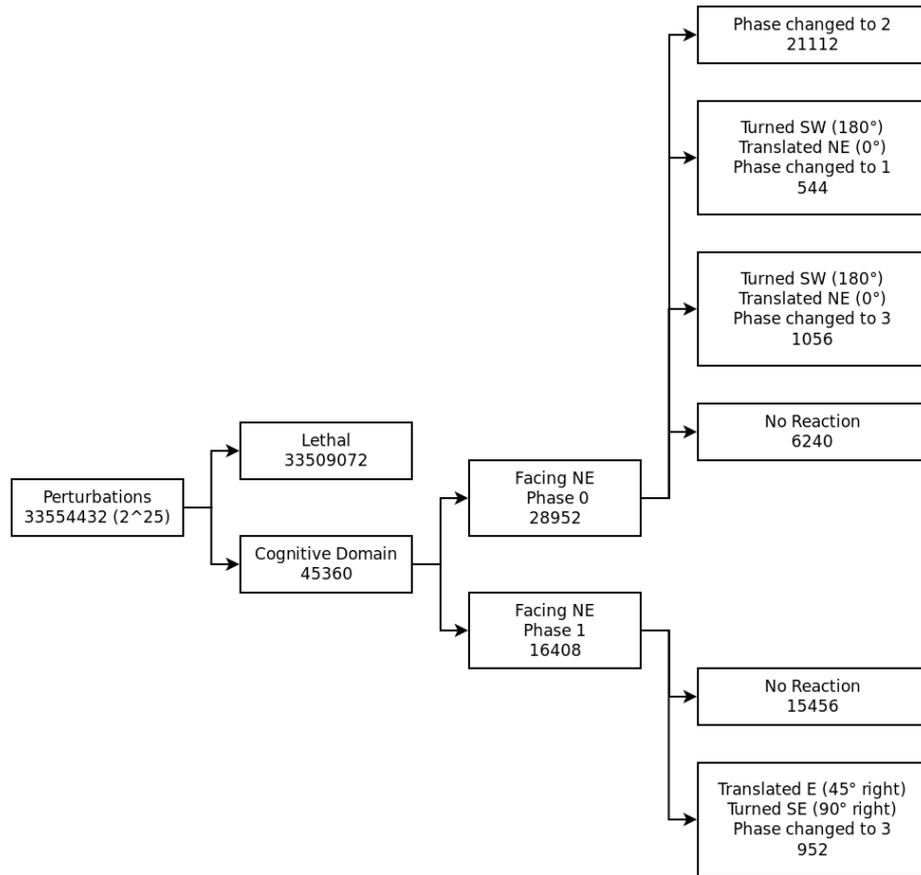


Figure 6: Statistics of glider reactions to perturbations. The whole range of possible perturbations to a glider is split by lethality, phase and finally reaction, for the shown number of perturbations. “No Reaction” means that the behavior is the same as if the glider was surrounded by off-cells alone (the 0-perturbation). Again, the two configurations facing north-east in phases 0 and 1 are used representatively for the remaining 14 configurations that are rotations and reflections of these two. Changes in direction and location have to be rotated/reflected accordingly.

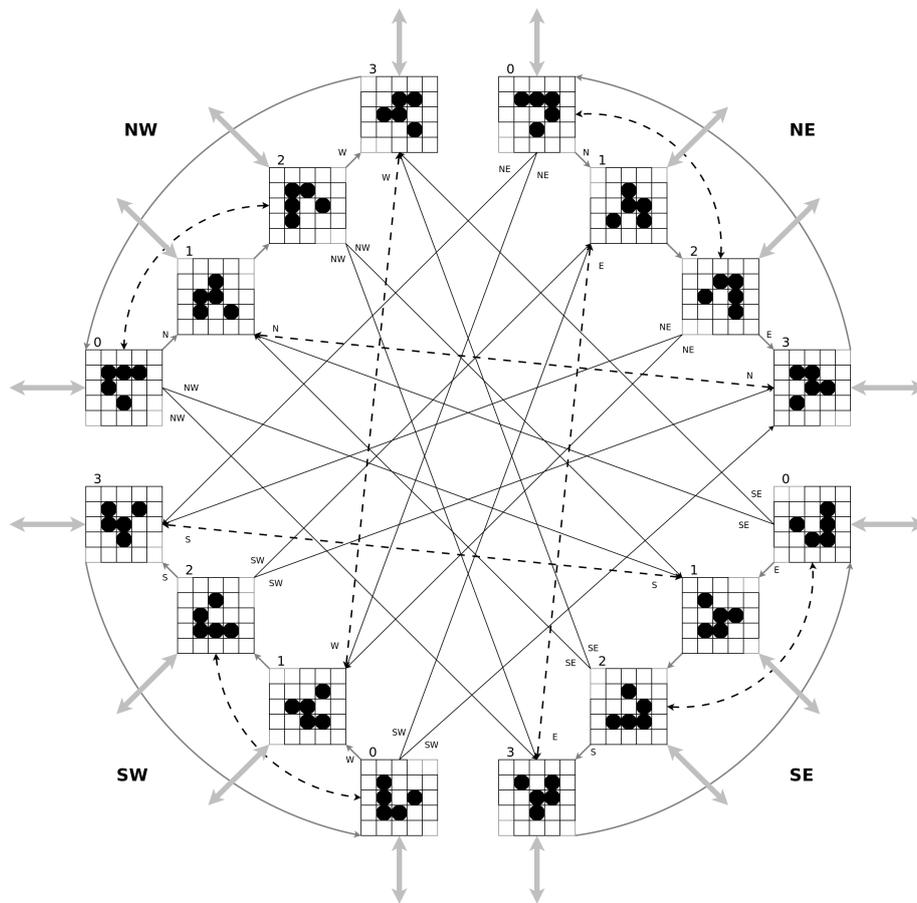


Figure 7: Life of a glider. These are all possible structural changes a glider can undergo. The network is split into the 4 directions the glider can move to and each phase is marked with its assigned number. Normal width gray arrows indicate expected behavior, bold gray arrows allow (de-)manifestation of a glider. Continuous black arrows indicate one-way behavior, whereas dashed black arrows work both ways. The arrows are annotated (at their origin) with the direction of translation that takes place. There is no possible event in the life of a glider not depicted here.

References

- [1] Randall D Beer. Autopoiesis and cognition in the game of life. *Artificial life*, 10(3):309–26, January 2004.
- [2] H. R. Maturana and F. J. Varela. *Autopoiesis and Cognition : The Realization of the Living (Boston Studies in the Philosophy of Science)*. Springer, August 1991.
- [3] Humberto Maturana and Francisco Varela. *The Tree of Knowledge: A new look at the biological roots of human understanding*. Shambala/New Science Library, Boston, 1987.
- [4] Barry McMullin. Computational Autopoiesis: The Original Algorithm. Technical report, Santa Fe Institute, 1997.
- [5] Barry McMullin. Thirty years of computational autopoiesis: a review. *Artificial life*, 10(3):277–95, January 2004.
- [6] Barry McMullin and Francisco J Varela. Rediscovering computational autopoiesis. Technical report, Santa Fe Institute, 1997.
- [7] Francisco J Varela, Humberto Maturana, and R. Uribe. Autopoiesis: The Organization of Living Systems, its Characterization and a Model. *BioSystems*, 5(4):187–196, 1974.