State Space Vectors

On Directionality Tools in Self-organizing Systems

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Abstract

As the complexity of artificial systems around us grow, it gets increasingly hard to keep all the details in mind. One way of avoiding having to tinker with details, would be to use self-organization. To aid the setting of the self-organizing systems on their intended paths, some yet undeveloped tools would be useful. These include a general model for representation of state space, representation of state space vectors, and state space vector calculus.

Keywords: State Space, Vectors, Self-organization, Artificial Life

1. Introduction

Self-organizing systems has been an area of research to and from since the mid of the previous century. There has been much debate about its usefulness, and even claims that it theoretically impossible (Foerster, 1960), something that might have a base in the difference between the various definitions of the concept.

Foerster defined the concept of self-organizing system as a system that decreases its level of entropy over time. To obey the second law of thermodynamics, this entropy would have to be absorbed by the suprasystem. When using this definition of self-organizing system, the question of self-organization largely became academic, since it could be reduced to redistribution of entropy within the suprasystem.

Later, Ashby defined self-organizing system as a system moving from "bad" to "good" organization, claiming that all systems strive for equilibrium (Ashby, 1962). He also added that self-organization was not a special condition, but something that is true for all *dynamic* systems acting under unchanging laws.

After the research discipline of self-organizing systems theory has been established, a FAQ collecting common definitions and questions has been written (Lucas, 2000). In it, self-organizing systems are described as when system structure appears and evolves without explicit pressure from the environment: the change agents are internal to the system. It is in this later sense I shall use the terms "Self-organization" and "self-organizing system".

In the following I shall propose some areas of research concerning the state spaces of the self-organizing systems.

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2. Why self-organization?

As the complexity of artificial systems around us grow, it gets increasingly hard to keep all the details in the mind at the same time. The human mind cannot grasp infinite complexity (Miller 1956). This might eventually set a limit to what systems can be handled and developed. So far, the usual method of solving the complexity has been by using the analytical approach and trying to split the problem or system into small building blocks (as an example, lines of code), and by combining these blocks into larger blocks (macros).

Implicit in this method is a reduction of the problem in question. To be able to design a system using traditional means, the designer must split the system into parts detailed enough to be possible to describe (as an example in code). However, some systems are not possible to handle this way, as is shown by the work with traditional artificial intelligence (Penrose, 1990). To retain the functionality of the system, the parts will be so many and disperse that the "reduction" resulted in something that was more complex.

To continue with the example of intelligence: Obviously construction of intelligence is possible, since it has been done accidentally by natural evolution (Darwin, 1859).

Since evolution is a mechanical and determined process (Varela and Maturana, 1987), it is possible to emulate it, something that indeed has been shown (Ray, 2000). Further, the principle of evolution is not something that is limited to biological life, but can be employed in practical situation (Husbands, Harvey, Cliff and Miller, 1997).

One alternative to traditional design by the analytical approach is to use a chaotic whole, and let that whole organize according to some internal principle. This principle might as an example be "natural" selection as in the case of biological evolution. The gain in using self-organization would be that detail design should not have to be tinkered with, since the system is meant to move more or less on its own accord towards the desired state.

When developing (or rather evolving) systems this way, it is implicit in the method that control by analysis is beside the point. Instead I propose the use of state spaces as a model for the behavior of the system. The state space of a system is every combination possible for the variables that are considered parts of the system, or in other words, the total variation the system can display.

3. An example implementation

As a part of a master thesis about self-organization, an example implementation has been made (Palmius, 2000) to study (among other things) the processes and problems associated with self-organization. The implementation of choice was a demonstration of artificial life and artificial evolution as an example of self-organization, since natural selection and evolution is an example of self-organization, although not the only one (Lucas, 2000).

In the habitat, creatures consisting of short algorithms bred and evolved. The limiting factor was the need to collect "food", and larger creatures needed more food. The intent with this was that the creatures would evolve more efficient ways of finding food then what was provided with the base algorithm.

The main outcome of the thesis was the idea of state space vectors. It was observed that if the system was studied from the viewpoint of its state space, it would be possible to describe "directions" through that state space. In other words, the system started in one state (location in state space) and moved into another state (location).

One of these vectors was the tendency that the average complexity of the creature population increased over time. This was explained by viewing the law of requisite variety (Ashby, 1956) as an attractor in the subset of state space where creatures had high complexity. Metaphorically it could be said that this attractor "dragged" the system through its state space towards a state where complexity was higher.

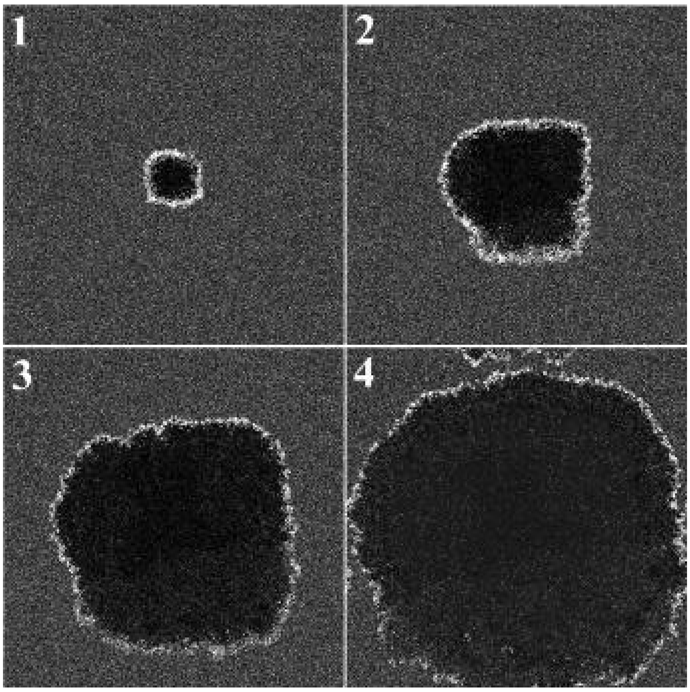

FIGURE 1: A state space vector in action. The population of a virtual habitat moving towards the borders of the habitat.

Another vector observed was the tendency of the population to move towards the borders of the virtual habitat. This was explained by viewing the total depletion of food in previously inhabited areas as a negative attractor. Here, the vector could be described as a negative force, repelling the system from a state where all the creatures were located in the middle of the habitat. In spite of countermeasures such as the introduction of food re-growth, this vector persisted, demonstrating the need of stronger opposing forces to construct a more desired resultant vector.

The common thing between both these phenomena was their directional qualities. The system started in one original state that was characterized as being of "bad" organization, and moved towards a state that was supposed to be characterized as having "good" organization. The definition of "good" organization was in this case "having many creatures with interesting (more complex) constitution".

The idea this has led to is the possibility of steering this kind of state space move by planting sufficiently strong attractors to lead the system state towards a desired subset of the system's state space.

4. What is needed?

In order to make self-organization even a remote possibility in the sense mentioned above, a few tools will have to be developed. I do not claim here to know how to develop these tools, I only propose that with them, self-organization might be practically usable.

4.1. State Space Representations

The first tool is a way of representing the state space of a system that is intended to self-organize. In order to plan a path, or at least set the system going in a desired direction with an intended goal, a map of the road is required or at least very usable.

However, this representation could prove to be rather difficult, as a system could be said to have one dimension per internal variable (Lucas, 2000). There is of course always the brute-force approach to the representation: Store information about every possible setting for every available variable in a database, and set indexes according to mutant neighborhood in state space. This might be theoretically possible, but somewhat cumbersome.

Let us picture a chessboard with its 32 pieces as a system with a state space. Each piece is a dimension in the state space, and every move of a piece moves the state space location into a mutant neighbor location. Now, with the brute-force approach, we would be required to store information about 64^{32} (approximately $6.2 * 10^{57}$) locations and their relations (minus the impossible locations such as two pieces in one square and so on). In other words, given that every state is a collection of 32 bytes describing the position of each piece (variable), we would have to store a collection of data several magnitudes larger than anything stored before. This is clearly not economically feasible.

Instead, another way will have to be developed in order to represent the state space of a system. I do not as of yet have a good view of how this representation model will look, but I propose that it might be possible to map key points in the state space, and from there describe their closest mutant neighbors. This would be an rough approximation of the interesting area.

4.2. State Space Vectors

The second tool, which depends heavily on the first, is a way of representing vectors in the state space of a system. Some points or areas in or of state space could be said to represent attractors for the self-organizing system (Lucas, 2000). With an attractor, there is a force "trying" to make the system move in a direction through state space. This direction and the force that causes the move in the direction, could be viewed as a force vector, and should ideally be representable as such.

In the AL/AE example above, a vector pushing the population distribution towards the outer regions of the habitat could be observed. This vector should, given good a representation of state space, be possible to represent as a path and a speed through the state space.

4.3. State Space Vector Calculus

When it is possible to represent vectors, it should be possible to treat them in much the same way as force vectors in a physical space. Opposing vectors should result in a standstill or a slight nudge in the direction of the stronger vector. Resultants should be calculable in the case of several attractors dragging into different directions.

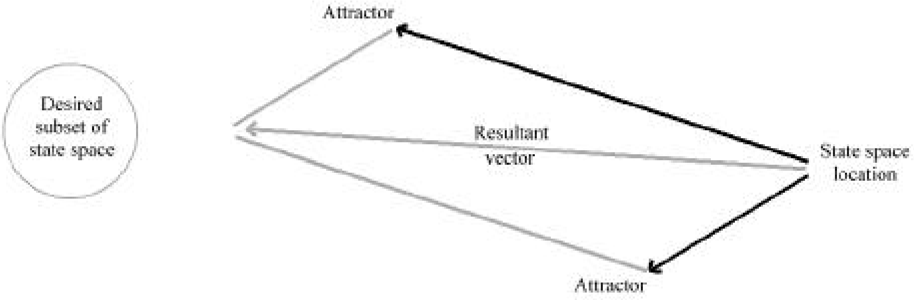

FIGURE 2: If the state space vectors are known, it should be possible to calculate a resultant vector.

With this tool available, it would be possible to set an approximated course through the state space of a system by placing several attractors. This would hopefully vectors with a resultant pointing towards the desired subset of state space.

To continue with the artificial life example above, we could imagine a situation where we wanted the average complexity of the creatures in the habitat to increase (which was the case in the example). Here we have two vectors: One based on the law of requisite variety (the survivability of a creature is better if it can display enough variety to handle all common situations), another is based on higher need for food if the creature is more complex and therefore larger. The first vector points towards the subset of statespace where complexity is high and creatures therefore implicitly are larger. The second points to the subset where the creature sizes are small and implicitly where complexity is low.

The resultant vector here points towards a subset of state space where creatures display a large variety, while retaining as small a size as possible. This vector was possible to see statistically afterwards, but given the tool of state space vector calculus, it should have been possible to predict by combining the known vectors and calculate their resultant.

5. Conclusions and summary

In the above I have proposed the usefulness of a model for representing state space and its vectors. I think a tool like this would be usable in many applications with self-organization as design principle. In principle, since the concept of attractors can be said to be common between most self-organizing systems, the vector model (when developed) should apply too.

Still, the thought of a model like this is only a rough sketch so far. There is still a long way between the ideas presented above, and a useful model. Furthermore, it could be discussed how many applications that can really use self-organization as principle. That one example of self-organization, namely evolutionary design, is useful and possible, has as said been shown. It remains to see if the model proposed above will be possible to develop.

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