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CS365: Artificial Intelligence Course Project

Auto-detection of patterns in Cellular Automata

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INTRODUCTION

Humans are curious, inquisitive beings. We strive to understand ourselves, the world around us and our place in it. We try to discover more things, and when we do, we try to find reasons for them. All the science before the twentieth century essentially had this goal in mind. We dreamed that one day we will be able to understand, predict and control everything.

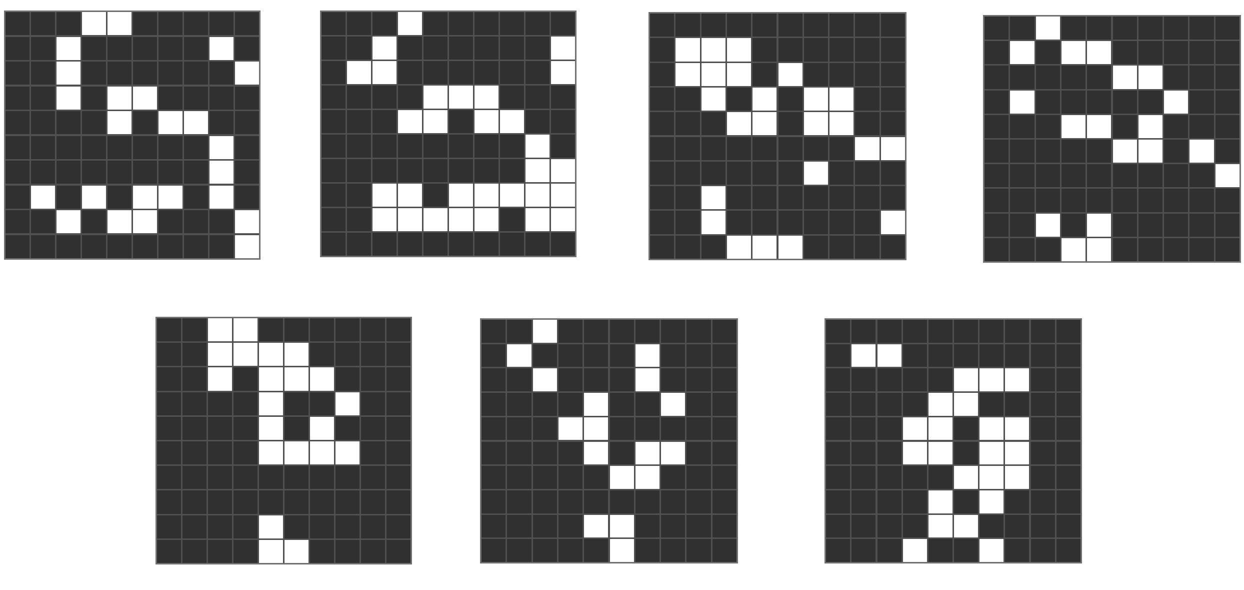
But the face of science has changed a lot in the last 100 years or so. This was the century that brought with it Uncertainty(Heisenberg), Undecidability(Turing) and Incompleteness(Gödel). We now know that the natural world is not as understandable and predictable as we once thought. The Newtonian view of the universe suggested that everything is governed by simple cause and effect relationships. This Newtonian universe could thus be effectively predicted given enough information. This model of the universe is no longer considered ideal. Chaos theory[1] tells us that small changes can cause dramatic differences in the behavior of (almost) all natural systems. Combine that with the impossibility of getting an exact measurement, and we get an essentially unpredictable universe.

What does this mean for us, apart from the immediate observation that we should not expect to find exact answers to some of our questions? Let us look at a system we explored, called "Conway's Game of Life"[2].

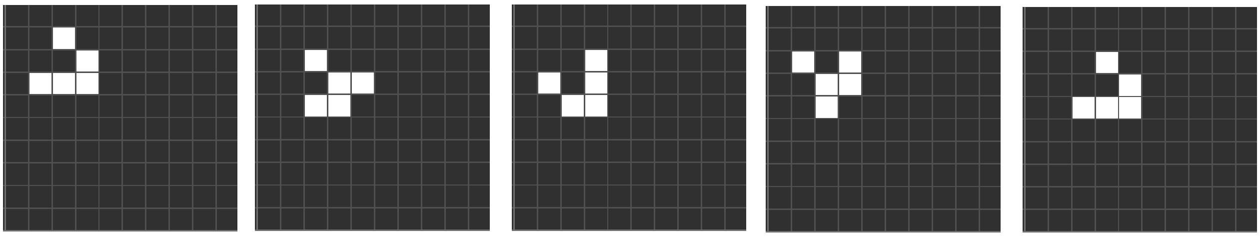
It is as simple as this -

1. An infinite grid consisting of cells, each of which can either be “alive” or “dead”.
2. A live cell with 2 or 3 alive neighbours remains alive in the next generation.
3. A dead cell with 3 neighbours becomes alive in the next generation.
4. A cell becomes/remains dead in all other cases.

When running a randomly initialized game of life grid for the first time, one finds it to be almost random:



But soon in this system, one recognizes interesting patterns forming out of the randomness:



We see interesting behavior in the system which we could not have predicted by just looking at the rules governing the system. This phenomenon is called “emergence”[9], or more specifically, spontaneous order[3].

OUR WORK

We concerned ourselves with the automatic detection of patterns which look interesting to humans(spaceships, oscillators) in a run of the Game of Life. We asked the question - what is it that humans look for when they see interesting patterns, and came to the realization that we tend to look for “blobs” of alive cells and track them through the generations. We define a blob to be a set of cells in which no group of alive cells is separated from all other groups by more than one dead cell. A blob seems to be interesting to us if it has a period - that is, if it repeats itself.

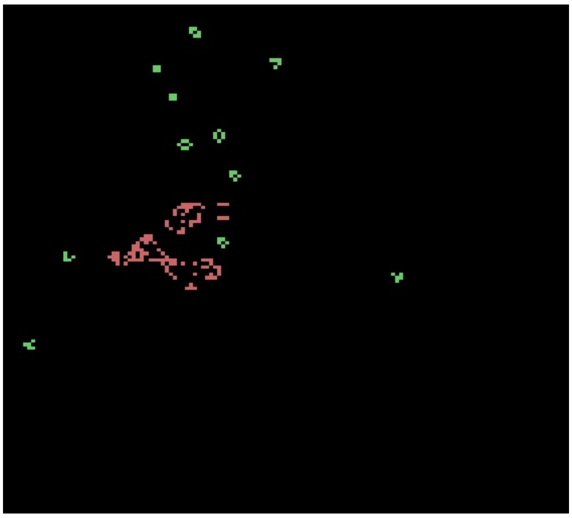
An approach to detect periodic blobs would be to keep the history of each blob and at any generation, compare the current configuration with all previous configurations. A match means periodicity. We formulated an algorithm:

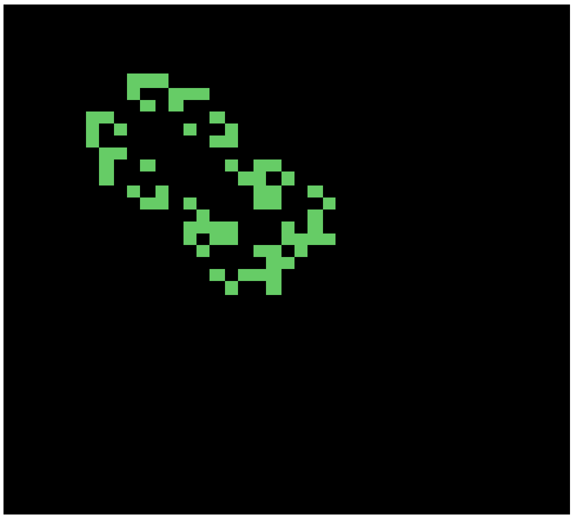
1. Detect all the blobs in a generation.
2. Compute the next generation of cells.
3. Detect all the blobs in the current generation and how they relate to the blobs from the previous generation.
4. Repeat.

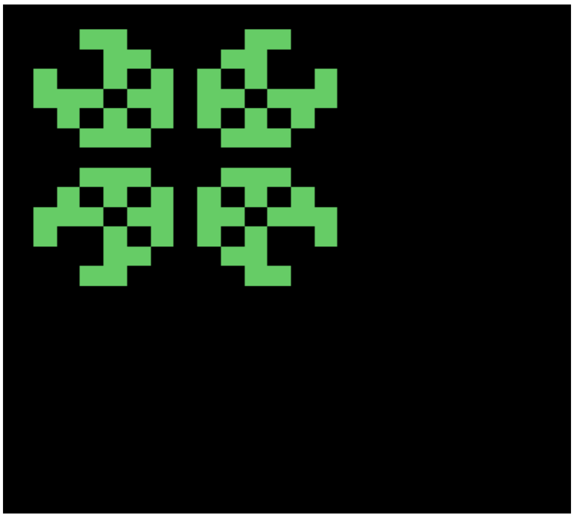
If a blob from the previous generation has one-to-one overlap with one from the current generation, we say that it is the very same “object”. Note that in the case where blobs split or join, we don't keep track of them.

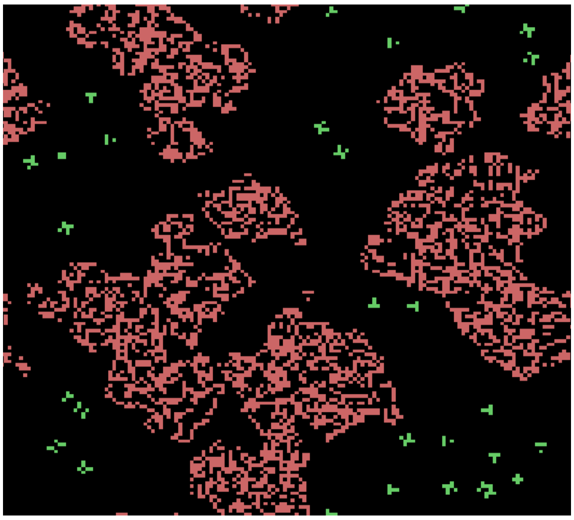
This procedure can recognize simple oscillators and spaceships which have only one blob. It cannot detect periodicity in patterns which produce things(guns, breeders), or are composed of many components which work together. Therefore, it can't detect a large number of patterns which do look interesting to humans but due to their complexity are very hard(or computationally expensive) to automatically detect.

Some of the screenshots of our output showing interesting patterns being detected out of randomness are shown below(in first three pictures). Our method also detects periodic patterns being generated in other 2-D rules of cellular automata like 34-Life(shown in bottom- right picture). This shows the concept of blobs is common to every rule of cellular automata generated such patterns:









The value of entropy for a system is $-\sum_{i=1 \text{ to } n} p_i \log(p_i)$, where the system can be in states from 1 to n and pi is the probability of the system being in the state i.
For a collection of cells, the probability of the collection being in a state(or configuration) i can be determined by the history of this configuration - specifically, the number of times this collection of cells has been in configuration i divided by the length of the history.

For a non-periodic collection of cells, the value of entropy will keep on increasing with n[10], as the total number of states of the system keeps on increasing in each generation. But for a periodic collection of cells, the value of entropy will be, on an average, $-\sum_{i=1 \text{ to } n} (1/p) \log (1/p) = \log p$, where p is the period of the configuration. As the logarithm function is one-to-one, if we find the period of a collection of cells, we are essentially calculating the entropy.

RELATED WORK

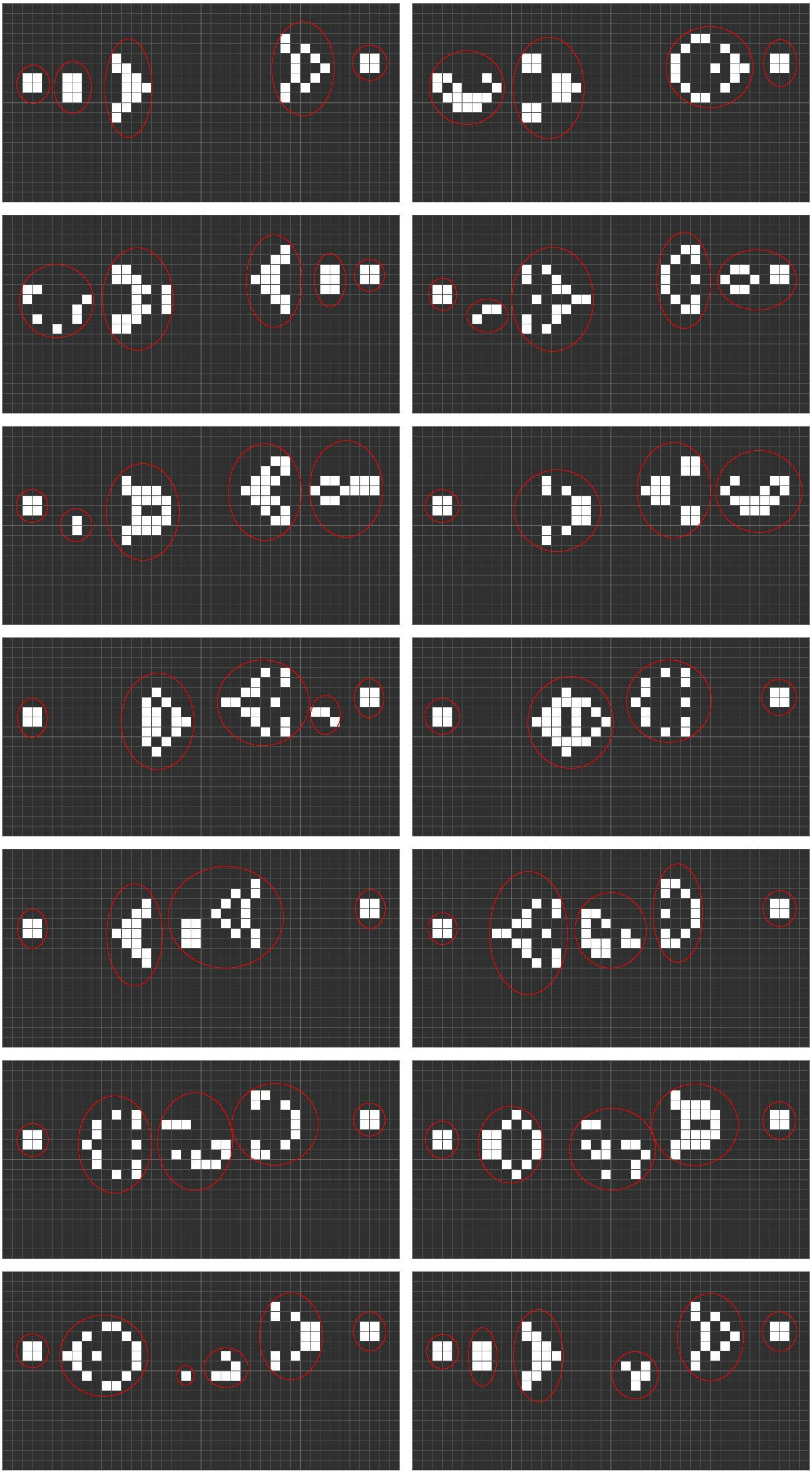
Martin Gardner, a famous writer when describing the gliders and spaceships wrote that “very large patterns are hard to find”. Most of the work has been done on finding the spaceships in game of life rather detecting the interesting patterns, some of them follow [4] [11]. The first automated finding technique developed which did a brute force search on bounded patterns/bounded number of live cells was limited to some kind of patterns(oscillators and spaceships with speed c/2 or c/4). This search was exhaustive in nature but the size of spaceships was limited to 12 x 15(due to the computational intractability). A new technique proposed by Dean Hickerson[4] was based on backtracking search program in which the program stored three states for a cell, live, dead, unknown. Initially every cell in a bounded large rectangle was unknown and then it did a BFS based on ‘legal’ cell states for generation over generation. The approach towards finding 'new spaceships' surrounded basically the above theme for years until Eppstein’s paper which came in 2000.
D. Eppstein[4] in his paper “Searching for Spaceships” used a search technique in his tool to find spaceships. He categorised the spaceships broadly in few sets(for example small spaceships with small period, long ones with small periods, small ones with very large periods etc.) then employed different search techniques depending on the complexity of pattern.

One of the implementation for detecting patterns in cellular automata is of H. Foundalis[5] who gave preference to speed of his algorithm for small patterns with small periods and not for the detection of large patterns with large periods. It stored the history of each cell in a dynamic rectangular grid of active cells and after every 32 generations, looked for the patterns of periodicity in its history. The period of whole structure of these cells would then be the least common multiple of period of every cell. In this way, though limited in the period, Foundalis’s algorithm was able to detect static patterns. For moving patterns he looked the same thing in 3 dimensions(3rd dimension for generations) and searched for periodicities along with the movement in 2 dimensions(x & y).

Our implementation is different from these implementations in the way that they are too 'machine-centric', or they don’t take into account how humans see these patterns. Although others have found a large number of patterns with such approaches as compared to us, we suspect that our approach might be a reasonable alternative approach.

LIMITATIONS AND FUTURE WORK

We are only able to detect very basic(and connected) patterns in the Game of Life, even though there are a lot of interesting patterns. In fact, there are what seems to be “colonies” of small components which work together to create a big interesting pattern. Consider the following structure, famously called “Gosper’s Glider Gun”:

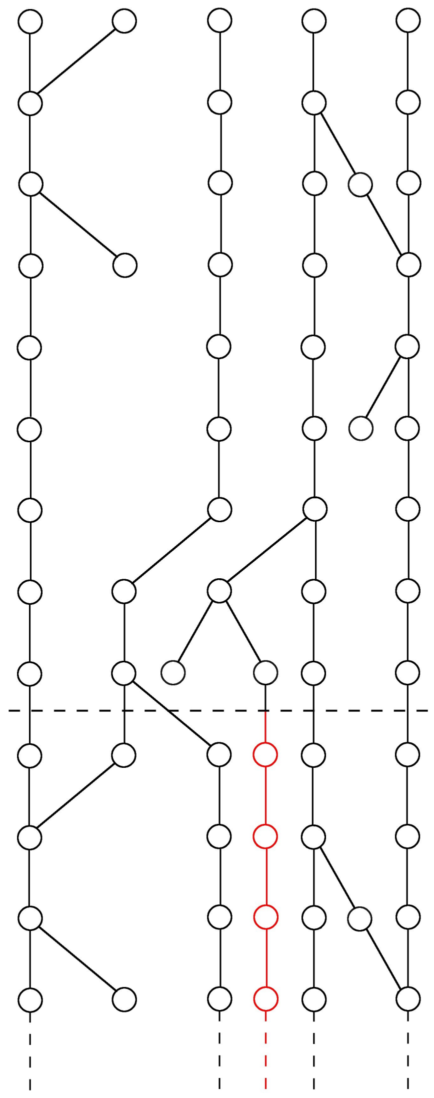


Note that the initial configuration is same as the final configuration, except that an offshoot(a glider) is produced, which will keep going in the bottom-right direction forever.

The task of auto-detecting such patterns is non-trivial. We formulated a solution that is likely to work in most of the cases:

Construct a layered graph from a run of a particular configuration in the Game of Life, where each layer consists of nodes corresponding to blobs from a particular generation. The layers are stacked in temporal order, and edges are formed between related blobs. A blob A in the current generation is said to be related to a blob B in the previous generation if B likely had an influence on A.

Here is a compressed version of our layered graph for the Gosper's Glider Gun, obtained after removing layers which don't change at all from the previous layer:



The horizontal dotted line shows the end of the first period of the gun, and the red offshoot is the glider that is produced at the end of this period. To find out whether a pattern is periodic or not, we will have to tell whether a subset of the nodes in a particular layer corresponds to the nodes in some previous layer. Note that, as the Game of Life has been proved to be Turing-complete[3], the problem of telling whether a pattern satisfies a given property or not is, in general undecidable. Therefore, there cannot be an algorithm which would detect all periodic patterns.

PHILOSOPHY

There is no doubt the Game of Life is incredibly complex. There are two fundamental reasons behind such complexity in a system. First, there are many components involved in the system. Secondly, the behaviour of the whole system is more complicated than what one would expect from the behaviour of individual components of that system. The interactions between these components results in complexity. Wolfram[6] postulates that since we see irreducible complexity(universal computation) in systems as simple as the Game of Life(and even simpler systems such as Elementary Cellular Automata[7]), most of the natural systems, which are more complex, can also perform universal computation. The idea of Computational Irreducibility[6] explains that if an observer and a system are computationally equivalent then it is not possible for the observer to predict the behavior of the system without performing an exact simulation.

IMPLICATIONS AND CONCLUSION

In his book [6], Stephen Wolfram suggests a radical paradigm shift in Scientific Enquiry. Wolfram says that conventional mathematics and engineering rely too much on increasing the scope of our understanding, on certainty and predictability, and as a consequence massively limit our discoveries and/or inventions. He says that a new way of exploring things is needed, the way of "systematic, empirical investigation of computational systems for their own sake."[8] This is a piece from his notes about Artificial Intelligence(an excerpt from the book)[6]:

"When electronic computers were first invented, it was widely believed that it would not be long before they would be capable of human-like thinking. And in the 1960s the field of artificial intelligence grew up with the goal of understanding processes of human thinking and implementing them on computers. But doing this turned out to be much more difficult than expected, and after some spin-offs, little fundamental progress was made. At some level, however, the basic problem has always been to understand how the seemingly simple components in a brain can lead to all the complexities of thinking. But now finally with the framework developed in this book one potentially has a meaningful foundation for doing this. And indeed building on both theoretical and practical ideas in the book I suspect that dramatic progress will eventually be possible in creating technological systems that are capable of human-like thinking."

Wolfram says that the conventional approach in engineering - building systems so simple that every aspect of them can be readily predicted is the reason we end up building systems much simpler than what we usually find in nature. Moreover, the traditional way of overcoming this shortcoming is by creating systems on top of highly complex rules. Wolfram further says that taking inspiration from cellular automata, if we build systems with very simple(but appropriate) underlying rules, we will be able to explore much better Engineering solutions than currently possible.

Wolfram has suggested "Causal Networks", an even more abstract system and simple system as compared to Cellular Automata. He mentions how, quite astonishingly, some of the key features of the physics of our universe, namely particles, gravity, special and general relativity seem to "emerge" from them.

Parallels can be drawn between what Wolfram suggests and the “scruffy” AI paradigm. The ultimate idea is that the exact understanding of human intelligence is unimportant and isn’t necessary for creating Artificial Intelligence. It is quite likely that a suitable system with very simple underlying rules would ultimately produce intelligence as great as our own.

“If the brain was so simple that we could understand it, then we’d be so simple that we couldn’t.”

– Lyall Watson

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