THE UNIVERSE AS A COMPUTER; THE BEGINNERS GUIDE

This article is an introduction to the history, ideas, methods and implications of the proposition that our universe is the result of some kind of computer program. The essay requires no detailed technical knowledge, but some understanding of the ideas in physics and basic computer technology. My objectives in writing this essay is to spread the word; not because I believe that we are living in a computer simulation but because I do believe it to be a valid proposition that physics needs to take seriously. Unfortunately this is not the case and I hope that if more of us ordinary folk start to ask questions then the more likely it will be that the physics community will have to address the issue. I am a trained physicist and have spent the last twenty years working on complex computer systems. For the last seven years I have been carrying out my own research in this area and I will discuss my own ideas at the end of the essay.

A CRAZY IDEA!

Sounds crazy doesn't it; like something out of the film, 'The Matrix'. Well it might surprise you to know that the Wachowski brothers[1] were not the first to have this idea. In fact it was an engineer called Konrad Zuse[2] who started thinking about this question. Back in the 1940s' Konrad was the first person to build an electronic programmable computer and he started to wonder what would happen if he programmed all of the theories of physics into his digital computer. If he ran the program, could it create a universe like ours within the computer?

Now before I go on it is important to remove preconceptions that can dilute the serious scientific value of this idea. Using the word 'computer' in this context can cause one to imagine beings in another universe sitting, or floating around what we see as a computer that contains our universe. Such ideas are a complete fantasy that has no place in a serious discussion. To remove such fantastical views, those who work in this area of research generalize the computer to a 'computational process'. This tends to remove any need to consider the underlying mechanism upon which the computational process operates and with it any romantic ideas regarding the deeper meaning of it all. The computational process is also an abstract idea that can be formulated in mathematical and logical ways enabling a level of scientific analysis.

There are many reasons why Konrad's early ideas wouldn't take off, and we will return to them later, but Konrad started the ball rolling and now there is a small but growing group of established scientists who believe that our universe may be the result of a simple

[1] They wrote the Matrix trilogy.

[2] Zuse proposed his ideas in a book entitled, 'Rechnender Raum', which translated means, 'calculating space'.

computational process that has the ability to generate a vastly complex universe. If this were the case, then our physics and hence our model of 'reality' would be molded by the fact that we are observing the universe from the inside and that below physics is another 'reality' that creates, what we perceive as our reality. These two types of realities are sometimes termed 'internal reality', that is the reality that exists because we, and hence physics exists. The other reality is 'external reality'; this is the underlying computational process that exists, even if we didn't. In general physicists in their day to day work do not consider 'reality'; only in the media, where it can make physics and the physicist sound more important than either may turn out to be.

One of the biggest 'bones of contention' for physics, but a motivation for people such as me, is quantum mechanics. There is no doubt that since its development in the early 1900s', quantum mechanics has been an amazingly successful and accurate way of predicting the behavior of the sub-atomic world. However it has uncovered behavior that is completely unintuitive to us. Many great minds have struggled to comprehend what quantum mechanics is telling us about the universe[3] but there is no agreed view, and in fact many physicists see this as a fundamental limitation upon our knowledge. In other words they believe that quantum mechanics is telling us that at the atomic scale we cannot know *how* the universe works but only *what* it is likely to do. However the intuition of many great physicists considered that quantum mechanics is only an approximation to another deeper mechanism of the universe. One of the most well know proponents of this view was Albert Einstein; when he said "God doesn't play dice", he was supporting the idea that the uncertainty and aspects of randomness that seem to be integral to quantum mechanics are just a lack of understanding of the underlying mechanisms that are approximately modeled by quantum mechanics. Later in this essay I will discuss another great 20th century physicist who, I believe had similar views, namely Richard Feynman.

Physics itself is starting to suggest that aspects of our universe that were once thought to be continuous may in fact be discrete and such discreteness would suite a computational model of our universe. For example there is a growing view that space and time are not continuous, but discrete and that at very small scales, known as the Plank scale space-time may actually break into separate space and time[4].

My great hero of physics is Richard Feynman; he was a great physicist with a 'no nonsense' approach to the subject and he had little time for speculation of what physics was telling us about any type of reality. To Feynman physics was just a set of tools for calculating things and he was keenly aware that there were several ways to mathematically describe a physical law and each mathematical description gave rise to a theory that could be interpreted in different ways. For example the law of gravity can be described by Newton's

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[3] In fact there are at least nine different interpretations as to what quantum physics is telling about the structure of the universe.

[4] For more information reference Lee Smolin and 'Loop Quantum Gravity'.

laws, or a relativistic approach in which gravity is the result of warping space-time and also by something called the 'minimum principle'.

Feynman was concerned that as one used physics at smaller and smaller scales, the amount of computation required increased. This situation is very unsettling and suggests that concepts such as 'infinitely large' and 'infinitesimal' are in fact not part of the underlying structure of the universe.

These ideas are reflected in a proposition called the 'finite nature hypotheses. Developed by Professor Ed Fredkin[5] of MIT, the hypothesis states that, *"at some scale, space and time are discrete and that the number of possible states of every finite volume of space-time is finite".* The restrictions placed upon descriptions of the universe using the finite nature hypotheses suggested that a computational foundation to the universe would be more appropriate. Over many years professor Fredkin and associates have been developing this idea further and this has lead to a new area of research termed 'digital mechanics'[6] that proposes an 'information processing' based theory for external reality.

The concept of information has become as fundamental in physics as concepts such as space, time, energy and matter. Information as a characteristic of the universe was introduced into physics through Boltzmann's analysis of entropy. Entropy is a measure of the number of potential patterns that a system can have and is hence linked to the amount of information we have about it. As entropy increases in a system our information about that system decreases. There are many other areas where the science of information, known as information theory can be used to derive, for example aspects of quantum theory. Once again the fact that physics is intimately linked with a characteristic that can be associated with computation may be telling us something.

A more philosophical approach to the general proposition was taken by Nick Bostrom[7], who used some plausible assumptions and a logical argument supported by a mathematical analysis to conclude that it is highly likely that we are living in a computer simulation.

So all of the points I have been discussing add credence to the idea that the universe may be discrete and computational at its heart. However for me personally, one of the most important insights, and a personal motivation came from Richard Feynman, who in his book The Character of Physical Law, stated, "*So I have often made the hypothesis that ultimately physics will not require a mathematical statement, that in the end the **machinery** will be revealed, and the laws [of physics] will turn out to be **simple**, like the **chequer board** with all*

[5] 'Finite Nature', Edward Fredkin, Department of Physics, Boston University.

[6] 'Digital Mechanics: An Informational Process Based upon Reversible Cellular Automata', Edward Fredkin, Boston University.

[7] 'Are You Living in a Computer Simulation', Nick Bostrom, University of Oxford and 'A Patch for the Simulation Argument',Nick Bostrom and Marcin Kulczycki.

its apparent ***complexities***". The significance of this statement, and the highlighted words, will become apparent as we discuss in more detail how such a proposition could be realized.

A Flight of Fancy

At this point I would like you to join me on a 'flight of fancy' to get a feel for how the internal reality that we sense around us could be generated by a computational process. Imagine that you are sitting at your PC looking into the futuristic landscape of your favourite computer game and assume that the characters in the game are like us; sentient beings. You watch as one of the characters jumps into his or her jet buggy and speeds of across an amazing landscape, but after a minute or two you get bored so you hit the accelerator key and time speeds up and the landscape passes by in a blur taking you character to their destination in a few moments. On leaving the buggy your character picks up a complex looking electrical device from the back of the vehicle and then sprints over to an awaiting galactic class starship. The starship leaves the planet's surface and we travel far into space until we watch as the ship passes too close to a black hole and is sucked into its core and the game ends. Through this, admittedly naive, thought experiment let us to look at some of the fundamental physical characteristics of our universe that are still abstract concepts using known theories.

From the perspective of the sentient character, they had travelled thousands or even millions of miles across their universe, but to us all of this 'space' is contained within a small memory chip within our computer. So maybe there is no need to get 'hung up' on the vastness of space, in fact the idea of the vastness of the universe becomes more comprehensible. You will see later that my model produces a full understanding of 'what space is', and this is in stark contrast to the contradictory viewpoints of space given by general relativity and quantum mechanics.

To understand time from the perspective of our character, it is important to realise that a 'computer' is what is known as a 'finite state machine'. This means that if we stopped the program running then the program's 'state' at that point would be defined by a finite set of data variables that have been 'set' by the program or by the programmer prior to its execution. So as the program is running there will be a point in our time when the object that is the character has been updated, given all of the other things going on around him. Therefore the character's 'consciousness' is dependent upon this change in his state. But, and this is the interesting bit, to the character there is no 'time' between these states as his perception is stuck until the next change of state; hence he is 'timeless'. So the character's states are linked together giving the appearance to the character of continuous time, when in fact, from our perspective it is discrete. Because of this stepwise state change space, and in fact everything he perceives, would seem continuous to the character. It is also worth noting that when we hit the accelerator button, 'time' would not speed up for the character because time for him is defined by him as a change between the current state and the next state and is not dependent upon the rate of that change. Once again you will see that my theory has a sophisticated implementation that enables the model to create a universe that has a relativistic view of time and space.

Whilst discussing the state change idea I want to briefly mention a characteristic of our universe that is absolutely vital to us, but is almost ignored by physics, and that is the thorny subject of 'consciousness'. I feel that the ideas above start to give a 'feeling' as to what consciousness may be and you will see later that my model does indeed start to shed light on this difficult concept.

So what about matter, well we conceptualize matter as a physical substance when in fact it is an interaction between two force fields. For example as I hit the keys on my laptop I feel a resistance to the key and I perceive the key as ultimately being made up of 'matter'. The truth however is that as the molecular structure that is my finger approaches the molecular structure that is the key the electromagnetic fields generated by the finger and key repel each other so nothing ever touches. The idea of there being any physical substance is an illusion. A similar argument can be made for all sub-atomic experiments, so although we may speculate the existence of quarks as 'matter', we don't truly know what the underlying physical meaning of matter is. To the character in our game 'matter' is similar to our perception in that, depending upon how the program is written its effects will be the interaction of fields between objects. At the quantum level 'matter, to our character may be as abstract as it is to us. However from our perspective the character's matter is just data that is manipulated by the program and physically represented by electrical charge in the computer's memory; so one man's matter is another man's data. Our virtual character highlights one of the problems that we also suffer from and that is that we both perceive our universe from within it and the only true way of understanding the mechanics or fabric of that universe is to view it from the outside. This means that the physics that our character may develop for his universe will be describing his interaction with it, as does ours. Another way of viewing this is to consider a very bright goldfish in a goldfish bowl. The goldfish may be able to work out that there universe is bounded (by the bowl) and that it is curved but it can never know that it is a goldfish bowl.

Having touched on matter I must mention 'energy'. This is a misunderstood concept and I think that Feynman gives a good understanding of it in his book The Character of Physical Law. In current physics 'energy' is a mathematical method that enables us to account for a quantity that remains constant in a closed system, even when there are physical changes in that system. Feynman has no time for understanding what energy is beyond a neat mathematical accounting tool. However, in general terms, both in our universe and in our characters, energy is a quantifiable characteristic that is associated with dynamic behaviour and state change. But from our perspective our character's 'energy' is a relationship between how the program reacts to specific data values that an object has leading to a specific change in the object's state.

The general point here is that if one looks at the universe as a computational process then many of the unfathomable physical characteristics that emerge from quantum mechanics can be seen in a much more intuitive way[8].

The flight of fancy we have just been on is very basic but it does highlight an important change in our conceptual boundaries. The game I have described is an application of what we call 'virtual reality' and the importance of this new aspect of computing is that for the first time we can conceive of creating a universe that we can view from outside. This is a view that current theories and physicists do not take and hence it may be a limiting factor in the ability of physics to delve into the structure of the universe. In fact it may be that quantum mechanics is telling us that the way we approach physics has reached a point where this introspective or self-referential approach can tell us no more. I am being a little disingenuous to physics as there is an equivalent paradigm that originates from Superstring theory. Part of this highly abstract theory is the idea of branes, these can be naively thought of as stretched out sheets of energy (or strings). It has been postulated that our universe exists on the surface of such a brane and that the universe was created from the collision of two or more such branes in a multi-universe. This is the first theory in physics that is capable of looking at our universe from the outside. However Super String Theory is a contentious theory that has arguably little experimental evidence to back it up[9].

So the next question is what makes the example I have just used such a poor one, and how can we improve upon it to a point where we could conceive of writing a program that actually simulated a universe like our own.

The problem with the game that we envisaged above starts with the program. You see most program are what are called functional or object orientated. Both of these approaches to programming need you to understand and define every type of object that you will have in your universe and every operation that you will perform on it before you can write the program! So for example in our game, our character is one object, but so is each of her weapons, and each of her enemies and vehicles and every object in the landscape such as each type of tree, bush and building; so you can see that in any real simulation of a universe there would be an almost infinite number of objects that you would need to have defined. This is one of the big problems with my flight of fancy because for our character to be a sentient being we would need to know all the details of the objects that made him sentient and to program this in. The problems don't stop there because we would have to account for every level of scale, so for example if our character could experiment with cells, molecules, atoms, protons, neutrons, electrons and even Quarks then we would have to program them in. We would also have to include all the operations that we could perform on these objects and this would include programming in the 'physics'. Programming in the physics raises another big problem and that is that our physics depends upon irrational

[8] Further reading: 'A cybernetic Interpretation of Quantum Mechanics', Ross Rhodes, July 11, 2001.
[9] 'Not Even Wrong', Roger Penrose.

numbers such as pi and other physical constants. But our computer can only represent a number to a particular level of accuracy, and as the number of calculations piled up the extremely small inaccuracies of the calculations would start to build exponentially and it would not be long before the results from the program broke down into a chaotic mess. Finally the program would require our physics to be complete and consistent so that other inaccuracies could not develop, and this is far from the situation that physics finds itself in. These are some of the reasons why Konrad Zuse's analysis was limited. This is easy for me to say given an understanding of a subject that was in its infancy when Konrad was putting forward his ideas. The subject that I speak about will be our next divergence and it is the study of complex behaviour. But before that it is worth mentioning that my own research suggests that most physicists base their objection to the 'computational universe proposition' based upon this naive model of a computational universe.

So what we need is to use a program that has one programmed object and a set of simple rules that enables it to build all other objects from this fundamental object. We also need this program to somehow generate its own rules for operations at the various scales and for different objects.

The Importance of Complexity

Before looking at the kind of programs that may solve our problem, it is important to briefly discuss a subject that Zuse was probably unaware of and this is the science of complex systems, or more formally the science of non-linear dynamic systems. Probably unsurprisingly this subject is a complex one, however for our purposes the main point is that the kind of simple programs that we need to develop will have to produce complex behaviour and through the subject of complex systems we can now have a much more scientific understanding of the dynamics and characteristics of such systems.

What has been discovered is that if you take a very simple system for which we know the physics and mathematical equations, a so called, 'deterministic system'; then it can show extremely complex behaviour. Such systems can show several strange characteristics:

- They can become 'deterministically chaotic[10]', that is their behaviour is completely unpredictable. This behaviour can also just come and go. The behaviour is termed 'deterministic chaos' to distinguish it from the more subjective understanding of chaos as a random process.
- From this complex behaviour can 'emerge' highly complex repeating patterns and structures.

[10] 'Deterministic' is used to stop any confusion with our preconception of 'chaos' as being totally random, in essence this system is determined as we know all of the physics.

- The only way to know how one of these systems will behave is to actually observe the system itself. There are no shortcuts to predicting its behaviour over a period of time that varies with the system and its state.
- Some of these systems can be modelled using mathematics but after a short period of time the model will start to diverge rapidly from the actual behaviour.

No one has yet come up with a good definition of what a complex system is but they do have certain features[11]:

- They have feedback, whereby the output from part of the system is used as input to the system.
- They are 'non-linear' and this means that a small change can lead to a disproportionate response.
- Because of the non-linearity they are very sensitive to their initial conditions, so a very slight change in the way you set the system up will have a dramatic effect on how it will behave.

Many systems have been shown to be complex such as the climate, stock market and animal populations and many more, so complex systems analysis is not dependent upon a computational approach; current physics can be analysed in the same manner.

A complex system can be viewed at many levels and can be thought of as a hierarchy of complex sub-systems with each of these systems being coupled to each other so that disturbances generated in one sub-system can be propagated to all the others. This can lead to very large systems having many islands of varying complex behaviour. Take as an example our universe, which consists of a vast number of galaxies that are complex structures, some of them have a level of stability, whilst others become unstable and explode into supernovae. Now the explosion of a galaxy does not tend to have a great effect upon our galaxy and hence these two sub-systems could be said to be 'loosely coupled', whereas closer galaxies could be destabilised by such an explosion. This idea that systems have areas of varying complex behaviour is vital to the general dynamics of complex systems.

So given these ideas of complex systems it may be possible to create a simple computer program that could generate a vastly complex system that may be a universe similar to our own, but not as complex, and more on that later.

What are Cellular Automata?

We are now at a point where we need to find a type of computer program, or more abstractly, a computational algorithm that is simple and uses a single object from which it can create very large, dynamic and complex structures and from which behaviours

[11] There are other characteristics but they are more technical and not required to be explained.

according to the laws of physics could 'emerge'. Fortunately there is a good candidate and they are called cellular automata.

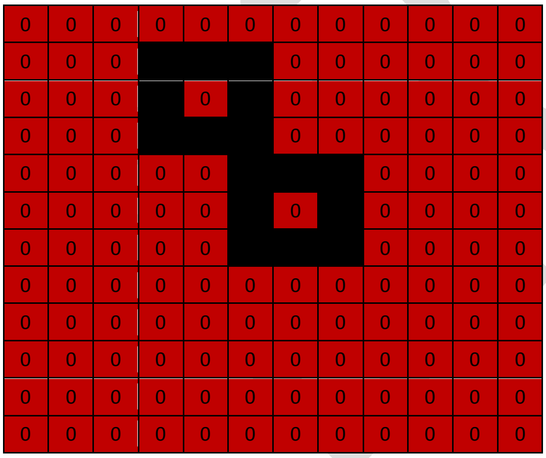
So what is a cellular automaton, well the name says it all. Consider a chequer board (remember Feynman); assume that each cell can have a state; let's say it can be either black or white. Now let's assume that whether a cell is black or white depends upon the state of its eight nearest neighbours and that each cell is an automata in that it is a separate computer that runs a program (or set of rules) that looks at its neighbours and its own state and decides what its new state should be.

So if we take a simple example:

Let's assume the following rules for each cell

Neighbouring states	current cell state	New cell state
>4 are black	Black	Black
>4 are black	White	Black
>4 are Red	Black	Red
>4 are Red	Red	Red
4 black and 4 Red	Black	black
4 black and 4 red	Red	Red

We now apply these rules to each cell in turn to create a new chequer board.



The new chequer board becomes (ignoring the boundary cells for simplicity):

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0
0	0	0				0	0	0	0	0	0
0	0	0	0				0	0	0	0	0
0	0	0	0				0	0	0	0	0
0	0	0	0	0				0	0	0	0
0	0	0	0	0	0		0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

As you can see there is a significant difference in the pattern, or distribution of states. This is a very poor example of what is known as a growth model in that each cell requires contact with a certain number of 'identical' states to survive. Of course you can apply the same rules to the new pattern and so on. You can probably see that our understanding of the dynamics of complex systems in a practical sense depended upon the development of both computational techniques and ever faster computers so that many iterations of these systems could be analysed and this is why such ideas have only been discovered in the last few decades. Cellular automata do not have to be two dimensional like my chequer board example. One can have as many dimensions as required, but of course the CA's become extremely complex and very difficult to visualise.

If you want to see how powerful and complex such models can become then I recommend you search the internet for example programs that implement John Conway's, 'Life', sometimes called, 'the game of life'. This is an ingenious but very simple cellular automaton that can create amazing quasi-stable patterns that seem to have purpose, and a behaviour that could not be predicted from the simple rules.[12]

There are many types of pattern that can emerge in the game of life including:

- Still Life: patterns that remain the same for varying numbers of iterations.
- Oscillators: patterns that oscillate between several patterns on a regular basis.
- Gliders: Patterns that move, some of which can generate other regular patterns whilst they are moving.

[12] This is sort of the definition of emergent behaviour in that the resultant behaviour could not be envisaged from the lower level components.

There is continuing research into finding new and interesting patterns from the game of life and recently Andrew Wade has discovered the first pattern that replicates itself[13].

As a trained physicist I can sometimes watch the changing pattern of the game of life and in the regular and repeating patterns and their complex interactions I wonder whether I am glimpsing the true nature of our sub-atomic universe.

There is also a growing synergy between the application of CAs and our mathematical based physics that suggest that physics is capable of modelling real physical systems that can be fully represented by specific cellular automata. One of the most successful areas where this is the case are lattice gas models. These are specific CAs that can very accurately generate the observed behaviour of gases under certain conditions. These gases are also modelled by traditional physics

Stephen Wolfram[14] has written a reference text on cellular automata and in his book suggests that they may be part of the substrate that lies beneath physics. In fact he is one of the prestigious scientists who support the proposition of a computational universe.

Another highly technical reference on cellular automata that addresses the idea that they may be fundamental to the substrate of our universe is 'Cellular Automata: A Discrete Universe', by Andrew Ilachinski.

Finally, I hope that now you can see that Richard Feynman's[15] statement mentioned in the 'background' section suggests that may be all the mathematical based physics is just an approximation, and underneath it all is a CA running on a machine that together create all the complexities of the universe. So I think I have reached the point where I can say that, for me, cellular automata seem to be a good way to go in developing computational theories of the universe and this is the road I have taken and one that I will now outline in a little more detail.

[13] 'First Replicating Creature Spawned in Life Simulator', New Scientist, 16 June 2010.

[14] A New Kind of Science, Stephen Wolfram.

[15] Feynman was intrigued by this idea and gave a talk with an associated paper entitled 'Simulating Physics on a Computer'

A Shot in the Dark

As I have already mentioned there are some well established scientists involved in this area of research but one gets the feeling that it is almost like an underground movement that fears to show its existence to the 'real' science that is being pursued. There are also a few papers and articles that are flying around on the internet from authors who do not have substantiated academic backgrounds. However some of this work seems very well researched and develops strong arguments and ideas.

The problem with a lot of the current research is that it is highly theoretical or anecdotal and no-one has seemingly attempted to develop a CA-based program that has the potential to generate a universe similar to our own. Now to an extent this is fully understandable as it is a huge undertaking and in fact may be impossible, so there's no better way to start this section than with a whole bunch of reasons why we shouldn't bother.

Firstly I must explain an idea that for me is critical to both making progress in developing a universe within a CA and analysing some of the ideas that will follow. There are two points of view from which a CA can be observed; one can observe it from within and for this to be the case the observer is themselves a pattern within the CA. I call this sort of observer 'the Simulant'. The other point of view is from outside the CA and this observer I term 'the Simulator'. I will discuss this later in more detail, but it should be pretty evident that a pattern observed by the Simulator will be very different from the same pattern observed by the Simulant as the 'physics of interaction' between the observer and pattern are very different in each case.

Let me start by discussing the sheer scale of the exercise to be undertaken. In his book, wolfram identifies the number of possible combination of rules for just one and two dimensional CAs with two possible states. Considering that from a simulant perspective our universe is at least three dimensional it is likely that the actual CA has many dimensions and with a very large number of states. This makes the number of possible CAs that could be developed absolutely vast. To surmount this problem to a degree I adopt a strategy that selects a sub-set of these possible solutions; however I would be the first to admit the sub-set is only a bit less vast than the total number. Once some progress is made then the form of the required CA may be able to be 'homed' in on.

Another problem is in the complexity of the CA dynamics; as I have already discussed, complex systems are very sensitive to their initial conditions. In practical terms this means that if I make a small change to my developing CA then it can have dramatic and unpredictable effects upon the resulting behaviour. This makes any evolutionary approach to improving the CA extremely difficult.

For example If I had changed one cell state in the initial pattern used previously, like so...

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0				0	0	0	0	0	0
0	0	0		0		0	0	0	0	0	0
0	0	0				0	0	0	0	0	0
0	0	0	0	0	0			0	0	0	0
0	0	0	0	0		0		0	0	0	0
0	0	0	0	0				0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

Then as you can see the resulting pattern is significantly different, although interestingly these two patterns can be seen as components of the previous result.

0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0
0	0	0				0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0
0	0	0	0	0	0		0	0	0	0	0
0	0	0	0	0	0			0	0	0	0
0	0	0	0	0	0		0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

This also means that in a hypothetical CA universe it would be dangerous to intervene once it had started calculating in case your change destabilised the results and wiped out the sentient beings that were evolving. Of course using a computer one could try out various changes whilst still being able to revert to the previous version.

It is worth mentioning that there is a view held by some who work in the area of complexity that experience of previous results coupled with acquired knowledge can be a more effective, or the only way to assess the likely behaviour of a complex system. In other words intuition can be a great benefit in the development of CAs and more generally in the analysis of complex systems.

You may say, that it would make sense to use some mathematical model of the evolving CA system to predict what the CA would do if I made a change, but this highlights a key characteristic of cellular automata. Stephen Wolfram has identified a property of CAs that he terms, ‘computational irreducibility’; this basically states that there is no more efficient way of encoding the dynamics of a CA than the CA itself, so any simulation or physics of the CA that may be created will always be an approximation. And the problem is that being a complex system it isn’t usually long before the errors in the approximation become huge and the results bare little relationship to what the system will actually do. Wolfram has gone further and suggested that real physical systems, like for example the weather system are also computationally irreducible, and from this one can argue that, if his assertion is true, that our physical world is in fact computational.

Another consequence of computational irreducibility is linked to a well known problem in computation called the halting problem. The problem is that given a CA, or more generally a computational algorithm, there is no way to know if it will ever stop, other than running the CA. So you can kick off a CA in a given initial state and it may run for seconds, minutes, days or years before it reaches a state where there are no changes from iteration to iteration. This makes it almost impossible to design a CA with a required outcome in mind because firstly you cannot simulate it to know if it will meet your needs and secondly you can never know if it will do it, or at some point halt! I will pick this up again in the next section when I talk about my own efforts in this area.

In summary computational irreducibility and the halting problem mean that there is no simpler way of accurately modelling the outcome of the CA than running it and then you can never know if it will produce the results that you are anticipating.

Another characteristic of complex systems that I subscribe to is that the seeming periphery of a system is in fact vital to its evolution. For example, for our own galaxy to be as it is required the rest of the material universes to interact in the early stages of the big bang so that the patterns that emerged are as they are. This means that a serious universe simulation would require vast computer resources. The fact that any practical CA models would be of minute scale in comparison to what is needed, will both affect the outcome dramatically and mean that only small scale structures (equivalent to sub-atomic structures) could be created.

Even if we could sweep away all the issues I have raised we still could not create a universe that is as complex as ours and the reason has to do with information. To set up a standard measure of information let’s assume that we could code all of the patterns in our universe with binary digits, like those used in a computer, then we would have a very large amount of information. The fact that any simulation that we may develop exists in our universe means that it will have far less binary information in it than ours. The amount of information available will ultimately limit the complexity of the simulation to something simpler than our own universe. It may be that there is not enough information in our universe to create a simulation that includes complex and sentient patterns and hence we could not prove directly that we may be a simulation. The best we can do is proof by inference; if we can create a simulated universe similar to our own, as viewed by a simulant in that universe then we could say that, by inference, our own universe could have the same origins. It is worth noting that importance of information helps to quash and philosophical ideas that there could be an infinite hierarchy of simulated universe as there would come a point where the simulated universe does not have enough information in it to generate a universe that is complex enough to generate its own simulated universe.

So being aware that I have just spent the last couple of pages shooting myself in the foot, let us now be more positive.

Research in this area may have more consequences than just answering questions that are directly related to the premise. This research brings together several fields of study including, current physics, complex systems, computation and computer technology. Richard Feynman[16] gave a keynote speech entitled 'Simulating Physics with Computers', and in the introduction he said "*it (the study of simulating physics on a computer) has to do with learning something about the possibilities of computers, and also something about the possibilities of physics*", and this is the important point; that this research may well make important contributions to the subjects upon which it is based.

Another point to consider is that we are looking at the development of this proposition in the same way as philosophers may have looked at physics over one thousand years ago. It is extremely early days in this research and who knows what revolutionary discoveries may be made and what levels of computer resources will be available in the future.

So now with a more positive attitude I want to describe some of the results from my own research into this area.

[16] R Feynman, Simulating Physics with Computers, California Institute of Technology, May 7th 1981.

My Ideas (this section is a very early draft)

Firstly the objective of my research is to deliver pragmatic solutions. I am not an academic but have spent my working life at the highly complex end of information technology; working on very large complex projects dealing with the development of operating systems, imaging systems for various medical scanning technologies and very large business systems.

My goal in this research is to develop cellular automata based solutions that have the potential to create a universe with similar physical characteristics to our own when viewed by a simulant.

To have any hope of achieving this I have to overcome the issues I have already mentioned.

The first paradigm to dismiss is the idea that solutions, and this applies to all sciences, have to be simple. But what does 'simple' mean in this context. I do not want to start developing a CA and stop, because it is no longer a simple or beautiful solution. At the moment any solution that makes progress is a good solution.

I somehow have to limit the number of possible solutions that I need to consider and to do this I make the assumption that our universe is indeed the result of a CA based computation. If this is the case then our universe is the only working example of such a universe that I know of, and it is a successful one as I exist in it. This is a sort of 'weak anthropic' argument. Given this assumption it would seem sensible to look for solutions that generated similar fundamental characteristics.

So to help me develop a working CA I decided that my design would implicitly include the creation of the fundamental physical characteristics that we see in our universe. This means that I don't have to try vast numbers of CAs in the hope that at some point such characteristics will emerge purely from the complex dynamics.

The characteristics that I have chosen to 'instantiate' into my design are:

- Space
- Relativistic time.
- Matter.
- Energy.
- Action at a distance (forces).
- Some relativistic characteristics.
- Some quantum mechanical characteristics.

I have developed several models that have, in one way or another, been major failures, however as I have refined the models I have reached a point where I can glimpsed the potential to encompasses all of these characteristics and this is the model that I will describe.

The model that I will describe is a two dimensional model (like a chequer board) but this is for clarity only and I am aware that a working model would need to have at least 3, if not more dimensions.

The chequer board is made up of a vast number of square cells, so vast that the entire simulated universe will reside in it. Being a square cellular structure each cell has eight nearest neighbours. The first thing to point out is that such a square cellular arrangement is highly inadequate. If one thinks of a simulant existing in this CA then they would only observe 8 distinct directions of movement. We on the other hand can 'divide' space into a seemingly infinite number of 'directions', think of a protractor with its 360 degrees or divide that down in seconds of an arc and even smaller. This means that any realistic model would have cells that are regular polygons with a very large number of sides and hence neighbours. It is worth noting that if we ever find that there is a quantum limit to space in this regard then it would support the idea of a CA based universe.

Now you may be asking yourself what happens when the cells at the edge of the board are calculated because they are missing some neighbours and this is a good question. My answer is that in my model opposite edges are joined to make a toroid (or donut shape in two dimensions) so that there are no edges. This becomes more problematic when you try to join the edges of a three dimensional cube, although an area of mathematics called topology has a solution, but for this explanation let's ignore the outer edges of the universe.

This next change is a fundamental difference to the kind of CAs I have been talking about. For the time being to my chequer board we must now add the chequers. So any cell in the CA can have associated with it an object (a chequer). This object will remain a little vague for the moment but I have called it a Simticle (SIMulated ParTICLE). The Simticle is what has a state (for example, black or white). A cell of the CA can have more than one Simticle and likewise a Simticle can be related to more than one cell. The state of a cell is defined by the number and type of Simticles that are associated with it.

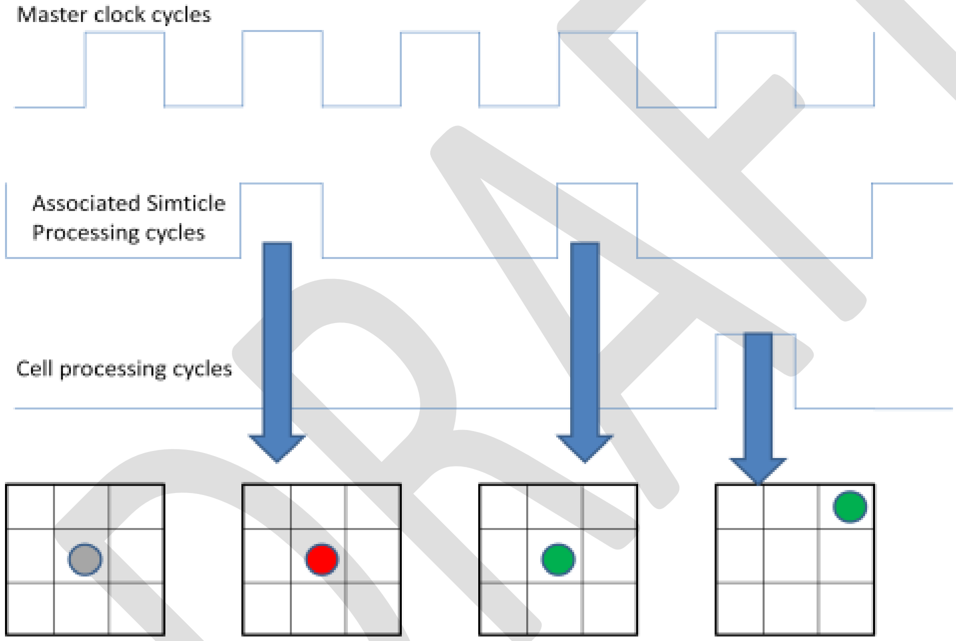
As with many CAs this chequer board and chequers is duplicated so that the newly calculated cells and chequers appear in the board that represents the entire states of the universe after a round of calculation.

Now the Simticle and the cell to which it is associated have their own set of rules that define how the cell's or Simticle's state will change when either is processed and the character of these rules will be discussed later.

This brings us to the question as how these cells and Simticles process. Well consider that each cell and Simticle is attached to the same clock, the clock ticks at a regular interval that I call the master processing frequency. Each cell and Simticle updates itself on an integer multiple of this master cycle and the number of cycles until it processes is dependent upon the state of the cell of Simticle. This means that on each master processing cycle some cells and some Simticles will be updated whilst others remain unchanged.

I don't want to get to far ahead of myself here but we will see that the cell is responsible for moving its associated Simticles to neighbouring cells, whereas the Simticle rules may cause it to generate other Simticles. It will also be seen that, for example a Simticle may change its state in a processing cycle but the cell does not process.

Below is a visual representation of this feature. The Simticle shown processes every two ticks of the master clock and hence its state and colour will change. The cell it is associated with processes every 5 ticks of the master clock. As you can see the chequer will change colour twice before it is moved by the cell. This is simplified as part of the processing for a cell or Simticle will be to calculate the next cycle on which it will process and this can vary each time it processes.



We will take a 'time out' at this point and look at what these design characteristics may mean to an evolving universe. To do this we need to ask ourselves a question. "What would a universe look like to a simulant that exists within it"?

To a Simulant the Simticles are 'matter' and they exist in relationship to each other through the cells on the CA, therefore to the Simulant the regular array of cells is space. For a simulant there is no 'physicality' to space, it is just a way of referencing one bit of matter[17] to another. In this model the idea of 'relativistic curved space' is just a model that the Simulant may develop, but to the Simulator (that is me), such a concept has no meaning in the model. From the viewpoint of the Simulant, a cell in the CA is dimensionless as there is nothing smaller against which it can be measured. In essence the cell is a 'singularity' and

[17] Mach view of space. Check

the Simulant could indeed observe an infinitely small space with a very large mass or energy (depending upon the state of the Simticle associated with the cell). Time and space are not related in a relativistic way however it may be that the CA rules mean that the simulant would create a theory in which this is the case.

A measure of time for the simulant requires a change of state and all measures of time are relative to a standard 'time' that itself is again defined by a pattern that changes state. If the Simulator decides to stop the program then there is no change in the universe and 'time stops' for the simulant! If the Simulator then restarts the program then there is no discontinuity for the simulant. 'Time' itself has no 'physicality'.

In my model nothing can happen more quickly than the frequency of the master clock frequency. This gives a maximum speed to velocity and changes of state similar to our observation of the constancy of the speed of light.

Simticles have a state and there are specific sets of states that will identify patterns of Simticles as being representative of different types of matter; so patterns of Simticles will become the quarks, protons, electrons etc of the Simulants universe. It is also likely that certain types of Simticles will represent forces that emanate from types of Simticles that are classified as matter. The idea of 'forces' in the model will be addressed at a later point in this essay.

Because a cell can have associated to it more than one Simticle it means that different types of particle can directly interact at a point in space (as mentioned before a point being a singularity).

Because a Simticle can be referenced by more than one cell it means that the Simulant will observe the quantum mechanical characteristic known as 'entanglement'. I won't go into entanglement in this essay but suffice to say that this observed characteristic of our universe is one of those completely non intuitive characteristics that reside in quantum mechanics. The basic result of entangled particles is that if you interact with one of them then the other 'instantaneously' changes its state, seemingly breaking the laws of relativity and the speed of light!

However hard she tries our Simulant cannot 'see' the structure within a Simticle as there is no pattern associated with it; however to the Simulator a Simticle is just some kind of data object. Once again this reflects ideas in quantum mechanics that there is a scale, called the 'Plank[18] scale', beyond which structure and known physics breaks down.

Because the rate at which a Simticle and cell change state is dependent upon their states there is a possibility of varying the rates such that to a Simulant observing another pattern, the rate at which the pattern changes state can change relative to the Simulant. The details

[18] After the great physicist Max Plank.

of this process will be discussed later but it enables ‘time’ to become relativistic to the Simulant, however to the Simulator there is no such relativistic component to the simulation.

Any Simulant is likely to be one of the most complex patterns in their universe and hence be comprised of vast numbers of interacting Simticles. Any object that the Simulant interacts with is also likely to have a vast number of Simticles and hence in is natural for measurements to be somehow statistically smeared across many iterations of the program. Therefore it should be no surprise that the Simulant would experience a universe that is in some ways quantum mechanical and statistical in its nature.

Remember that in my model there are in fact two CAs and hence there are two parallel universes, with from the Simulators perspective one master clock cycle between their states. To the simulant there is no concept of the master clock cycle and time will be continuous. However I believe the fact that there is a fixed instance of the simulant and one that is being updated is vital to an understanding of consciousness. I believe this system enables a sentient being to be self aware (that is the old instance of the Simulant) and that consciousness may be an emergent property that is generated by the transition from one CA state to another.

Although it may not be apparent to the Simulant there is a discrete level of processing at the smallest scales, that being the cell and the Simticle and within the model design there are no true ‘infinities’ and this accords with some of the constraints of the ‘Finite Nature’ hypothesis.

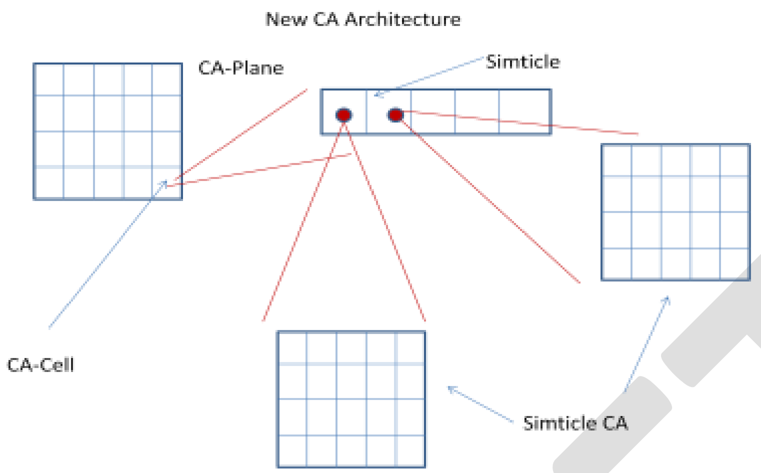
Before I move on I want to say that I get very excited about these ideas (sad in know). In the few paragraphs above I have managed to make comprehensible some of the incomprehensible constructs within physics and our observable universe. Constructs such as entanglement, matter, relativity and singularity, only exist within the abstract mathematical formulations of physics, whereas a CA based approach creates a universe that is more comprehensible to the human mind. The other advantage of such models is that these ‘physical characteristics’ come for free and do not depend upon the specific dynamics of the model. In essence this leaves the dynamics of the model to generate complex patterns and not focus on the emergence of fundamental physical characteristics.

So far there are key physical characteristics in my ‘hit list’ that I have not touched upon and to do so I need to develop my model a little further.

I have already mentioned that the cell is a reference for one or more Simticles. To practically implement this idea in a CA I want you to think of each cell as actually a one dimensional CA, that is each cell is in fact a ribbon of cells with each of these cells being able to be associated with only one Simticle. Another way of viewing this is that each square on the chequer board has a set of little shelves in which you can place one chequer on each shelf.

Now it gets a bit more difficult. The Simticle that I have refrained from describing is itself a two dimensional CA. So each chequer is in fact a chequer board!

Below is a diagrammatic representation of the components of the CA as described.



Because this model has a CA within a CA within a CA I call it a' nested CA architecture'.

WHERE DO PARTICLES COME FROM?

The state of the Simticle is defined by the state of its CA. Fortunately the CA of the Simticle is very simple. Firstly the Simticle CA has a limited number of cells (the board has limited number of squares). Secondly the cells of the Simticles CA can have one of two states, let's call them 'M' and '0'. As I have mentioned the state of the Simticle CA defines the state of the Simticle. From the Simulant's perspective let's concentrate on how three physical characteristics of matter are supported, those being mass, direction of motion and speed.

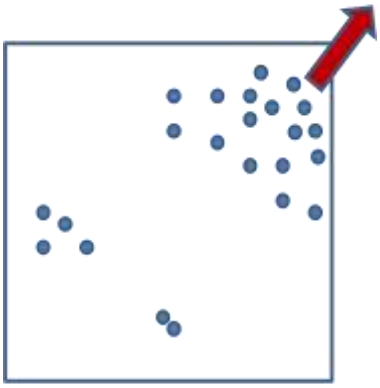
One of the rules for the Simticle CA is that all 'M' states want to group together. 'M' states are never destroyed but they can move to a '0' neighbour to maximise the number of M neighbouring states.

The number of M states is a measure of the Simticles 'mass'; the more M states a Simticle has the more massive it is.

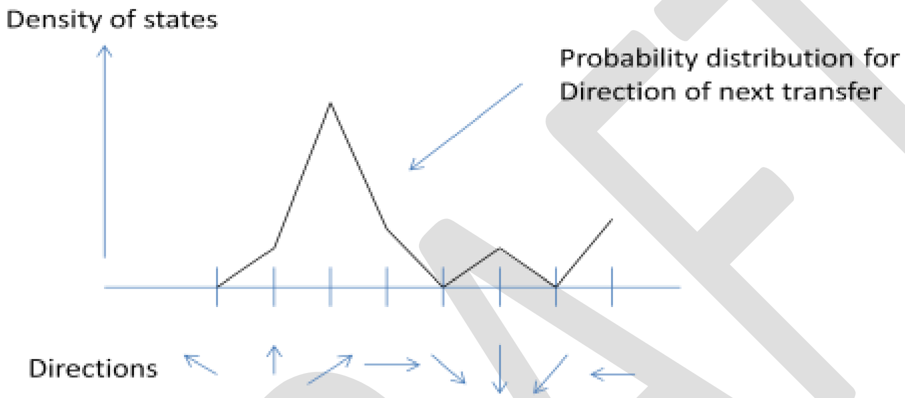
The distribution of the M states in a Simticle is related to its probability of moving in that direction when the Simticle is processed.

This idea has the ability to enable some matter to have a mass and also inertia, in other words a bias towards movement in its current direction.

For example the following distribution of M states in a Simticle CA:



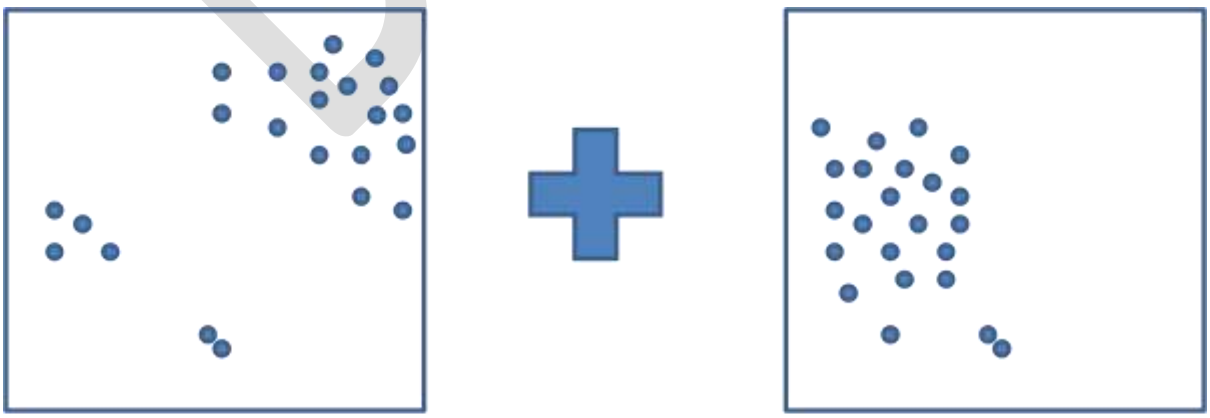
This state may lead to the following probability distribution for direction of transfer at the next processing cycle.



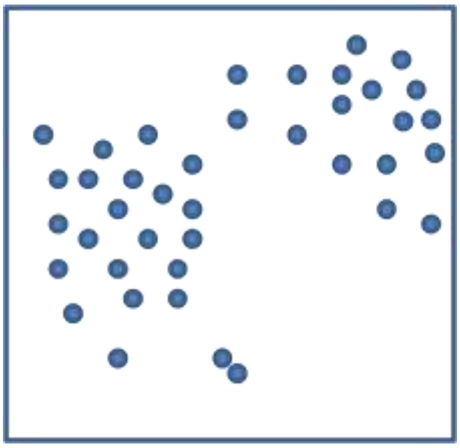
The rule for grouping states in the Simticle CA runs on every master processing cycle, so this action occurs at the speed of light and with each cycle the small groups of states are attracted to the largest group.

If two Simticles occupy the same cell in space then the states are superimposed into one Simticle and this gives a new distribution to the likelihoods of each direction.

For example



Would lead to a new Simticle with the following distribution of M states:



And this new Simticle will have a different direction of transfer that is the dependent upon its distribution. It should be also noted that these patterns will group into a tighter pattern and hence the distribution of directions of motion will change over time until the states reach a steady state.

If we consider a three dimensional CA then these states could be construed as rotating and this could give rise to a characteristic that a Simulant would perceive as angular momentum or spin.

Now these Simticles that have M states are termed M-Sims and the rules that apply to them both within their own CA and with neighbouring cells of the universe mean that Simulants see them as patterns of matter.

There are two special M-Sim patterns that I want to quickly discuss and those are at the limit, that is an M-Sim with one M-State and a M-Sim for whom every cell within its CA has a M-state.

From what I have previously said an M-Sim with one M-State will run the grouping rule but of course it has no other M-States to find so it would move randomly from cell to cell trying to find other M-states. This means that the M-Sim is the least massive particle possible and its direction of motion will be completely dominated by the influence of its neighbouring cells in the universe. Therefore it would be construed has having zero or minimal inertia.

An M-Sim with a full complement of M-states is the most massive fundamental particle and has no preferred direction. However this M-Sim is very unstable because when it moves to a neighbouring cell it will merge with all the Simticles in that cell. Now as this M-Sim is ‘Full-up’ it will generate new Simticles that distribute all of the states associated with the merging Simticles. This means that this is a very ‘short’ lived but massive particle. In general in our universe we observe that the more massive fundamental particles are unstable and short lived.

FORCES AND INTERACTIONS

There is another type of Simticle that has different internal states. These Simticles, called F-Sims have two states called ‘E’ and ‘0’. Now F-Sims do not have a grouping rule so when they are created the distribution of E-states within the F-Sim’s CA remains constant. The F-Sims do not interact with other F-Sims so that in the universe their direction of motion is fully defined by their inertia and not by external influences.

F-Sims are created in two ways, either as a by-product of an interaction of two or more M-Sims or they are emitted by an M-Sim, depending upon its state.

F-Sims ‘carry’ the influence of the M-Sims from which they are generated and as such the neighbouring cell to which an M-Sim transfers depends upon the cumulative state of the F-Sims in the neighbouring cells. From this you can probably realise that F-Sims are seen by the Simulant as carriers of ‘force’. Now it may be the case that there is a CA out there from which the observed characteristic of ‘action at a distance’ emerges but it is so critical for the formation of pattern that I am trying to instantiate the seeds of this characteristic into the design of my CA. At present I have to say that I am ‘uncomfortable’ with the way in which I approach this aspect of the universe. This is such an important issue that I would like to make a small diversion from our current course.

There are several reasons why force, and in particular gravity, is a problem in universe simulations and in physics as it is today.

There are particular instances where I feel that physics is telling us something fundamental about the structure of our universe and the model of gravity given by general relativity is one of them. Physics has so far failed to integrate gravity with any other theories of other forces and it remains incompatible with many fundamental aspects of quantum mechanics. The reason is that gravity may be viewed as the result of warping space time and this warping causes matter to follow the gradient of the warped space-time. Our models of other forces are very different and are based upon a value or magnitude of that force at points in space. The variation of these ‘point like’ magnitudes may be encompassed in theories that use ‘force fields’ or force carrying particles. The idea of a gravitational field is a warping of space-time and that of a gravitational force carrying particle (the graviton) is the point of interaction with one of these travelling waves of space-time.

This indicates to me that gravity must be of a fundamentally different character to other forces and yet I find it difficult enough to identify possible ways of instantiating other forces into CA models, let alone gravity! In fact I believe that it may be that gravity is a strong argument against a computational model of the universe as described by CAs. For the time being I try to avoid gravity in my models and in fact this isn’t as big a problem as you would expect, for we will see in the ‘Big Bang’ section that in my model, gravity is not ‘turned on’ until a stage in the big bang that is beyond the point for which I can analyse any such models.

So for the time being there is no gravitational F-Sim (or G-Sim), however the other interactions that are viewed by a Simulant as the strong force and the electroweak force must be accommodated.

The problem with forces at the smallest scales is that the influence is the same for all points in space that are an equal distance from the source and somehow this characteristic has to be evident from the CA model.

Another big problem for these sorts of model are to understand how the electromagnetic force can either emerge or by instantiated. It is relativistic as the magnetic component varies with the relative velocity between the charge and observer (not sure observer is correct)

$E=MC^2$!

The big Bang

Consciousness

How can we prove it

These ideas introduce the concepts of inertia, mass and the conservation of mass into the CA universe.

The Simticles I have been describing so far are what the Simulant would see as matter but there is another type of Simticle that has the same structure but will be conceived by the

My latest CA

Note from ..\..\..\Research notebook\Linked notes to mindmap\V2 Model Outline.docx

What was wrong with the earlier versions.

Research varies from highly mathematical works on the number of possible CA solutions that can create a universe to more anecdotal analysis comparing the characteristics of CAs with the behaviour of quantum mechanical based systems. However to my knowledge no one has put forward a strategy for developing a CA that could create a complex universe or the outline of the required CA architecture. This is where my interests lie and I will discuss my own research in the next section.

I spent my working life in industry and had to deliver solutions and that is the focus of my research to develop a CA that has the potential to generate a universe that has similar levels of stability, diversity and complexity as our own and the potential to create complex a sentient patterns.

This is a tall order; in fact, even if my proposition is true my objective is likely to be impossible. So let me start with the negative stuff and tell you why I am on a beating to nothing.

The only way to prove the proposition is by inference. If we can use computational means to generate a universe that has similarities to our own, when, and this is very important, viewed from within, then we can infer that our universe could also be generated by such a process.

Vast number of possible solutions

Philosophical

SUMMARY