Economic Observer Theory

Natural emergence, the computational observer, and the origins of symbolic value

Steph Macurdy, Wolfram Blockchain Labs

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Causal Invariance in Blockchain Systems

Distributed computing in adversarial or “Byzantine” environments relies on a single, critical parameter: a trusted notion of time. Without a global clock, each node can arrange incoming transactions differently, resulting in conflicting states rather than a unified ledger. Early consensus protocols like Bitcoin tackled this “clock problem” by embedding time directly into the chain of blocks—what Satoshi Nakamoto originally called a “timechain.” This approach, however, couples time with state updates, meaning that every new block includes both the marker for a moment in time and the corresponding state changes. While effective for security, this bundling inherently limits throughput and stalls global progress until nodes agree on each successive block.

Subsequent innovations in Proof of Stake (PoS) consensus, as seen in Tendermint, sped up block times by reducing the number of validators and improving coordination. Sharding theoretically multiplied throughput further by creating multiple “local clocks” that operate in parallel, though inter-shard synchronization still introduces significant latency. These improvements hinge on the same core concept: transactions remain locked behind block production, because the system’s sense of time is inseparable from updates to state.

Solana’s Proof of History (PoH) mechanism marks a turning point by producing a granular, verifiable clock independent of—and continuous alongside—state updates. Instead of waiting on block production to confirm the passage of time, PoH weaves timestamps into each transaction, allowing all nodes to order events the same way without lengthy synchronization rounds. As with modern telecommunications’ transition from code division to time division multiple access, blockchain can scale more effectively once it is freed from bundling time and state into single “blocks.”

With this separation in place, block producers and validators can process transactions asynchronously, significantly boosting throughput and slashing finality times. The result moves permissionless networks closer to the performance of centralized systems like Google’s Spanner while preserving decentralized security models. Most importantly, it reframes how we conceive of transaction ordering. Once time becomes a verifiable stream rather than a discrete event, we open the door to far more flexible and efficient arrangements of state changes.

Yet, even as we acknowledge the pivotal role of time, there may be a deeper principle at work—one that does not rely on temporal markers at all. In this essay, we will explore **causal invariance**, a more powerful sense of ordering that depends not on clocks or timestamps, but on the intrinsic relationships between events themselves. This shift moves us beyond merely replacing slower clocks with faster ones and toward an entirely new way to conceptualize consensus, security, and scalability.

The Wolfram Physics Training Course

Written by Justice Evans-Hunter, Wolfram Institute

An introduction to and conceptually focused walkthrough of the Wolfram Model framework, serving as a gateway to its materials and resources spread across the internet, for beginners, enthusiasts, and experts alike.

Section 1 : Foundations

Step 1 : Prerequisites

Before studying the work of Stephan Wolfram, The Wolfram Physics Project, and the work of most projects that come out of the Wolfram Institute, it helps to have a little background in some fields of study, and have some concepts under your belt. If you don't know what these are, below are some helpful links to videos for easy consumption along with a bite sized definition :

Complex Systems
A basic Introduction to Complex Systems, which introduces networks and how they get used to model systems.

Isomorphism & Graph Isomorphism
Equivalence Relations : what an "=" sign means and how equivalences are proved.

Transformations
Transformation is just an important concept in general. Needs a very good video that explains it in a way that is both general, and the way we should have learned it in school (that rotation, scale, affine, translation, matrix are all transformations, and that *preservation* of transformations prove Invariance (physical laws) and visa versa.

Invariance
Closely related to Isomorphisms : Equivalence relations where (mathematical) objects do not change under transformation.

Turing Machines
What they are and how one proves that something is equivalent to a turing machine

Turing Universality
the idea that something is capable of computing any computable function

Halting Problem
Proof that one can not construct a Universal Truth Machine.

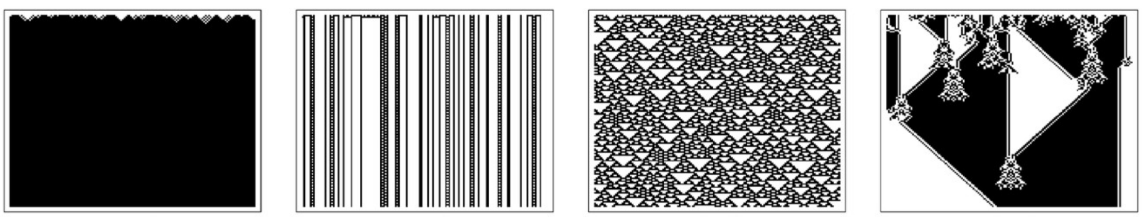
[Godel Incompleteness]
Explains the importance of Consistency, Decidability, and completeness, and the history of Hilberts Program vs Godel's Program and how Hilberts program [A complete, decidable and consistent theory of mathematic] was shown to be false.

Step 2 : New Kind of Science

A New Kind of Science, a book written by Stephen Wolfram in the 1980's and published in 2002 sets the foundations of the Wolfram Model. The book is split into three distinct arcs:

The first arc is a set of experiments where wolfram exhaustively runs classes of rules, and makes observations about their behaviour. He observers three key properties about these systems:

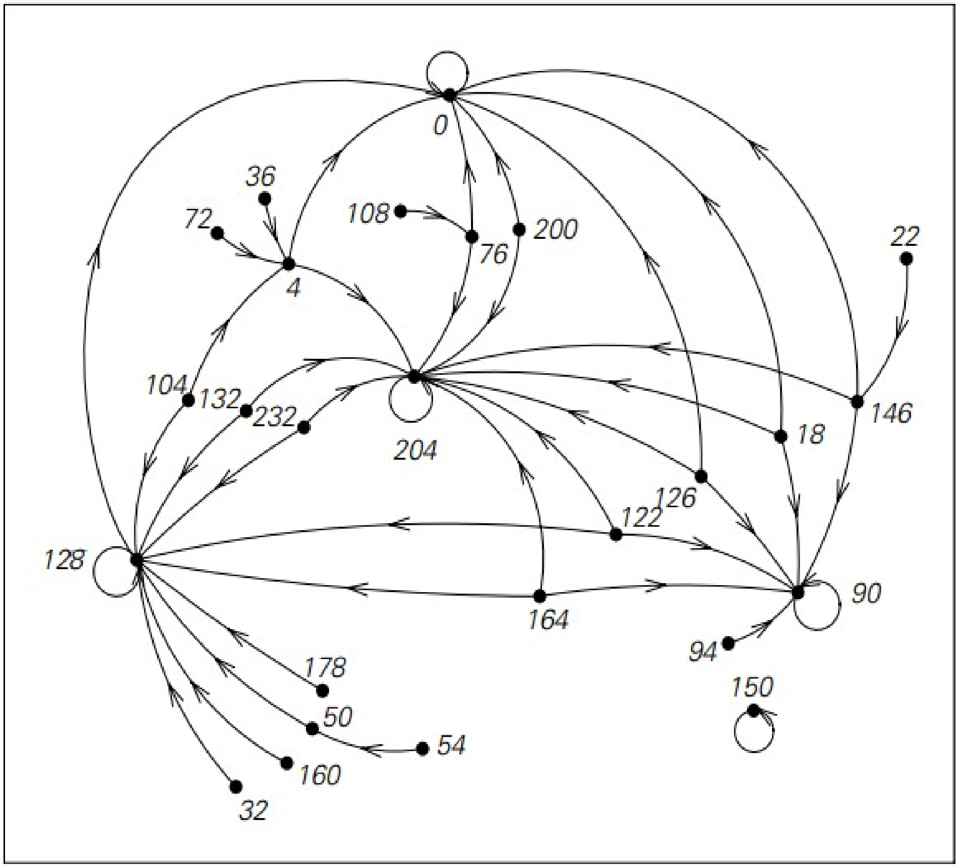
1. That many simple rules can perform arbitrarily complicated behaviour, specifically behaviour that can not be described by mathematical equations.
2. That rules typically fall into 4 classes of behaviour : Homogenous, Patterned, Random and Complex.
3. That rules can emulate the behaviour of other rules.



class 1 class 2 class 3 class 4

The second arc of the book is spent making connections between computational rules and how they show up in nature, in system analysis and in fundamental physics.

The third and final arc of the book is spent formalizing the observations made in these experiments, by first showing the Elementary Cellular Automata Rule Class emulating each other under different initial conditions. Wolfram and Cook then prove the universality of Rule 110, strongly implying that any rule within this rule class, when given the right initial conditions can lead to an emulation of Rule 110, therefore proves the entire rule class as Turing Universal.



In the Final Chapter, Wolfram poses this as strong evidence for **The Principle of Computational Equivalence** : That practically any system that follows rules, are computationally equivalent to a Turing universal machine, capable of computing any computable function.

"The answer is the Principle of Computational Equivalence, which states that, in effect, most rules will be equivalent in their computational capabilities—and in particular they will be capable of universal computation, so that any given rule can always "run a program" that will make it emulate any other rule."

Excerpt from : [The Concept of the Ruliad]() - Stephen Wolfram

The Principle of Computational Equivalence then also gives explanatory power to **The Phenomenon of Computational Irreducibility**, and explains why many rules fail to be described by mathematical equations : Trying to predict or condense what a system following rules will do, is as hard as trying to solve the halting problem, and therefor can not construct a universal truth machine that gives us the answer. Operationally, a system can under different initial conditions emulate arbitrarily complicated rules and therefore to describe what they do, is nothing short of "they do everything."

In the same vein, **Computational Reducibility** also takes form: Since all systems are capable of computing any computable function under Computational Equivalence, then, there is also an infinite number of different patterns and regularities that these systems have access to. This feature forms the basis for doing science and mathematics.

These three ideas are core to understanding the Wolfram Model. The star of the show is the Principle of Computational Equivalence but all three ideas are core to understanding the Wolfram Model, and they will play major roles in every aspect of it, from the Ruliad, to Observer Theory, Multi-Computation and Ruliology. I personally recommend watching the 16 part lecture series Wolfram made on the book, because he explains things with his point of view 20 years after its release, in the context of the 2020 Physics Model.

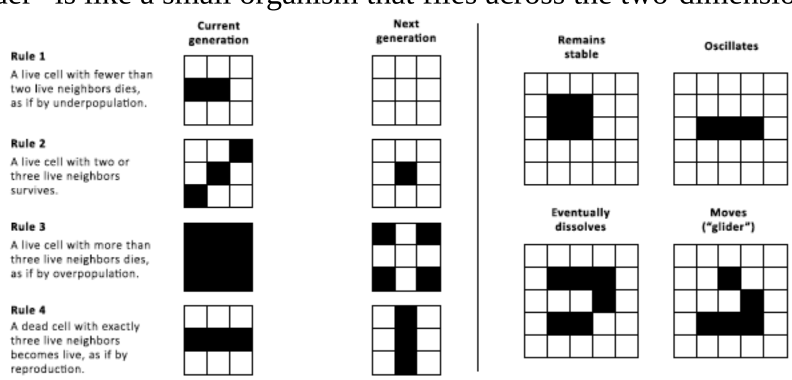
[What We've Learned from NKS Chapter 1: The Foundations of a New Kind of Science]

Summary—A New Kind of Science

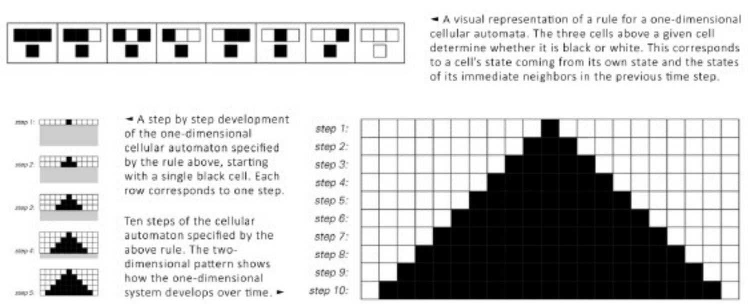
Wolfram's core research interest is the origin of complexity in the world. The central result of Wolfram's work pertains to complexity in discrete systems. How complex can discrete systems be and where does that complexity come from? Through a careful research program, Wolfram isolates the complexity that arises in discrete systems and meticulously investigates its origin. In the process, he starts from the simplest systems that can be easily understood, makes a number of key observations, and then methodically generalizes through a search of a very large number of other discrete systems. The result is a striking discovery about the origin of complexity in discrete systems. The following explanation begins from cellular automata, the simplest easily understood discrete systems, and then generalizes to reach Wolfram's central discovery.

Cellular Automata

Cellular automata are a particular type of simple, rule-based system. They are typically made of squares and studied in one dimension (e.g., a line of squares) or two dimensions (e.g., a grid of squares). They can be other shapes as well, even irregular ones. What matters is that there are a finite number of them; these are the "cells" in "cellular" automata. Each cell then has a "state," drawn from a finite list of states (e.g., white/black, filled/unfilled). The system then changes, step by step, in accordance with a finite set of rules. These rules are usually very simple and depend only on a cell's and its neighbor's state; hence "automata." Wolfram's core research interest is the origin of complexity in the world. Cellular automata were first invented by Stanislaw Ulam and John von Neumann in the 1940s. They became famous through the work of John Conway, who in 1970 published a description of the "Game of Life," a two-dimensional cellular automaton that seemed to have features that intimated physical and biological structures. Here are the rules of the cellular automaton in the Game of Life, as well as an example of a system evolving according to its rules. Note that the "glider" is like a small organism that flies across the two-dimensional grid:

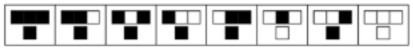


The Game of Life was later shown to be highly fruitful. In 1970, a team led by Bill Gosper found a repeating pattern in the Game of Life that would produce an endless stream of gliders. In 1982, Conway proved, using glider guns and other structures, that the Game of Life is “Turing complete,” meaning that one can implement a computer in it. It is now possible to find amazing demonstrations online of what is possible in the Game of Life. The flexibility and expressiveness of systems like the Game of Life, as well as the simplicity of their rules, have led many to conjecture that the universe is a cellular automaton, as the inventor of the first programmable computer, Konrad Zuse, did in 1967. The power and potential relation to physics and biology were, as a result, on their way to being widely recognized in 1981, when Stephen Wolfram first took an interest. Wolfram’s concern, however, was not with cellular automata as such. Rather, Wolfram’s research interest pertained the origin of complexity in nature, for instance in biology, and how that complexity is consistent with the universal tendency towards disorder posited by the Second Law of Thermodynamics. Cellular automata were, and are, a perfect example of simple systems in which to study complexity. In order to study how complexity arises in simple systems, Wolfram sought to find the simplest systems to work with. Conway’s Game of Life was two-dimensional and also required a somewhat complex starting condition to yield any sort of complex result. As a result, Wolfram decided to work instead with one-dimensional cellular automata (i.e., a line of squares), with only two conditions (i.e., 5 Institute Report 6 white/black), with rules that referred only to the state of the cell and its immediate neighbors, starting with an initial condition of all cells white except one. This was meant to eliminate the possibility that any observed complexity in such systems could arise from complexity in the rules or initial conditions. Here is an example of one of the cellular automata that Wolfram studied. As stated, the cellular automaton itself is a row of squares. Its initial condition is a single black square. The rules for its evolution are shown here, where the state of a cell at a given time (apart from the initial condition) is a deterministic result of the state of the cell and its two immediate neighbors at the immediately preceding time. The behavior of the cellular automaton itself can then be displayed on a two-dimensional grid, as displayed, with the arrow of time going down:



Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 24.

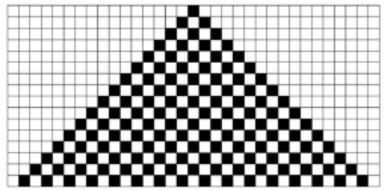
The cellular automaton displayed just above exhibits very simple behavior. From the perspective of each time-step, it is simply a black line that grows in both directions; from a God’s-eye, the pattern is a black triangle. Wolfram found other simple patterns, also arising from rules of similar complexity. These rules can be considered to be repeating or repetitive:



◄ A different cellular automaton rule. This one specifies that a cell is white if the cell directly above it is white or if all three cells directly above it are white. This corresponds to it or it and both of its neighbors having been white on the previous time step.

Sixteen steps of the cellular automaton specified by the above rule, again starting from a single black cell. This pattern, like the previous one, is simple and repetitive.

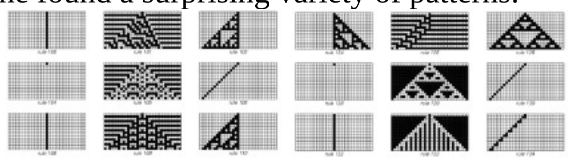
Wolfram named the cellular automata by converting their rules into base 2. On that scheme, the above image is Rule 254. This one to the right is Rule 250. ►



Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 25.

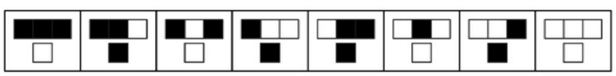
Not all patterns are equally repetitive, however. Searching through the 256 patterns of this type, i.e., one-dimensional cellular automata with two states whose rules reference only the previous states of a cell and its neighbors, he found a surprising variety of patterns:

A variety of different one-dimensional cellular automata, each started from a single black cell. ►



Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 54.

Apart from repetitive patterns, Wolfram also found nested patterns, which are also repetitive in some sense, but which clearly differ with respect to our intuitive notion of complexity. This is the nesting produced by Rule 90:

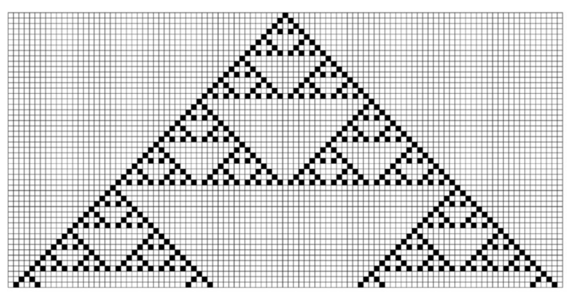


◄ Another simple cellular automaton rule. This rule says that a cell should be black if exactly one of its neighbors was black on the previous step, and otherwise white.

Fifty steps of the cellular automaton specified by the above rule, again starting from a single black cell. The result is a nested pattern.

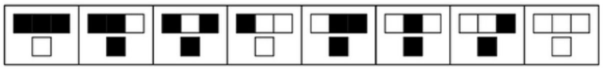
Nested patterns are characterized by parts being embedded in similar parts.

This rule is called Rule 90. ►



Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 25.

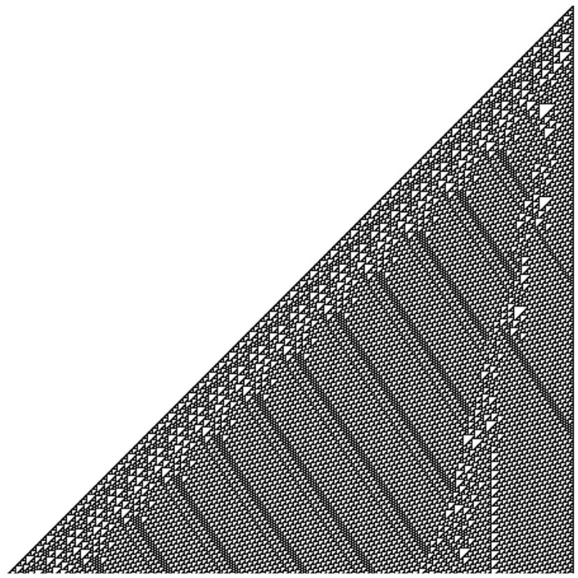
A third type of pattern also shows up, which contain neither repetition nor nesting, but instead a certain type of randomness. For instance, Rule 30 shows recognizable patterns going down the left, but on the right side shows a local randomness that no one, to date, has been able to find regularities in. Rule 30 appears to be so persistently random that Wolfram actually uses its central column of cells to generate random numbers in his mathematics software Mathematica — a method that ends up being more random than many random number generators. 7 Institute Report There is a fourth type of pattern as well, which ends up being the most consequential. This one is neither random nor involves nesting, but instead is irregular, with a stable background pattern and visible structures which move across it and interact in surprising ways. Rule 110 exhibits this sort of pattern, with the visible structures interacting erratically for about 2,780 steps before the pattern stabilizes.



◄ An important cellular automaton, yet still extremely simple. It says that a cell should be white if it and its neighbors were all the same color on the previous step, or if just its leftmost neighbor was black.

This rule produces a pattern only to the left, yielding a right triangle rather than a pyramid. It has regular bands that head of to the left, a recognizably regular pattern in the background, and irregular elements that seem to move across the background pattern..

This is called Rule 110. ►



Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, pp. 32-33.

From the investigation of these simple cellular automata, it is possible to see that these four forms — repetitive, nested, random, and irregular — arise in simple cellular automata with simple initial conditions. At least three of these forms deserve to be called “complex,” namely, the nested, random, and irregular forms. The fact that the rules and initial conditions are so simple rules out the possibility that the complexity arises from the complexity of the rules or the complexity of the initial conditions. The next question is whether that complexity may nevertheless vary with the complexity of the rules or initial conditions. Wolfram investigates more complex cellular automata, including ones with three or more states, ones with a continuous range of states, ones with rules that rely on next-neighbors and other cells, ones in two and three dimensions, and with hexagonal and other shapes of cells. He also examines different initial conditions, including complex ones and ones generated randomly. He finds that in all cases, adding complexity or randomness to the rules or initial conditions does not produce greater complexity or complexity of a recognizably different type.

Other Discrete Systems

A natural next question is whether the foregoing applies to cellular automata in particular, or if the mechanism of complexity that Wolfram has isolated also shows up in other simple systems. Wolfram finds that the phenomenon generalizes. He looks at mobile automata, which are cellular automata that update only one cell at a time, substitution systems, where blocks are replaced with other blocks at each time-step, Turing machines, symbolic systems, systems based on constraints, and other systems as well. He even examines systems that pertain to the discrete representation of numbers, such as the decimal expansions of real numbers in binary.

In almost all cases, Wolfram finds that the same types of patterns arise: repetitive, nested, random, and irregular. Some systems produce irregular patterns more or less frequently. Some systems, only produce repetitive and nested patterns. Some, such as the decimal expansions of numbers, repetitive, nested, and random patterns, but not irregular ones like Rule 110. Further, Wolfram again found that in no cases was there behavior that seems more complex or that indicates a further type of complexity.

The foregoing observations yield Wolfram's central discovery, which is that complexity arises in discrete systems in a manner unrelated to complexity in the rules or initial conditions of those systems. There are discrete systems that do not yield the relevant complexity, and many discrete system types yield it only rarely. There is nevertheless a de novo origin of complexity that had never been previously isolated or thoroughly explored. Wolfram's central discovery is that there is complexity intrinsic to discrete systems.

This sample of discrete systems with simple rules was examined by Wolfram using a computer. The code for reproducing the experiments is publicly available and there are, to date, no indications of error or exception. Wolfram was also unable to find an efficient method for searching for patterns of interest, so he examined the different systems by brute force, investigating a truly staggering number of possibilities. This reduces the likelihood of any selection effects. Many discrete systems also can implement one another, which reduces the likelihood that the systems Wolfram investigated are somehow unique or distinctive.

Given the evidence marshaled, it is reasonable to conclude that Wolfram's central result has been established. The greatest doubt arises from the fact that Wolfram assumes, quite reasonably, that the classification of types of complexity that he finds intuitive will also be broadly recognized by other people. For further results and applications arising from the central finding, it is in fact necessary only that nested, random, and irregular be distinguished from each other and from other patterns. From a scientific perspective, it is enough to do an empirical study of human classification tendencies, showing that people in fact reliably enough identify and distinguish the relevant types of pattern.

Step 3 : The Ruliad

The work of *A New Kind of Science* and the Principle of Computational Equivalence tells us that systems can emulate each other's behavior and, therefore, all perform computations as sophisticated as any other system. As sophisticated as a Turing universal machine. In some sense, we can state colloquially that all systems ***are*** just a single Turing machine, and that the boundaries we have set for any particular system is an illusion.

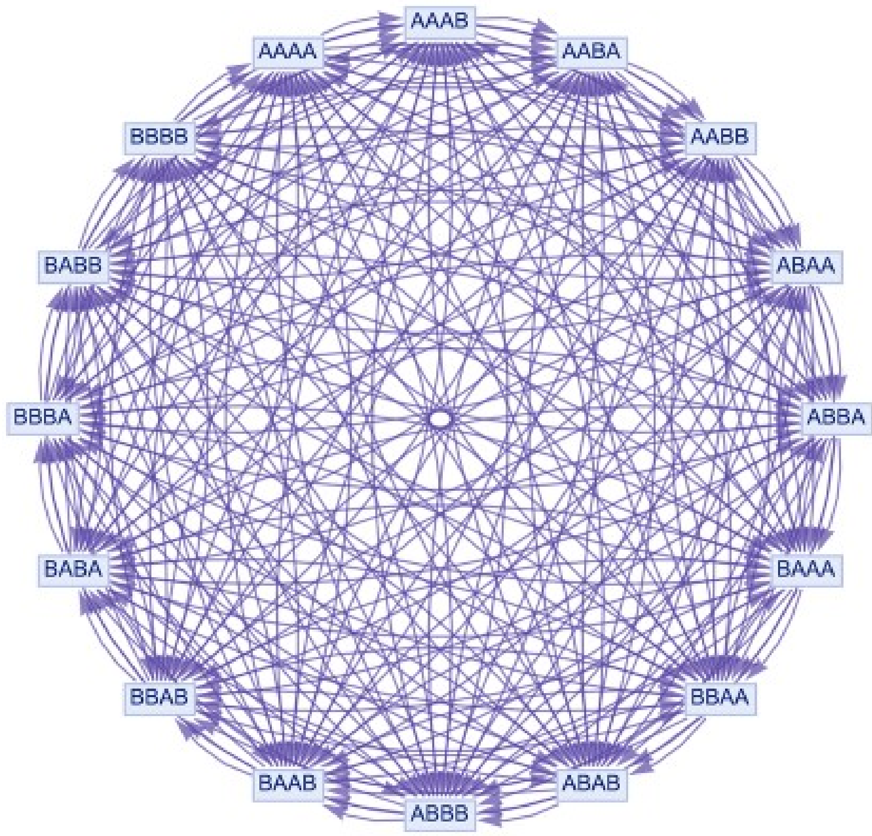
To dig deeper into this, we can ask a logical question: If a single rule can compute the universe, and all rules are computationally equivalent to each other, then does it actually matter what rule the universe is running on? Why would it be running on this rule rather than any other rule?

The logical conclusion is that the universe isn't just running a single rule—it is running all possible rules. What exists is not a collection of separate systems or particular rules; rather, what actually exists is this abstract Turing Machine space of all possible rules.

Imagine we successfully identify a rule that describes everything about our universe. Then the obvious next question will be: "Why this rule, and not another?" Well, how about if actually the universe in effect just runs every possible rule? What would this mean? It means that in a sense the "full story" of the universe is just the ruliad.

Excerpt from : The Concept of the Ruliad - Stephen Wolfram

So when we look at any system, we aren't really looking at the system itself—we are looking at something deeper. We are looking at this *Ruliad* object: a slice of it, a sample of it, a limited



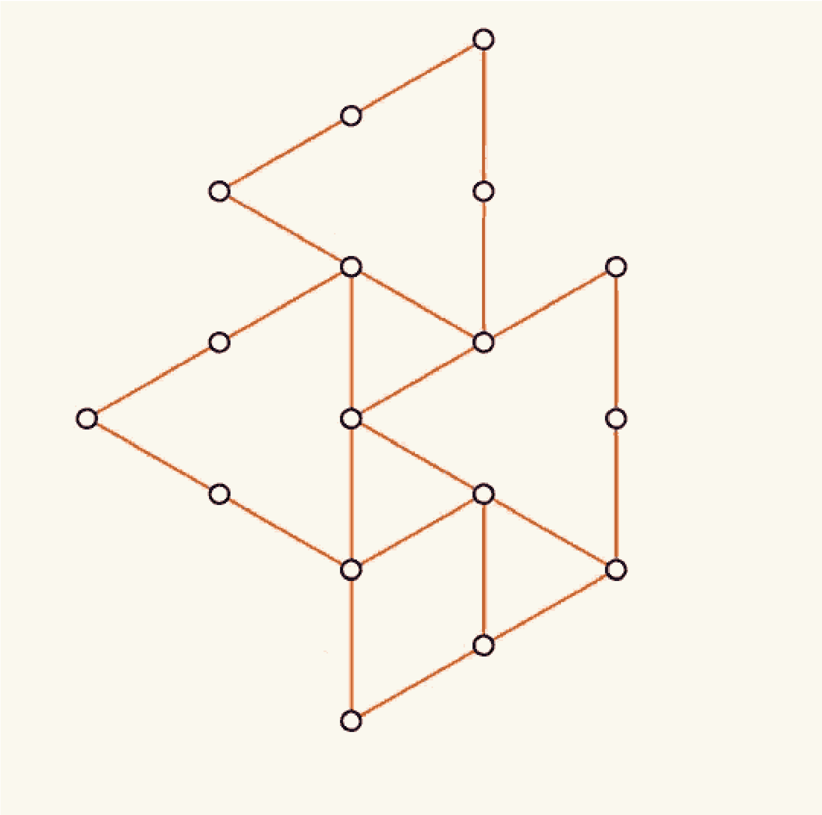
perception of it.

The *Ruliad* is the most important object in the Wolfram model, and it is the "true ontology." To understand Wolfram Physics and conduct faithful science, we need to study how we interface with this object.

Some properties of the *Ruliad* are that it is maximally symmetric and countably infinite. In this infinite limit, all mappings are bijective (one-to-one), and for all subsets of the *ruliad*, all mappings are surjective. In other words, subsystems embedded in this object cannot perceive it without consolidating information about its structure. This plays an important role in observer theory and, subsequently, the Wolfram Model of Physics.

Step 4 : Observation & Observer Theory

The properties of the Ruliad elicits another series of questions about how it can be perceived. That because, any subsystem of the Ruliad can only map Surjectively onto it, then any subsystem that exists inside of this object will consolidate information about its structure.



This animation illustrates the key properties of this limitation.

The first statement to make about it, is that the rotation is in some sense an illusion of our perception. What's actually occurring is a continuous translation of each coordinate, to other coordinates.

But the second more important statement, is that when points overlap to the same coordinate, the object's geometry gets occluded, where one can no longer perceive the true geometry of the object. Take note of what this means on the numeric level. In a 2d coordinate system, it means that several points share the same coordinate IE: (2,3), (2,3), (2,3)... In a 3d coordinate system those points may actually be (2,3,1), (2,3,4), (2,3,8)...

From different perspectives of this underlying object, we fail to perceive the underlying data structure, because we are forced to consolidate information about that data structure when looking at it from a particular point of view.

Lastly, we conclude that from many view points, we could describe this same object in several different, but equally meaningful ways. In the next section, we will find that this property is responsible for physics as we currently know it, and sets the basis for Wolfram's view, that other observers can have completely different descriptions for physical laws that are equally valid.

We will also find that this is an equivalent interpretation to the merging behaviour of the hypergraph evolution in the Wolfram Model, and therefore it is this limitation that allows many observers to perceive the same fundamental laws of physics.

If we imagine the infinitely complex structure of the Ruliad as a structure similar to this animation, then there will be an infinite number of such viewpoints and is therefore computationally irreducible, but also an infinite number of regularities in those viewpoints. It's worth mentioning, that time is also a data structure subject to the same property to perceive it by an observer.
29:10 - 31:45 Can AI Solve Science (https://www.youtube.com/watch?v=goYaSkxG8LA&t)

Wolfram explicitly uses the same example, of a box of random particles, then when rotating the box, finds that actually those particles were aligned in a series of stripes, and that this is what it means for the underlying data structure to have regularity (reducibility) in it by way of how we perceive it. Show a snippet of this example, it’s very important.

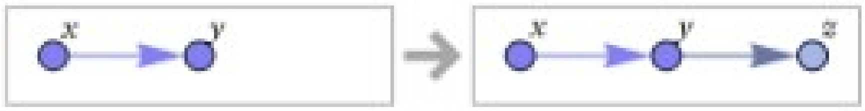
Section 2 : The Wolfram Model

Step 5 : The Wolfram Model

With New Kind of Science, The Ruliad and Observer Theory under your belt, you are now prepared and properly equipped to understand the weight and importance of the Wolfram Model.

Space
The Wolfram Model begins by stating that space is made of discrete information structures called “Atoms of Space.” They have no properties other than that they are unique, and that they can have relationships to each other. The objects are represented as nodes, and the relationships are represented by edges that connect those nodes. This forms a network graph, and more precisely a hypergraph, which generalizes this representation.

Rewrite Operations
We then introduce the dynamics of the model, which is to apply rewrite operations, a **rule** that change a set of nodes and edges, into another set of nodes or edges For instance :



Whenever there is a relationship that has the form “XY” it changes to “XYZ” at no particular time. In other words this relationship…this rule… just eternally exists, such that all relations change in this way.

That’s pretty much the Wolfram Model in a nutshell! **Everything else that happens from here on out, is a consequence of observers embedded in this model, and how they perceive the evolution of its structure.**

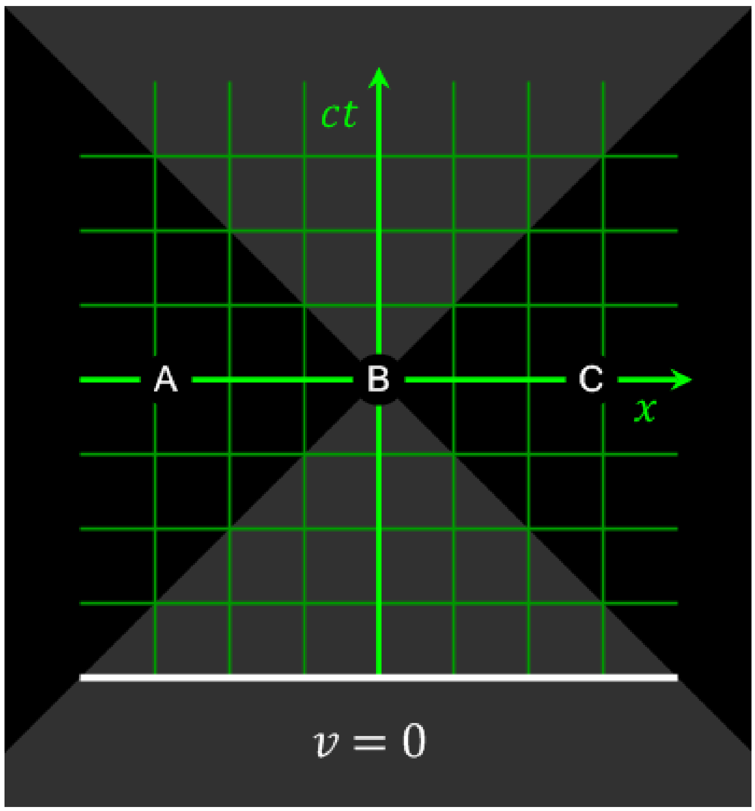
Time & Relativity
As previously shown, there is not yet a notion of time. Rewrite operations just “are,” anywhere they apply, and so you can imagine that if this is the case, then the hypergraph should just apply all of these operations at once. For an observer that knows everything about the graph, this

would be true (The Ruliad), but once we embed ourselves in this graph, we become forced to decide which events must come first, and which ones must come next in a causal order.

Say that if we have an evolution like this:

Then we must force the constraint that XY needed to happen before XYZ happens, since XYZ depends on XY, for an observer that can only see one of these operations occur.

In the large limit, this structure forms the notion of directed time (causality) for an observer: That in order for an event to happen, a previous event must have had already happened. We also start to see how this ambiguity in the structure from an observer's perspective creates the notion of relativity : That if we have two or more of these operations that occur in two different places, say XY -> XYZ over here, and XY - XYZ over there, we have to perceive these in a causal order…where one of those events has to come prior to the other one, and that, depending on where you are embedded in this evolution determines which one happened for them first! (Relativity of Simultaneity)



Quantum Mechanics

Another property of this evolution that we are forced to obey as a consequence of embedding ourselves into it's structure, is the ambiguity of possible rule operations that could have occurred.

As it would turn out, these possible rewrite operations that could happen, are all valid, and what an observer gets to distinguish as having happened, are the ones that converge to the same results. We depict this ambiguity as a branchial multi-way graph, and when many of the operations that could have occurred, converge to the same result, this is what we perceive as definite events happening. As shown earlier in the observer theory section,this is the merging behaviour of this graph, that not only branches out but also merges together. It's this merging that gives us as observers the permeability in the world that we observe, from the set of all possible histories that could have happened.

Big Picture

In summary, Thermodynamics, Relativity, and Quantum Mechanics all result from the ambiguity of observing the Ruliad object, because we as observers are forced to sequentialize and consolidate it in some way!

We can model all of these ambiguities as multi-way graphs or spaces. *Branchial Space* is the geometry of those branching and merging events in the hypergraph evolution…a multiway causal graph is the geometry of the causal order of the hypergraph evolution…Rulial space is the space of rules and so on…The Wolfram Model heavily implies, that all systems can be modeled as Wolfram models and have geometries and properties of this kind. This is why you might hear Wolfram often, talk about relativistic effects and particles in say an economic system.

"The analog of particles in Ruliad space, are concepts"

All of these representations are descriptions…slices…samplings of the Ruliad object. It is our view of its geometry.

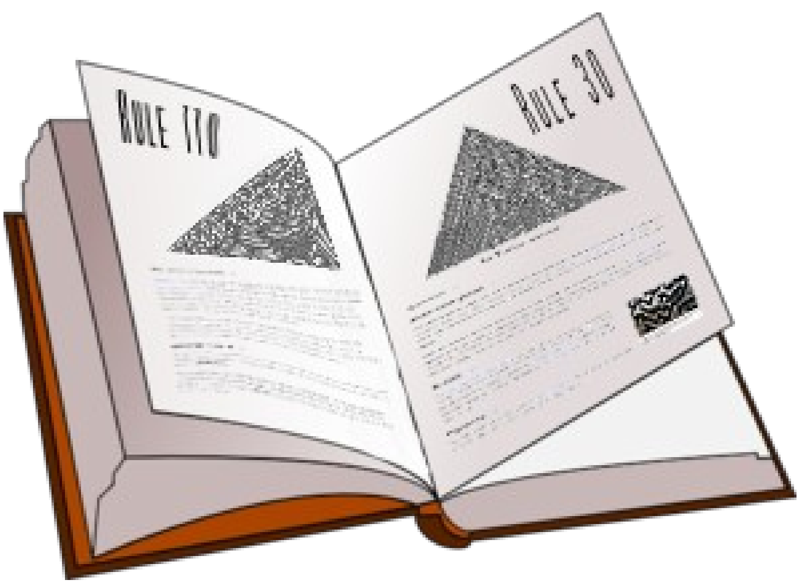
Technical
For those that are looking to go beyond the beginner, more conceptual introduction here and into technical details like Lorentz Symmetry preservation/violation, Here are links to several important resources.

https://www.wolframphysics.org/technical-introduction/introduction/
Wolfram Physics I: Basic Formalism, Causal Invariance and Special Relativity
Wolfram Physics II: Emergent Hypergraph Geometry and General Relativity
Wolfram Physics III: Completion Procedures and Basic Quantum Mechanics"
Wolfram Physics IV: Multiway Invariance and Advanced Quantum Mechanics

Section 3 : Applied Science Foundations

Step 6 : Ruliology

Ruliology might sound like an unusual name, but it actually makes a lot of sense. Similar to how Biology is "The study of organisms" or how Geology is "The study of Earth…"



Ruliology is the study of rules.

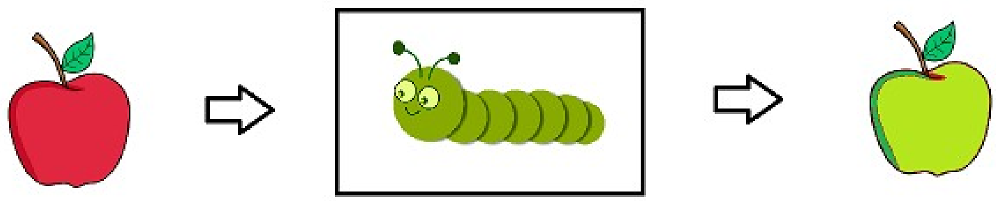
The job is rather straightforward and simple : **Run rules, and see what they do. That is what Ruliology is.** Picture in your imagination, that you have an encyclopedia, where there is a page for each rule, you document it's properties, what other rules it might be similar to and what things that rule could be used for…in the same way you might have a rock where you talk about its physical properties, it's appearance, or how it reacts to other materials.

In another valid interpretation of Ruliogy, you might imagine something more like a genealogy rather than an encyclopedia, Where you have an ancestry that shows the relationships between different rules, reminiscent of Multiway Graphs, or the Tree of Life.

But what is a rule? What does it mean to run one? And how do we run them?

A rule is a symbolic abstraction, and operationally, you can think of a rule as an input/output interface. To run a rule, means to exercise the abstraction, such that you have some input, and some kind of instruction that changes the input, into the output.

If I have a red apple in my hand, and in front of me a machine, that turns red apples into green apples, then this collection of the red apple [input], the machine with the instruction [instruction], and the green apple [output] is the running of a rule.



This machine need not be made out of metal, nuts or bolts. The machine could be…the funny caterpillar on your window sill that through whatever cellular mechanism turns the red apple into a green apple.
This example is the tip of the iceberg as you can imagine. The extent to which you can give an input a set of instructions to produce an output is one of the key ideas behind todays modern computer revolution. A rule can be as long and complex, or as short and as elegant as you can imagine. They can make perfect sense…or they might make no sense at all. They can be formal and rigorous, or natural and creative. In Step 7 - Multi-computation, we talk more about the extent of this variability in rules and what they do.

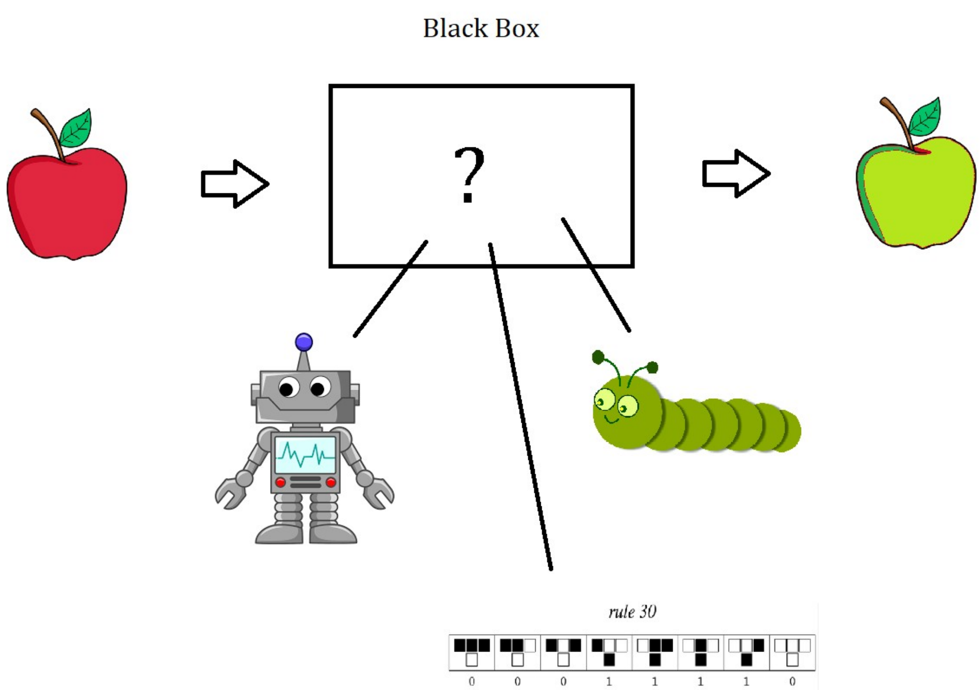
In summary, this is the purpose of Ruliology…to explore the infinite landscape of possible rules that exist, and then just, see what they do. Documenting how they work, and how they might be meaningful to us.

Step 7 : Multi-Computation

If one takes the idea of Computational Equivalence to its logical conclusion, then Ruliology, the study of rules, ultimately means that what every rule does is essentially "everything" since all rules are computationally equivalent to that of a Turing Universal Machine. For Ruliology, it isn't very meaningful to write on every page of the previously imagined encyclopedia that every rule "does everything" on each of its pages. This is where Multi-computation steps in to provide operational meaning both to Ruliology and a more powerful way for thinking about this property.

The idea of Multi-Computation is to imagine or construct every system as a sort of blackbox, where the system is computationally irreducible. Unlike Computational Reducibility which seeks to reduce systems down into a shorter description from regularities, Multi-Computation is a sort of inverse approach that seeks to exploit the phenomenon of computational Irreducibility instead.

This black box has the answer to any question you wish to ask it. The problem of finding the answer to your question, is how to navigate the "infinite landscape" inside this blackbox. **Multi-computation is a mapping of this landscape, and how to navigate it is an exercise in observation**…in doing "observer theory."



For example,You can imagine this page as a “mini-ruliad” where the words and all it’s information exist eternally all at once to us. However in order for us to process the information content on this page, you have to lumber through each word in sequence, one at a time. This is the modern computational paradigm where one has to process things in a single order.

But imagine instead, that you were an army of ants that could do an operation on each word. Now, you would be able to process the information content of this page all at once, almost as if you were looking at an image or a painting.

We’ve gone from looking at a sequentialized form of computation, to a non-sequentialized, more powerful form of computation.Rather than lumbering through one thread of time, we are exploring many, if not all threads of time in this mini-ruliad, and we do this by changing our perspective to a new one…, **the act of changing our perspective is an exercise in running a rule (the operation done by the ants)**.

Multi-Computation therefor gives rise to a reunification with Ruliology despite their aforementioned incongruence : We study rules and what they do, so that we can give ourselves new perspectives that take advantage of either the Computationally reducible properties, or the computationally irreducible properties of systems, and we do multi-computation in order to map and explore the computationally irreducible landscape.

Changing Perspective = Running Rules = Navigating Rulial Space.

Reading a book in less than a few seconds as if it were like a painting on the wall, is akin to a super power as Wolfram often states when talking about this paradigm. Computationally Irreducible processes contain a lot of power, because it is the ability to program any system, to compute any computable function:

If we want machine learning to be able to do the best it can, and perhaps give us the impression of “achieving magic”, then we have to allow it to show computational irreducibility.

Worth mentioning the idea of getting ***many*** answers to the question (the question posed to the black box), and not receiving just a single answer being the objective. IE: creating a program like Photoshop, allows people to explore the space of possible images (“expansion” in rulial space)

Also worth mentioning is to include the “*propagation of concepts is particles in rulial space*” which Wolfram often talks about, is directly referring to this idea of exchanging a perspective from one observer, to another observer (the same thing as getting some observer [A] to follow the same rules as another observer [B]) This is not directly related to multi-computation only, but it makes sense to be in this section after the above examples and explanation, so this might be the best section to put that in.

Links

This part of the paper introduces an integrative framework for understanding this Emergence, from physics to blockchain to economics. It traces a path from Wolfram's Computation, to Deacon's Teleodynamics, to Nakamoto's Proof-of-Work. Wolfram's framework of computational equivalence and the role of the observer set the stage, highlighting how an epistemological choice—viewing all processes as computations—carries ontological consequences for what we can know about reality, with wide ranging implications about irreducibility and emergence. Deacon's framework articulates how spontaneous, non-spontaneous, and end-directed (purpose-driven) processes emerge through layers of constraints, establishing a hierarchical theory of emergence, with causal explanations for origins of life, consciousness, and symbolic systems. Nakamoto's Bitcoin and consensus mechanism "proof-of-work" establishes the engineering schematics and infrastructure for quantifying various parameters of emergent "symbolic value" in Internet Protocols (TCP/IP). Because blockchain protocols are undergoing such radical transformation through evolutionary trial-and-error, there is a strong expectation that a new protocol will emerge with more precise and scalable properties for quantifying computation, work and "symbolic value." Downstream implications of this possibility are in the fields of complexity science, economics, game theory, distributed computing, quantum cryptography, Artificial Intelligence, smart contracts, and beyond—ultimately making a rigorous universal connection between the computational, the physical and the social. By connecting these insights from Wolfram's *New Kind of Science*, Deacon's *Incomplete Nature*, and Nakamoto's *Bitcoin*, this thesis offers an articulation of how fundamental computational constraints shape scale-invariant emergence, give rise to symbolic value, and ultimately enhances our scientific understanding of reality.

Beginning with an assumption that all processes can be modeled as computations—a perspective that shapes an observer's understanding (epistemology) and the nature of what one can observe (ontology)—we employ Wolfram's **Principle of Computational Equivalence** which states that systems in nature reach a maximal level of computation, rendering them effectively equivalent in sophistication to one another—and to us, their observers. This universal equivalence establishes an ontological boundary, described by Wolfram as "**computational irreducibility,"** where beyond a certain threshold the behavior of systems cannot be shortcut by simpler methods; it must be "computed" step by step.

Computational irreducibility generalizes the **second law of thermodynamics**, restated here as the "**Second Law of Statistical Mechanics**," and offers a broader perspective on what an observer can predict or reduce, invariant to any system of any scale. **Emergence** arises along a spectrum of irreducibility, where the boundary of reducibility-to-irreducibility establishes a constraint that prevents a full reduction of events, yet where *repetitive*, *nested*, *asymmetric*, *irregular*, and *random* phenomena still materialize. Deacon's hierarchical theory of **Teleodynamic** emergence accounts for transitions between these patterned sequences, to aid in explanation between spontaneous, non-spontaneous and end-directed (i.e., purpose-driven) changes. Deacon highlights how cause-and-effect relationships unfold in physical reality, which becomes useful in understanding the cause-and-effect relationships of observers in cultural, economic, technological, and symbolic reality. Together, Wolfram and Deacon's frameworks afford an ontological understanding of Emergence.

Finally, these ideas are illustrated with **blockchain** technology. Nakamoto's conception of "proof-of-work" in Bitcoin exemplifies how computational irreducibility enforces a physical and verifiable boundary condition, which ultimately runs the logic that generates the container and the self-organizing infrastructure for facilitating **symbolic value**. In this sense, "proof-of-work" establishes a physical constraint (thermodynamic) and a reducible validation constraint (morphodynamic) which generates an emergent, observer-dependent notion of value that can be used as a downstream constraint in economic, cultural and technological systems (teleodynamic). "Proof of work" consensus establishes a revolutionary new process for understanding and quantifying the end-directed work of observers by connecting irreducibility, work, and symbolic value together in a quantified system. "Quantified" implies measurement capability, potentially as number of hashes per second or kilowatt hours per computation. Where, how and why one would use such a system is partially left unarticulated and open-ended by the author. However, the three most important takeaways claimed in this thesis are: 1) that a rigorous engineering schematic for creating "symbolic value" systems now exists as open-source code 2) a precision measurement system, akin to the atomic clock for time, telescope for stars, and microscope for bacteria, now exists for "symbolic value" and 3) a protocol of physical constraints can be employed to cultivate emergent, symbolic forms of non-organic life; from smart contracts to artificial super intelligence, and constrain their end-goals.

Below is an outline that attempts to walk through the basic logic of the emergence framework, from “Observer” through “Symbolic Value.” Feedback is most welcome, my own comments included in the Word file.

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0. Computational Observer

- All processes are viewed as computations
- This is an epistemological decision that determines an ontological perspective
- Computation is a generalization made to enable observers like us to most accurately understand many different kinds of systems and processes.
- This model should offer causal explanatory power greater than other models.
- Assumptions:
    - Observers like us are:
        - 1) computationally bounded
        - 2) perceive persistent state through time

1. The Principle of Computational Equivalence

- The computational sophistication of many different kinds of systems and processes has a maximum upper bound.
- It says that systems found in the natural world can perform computations up to a maximal "universal" level, and that many systems do in fact attain this maximal level of computational power. Consequently, many systems are computationally equivalent.
- For example, the workings of varied systems such as the human brain or the weather can, in principle, compute the same things.
- Computation is therefore simply a question of translating inputs and outputs from one system to another.
- Turing completeness is one way of determining evidence of this across observed systems and simple rules.

2. Resulting Computational Irreducibility

- Past some low threshold, any real system may exhibit essentially the same level of computational sophistication. This implies that observers will tend to be computationally equivalent to the systems they observe.
- This implies that those observers will consider the behavior of such systems as computationally irreducible.
- There won’t be a shortcut to understanding the system beyond the explicit evolution of the system step by step.
- In the end, complexity is a result of computational irreducibility from the principle of computational equivalence, and observations in practice will demonstration that observers are computationally equivalent to systems they’re observing.

3. Implications of an Unprecedently Broad Principle of Computational Equivalence—Invariance!

- The benefits of the broadness of the principle of computational equivalence are that it offers a framework of understanding to observers of systems at all scales.
- This implies that computational equivalence, and thus computational irreducibility, are invariant phenomena.

- This implies that observers of systems at different scales are bounded by upper and lower thresholds.
- This is akin to the general boundedness that the 2nd law of thermodynamics implies, but broader and more applicable to computational systems (which will be useful in the teleodynamic analysis).
- The second law of thermodynamics is an articulation downstream of the principle of computational equivalence, not the other way around.

4. The Fundamental Constraints

- Emergence is a phenomena arising from and defined by boundary conditions, not by the thing in-of-itself. The thing itself wasn't "there" prior, and the rule that produces it doesn't have the outcome embedded (or knowingly embedded) in the rule itself. Therefore, it is not helpful, useful, or productive to define emergence by what it is, rather it is best defined by the constraints defining what it is not.
- Irreducibility is a phenomena that defines the boundary condition for what an observer can know about a computational system. Beyond some threshold is a boundary that no longer contains reducible information. However, if boundary conditions without any reducible information display a signal of information, it means work has occurred and that is a signal defined by the absence of information.
    - Computational Irreducibility – Upper boundaries
        - Generic equivalence in computational sophistication
        - Boundedness of observers (we are finite)
        - Pure Randomness (does pure randomness exist in reality?)
    - Computational Emergence – Lower boundaries
        - Repetitive
        - Nested
        - Random
        - Asymmetric
        - Irregular
- Irreducibility is a potent engineering mechanism for establishing boundary conditions to cultivate emergence.

5. Cause-and-Effect(s) of Emergence

- What causes events to occur? (Aristotle's *material*, *efficient*, *formal* and *final* causality explained by Deacon)
- Some events occur ***spontaneously*** because probabilistically they are so likely to happen as to be considered an inevitable occurrence. Only external work could violate this tendency.
- Some events occur ***non-spontaneously***, meaning they occur in such unlikely probabilities that an explanation requires new understandings or external work imposed on the system.
- Non-spontaneous events may require an explanation inclusive of the observer because said observer is central to the cause-and-effect relationship.
- Terrance Deacon's "Incomplete Nature" articulates a theory of cause-and-effect relationship between *spontaneous*, *non-spontaneous*, and *end-directed* changes which affords greater scientific understanding.

- In this theory of emergence; three hierarchical levels of system processes (or dynamics) are needed to explain the cause-and-effect relationships of any system:
    - 1) thermodynamics (i.e. non-symmetric, spontaneous)
    - 2) morphodynamics (i.e. symmetric, non-spontaneous, self-organization)
    - 3) teleodynamics (i.e. asymmetric, end-directedness).
- Each level is dependent upon the one below it, meaning there can be no teleodynamic process without a morphodynamic process, and no morphodynamic process without a thermodynamic process.
- Observers like us are in pursuit of reducibility (by our nature of "end-directedness"), to save ourselves from expending excess computational work and prolong/preserve ourselves.
- Observers like us will find ways to reduce or equivalence states together to extract a reducible insight that is useful for our end-directedness (like temperature, pressure, price, etc).

6. 'Via Negativa'

- Constraint is a negative property of a collection or ensemble. It is a way of referring to what is not exhibited, hence 'negativa', but could have been, at least under some circumstances.
- The term *constraints* denotes the property of being restricted or being less variable than possible, all other things being equal, and irrespective of why it is restricted. Something will tend to be assessed as being more orderly if it reflects more constraint. We tend to describe things as more orderly if they are more predictable, more symmetric, more correlated, and thus more redundant in some features.
- To the extent that constraint is "reduced variety," there will be more redundancy in attributes. The advantage of this negative way of assessing order is that it does not imply any modeled conception of order, regularity, or predictability.
- To avoid a modeled conception of order, regularity, or predictability in a physical substance or substrate, as in a CA rule or in a material, we eliminate the hard problem of explaining where order physically exists. (Best explained by constraints and absence).

7. A New Kind of Science

- While discrete, bottom-up physics preserves emergence, it loses precision simply because of the implication of the Principle of Computational Equivalence. Meaning, the modeling of the intricate molecular details are inevitably lost at some threshold relative to bounded computational systems of observers like us.
    - The implied mission of the field of Complexity Science is to fill the gap between irreducibly complex systems and non-emergent mathematics.
- Therefore, any model, innovation, or technology that increases the capacity to reduce or equivalence states is work that observers will inevitably exploit.
- The belief that observers can preserve emergence or repeatedly produce the effects of emergence in a way that ultimately reduces their work will explain why observers will exploit models, innovations and technologies. In Wolfram's terms, "in a sea of irreducibility there will be pockets of reducibility." Just like the thermometer for temperature, barometer for pressure, or price for markets, these aspects are useful for observers which afford something useful in it's reduction or equivalence.

- Reduction or equivalencing occurs at all scales, it is invariant in its application.

8. Example: Blockchains and “Proof-of-Work” in Bitcoin

- Wolfram has previously pointed out that Bitcoin's "Proof of Work," while juvenile in its construction, employs computational irreducibility to establish a boundary condition beyond which "work" can be provably verified to have occurred.
- This proof, while expensive in its production, potentially significantly reduces the total amount of "work" that all participating downstream constituents of the protocol require, indefinitely into the future.
- The connection between the “expensive” physical-computational “work” and the resultant “cheap” validation proof, with the intrinsically produced token, is where a container of symbolic value emerges.
- The symbolic value container is defined solely by the network's constraints; specifically computational irreducibility.
- This is a specific kind of "value," which will be interpreted differently by each observer who reads this.
- In this case, “value” is the description of the empty container unit AND the physical infrastructure/processes which facilitates the container unit.
- Ultimately, the facilitation infrastructure can imbue the value container with additional constraints, determined by end user’s goals/objectives.

9. Predictions and Conclusions

- Causal invariance will appear in blockchain consensus mechanisms.
- "Symbolic value" will become a well-defined object in a NKS and Teleodynamic framework; not by the physical substance it's composed of, nor the physical substrate that facilitates it, but by the features left absent by the physically overlapping constraints imposed upon it.
- This story begins with the fundamental constraint defined by the principle of computational equivalence.
- In conclusion, this is a thesis that spans the range from the very bottom of Computation to the very top of Symbolic Value in physical systems that we as observers find meaningful. It offers causally powerful explanations for why and how emergence can occur at various levels of scale and uses the fundamental constraint of computational irreducibility to get us there. Blockchains are an example of this framework and are used to demonstrate the invariance of this explanation at a different scale. This thesis also makes a claim that "symbolic value" in economic space will be most rigorously be defined by a blockchain system, and therefore, should be the center of our exploration. My prediction is that as observers of the kind we are, we'll see scientifically rigorous accounts of "value" in the evolution of blockchain systems which will help unlock our understanding of the connection between Computation, Physics and Economics in the world.

Title: Natural Emergence: A thread connecting Wolfram's Physics, Deacon's Emergence and Nakamoto's Proof-of-Work

I. Introduction

- Briefly introduce money as an **information system**
- Introduce blockchain as a **communication system** that facilitates money with reduced errors
- Present the core question: **How can a monetary system scale effectively while maintaining integrity?**
- State the need for a foundation in **novel physics and emergent dynamics**

II. Money as an Information System

- Define money as a **representation of value, work, and trust**
- Historical evolution: **From barter to commodity money to fiat to digital**
- The problem: **Distortions in value representation due to centralization, inflation, and inefficiencies**
- Introduce the **need for energy as a foundation for money**

III. Blockchain as a Communication System

- Explain how blockchain **reduces errors in money transmission** (trustless verification, decentralized consensus)
- Discuss its ability to **preserve integrity and security in monetary exchange**
- Introduce the **challenge of scalability** and **why time as a concept matters**

IV. Novel Theories Contextualizing Money and Blockchain

(Leverage existing sources to avoid excessive explanation)

1. **Physics Perspective:**
   - Time as a constraint in computational and monetary scaling
   - How blockchain's structure interacts with the **flow of time and entropy**
2. **Emergent Dynamics Perspective:**
   - How money emerges as a **complex adaptive system**
   - How blockchain **enhances emergent order and reduces noise in monetary signaling**

V. A Detour into Time: Scaling the Monetary System

- Introduce a **novel theory of physics** that redefines time as a functional component of economic scaling
- Explain **why energy and work must be foundational** for an enduring monetary system

- Explore the **limits of traditional financial systems vs. blockchain-based systems under this new framework**

VI. Computational Irreducibility & The Basis of the Known

(New Detour)

- **Computational Irreducibility**: Certain processes cannot be predicted or simplified—only **computed step by step**
- How **irreducibility constrains what is knowable** and defines **the provable**
- **Blockchain and irreducibility**:
  - Consensus mechanisms rely on cryptographic **provability**, but certain economic behaviors remain **emergent and unpredictable**
  - The **irreducibility of economic dynamics** makes **decentralization necessary** (no central planner can predict or optimize everything)
- **Why irreducibility is foundational to knowledge**:
  - **Provability emerges from constraints** on what can be computed
  - The intersection of **formal systems (math, cryptography) and emergent systems (economics, social structures)**

VI. Energy as the Foundation of a New Monetary System

- The necessity of **energy-backed money**
- How energy, **as work and information**, creates a robust and scalable monetary foundation
- How **emergent dynamics explain energy's role in stabilizing economic systems**

VII. Conclusion

- Summarize the key points
- Present implications for **monetary policy, blockchain design, and future systems**
- Address open questions for **further research and application**

This paper introduces the general chain of reasoning for understanding a novel blockchain architecture based on current challenges observed in monetary systems and economic measurement. The Quai / Qi architecture is designed to **provably minimize entropy** in a *distributed, adversarial environment*, thereby enhancing **trust** and **safety** among network participants. The provable minimization of entropy **eliminates the conventional "notion of time"**—a bottleneck in many consensus protocols as described above—where the system ensures both **consistency** (a global, conflict-free ledger state) and **liveness** (uninterrupted network progress despite sharding).

Using Wolfram Research tools and the Wolfram Physics framework, an exploration into causal invariance multi-way hypergraphs is made to deepen our understanding of the Quai <> Qi consensus architecture. Practically speaking, this architectures creates a high-throughput scenario which allows for the secure scaling of transactions in a consistent manner across an adversarial environment. Theoretically speaking, this architecture has potentially significant implications regarding our understanding of time, space, and the causal relationships of multi-way hypergraphs. These implications are researched near the end of the paper, along with an exploration of the autocatalytic relationship of AI and blockchain.

The second major innovation in architecture is a dual token system, which bypasses a traditional obstacle in monetary systems known as "Gresham's Paradox." In summary, a dual token architecture disaggregates the speculative characteristic of a store of value token from the unit measurement of accounting characteristic.
Lastly, the protocol **intrinsically tokenizes its cost of production**, linking issuance directly to a universally demanded resource—energy. This design feature provides a *stable unit of account* and taps into a **universal demand curve**, thereby aligning monetary value with real-world economic fundamentals.

Every cryptocurrency proposes to replace fiat for the same reasons—decentralization, inflation resistance, independence from central control, and trust embedded in a tamper-proof ledger. Yet, despite these promises, significant cryptocurrencies remain fiat in essence: their value is derived purely from collective belief, without intrinsic backing by any fundamental factor of production. The flaw of fiat currency lies in its detachment from real economic value. This statement is somewhat controversial, as many claim that proof of work blockchains are backed by an expenditure of electricity and compute. Also, proof of stake blockchains argue that the blind and gross expenditure of electricity and compute is wasteful, and therefore adopt a consensus design which reduces this expenditure. While Proof of Work does convert an intrinsic factor of production into consensus, it fails to disaggregate the characteristics of money for greater precision.

Over time, fiat currencies become divorced from productive activity, as their volume in circulation is not anchored to any tangible resource. In contrast, commodity-backed currencies necessarily align incentives with economic value creation. Historically, the U.S. dollar was backed by gold—expanding the money supply required accumulating and storing more gold in the Federal Reserve. This system ended in 1971 when the U.S. could no longer fulfill its obligations to redeem dollars for gold, severing the link between money and fundamental production constraints.

Gold, while a scarce commodity, is not an essential input in most industrial processes. In an ideal system, a currency should be backed by commodities that drive economic expansion and technological progress. If we consider capitalist markets as an evolutionary search algorithm optimizing for maximum returns, the choice of a commodity to back currency becomes the fundamental reward function that guides enterprise.

The most critical factor of production across all industries is energy, and will be a conversion of fuel into electricity, due to the increasing need for steady clean electrical output for computation and electric vehicles. Economic prosperity has always been tied to the availability of cheap and abundant energy. The Industrial Revolution was powered by coal, followed by the transition to oil and refined fuels, each unlocking new levels of material wealth and productivity. Simply put, there are no energy-poor wealthy nations. Aligning financial incentives with energy production means directly fueling economic growth.

A currency backed by energy would naturally align humanity’s progression along the **Kardashev scale**, which measures a civilization’s energy consumption and technological capability. The ultimate goal of capitalism is to explore the space of possible business models that maximize returns. If economic returns are denominated in energy, capital allocation will be optimized for increasing energy availability—creating a self-reinforcing cycle of industrial expansion and technological advancement.

Fiat currencies, in contrast, often incentivize speculative excess and capital misallocation. Traditional commodity-backed currencies, like gold, encourage stockpiling non-productive assets rather than reinvesting in value-generating activities. An energy-backed currency, however, would establish a direct link between financial returns and the fundamental driver of economic progress.

The most effective way to align economic incentives with maximum growth is to denominate value in energy. By backing currency with energy, we ensure that financial incentives promote productive investment rather than speculative boom-and-bust cycles. Quai Qi's approach represents a leap beyond fiat-for-fiat replacements, leveraging blockchain to create an **incentive structure that orients individuals toward maximal positive-sum games.**

From first principles of **thermodynamic capitalism** to the pragmatic realities of market psychology, the conclusion is clear: **energy-backed currencies are the future of economic expansion and societal abundance.** Fiat’s days are numbered, and the transition toward a more rational and productive monetary system is already underway.

The Quai Qi network protocol intrinsically tokenizes its cost of production by linking issuance directly to energy—a universally demanded resource. This design creates a stable unit of account, grounded in real-world economic fundamentals, rather than speculative belief. By tying monetary value to energy production, Quai aligns economic incentives with the physical constraints that govern industrial and technological expansion.

By unifying these two principles—time-independence via entropy minimization, and cost-of-production tokenization—the Quai Qi architecture promises traditional proof-of-work security, throughput scaling beyond traditional proof-of-work systems, and a universal common denominator for measuring the opportunity cost of sovereign economic agents.
Let's dig into the importance of entropy minimization within information systems and complexity science.

Trust as an Entropy-Reduction Mechanism. Trust lies at the heart of all social and economic systems. In information-theoretic terms, trusting someone or something means reducing the uncertainty—entropy—in one's model of the world. When we trust a counterparty, we prune the space of adverse outcomes, allowing us to focus on higher-level collaboration and exchange. This reduction in complexity underpins the efficient functioning of markets, organizations, and entire civilizations.

Modern economies thrive on trust precisely because lowering uncertainty around contracts and institutional processes decreases the overhead needed to verify and enforce agreements. Where institutional transparency and the rule of law are robust, social and commercial interactions benefit from shared confidence that commitments will be upheld. Yet as organizations become more complex, trust can become tenuous. Opaque processes—which are difficult to audit or too convoluted to understand—risk eroding this foundational certainty, making it harder for large-scale cooperation to endure.

In digital environments, cryptography offers a powerful means of verifiable trust. Cryptographic primitives (e.g., digital signatures, hash functions, irreducibility) reduce entropy by collapsing broad possibilities—such as "this data could have come from anyone"—into a single, verifiable truth: "this data definitely came from a known party and has not been tampered with." This conversion of uncertain states into mathematically certain ones drastically curbs fraud, counterfeiting, and other adversarial behaviors, allowing online systems to function with minimal reliance on trust in any central authority.

Likewise, Byzantine Fault Tolerance (BFT) protocols illustrate how cryptography and consensus logic can institutionalize trust in adversarial settings. When participants (nodes) in a network verify digital signatures and follow algorithmic rules (e.g., verifying blocks, proposing new ones), they can agree on a single consistent ledger state—even if some nodes behave maliciously. The guarantee of correctness in such a ledger relies on math and aligned incentives rather than on a central actor's goodwill.

In distributed computing—particularly when adversarial actors might be present (Byznatine environments)—one crucial challenge is developing a consistent (trusted) notion of time so that all nodes in a network can maintain a coherent view of events.

Traditional blockchains (Bitcoin, Ethereum, Cardano) embed time directly in their state updates: each new block includes a cryptographic pointer to a "previous time," effectively chaining together both time and state transitions. While this promotes security, it also means the network must frequently synchronize, limiting throughput and increasing latency.

Solana’s core consensus innovation essentially separates time and state in a mechanism called “Proof of History,” dramatically increasing bandwidth and reducing latency. Though research on “causal invariance” points to deeper methods of ordering events—beyond simple timestamps—by focusing on intrinsic relationships between state updates rather than relying on a global clock entirely.

Economic incentives further reduce entropy by making desired actions more probable. Charlie Munger famously said, “show me the incentives and I’ll show you the outcome,” someway anticipating a definite outcome based on an economic agent’s telos.

Bitcoin’s core insight was to link cryptographic proof-of-work with a well-calibrated incentive structure (block rewards + transaction fees). This combination motivates participants to follow the protocol, since honest mining or validation is financially rewarding while malicious actions tend to be prohibitively expensive or unprofitable. Thus, trust in the network arises naturally, grounded in incentives rather than in personal or institutional reputation.

Such incentive frameworks, now common in blockchain platforms, show how cryptography and economics can be fused to create robust, trust-minimized environments. As global systems become increasingly digital and complex, these “trust by design” mechanisms offer a scalable way to coordinate billions of participants, each with varying levels of reliability or goodwill.

Because institutional processes generally tend to become more intricate over time, the risk of illusory certainty grows, where hidden dependencies and opaque decision-making can degrade trust if outcomes cannot be transparently audited.

Trust also manifests in monetary systems. Historically, money is defined by its three core functions:

1. Medium of Exchange (MoE)
2. Store of Value (SoV)
3. Unit of Account (UoA)

Money as an information system can signal value(s), reduce the complexity of trade & barter, and ensures purchasing power can be transferred over time with proper accounting.

However, when economies rely on a single currency to provide all three functions of money simultaneously, this bundling can often mask deeper signals in the economy, potentially distorting how capital and resources are allocated.

Early economies often aggregated these monetary functions into one vehicle (e.g., gold served as MoE, SoV, and UoA), simplifying everyday transactions. As economies matured, many began disaggregating them naturally—for instance, using gold primarily as a SoV and fiat currency as a MoE. While this separation can sharpen clarity for specific functions (like saving versus spending), it may centralize power around the unofficial numeraire unit of account and create new incentive misalignments.

This disaggregation is particularly relevant today, as global trade and digital networks have multiplied the complexity of financial instruments and payment systems. Controlling the numeraire—the means of production (supplier of money) and "measuring stick" for goods and services—confers immense influence, often wielded by central banks or dominant nation's currencies (like the U.S. dollar, British Pound, Japanese Yen, Dutchmark, or Chinese Yuan).

Two primary concerns arise from how economies bundle or separate the functions of money:

1. Aggregating all three functions in a single currency can foster systemic mispricing and obscure real value, particularly if external factors (e.g., inflationary policies) undermine the currency's SoV role.
2. Centralizing power around an (un)official numeraire can distort incentives, limit access for certain participants, and enforce usage patterns that do not serve everyone.

Over time, these problems can lead to gross capital misallocation and degrade money's capacity to act as an accurate information system. When a currency's integrity is compromised—through chronic inflation, restrictive policies, or opaque governance—markets lose the reliable price signals they need to allocate resources efficiently. The result can be wasteful spending, speculative bubbles, broader environmental or social externalities, and accelerate system-wide entropy.

Blockchain technology offers a compelling alternative by enabling:

- More granular disaggregation of money's core functions
- Algorithmic enforcement of monetary rules (e.g., supply constraints)
- Permissionless accessibility, allowing anyone with an internet connection to participate

The insurance of transparency in issuance, transfers, and governance reduces reliance on trusted intermediaries. Early experiments with Bitcoin and Ethereum showcased how such a framework could minimize distortions by programmatically limiting supply or automating certain monetary functions. Nonetheless, achieving universal adoption and stable value remains an ongoing challenge for cryptocurrencies. Additionally, the major medium of exchange facilitated on blockchains is a fiat based dollar token, which warps some of the decentralized and permissionless functions originally intended by blockchain-based currencies.

Disaggregating money's roles and removing centralized control of the numeraire help:

- Mitigate economic distortions by anchoring currency issuance to transparent and predictable rules
- Enhance decision-making by providing unmanipulated price signals
- Improve accessibility worldwide, avoiding the pitfalls of local capital controls or inconsistent policies
    - Note: Regulatory regimes have still found ways to deny access/clarify regulations, or take enforcement actions on individuals or affiliated organizations (tornado cash, silk-road, wikileaks, operation chokepoint 2.0, etc.)

When consensus algorithms are open-source and verifiable, trust becomes a function of math and incentives—rather than institutional decree.

Additional Criteria for a Sound Currency. A robust currency—beyond fulfilling MoE, SoV, and UoA—should also exhibit:

1. Universal demand (life-systems everywhere require it's use)
2. Stable value (limited volatility relative to universal demand)
3. Supply constraints (fixed supply or a predictable rate of issuance)

Fiat currencies often fail on the third criterion due to periodic expansions of the money supply, particularly during crises. Bitcoin and Ethereum fulfill supply-constraint criteria but do not yet command universal demand nor exhibit the stability needed for widespread usage as a store of value.

In 1971, the United States ended the gold standard, removing an external supply constraint and granting more unilateral control over money creation. Subsequent policies (e.g., during 2008–09 or 2020–24) further violated supply constraint principles, expanding the money supply to spur economic growth or mitigate crises. While such measures can address short-term problems, they introduce long-term distortions, weakening the dollar's reliability as a stable store of value and contributing to an inflated pricing of assets.

Leading cryptocurrencies, such as Bitcoin and Ethereum, do maintain strict or predictable supply rules, thus satisfying the supply-constraint requirement. However, they generally lack:

- A truly universal demand curve, since adoption remains limited compared to global fiat usage
- A stable price, with significant volatility driven by speculation and market sentiment

In response, many blockchain users adopt dollar-pegged stablecoins, revealing an enduring reliance on fiat reference points and indicating that purely "on-chain" solutions to stability are still evolving.

One promising approach is tying currency issuance to energy usage, a universally demanded commodity. By anchoring monetary creation to energy usage—which underlies everything from photosynthesis to industrial production—issuance can be algorithmically tethered to a fundamental and globally relevant resource. This approach potentially yields:

1. A more stable unit of account, since energy demand is less speculative and more predictable
2. A universally relevant demand curve, as all forms of life and economic activity require energy
3. Supply constraints enforced through the cost of producing or securing energy

Historically, thinkers and innovators such as Thomas Edison, Henry Ford and Buckminster Fuller have noted that an energy-based currency might avoid the pitfalls of both unconstrained fiat and volatile market fluctuations. By incorporating cryptographic verifiability and distributed consensus, such a system can ensure that supply and pricing remain transparent, tamper-proof, and accessible worldwide.

The Quai / Qi Network serves as a cutting-edge culmination and illustration of these ideas, introducing an energy-based digital currency (via the cost of production, called Qi) while also pioneering a new consensus approach known as Proof of Entropy Minimization (PoEM). This mechanism addresses the “clock problem” prevalent in distributed computing—i.e., how to order events consistently without a global clock—by prioritizing the intrinsic relationships among hashes rather than relying solely on timestamps.

Through this approach, PoEM aims to achieve what Stephen Wolfram terms “causal invariance.” In Wolfram’s work, certain rules yield the same overall causal network (the same perceived history) no matter how events are updated or in what order. Applied to distributed networks like blockchains, this means that transaction ordering remains globally consistent—even under adversarial conditions—without artificially stalling the entire network to synchronize on each block. Effectively, Quai can validate hashes precisely and intrinsically, preserving a coherent global state while mitigating or eliminating the need for a rigid clock. This design enables Quai Network to shard work without sharding state, which ulimtately allows it to significantly scale to deliver high throughput, low latency, and maintain robust security.

On the monetary side, Quai / Qi Network ties token issuance to energy costs, creating an asset (Qi) whose supply constraints and valuation reflect real-world energy inputs. By combining a permissionless, scalable consensus layer with an energy-based currency, Quai / Qi Network aims to satisfy every major criterion of a sound monetary system: reducing distortions, ensuring transparency, and cultivating a universal unit of account. In this sense, Quai / Qi Network pushes digital currencies toward “the purest monetary forms” ever conceived—those backed by cryptography, universal demand (energy), and mathematically governed supply rules.

This opens the scientific door to studying economics through the lens of blockchains and a universal unit of account which may have profound consequences on how humans value trust in each other and how humans systematically embed trust in our institutions.

From the foundational importance of trust (viewed as entropy reduction) to the emergence of energy-based digital currencies, the evolution of monetary and consensus systems follows a clear arc. Cryptography and economic incentives combine to create trust-minimized frameworks. Blockchain platforms disaggregate and algorithmically enforce monetary functions. And finally, new systems exemplify how an universally demanded reference rate and causally-invariant consensus can address the persistent challenges of security, throughput, stability, and universal demand in distributed adversarial networks. By tying currency to a fundamental resource and ensuring transaction ordering through intrinsic relationships rather than global clocks, Quai / Qi Network aims to transform the way we conceive of trust, money, and large-scale coordination in the digital, informational, intelligent and agentic ages.

So, in order to scientifically study economics with a physics based framework and enabling ourselves the wealth of tools from all previously understood sciences, we adopt a computational economics and then build up from there. However, pure computation does not incorporate a sense of energy budget and thermodynamics within the system, so we require a hierarchical ratcheting of complex systems from thermodyanmcs and spontaneous change to teleodynamic systems which still obey thermodynamics but can perform non-spontaneous change to end directed goals. For this, we turn to Terrance Deacon’s non-intuitive framework for understanding systems.

Abstract

Money is an emergent symbolic phenomena of economic adaptive systems which can 1) dynamically change the resource allocation mappings based upon value aggregations that are facilitated by markets mechanisms and 2) can change time preferences of those value aggregations. Economics is the study of resource allocation systems. Emergent phenomena are best defined by their boundary conditions, also known as constraints more generally.
To this inquiry, the most relevant philosophies of constraint are developed by Wolfram's Principle of Computational Equivalence and by Deacon's Incomplete Nature. More specifically, by Wolfram's demonstration of computational irreducibility and by Deacon's demonstration of hierarchical thermodynamics. To understand emergence we need to understand these two frameworks and philosophies of constraints. First we go down into Wolfram and then we go up into Deacon. Wolfram's articulation is scale invariant, meaning it applies the same at all hierarchic levels. Deacon's articulation is scale dependent, meaning it matters how the evolution occurs and at what level of the hierarchic processes currently operate. Together, these two frameworks afford a ratchetting upward from fundamentally simple, computational programs to complex adaptive systems like economies.

From this vantage point we can return to our original question, "what is money" and reframe it by saying money is symbolic value. We use Bitcoin as a direct example and blockchains as general examples to demonstrate how constraints produce emergence in the same way many other emergent phenomena arise, but at the scale of the global economy. Defining money more generally as symbolic value has important implications because then we can understand money as an information processing system for the efficient allocation of resources (economics) and as a platform to explore the space of all possible transformation rules of symbolic value expressions. Our expectation includes a new measurement system for economic value, a new theory of economics, and a novel (emergent) economic agent. This will impact the fields of economics and governance.

Introduction: Energy-based Money

1. Historically, money has served three basic functions:
    a. Medium of exchange (MoE)
    b. Store of value (SoV)
    c. Unit of account (UoA) or Measure of Value (MoV)
2. Economies tend to aggregate these three functions of money in a single currency to reduce the overall transactional complexity. Ex: gold
3. Advanced economies tend to use two currencies to disaggregate the functions of money. This can help improve the resolution of the various functions of money, but it also affords disproportionate power via money creation and enforcement to the official Numeraire. Ex: gold (store of value) + dollar (medium of exchange).
4. Two main problem sets emerge:
    a. The tendency to aggregate the three functions of money in a single form can lead to large scale economic distortions in value judgements and decision making.
    b. The affordance of power to the official numeraire can lead to misaligned incentives between controller and constituents, indiscriminate enforcement of monetary usage, and strict limitations on access.
5. Ultimately, these problems lead to the misallocation of capital and the degradation of the information processing component of our economic resource allocation system. Major effects include economic leakage and environmental degradation.
6. With the emergence of blockchain-based digital currencies:
    a. The three functions of money can be disaggregated with greater nuance and precision.
    b. The official numeraire can become algorithmically enforced.
    c. The accessibility can be made permissionless.
7. By disaggregating the three functions of a currency, disintermediating the Numeraire, and making access broadly available **should** reduce economic distortions and improve decision making.
8. Voss believes there exist three additional criteria for what constitutes a good candidate for something to qualify as a currency:
    a. A universal demand curve.
    b. A stable value.
    c. Supply constraints:
        i. A fixed supply; or
        ii. A **fixed rate of supply** may be a necessary concept because of the inability to know how much supply is needed.
9. Since 1971 when the United States went off the gold standard and switched to a fiat currency regime it violated criterion 8(c(i)), above. More recently, the United States has drastically increased the rate of supply (2008-09, 2020-24) violating 8(c(ii)), above. The effects of this are a misallocation of capital and extraordinary inflation in the value of dollar denominated assets.
10. By contrast, current digital currencies satisfy criterion 8(c), above. But they generally violate criteria 8(a) and 8(b). While Bitcoin and Ethereum are becoming more universally accepted as currencies, demand for them is less than universal. Additionally, the value of these currencies is below the level of stability necessary for them to serve as a store of

value. We are seeing broad adoption of US Dollar denominated “stable coin” tokens to fill this gap.

11. By introducing energy-based money into a disaggregated blockchain-based monetary system, it can resolve the ills of fiat currencies AND establish a stable asset with a universal demand curve that are algorithmically enforced. Ultimately, this means that digital currencies can evolve to become the purest form of currencies that people have invented.
12. One blockchain that has created a disaggregated digital currency with an intrinsic stable value is Quai Network and their energy based money.

Computational Irreducibility is the ultimate constraint. A basic science and philosophy of constraints is undertaken here. Kauffman and Deacon research ratchets up from Wolfram's New Kind of Science. It is demonstrated in many systems, Bitcoin one of them. By deepening an understanding into irreducibility, one may reveal greater understanding of emergence. It is detecting emergence which offers causal power to observers like us. New things, novel innovations and key discoveries are possible when witnessing emergence. Bitcoin is an example of engineering with irreducibility, and it's possible to engineer new protocols and potentially biotic-like systems with it.

One example of emergence is what occurs in Proof of work blockchains, like Bitcoin. Bitcoin undergoes reciprocal catalysis and self-assembly, akin to that of biotic systems. Irreducibility is employed, in the form of a 256-bit Secure Hashing Algorithm (SHA-256), to define and constrain the parameters of it's protocol which result in predictable (reducible) outputs. Bitcoin achieves scale invariant consensus while generating verifiable proofs that ultimately require the total net work it's constituents must perform.

1. A layer of irreducible computation (randomness): SHA-256
2. A signal appears (reduction in shannon entropy): # of leading zeros of a hash
3. Propagate signal for validation to neighbors: gossip protocol
4. Neighbors validate the known rule: easy to verify and difficult to spoof, using one-way hash functions (consensus reached)
5. Consensus updates state: network updates to new state and returns to process #1 (causal closure)
6. Container emerges: Shared reduction in work occurs as consensus is reached, shared trust ensues. Symbolic container for arbitrary signals like money, property rights, identity, credentials, programs, data, etc emerges (Bitcoin).
7. Reduction in work means greater predictability

In "The evolution of the abiotic..." section we attempt to extend our analysis to the abiotic universe. We find that our analysis that considers information as constraints is equivalent to the statement that information consists in boundary conditions and in global constraints. But, in classical and quantum physics, boundary conditions\[LongDash]like the cylinder and piston\[LongDash]are only partially causal for what occurs. Physicists often "put in by hand" the boundary conditions of a problem, such as the behavior of the cylinder, piston, and working gas system. But in the unfolding of the biosphere or universe since the Big Bang, the very coming into existence of new boundary conditions\[LongDash]information we argue\[LongDash]is itself part of the full dynamics of the total system. We thus assume a context with information understood as boundary conditions on the release of energy that makes diverse processes happen. So we argue that in the proper union of matter, energy and information it is precisely the union of matter, energy, and boundary conditions that, in an expanding and cooling universe, progressively break symmetries, invade the Adjacent Possible, and cause an increasing diversity of events, processes and structures to come into existence. The evolution of the biosphere is but one case of this general process. -Kauffman, Propogating organization

What is required is that, in the non-equilibrium setting, a displacement from equilibrium that is a source of free energy must be detected by at least one measurement; a physical system able to couple to that source of free energy must have come to exist and must actually extract free energy, and must release that energy in a constrained way to carry out actual work. Thereafter, this work may propagate. If we conceive of an abiotic physical system able to carry out these processes of measurement and work extraction in the abiotic universe, it will have to be an abiotically derived system able to perform such measurements, recording the results, and employ the record of the measurements to extract actual work. Such a system will be a case of propagating organization with boundary conditions as constraints, including measurements in the record as constraints on the behavior of the system conditional on the recorded measurements, and the constrained release of energy in work. Whether the coming into existence in the universe of such a system is plausible abiotically is certainly open to question but may be worthy of consideration.

"Another formulation of the Second Law talks about the impossibility of systematically "turning heat into mechanical work". At a computational level, the analog of "mechanical work" is systematic, predictable behavior. So what this is saying is again that systems tend to generate randomness, and to "remove predictability". In a sense this is a direct reflection of computational irreducibility. To get something that one can "harness as mechanical work" one needs something that one can readily predict. But the whole point is that the presence of computational irreducibility makes prediction take an irreducible amount of computational work--that is beyond the capabilities of an "observer like us".." (Wolfram)

While Bitcoin does involve a process of measurement (solving cryptographic puzzles), recording (the blockchain), and work extraction (miners expend energy and receive rewards), it does not fit neatly into the scenario described in the passage (above). The passage imagines a spontaneously arising abiotic system in nature that autonomously detects and exploits sources of free energy\[LongDash]without human design or intervention. By contrast, Bitcoin is a human-engineered system, running on technology purposely built and powered by external energy inputs. So although there are intriguing analogies (measurement, record-keeping, threshold-based rules), Bitcoin is not itself an example of a purely abiotic system that spontaneously organizes in the universe.

Information creation, we argue, arises in two ways: first information as natural selection assembling the very constraints on the release of energy that then constitutes work and the propagation of organization. Second, information in a more extended sense is "semiotic", that is about the world or internal state of the economy and requires appropriate response. The idea is to formulate explanatory hypotheses on how information can be captured and rendered in the expected physical manifestation, which can then participate in the propagation of the organization of process in the expected biological work cycles to create the diversity in our observable biosphere. -Kauffman, Propogating organization

Any property of a physical medium can serve as a sign vehicle of any type (icon, index, or symbol) referring to any object of reference for whatever function or purpose because these properties are generated by and entirely dependent upon the form of the particular interpretive process that it is incorporated into.

Thus, we should not ask what it is about some sign vehicle that makes it an icon index, or symbol. These are not sign vehicle intrinsic properties. Intrinsic properties are not what make something semiotic. Sign vehicle properties aren't irrelevant, of course. But intrinsic properties are merely semiotic affordances (to borrow a concept from ecological psychology). They may or may not be utilized for any semiotic purpose. Often the semiotically relevant property of a sign vehicle is only one of its many attributes, and not necessarily the one most salient. What matters is how the relevant property is incorporated into an interpretive process, because being interpreted is what matters.

So when in the title of this essay I ask "How molecules became signs?" I am actually asking "What form of molecular process is necessary and sufficient to interpret some property of a molecule as providing information about other molecular properties?" In Peircean terms, this amounts to asking what sort of molecular system is competent to produce the interpretants that can bring this re-presented property into useful relation with that system?

Philosophy of Emergence

1. Principle of Computational Equivalence
2. Hierarchy of Thermodynamics
3. Symbolic Observer

Emergence is a phenomena arising from and defined by boundary conditions, not by the thing in-of-itself. The thing itself wasn't "there" prior, and the rule that produces it doesn't have the outcome embedded (or knowingly embedded) in the rule itself. Therefore, it is not helpful, useful, or productive to define emergence by what it is, rather it is best defined by the constraints defining what it is not.

Computational irreducibility is a phenomena that defines the boundary condition for what an observer can know about a system. Beyond some threshold is a boundary that no longer contains reducible information.

However, if said boundary conditions randomly displays a configuration that could be interpreted as a signal, then it could probabilistically be implied that work has occurred. Whether work has actually occurred is irrelevant. A false positive is detected, and in this condition of interpretating probable work, it can become a useful signal. Curiously, this signal is foregrounded precisely by the background noise (or absence of information), ultimately inverting irreducibility to become an intentional source of signal detection.

False positive is useful information.

(NEED TO PROVE THIS CLAIM): This is the basis of many important observations (CMBR, LIGO), and is the fundamental basis of Bitcoin's "proof of work" consensus.

Philosophy of Emergence: Part II

To fully empower the causal efficacy of a theory of emergence, one opens to power of transformation rules on symbolic expressions and a hierarchy of thermodynamics in order to see the full opportunity set in emergent paradigms. In order to see blockchains for their full potential, you'll want to understand computation. And computation is a choice made by the observer (epistemically) which has ontological consequences for perspective of the world.

Summary—Incomplete Nature

Deacon describes a nested hierarchy of dynamical processes—thermodynamic, morphodynamic, and teleodynamic—to explain how higher-level organization like life and mind can emerge without violating physical laws. The core idea is that each step in the hierarchy introduces new forms of constraint and feedback that build on, but do not replace, simpler physical processes.

1. **Thermodynamics (Homeodynamics)**
   At the most basic level, everything is governed by the second law of thermodynamics, which drives systems toward higher entropy (disorder) unless energy is continually supplied. This realm is about things "falling" into equilibria—like heat flowing from hotter to cooler regions or gases spreading out evenly in a container. It provides the backdrop: materials and energy flow in predictable ways, always trending toward equilibrium unless something else "pushes" or constrains them.
2. **Morphodynamics**
   Sometimes, if energy (or some resource) keeps flowing through a system, order-forming processes can appear temporarily, even though overall entropy in the larger environment still increases. Examples include the swirling structure of a hurricane or the orderly hexagonal pattern of convection cells (Bénard cells) in a heated fluid. These processes spontaneously create pattern and coherence (like whirlpools or chemical waves) because incoming energy nudges the system away from simple equilibrium and into self-organized structures. Yet without continual input, they collapse back to basic thermodynamic chaos.
3. **Teleodynamics**
   The next layer—teleodynamics—arises when a system harnesses and *maintains* these order-forming processes to serve its own persistence. Living organisms do precisely this: they continually assemble and repair themselves, using energy and raw materials from their environment to stay far from thermodynamic equilibrium. The "purposeful" behaviors we see in living systems (growing, reproducing, seeking nutrients) reflect the fact that they are organized around perpetuating their own structure. It is not that physics is suspended; it is that an internal web of constraints keeps the system going against the dissolving pressure of entropy. This *end-directedness* or self-maintenance is the defining feature of teleodynamics.

Together, these nested levels show how something as seemingly purposeful as life (teleodynamics) can be anchored in self-organizing processes (morphodynamics) which, in turn, rely on basic thermodynamic laws. No new physics is introduced at higher levels, but each stage adds constraints and feedback loops that enable the emergence of more complex, goal-like organization.

In Deacon's framework, **work** is best understood as the *active* process of bringing about changes that would *not* happen spontaneously in accordance with normal thermodynamic decay. A system has to put in effort (in a physical sense) to locally reduce entropy or sustain structure. Deacon highlights several key points:

1. **Contrary to Spontaneous Decay**
   Under ordinary thermodynamics, everything trends toward disorder (entropy increases). *Work* counters this by pushing against—or redirecting—what would otherwise be a natural slide toward equilibrium. Whether it's a living cell rebuilding damaged parts or a self-organizing vortex in a non-living system, any local increase in order still conforms to overall entropy increase, but it requires work to "carve out" and maintain that order.
2. **Requires Energy and Constraint**
   Work cannot be performed without both a source of energy and some *constraints* that channel energy into producing a desired outcome. In living organisms, enzymes, membranes, and metabolic pathways supply that scaffolding: they constrain how energy is used, ensuring it goes into building and maintaining structure rather than dispersing randomly.
3. **Goal-Directed in Teleodynamic Systems**
   In teleodynamic (living) systems, work actively supports the organism's continued existence. The system's parts cooperate in *consequence-organized* ways—actions today preserve the system's form and functions for tomorrow. It isn't just random pattern formation: it's structured, *end-directed* work that underpins the persistence, growth, and reproduction of the organism.
4. **Linked to Information**
   Deacon often ties work to the idea of *information*. Work is what *actualizes* an outcome in the material world, guided by informational constraints (like genetic instructions or interpretive processes in the brain). While energy is the raw fuel, information determines *how* that energy is used, effectively shaping the work so that new organization can arise and be maintained.

In short, for Deacon, work is the *engine* that drives local reversals of disorder by channeling energy through physical, chemical, or biological constraints. This labor against thermodynamic decay is central to self-maintenance and evolution in living systems.

For Deacon, **information** is fundamentally about *constraint* and *interpretation*. He sees it not merely as a physical quantity (like bits), but as something anchored in "absences" that *make a difference* for a system capable of *interpreting* those absences. On a simple level, information can be understood as a difference that has causal impact (in Gregory Bateson's famous phrase, "a difference that makes a difference"). Yet Deacon emphasizes that this impact depends on a higher-level process—what he calls *teleodynamics*—that uses these differences to preserve or enhance its own integrity. In other words, a DNA sequence has no informational value on its own; it only becomes *information* because the cellular machinery "reads" and "acts" upon it. Likewise, the meaning of a word isn't inherent in the written letters, but emerges from the way a mind interprets and responds to that arrangement of shapes. Throughout Deacon's work, **information** is thus inseparable from the constraints, context, and interpretive processes that give signals their functional and meaningful roles.

The Economy

An economy, however it’s border, boundary or function is defined, is a complex adaptive system. What is a complex adaptive system? I will argue that the complex part is rather trivial (or generic) and the adaptive part is scale-dependent upon the observer.

When we treat an economy as a *supervenient* structure, we mean that it arises out of the intricate mesh of underlying human behaviors, needs, goals, and relationships—yet it has properties and dynamics that can’t be reduced to any single individual or transaction. Deacon’s notion of *teleodynamics* offers a useful lens here: much as a living organism organizes itself around preserving and reproducing its structure, an economy emerges out of human agents who themselves act with ends in mind—pursuing survival, profit, or well-being, each in their own context.

Still, in looking at the system as a whole, certain large-scale economic “patterns” develop that exceed any one person’s intention or awareness. These emergent patterns—like market cycles, inflation, or waves of technological innovation—mirror the way living systems push resources around to maintain coherence at a higher level. And just as no single cell “knows” or controls the organism’s entire functioning, no single participant in an economy fully orchestrates the system’s aggregate behavior.

By “coarse-graining” our perspective—abstracting away from the myriad personal reasons and psychological nuances behind each transaction—we start to see the economy as a cohesive, self-maintaining (or sometimes self-disrupting) process. We recognize *information flows* (e.g. prices, interest rates) that guide and constrain action, much like genes and signals guide a cell. What emerges is an entity that is more than just the sum of individual choices: it has its own feedback loops, self-corrections, and tendencies that reflect, but do not merely replicate, the teleologies of the humans within it.

From this vantage point, an economy exhibits a *teleodynamic* logic of its own. Individuals remain the foundational drivers—shaped by their goals and interpretations of signals—yet their combined interactions generate higher-level regularities. This duality of top-down constraints (like laws or shared cultural norms) and bottom-up behaviors (countless human decisions) yields a system that, in many ways, governs itself for continued function. It maintains a recognizable form—one we can describe, analyze, and even forecast—even as the daily activities of its participants constantly shift and evolve.

Deacon’s overall picture ties together thermodynamics, work, and information into a framework where *teleodynamics*—the capacity for self-maintenance and end-directed behavior—emerges at the biological and mental levels. First, the thermodynamic backdrop sets the stage, outlining how energy naturally disperses and disorder tends to increase. Next, *work* appears as the means by which systems push against this drift toward equilibrium, redirecting energy and materials in ways that preserve or elevate local order. Under *morphodynamics*, non-living systems like whirlpools or convection cells show *self-organizing* patterns when energy flow is sustained, but they lack genuine self-interest; they arise and fall, unconstrained by a goal. In *teleodynamics*, by contrast, organisms both self-organize and actively *maintain* that organization for their own persistence. This higher-level pattern is driven by *information*—structured differences that become meaningful for the system interpreting them—so that the system can keep itself going, repair damage, and even reproduce its form across generations.

What makes Deacon's account especially relevant to an *economic observer* is the insight that teleodynamic principles do not merely operate at the scale of cells or creatures. Whenever entities (people, firms, markets) continuously interpret signals—differences that matter—and harness energy or resources to achieve end-directed objectives, they exhibit teleodynamic-like processes. In economics, "information" can direct purposeful action: market signals (e.g., prices, interest rates, or consumer trends) shape how agents allocate resources and perform "work" to maintain or grow their ventures. This is akin to a cell reading its DNA: there is no inherent value in the raw bits themselves; the system's *interpretation* of signals, and the constraints that guide actions, are what give them teleodynamic force. By viewing markets or economies through this lens, we see them as constrained, self-maintaining processes—living, in a metaphorical sense—where "false positives" or background noise can become "useful signals" that prompt new directions and innovations. Just as in life, the "absences" or gaps in information within an economic arena can become defining features that drive purposeful behavior in pursuit of continued viability.

1) Private key introduction
    a) List 24 private key phrases dramatically
    b) List the set of economic transformations rules that can be performed, be exhaustive
2) Introduce the course
    a) We want to understand the philosophy of:
        i) Computation
            (1) Transformation rules of symbolic expressions
            (2) Computational observer
            (3) Computational irreducibility
            (4) Wolfram Physics
            (5) Wolfram Language
        ii) Emergence
            (1) Constraints and boundary conditions
            (2) Causality
            (3) Work and Information
            (4) Scale
            (5) Complex Adaptive Systems
        iii) Complex Adaptive Systems
            (1) Simple programs
            (2) Life
            (3) Homo Economicus
            (4) Network economies
            (5) Work and Information
            (6) Proof of Work and Bitcoin
            (7) Blockchain
            (8) Thermoeconomics
    b) We want to understand blockchains and how they work and we think this is a helpful framework
    c) We want to apply this understanding to the realm of work and life
        i) Investing/speculation
        ii) Permisionless systems for finance
        iii) Opt-out from current systems
        iv) Innovative ways of building new systems
        v) Scientific exploration
3) UTXO Alliance
    a) Place to funnel developers, learners and job seekers
    b) Agnostic place where we can pull from experts and infrastructure
    c) Professionally good to develop

Theses:

1. Engineering with Irreducibility (constraints and proof of work)
2. Autocatalysis in Blockchain Systems (biological analogy)
3. Causal Invariance in Blockchain Consensus (Proof of entropy minima)
4. Transformation Rules of Symbolic Value Expressions (smart contracts)
5. Universal Opportunity Cost as Unit of Account (energy money)
6. Proof of Work in Economic Systems (Computational Thermoeconomics)

7. Reciprcocal Catalysis in AI + Blockchain systems (Life)
8. Time Doesn’t Exist (Causal Invariance)
9. Entropy Minimization is Ground Truth
10. Computation, Work, Value (Computational Thermoeconomics)

Asymmetric

A property of processes or structures that do not exhibit symmetry; that is, having parts that fail to correspond to one another in shape, size, or arrangement. Asymmetrical systems naturally arise in nature, like prime numbers, or rule 110 cellular automata.

Blockchain

A distributed ledger technology where data are grouped into blocks that are cryptographically linked. Blockchains rely on consensus mechanisms (like proof-of-work) that leverage computational irreducibility to validate proofs which guarantee trust and security without central authority.

Boundedness of Observers

Refers to the finite or limited capacity of observers—whether in computational power, memory, or time. Because observers cannot out-compute certain systems, they become subject to irreducibility constraints.

Causal Invariance

A principle suggesting that the ultimate outcomes of certain computational or physical processes remain consistent despite variations in their intermediate sequences or paths. In blockchain context, it implies consistency of state despite different validation or block order sequences.

Computational Emergence

A lower bound phenomenon (in this framework) indicating that new, higher-level structures, patterns, or properties arise out of boundary conditions in complex systems, rather than being explicitly encoded in the initial rules or components. Examples include repetitive, nested, asymmetric, irregular, or random patterns.

Computational Irreducibility

The notion that past some threshold, a system's behavior cannot be shortcut or predicted by any simpler computational method than actually simulating the system step by step. In other words, there is no "closed-form" or faster algorithm to determine its future states (as known in mathematics)—this applies universally to many natural and artificial systems.

Computational Observer

An entity (like a human or machine) that treats all processes as computations. This perspective shapes both how the observer acquires knowledge (epistemology) and what can be known about the world (ontology). Such an observer is themselves computationally bounded.

Constraint

Any factor that limits or bounds the behavior of a system. In computational and physical contexts, constraints can be physical, energetic, or logical/informational—preventing certain states while allowing others. Constraints often give rise to emergent properties by defining the boundary conditions within which a system can evolve.

Epistemology

The branch of philosophy concerned with the theory of knowledge—how we know what we know, what justifies our beliefs, and what the limits of knowledge may be. In the context of computational observers, epistemology focuses on how observers acquire, structure, and validate information about the systems they study.

Equivalence of State Through Time

An idea that observers maintain some form of continuity or consistent memory across time, allowing them to identify patterns or regularities, yet remain constrained by computational bounds.

Invariance

A principle or property remaining unchanged under certain transformations or across different contexts/scales. In this framework, **causal invariance** is one example; it suggests that the final outcome of a process is the same even if the intermediate steps are permuted. More broadly, **computational irreducibility** is considered invariant across different scales and systems, which ultimately generalizes the second law of thermodynamics into the law of statistical mechanics.

Irreducibility (as an Engineering Mechanism)

Using irreducibility as a tool to define boundary conditions or constraints in systems. By intentionally imposing aspects of a system that are impossible to shortcut, it is possible to cultivate boundaries for emergent behaviors (e.g., proof-of-work schemes).

Morphodynamics

A level of emergent behavior in Terrance Deacon’s hierarchy. It focuses on self-organizing processes that emerge from lower-level thermodynamic processes but are not themselves spontaneous. Morphodynamics show symmetry and pattern formation (e.g., crystal growth). Morphodynamics can only emerge from thermodynamics, and can give rise to a higher level called Teleodynamics.

New Kind of Science (NKS)

Stephen Wolfram’s computational framework suggests that simple rules can yield the entires spectrum of simple-to-irreducibly-complex behaviors, illuminating a key insight into complexity science, scale invariance, the second law of statistical mechanics, observer theory, metamathematics, physics, and a wide variety of other fields including philosophy, biology, economics and foreign intelligences.

Observer-Dependent Notions of Value

The idea that "value" is context-specific and emerges from the interplay between physical constraints and the subjective interpretations of those constraints by observers. For instance, Bitcoin's proof-of-work mechanism creates a container for "symbolic value," judged differently by each participant.

Ontology

The branch of philosophy that deals with the nature of reality or being—what fundamentally exists in the world and how those entities relate to one another. In a computational framework, ontology pertains to how the observer's approach (e.g., treating all processes as computations) defines what "is" within the scope of that model.

Principle of Computational Equivalence (PCE)

Wolfram's hypothesis that many systems—biological, physical, or technological—attain the same maximal computational sophistication. Once a system passes a low-level threshold of complexity, it becomes universal in computational power, evidenced by Turing-completeness, which implies an equivalence to those systems.

Proof-of-Work (PoW)

A consensus mechanism (e.g., in Bitcoin) that uses computational irreducibility as a boundary condition. Nodes must perform costly computational "work," which can then be verified cheaply by the validating network, forming the basis for trust and security in a decentralized environment.

Randomness

The aspect of a system's behavior or initial conditions that is unpredictable or cannot be trivially compressed into a simpler rule. Randomness can be part of both emergent processes and irreducible computations, making outcomes difficult or impossible to predict.

Second Law of Statistical Mechanics

A broader interpretation of the second law of thermodynamics, applied to general computational or informational contexts. To the bounded observer, the second law of thermodynamics arises. A computationally bounded observer observing thermodynamic, morphodynamic or teleodynamic work may not necessarily use the historical interpretation of thermodynamics to comprehend work occurring a levels higher in the hierarchy of work and information.

Symbolic Value

Value that is defined not by the physical substrate but by the constraints or rules that limit its production, validation or use. In proof-of-work blockchain systems, “symbolic value” emerges in a functional container unit from the validation of a process which cannot be spoofed. The system facilitating the functional container unit does not define it’s symbolic value, but the absence created by the container is established to be valued by the end-directedness of the end-user.

Teleodynamics

The highest-level process in Terrance Deacon’s hierarchy, referring to systems that exhibit end-directed behaviors (i.e., purpose-driven or goal-driven processes). Teleodynamic processes depend on morphodynamic and thermodynamic layers to exist and cannot be explained solely by spontaneous or self-organizing phenomena. Teleodyanmic work helps explain cultural, economic, technological and spiritual work in human systems and offers explanation through physical processes to validate that work.

Thermodynamics

Traditionally, the branch of physics dealing with heat, energy, and work. In Deacon’s framework, thermodynamics represents the most basic, spontaneous level of physical processes—necessary for higher-level emergent phenomena to build upon. This background constraining layer is more precisely articulated by Wolfram’s computational irreducibility and establishes a signal detection layer for work.

Turing-Completeness

A measure of a system’s computational universality indicating it can perform any computation that a Turing machine can, given enough time and resources. In this context, Turing-completeness signifies that many natural and artificial systems reach a universal threshold of computation.

Scale Invariance

A specific type of invariance where the system’s underlying properties or behaviors remain consistent when viewed at different magnitudes (e.g., microscopic vs. macroscopic levels). For instance, certain fractal patterns or statistical distributions in nature exhibit scale invariance, meaning their complexity remains similar regardless of the scale at which they are measured.

Wolfram’s Four (or Five?) Classes of Complexity

Stephen Wolfram’s classification of cellular automaton behaviors, generalized here to describe complexity in natural or computational systems. The four classes are:

1. **Repetitive**: The system quickly settles into a stable, repetitive pattern (e.g., a fixed point or cycle).
2. **Nested**: The system produces self-similar, fractal-like structures that replicate at multiple scales.
3. **Random**: The system's outcomes appear disordered or pseudo-random, with no obvious repeating pattern.
4. **Irregular** (sometimes referred to as "complex"): The system exhibits complicated structures or behaviors that are neither fully repetitive nor purely random, often with emergent features.
5. **Asymmetric:** Asymmetrical systems naturally arise in nature, like prime numbers, or rule 110 cellular automata. One-way hash functions like SHA-256 as example.

Work

In thermodynamics and physics, "work" is the energy transferred to or from a system when a force is applied over a distance. In computational or informational contexts, it refers to the demonstrable expenditure of resources—time, energy, processing—for a specific purpose. Proof-of-work blockchains, for example, require participants to perform and show evidence of computational "work" that expends real energy.