Quantifying Work, Eliminating Time, and Minimizing Entropy

Causal invariance, entropy minimization, and energy-denominated money

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Intro

Solving a practical problem like reducing the error rate in the information system that is money. Scaling digital money while removing the intermediaries and providing guarantees of security. Several new innovations have revealed a connection to physics, complexity science, and transformation rules of symbolic expressions. To track the understanding, we dive into proof of entropy minima and it's connection to causal invariance and then build up from complexity science. Constraints and how constraints propagate in relation to work and gradient dissipation is best articulated via Deacon and Kauffman. This offers the intuition of seeing emergence and semiotics in new systems, which is the original attempt of how to solve a practical problem of a monetary system. What constraints are useful, where do I place the constraints, how to incentivize behavior and produce trust, and what are the emergent properties from that system that allow for further propagation of information. How does it relate to biotic and abiotic systems? To have an example connected to fundamental physics, explore tools and frameworks from complex systems and be practically useful with upside makes for this emergent exploration incredibly potent. The first part will establish the pursuit of scaling in blockchains, which will connect to wolfram physics multiway hypergraphs, which provide an intuition of transformation rules of symbolic expressions and complexity can arise from, then the intuition of computational irreducibility and how that informs constraints in what can be known, which is useful in identifying constraints throughout systems from physics to chemistry biology and cybernetics which brings us back up to the internet, blockchains, and monetary systems. From there, we look again at blockchains and the set of experimental innovations that may unlock the next stage of emergent growth in our economic systems.

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.

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.

This part of the paper introduces an integrative framework for understanding this Emergence, from physics to blockchain to economics and human based challenges. 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.

Introduction

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.
    - Can this be generalized from the second law of thermodynamics to the second law of statistical mechanics?

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.

This paper introduces an integrative framework for understanding Emergence. 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.

A Full Introduction

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.

Who is our observer and what assumptions are we making?

Meditation, Soccer, Video Games

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.
    - Can this be generalized from the second law of thermodynamics to the second law of statistical mechanics?

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

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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

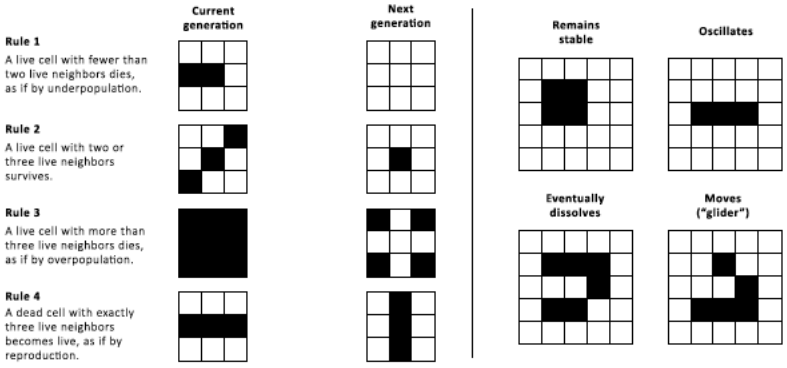
To fully empower the causal efficacy of a theory of emergence, one opens to power of transformation rules on symbolic expressions and a hierarchy of thermodynamics in order to see the full opportunity set in emergent paradigms. In order to see blockchains for their full potential, you'll want to understand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

Summary—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.

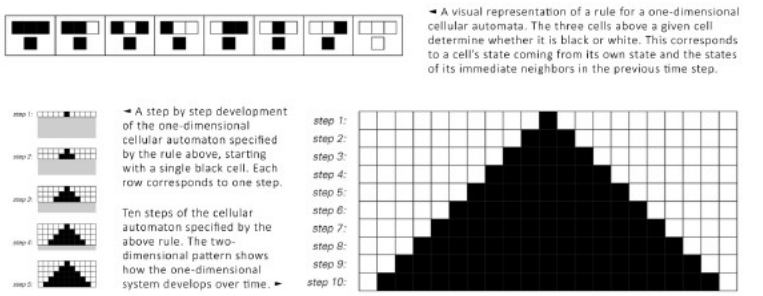
Cellular Automata

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:



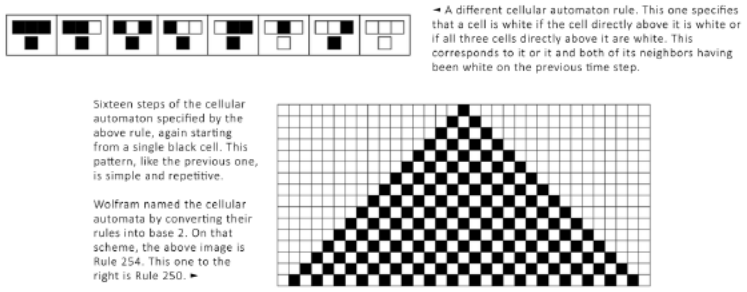
The Game of Life was later shown to be highly fruitful. In 1970, a team led by Bill Gosper found a repeating pattern in the Game of Life that would produce an endless stream of gliders. In 1982, Conway proved, using glider guns and other structures, that the Game of Life is "Turing complete," meaning 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:



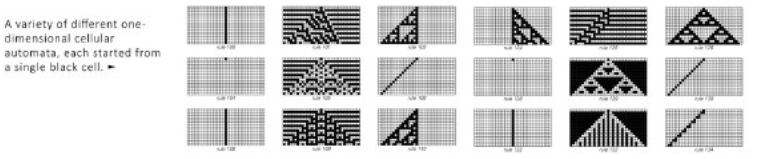
Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 24.

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:



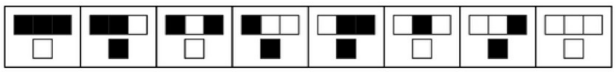
Images adapted with permission from S. Wolfram (2002), A New Kind of Science, Wolfram Media, p. 25.

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:



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:

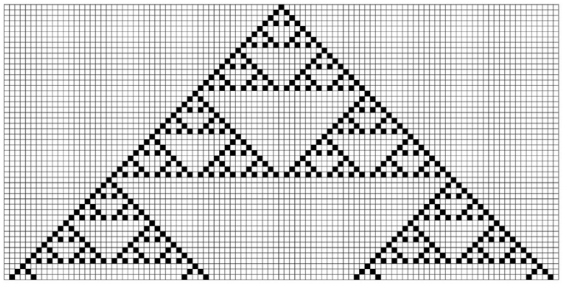


◄ Another simple cellular automaton rule. This rule says that a cell should be black if exactly one of its neighbors was black on the previous step, and otherwise white.

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

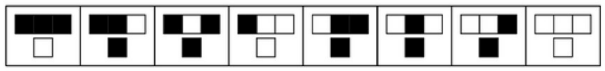
Nested patterns are characterized by parts being embedded in similar parts.

This rule is called Rule 90. ►



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

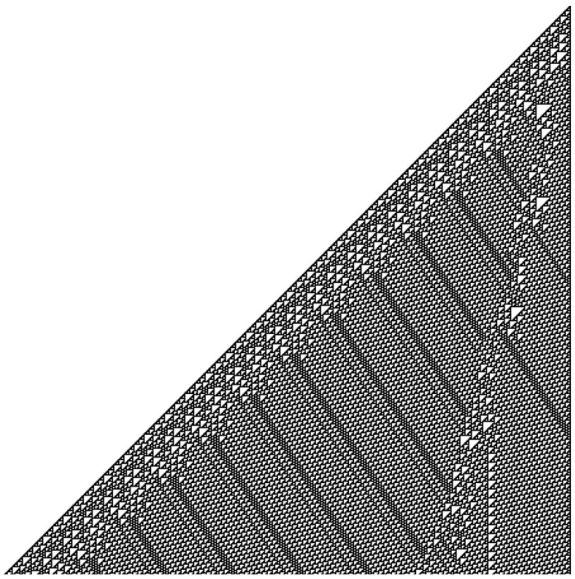
A third type of pattern also shows up, which contain neither repetition nor nesting, but instead a certain type of randomness. For instance, Rule 30 shows recognizable patterns going down the left, but on the right side shows a local randomness that no one, to date, has been able to find regularities 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.

Summary—Incomplete Nature

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.

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

Other 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)