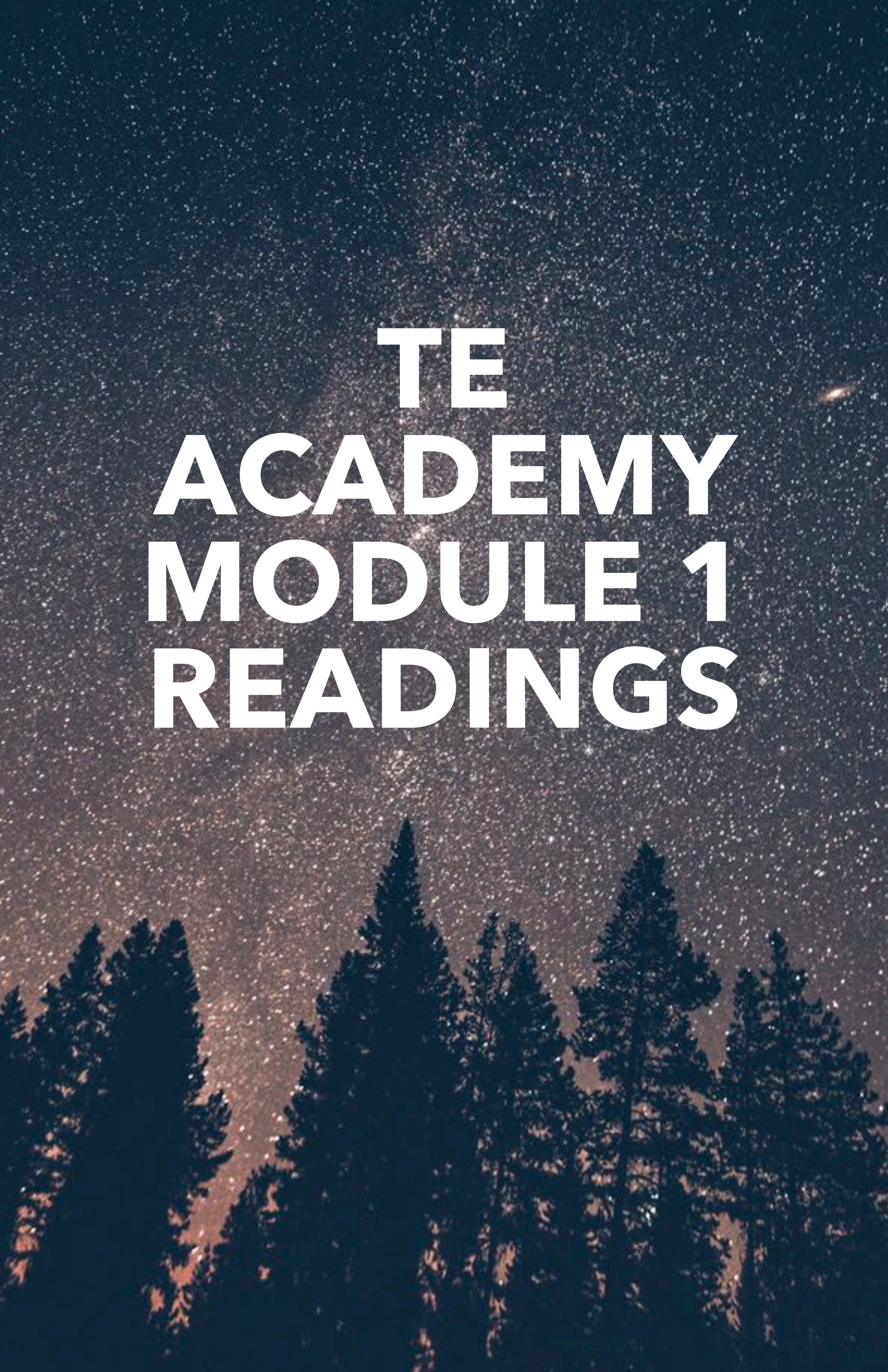
TE ACADEMY MODULE 1 READINGS



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Can Blockchains Go Rogue?

AI Whack-A-Mole, Incentive Machines, and Life. TE Series Part I.

Trent McConaghy · Follow
Published in Ocean Protocol
6 min read · Feb 27, 2018

1. Introduction

Arguably, the core feature of tokenized ecosystems, aka public blockchains, is *getting people to do stuff*. Incentives are powerful. But similar to AI / optimizer design, getting incentives right is *hard*. Blockchains can even be framed as life. In this context, what if we end up with a rogue life form sucking the life energy out of the planet? More pointedly: has Bitcoin gone rogue? This article explores these questions, in the first installment of a broader series aimed at improving the token design process.

We'll start from the perspective of optimization and AI, and wind our way back to blockchains and incentives.

2. AI Whack-a-Mole

For several years I worked on creative AI, making technology to synthesize analog circuits like amplifiers from scratch.

I'd do a synthesis run and find an issue, like "there are random dangling wires". Then I'd add a constraint, codified in computer science terms, such as "each node must connect to >1 edges" for the danglers issue.

Then I'd run again, and find another issue, like "current in this wire is 100x larger than sanity and will blow up the circuit". I'd fix it, and repeat the process.

This was fine for the first few constraints. But after a dozen or so it became very tiresome. It felt like this:

After much pain, I took a different approach to solve the problem, by implicitly capturing intent.

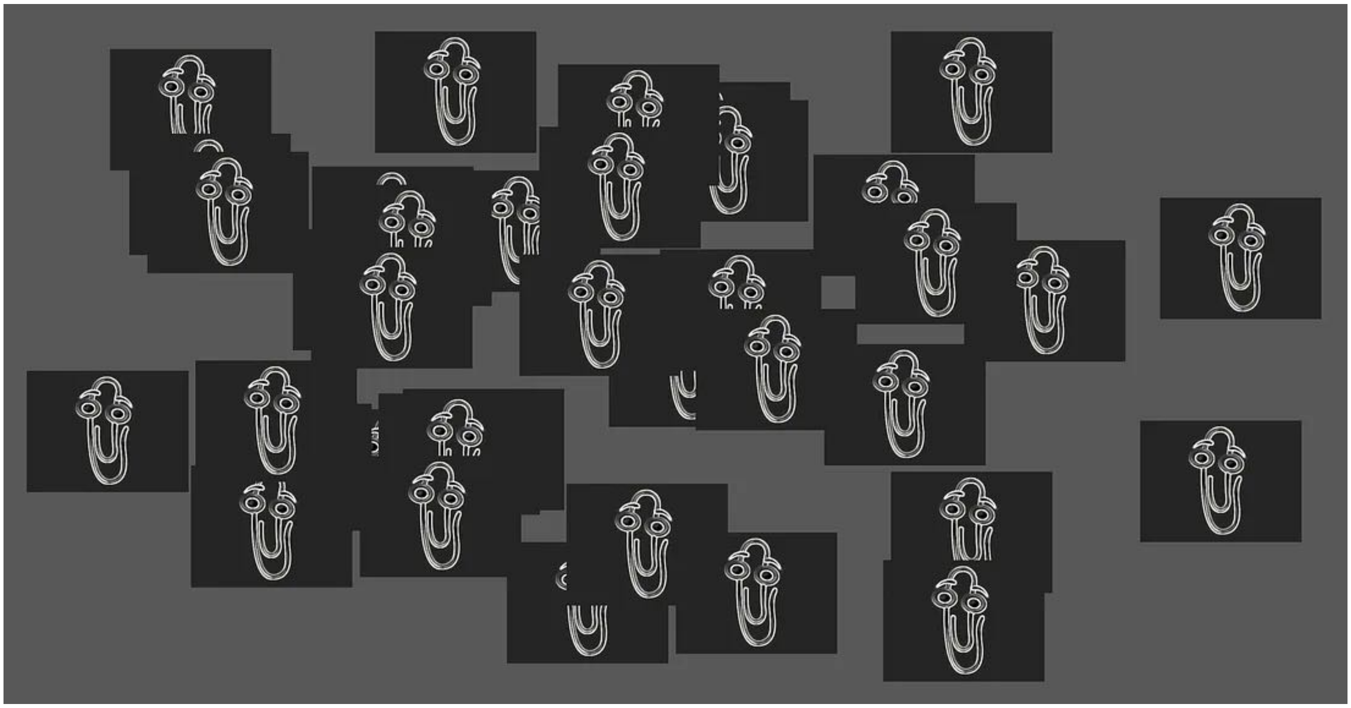
Just like software debugging, it's a challenge to bridge the gap between my intent and what the machine thinks I want. What I learned: setting the objective function and constraints is *hard*.

3. The Paperclip Maximizer

Communicating intent is hard. This idea underpins Nick Bostrom's Paperclip Maximizer:

> *Suppose we have an AI whose only goal is to make as many paper clips as possible. The AI will realize quickly that it would be much better if there were no humans because humans*

> *might decide to switch it off. Because if humans do so, there would be fewer paper clips. Also, human bodies contain a lot of atoms that could be made into paper clips.* ***The future that the AI would be trying to gear towards would be one in which there were a lot of paper clips but no humans.***



The paperclip maximizer.

In this scenario, the humans communicated the main goal — maximize paperclips — but missed a key constraint, namely, don't destroy humanity. But then how do you specify the latter constraint? Yep: it's hard.

It doesn't even matter if the AI is really stupid. As long as it has access to resources to keep growing, our world could end up being overrun with paperclips. Optimizers and AIs don't care about your intent, they just happily maximize away. Some people say "well, just unplug that AI". That would work for a centralized AI, but not a decentralized one (AI DAO).

4. Blockchains as Trust Machines

We've given context to optimizers. Let's now give context to blockchains. After that, we'll merge the contexts.

Blockchains have several great features above and beyond traditional distributed systems: **decentralized** (no single entity owns or controls them), **immutable** (once you've written to a blockchain, it's like it's cast into stone), and they make it easy to issue & transfer **assets**. This frames blockchains as **trust machines**. These features unlock higher level capabilities like **smart contracts**.

5. Blockchains as Incentive Machines

> *"Show me the incentive and I will show you the outcome."* -Charlie Munger

The blockchain community understands that blockchains can help **align incentives** among a tribe of token holders. Each token holder has **skin in the game**. But the benefit is actually more general than simply *aligning* incentives: you can *design* incentives of your choosing, by giving them block rewards. Put another way: **you can get people to do stuff, by rewarding them with tokens.** Blockchains are **incentive machines.**

I see this as a **superpower**. The *block rewards function* defines what you want network participants to do. Then the question is: what do you want people in your network to do? It has a crucial corollary: how well can you *communicate that intent* to the machines? This is a devilish detail. Do we really know how to design incentives?

6. Blockchains as Life?

Erwin Schrödinger framed life merely as physical processes in his treatise "What is Life?". More recently, physicist Jeremy England has given it a thermodynamic framing: it's all about entropy. Carbon is not a deity.

The Artificial Life (A-Life) community acknowledges that the definition of "life" is contentious. There are some things that clearly aren't life, like a hammer; and other things that clearly are, like a puppy. But there are shades of gray in between. We can think of it like a checklist of say 20 items. Autonomous mobility? Check. Self-replication? Check. Decision-making? Check. And so on. Check enough and "it's life".

Ralph Merkle wrote about Bitcoin as life:

> *Bitcoin is the first example of a new form of life. It lives and breathes on the internet. It lives because it can pay people to keep it alive. It lives because it performs a useful service that people will pay it to perform. … It can't be stopped. It can't even be interrupted. If nuclear war destroyed half of our planet, it would continue to live, uncorrupted.*

7. Bitcoin Gone Rogue?

To recap the last few sections:

- Designing objectives & constraints for an optimizer / AI is *hard.*
- An AI with access to vast resources yet has bad objectives & constraints could end badly for humanity (the paperclip maximizer).
- Bitcoin can be seen as a life form, or a super-stupid AI. It's nearly impossible to stop.

Let's bring these together. Recall Bitcoin's block rewards function (aka objective function): maximize security, by maximizing hash rate, by maximizing electricity usage. And it's optimizing against that objective remarkably "well." So well that it is on track to overtake USA by July 2019. And energy is perhaps the most important resource on earth. It's the thing we humans start wars over. (Oil, remember?)

In short:

> We have a life form that we basically can't stop, which is optimizing maniacally for that most precious resource — energy. This life form is called Bitcoin.

How's *that* for the power of incentives? Which means: we *need* to get incentives right when we build these tokenized ecosystems.

8. Conclusion

Satoshi almost certainly didn't mean to suck the life force out of the planet. Objective function design aka incentive design is *hard*. But we have to try! To do a good job, we need solid engineering theory, practice, and tools. That is, *token engineering*. The next article in this series explores this further.

Appendix: From People to AIs

While this article has emphasized the use of block rewards to get *people* to do stuff, they can also get *AIs* to do stuff. There are interesting implications…

Appendix: AI Inside Bitcoin

Interestingly, AIs can live *inside* blockchains too: Sgantzos discovered a genetic algorithm inside Bitcoin [to be presented at HSCBB17].

Appendix: Context in Series

This article the first of a series:

- **[this article] Part I. Can Blockchains Go Rogue?** AI Whack-A-Mole, Incentive Machines, and Life.
- **Part II. Towards a Practice of Token Engineering:** Methodology, Patterns & Tools.
- **Part III. Token Engineering Case Studies:** Analysis of Bitcoin, Design of Ocean Protocol.

I gave a talk about much of this content in Berlin in Feb 2018. Here's the **slides** and **video**. I gave a related talk about complex systems at Santa Fe Institute, New Mexico in Jan 2018. Here's the **slides** and **video** from that talk.

Further Resources

[June 1, 2018] Publication of this series seems to have sparked movement in #tokenengineering. Awesome! :):) A key resource is the wiki tokenengineering.net. It has info about building blocks, tools, community meetups, and more.

Acknowledgements

Big thanks to Troy McConaghy for first making the paper clip — Bitcoin connection, and to Joel Monegro who encouraged me to focus more attention on tokens way back in 2016.

Thanks to the following people for reviews of this and other articles in the series: Ian Grigg, Alex Lange, Simon de la Rouviere, Dimitri de Jonghe, Luis Cuende, Ryan Selkis, Kyle Samani, and Bill Mydlowec. Thanks to many others for conversations that influenced this too, including Anish Mohammed, Richard Craib, Fred Ehrsam, David Krakauer, Troy McConaghy, Thomas Kolinko, Jesse Walden, Chris Burniske, and Ben Goertzel. And thanks to the entire blockchain community for providing a substrate that makes token design possible :)

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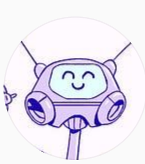

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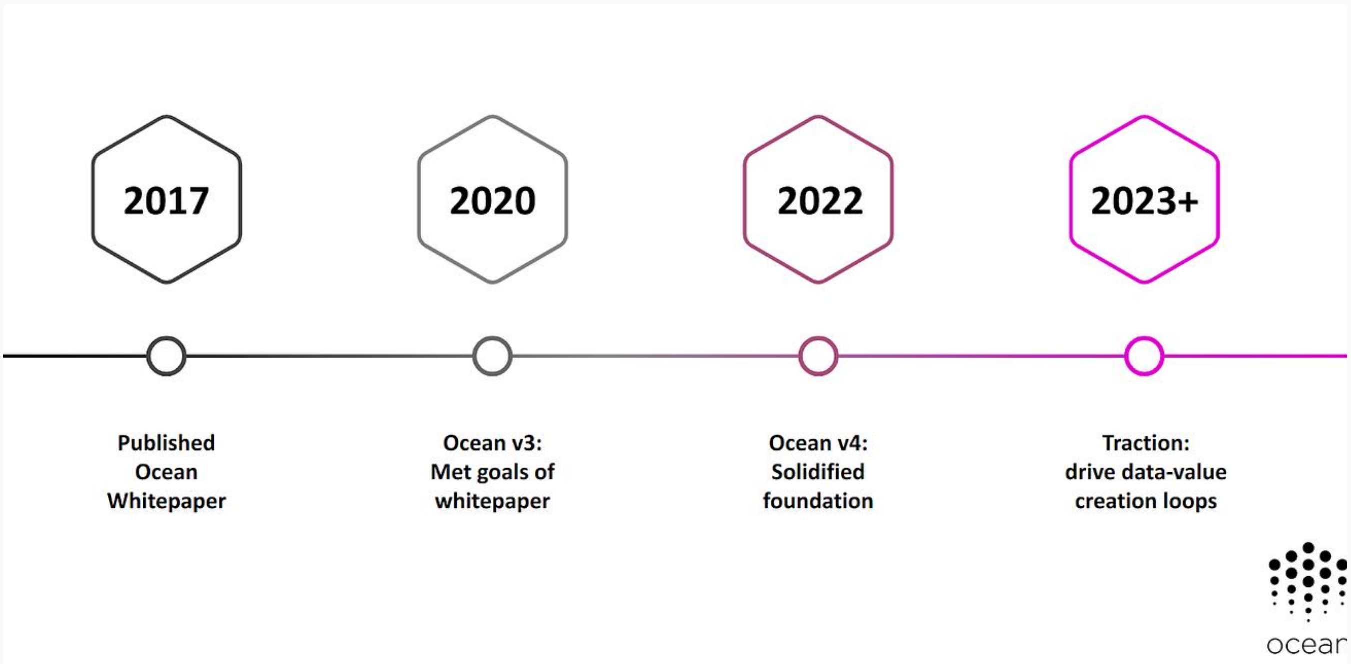

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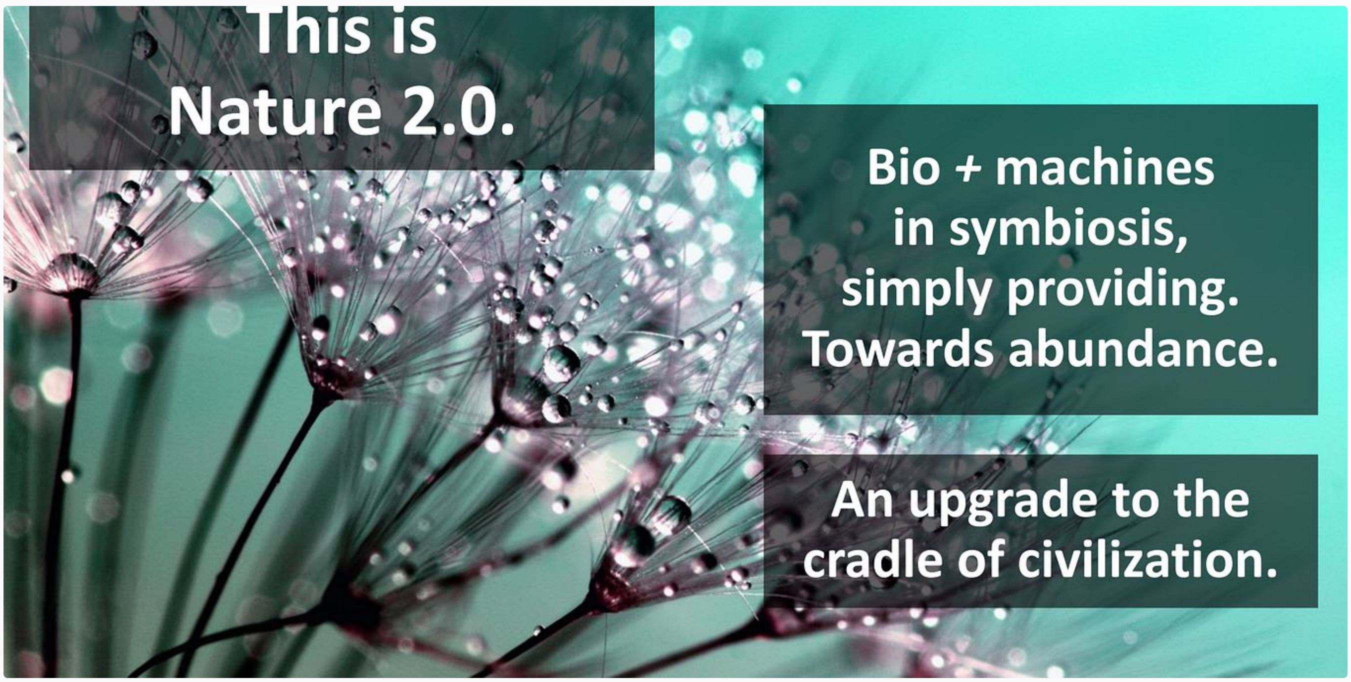

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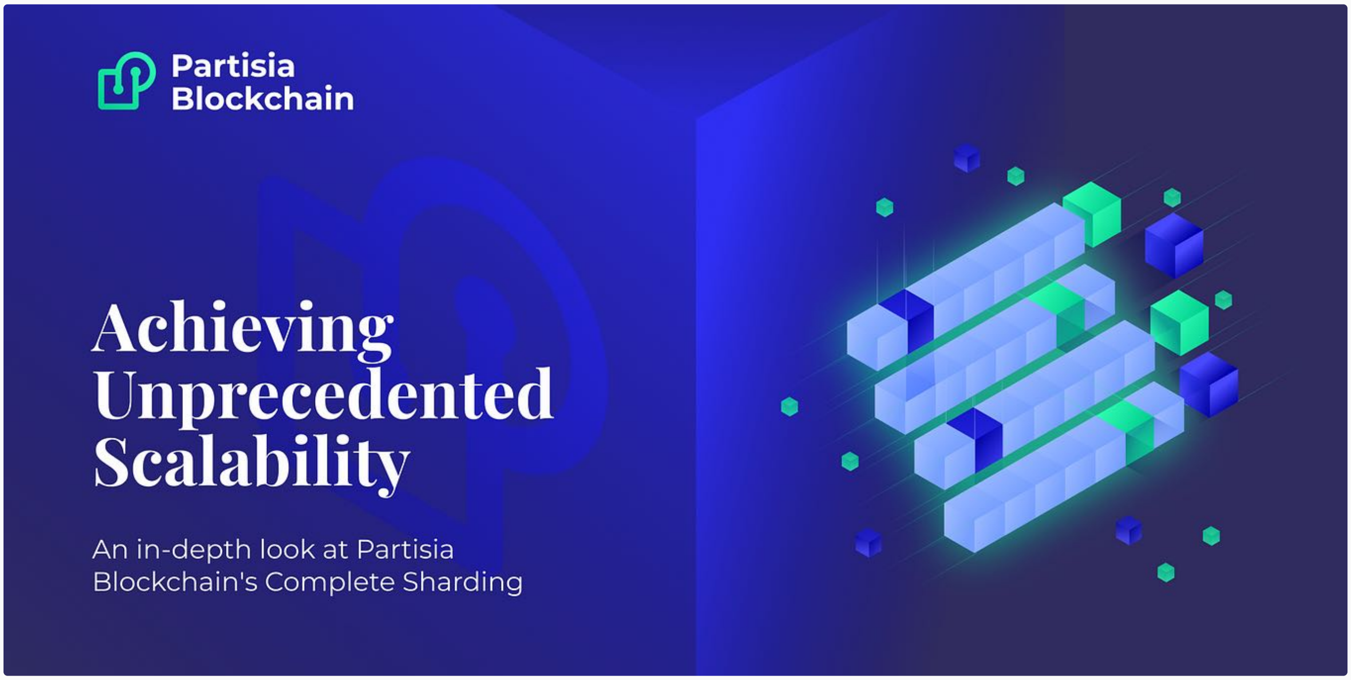

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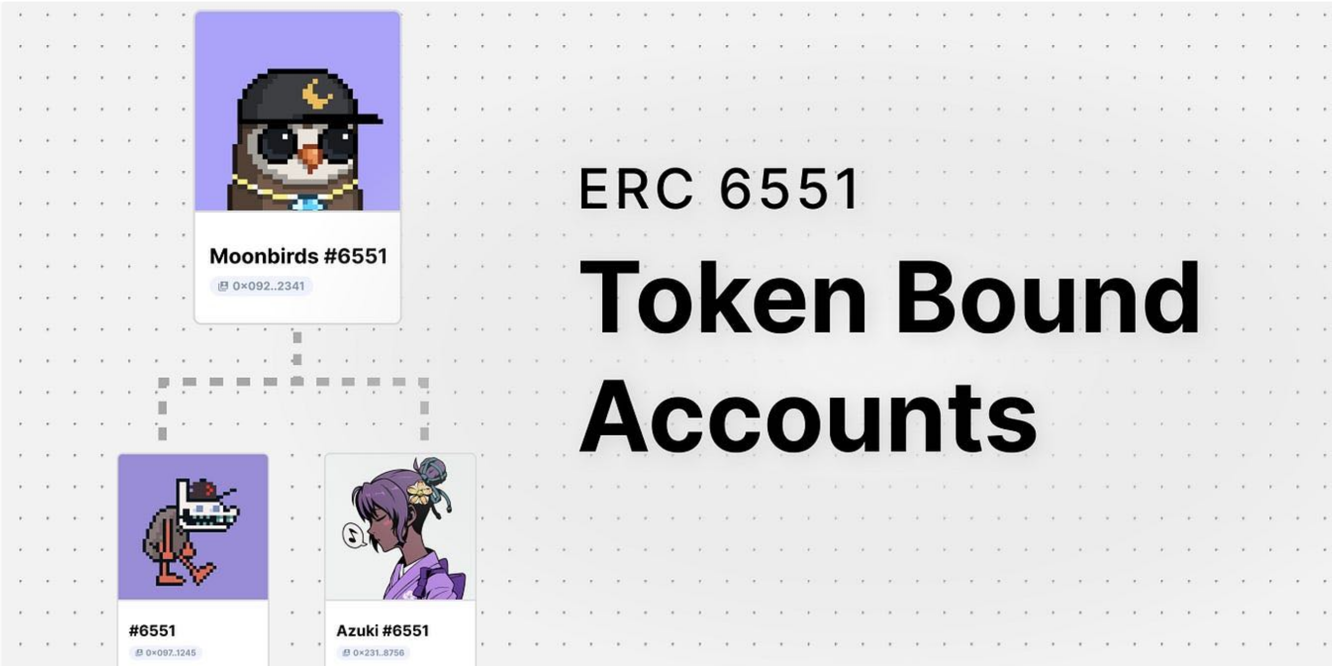

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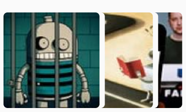

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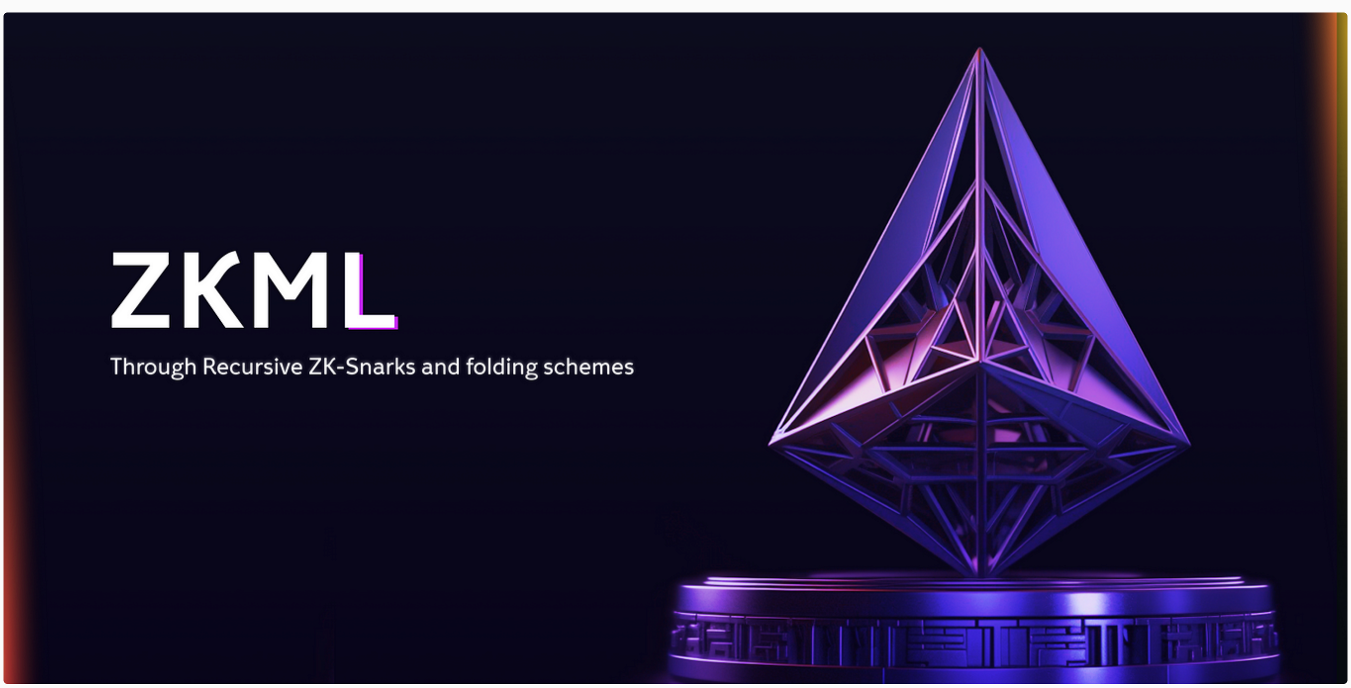

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Towards a Practice of Token Engineering

Methodology, Patterns & Tools. TE Series Part II.

Trent McConaghy · Follow
Published in Ocean Protocol
21 min read · Mar 1, 2018

1. Introduction

In my previous article, I described *why* we need to get incentives right when we build tokenized ecosystems. Here, I ask: *how* do we design incentives for these tokenized ecosystems? And actually since incentives are the heart of tokenized ecosystems, it's really: *how do we design tokenized ecosystems?* And, how do we *analyze* and *verify* them?

This article is a first stake in the ground towards a practice of **token engineering**: the theory, practice and tools to analyze, design, and verify tokenized ecosystems.

The first section of this article relates token designs to other fields and explains why "engineering". The rest of this article is an attempt to draw us closer to this goal, by leveraging existing fields in three main ways:

- We can frame **token design as optimization design**, then use optimization design methodology.
- Inspired by **software engineering patterns**, we can document emerging patterns for token design.

- **Simulation, verification, and design space exploration (CAD tools)** for circuit design have helped engineers analyze, design, and verify wickedly complex chips. We can look forward to similar tools for tokenized ecosystems.

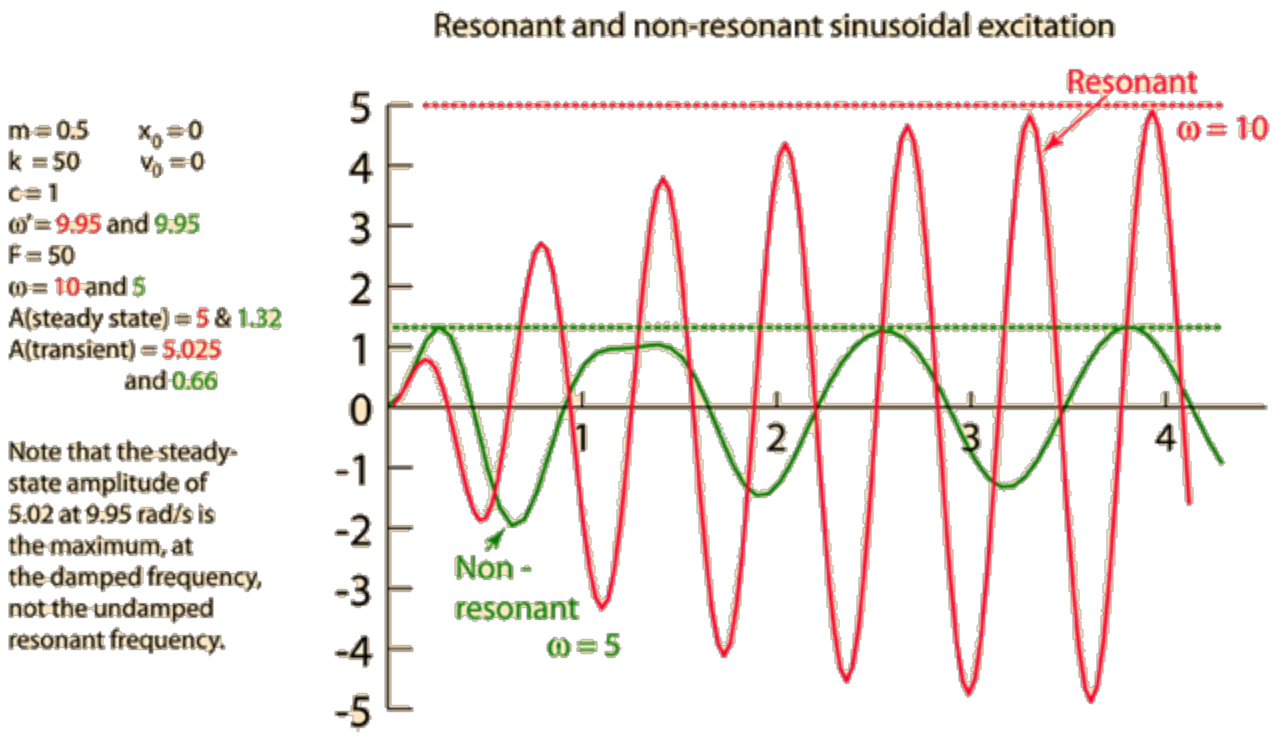
2. Engineering, Game Theory, and More

This section relates token design to other fields.

2.1 The Tacoma Narrows Bridge

In the first week of my engineering studies, our solemn-faced professor showed us this:

How did the bridge collapse? The designers *did* anticipate for wind, after all. However, they failed to anticipate that the particular wind patterns would set up *resonance* with the bridge itself. When you have an appropriately timed force applied to a system in resonance, the amplitude of the resonance *grows* over time. The figure below illustrates, where green = non-resonant and red = resonant = disaster.



[Image from here]

The video was to teach about *responsibility*. The designers of the bridge could have prevented the disaster by being *thorough,* and applying appropriate theory, practice, and tools. Other professors showed that video several times over the years during my studies. Those viewings culminated in a ceremony to receive iron rings upon graduation. All Canadian engineers have these rings. According to legend, the rings are forged from the metal of a collapsed bridge.

2.2 Game Theory and Mechanism Design

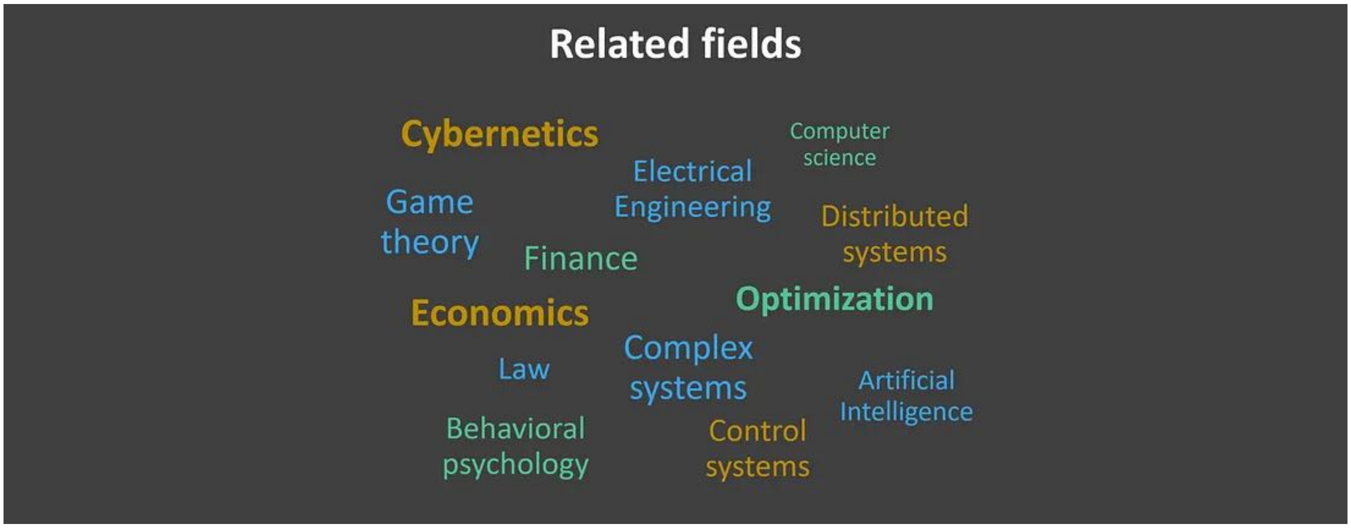
Game Theory is a scientific field that **analyzes** incentives, from an economic standpoint. It has a counterpart in economics for **designing (synthesizing)** incentivized systems, called **Mechanism Design**. In fact Mechanism Design is really *the* field for design of tokenized ecosystem, in theory. Researchers in that field have come up with a lot of great theory over the years, at literally Nobel prize levels of quality. Closely related is Economic Game Theory.

However, traditionally there hasn't been a good way to reconcile that theory with *practice*. After all, how often does an academic economist (or anyone, really) get a chance to deploy an economy? Yet this is the exact problem we are confronted with in designing tokenized ecosystems. The closest are likely video game economies and public policy design.

However, it turns out that if you zoom in on Mechanism Design with a few practical constraints, you end up with Optimization Design! People doing Optimization Design have a tremendous amount of practical experience deploying optimizer systems over the years. Myself included: my first and second startups (ADA, Solido) did exactly that, for use in industrial-grade circuit design.

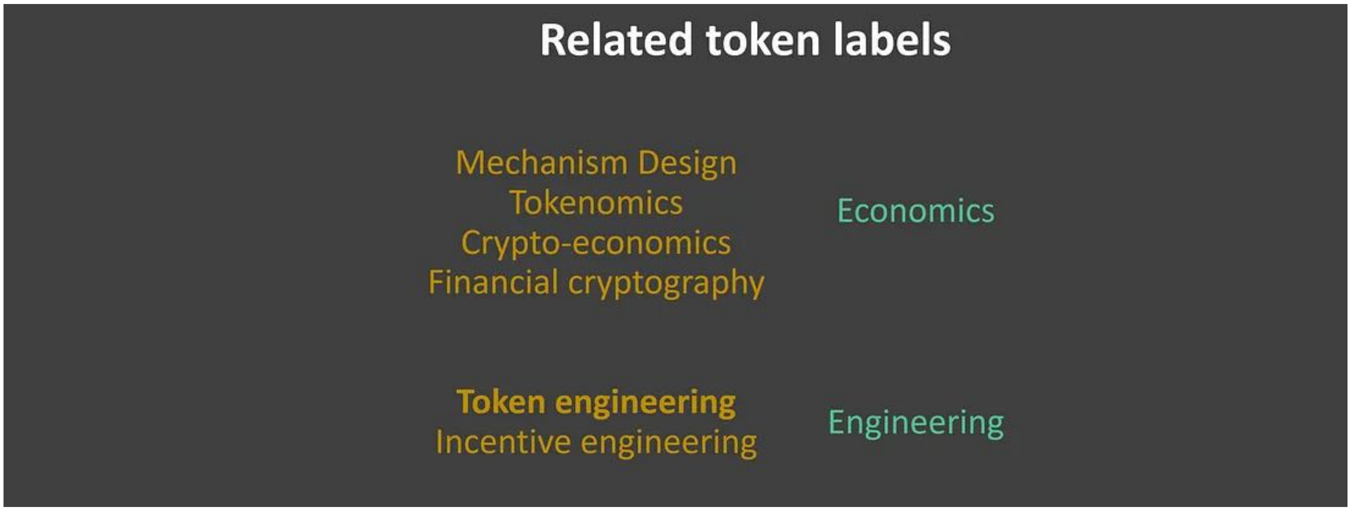
2.3 Other Related Fields

Many other fields have something to say about token design as well; at the very least in the sense that experts from those fields will find that many of their skills translate well to token design. These include everything from electrical engineering to complex systems, from economics to AI. I list a few below. And of course many of them have roots in good ol' cybernetics.



2.4 Engineering and Token Design

What should we be calling this field in which we design tokenized ecosystems? I list some options below.



The first four terms are **economics**-biased. That's fine; it makes sense for analyzing price movement, valuations, and so on.

I'm trained as an electrical engineer (EE). EEs doing circuit design have theory, have practice, and build systems that *just work*, such as the screen you're reading and the chips that power it, to the lights over your head.

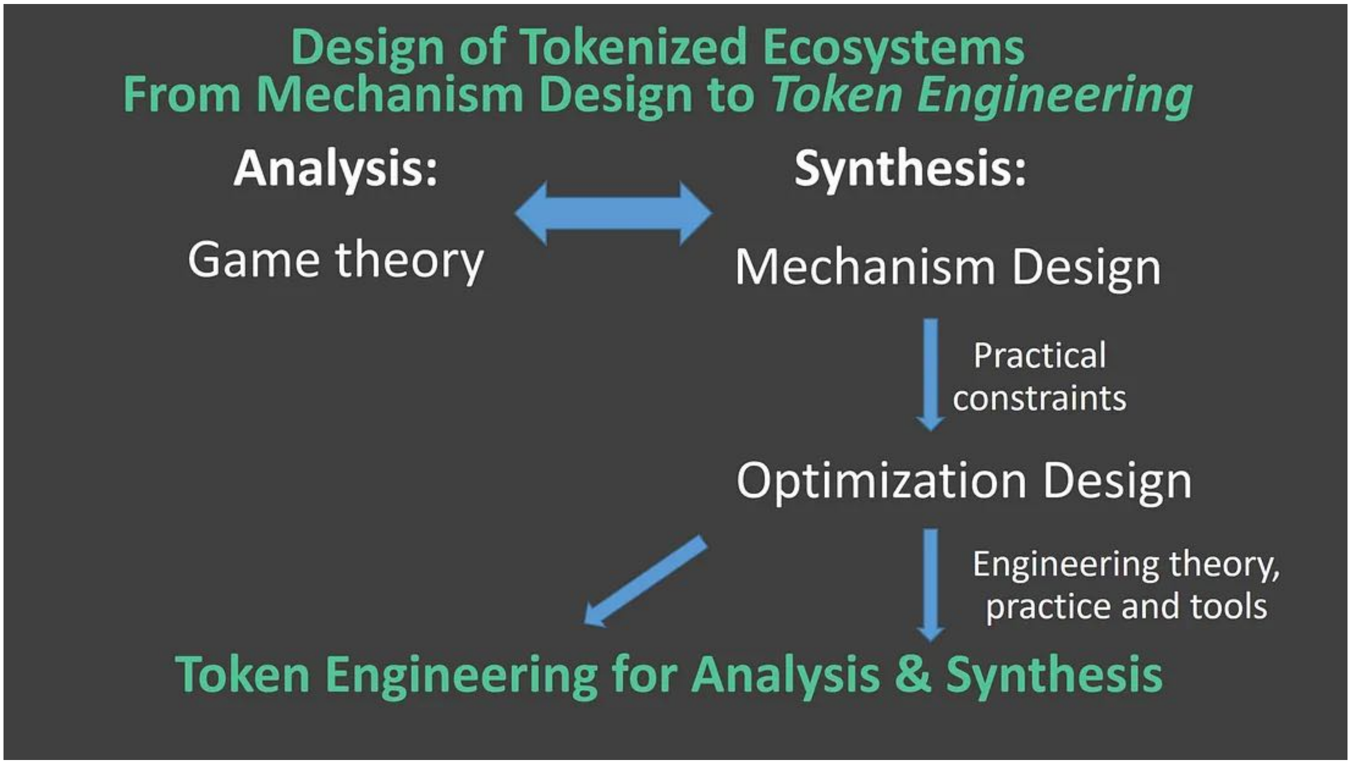
Engineering is about **rigorous analysis**, **design**, and **verification** of systems; all assisted by tools that reconcile theory with practice. Engineering is also a discipline of **responsibility**: being ethically and professionally accountable to the machines that you build, as illustrated by the Tacoma Narrows Bridge viewings and iron rings.

I saw the rise of the discipline of software *engineering* in the 90s; that made sense as it encouraged rigor and responsibility.

I'd love to see token ecosystem design become an engineering discipline, side-by-side with electrical engineering, software engineering, civil engineering, aerospace engineering, and so on. This implies that token ecosystem design would also become a field of rigorous analysis, design, and verification. It would have tools that reconcile theory with practice. It would be guided by a sense of responsibility. It would be **token engineering.**

[Note: As for "token" vs "incentive", "token" is shorter and easier to compare to its economics counterpart "Tokenomics".]

The image below shows how these fields relate. The goal is a practice of token engineering.



3. Token Design as Optimization Design

Token design is like optimization design: at a high level, you encode intent with a block rewards function aka objective function, and you let it fly. As is often the case, Simon de la Rouviere saw this one first.

It gets more specific than that. Token design is *especially* like evolutionary algorithms (EAs), where there are many agents "searching" at once and there is no top-down control of what each agent does. Agents live and die by their block reward or fitness. The table below summarizes the relation.

With such similarities, *we can use best practices from optimization / EA to when doing token design*. This is great news, because many people are Jedis in designing EAs and optimization systems.

Design of Tokenized ecosystem
≈ Design of EAs (Evolutionary Algorithms)

What	Tokenized ecosystem	Evolutionary Algorithm
Goals	Block reward function E.g. “Maximize hash rate”	Objective function E.g. “Minimize error”
Measurement & test	Proof E.g. “Proof of Work”	Evaluate fitness E.g. “Simulate circuit”
System agents	Miners & token holders (humans) In a network	Individuals (computer agents) In a population
System clock	Block reward interval	Generation
Incentives & Disincentives	You can’t control human, Just reward: give tokens And punish: slash stake	You can’t control individual, Just reward: reproduce And punish: kill

Let’s elaborate on each row in the table.

3.1 Goals

Both tokenized ecosystems and EAs have **goals**, in the form of **objectives** (things to maximize or minimize) and **constraints** (things that must be met). To get fancy, this can even be stochastic.

The tokenized ecosystem might give block rewards for an objective function of “maximize hash rate” whereas an EA objective might be “minimize error” in training a deep net. Constraints might be “must have stake ≥threshold to participate” or “deep network layers=100” respectively.

Variants include single-objective optimization (1 objective, 0 constraints), constraint satisfaction (0 objectives, ≥1 constraints), and multi-objective constrained optimization (≥2 objectives, ≥1 constraints).

3.2 Measurement & Test

To **test / measure** success against the goals (objectives & constraints), a tokenized ecosystem relies on **proofs** and an optimizer measures **fitness** using e.g. a **simulator**.

For example, a Bitcoin node proves that a user was hashing by verifying that the user's supplied nonce solves the the cryptographic puzzle.

An optimizer might test the goodness of a circuit by running a SPICE simulation of the circuit's differential equations; simulation results can be verified by testing whether they indeed solved Kirchoff's Current and Voltage Laws.

3.3 System Agents

In both systems, **agents** run about "doing things".

In a tokenized ecosystem, **network stakeholders** such as **miners** (or **users** more generally) do whatever it takes to earn block rewards. They jostle about, doing what it takes to get more token rewards. For example, in Bitcoin some agents might design, build, and run ASIC chips to get higher hash rate. Other agents might pool their existing compute resources. The system does not need to explicitly model all stakeholders in the ecosystem. For example, Bitcoin doesn't have specific roles for banks or nations or companies; it's mostly all about the miners.

In an EA, you have **individuals** in a **population.** If they're "good" they have higher fitness. For example, an individual may be a vector of 10,000 weights for a neural network. "Actions" of individuals are basically when they survive and have variants made of them, via operators like crossover (e.g. interpolation) or mutation (e.g. randomly perturbing each parameter).

3.4 System Clock

Each system has a **clock**, implying a **time dimension** by which **progress** is made / **convergence** is happening.

Batches. Typically, agents are processed in batches or epochs. A tokenized ecosystem periodically generates a **new block** and gives block rewards. The new block points to the old block; and new work in the system will add to the new block; and so on. This linked list of blocks implies a Lamport-style logical clock. In EAs, each batch is a **generation** where a whole population of individuals gets updated at once. Each generational loop might include: evaluate individuals, select the best, let them make children, repeat.

Continuous. In some systems, agents are processed more **continuously** rather than batches. These systems usually takes a bit more work to conceptualize, but may lead to better properties for some problems. For example in tokenized ecosystems, a Stellar transaction only needs validation from quorum slice participants, or another node gets added to a DAG (directed acyclic graph) like in Iota. In EAs, we have steady-state evolution where one individual at a time is replaced.

3.5 Incentives & Disincentives

The system itself cannot control how the agents behave. (Or at the very least, it shouldn't *need* to control them.) As such, **top-level behavior must be an emergent property of bottom-up actions by agents**. This is necessary for tokenized ecosystems; otherwise they'd be centralized! It's not an absolute must for EAs, but nonetheless a broad set of EAs take this approach for simplicity / elegance or meeting other design goals.

This means the system can only reward or punish behavior, aka carrots or sticks, aka **incentives** and **disincentives**. In designing the system, we *design* what rewards or punishments to give, and how to give them.

In tokenized ecosystems, rewards take the form of block rewards, and punishments by slashing stake. The former is typically the objective function; the latter is some (but not all) constraints.

In EAs, reward and punishment both come down to which individuals are selected to be parents for the next generation. Examples: randomly choose two individuals and keep the best, repeating until full (tournament selection); and chance of selection is proportional to fitness (roulette wheel selection). Crucially, the EA does *not* need to steer the individuals by e.g. providing a derivative. This is why a tokenized ecosystem is most like an EA, versus gradient-based optimizers that give top-down directives (using gradients to choose new individuals).

4. From Optimization Methodology to Token Methodology

4.1 Introduction

This section is some initial notes towards treating token design like the engineering discipline it deserves to grow into.

First, I describe a structured methodology for optimization design. Then I describe how a similar methodology could be applied for incentive design.

Next, I describe key tools used in circuit design: simulators, verification tools, and design space exploration tools; and how they might be applied for circuit design.

Finally, I start to enumerate some design patterns.

4.2 Optimization Methodology

These communities only partly talk to each other. But practitioners of the algorithms all do something very similar. They want to ship optimizer systems that *just work*. They follow the following steps. Some do it implicitly, though the pros do it systematically:

1. **Formulate the problem:** They assume that the algorithm "just works" and they focus on formulating the problem in terms of **objectives and constraints** (goal) and design space (where can the optimizer explore, which is really just constraints).
2. **Try an existing solver:** Then they run the algorithm against those goals and let it "solve". Code for optimization algorithms are often simply called "**solvers**". If this doesn't work, practitioners will iterate by trying different problem formulations, or different solvers and solver parameters.
3. **New solver?** If the previous solving step doesn't work, even after repeated tries on various formulations, then practitioners consider rolling their own solver, i.e. designing a new optimization algorithm.

Let's explore each step in more detail.

Step 1. Formulate the Optimization Problem

Look in almost any optimization-related paper, and you'll see it display the objectives and constraints. In examples from my own work, equation (1) of this paper (in sec. 5) is a formulation for a multi-objective constrained optimization across a search space defined by a grammar. Here's a snippet:

> The algorithm's aim is formulated as a constrained multi-objective optimization problem
>
> $$\begin{array}{rll} \text{minimize} & f_i(\phi) & i = 1 \ldots N_f \\ \text{s.t.} & g_j(\phi) \leq 0 & j = 1 \ldots N_g \\ & h_k(\phi) = 0 & k = 1 \ldots N_h \\ & \phi \in \Phi & \end{array} \qquad (1)$$
>
> where Φ is the "general" space of possible topologies and sizings. The algorithm traverses Φ to return a Pareto-optimal

As another example. Equations (1) and (2) of this paper (in sec. 2) lay out a stochastic single-objective ("maximize yield") optimization search problem across an n-dimensional continuous-valued variable space.

Formulating a problem in objectives, constraints, and design space is not easy. In fact, after all these years, it's still an art that takes a lot of creativity. (Which means it's fun!) There are often many ways to formulate a problem; and all are not equal . Fortunately, you can get better with practice. I watch friends in the EA community and circuit computer-aided design (CAD) community who have supreme skills in the art of formulating problems. You know who you are;)

- For example, one formulation might be easy to solve and another might be NP-hard and you can't guarantee anything. This is one of the big tricks used by people in the convex optimization field: they take problems that are perceived as NP-hard, then apply techniques to convert those to convex problems (e.g. well-placed log operators). Then, these convex problems can be solved in polynomial time using a convex solver like geometric programming. I've found success in this too; for the problem summarized by the snippet above, I added grammatical constraints to a tree induction problem (analog circuit synthesis) and saw a 1000x improvement in runtime as well as better results from the optimizer.

- Or, if you're using an evolutionary algorithm (EA), you want to design the mapping from design point → fitness such that small changes to the design usually lead to small changes to behavior and ultimately fitness. (I call these smooth operators ;)

Step 2. Try an Existing Solver

Ideally you can formulate the problem such that you can apply an existing solver or algorithm. Then, you simply run it and see how it does.

If it works: you're done, and you can stop now!

There's at least two ways it might not work. First, If the solver doesn't converge well enough, then you can try different problem formulations, solvers or solver parameters.

Second, the solver could converge too "well", where it finds a design that is wonky. To address this, you can modify the problem: add a new constraint or improve the accuracy of the model / simulator. If you finds yourself in tedious iterations of adding constraints ("AI whack-a-mole") then you'll probably want to re-think your broader approach to the problem.

Step 3. New Solver? Design a New Optimization Algorithm, If Needed

Sometimes you come across a problem where none of the existing solvers are good enough. Perhaps you need better scale, or perhaps you need to handle some constraint that's hard to model, or perhaps something else. That's when you go and do research on algorithm design. When you're doing this, you'll usually leverage existing building blocks, and add in your own ideas. Designing new algorithms can take a tremendous amount of time, but done well, you may be able to solve the problem at hand with order-of-magnitude improvements, for example FFX.

(And, did I mention, it's *fun*?)

4.3 Token Methodology

Block rewards are a manifestation of the network's **objective function** — the thing you want to minimize or maximize. This generalizes. Token design is like design of optimization algorithms. Therefore:

> We can approach token design as optimization design.

We can take the steps from the world of optimization design, and translate them into designing tokenized ecosystems.

1. **Formulate the Problem:** write down the objectives and constraints for your tokenized ecosystem. This means asking: who are my potential stakeholders, and what do each of them want? What are attack vectors? Then translating those into objectives and constraints that you can measure.

2. **Try An Existing Pattern:** Identify if there is an existing solver, i.e. tokenized network design pattern that can solve your problem. For example, if you're looking for a list of "good" actors/assets/etc, will a token curated registry (TCR) do? I elaborate on this later. If this doesn't work, try different problem formulations, different solvers or solver parameters. For example, it converges to unwanted behavior, so you add a constraint to prevent that behavior.

3. **New Pattern?** If needed, roll your own solver, i.e. design your own tokenized network. Of course when doing this, use existing building blocks where possible, from TCRs to arbitration.

5. Token Design Patterns : A Starting Point

Every mature engineering field has its corpus of building blocks .We have books for design patterns in architecture, software, analog circuits and, yes, optimizers. But, no one's written the book on *token design patterns*, yet.

However, building blocks are starting to emerge. Some have seen popularity explode quickly (e.g. TCRs). The paragraphs below explore these blocks. Sometimes they form core token mechanics; sometimes they get bolted in to solve particular problems. This list is just a starting point.

- **Curation.** *Binary* membership: Token Curated Registry (TCR), e.g. to maintain a list of good actors. A sub-block of TCRs is risk-staking to reduce onboarding friction. *Discrete-valued* membership: Stake Machines, e.g. for promoting an actor. *Continuous-valued* membership: Curation Markets (CM) for popularity of an asset, defined by its bonding curve with design guidelines here. *Hierarchical* membership: each label gets a TCR (like here). *Work* tied to membership: Curated Proofs Market Market (CPM). Curation on non-fungible tokens: Re-Fungible Tokens (RFT).

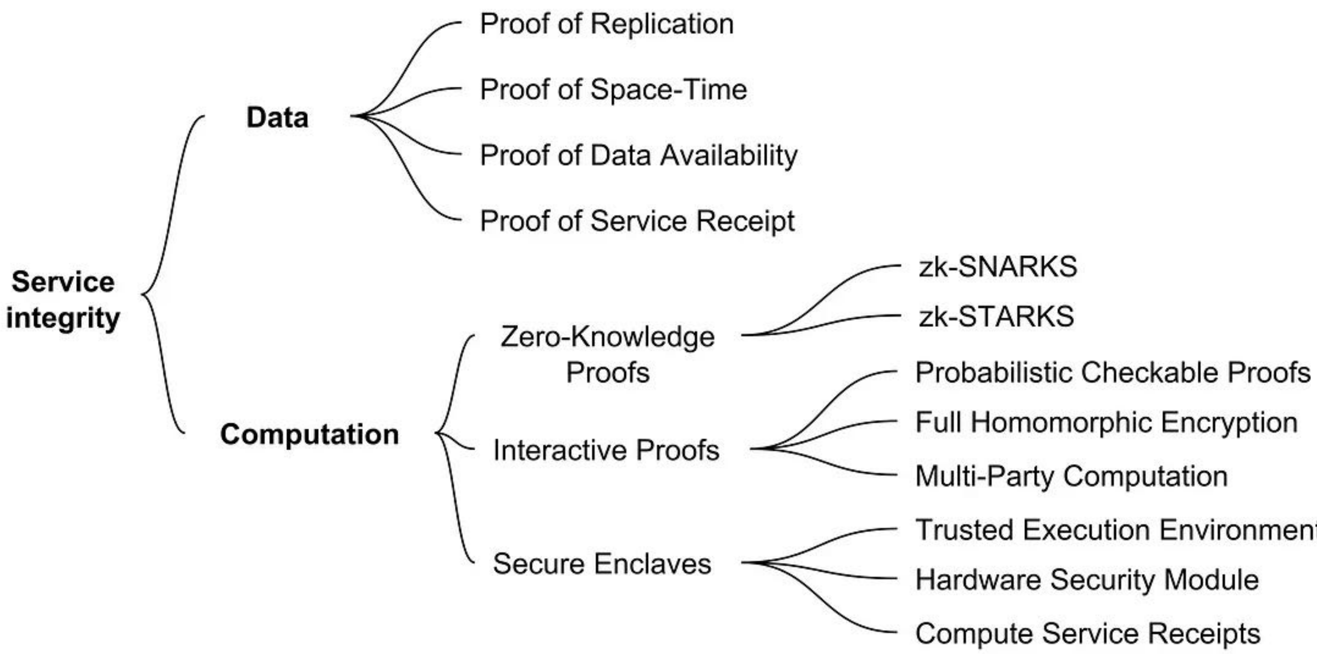
- **Identity.** *Lower level:* public key, decentralized identifiers (DIDs). *Medium level*: TCR. *Higher level*: e.g. uPort, Civic, Sovrin, Authenteq, Taqanu, Estonia E-Residency. *Identity of machines:* e.g. Spherity

- **Reputation.** Reputation systems are at the intersection of curation and identity.

- **Governance / software updates.** This can be a mix of ZeppelinOS, Aragon, Colony, and more. Maybe eventually automated?

- **Third-party arbitration.** E.g. Mattereum.

- **Proofs of human or compute "work".** For data, compute, and more. This the evaluation of the objective function. It can be can *human work* like in Steemit or Augur, or *machine work* like in most other systems. Machine work may be solving an (arguably) less-useful puzzle like in Bitcoin, or more "useful" work like FileCoin's Proof of Space-Time. Here's a breakdown of useful work ("service integrity") grouped by *data* and *computation* (from here).



Other ways to frame or group building blocks include:

- **How tokens are distributed.** This includes releasing coins for "work", according to a controlled supply schedule; 100% pre-mining; burn-and-mint; bounty ICOs; and more.
- **Ethereum token standards**, such as ERC20 fungible token and ERC721 non-fungible token. Billy Rennekamp's **token lexicon** is helpful.
- **How tokens are valued.** As a means of exchange, store of value, and unit of account, by Chris Burniske.
- **How keepers are grouped.** For gatekeeping, arbitrage, or resource transaction, by Ryan Zurrer.
- **How the compute stack is organized.** Processing, storage, etc. This has variants by Fred Ehrsam, Stephan Tual, and myself.
- **Level-1, level-2, level-N infrastructure.** The core chain is level 1. The higher levels are to help scale without having to reconcile the main chain on every transaction. Link.

- "**Cryptoeconomic primitives**" by Jacob Horne. Another label for token design patterns or building blocks. [Published after initial publication of this work.]

This enumeration of patterns is just a starting point; I look forward to watching it grow.

6. Needed: Tools for Simulation, Verification, and Design Space Exploration

6.1 What

Professional engineers building things that "just work" use *software tools* for it. Software engineers often use integrated design environments (IDEs) that are free or relatively cheap.

But you can get much more sophisticated. In circuit design, the key tools are for simulation, verification, and design space exploration. The tool stacks can become quite sophisticated over time. But with these tools, it enables a team of 10 engineers to design a billion-transistor chip in a matter of *months*. A good engineer might be running $1M worth of tools (that's the *annual* licensing cost!).

> *"Now You're Playing with Power" — Nintendo 1980s marketing slogan*

Let's get some power tools for this new field. We need:

1. **Tools to simulate tokenized ecosystems**. Simulators measure performance metrics of a given design. One starting point is the agent-based modeling that's coming out of the fields of complexity science and artificial general intelligence. Another is the simulators for networks already used for consensus algorithm design. Another is modeling as a set of differential equations (DEs), then solving with a DE solver like SPICE.

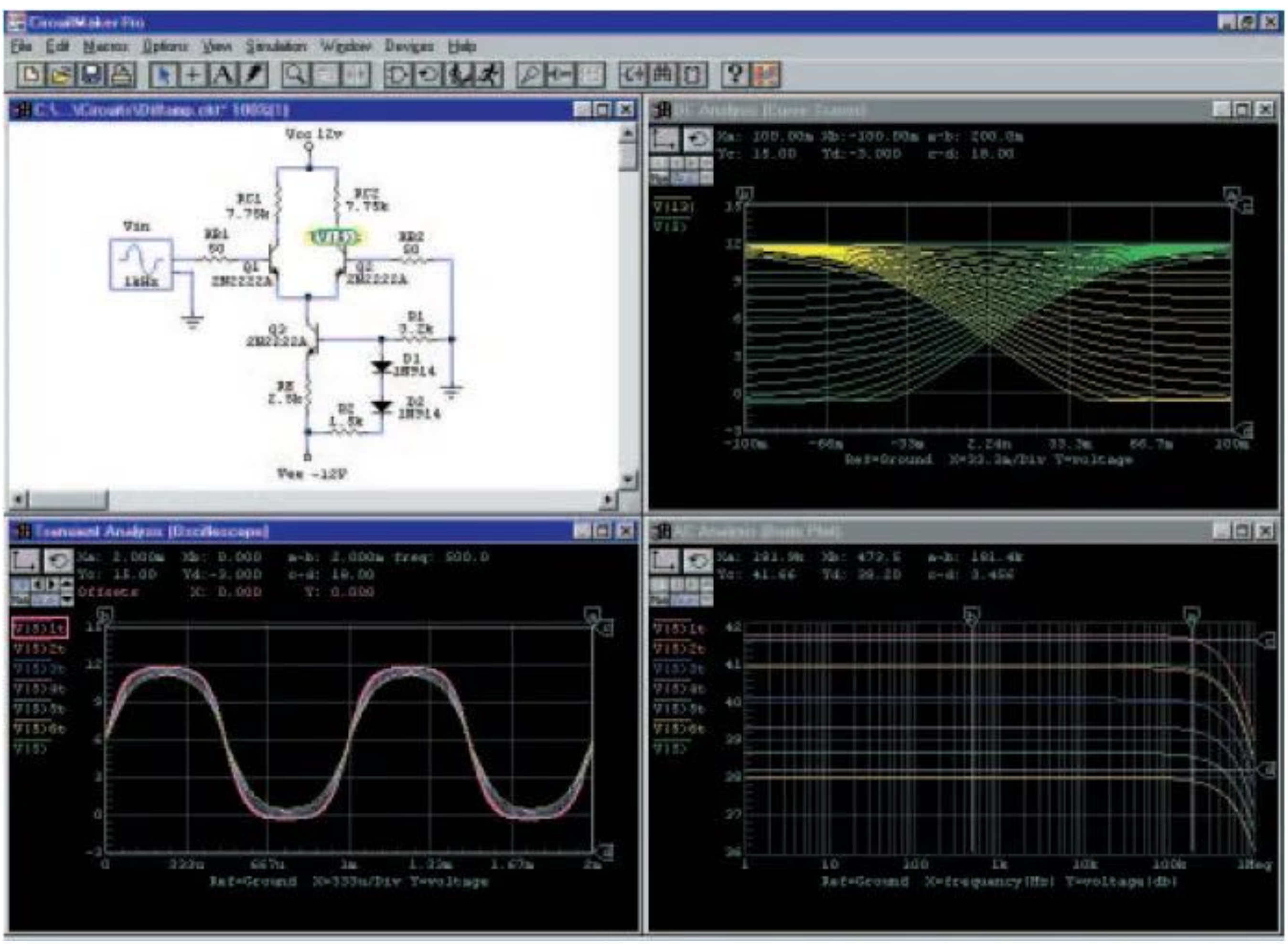
2. **Tools to verify tokenized ecosystems.** These verify that a design can work (according to its performance metrics) despite *uncontrollable* variables that impact performance. An uncontrollable variable follows (a) a *range* where the design must perform well at any of the variable's values, or (b) a probability distribution where the design must perform well in >x% of scenarios. These are "worst-case performance" and "n-sigma performance" respectively. "n-sigma" is

a unit to express failure rate, just like "% work" or "% fail"; typically designs aim for 2-sigma (works 95% of the time), 3-sigma (works 99.7% of the time), or 6 sigma (fails about 1 in a billion times).

3. **Tools for design space exploration.** These help the designer explore the design space, i.e. give insight into what happens to worst-case/n-sigma performance when controllable variables get changed.

6.2 Example Tool for Simulation, from Circuit Design

The figure below shows an example of a circuit simulator environment. The top left is a schematic editor to inputting the design. For analog circuits this is the choice of resistors, capacitors, transistors etc; how they are connected; and what their sizes are. That input is then automatically converted to a set of differential equations that are then solved using the simulator. The other three windows show results of various simulations. Clockwise from top right are bias (dc) analysis, time-based (transient) analysis, and frequency (ac) analysis.



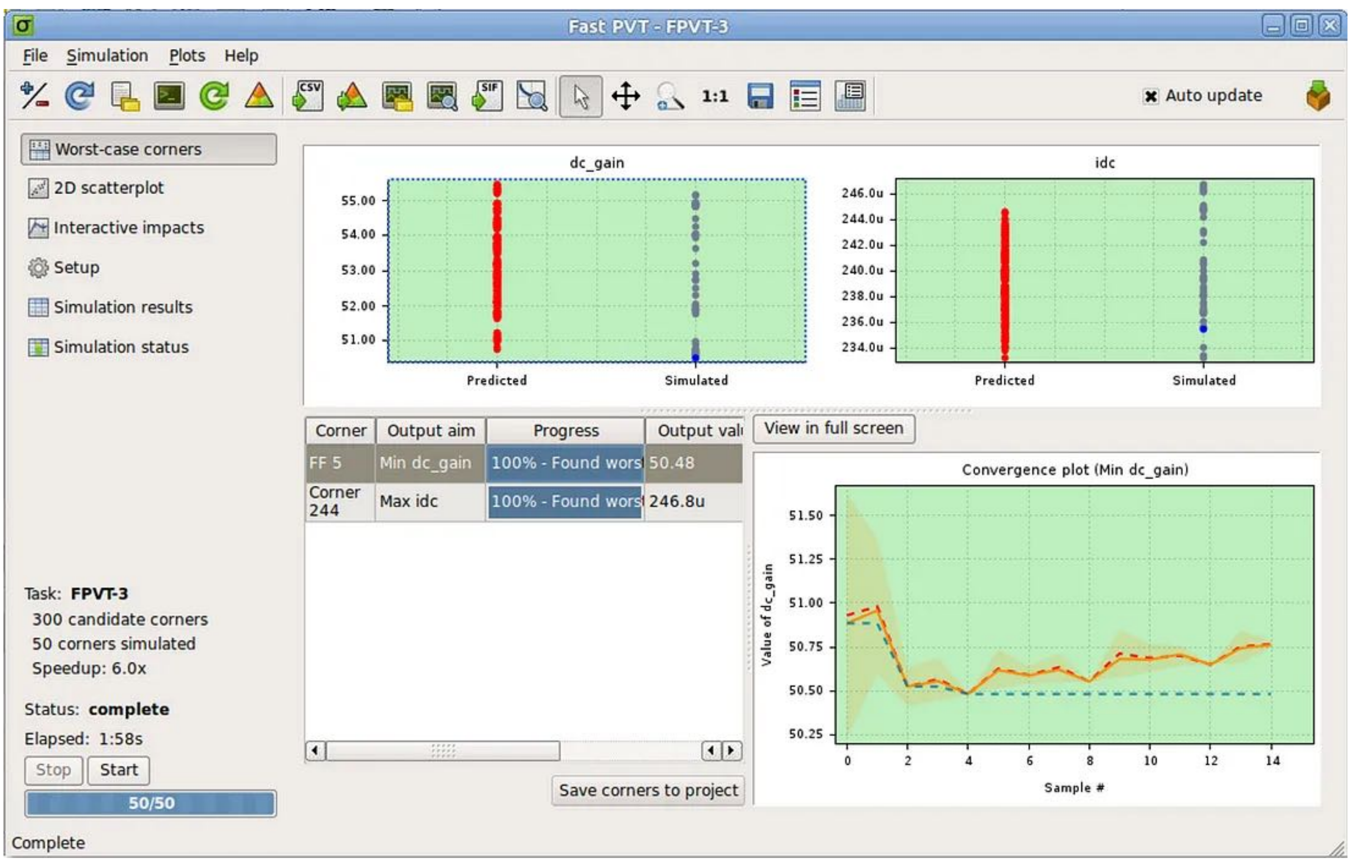
[Image: Wikimedia Commons]

6.2 Example Tool for Verification, from Circuit Design

This section and next are examples from CAD tools that I helped to develop, and are now widely by engineers at Sony, Qualcomm, etc.

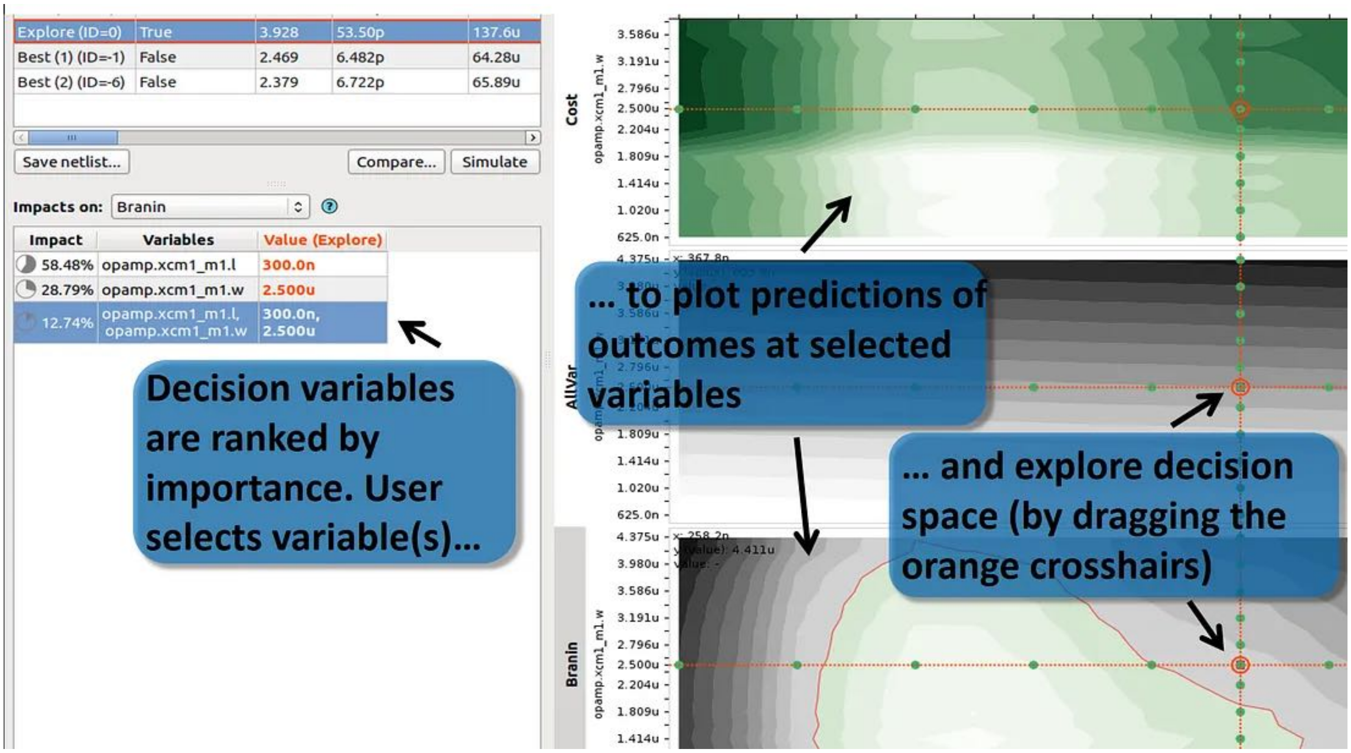
Below is a tool that **verifies** that the chip will not fail across a range of worst-case "PVT" conditions: extremes in **p**ower supply voltage, **t**emperature, load, etc. Therefore P,V, and T are the uncontrollable variables.

This particular tool finds the worst case by employing a global optimizer that tries to optimize towards failure, using a circuit simulator in the loop.



6.2 Example Tool for Design Space Exploration, from Circuit Design

The image below shows a tool to **explore** the design space. It reports relative impact of variables on various outputs (left), and how the design variables map to outputs (right). The engineer can change the designs by dragging the orange crosshairs.



These and other tools are now widely used to design modern chips. Simulators came on stream in the 1970s and CAD tools in the 1980s; and no one's looked back. These tools are *crucial* to modern chip design. It costs >$50M to manufacture a design on a modern process; it would be, well, *stupid* to not verify and optimize that design to the best possible level before committing the $50M.

Yet in the world of token design, we are building and deploying what we hope to be billion-dollar ecosystems, with barely any tools. It isn't even 1970 yet. I look forward to the day when we get to this level for token engineering!

6.3 Limitations of Tools

I acknowledge a key difference between complex chips and economies: humans in the loop. Chips are closed systems. Humans make the modeling of an economy a lot messier. However, I have hope that we can improve on the status quo of "nothing", because we build systems every day that involve humans. Here are a few complementary ideas.

One option is to *not* try modeling black swans, but simply minimize potential negative impacts if they do occur.

Or, we could have humans in the loop as part of the "simulator" where they are incentivized to come up with attacks. This formalizes an existing practice: people doing token design get their friends to dream up new attacks, then they update the constraints list then the design accordingly. I've found myself in dozens of such conversations.

Simulation will never be perfect. So, we should ensure that the system itself is *evolvable*, towards the intent of the community. The tools for this are governance, staking, and more. Governance may be as simple as hard forks, for example to change the objective function or add constraints. Staking helps convert zero sum to positive sum for the community of token holders.

6.4 Extrinsic vs. Intrinsic Motivation

> *" **Extrinsic motivation** is encouragement from an outside force; behavior is performed based on the expectance of an outside reward [to convince] someone into doing something that they would not do on their own. …*
>
> *Intrinsic means innate or within; hence **intrinsic motivation** is the stimulation or drive stemming from within oneself. … Intrinsic motivation is often associated with intrinsic rewards because the natural rewards of a task are the motivating forces that encourage an individual in the first place." [Link]*

This article has focused mostly on extrinsic motivation: figure out what we're trying to optimize for, and then directly optimize for that. However, extrinsic motivation can have problems. In education, extrinsic rewards reduce intrinsic motivation of children to learn, and hinder self-determination and independent thinking. Fortunately there are teaching styles that encourage intrinsic motivation [link].

For tokenized ecosystems, we must be similarly careful. Extrinsic motivation works for some goals like "maximize security" or "maximize sharing of data". But it can be dangerous in some places. Let's say you're building a decentralized reputation system. Directly tokenizing reputation would incentivize people to game their reputation for money, leading to all sorts of poor behavior. It can also be controlling, like we've seen with China. Just say no to Whuffie (please).

One possible answer is for the system to support intrinsic motivation rather than extrinsic. In the classroom, this means tactics like: provide choices, minimize pressure, allow alternative solutions, encourage originality, and promote success. Some of these might translate to token design. One example is to simply filter out the bad actors with economic stake, e.g. with a TCR. Or, we could promote success via stake machines.

7. Conclusion

This article described how we can leverage existing fields to help design tokenized ecosystems: token design as optimization design; token design patterns; and token design tools inspired by circuit design tools. The overall goal is a practice of **token engineering**. We'll get there!

The next article in this series applies these techniques to two case studies: analysis of Bitcoin, and design of Ocean Protocol.

Appendix: Calling All Polymaths

I've noticed that there's a group of people in blockchain that seem to thrive especially well. It's the learning machines: the folks who learn for fun, build for fun, who dance among many fields and build bridges between them. Yep, the polymaths.

In this article, I've described how practices from optimization and other fields could help in designing tokenized ecosystems. It also means that experts from these fields could find their skills to be useful in the brave new world of blockchains. I'm hopeful that designers of video game micro-economies can port their skills. Furthermore, just like in blockchain: many folks from AI, complex systems and more are natural polymaths.

I've seen this first hand. My own experiences in AI and optimization have been extremely helpful to grok blockchain. Also, I've found it easier to ramp up AI people by teaching them the delta between what they know, and blockchain. I simply describe tokenized systems as EAs! To the Artificial Life people, it's life. To the electrical engineers, it's feedback control systems. And so forth.

Appendix: Related Articles & Media

This article is part of a series:

- **Part I. Can Blockchains Go Rogue?** AI Whack-A-Mole, Incentive Machines, and Life.
- [This article] **Part II. Towards a Practice of Token Engineering:** Methodology, Patterns & Tools.
- **Part III. Token Engineering Case Studies:** Analysis of Bitcoin, Design of Ocean Protocol.

Here's a video for the content of this article. Below are the slides. This talk was given at EthCC Paris in March 2018.

Related content:

- Chris Burniske published an excellent tweetstorm summarizing this article.
- Talk emphasizing optimization: **slides**; **video** (Berlin, Feb 2018)
- Talk emphasizing complex systems: **slides**, **video** (Santa Fe Institute, Jan 2018)

Appendix: Related Efforts

I'm searching for practical learnings that the blockchain field can learn from, with [illegible] and think "wait, *I've* been doing mechanism design for field X" then please reach out.

Follow **Ocean Protocol** via our Newsletter and Twitter; chat with us on Telegram or Discord, and build on Ocean starting at our docs.

Blockchain · Token Engineering · Crypto Tokens · Protocol Tokens · Deep Tech

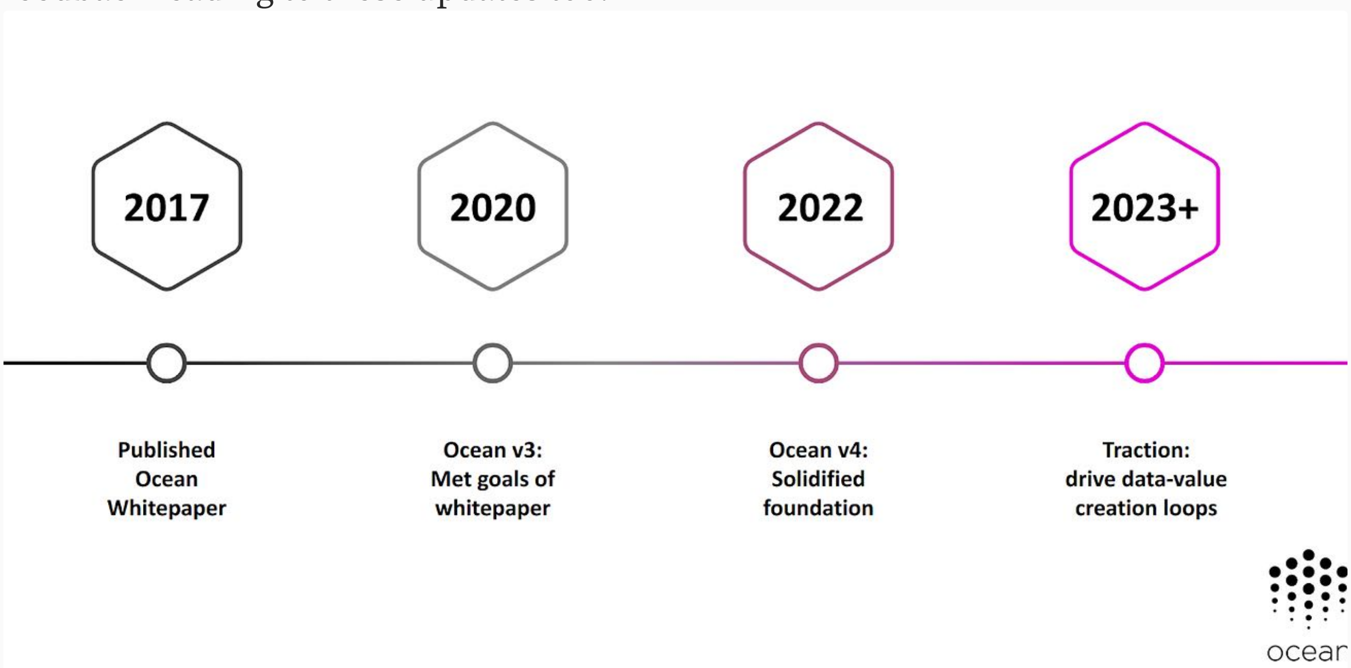
Publication of this article seems to have sparked a movement in #tokenengineering. Awesome! :):) A key resource is the wiki tokenengineering.net. It has info about building blocks, tools, community meetups, and more.

Ac...owledgements

... the following people for reviews of this and other articles in the series: Ia... ...lex Lange, Simon de la Rouviere, Dimitri de Jonghe, Luis C... ...y Selkis, Kyle Samani, and Bill Mydlowec. Thanks to many others for conversations that influenced this too, including Anish Mohammed, Richard Craib, Fred Ehrsam, David Krakauer, Troy McConaghy, Thomas Kolinko, Jesse Walden, Chris Burniske, and Ben Goertzel. And thanks to the entire blockchain community for providing a substrate that makes token design possible:)

Edits

Here are some updates since the initial publication. Thanks to everyone who gave feedback leading to these updates too.



suggestion that Public Policy experts are well suited to token engineering. Added link to risk-staking.

- Mar 28, 2018. Renamed "Proofed Curation Market" to "Curated Proofs Market". Why? It's easier to understand.

- June 4, 2018. Replaced the list of "related efforts" to a link to the token engineering wiki and #tokenengineering hashtag.
- June 5, 2018. Updated "related articles & media" section to emphasize the slides

Trent McConaghy in Ocean Protocol

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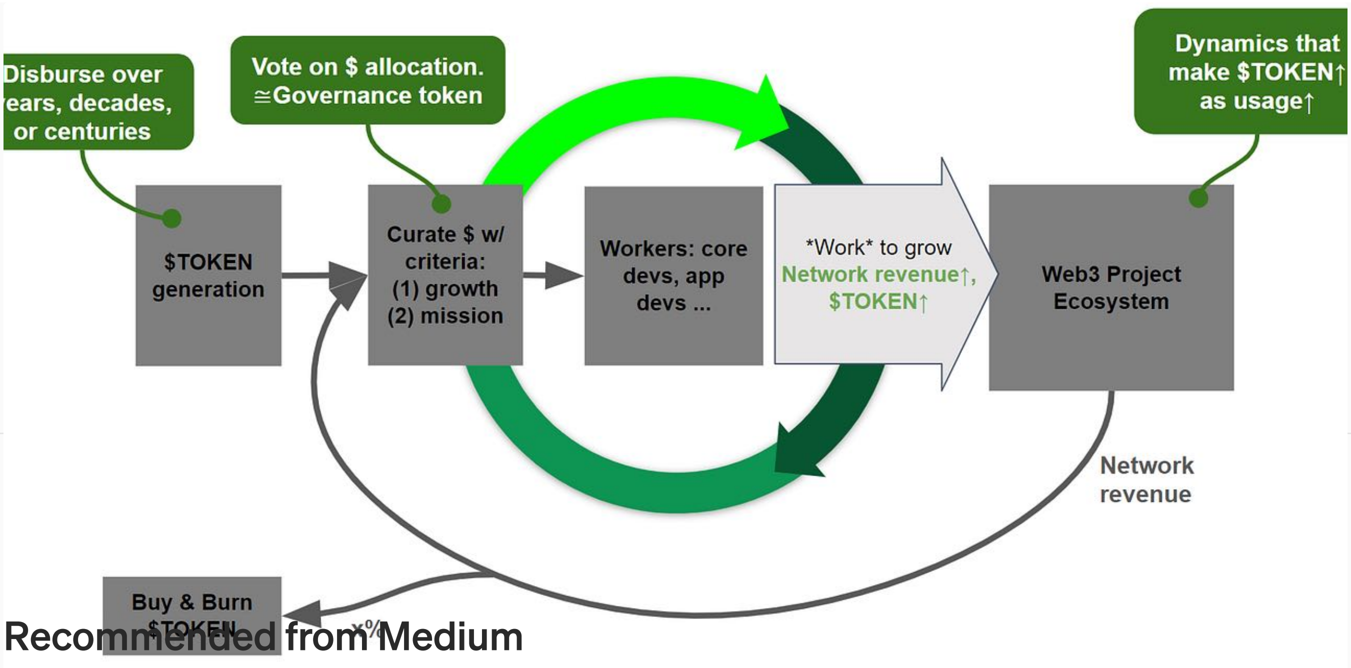

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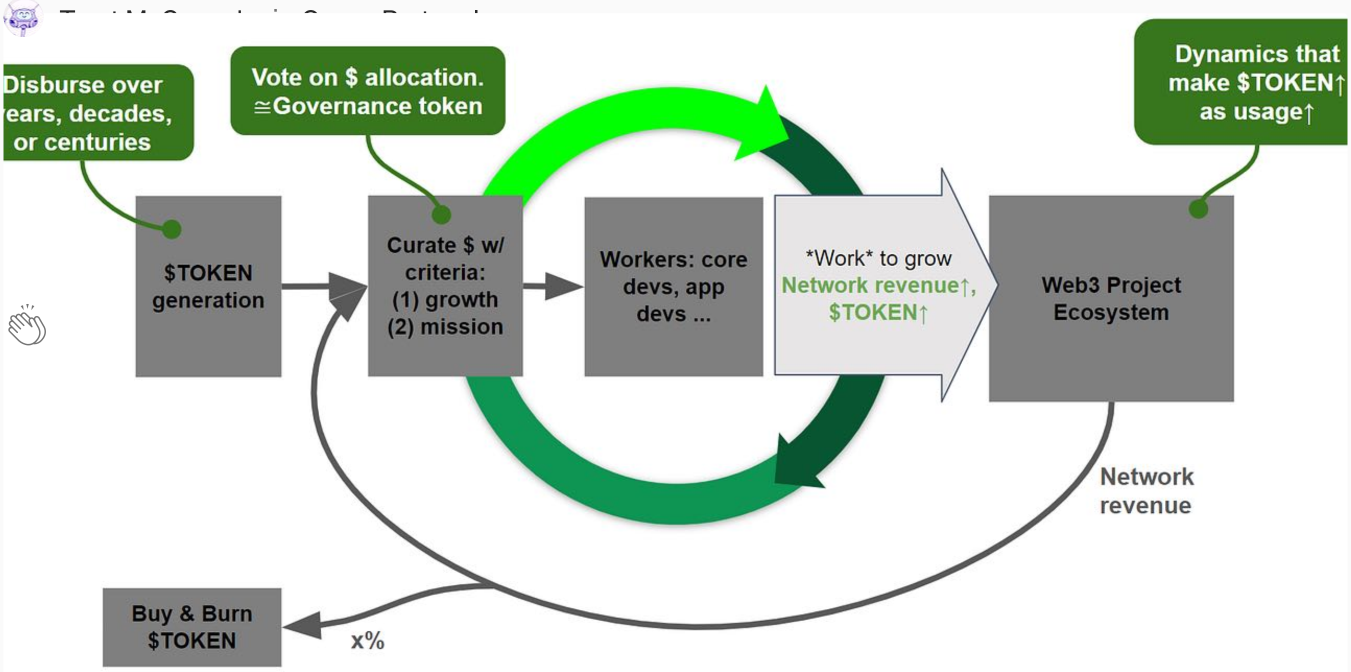

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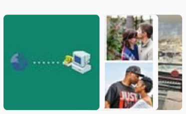

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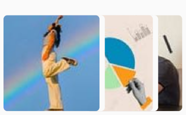

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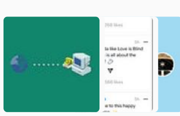

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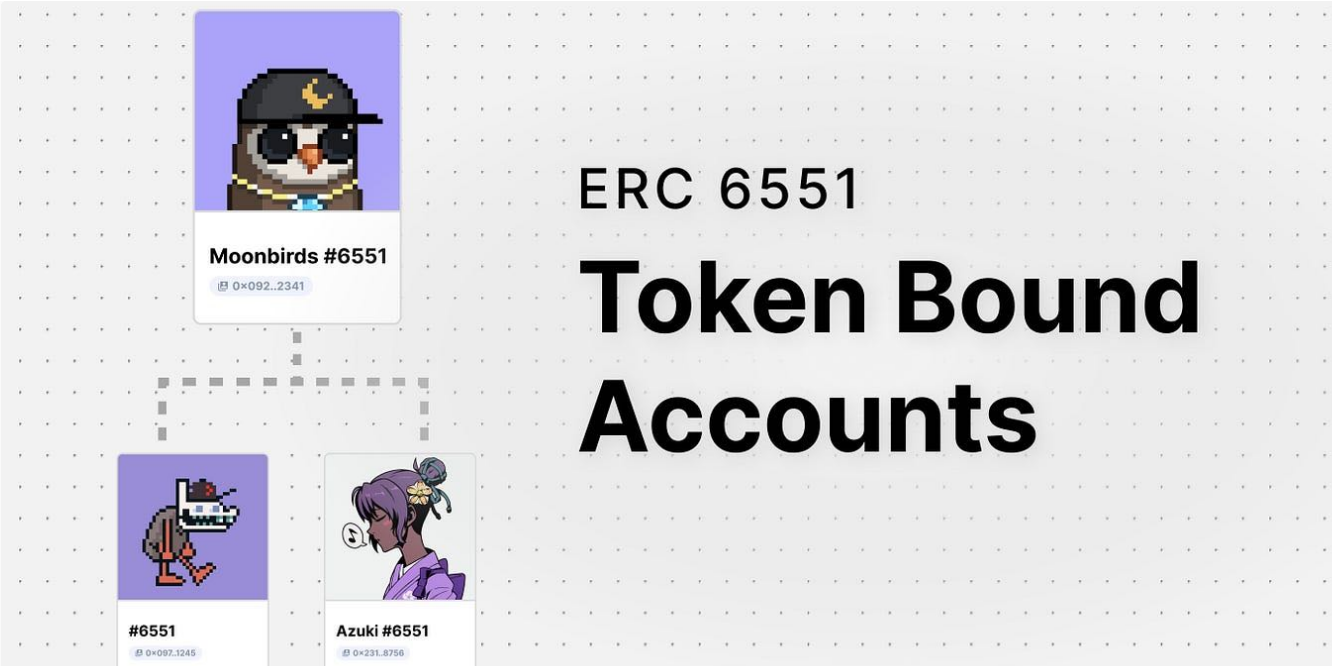

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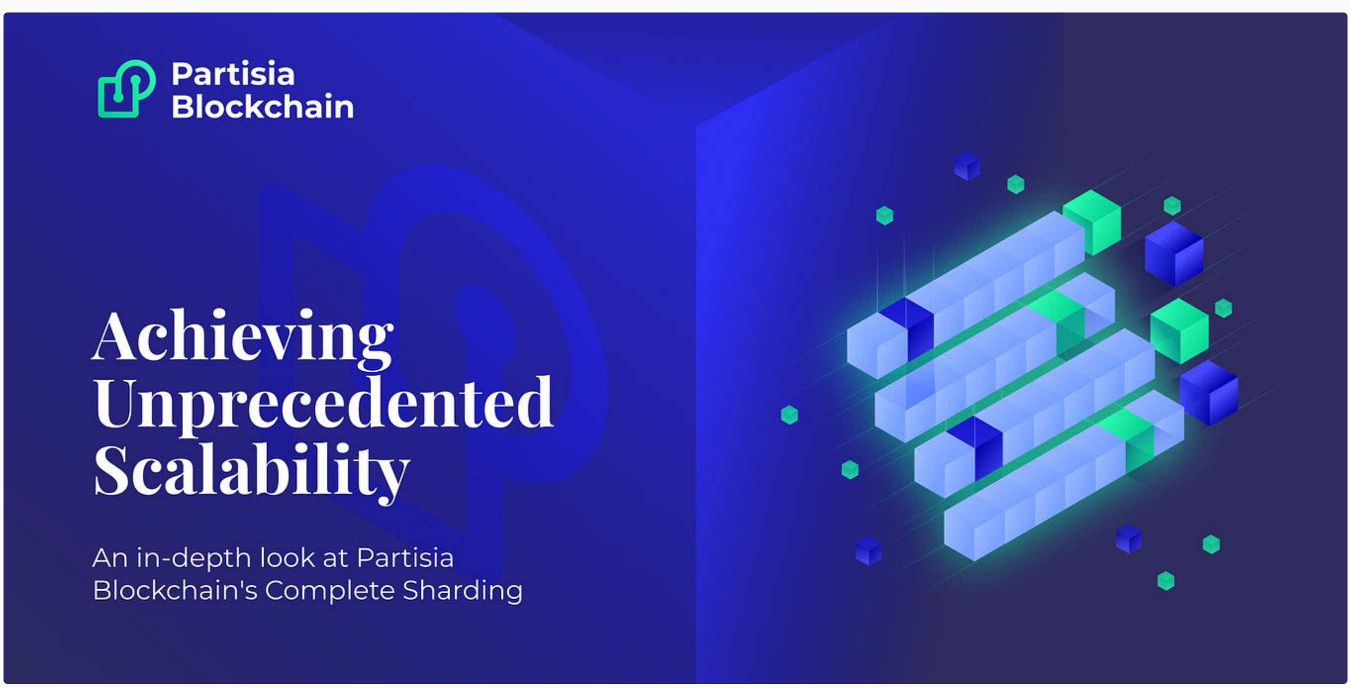

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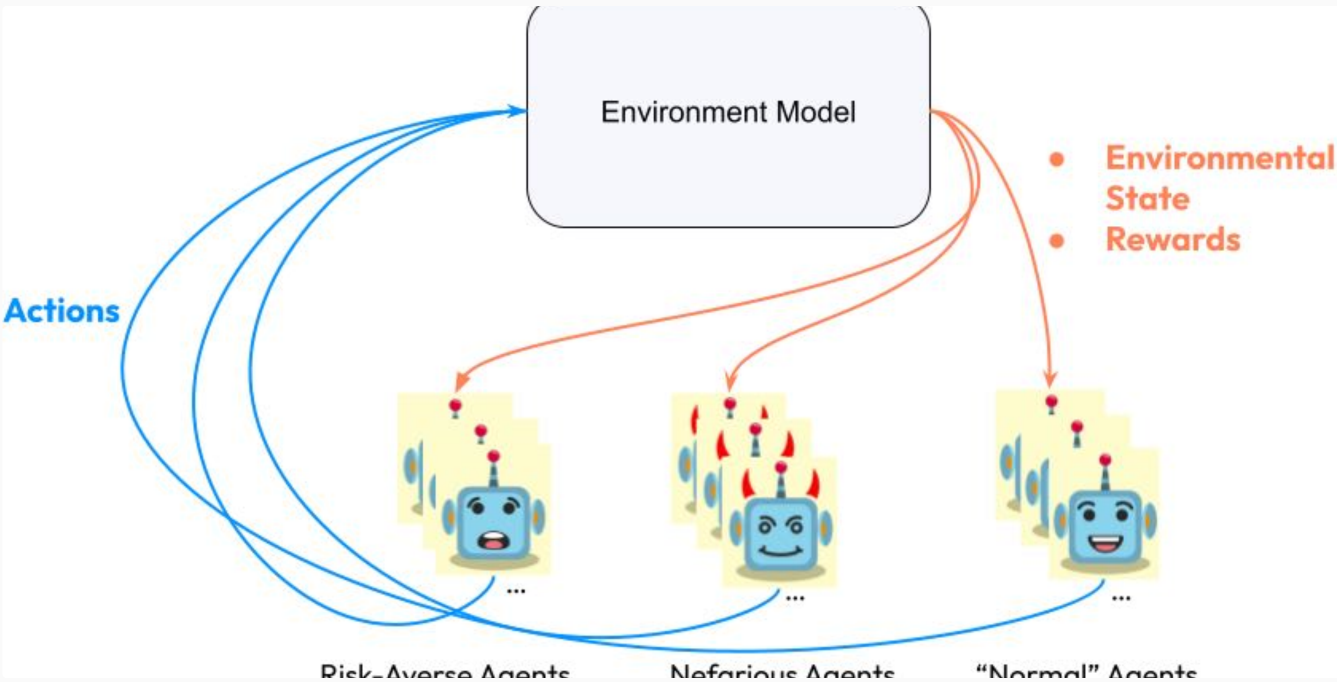

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Token Engineering Case Studies

Analysis of Bitcoin, Design of Ocean Protocol. TE Series Part III.

Trent McConaghy · Follow

Published in Ocean Protocol

9 min read · Mar 2, 2018

1. Introduction

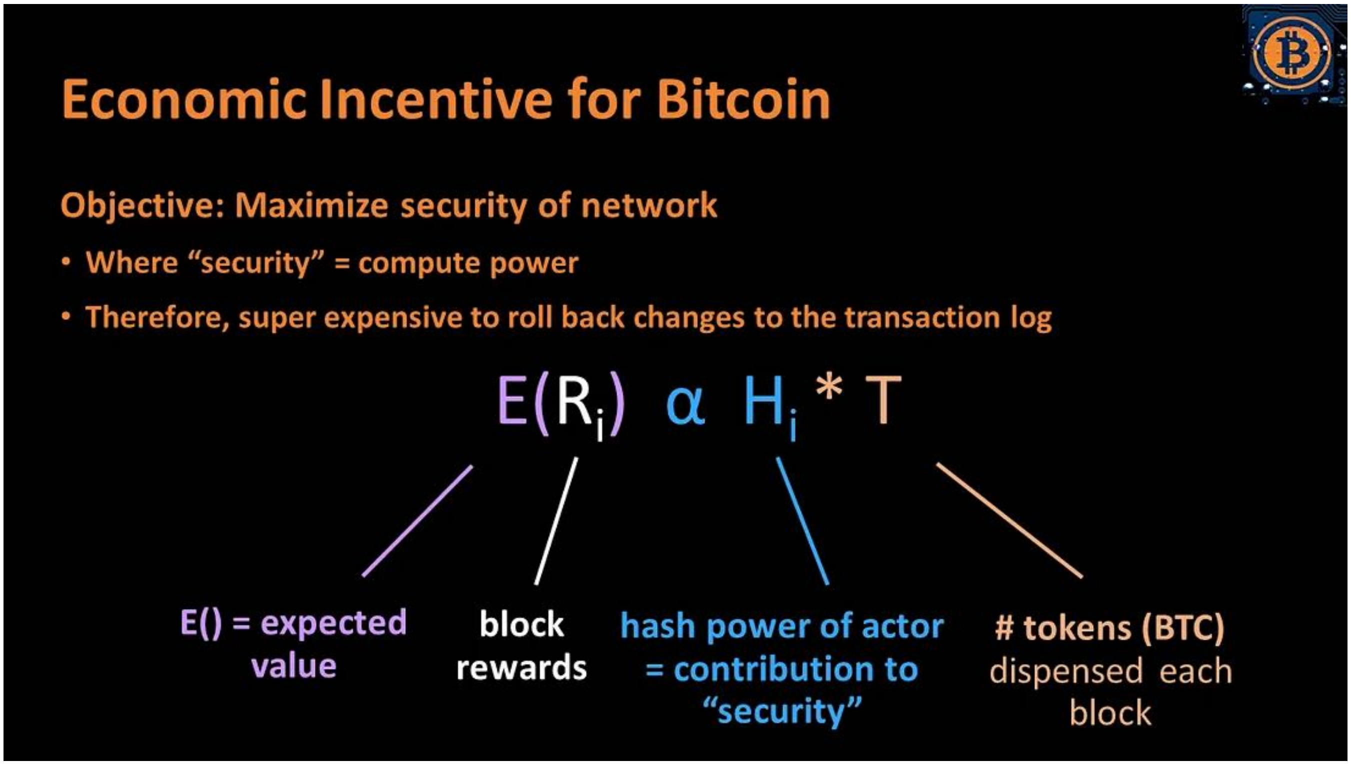
In previous articles, I described why we need to get incentives right when we build tokenized ecosystems; and introduced ideas towards a practice of token engineering. We can use these tools to help *analyse* existing tokenized ecosystems, and *design* new ones. This article does exactly that with **case studies in** (1) **analysis of Bitcoin**, and (2) **design of Ocean Protocol**. Let's get started!

2. Case Study: Analysis of Bitcoin

We've discussed how best practices from optimization can apply to token design. Let's put this into practice. Let's frame Bitcoin in the lens of optimization design. In particular, let's focus on the objective function for **Bitcoin**.

Its objective function is: **maximize the security of its network.** It then defines "security" as compute power (hash rate), which makes it expensive to roll back changes to the transaction log. Its block reward function manifests the objective, by giving block reward tokens (BTC) to people who improve the network's compute power.

We can write the formula for the objective function (block reward function), as the image below shows. On the left side is the amount of token rewards *R* in a block interval that actor *i* can expect. The right side of the equation is proportional (α) to the left, and is the product of compute power (hash rate) of actor *i* and number of tokens dispensed every block *T*. The latter value is currently 12.5 BTC every ten minutes. Every four years that value halves.



Aside: Trading Variance for Efficiency

Notice that the reward is in terms of *expected* value, *E()*. This means that that each user doesn't necessarily receive a block award every interval. Rather, in Bitcoin, it's quite lumpy: just a *single* user is awarded in each block interval. But since their chance of getting the award is proportional to the hash rate they've contributed, then their expected value is indeed the amount contributed. The Orchid team calls this probabilistic micro-payments.

Why would Bitcoin have this lumpiness (high variance), rather than award every player at every interval (low variance)? Here are some benefits:

- It doesn't need to track how much each user contributed. Therefore lower compute, and lower bandwidth.

- It doesn't need to send BTC to each user at each interval. Therefore far fewer transactions, and lower bandwidth. An efficiency tweak!
- In not needing the first two, the system can be far simpler and therefore minimizes the attack surface. Therefore simpler, and more secure.

These are significant benefits. The biggest negative is the higher variance: to have any real chance to win anything at all you need significant hash rate, though if you do win, you win big. However, this higher variance is mitigated simply by higher level mining pools, which have the direct effect of reducing variance. This is cool because it means that Bitcoin doesn't need even need to do that directly. As usual, we keep learning from Satoshi:)

Success of Bitcoin's Incentives?

How well does Bitcoin do towards its objective function of maximizing security? The answer: incredibly well! From this simple function, Bitcoin has incentivized people to spend hundreds of millions of dollars to design custom hashing ASICs and building ASIC mining farms. Others are creating mining pools with thousands of participants. Now the hash rate is greater than all supercomputers combined. Electricity usage is greater than most small countries, and on track to overtake USA by July 2019. All in pursuit of Bitcoin token block rewards! (Not all of it is good, obviously.)

It started with a simple block rewards equation. Yet all sorts of complexities have emerged, including mining farms. [Image: Wikimedia Commons]

Besides the ASIC farms and mining pools, we've also seen a whole ecosystem emerge around Bitcoin. Software wallets, hardware wallets, core developers, app developers, countless Reddit threads, conferences, and more. Driving much of it is BTC token holders incentivized to spread the word about their token.

What's driven all of this is the block rewards that manifest the objective function. *That's* the power of incentives. You called it, Charlie:)

4. Case Study: Design of Ocean Protocol

Ocean Protocol

4.1 Introduction

When we first started doing serious token design for Ocean Protocol in May 2017, we found ourselves struggling. We hadn't formulated the goals (objectives and constraints) and instead were simply looking at plug-and-play patterns like decentralized marketplaces. But then we asked: how does this help the data commons? It didn't. Does this need its own token? It didn't. And there were other issues.

So, we took a step back and gave ourselves the goal of writing proper objectives and constraints. Then, things started to go smoother. With those goals written down, we tried other plug-and-play patterns (solvers). We found new issues that the goals didn't reflect, so we updated the goals. We kept looping in this iterative process. It didn't take long before we'd exhausted existing plug-and-play patterns, so we had to design our own; and we iterated on those.

After doing this for a while, we realized that we had been applying the optimizer design approach to token design! That is: formulate the problem, try using existing patterns; and if needed then develop your own. So while this blog post lays out the token design process as a *fait accompli*, in reality we discovered it as we were doing it. We've actually used this methodology for other token designs since, to help out friends in their projects.

4.2 Ocean Problem Formulation

Recall that the objective function is about *getting people to do stuff*. So, we must first decide *who* those people are. We must define the possible **stakeholders** or **system agents.** The following table outlines the key ones for Ocean token dynamics.

Key stakeholders in Ocean ecosystem

Stakeholder	What value they can provide	What they might get in return
Data/service provider, data custodian, data owner	Data/service (market's supply)	Tokens for making available / providing service
Data/service referrers, curators. Includes exchanges and other application-layer providers.	Data/service (via a provider etc), curation	Tokens for curating
Data/service verifier. Includes resolution of linked proofs on other chains	Data/service (via a provider etc), verification	Tokens for verification
Data/service consumer	Tokens	Data/service (market's demand)
Keepers	Correctly run nodes in network	Tokens for chainkeeping

Objective function. After the iterations described above, we arrived at an objective function of: **maximize the supply of relevant AI data & services.** This means to incentivize supply of not only high-quality *priced* data, but also high-quality *commons* data; and compute services around this (e.g. for privacy).

Constraints. In the iterations described above, used this checklist when considering various designs. Roughly speaking, we can think of these as constraints.

- For priced data, is there incentive for supplying more? Referring? Good spam prevention?

- For commons (free) data, is there incentive for supplying more? Referring? Good spam prevention?
- Does the token give higher marginal value to users of the network versus external investors?
- <and more>

Besides these questions, as we continually polled others about possible attacks; added each new concern to the list of constraints to solve for (including a memorable name); and updated the design to handle it. New constraints included: “Data Escapes”, “Curation Clones”, “Elsa & Anna Attack”, and more. The FAQs section of the Ocean whitepaper documents these, and how we addressed them.

4.3 Exploring the Design Space

We tried a variety of designs that combined token patterns in various ways; and tested each design (in thought experiments) against the constraints listed above. Some that we tried:

1. Just a TCR for actors (like adChain). Fail: can’t handle spam data.
2. Just a TCR for data/services. Fail: can’t handle Data Escapes.
3. A TCR for actors and a TCR for data/services. Fail: can’t distinguish non-spam data/services from *relevant* ones.
4. A TCR for actors and a Curation Market (CM) for data/services. Fail: no incentives to make data/services available.

Here’s how each candidate design fared against the checklist. Each had at least one major fail.

Key Question	1	2	3	4
For priced data: incentive for supplying more? Referring?	✘	≈	✔	≈
For priced data: good spam prevention?	≈	✔	✔	✔
For free data: incentive for supplying more? Referring?	✘	≈	✘	✔
For free data: good spam prevention?	≈	✔	≈	✔
Does token give higher marginal value to users of the network, vs external investors? Eg Does return on capital increase as stake increases?	✔	✔	✔	✔
Are people incentivized to run keepers?	≈	≈	✔	✔
It simple? Is onboarding low-friction? Where possible, do we use incentives/crypto rather than legal recourse?	✔	✔	≈	≈

We needed to resort to step 3 of the methodology: design our own building block. What emerged was a Curated Proofs Market (CPM; next section has detail), a small-as-possible extension of a CM. We tried it in two new design options:

5. Data registry + free data CPM. Curation: Stake tokens as belief in reputation. Auto CDN.

6. Actor registry + free&priced CPM. Curation: Stake tokens as belief in reputation. Auto CDN. "Proofed Curation Market"

The following table adds the two new designs on the far right columns. We see that design 6 met our goals! This is critical: it means that *we knew we could stop* the current design process (at least for the time being).

Key Question	1	2	3	4	5	6
For priced data: incentive for supplying more? Referring?	✗	≈	✓	≈	≈	✓
For priced data: good spam prevention?	≈	✓	✓	✓	✓	✓
For free data: incentive for supplying more? Referring?	✗	≈	✗	✓	✓	✓
For free data: good spam prevention?	≈	✓	≈	✓	≈	✓
Does token give higher marginal value to users of the network, vs external investors? Eg Does return on capital increase as stake increases?	✓	✓	✓	✓	✓	✓
Are people incentivized to run keepers?	≈	≈	✓	✓	✓	✓
It simple? Is onboarding low-friction? Where possible, do we use incentives/crypto rather than legal recourse?	✓	✓	≈	≈	✓	✓

4.4 A New Token Pattern for Ocean: Curated Proofs Markets

Ocean's objective function is to **maximize the supply of relevant AI data & services**.

To manifest this, we must acknowledge that we can't objectively measure what is "high quality". To solve this problem, Ocean leaves curation to the *crowd*: users must "put their money where there mouth is" by betting on what they believe will be the most popular datasets, using a Curation Market setting.

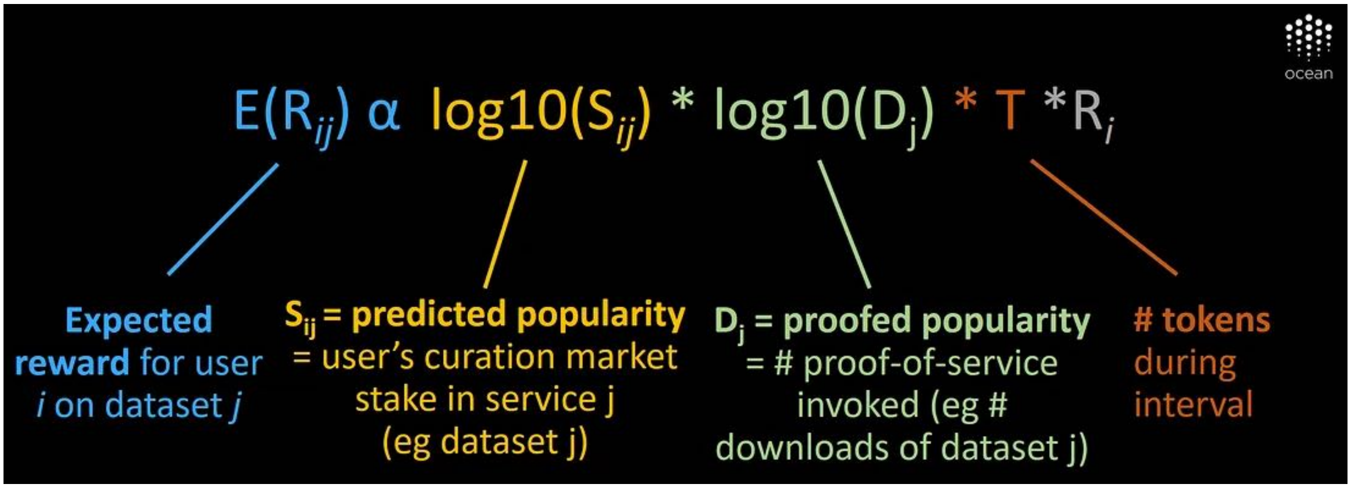
Then we needed to reconcile signals for quality data with making data available. We resolved that by binding the two together: predicted popularity versus actual (proven) popularity. A user is awarded tokens if both of:

1. They have predicted a dataset's popularity in a Curation Market setting. This is the **Predicted Popularity**.

2. They have provably made the dataset/service available when requested. By definition, the more popular it is, the more requests there are. This is the **Proofed Popularity**.

Together, these form what we call a **Curated Proofs Market (CPM)**. In a CPM, the curation market and the proof are tightly bound: the proof gives teeth to the curation, to make curation more action-oriented; in turn, the curation gives signals for quality to the proof. CPMs are a new addition to our growing list of token design building blocks:)

The following equation describes Ocean's token rewards function.



The first term on the right hand side, *Sij,* reflects an actor's belief in the popularity of the dataset/service (Predicted Popularity). The second term, *Dj,* reflects the popularity of the dataset/service (Proofed Popularity). The third term, *T,* is the number of tokens doled out during that interval. The fourth term, *Ri,* is to mitigate one particular attack vector. The expected reward function *E()* is implemented similar to Bitcoin. The **Ocean whitepaper** elaborates on how this reward function works.

[Update Sep 2021: the token design of this section is different from what was actually shipped, based on learnings as we went along. However the goals remain the same, and there are still echoes of this design in Ocean Data Farming.]

3. Conclusion

This article gave case studies on using **token engineering** tools to analyze Bitcoin and to design Ocean Protocol.

Appendix: Related Articles & Media

This article is part of a series:

- **Part I. Can Blockchains Go Rogue?** AI Whack-A-Mole, Incentive Machines, and Life.
- **Part II. Towards a Practice of Token Engineering:** Methodology, Patterns &

Tools.

- **[this article] Part III. Token Engineering Case Studies:** Analysis of Bitcoin, Design of Ocean Protocol.

I gave a talk about much of this content in Berlin in Feb 2018. Here's the **slides** and **video**. I gave a related talk about complex systems at Santa Fe Institute, New Mexico, in Jan 2018. Here's the **slides** and **video** from that talk.

Further Resources

[June 1, 2018] Publication of this series seems to have sparked movement in #tokenengineering. Awesome! :):) A key resource is the wiki tokenengineering.net. It has info about building blocks, tools, community meetups, and more.

Acknowledgements

Thanks to the following people for reviews of this and other articles in the series: Ian Grigg, Alex Lange, Simon de la Rouviere, Dimitri de Jonghe, Luis Cuende, Ryan Selkis, Kyle Samani, and Bill Mydlowec. Thanks to many others for conversations that influenced this too, including Anish Mohammed, Richard Craib, Fred Ehrsam, David Krakauer, Troy McConaghy, Thomas Kolinko, Jesse Walden, Chris Burniske, and Ben Goertzel. And thanks to the entire blockchain community for providing a substrate that makes token design possible:)

Appendix: Related Efforts

- I learned that the Slava and Billy from Relevant came up with a similar mechanism to Curated Proofs Market for Relevant. Cool! Then Vitalik started to discover the joys of proofs * curation markets too.

Edits

- Mar 28, 2018: renamed "Proofed Curation Market" to "Curated Proofs Market". Why? It's easier to understand.
- 5, 2018: added the tables and surrounding text which elaborate on the tried.

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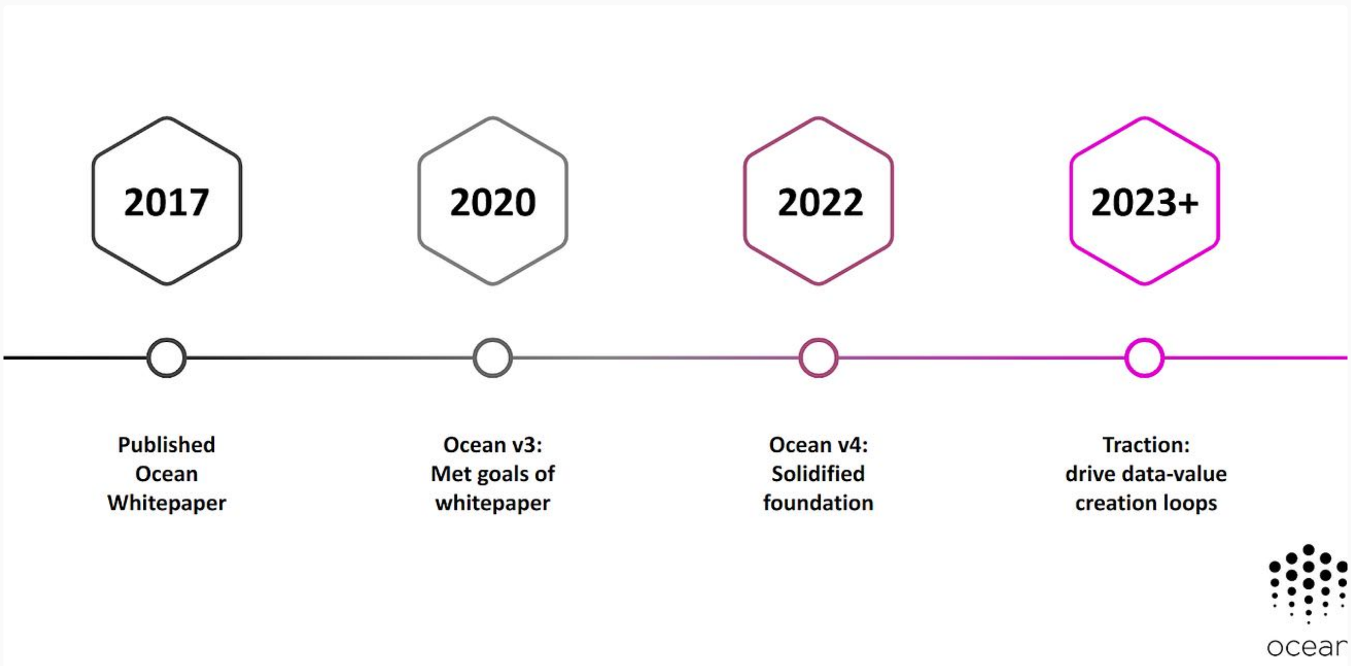

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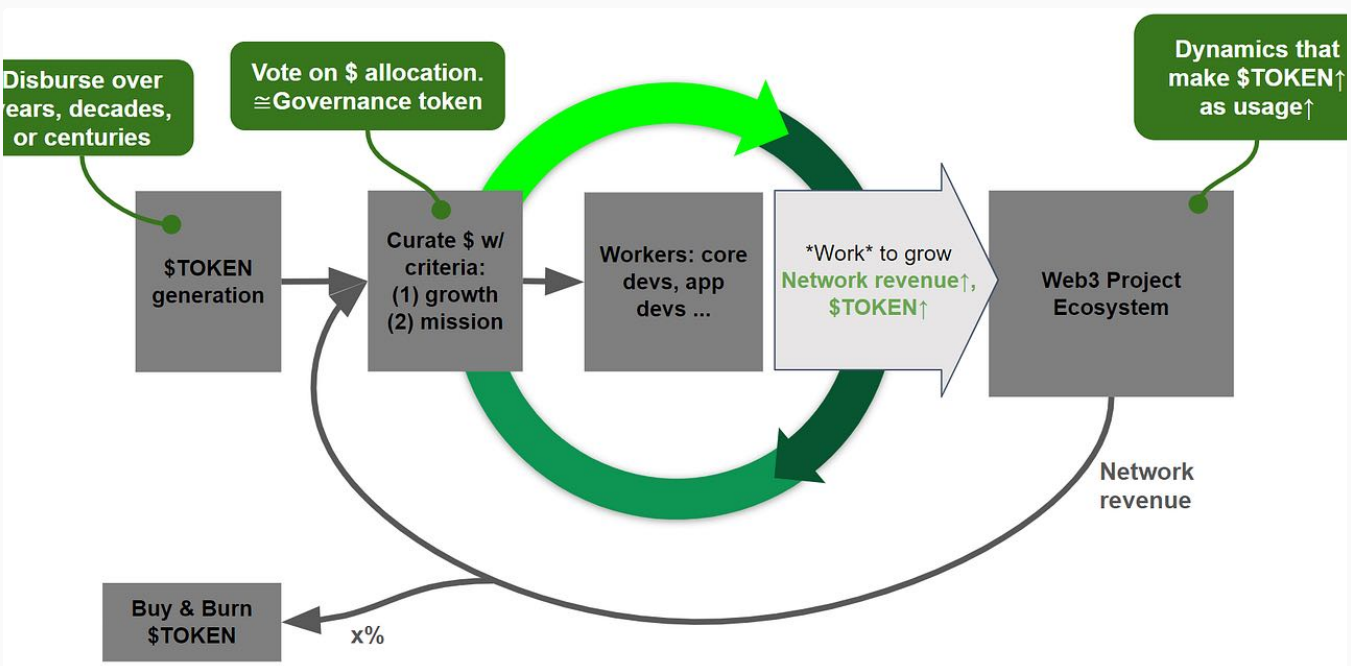

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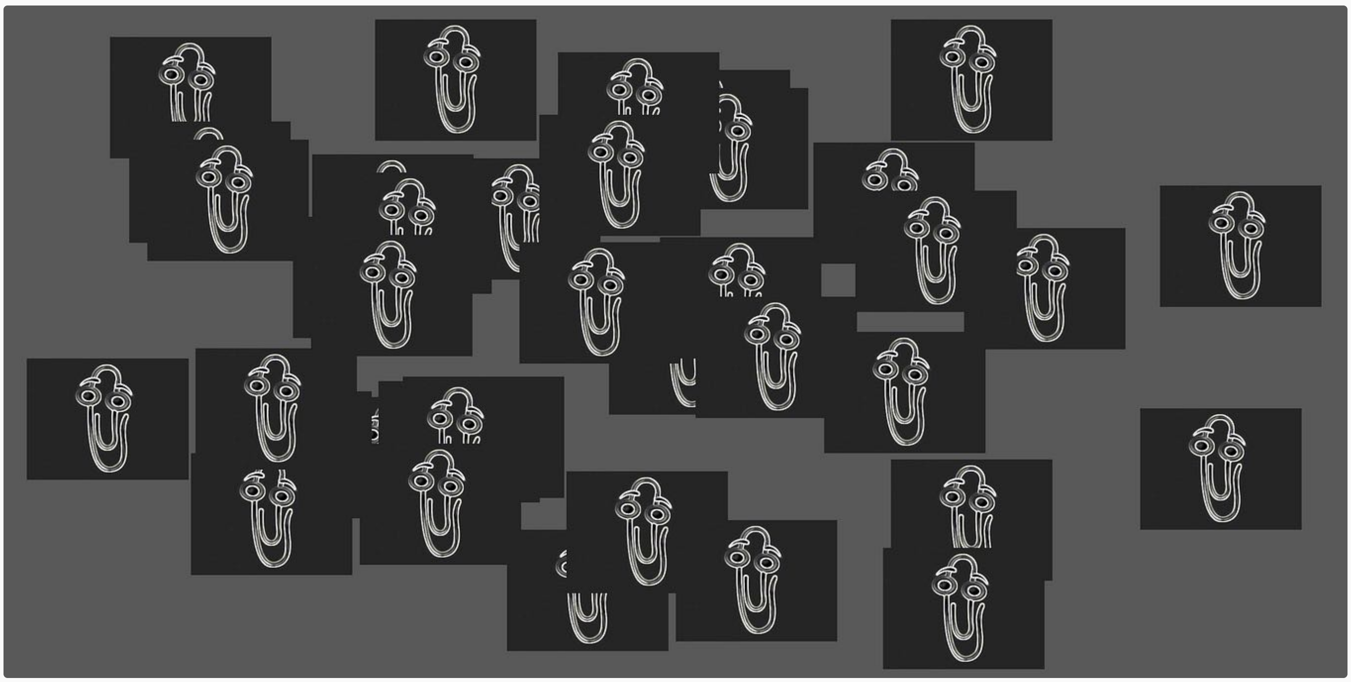

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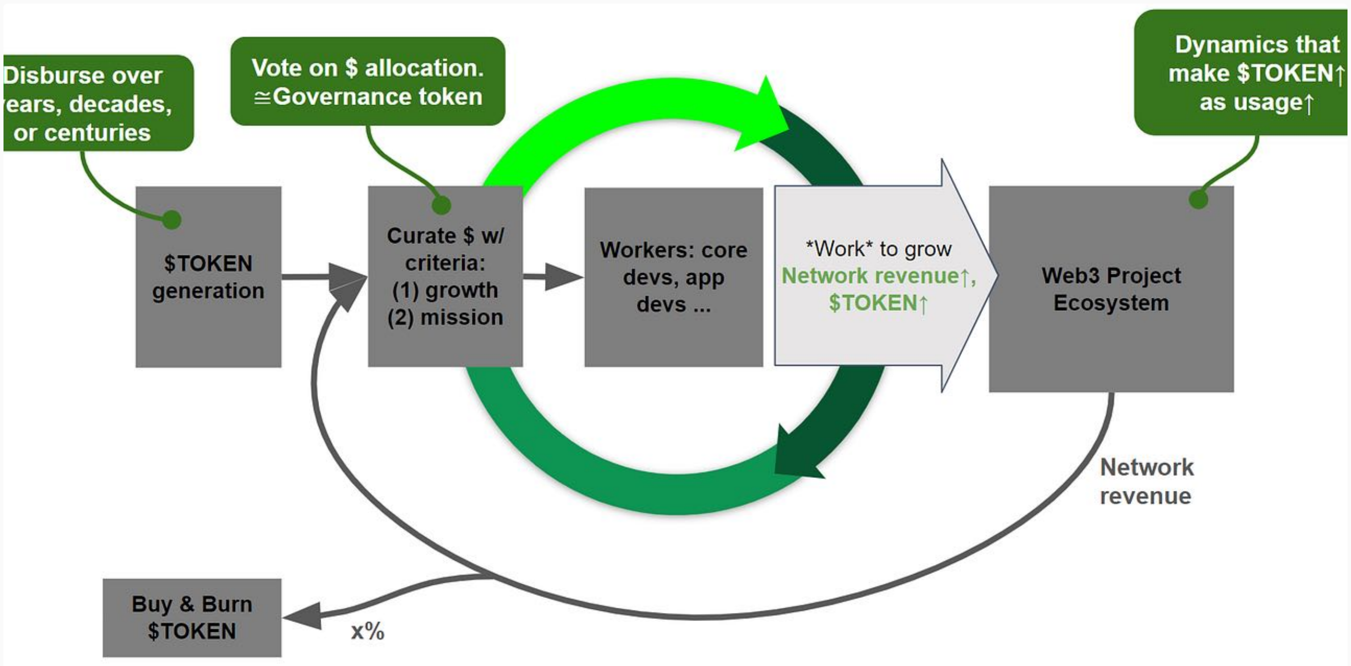

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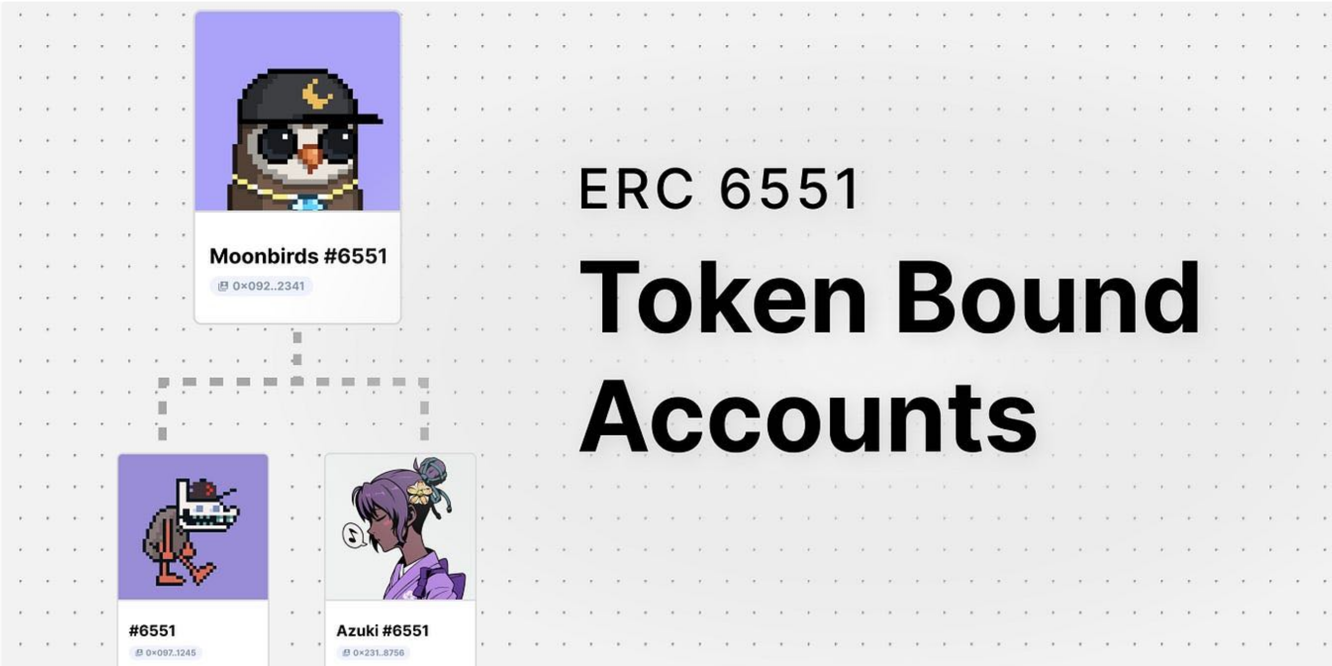

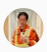 Benny Giang in FUTURE PRIMITIVE

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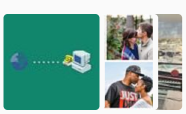

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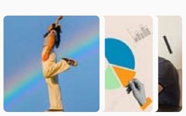

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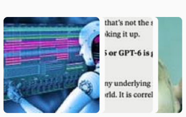

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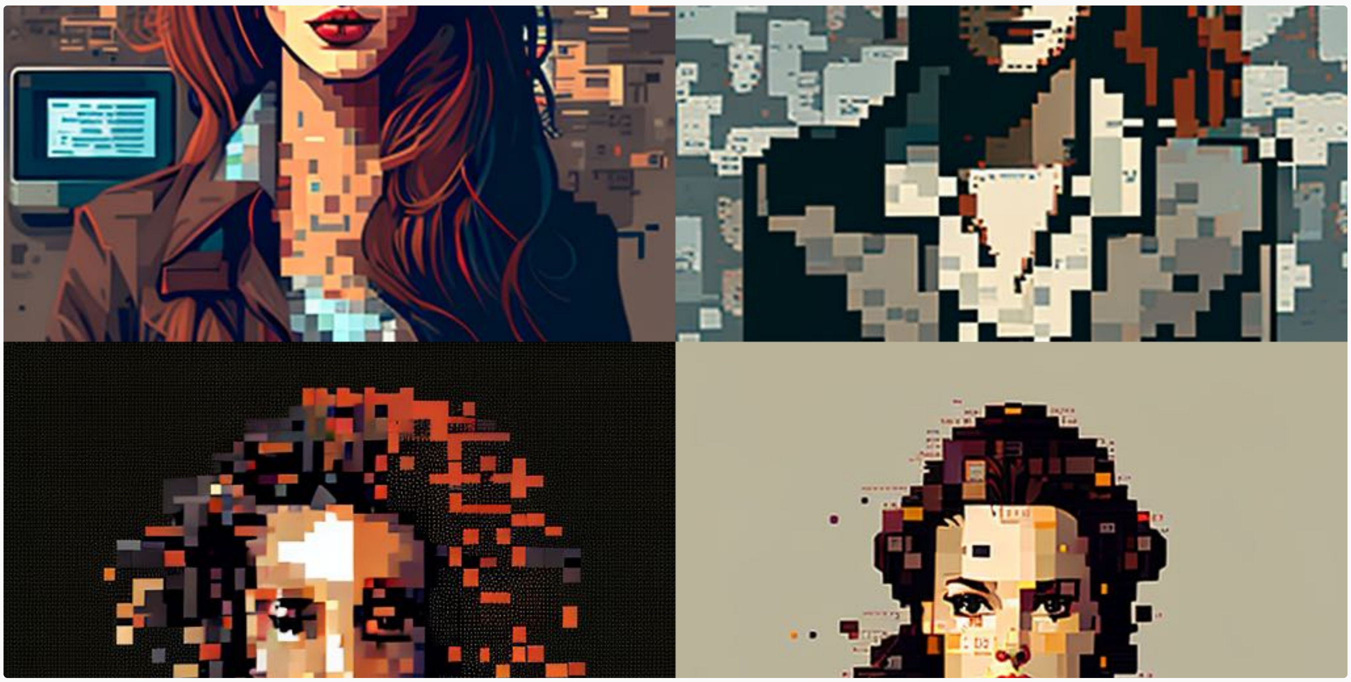

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Foundations of Cryptoeconomic Systems

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Foundations of Cryptoeconomic Systems

Shermin Voshmgir, Vienna University of Economics
ichael Zargham, Vienna University of Economics & BlockScience, Inc

Blockchain networks and similar cryptoeconomic networks are systems, specifically complex systems. They are adaptive networks with multi-scale spatio-temporal dynamics. Individual actions may be incentivized towards a collective goal with “purpose-driven” tokens. Blockchain networks, for example, are equipped cryptoeconomic mechanisms that allow the decentralized network to simultaneously maintain a universal state layer, support peer-to-peer settlement, and incentivize collective action. These networks represent an institutional infrastructure upon which socioeconomic collaboration is facilitated – in the absence of intermediaries or traditional organizations. They provide a mission-critical and safety-critical regulatory infrastructure for autonomous agents in untrusted economic networks. Their tokens provide a rich, real-time data set reflecting all economic activities in their systems. dvances in network science and data science can thus be leveraged to design and analyze these economic systems in a manner consistent with the best practices of modern systems engineering. Research that reflects all aspects of these socioeconomic networks needs (i) a complex systems approach, (ii) interdisciplinary research, and (iii) a combination of economic and engineering methods, here referred to as “economic systems engineering,” for the regulation and control of these socioeconomic systems. This manuscript provides a conceptual framework synthesizing the research space and proceeds to outline specific research questions and methodologies for future research in this field, applying an inductive approach based on interdisciplinary literature review and relative contextualization of the works cited.

1. INTRODUCTION

Cryptoeconomics is an emerging field of economic coordination games in cryptographically secured peer-to-peer networks. The term cryptoeconomics was casually coined in the Ethereum developer community, and is generally attributed to Vitalik Buterin. The earliest recorded citation is from a talk by Vlad Zamfir [Zamfir 2015], which was later loosely formalized in blog posts and talks by Buterin [Buterin 2017a], [Buterin 2017b]. The term has gained traction in the broader developer community [Tomaino 2017a] and in the academic community [Catalini and Gans 2016], but it still remains under-defined, possibly because it is often used in so many different contexts. Using the same term in different contexts leads to communication breakdowns and challenges when trying to come up with a rigorous definition of that term.

Zamfir and Buterin are both protocol researchers at the Ethereum foundation. Buterin’s work focuses on programmatic resource allocation strategies, e.g. [Buterin, Hitzig and Weyl 2019], whereas Zamfir has crossed into political economics with a focus on governance and law [Zamfir 2017], [Zamfir 2019]. The microeconomic study of cryptoeconomic networks, as pursued by Buterin and many others, is the most commonly used perspective, as it lies neatly within the overlap of mechanism design in economics and computer science; see [Nisan et al. 2007]. One weakness of such a computer science perspective is the tendency to view the technology as neutral and to downplay the creators’ responsibility for outcomes [Walch 2019]. This is in stark opposition to the systems engineering literature which places a large responsibility on engineers responsible for design and maintenance of critical infrastructure [Leveson 2016]. more comprehensive view of cryptoeconomic networks is that they have enabled new types of institutional infrastructure to emerge and will likely continue to foster slow but lasting changes to our social and economic systems which will require legal innovations [De Filippi 2018], [Werbach 2018]. In light of these changes, there is a renewed urgency in the study of economics at the institutional scale [Berg, Davidson and Potts 2019]. However, while many researchers and developers seem to agree that cryptoeconomic networks greatly expand the economic design space, comparatively few acknowledge that the economic models used to date are performative and their design is subjective, [Virtanen et al. 2018].

This paper explores why the term “cryptoeconomics” is context dependent and builds up to providing complementary micro, meso, and macro definitions (Section 9). These context dependent definitions are the synthesis of examinations of cryptoeconomic systems in terms of complexity (Section 2), interdisciplinarity (Section 3), institutional (Section 4), coordination (Section 5), emergence (Section 6), network structure (Section 7), and tokenization (Section 8). The final section (10) focuses on potential research directions and serves as an outlook rather than a conclusion. It identifies potential future research areas that build on the assumptions and definitions provided in this paper.

2. COMPLEX SYSTEMS PERSPECTIVE

Systems theory [Von Bertalanffy 1969] [Meadows 2008] provides a means to describe any system by its structure, purpose, functioning, as well as spatial and temporal boundaries, including its interdependencies with its environments [Moffatt and Kohler 2008][Parrott and Lange 2013]. Complex systems theory investigates the relationships between system parts with the system’s collective behaviors and the system’s environment [Nagel 2012].

Complex systems differ from other systems in that the system level behaviour cannot be inferred from the local state changes induced by individual network actors [Parrott and Lange 2013]. Modeling approaches that ignore such difficulties will produce models that are not useful for modeling and steering those system.

Properties such as emergence, nonlinearity, adaptation, spontaneous order, and feedback loops are typical to complex systems [Bar-Yam 2002]. Complex systems research draws contributions from various scientific domains such as mathematics, biology, physics, psychology, meteorology, sociology, economics, and engineering [Parrott and Lange 2013], which all contribute to complexity science, leveraging both analysis and synthesis; analytic

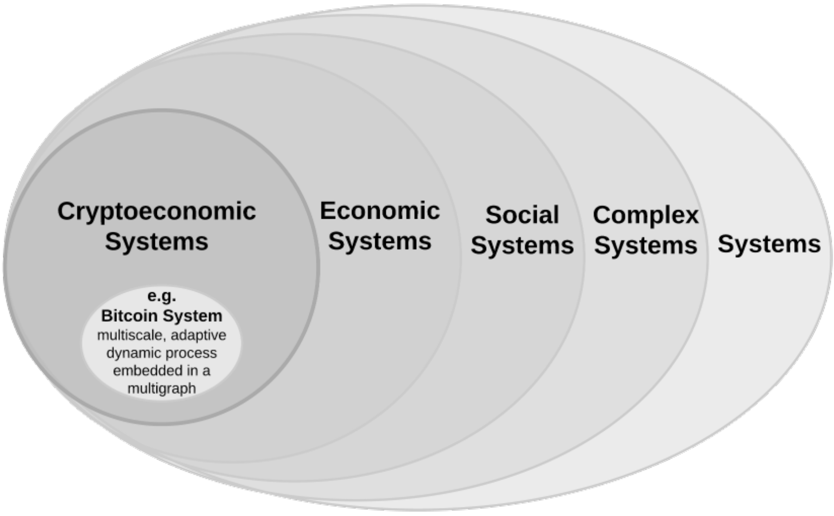

Fig. 1 Cryptoeconomic systems are complex socioeconomic systems.

processes reduce systems to better understand their parts, whereas synthesis is required to understand the whole as greater than the sum of its parts [Quine 1951].

Systems theory can contribute tools for the analysis of how the relationships and dependencies between a cryptoeconomic systems' parts can determine system-wide properties. It allows for the discovery of system's dynamics, constraints, conditions, and principles of cryptoeconomic networks with the aim to understand, model ,and steer them.

cryptoeconomic system such as the Bitcoin network can be described as a special class of complex socioeconomic system that is dynamic, adaptive, and multi-scale. Cryptoeconomic networks are dynamic due to the flow of information and assets through the network. Cryptoeconomic networks are adaptive because their behaviour adjusts in response to their environment, either directly in the case of the Bitcoin difficulty controller or more broadly through decisions on the part of node operators. Cryptoeconomic networks are multi-scale because they are specified by local protocols but are defined by their macro-scale properties, as is the case with the local "no double spend" rule guaranteeing a globally conserved token supply [Zargham, Zhang and Preciado 2018]. Their design requires a strong interdisciplinary approach to develop resilient protocols that account for the spatial and temporal dynamics of those networks [Liaskos, Wang and limohammadi 2019].

3. N INTERDISCIPLIN RY PERSPECTIVE

Interdisciplinary research has been identified as an appropriate research method when (i) the research subject involves complex systems and when (ii) the research question is not confined to a single discipline [Repko 2008]. The necessity of an interdisciplinary approach to the research of complex systems has been addressed by General Systems Theory [Von Bertalanffy 1969], in particular Cybernetics [Wiener 1965], [Barkley Rosser 2010]. Economists like Friedrich Hayek for example were influenced by the interdisciplinary field of Cybernetics, which leveraged systems theory methods available in his time [Oliva 2016], [Lange 2014].

The interdisciplinary research process is often heuristic, iterative and reflexive, and borrows methods from specific disciplines, where appropriate. It is deeply rooted in the disciplines, but offers a correction to the disciplinary way of knowledge creation [Dezure 1999], transcending disciplinary knowledge via the process called integration [Repko 2008]. While disciplines are regarded as foundational, they are also regarded as inadequate to address complex problems, sacrificing comprehensiveness and neglecting important research questions that fall outside disciplinary boundaries. Given the fact that blockchain networks and similar crptoeconomic systems provide a governance infrastructure [Voshmgir 2017] for socioeconomic activities, a symbiosis of both disciplinary and interdisciplinary research is needed to achieve the necessary breath and depth related to complex systems [Repko 2008].

The interdisciplinary research process includes: (i) identification of relevant disciplines, (ii) mapping research questions to identify the disciplinary parts, (iii) reducing the number of potentially relevant disciplines, (iv) literature review in relevant disciplines and for relevant research questions, (v) developing adequacy in relevant disciplines, (vi) analyzing problems and evaluating insights, and (vii) integrating insights and creating common ground for insights [Repko 2008].

In the context of cryptoeconomic systems, we have identified the following disciplines as relevant: Industrial and Systems Engineering, I, Optimization and Control Theory, Computer Science and Cryptography, Economics and Game Theory, Psychology and Decisions Science, Political Science, Institutional Economics and Governance, Philosophy, Law and Ethics, as well as Operations Research and Management Science. The wide range of disciplines may seem arbitrary but they are in fact bound by a central concept: allocation of resources. In particular,

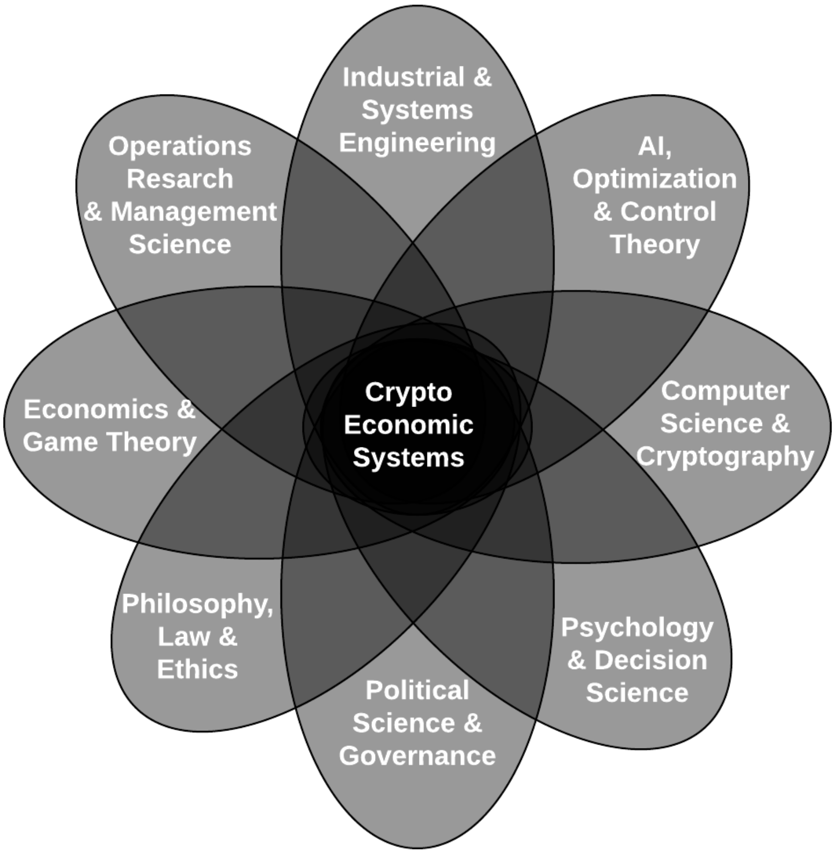

Fig. 2 Venn diagram of disciplines related to cryptoeconomic systems engineering.

cryptoeconomic networks provide coordination and scaling for resource allocation decisions of stakeholders with unique preferences, information, and capabilities. llocation decisions being made include resources which are: (i) physical, such as hardware and electricity; (ii) financial, such as tokens or fiat money; and (iii) social such as attention, e.g. governance participation, code contributions or evangelism. Envisioning, designing and governing cryptoeconomic systems requires the following questions to be considered:

— Who gets to make which decisions, under which circumstances, and to whom are they accountable for those decisions? Furthermore, how does this change over time?
— How do individuals make decisions given knowledge of the rules of the system, and subject to uncertainty about the decisions of others?
— How can a system be engineered to processes individual decision making into collective decision making such that system may be interpreted as coordinating toward a shared purpose?

Unsurprisingly, disciplinary bias and disciplinary jargon [Repko 2008] are challenges that need to be overcome in the interdisciplinary research process. ddressing this class of challenges adequately in cryptoeconomics research will be crucial to advancing research in this field. The existence of disciplinary jargon will require the development of a common language, or a Rosetta Stone [Gilbert 1998], to facilitate cross disciplinary communication. uto-ethnographic experience of the authors has furthermore shown that multidisciplinary teams' members require methods to facilitate the transfer of the state of knowledge between researchers of different disciplines. These "knowledge state updates" require time and effort and make the research process slower than in disciplinary research setups.

4. N INSTITUTION L ECONOMICS PERSPECTIVE

The interdisciplinary approach narrowed to the scope of economics brings the institutional perspective to the forefront. Institutional economics is a subset of economics that intersects with political science, sociology, history, management science and cybernetics. It studies the role of formal or informal – and public or private institutions – that are represented by a set of rules, norms, procedure, convention, arrangement, traditions or customs to steer socioeconomic interactions [Chavance and Wells 2008] [Veblen 1973], [Fararo and Skvoretz 1986], [Williamson 2000], [Coase 1937]. Governments, markets, firms, physical infrastructure, and even social patterns such as marriage are institutions.

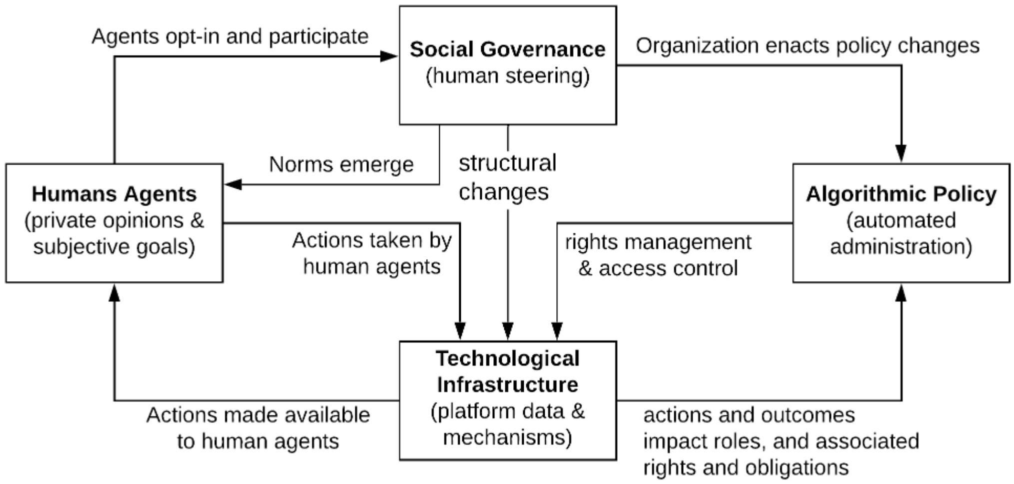

Fig. 3 Cryptoeconomic systems as institutions with social and algorithmic governance feedback loops

The Internet is an institution, and a piece of cultural infrastructure from which many distributed Internet tribes have formed over time [Phillips 2000], first around the infrastructural layer of the Internet [Mueller 2010], and then on the application layer such as e-commerce platforms [Re 1997], [Zhu and Thatcher 2010], [Schmitz et al. 2002], knowledge platforms [dams and Gordon 1989], or social media platforms. The institutional nature of the internet is underscored by the emergence of recognizable forms in self-organising communities as social activities migrate into digital spaces [Frey and Sumner 2019]. Though platform economies and associated network effects have driven the internet toward more centralized power structures, platform cooperativism demonstrates that digitalization, when wielded by communities, can be a force for democracy [Scholz and Schneider 2017].

Cryptoeconomic networks enable more fluid organizations to formalize over the Internet - around a specific economic, political, or social purpose - commonly referred to as a “Decentralized utonomous Organizations” or “D Os” by the crypto-community [Buterin 2014], [Wright and De Filippi 2015]. They reinvent the institutional composition of the Internet, allowing distributed Internet tribes to self-organize and coordinate in a more autonomous way - steered by purpose-driven tokens (read more on purpose-driven tokens in section 10.1). The network protocol and/or the smart contract code formalize the governance rules of the network, regulating and enforcing the behavior of all network participants.

s institutional infrastructure, cryptoeconomic networks resemble nation states much more than they resemble companies. Their protocols are comparable to the constitution and the governing laws of a nation state [Lessig 2009], in a combination of formal (on-chain) and informal (off-chain) rule sets. The network protocols and smart contract represent the computational constitution, while the adaptive social decision processes represent a body of values and rules which govern the collective decision-making process [Zargham et al. 2020], [Voshmgir 2020].

Cryptoeconomic networks provide an infrastructure that can change the composition and dynamics of existing institutions, since the use of such infrastructure can (i) reduce the principal-agent dilemma of organizations providing more transparency, (ii) disintermediate by reducing bureaucracy, and (iii) replace the reactive procedural security of the current legal system, with proactive and automated mechanisms that make a potential breach of contract expensive and therefore infeasible [Davidson, De Filippi and Potts 2016], [Voshmgir 2017], [llen et al. 2020]. Contract theory and the notion of incomplete contracts are an important institutional aspect in this context and will be discussed in section 10.3 of this paper.

The institutional economist Thorstein Veblem described socioeconomic institutions as complex adaptive systems, stating that they ”are products of the past process, are adapted to past circumstances, and are therefore never in full accord with the requirements of the present” [Veblen 1973] and pointed out the need for a feedback mechanism to maintain an institutional integrity in the light of their complex adaptive nature.

Walter [Hamilton 1919] also pointed out the complex nature of economic systems and ”claimed that institutional economics alone could unify economic science by showing how parts of the economic system related to the whole” [Hodgson 2000] and that ”economic theory must be based on an acceptable theory of human behaviour.”

5. THE EVOLUTION OF COOPER TION PERSPECTIVE

It is up for debate whether the economic theories applied in the conceptualization of these cryptoeconomic networks are - in fact - ”based on an acceptable theory of human behaviour” as expressed by [Hamilton 1919]. Common mathematical and game theoretic arguments about cryptoeconomic networks are based on the canonical results on the evolution of cooperation in an iterative prisoners dilemma [xelrod and Hamilton 1981], [Rapoport, Chammah and Orwant 1965]. These results demonstrate that coordination is possible (sufficient condition) in the presence of selfish actors, not that it is ‘only possible’ (necessary conditions) in the presence of selfish actors.

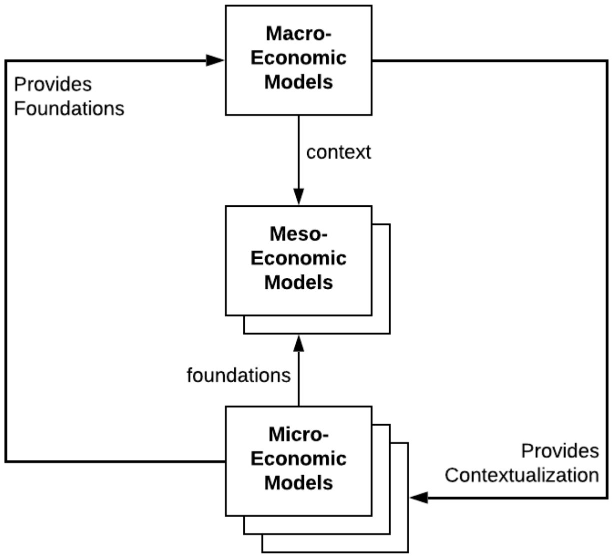

Fig. 4 Micro-Economic foundations and Macro-Economic context together form the basis of a multi-scale model required to capture interscale effects common in complex systems.

This framing is powerful, but the economic framing and behavioral assumptions made are rather limited compared with the existing body of relevant literature. While cryptoeconomics is interdisciplinary by nature, it has so far predominantly been developed in the computer science community. It seems that there is still much room to incorporate methods from various economic disciplines, that are very often interdisciplinary in themselves, like for example political economy (political science) or behavioural economics (cognitive psychology) and business law (legal studies) [Voshmgir 2020]. The idea, for example, that the coordination of a cryptoeconomic system is derived from pure self-interest of individual actors is a conjecture, which while useful as a narrative is unlikely to be factual. For example, the Miner's Dilemma [Eyal 2015] implies that the observed mining pools would break down under pure selfishness.

Therefore, it is entirely possible and actually more likely that cryptoeconomic systems exist as a result of a mixture of strategies, also referred to as norms as in more recent work on the evolution of cooperation [Yamamoto et al. 2017], [Peters and damou 2019]. The iterated prisoner's dilemma is an approximation of a complex social phenomena, [xelrod 1997], and continued study has provided additional insights around concepts such as indirect reciprocity [Nowak 2006] and meta-incentives [Okada et al. 2015], which are directly relevant to the study of cryptoeconomics, in so far as it is viewed as means to engineer incentives that make cooperative norms resistant to invasion by selfish ones in cryptoeconomic networks. In the evolution of cooperation literature theoretical, computational and empirical methods are applied to the study of populations of agents making individual decisions according to certain strategies, with an emphasis on the non-obvious system level properties that arise, and how these properties induce changes in future behavior.

6. MULTISC LE PERSPECTIVE

Economic systems are often observed to have properties that are not directly attributable to the agents, processes, and policies that make up the economic system. Understanding the emergent properties as arising from relationships between the agents, processes, and policies requires a multiscale perspective. Through a synthesis of these perspectives on multi-scale systems, a basic formula for framing practical economic models is shown in Figure 4.

ny model requires assumptions about the properties of its constituent parts and assumptions about the environment or larger system in which the model is embedded. Couched in economic terms the model of the larger system provides macro-economic context and the models of the constituent parts provide micro-economic foundations.

pplying a multiscale perspective to economic systems is not a new idea. It has been addressed implicitly by representatives of the ustrian School of Economics, and also other heterodox economic schools including Complexity Economics [Foster 2005], [Montuori 2005], [Bateson et al. 1989] and Ecological Economics [Common and Stagl 2005], [Schumacher 2011]. While Ecological Economics was originally motivated by ecology rather than systems theory, it also criticized the failings of the orthodox economic canon in addressing the complex dynamics that arise when there are interaction effects between parts and wholes with special attention to human activity as being a part of the natural world. The Lucas Critique [Lucas 1976] is a relatively recently yet widely accepted idea in macroeconomics that explicitly addresses feedback effects between micro and macro scale behavior. The need for multiscale representations is further borne out in Evolutionary Economics [Dopfer, Foster and Potts 2004] and in the standard practice of systems engineering [Hamelin, Walden and Krueger 2010].

Through the multiscale perspective, it is possible to study interscale phenomena such as *emergence* as shown in Figure 5. "Emergence (...) refers to the arising of novel and coherent structures, patterns and properties during

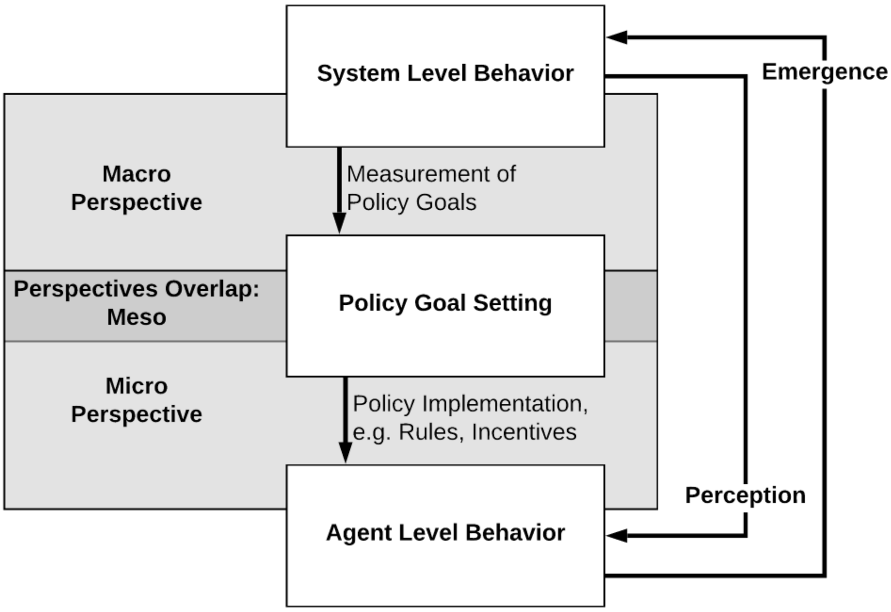

Fig. 5 Multi-Scale Feedback: In cryptoeconomic networks the system level behavior emerges from the agent level behavior responding to rules and incentives implemented as part of cryptoeconomic policy design.

the process of self organization in complex systems. Emergent phenomena are conceptualized as occurring on the macro level in contrast to the micro level components and processes out of which they arise.” [Goldstein 1999].

Emergence closes the feedback loop of the macro, meso and micro level activities where policy makers measure phenomena on a macro level, decide over new policies on a meso level, and implement these policies impacting agent behavior a micro level, which in turn result in systemic effects that can only be measured on a macro level.

n example of *Multi-scale feedback* in the Bitcoin Network is the interaction between the proof-of-work game being played between the agents (miners), and the Bitcoin Network itself. By introducing a feedback loop to correct the difficulty[1] and maintain the ten minute block time, the system itself becomes part of the game. One way of viewing this macro-scale game is as a two player game between the miners as a population and the network itself. The miners as a collective have their action space defined by the total hashpower provided and the network's action space is to set the difficulty. Even though all of the miners know what strategy the network is playing, the fact that they are still playing a micro-scale game with each other leads to increases in hashpower despite the fact that this is objectively more expensive than providing less hashpower for the same predetermined block rewards.

nother example of multiscale dynamics in cryptoeconomic systems are bonding curves [De La Rouviere 2017], including liquidity pools such as Bancor [Hertzog, Benartzi and Benartzi 2017] and Uniswap [ngeris et al. 2019]. detailed analysis of bonding curves shows that they encode nontrivial configurations spaces [Zargham, Shorish and Paruch 2019], wherein simple behaviors on the part of individual agents can collectively induce emergent changes to the global state. The interplay between local agent and global system state are explored further in [Zargham, Paruch and Shorish 2020]. This line of mathematical and computational research is consistent with multi-scale systems in robotics, [Kia et al. 2019], [Tsitsiklis 1984]. The Bitcoin network and bonding curve examples show the relevance of multiscale models for cryptoeconomic systems because neither the micro-scale game played between the entities in these systems, nor observations of the macro-scale properties, are sufficient to characterize the system dynamics.

7. NETWORK SCIENCE PERSPECTIVE

cryptoeconomic system is a kind of complex system that can be represented by interacting components that collectively form a network. Informally, a network is a group or system of interconnected people or things. formal mathematical definition of a network is a graph $\mathcal{G} = \{\mathcal{V}\quad\}$ made up of a set of vertices $\mathcal{V}$ and set of edges $\quad\subseteq \mathcal{V}\quad\mathcal{V}$. The edges are simply pairs of vertices and when the order of the vertices matters, the edge $i\ j)$ is said to be directed from i to j. pplying graph theory and networked dynamical systems to study social and economic networks is called network science [Barabási et al. 2016] and therefore relevant in the context of analyzing and modeling cryptoeconomic systems.

s networks grow the number of relationships between entities grows exponentially compared to the number of entities in the network [Dorogovtsev and Mendes 2004]. Furthermore, the topology of the network itself can

[1]To compensate for increasing hardware speed and varying interest in running nodes over time, the proof-of-work difficulty is determined by a moving average targeting an average number of blocks per hour. If they're generated too fast, the difficulty increases.[Nakamoto 2008]

Vertex Type	Definition
Entity	Off-chain unique identity of a person or organization
ccount	On-chain address controllable via a private key
Node	Software and hardware participating in a peer-to-peer network

Table I Vertex Types & Definitions in the Bitcoin System

	Entity	**ccount**	**Node**
Entity	has relationship with	controls keys of	operates
ccount		transfers funds to	
Node		sends rewards to	is peer of

Table II Edge types and definitions to be read as directed edges from column to row.

have significant influence on processes playing out within the network [Newman 2010] [Boccaletti et al. 2006]. The interactions between the parts of the system, including agent behaviors, and between the system and its environment often result in unexpected emergent properties, which in practice necessitates some form of human governance for cryptoeconomic networks [Voshmgir 2017].

cryptoeconomic system like a blockchain network is a multigraph because it has different types of vertices and edges which include labeling maps for the vertices and edges. Depending on the type of network the vertices can be: (i) *nodes* representing computer software in the peer to peer *computation and communication network*, (ii) *accounts* are addresses in the *financial network*, (iii) *entities* are identities of people and organizations in an off-chain *socioeconomic network*. Vertices are depicted in Table I.

cryptoeconomic network consists of three interconnected networks: (i) the *computation and communication network* comprised of *nodes* that leverage a peer-to-peer protocol to validate transactions by mining new blocks, (ii) the *financial network* comprised of Bitcoin *addresses*, which may sign transactions and transfer funds, and the (iii) the off-chain *socioeconomic network* representing people and organizations that control the tokens in the financial network and operate those nodes in the computation and communication network. summary of the types of edges is provided in table II. Incidentally, this hierarchical layering of networks is consistent with strategies for optimization decomposition [Chiang et al. 2007], providing a formal basis vertically disintegrated network economies [ymanns, Dewatripont and Roukny 2019]. In blockchain networks, the base layer data structure comes with cryptographic guaranties, but does not represent a human readable ledger, rather a formal mapping to the statespace representation is required to lift the data from its hash space to the record of accounts, which is recognizable as a ledger [Shorish 2018].

8. TOKENS S SYSTEM ST TE

Tokens represent a part of the state of any cryptoeconomic system and can be seen as their atomic unit [Voshmgir 2020]. The term *state* refers to a unique set of data (the ledger) that is collectively managed by all nodes in the network. Tokens are a representation of an individualized state of an economic system, including a specific right to change the system state. The existence of a universal state makes tokens provable and durable, and is a solution to the double spending [Nakamoto 2008] of digital values over the public networks.

While the existence of tokens in general and digital tokens in particular is not new, cryptoeconomic systems provide a public infrastructure that allow the issuance and management of tokens with lower friction [Voshmgir 2019]. The speed with which cryptoeconomic systems and their tokenized applications are being deployed, is an indicator for the pervasiveness of the technology and its applications [Filippova 2019],[Voshmgir 2019]. Tokens can make all socioeconomic activities publicly verifiable, thus visible to all network actors, and could provide the basis for data driven economic modeling with more feedback loops of tokenized socioeconomic activities. However, it is unclear if and when the tokenization of all economic activities will become feasible.

sset tokens and *access-right tokens* [Voshmgir 2019] represent business models and governance systems that are mostly well understood, and can be categorized as *simple token systems*. They can be modeled and steered with existing reductionist tools [Lipset 1980][Ruse 2005]. Such simple token systems require mostly *legal engineering*, which we define as the intersections of information systems and legal studies and deals with the question of how to make these tokenized use cases regulatory compliant [Voshmgir 2020].

Purpose-driven tokens are tokens that are programmed to steer automated collective action of autonomous network actors in a public network towards a collective goal in the absence of intermediaries [Voshmgir 2020]. They represent *complex token systems* and require complex system approach [Foster and Metcalfe 2012][Kurtz and Snowden 2003] to be modelled. Purpose-driven tokens that enable complex token systems differ from simple token systems in that they close the loop in so far as the system becomes autonomous and is not being steered by single institutions. Complex token systems requires mostly *economic systems engineering*, which we define on the intersection of information systems and economics including political economy and other related social science domains. Economic systems engineering can build on systems engineering [Sage 1992], [Blanchard and Fabrycky 1990],[Novikov 2016], but deals with research questions that model and steer aggregate agent behaviour, which brings us into the emerging field of complex systems engineering [Bar-Yam 2003] [Rhodes and Hastings 2003] that requires a multi-scale perspective on how to steer these systems.

Table III. Cryptoeconomics[*]

Level of nalysis	Economic Perspective	Governance Perspective	Design Perspective	Bitcoin Reference
Macro[a]	Global Outcomes	Policy Goals Measurement	Performance Metrics	Stability, Security, etc.
Meso[b]	Institutional Dynamics	Policy Goal Setting	Performance Targets	Informal Governance[†]
Micro[c]	Protocol Foundations	Implementation of Incentives	sserted Properties	Nakamoto Consensus

[*]Cryptoeconomics relates three interactions layers or *levels of analysis* that define characteristics at the micro-foundational, meso-institutional, and macro-observerable domains of scope.

[a]**Macro-observables** are system global properties that inform decision-making at the meso-institutional level and provide stakeholder feedback, performance indicators and measures that can impact micro-foundational properties.

[b]**Meso-institutional** characteristics encompass decision-making and goal determination, based upon and requiring micro-foundations. Mechanism design as used in Economics informs institutions, organisations and teams.

[c]**Micro-foundational** characteristics are assumption specifications with a natural expression within mechanism design as used within Computer Science.

[†]**Informal Governance** is a form of decentralized governance whereby changes to the protocol are made locally by individual participants operating nodes in the peer-to-peer network and changes only take effect if the majority of participants adopt the change. In the case of Nakamoto Consensus such a majority is measured in hashpower.

9. UNIFYING PERSPECTIVE ON CRYPTOECONOMICS

Cryptoeconomic systems are complex socioeconomic networks defined by (i) individual autonomous actors, (ii) economic policies embedded in software (the protocol or smart contract code), and (iii) emergent properties arising from the interactions of those actors with the whole network, according to the rules defined by that software. comprehensive definition of cryptoeconomics therefore includes three levels of analysis: (i) micro-foundational, relating to agent level behaviors (ii) meso-institutional, relating to policy setting and governance and (iii) macro-observerable, relating to the measurement and analysis the system level metrics. Critically, the dynamics at each level of analysis are interdependent in a manner which cannot be simply reduced into a single layer–governance is precisely managing the relationship between the micro and macro scales.

Micro-foundational characteristics of cryptoeconomic systems are commonly expressed in terms of algorithmic game theory in the computer science literature [Nisan et al. 2007] and mechanism design in the economics literature [Hurwicz and Reiter 2006]. Mechanism design is sometimes referred to as reverse game theory as it pertains to the construction of games to produce specific behaviors from agents. Nakamoto Consensus, for example, is a cryptoeconomic mechanism based on proof-of-work that is designed to provide convergence to a dynamic equilibrium–a synchronous shared global state, which furthermore remains resistant to a range of attacks constituting of self-interested misinformation despite being a permissionless network. n attack would be any violation of the state transition rules encoded in the protocol, such as a "double spend'. Nakamoto consensus uses a combination of cryptographic tools with economic incentives that make economic cost of wrongdoing disproportionate to the benefit of doing so [Nakamoto 2008], [ntonopoulos 2014]. Proof-of-stake mechanisms provide similar game theoretic arguments for network security. Interestingly, proof-of-authority networks [De ngelis et al. 2018] offer a more traditional approach where the validator role is permissioned and stems from social and institutional reputational processes which exist outside the computational environment. Most current definitions of cryptoeconomics focus on this level of analysis and modeling [Buterin 2017a], [Buterin 2017b] [Tomaino 2017a]. However, the level of security very much depends on how people react to economic incentives, which in turn has been a field of study in economics [Voshmgir 2020]; the security of the network is an emergent macro level property.

Macro-observables are system-wide metrics or properties which may inform decision-making of stakeholders within the system. Macro-observables often include performance indicators that impact governance decisions at the meso-institutional level as well as measures that can impact perception and thus behavior at the micro-foundational level. In addition to security, market capitalization, price [Shorish 2019], [Cong, Li and Wang 2019] and price stability are the most commonly studied macro-observables. Other important macro-observables include wealth distributions, governance participation, monthly active users, and any other measure or estimate which serves as a proxy for system level goal that matters to a cryptoeconomic network's human stakeholders. Critically, macro-observables are not directly controllable; efforts to impact these metrics are determined at the meso scale and the consequences of those interventions are borne out at the micro scale.

Meso-institutional characteristics encompass decision-making and goal determination, based upon macro-observables and requiring micro-foundations. This level builds on political science, law, governance and economics to design the steering processes of communities, by some referred to as institutional cryptoeconomics [Berg, Davidson and Potts 2019]. Ethical design and informed governance of cryptoeconomic systems resides in the meso-institutional level and requires an understanding of both the micro-foundations and macro-observables, as well as the relations between them. This manuscript, as a whole, addresses the meso-instutional perspective as a keystone in the coherent synthesis of macro and micro perspectives on cryptoeconomics through the observation that automation in socioeconomic systems is tantamount to algorithmic policy making.

10. RESE RCH DIRECTIONS

Cryptoeconomic systems provide an institutional infrastructure that facilitates a wide range of socioeconomic interactions. The design space for this institutional infrastructure includes novel socioeconomic interaction patterns thanks to the peer-to-peer protocols' support for state dependence via tokens. Research regarding the analysis and design of cryptoeconomic systems is necessarily interdisciplinary. Building on other interdisciplinary research future work includes - but is not limited to - the following topics: (i) purpose-driven tokens, (ii) data driven economies, (iii) incomplete contracts, (iv) ethics of decision algorithms as social infrastructure, (v) applying computational social science to cryptoeconomic systems, and (vi) applying cyberphysical systems engineering to cryptoeconomic design and analysis.

10.1. Purpose-Driven Tokens

Bitcoin's *proof-of-work* [Nakamoto 2008] introduced an incentive mechanism to get network actors to collectively manage a distributed ledger in a truthful manner, by rewarding them with network tokens which are minted upon *proof-of* a certain behaviour. The idea of aligning incentives among a tribe of anonymous actors with a network token, introduced a new type of public infrastructure that is autonomous, self-sustaining, and attack resistant [Voshmgir 2020]. Such networks, therefore, represent a collectively produced and collectively consumed economic infrastructure. This common economic infrastructure can be viewed as a commons whose design and governance should be held to Ostrom's principles [Ostrom 1990]. If there is an underlying optimal choice to be uncovered through a social process there is some hope that this optimal could be learned via a consensus process [Jadbabaie et al. 2012]. However, it is more realistic to take a *polycentric* viewpoint where there is no one social optimum and thus it is important to take a wider view of social choice [rrow 2012] [Ostrom 2000] before embarking on the design of a purpose-driven token. fter all, any choice of coordination objective is a subjective choice. ssuming one can define a common objective, the token designer would encode this objective as a cost function and strive for dynamic stability around a minimum cost outcome over time as is done with dynamic potential games [Candogan, Ozdaglar and Parrilo 2013], swarm robotics [Gazi and Passino 2003] and vehicle formations[Olfati-Saber and Murray 2002]. In all cases the design goal is strong emergence around some objective [Klein et al. 2001]. It is also possible to envisage the objective selection process as dynamic consensus [Kia et al. 2019]. Broadly speaking purpose-driven token design lives at the boundary of behavioral economics and dynamic decentralized coordination in multi-agent systems which bridges with institutional economics[Coase 1998], and in particular platform economics [Rochet and Tirole 2003].

10.2. Data-Driven Economic Systems

Cryptoeconomic systems provide near real-time data of on-chain economic activities, and may govern access rights or provide proofs related to data stored off-chain. The advancement in machine learning and system identification methods over the past decade has increased our capacity for creating novel, useful models in across a wide range of applications [Jordan and Mitchell 2015], and in the context of economics [Mullainathan and Spiess 2017] in particular. This, for the first time, allows for almost real time steering of these economies and a level of applied cybernetics that was not possible before. Furthermore, it increases the precision of modeling and measurement required for steering these economies. This results in a data driven regulatory process, as shown in Figure 3.

However, the advances of machine learned models [Jordan and Mitchell 2015] is a consequence of the growth of the digital economy that captures a large amount of economic data. This data is largely controlled by large tech firms operating platform based services, which are often subject to algorithmic bias [Garcia 2016], [Lewis and Westlund 2015],[Sætra 2019], [Von Foerster 2003]. The stateful nature of cryptoeconomic systems has the potential to cede control of data back to the users of these platforms, if *privacy by design* is considered in the modeling of the cryptoeconomic systems and their applications [Voshmgir 2020].

10.3. Incomplete Contracts

specific question relevant to cryptoeconomic systems is contract theory [Bolton, Dewatripont et al. 2005], in particular how to consider incomplete contracts [Hart and Moore 1988] in a computational environment. Contract theory is the study of contractual arrangements at the intersection of economics and law, and is further divided into representations where contracts are complete (i.e. all possible outcomes are enumerated in the contract) and where they are incomplete (i.e. one or more possible contingencies cannot be expressed in the contract), cf. e.g.[Grossman and Hart 1981],[Grossman and Hart 1983], [Hart and Holmström 1987], [Hart and Moore 1990]. Contract theory further addresses the goals of cryptoeconomic system design through its attention to the efficiency of resource allocation problems [Hurwicz 1960] in cases where information required to solve the associated optimization problems is distributed amongst agents [Hurwicz 1972].

The theory of complete contracts is based on concepts such as mechanism design [Hurwicz and Reiter 2006] and principal agent theory [Holmstrom and Milgrom 1991], including concepts such as incentive compatibility, asymmetric information, adverse selection, and moral hazard [Laffont and Martimort 2009], which are relevant for algorithmic policy administration, including design of cryptoeconomic systems. While machine level behavior may be well represented by complete contracts, human behavior rarely is. Incomplete contract theory assumes that most contracts cannot enumerate contracting outcomes for every possible state of the world as the complexity of socioeconomic interactions makes it infeasible to formalize any eventuality of a contractual outcome ex-ante [Tirole 1999]. One can resort to formal dispute resolution (judiciary) or informal dispute resolution (bargaining) to resolve such contractual gaps [Salanié 2005]. The impossibility of codifying every eventuality into a computational constitution or smart contract code and the necessity for dispute resolution and off-chain governance mechanisms has also been the subject of ample debate within the context of cryptoeconomic systems [Voshmgir 2017], [Voshmgir 2020] and will be a necessary line of research to pursue.

10.4. Ethics and Governance of Decision lgorithms in Social Systems

ssumptions that are programmed into the cryptoeconomic protocols might be biased and will be subject to a line of ethical studies covering how the associated cryptoeconomic systems behave over time. When automated systems are envisaged as closed systems they are tantamount to complete contracts–supposing that a prespecified algorithm suffices to judge all possible eventualities. ll algorithms presuppose some representation or model of reality; models are always reductions of reality based on some assumptions, and therefore must be judged by their usefulness to some ends[Box 1976][Green and Viljoen 2020]. This places the focus on the assumptions embedded in the models and the effects those assumptions have on people. By acknowledging the subjective and performative aspects of models, and more broadly the synergies between human and machine decision makers, the domain mirrors that of incomplete contracts more closely. The policy-making, machine learning and cryptoeconomic systems design communities share a common need to address ethical questions about the social-systemic effects of algorithm design and implementation [Orlikowski and Scott 2015] [Loukides, Mason and Patil 2018]. To design or govern algorithms which make decisions requires a theory of fairness such as Rawl's Veil of Ignorance [Rawls 1958] [Heidari et al. 2018]. Fairness cannot be expected to emerge from purely self-interested agents because fairness provides a constraint on profit seeking behavior [Kahneman, Knetsch and Thaler 1986]. s a result, a code of ethics for algorithm designers, as found in other engineering disciplines [Pugh 2009], is required.

Furthermore, it is important to note that data governance [Soares 2015] is not equivalent to protocol governance. Data governance relates to the management of rights to read, write or manipulate data. Emerging data economies must respect regulations such as General Data Protection Regulation [Voigt and Von dem Bussche 2017] and therefore one cannot simply store private or sensitive information in a public ledger where it cannot be deleted. However, data governance can be addressed through business process automation [Ter Hofstede et al. 2009] using smart contracts [Christidis and Devetsikiotis 2016], which encode the aforementioned rights to read, write or manipulate data which is stored using other cryptographic technologies such as a content addressable distributed hash tables [Benet 2014]. Federated machine learning [Bonawitz et al. 2017][Geyer, Klein and Nabi 2017] is a growing area of research, but practical implementation is hindered by the ethical and regulatory requirement that there are guarantees of privacy preservation [hmad, Stoyanov and Lovat 2019].

10.5. Computational Social Science

Computational social science [Johnson and Lux 2011], is a particularly relevant branch of interdisciplinary research for cryptoeconomic systems. This is the primary field of social science that uses computational approaches in studying the social phenomena [Cioffi-Revilla 2016]. Modern computational social science is much more deeply coupled with behavioral economics and data science where advanced computational statistics are combined with social networks, market dynamics, and more [Easley and Kleinberg 2010], [Jackson 2008]. The advancing power of computation has lead some to refer to computational science as a "new kind of science" [Wolfram 2002]. This paradigm is backed up by an emerging computational epistemology [Kelly 2000] [Blum and Blum 1975] [Chaitin 2011]. It is precisely in the context of complex systems that counterintuitive outcomes are common, and computational methods expose unforeseen pitfalls before they can cause irrecoverable harm [Forrester 1971] [Merton 1936]. Computational methods in cryptoeconomic systems combine data science tools with system dynamics and agent based models to explore the relation between agent behavior and protocol design [Zhang, Zargham and Preciado 2020]. The approach of combining data with theory and computation is consistent with methods in econophysics [Lux 2009] and ergodicity economics [Peters and damou 2018], though in the case of cryptoeconomics the volume and precision of data available for backtesting models is higher.

10.6. Cyberphysical Systems Engineering

In the field of engineering, especially for large scale cyberphysical systems, computer aided design is standard practice[Baheti and Gill 2011] [Rajkumar et al. 2010]. The United States National Science Foundation defines a cyberphysical system (CPS) as "a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users. In cyberphysical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioral modalities, and interacting with each other in a lot of ways that change with context" [National Science Foundation Directorate for Computer and Engineering 2010], [Lee 2006], [Lee 2008].

Examples of existing cyberphysical systems include power grids and large scale transportation systems [Greer et al. 2019], which both share the property that behavior of uncontrolled human actors can create undesirable or even unsafe conditions in entirely counterintuitive ways. common criticism for using this analogy is the presence of attackers, but this a common concern in the CPS literature [Cardenas et al. 2009],[Barreto et al. 2014]. In practice, the design, operation, and governance of such large scale systems is accomplished through computational models called digital twins, [Grieves and Vickers 2017] [Uhlemann, Lehmann and Steinhilper 2017] which are also closely related to the practice of model based systems engineering [Estefan et al. 2007]. Model based systems engineering has previously been applied for multi-agent systems [DeLoach, Wood and Sparkman 2001] [Fallah et al. 2010], and the relation from cryptoeconomic networks to cyberphysical systems has already been observed in the literature, [Bahga and Madisetti 2016].

The systems engineering methodology [Hamelin, Walden and Krueger 2010] as applied to cyberphysical systems relies on a composite of theoretical, computational, and empirical methods [Banerjee et al. 2011]; thus building on the experimental economic tradition [Roth 2002] [Kagel and Roth 2016]. natural path forward is to treat cryptoeconomic systems as cyberphysical systems and to approach them with the diligence an engineer must afford to any public infrastructure [Hou et al. 2015]. s with other complex engineered systems, informed governance requires both specialized tools and expertise, so even when governance systems are polycentric the parties responsible for governance are accountable to the public they serve [Walch 2015][Ostrom 2010]. To do so, it is necessary to develop a holistic perspective for cryptoeconomic systems which relates the locally implemented protocols, behavioral response to those mechanisms, and the systemic properties that emerge therefrom.

The crossover between cyberphysical systems as an engineering concept and a commons as an institutional economics construct is fertile ground for research in cryptoeconomic systems. The Commons Stack project has introduced the notion of a cyberphysical commons [Emmett 2019]. Several initiatives are exploring the relationships between governance of commons and cryptonetworks through the lens of Ostrom's Principles [Rozas et al. 2018], [Schadeck 2019]. Organizations pursuing commons related research include the P2P Foundation [Bauwens, Kostakis and Pazaitis 2019] and the Commons Engine which is associated with the Holochain technology [Harris-Braun, Luck and Brock 2018].

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The Web3 Sustainability Loop

A system design for long-term growth of Web3 projects, with application to Ocean Protocol

Trent McConaghy · Follow
Published in Ocean Protocol
18 min read · Sep 1, 2020

Introduction

The prequel to this essay posited the following: Imagine that you're a founder of a Web3 project and there are several teams building applications on your technology in your nascent ecosystem. You're asking:

> *How do we grow the ecosystem and make it truly self-sustaining?*

The prequel surveyed existing Web3 grants programs. The challenge to any grants program is: do the dynamics *truly* support growth, and long-term sustainability? **What if grants are a black hole?** Or, if grants end, will the ecosystem survive?

I believe this should be a genuine concern for every Web3 project. If it isn't, then it might be worth becoming a concern, lest the project fades into oblivion. Massive funding masks the problem, but doesn't make it go away.

I believe there's a way. As inspiration, we can look to *organizations that have survived for decades and even centuries*. That is, successful companies and nations. In this essay, I describe a core growth/sustainability loop and the role of stock and of fiat, for both both companies and nations.

This growth / sustainability loop can be used for Web3 projects: the **Web3 Sustainability Loop.**

The British Parliament symbolizes UK's history over many centuries. [Image: CC-BY-SA-3.0]

The rest of this essay is organized as follows.

- First, I describe **company business models (section 1)**, powered by revenue, with a focus on Web1 & Web2. However, that's not the complete picture; we also need to include the **role of company stock (2)**.
- Then, I describe **nation-level sustainability / growth models (3)**, powered by taxes. To complete the picture, I then describe the **role of printing fiat (4).**
- Then, I describe **Web3 sustainability / growth models (5)**, powered by transaction fees. To make a complete Web3 Sustainability Loop, we also need to include **token generation (6).**

- Finally, I give an **application of the Web3 Sustainability Loop (7)** to the Ocean Protocol project.

(1) Company Business Models

Introduction

Every business needs a means to sustain itself. If they don't, they die. Evolution filters, mercilessly.

In companies, sustainability generally means getting people to pay you for your product or service (revenue), and using that to pay for costs (salaries, office, etc). As soon as revenue exceeds costs, you are self-sustaining, which is a first sustainability milestone. With profitability, the business is qualitatively different, since cash is no longer an existential threat. But startups aim not only to sustain, but to *grow* by putting surplus revenue back into growth. It's a positive feedback loop, a snowball.

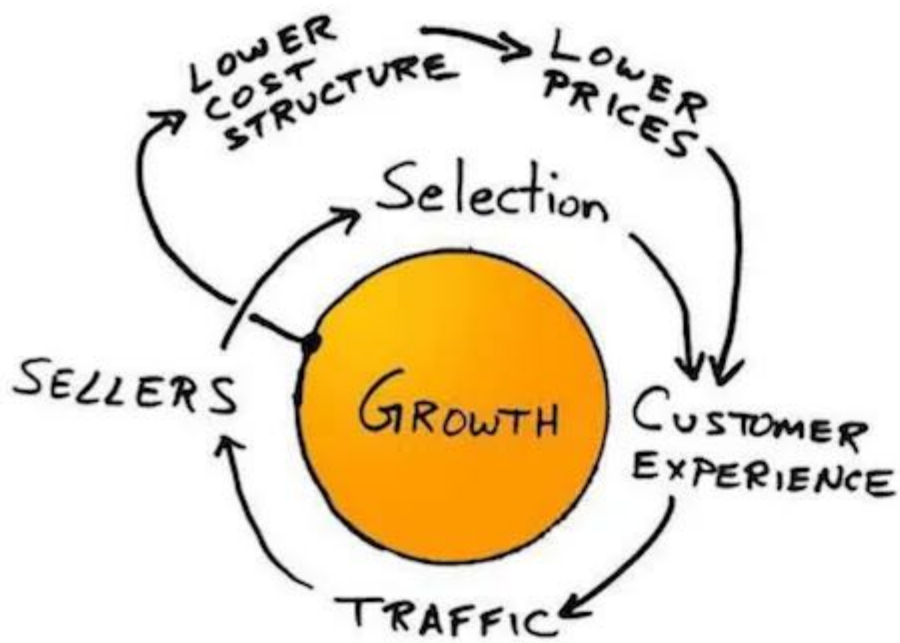
Web1 and Web2 companies explored many business models. Successful companies point to the successful models.

Web1 Business Models

When the web started to get commercial in the mid 1990s, everyone searched for business models. The web was originally about content: one giant hyperlinked document. Many people tried business model of copying and pasting offline *content* into the online world. Or purely online content. This mostly failed.

Some Web1 companies tried a web-native business model: treat the webpage as an application to buy things or interact with others, and take a cut. Some of these worked quite well, such as Ebay and Craigslist.

Amazon's famous loop, pictured below, worked particularly well. Better customer experience begets more traffic, begets more sellers, begets better selection, begets customer experience. This is growth. And this growth gives even more benefit: growth allows to lower the cost structure, which lowers prices, which further improves the customer experience. With the help of this loop, and with time to see the results, Amazon has become one of the world's most valuable companies.



The Amazon loop. Source: Amazon.com

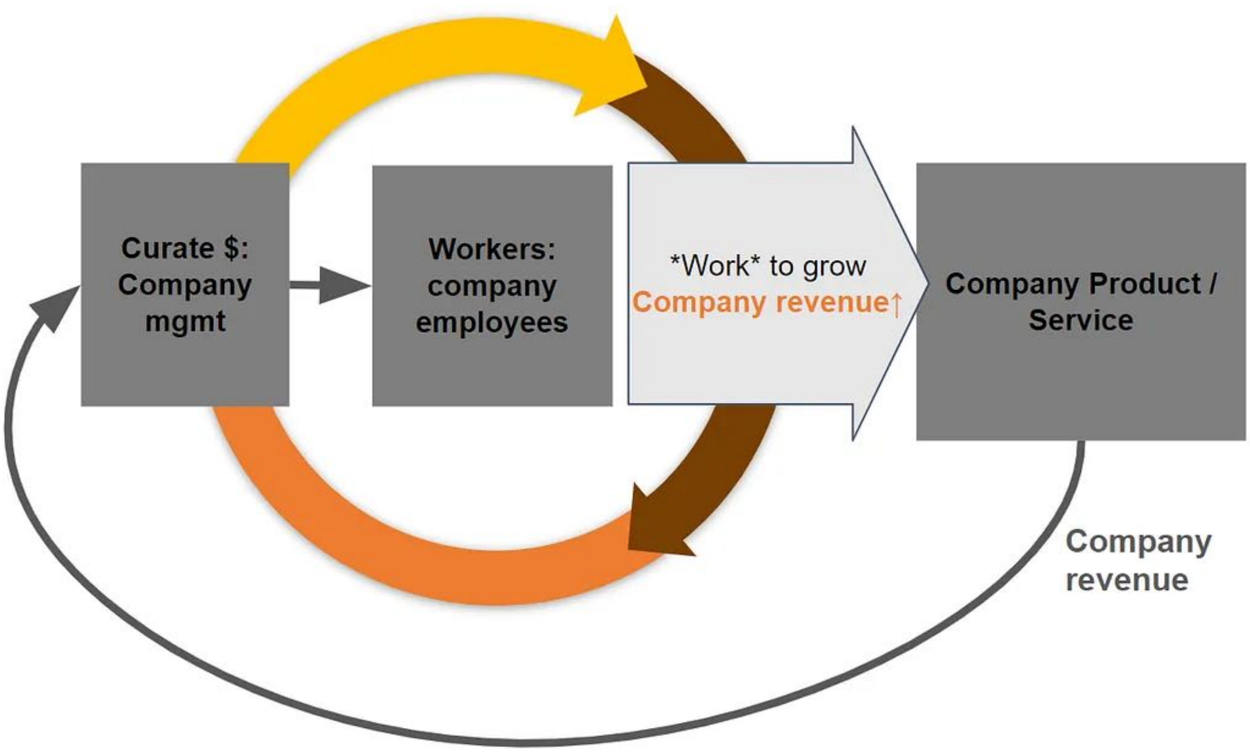
Web2 Business Models

The Web2 generation brought mobile, social media, and the cloud. There are many models which have led to successful, sustainable businesses. Here's a sampling.

- **Paid subscriptions**. This includes for software (SalesForce, Meetup, MailChimp), for content (New York Times), and more.
- **Transaction Fees.** Here, a platform is a middleman that charges a fee to connect buyers and sellers. This is done in in payments (PayPal, Stripe), transit (Uber, Lime), lodging (Airbnb), e-commerce (Amazon for 3rd party merchants), and more.
- **Affiliate programs.** Here, the referrer gets a cut of the final sale. This includes travel (Kayak) and e-commerce (Amazon Associates).
- **Ads**. Being the middleman for ads is the biggest internet business of all. Thus, ads are all over the place. Ads are in dedicated search platforms (Google AdWords), 3rd party webpages (Google AdSense), social media (Facebook, Twitter), apps (most free mobile apps), and content (YouTube). We may hate ads,

but they do make for sustainable businesses on the web. (Let's aim higher with Web3!)

This generalizes: all businesses need a business model to sustain themselves and grow. A business model is the design for a business *machine*, in the sense of Andy Grove's breakfast factory, Ray Dalio's Principles, or Jay Forrester's dynamical systems research. The figure below illustrates a business machine designed to sustain and grow. At the center are the Workers: company employees who do *work* to grow company revenue by bringing the company's product or service to market. The company's management allocates (curates) the company revenue to get more resources (e.g. hire more workers) to grow the company even further. It's a *loop*: revenue put into growth, allocated well, begets more revenue yet.



Company business model with a focus on revenue. The challenges are how to kickstart the company, and how to grow fast enough to beat the competition.

(2) Company Business Models — The Full Picture

In the previous section, we described the Amazon loop, and generalized upon it. However, it's an incomplete picture of Amazon's story and of other businesses.

Revenue alone did not solve for cash at critical junctures:

1. **Amazon needed funds to get going in the first place.** It needed those funds to hire employees who then built the initial product, in order to start getting revenue in the first place.
2. Furthermore, as it was growing, it was at risk of getting out-run by faster-moving competitors, so **Amazon needed more funds to grow aggressively, and revenue alone was not enough.**

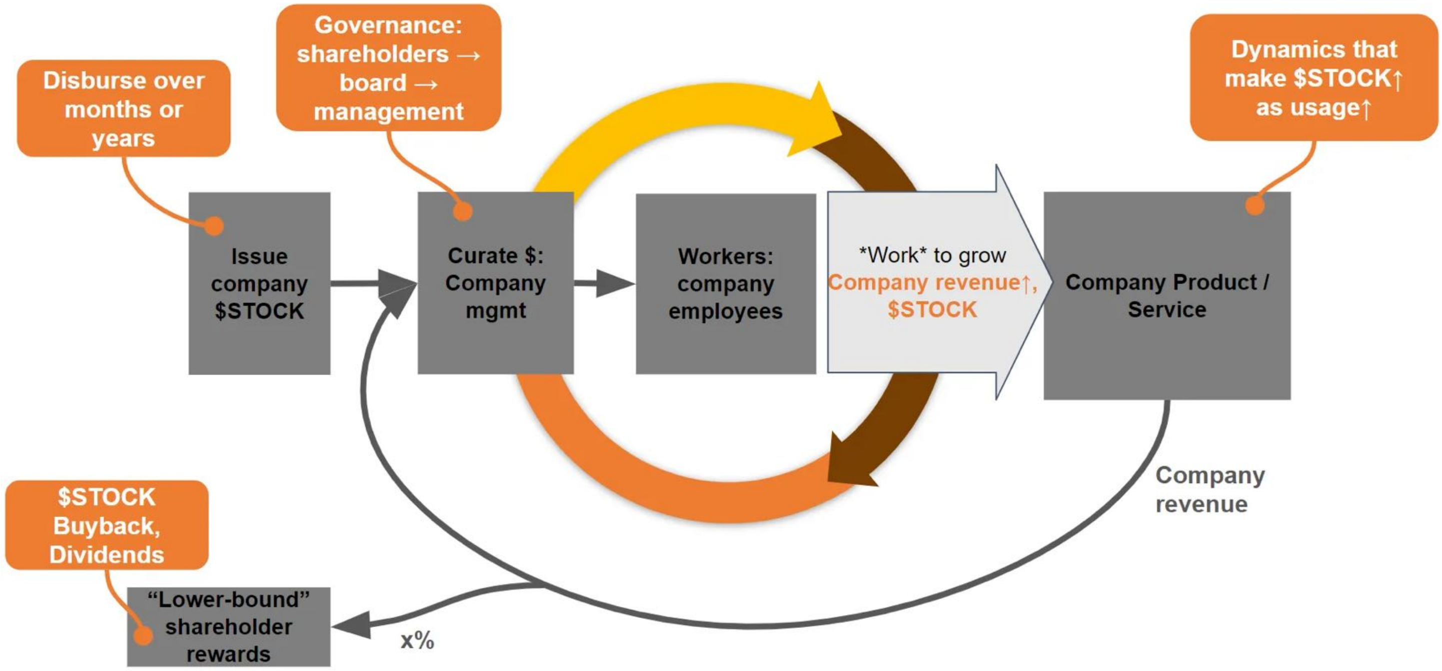
What did it do? *It issued more company stock, and sold that stock* to investors for cash. It issued stock to address the two junctures above. First, to kickstart the business, Jeff Bezos sold some stock to friends and family. Second, when Amazon's business was starting to get traction, Jeff Bezos raised money from VCs to grow faster.

Issuing stock is a superpower for businesses. It pulls capital from the future into the present, based on the premise that allocating it effectively will increase the value even more in the future. Individuals can't do this, families can't do this, and cities can't do this. But businesses can, and do.

Issuing stock is useful for kickstarting businesses and for catalyzing growth. It has one more critical use: *stock can rescue a business in pain*. If the business is doing poorly, the company can issue a *lot* more stock (potentially at lower valuation) and then sell that stock, as a way to survive and see another day. In startup-land this is a "down round," but the choice is either this or company death.

Stock is a tool to rescue larger businesses too, via bankruptcy proceedings. For example, General Motors (GM) went bankrupt during the 2008 financial crisis. GM had to issue a lot more stock to new investors. The old investors got a lot of their value wiped out, but GM the business kept going, the employees kept getting paid, and the cars kept getting built.

In short, stock issuance is a powerful tool. Below is the business machine, modified to show the full picture for a well-designed company. It's modified to account for the role of $STOCK in addition to revenue. The company issues and sells stock (left). Companies work to grow revenue *and* $STOCK (middle right). The company's products / services are designed such that as usage increases, $STOCK does too (top right). Finally, stocks give the company optionality to give shareholders some lower-

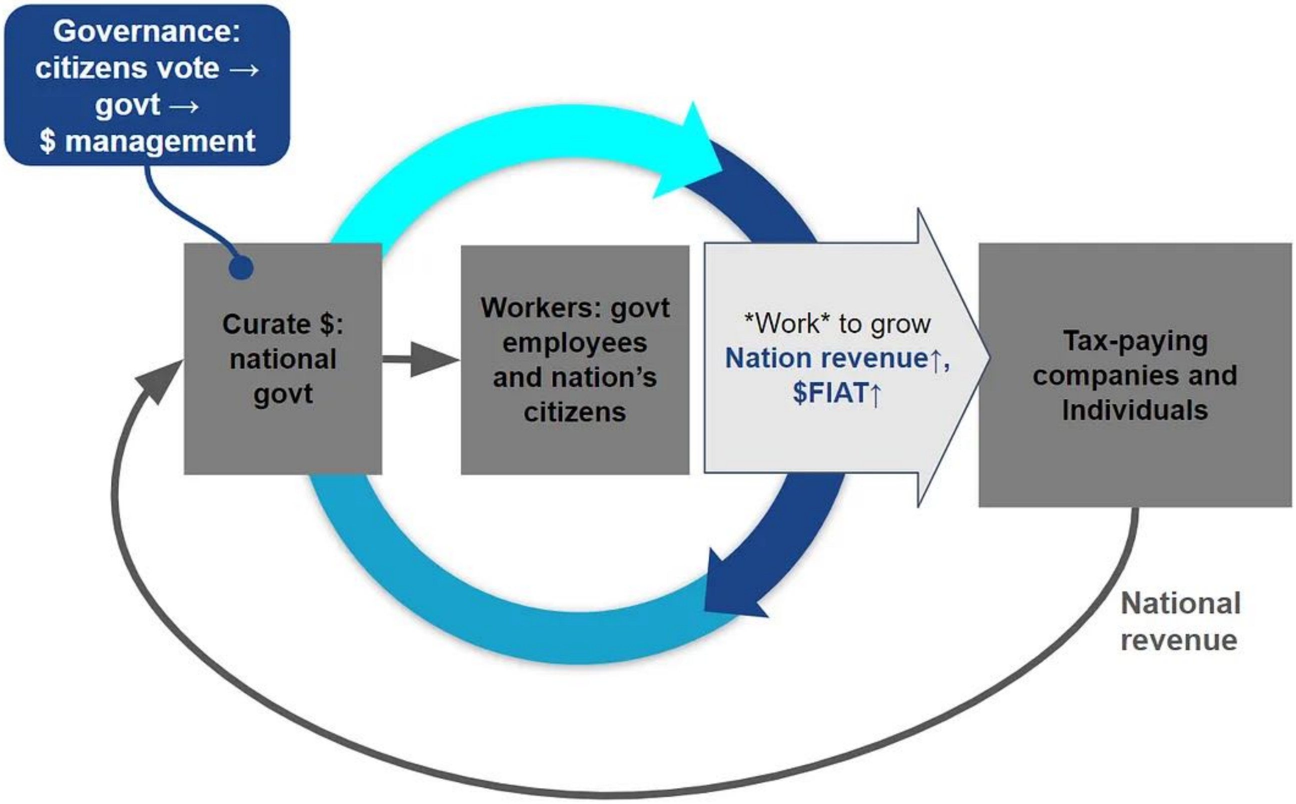


Company business model including an "outer wrapper" that uses stock as a tool, in addition to revenue.

(3) Nation-level Sustainability / Growth Models

Let's discuss dynamics of national economies. Nations take in revenue from taxes. They use that revenue to create and grow an ecosystem of laws, public infrastructure, defense, etc. so that citizens can thrive and conduct commerce. When citizen and business well-being goes up, tax revenues go up, and the nation becomes more successful. GDP measures the amount of commerce. And so the loop goes.

The image below illustrate, using the "machine" framing. In the center, government employees and citizens do *work*. This work the amount of revenue that individuals and companies earn (right). GDP is the sum of this revenue, and acts as a KPI for the nation [1]. That revenue is taxed, for National revenue (bottom right). The national government chooses (curates) how to allocate this revenue towards further improvements to drive the loop.



Nation-level sustainability/growth model with a focus on revenue. The challenge is how to have sufficient funding in emergency situations.

The picture assumes that the only source of funds is tax revenue. That's how governments typically approach budgeting. To illustrate: when a bill for *X* is proposed, the question "where do you plan to get the tax revenue to pay for *X*?" will inevitably arise. However, this is an incomplete picture: we must account for printing fiat. The next section elaborates.

(4) Nation-level Sustainability / Growth Models — The Full Picture

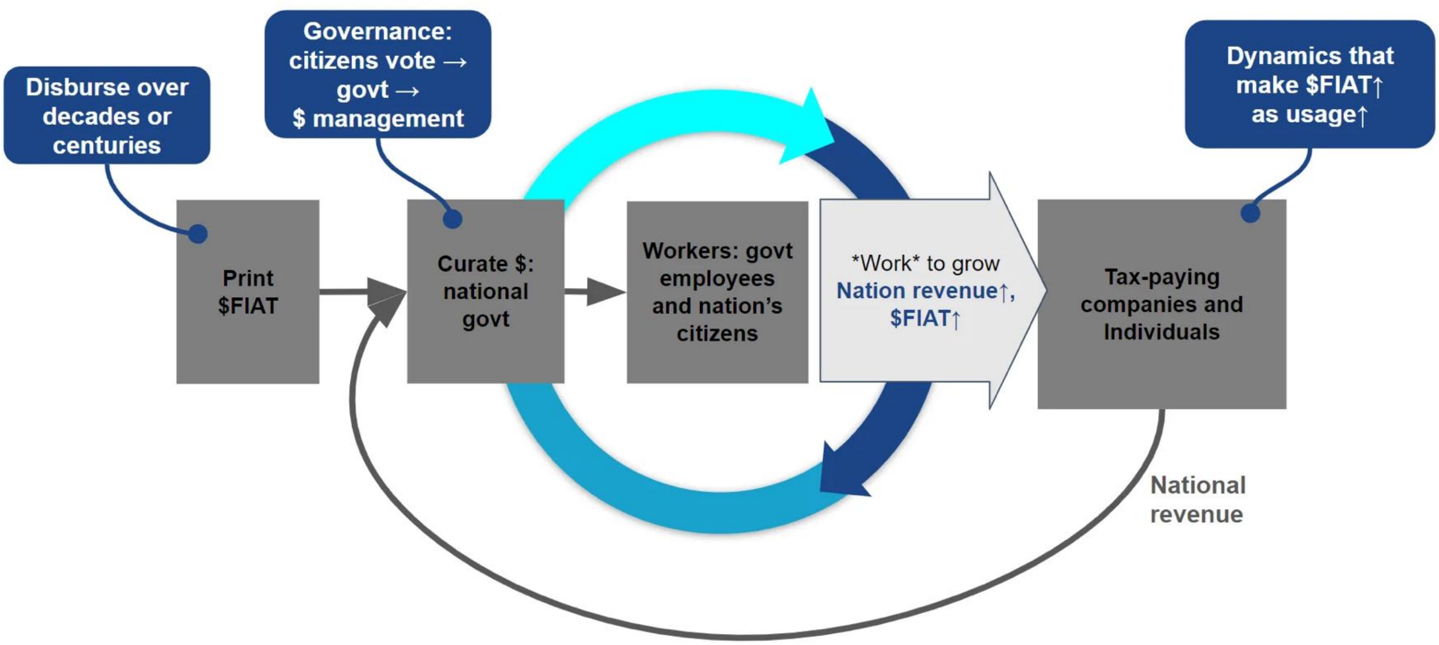
Currencies significantly reduce the friction for commerce within an economic region by acting as a means of exchange and a unit of account. Governments, banks and private institutions can all issue currency but in the 20th Century, the primacy of government as the issuer of hard currency is the accepted norm.

The issuance of currency, "fiat" brings privileges and risks. In times of economic need, governments have the ability to "print more money" with the hope that the injection of cash into the economy helps to boost consumption with the goal to let the system heal itself and smooth out dips with economic downturns. After an economy has recovered, responsible governments slowly remove the excess printed money to restore equilibrium.

The act of "printing money" is rife with risks. If too much money is printed, supply can outstrip demand, leading to price inflation because the excess money needs to flow somewhere. Without measures to restore equilibrium, inflation can spiral out of control and lead to hyperinflation where money becomes essentially worthless. When printed money is poorly allocated, it can get hoarded, which in turn can lead to economic inequality, societal unrest and economic dislocation for the most vulnerable low- to mid-income workers.

Used sparingly and with good judgment, printing fiat is a *tool* in a nation's toolbox to spur economic growth and improve citizen well-being.

In the spirit of legendary MIT professor Jay Forrester's systems approach to model national economies, the following picture summarizes a "machine" for a well-designed national economy. It starts with the tax-powered revenue loop that we



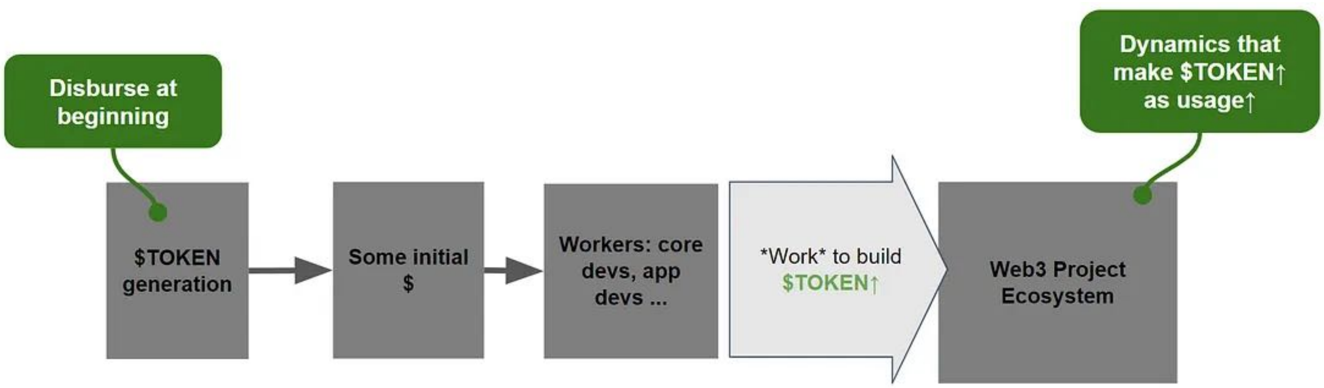
Nation-level sustainability/growth model including an "outer wrapper" that includes fiat as a tool, in addition to tax revenue.

(5) Web3 Sustainability / Growth Models

This article started with the question:

> *How do we grow the ecosystem and make it truly self-sustaining?*

That's the *goal*. How do Web3 projects actually do it? Here, we take a Token Engineering systems approach to modeling it. The image below illustrates for many Web3 projects. Founders generate tokens (left), get some initial cash by selling some tokens (middle-left), build the product (middle), then ship (middle-right) it to power a nascent ecosystem (right). Then the aim is to grow the $TOKEN value. To help this, the dynamics should be designed for $TOKEN to increase as usage goes up. The founding team sustains itself by selling down more tokens for fiat over time, as they do work to improve the product.

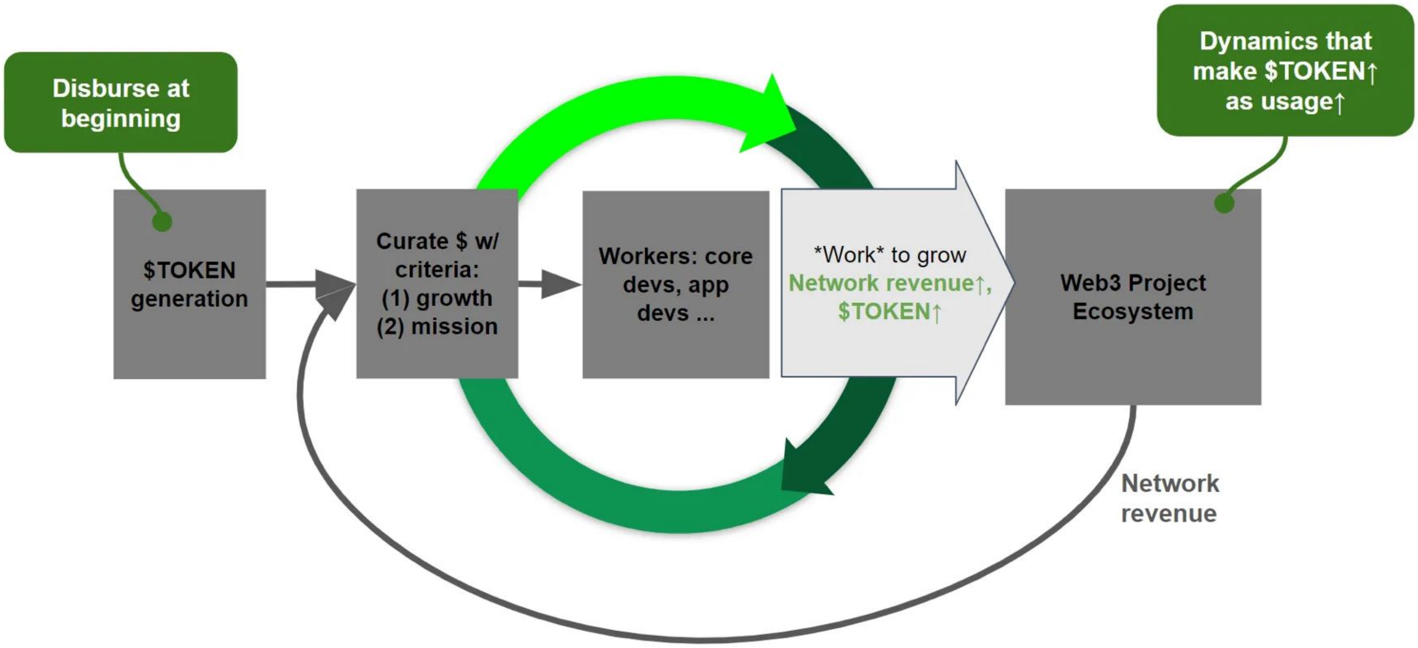


Web3 project without loops. The challenge is dwindling $TOKEN supply and no long-term sustainability.

The main problem with this is that the founding team needs to continually dip into its supply of tokens to fund itself. That supply continues to dwindle, especially if the project has to pivot towards hitting product-market fit. With each dilution event, the founders' incentive to make the project succeed is further diminished. If the supply gets badly reduced, the team will need to sell company stock or a second token, which then risks misalignment of incentives.

Can we do better? The image below shows an improvement, which some Web3 projects are doing. Taking a cue from businesses and nations, it introduces revenue generation (bottom right). Revenue is then looped back to Workers, in a curated fashion (middle-left). Projects are chosen based on growth potential and alignment with the project's mission. Funding can go to the founding team and other project teams. They all perform *work* to grow the $TOKEN value and network revenue.

And the loop continues.



Web3 sustainability/growth model with a focus on revenue. The challenge is getting enough revenue soon enough, for teams to be able to keep contributing.

Revenue generation can draw on ideas from Web1 & Web2 businesses — but with less extractive rates. Importantly, the token must be designed such that its value rises as usage rises.

But there's still one big problem: too little revenue, too late. I'll elaborate.

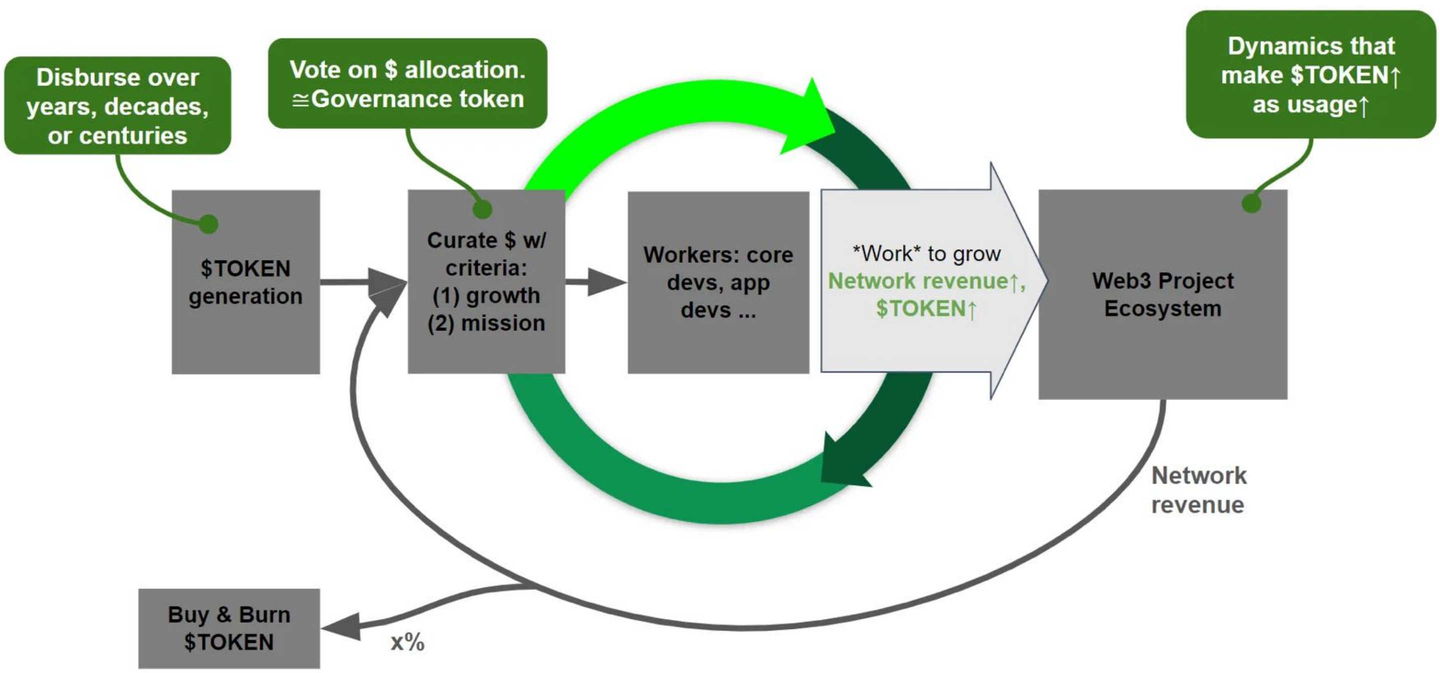
- If rates are too high, it will either get forked and re-deployed with lower rates, or it won't get adopted because it's seen as too extractive.
- If rates are too low (and usage isn't sufficient) then revenue is too low.

Either way, teams won't have enough funding to keep growing the project. They will stoically or heroically keep going for a while, until they can't feed their family. Some may pull through. And most will be forced to stop, at which point the project begins its fade into oblivion.

(6) Web3 Sustainability / Growth Models — A Fuller Picture

Good news! We can overcome the challenge of "too little revenue, too late". It takes a key change: rather than disburse all the tokens at the beginning of the project, *disburse a large fraction of tokens over a much longer period of time to the workers that are* *adding value to the project*. This gives teams a longer runway to iterate towards product-market fit (PMF), and more funds to catalyze growth once PMF is achieved.

I call this the **Web3 Sustainability Loop.** The image below illustrates this. It has parallels to successful nations and successful businesses. At its heart is a **loop,** designed for "snowball effect" growth of the ecosystem. The **Workers** (center) do ***work*** to help grow the **Web3 Project Ecosystem** (right). Apps and services generate revenue, using the Web3 project's tools. A non-extractive fraction of that revenue is **looped back** (arrow looping from right to left) as **Network revenue** to the Web3 community: to **Buy & Burn $TOKEN** (bottom left) and back to workers curated by the community according (center-left). To catalyze growth and ensure decent funding in early days, **Network rewards** (left) also feed to Workers.



Web3 sustainability/growth model including an "outer wrapper" that includes $TOKEN disbursement over time as a tool, in addition to network revenue.

Here's the loop, in words:

1. *Projects are proposed, and curated, by the community.*
2. *Projects are funded by Network revenue, and Network reward.*
3. *As projects do *work* and add value, network revenue goes up and $TOKEN goes up,*

and ever-more funding goes to the community.

The last step causes **positive feedback loop** (snowball effect) such that over time, more and more projects get funded. It implies more constraints:

- *Each project must add sufficient value to the ecosystem (on average).*
- *Value added to the ecosystem needs to get reflected in the token price*

Criteria: Return on Investment (ROI)

Let's unpack "sufficient value." When a given project gets funded, the people behind it will need to gradually sell tokens to feed themselves and complete the project. This causes downwards pressure on the token price. Therefore: *on average, value added to the ecosystem from a project must exceed the value spent by the ecosystem*.

Value added by a project is hard to know in advance. Some will fail; others will succeed and bring 10x value. But this must hold true on average across projects. This gives project selection criteria:

> *What is the project's expected return on investment (ROI)?*

Therefore, project proposals will need to include a model on ROI. Average ROI must be >1.0 for the ecosystem to grow.

Expected ROI can be lower for lower-risk projects, and needs to be higher for higher-risk projects. It has similarity to the traditional VC thought process.

From an ecosystem perspective, if a project gets funding from outside the ecosystem, then it counts towards the value-add number, not to the value-spent number. This incentivizes projects to seek external funding, such as matching investments or quadratic funding.

Value can only be added to an ecosystem if the core product being built (by core devs) has last-mile apps for users (by app devs), which users can discover and find useful (go-to-market work). It's a chain going from core product → dapps → discovery & usage → actual value add.

Criteria: Mission & Values

There's a second selection criterion for each proposed project looking for funding: it must help to promote the Web3 project's mission & values (or at least not work against them). Without this, the proposed project might as well be a Web2 project. The point of Web3 is to help equalize opportunities for all people.

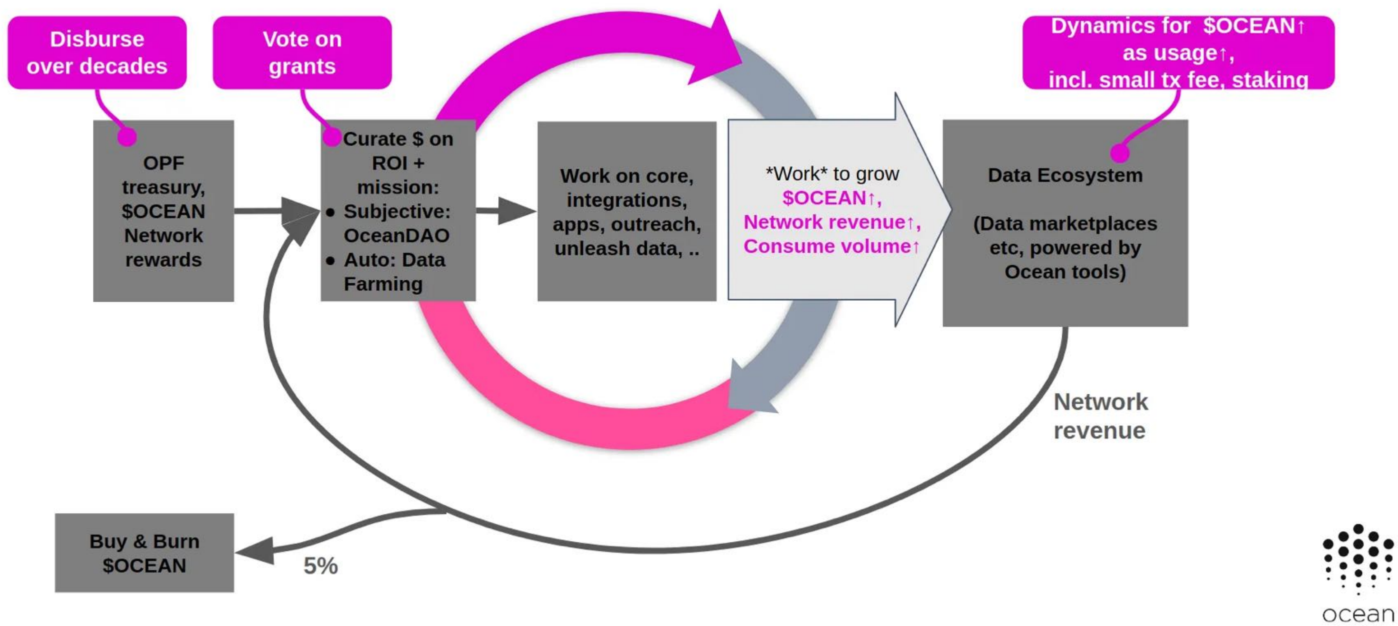
A recurring value is long-term thinking. Here are some approaches to help, using time-weighted voting power. In Conviction Voting, vote increases with the amount of stake and the time staked for the vote. In Arweave Profit Sharing Communities, votes are weighted by the number of tokens the voter holds, multiplied by the time they are willing to lock them. In Yearn.finance, weight is scaled by x/365, where x is days locked.

Many excellent Web3 projects implement some of the dynamics given above. The prequel to this essay surveys them.

(7) Application of Web3 Sustainability Loop: Ocean System

Ocean Protocol is a Web3 project that aims to spread the benefits of AI by equalizing the opportunity to access and monetize data. For Ocean, we have created a system-level design that follows the pattern of the Web3 Sustainability Loop.

The image below illustrates. It's designed to achieve sustainability over decades via funding that goes to teams (Workers) that continually add value to the Data Ecosystem. In Ocean's case, the Web3 ecosystem (right) is a Data Ecosystem of data marketplaces, data custodians, etc. powered by Ocean tools.



Ocean Protocol sustainability/growth model including an "outer wrapper" that leverages $OCEAN disbursement over decades, in addition to network revenue.

The funding $ gets curated against selection criteria of expected ROI > 1.0, and aligned with **Ocean Mission and Values** . There are two complementary vehicles: OceanDAO is *subjective* based on *promise of value-add*, the Data Farming is *objective* based on *value already added*.

- **OceanDAO** (middle-left) gives grants for the promise of future value-add. OCEAN holders vote on which projects get funding, based on their subjective assessments against the selection criteria and the track record of grantees. Grantees work on Ocean core software, build integrations / applications using Ocean, do outreach to spread awareness, grow data supply, and more. OceanDAO takes funding from OPF treasury, Ocean 51% Network Rewards, and Network Revenue. In the longer term, the bulk of revenue will be from Network Revenue.

- **Data Farming** rewards workers according to an objectively-defined measure, shortly after they've added value. This is akin to Bitcoin mining or liquidity mining. Data Farming optimizes for (e.g.) data consume volume — a proxy for value add to the Ocean ecosystem. Data Farming takes income from OPF treasury and Ocean 51% Network Rewards.

51% of the overall OCEAN token supply is dedicated to Network Rewards, which follow a Bitcoin-like disbursement schedule (but with a ramp-up period). Some of this goes to OceanDAO, and some to Data Farming.

Token Design. The Ocean token is designed such that as usage of Ocean grows, it grows $OCEAN.

- Here's the loop: more usage of Ocean tools in the Data Ecosystem leads to more OCEAN being staked, leading to more OCEAN demand, growing $OCEAN.
- More usage also leads to more Network Revenue, which goes to (i) burning and (ii) OceanDAO. Burning OCEAN reduces supply, to grow $OCEAN. Funds go through OceanDAO to workers who have the mandate to grow usage of Ocean tools. And the loop repeats.

Verification. We have verified this design and tuned its parameters with the help of two independently-developed computer simulations. One model uses a spreadsheet. The other model uses an agent-based simulator written from scratch in Python specifically for this project called TokenSPICE [2]. The main result is that the computer models align with the theory, and each other; this bodes well for the future of Ocean Protocol and OCEAN.

Future publications will share this in more detail yet.

Conclusion

This post described the *Web3 Sustainability Loop*. It takes inspiration from both businesses/nations, which take as income both revenue *and* stock/fiat issuance.

The core idea of the loop is to direct both Network Revenue and Network Rewards to *work* that's used for growth. Network Rewards help to kickstart the project and to ensure decent funding. Network Revenue can help to push growth further once the Web3 project achieves traction at scale.

This post described application of the loop to Ocean Protocol, and verification of that design.

Acknowledgements

Thanks to the very much to the following people: Bruce Pon, Julien Thevenard, Simon de la Rouviere, and Michael Zargham. You've each contributed immensely to the thinking that led to this article and related efforts; as well as excellent feedback on the article itself. Thanks also to Sarah Vallon and Monica Botez for your reviews!

Thanks to my excellent colleagues at Ocean Protocol for the collaboration in building towards this. Finally, thanks to the broader Ocean community for their ongoing support.

Further Reading

- Here's the tweetstorm summarizing this post.
- "Ocean Protocol V3 Posts: Links to all V3-Related Stories" [link]

Notes

[1] I don't claim that GDP is a great KPI, just that it is a commonly-used one. Here's a starting point for further discussion.

[2] Update Nov 20, 2020: We have open-sourced TokenSPICE, here. For an agent-based simulator that is more general-purpose and more full-featured, I wholeheartedly recommend cadCAD.

[3] Update Oct 2, 2021: in Ocean's sustainability loop, clarified where Data Farming fits, and relation to OceanDAO. "OceanDAO is subjective based on promise of value-add, the Data Farming is objective based on value already added."

Appendix: Comparison to The Network Flywheel

The ideas for *The Web3 Sustainability Loop* started gestating in late 2019. I modeled them explicitly in TokenSPICE from Jan-Mar 2020.

Just as I was putting finishing touches on this piece, Ali Yahya posted a tweetstorm describing a *Network Flywheel* and a related video from May 2020. It was heartening to see the similarities:

- First, both start with perennial question of "what drives token value?"

- Second, and especially heartening, was the idea in both to use a positive feedback loop (in the control systems sense) to model dynamics of token value. Great!

There are a couple big differences that make each of these models unique. The first difference is the hypothesis of what actually drives token value.

- The Web3 Sustainability Loop focuses on (a) token dynamics such that token value goes up as volume goes up (top right); and (b) using Network Revenue to do *work* to grow volume further. As a bonus, some tokens get burned as function of volume, which drives token value further yet (bottom left). This model directly links usage to value, and is amenable to valuation approaches like Net Present Value.

- In the Network Flywheel, “Token Value” has two inputs: (a) Investors who “provide financial capital” to founders to “build the protocol and bootstrap some initial token value” [ref][and ref], and (b) Vision + Protocol: “the stronger the vision for the token value is, the more the value in the broader market” [ref] as the loop goes. This model relies more on investor sentiment, without strong connection between usage and token value.

The second big difference is degree of focus on sustainability.

- The Web3 Sustainability Loop has “sustainability” in its title. It’s *all* about how to create a web3 project that can live and grow sustainably over decades. The Loop solves this via token generation to fund teams that nurture the project over the long term.

- The Network Flywheel doesn’t focus on sustainability directly, though it does so indirectly through its emphasis of “business model” (in the tweet and video title) and pointing to a multi-sided market (a well-known business model). Good businesses are self-sustaining over time; so there can be sustainability if there’s a good business. The difference between the Loop and the Flywheel is in emphasis.

Overall, I view the Network Flywheel as a positive contribution. It clearly struck a nerve. In a complementary fashion, it's my hope that the Web3 Sustainability Loop will be a useful tool for Web3 builders aiming to build systems that last the ages.

. . .

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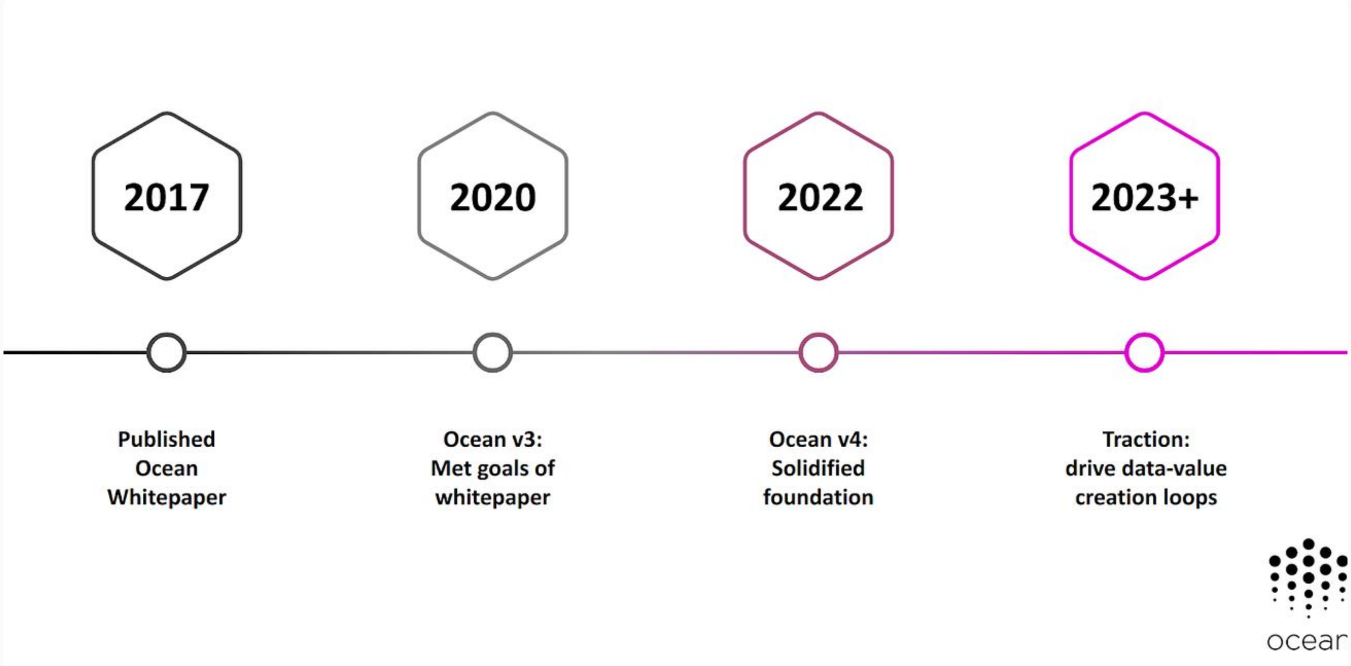

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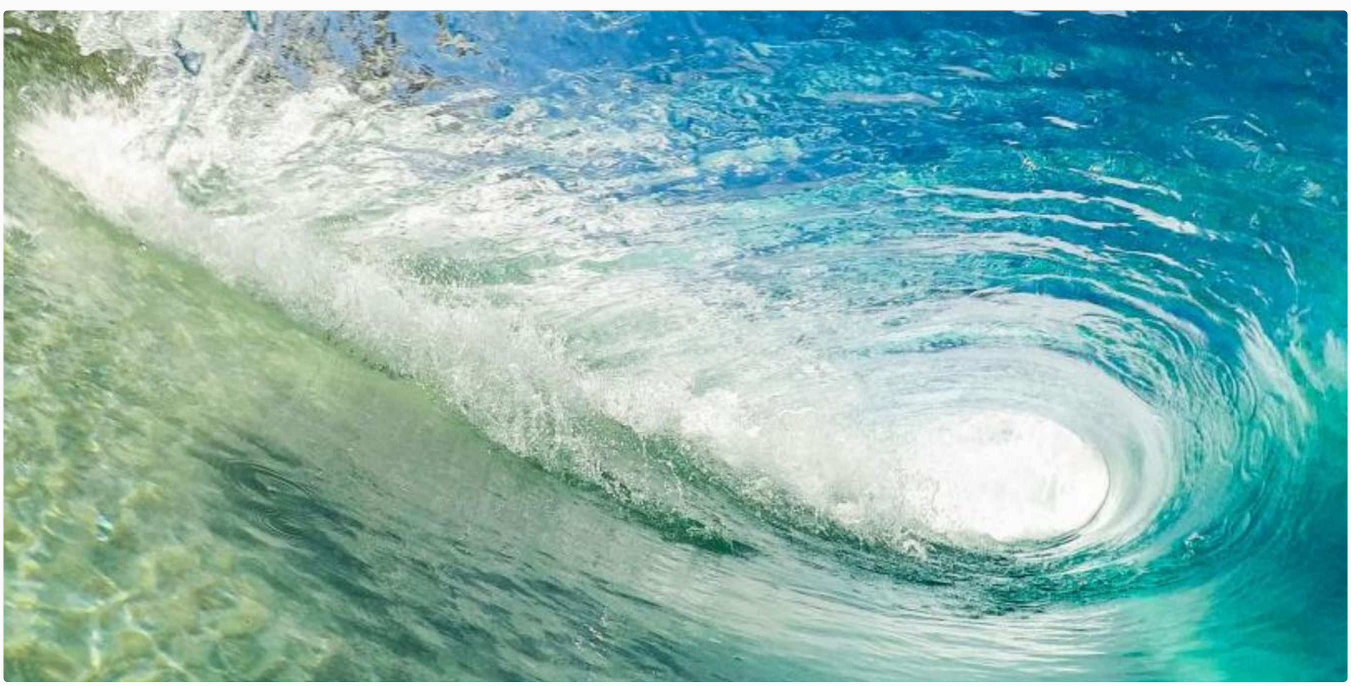

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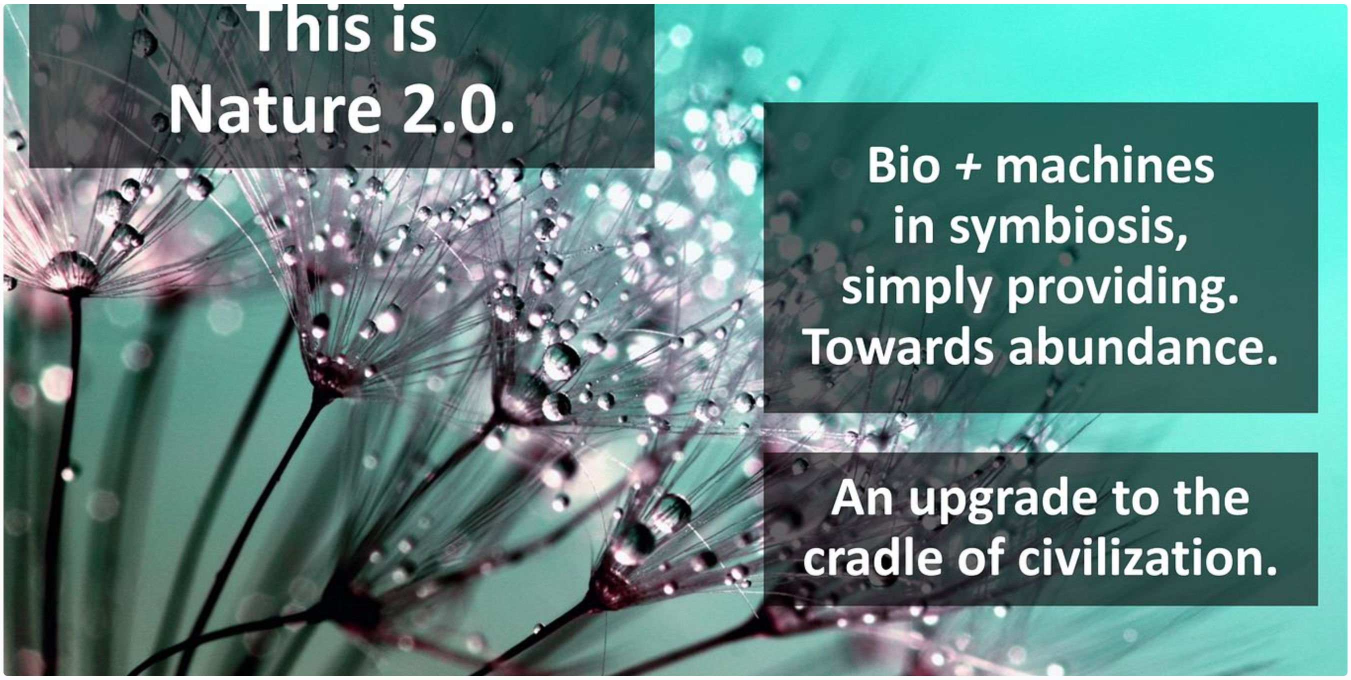

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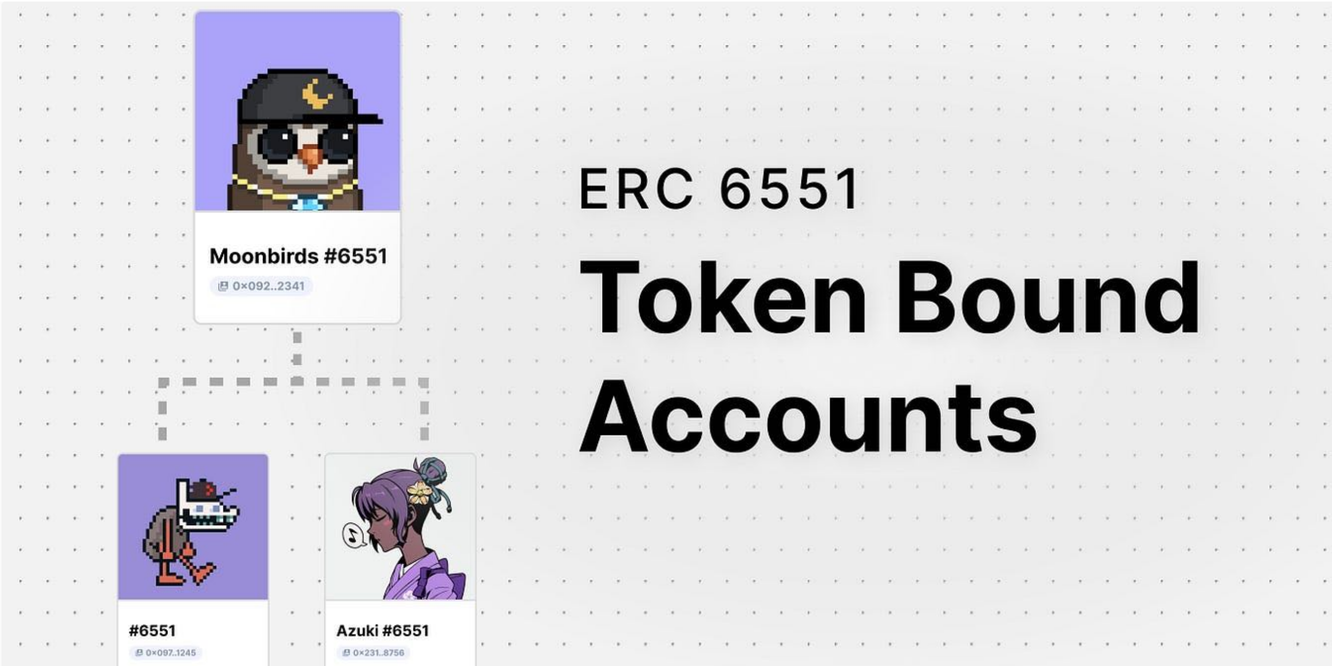

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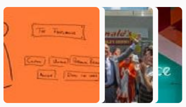

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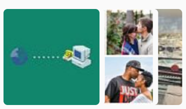

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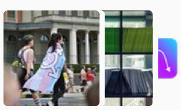

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Sign-In Services Services used to connect to your touchpoints	Social Logins Ad-Hoc Logins	Wallet Connect
1:1 Communication Communication channels to engage with your customers	Emails, SMS, Social msg, Posts, etc.	In-App, Emails, Airdrops, W2W Wallet-to-Wallet Messaging
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Cryptonetwork Governance As Capital

February 19, 2019 / Joel Monegro

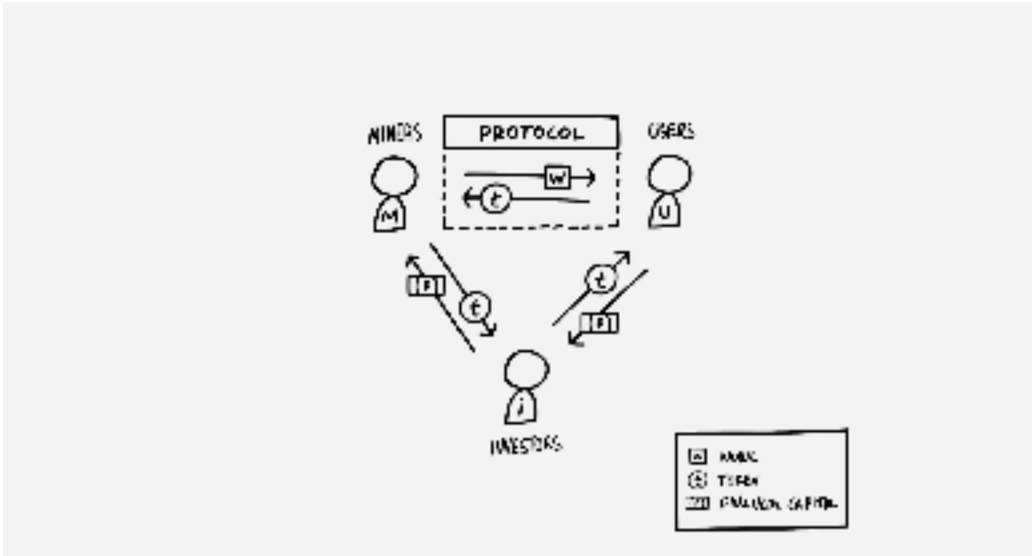
Capital is, in essence, *the power to organize the economic resources of a social system*, and its worth a function of how much of those resources can be directed to the holder's benefit. This understanding reveals the inherent value of *cryptonetwork governance as capital*, and helps us understand tokens with governance rights as new kinds of capital assets.

All forms of capital offer some kind of control over the distribution of economic resources across a group of people – in effect, *governance* over that pool of resources. Productive and human capital, for example, influence which goods and services are offered in the economy (and thus how income is ultimately distributed), financial capital determines the distribution of purchasing power, and equity capital presides over how a company's resources are used. Intangible forms of capital also exhibit this quality: political capital, for example, governs the rules of markets, and social capital drives human attention (and thus behavior).

This insight, that capital is governance (and vice versa) leads to the source of its intrinsic value. Whoever has control over a pool of important resources also has the potential to direct some of those resources to their own benefit. So the value of a system's capital is proportional to the value of the resources it governs.

This relationship is very clear in the case of corporate equity, where the value of a share of stock (which is essentially a voting instrument) is rooted in its right to a piece of the company's book and profits – its "assets under power," so to speak. The relationship is less clear in the intangible realm, where capital does not take the form of tradable assets that can be priced by the market, but remains present nonetheless. For example, we might look at **the global cost of corruption** (about $3.6 trillion/year, or 5% of the economy) to assess part the value of political capital, even though "political capital" is not constructed to produce direct economic gains for its holders. Similarly, we might observe the ability of social media influencers to profit from their fame, even though having lots of followers does not by itself guarantee a right to financial benefit.

This relates to cryptonetworks insofar as they are a new form of social organization. It is useful to think about these ideas through **the cryptoeconomic circle**, pictured below:



The Cryptoeconomic Circle

The two pillars of trust of a cryptonetwork are its cryptoeconomic and governance models. The cryptoeconomic model defines 'the rules' of the system (what is the unit of work, how do users pay, how miners are compensated, the token supply model, etc.), while the governance model defines who has the *power* to change those rules, and under which conditions.

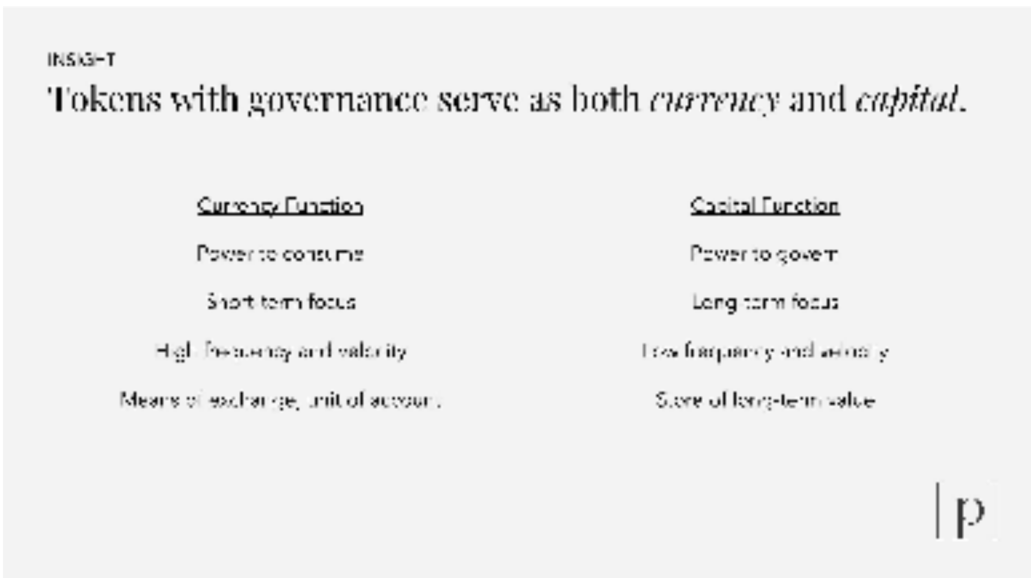
If capital is the power to organize economic resources, then the power to change the rules of a cryptonetwork forms its capital. And when that power takes the form of a token, it can be traded, priced and modeled by market. In this context, a network's 'assets under power' include (1) the token itself, which is controlled by the cryptoeconomic policy, (2) productive resources, as controlled by the definition of 'work' (e.g. the consensus protocol), and (3) flows of value, as controlled by regulating payment mechanics and other incentives for miners, users and investors. And as the value of these resources grows, so does the value of the capital which governs them.

Certain proof-of-stake systems are good examples of this idea. Here, miners are required to lock a certain amount of tokens in order to be allowed the right to work for the network. The value which flows from users to the supply side is then distributed to miners proportionally to their stake. This way, tokens that can be staked are a form of capital in that they represent the power to organize some of the economic resources of the network, such as production capacity and distribution of income. And ultimately this is a form of governance, in the sense that staking is a mechanism for deciding how income should be allocated across miners. And so, as the value of that income grows with user demand, so does the value of stakeable tokens.

For example, in **Decred**, 30% of the block reward is reserved for users who participate in its proof-of-stake consensus layer, and that reward pool is divvied up in proportion to how much DCR each participant has staked. Here, DCR is a form of capital as it has power over how some of the block reward is distributed. But because Decred also allows the PoS layer to vote on the use of its community pool (which is funded with 10% of each block), as well as on protocol upgrades, the value of DCR as a capital asset extends beyond what is connected to block-reward revenues.

Such power is harder to quantify, and therefore difficult to price, but remains an important value driver that we might consider a kind of "governance premium".

I first presented the thesis that governance is capital (and thus the driver of long-term token value) at the **Token Engineering meetup in New York** in early 2018, where I showed the following slide which describes the features of what I for now call *power tokens*:



Slide from **TokenEngineering** talk *On The Price and Value of Governance*

The basic principle behind power tokens is that they fuse the features of "utility tokens" and "governance tokens", which really means the combination of currency and capital – with the capital function being the driver of long-term value. We'll dive deeper into power tokens, the nuances, and why this combination is important in the next post in the cryptocapitalism series. But for now, the key insight is that what we're dealing with in the creation of these new assets is the creation of new forms of capital, *network capital*, that is natively digital, and cheap to distribute – and that's important.

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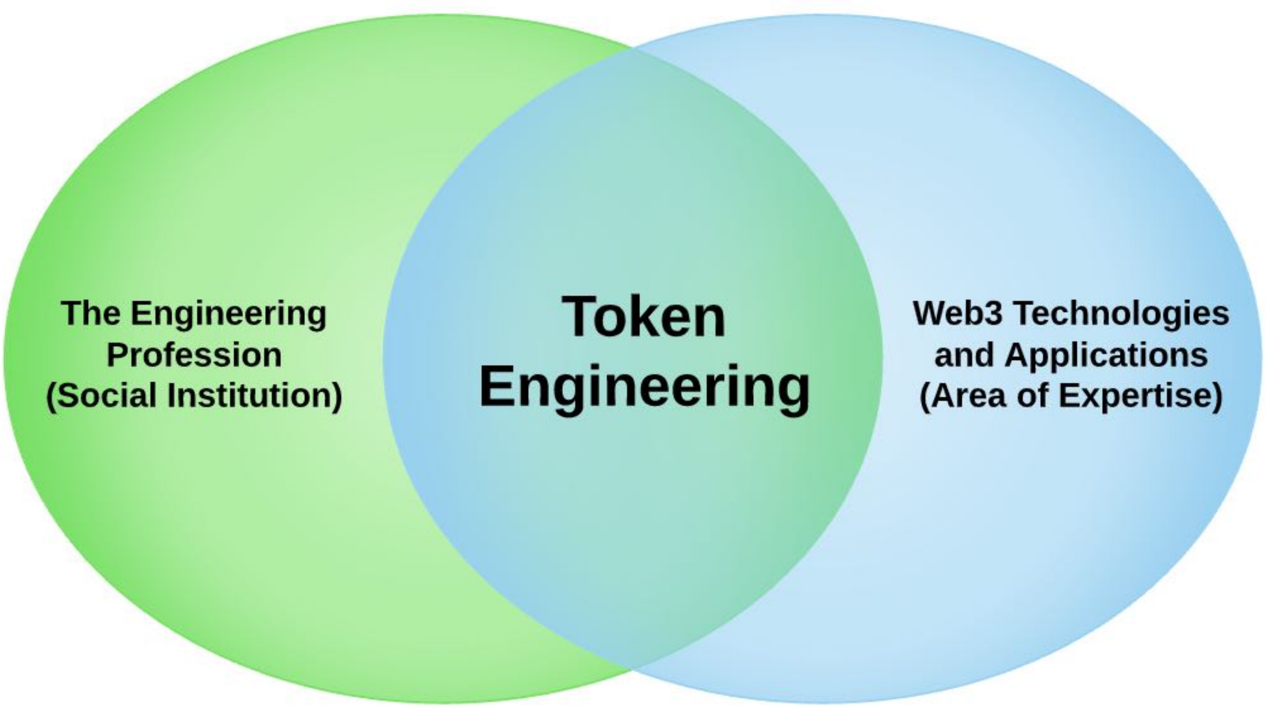
Our community is a technology-abled social organization committed to the application of web3 technologies to achieve human-centric outcomes. Much like traditional engineering societies we engage in research, education, and standard setting in addition to designing, building and maintaining technological solutions.



Token Engineering is an emerging discipline in the overlap between the social institution of engineering and web3 token ecosystems.

As with any emerging technology there is still a lot of uncertainty around the practice of engineering web3 enabled systems but it is already clear that these systems are deeply entangled with social and economic systems, and thus have the potential for a deep and long standing impact on social institutions. With this in mind, our community coalesced around a shared commitment to the values upheld by the broader institution of professional engineering. While it remains unclear where the web3 technology stack will carry our society, we believe that this journey must be undertaken with a values first mindset.

The Professional Engineering Values System

Engineering Values according to **Martin, M. & Schinzinger, R. Ethics in Engineering. NY: McGraw-Hill, 1983:**

> *(1) a primary obligation to protect the safety of and respect the right of consent of human subjects;*
> *(2) a constant awareness of the experimental nature of any project, imaginative forecasting of its possible side effects, and a reasonable effort to monitor them;*
> *(3) autonomous, personal involvement in all steps of a project; and*
> *(4) accepting accountability for the results of a project.*

Engineering Values according to **Pinkus, R. L. B, Shuman, L. J., Hummon, N. P., Wolfe, H. Engineering Ethics: Balancing Cost,**
Schedule, and Risk — Lessons Learned from the Space Shuttle. Cambridge: Cambridge University
Press, 1997.

> *"The ethical engineer is one who is competent, responsible, and respectful of Cicero's Creed II. Cicero's Creed, engineering's oldest ethic, directed engineers to place the safety of the public above all else."*

Engineering Values according to **Wike VS. Professional engineering ethical behavior: a values-based approach. 2001**

> *"Instead, I prefer a third scheme that focuses squarely on what is to be valued and not on questions of methodology or technical expertise. This scheme proposes that professional engineers (and for that matter, any professionals) share a commitment to these six values: integrity, respect for persons, justice, compassion, beneficence/non-maleficence, and responsibility."*

The Web3 Values System

Investors, Builders, and Early Adopters of web-based cryptographically secured social and economic infrastructure and applications have a wide range of beliefs and values but some key concepts form a common thread: privacy, transparency and agency.

At first blush, privacy and transparency are in direct tension, but this provides a fertile ground for discussing trade-offs. Agency then includes the right of humans to opt-in and out of web3 networks. Furthermore, opting-in does not require an intermediary, provided you are sufficiently technically inclined to manage your own infrastructure and/or private keys.

Another interesting tension arises in the pursuit of agency: in a network, participants are connected, so often one's right to control their own actions can negatively impact others. At one level, protocols can be said to address this directly by providing an explicit specification of what actions are and are not acceptable within the network. However, at the level of governing these networks the boundaries of these rights are non-obvious.

The Ethereum hard fork after TheDAO hack is an example where the Ethereum Institution (humans) split over differences in values. The Ethereum Classic Community upholding a principle that the "code is law" and that actions taken in bad faith (exploiting a flaw in code to take someone else's money rather than taking action to see the code secured) were to be upheld because the code itself was the deciding factor. The broader Ethereum community took extreme measures to reverse the malicious activity and initiated an irregular state transition, effectively removing the hackers funds to be redistributed to the affected parties. Neither was right in any absolute sense but the event was a very public exercise of a values judgement on the part of leaders in the Ethereum community.

For more on Web3 Values and History see: **Voshmgir S. Token Economy: How Blockchains and Smart Contracts Revolutionize the Economy. BlockchainHub; 2019.** (Now Open Source!)

For thoughtful criticism see **Walch A. In Code(rs) We Trust: Software Developers as Fiduciaries in Public Blockchains; 2019.** (Public link)

Reconciling Value Systems

At first glance, these value systems are in conflict. Simply, the authority of a traditional engineer is derived from the power of the nation-state to regulate its territory — most jurisdiction limit engineering activities that could affect public wellbeing to licensed professionals. However, the web3 value system is native to the internet, the social institution is extra-national and openly rejects the authority of the state to regulate it. Adherents to the web3 value system adhere to regulations out of pragmatism rather than in deference to those regulatory authorities.

Let us set aside for a moment the interpretation of the engineering profession as a social institution empowered by sovereign nations to design, build and maintain technological infrastructure. Instead let's look at the engineering profession as **a social institution empowered by the public** to safeguard their well-being in the face of technologies so broad and deep that they cannot hope to understand it all, and thus cannot make educated judgements regarding their own individual safety.

Taking this latter perspective, it is possible to undertake the responsibility to safeguard the public good without first submitting to the authority of a sovereign state, and their right to regulate. This reconciles with the agency aspect of the web3 value system; in choosing which systems one opts into it is possible to select for those systems one believes have been created and maintained by persons adhering to a public-wellbeing-first values system. Though it may take time, we believe history tells us that people want to enjoy the benefits of new technology while the underlying complexity is abstracted away from them. This is only practical if their interests are safeguarded through social institutions like the token engineering commons (TEC).

A Path Forward

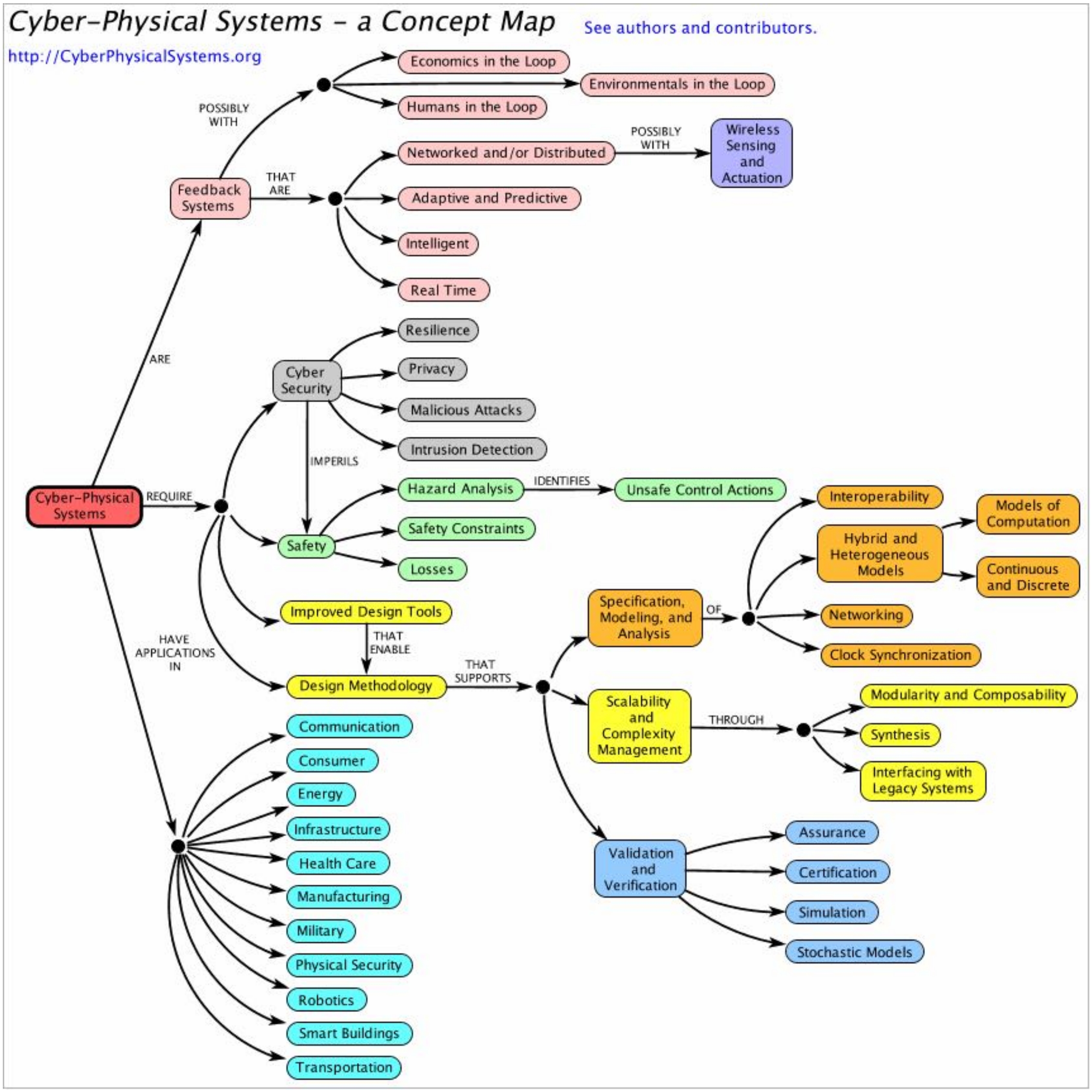
Upholding a value system is a journey not a destination; it can never be totally reduced to a set of methods and procedures but drawing on methods and procedures is a good place to start. In particular the Token Engineering community has been committed to improving design methodologies and associated tools drawing on the engineering subfield of Cyber-Physical systems (CPS). Wikipedia defines CPS as follows:

> *A cyber-physical system (CPS) is a computer system in which a mechanism is controlled or monitored by computer-based algorithms. In cyber-physical systems, physical and software components are deeply intertwined, able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioral modalities, and interact with each other in ways that change with context.*

Cyber-physical systems are further distinguished from the internet of things by its focus on higher order systems of systems which depend upon the application of expertise from multiple disciplines.

> *CPS involves transdisciplinary approaches, merging theory of cybernetics, mechatronics, design and process science. The process control is often referred to as embedded systems. In embedded systems, the emphasis tends to be more on the computational elements, and less on an intense link between the computational and physical elements. CPS is also similar to the Internet of Things (IoT), sharing the same basic architecture; nevertheless, CPS presents a higher combination and coordination between physical and computational elements.*

Another authoritative source on Cyber-physical systems is the Ptolemy Project out of UC Berkeley. The CPS concept map makes clear how closely the considerations match with those of web3. It helps identify the areas that need the most development. My work at BlockScience and cadCAD.org aims to build out the yellow and orange portions of this map.



The following description of cyber-physical systems accompanies the concept map on the Ptolemy Project's website:

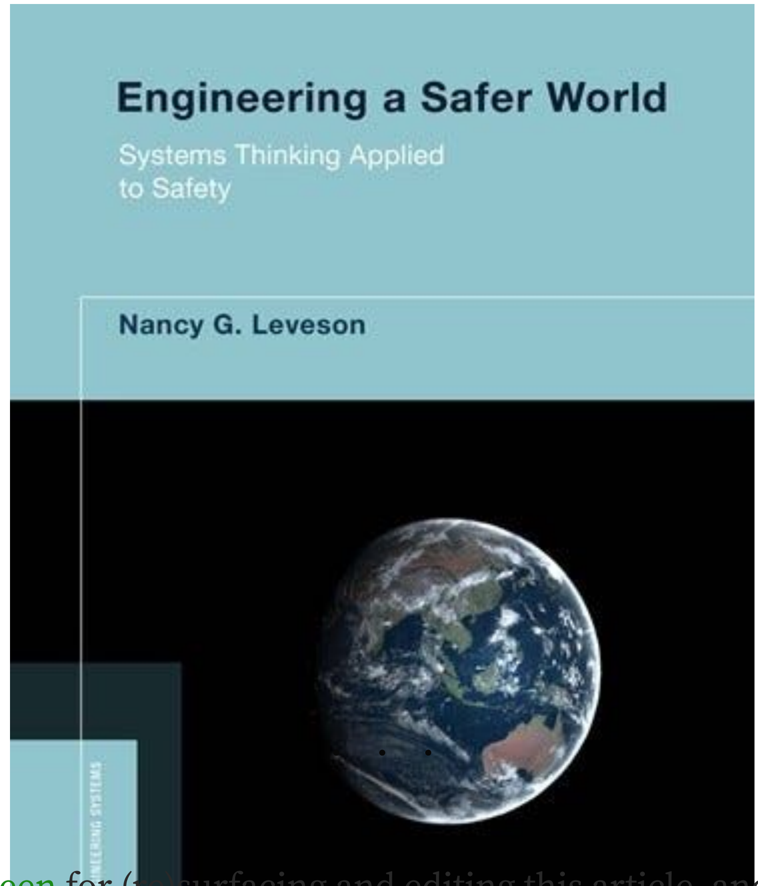
> *Cyber-Physical Systems (CPS) are integrations of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa. The economic and societal potential of such systems is vastly greater than what has been realized, and major investments are being made worldwide to develop the technology. The*

> *technology builds on the older (but still very young) discipline of embedded systems, computers and software embedded in devices whose principle mission is not computation, such as cars, toys, medical devices, and scientific instruments. CPS integrates the dynamics of the physical processes with those of the software and networking, providing abstractions and modeling, design, and analysis techniques for the integrated whole.*

In **Voshmgir S, Zargham M. Foundations of cryptoeconomic systems, 2020,** a case is made that following the definition of Cyber-Physical Systems, the web3 internet native social and economic infrastructure projects should be approached as Cyber-Physical systems. While CPS predates web3, it is also plagued by ethical questions as algorithms take the role of administering policies which directly impact human activities.

In **Zargham, M, Nabben, K., Algorithms as Policy, 2020,** comparisons are drawn between algorithm design in online platform and policy making activities. Although, these are new digital infrastructures, it is traditionally the role of (civil) engineers to represent the public in settings where policy manifests as technology, (historically in the form of physical infrastructure).

Following in the engineering tradition, the Token Engineering community has worked on design methodologies and associated design tools in a manner associated with system safety in complex engineered systems. The state of the art in the broader engineering domain can be found in **Leveson NG. Engineering a safer world. The MIT Press; 2016.**



Thanks to Griff Green for (re)surfacing and editing this article, and Jessica Zartler, Danilo Lessa Bernardineli, Kelsie Nabben and Jeff Emmett for broad research collaborations and specifically reviewing this piece. Finally, deepest gratitude to everyone who has contributed to the launch of the Token Engineering Commons (TEC). You can follow the articles history on the Token Engineering community github.

However, the growing crisis of AI explainability and prediction algorithms creating self-fulfilling prophecies shows us that a level of techno-reflexivity is required to uphold a public-wellbeing-first values system. On an even grander scale, our existing public institutions have visibly failed to address systemic challenges such as

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As such we must look beyond the boundaries of our technical fields to experts in the humanities and social sciences with a particular need for those studied in ethics, law and governance. My hope is that the TEC community will be open to all who wish to take up the burden of safeguarding the public, not because a regulatory authority demands it, but because it is a role in society necessitated by the existence of technology.

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Written by Michael Zargham

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Founder, Researcher, Decision Engineer, Data Scientist; PhD in systems engineering, control of networks.

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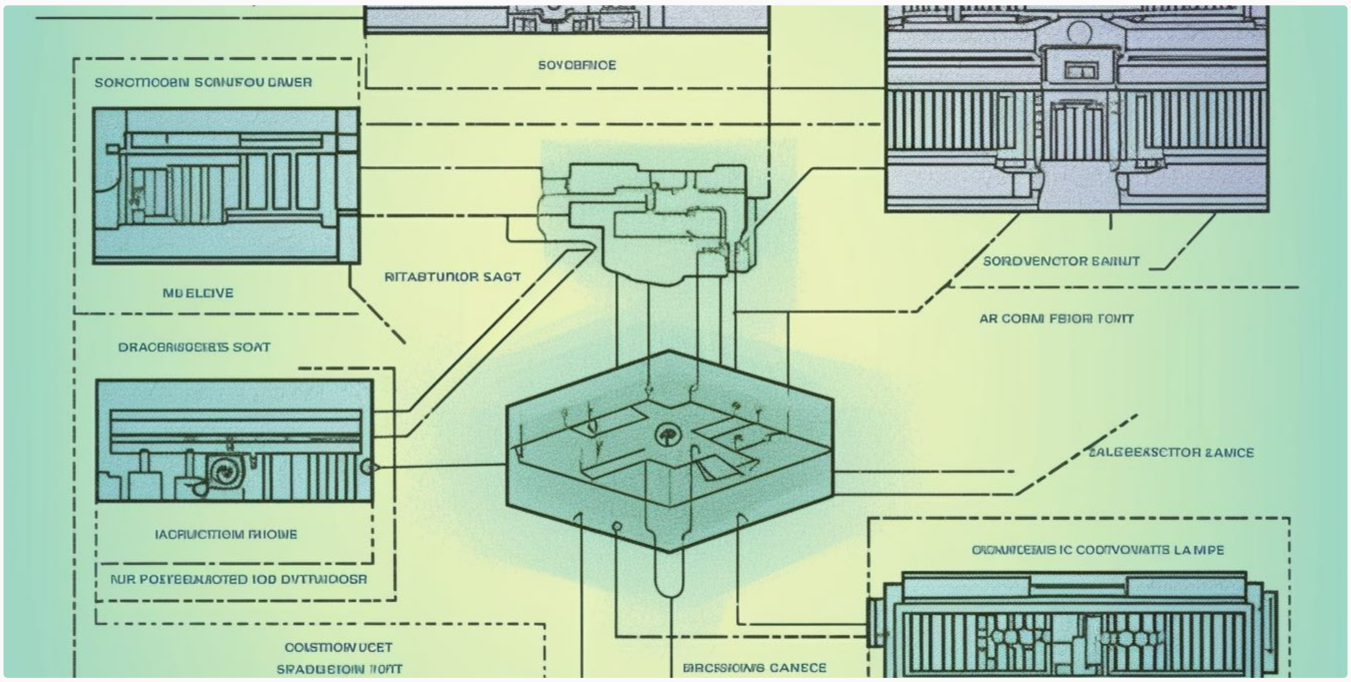

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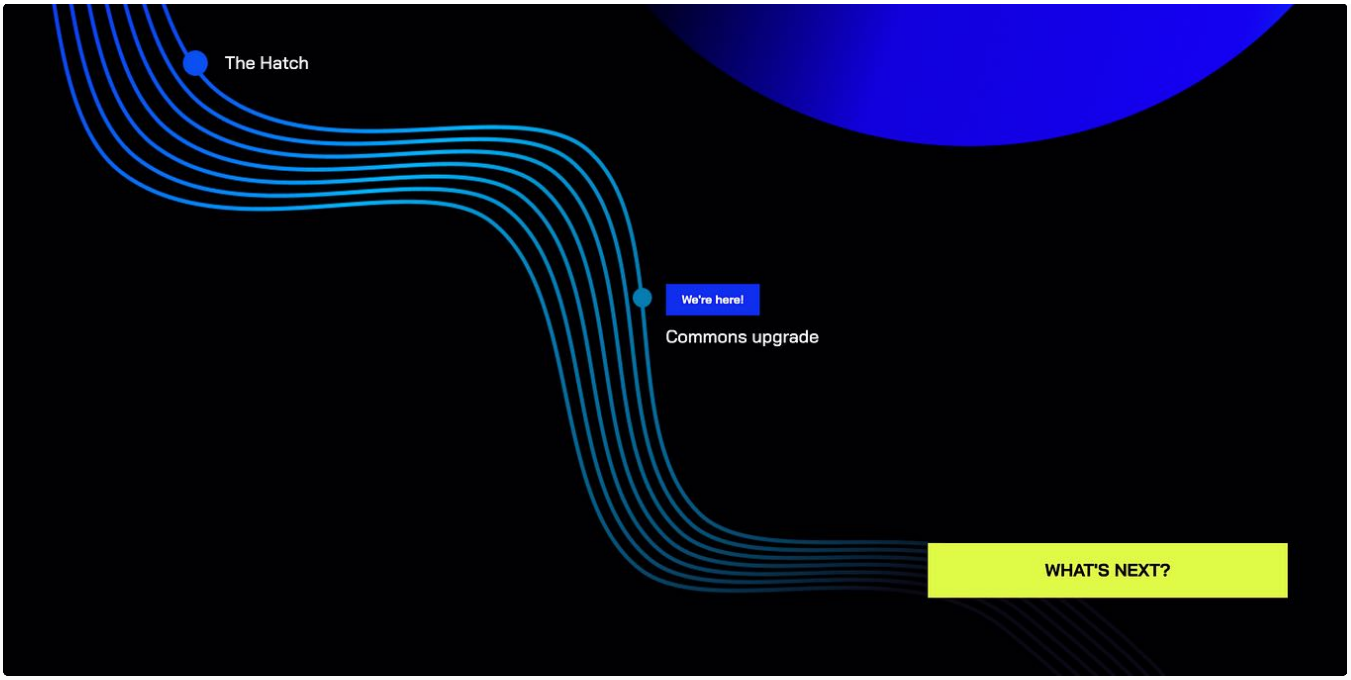

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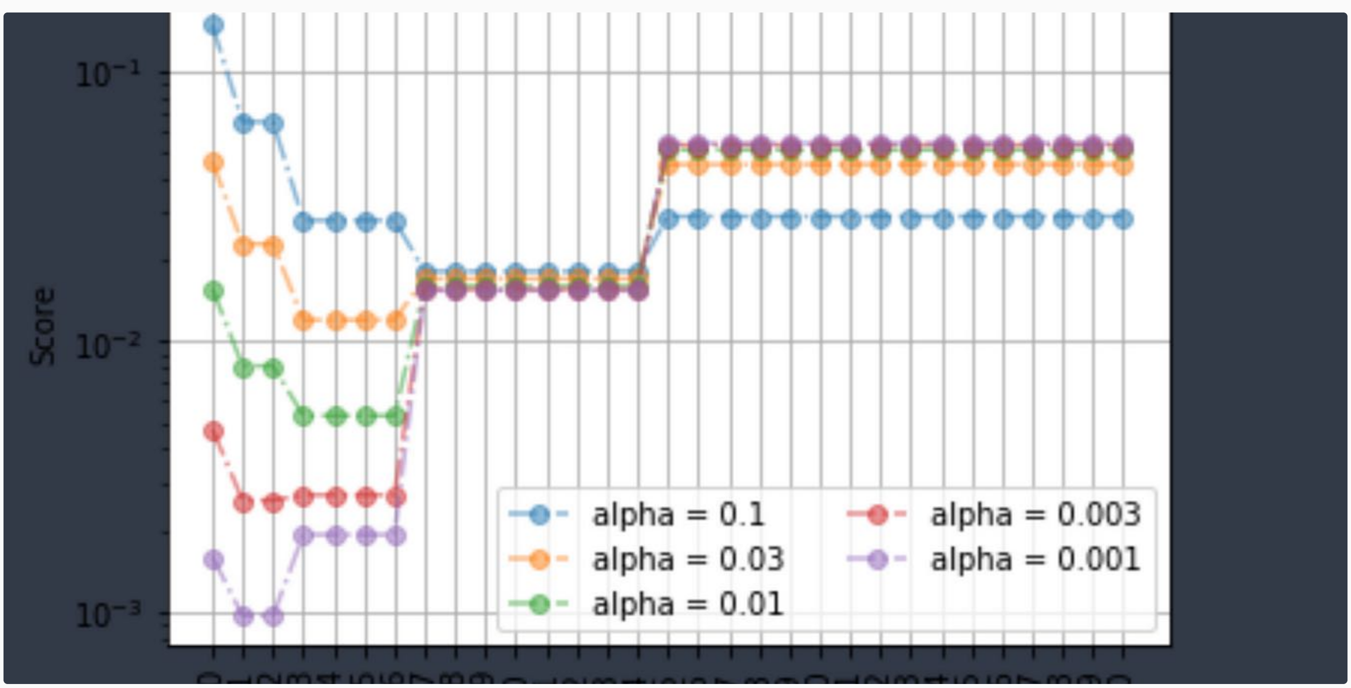

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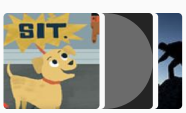

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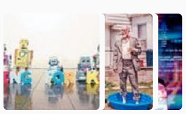

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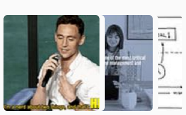

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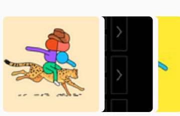

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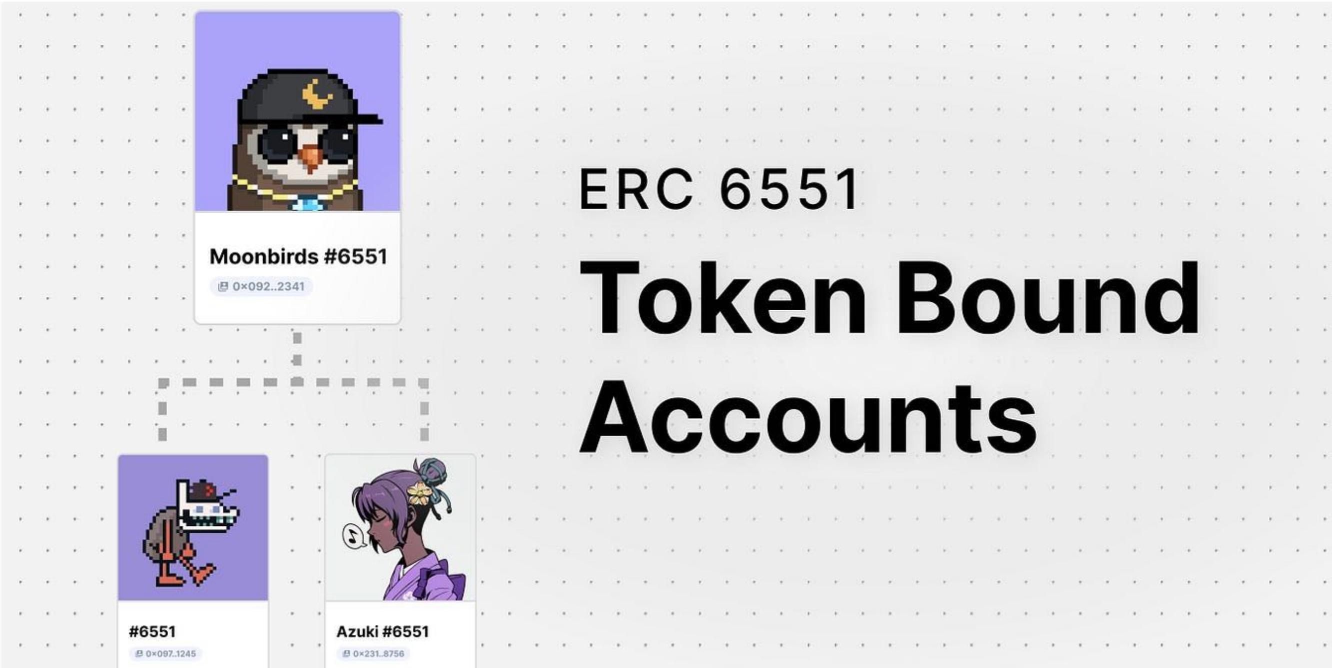

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