SENSOR NETWORKS AND SOCIAL CHOICE

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Research Proposal at the request of Frank Wang of X-Order Research firm.

Abstract. This research is motivated by the need to aggregate community knowledge or preferences into coordinated decision-making without imposing structural or modeled biases. While broad questions of algorithmic governance are pervasive, proper scientific treatment of the problem is lacking. BlockScience team proposal a definition of coordinated social choice using the interdisciplinary field of complex systems science. In particular, we shift social choice from one shot voting games into an evolutionary system where preferences shift in time and social preference is modeled by sensor fusion where the actions of agents are signals and a blockchain network serves the role of sensor. Various models and assumptions regarding social utility and associated coordinated decision processes will be explored.

1. Introduction

Consider a community of interacting agents who decide to follow a set of shared rules. Over time the membership of this community may evolve, as well as the needs of community and thus the suitability of the rules may change. The question of autonomous governance is that of evolving the communities shared rules such that it remains suitable for a heterogeneous population of agents over time despite both internal and external changes. Internal changes may include number, nature, and utilities of agents whereas external changes include anything not exclusively of or related to the agents within the community. So stated the problem cannot be directly addressed but the structure of the problem as hierarchical and evolutionary is immediate. This abstracted problem is diagrammed in Figure 1.

In the context of blockchain technology where the governance problem appears most readily as one wherein the community members are agreeing on a protocol or shared code-base and stake in decision making is represented by holding crypto-assets, more precise definitions may be constructed without too much loss of generality. The research proposal below, aims to characterize variations of this governance problem the further both theoretical understanding and practical solutions using mathematical techniques from a variety of disciplines.

The author of this proposal has engaged in discussions of proper problem definition with regard to such self managed communities with executives from the Aragon OS (`aragon.org`) and Zeppelin OS (`zeppelinos.org`) projects both of which aim to use their ERC-20 tokens as a means of encoding voting rights of a fashion while decentralizing control of community decisions around their respective

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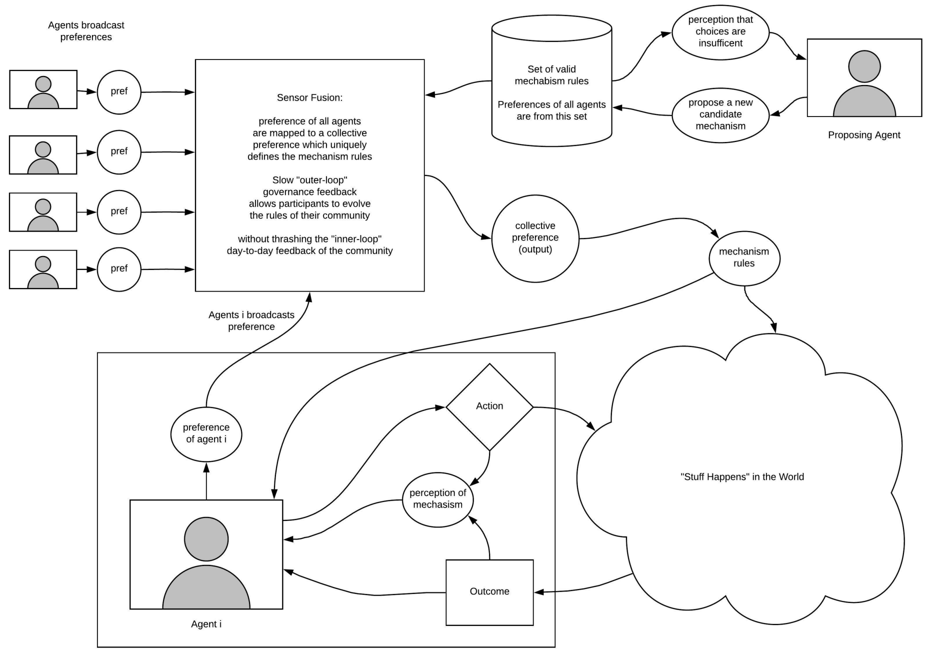


Figure 1. Visual Representation for considering formally the multi-layer means through which a community manages its own mechanisms where those mechanisms are encoded in software, without a-priory assumptions about utilities, fairness or the interactions between agents actions and the outside world.

code-bases. Similar discussions with Blockchain ecosystem investors from Coinfund (`blog.coinfund.io`), Outlier Ventures (`outlierventures.io`) and Placeholder Ventures (`www.placeholder.vc`) have raised similar scope and challenges. It is understood that governance is a fundamentally human phenomenon that requires both technical and social research in order to discover and better implement evolutionary socio-technical systems. The author further acknowledges the influence of former PhD advisor Ali Jadbabaie, director of the Socio-technical systems center at MIT (`http://ssrc.mit.edu/about`) and of collaborator Victor Preciado, at the Warren Center for Network and Data Science at Upenn (`http://warrencenter.upenn.edu/`). Formalization of economic and social systems as dynamical systems built on the mathematical frameworks under development in our working paper, [1]. Much of my thinking is based on the foundation laid in the early 2000's by my undergraduate advisor Reza Olfati-Saber, who has made major contributions to decentralized sensor fusion and coordination, [2, 3] and proposed its suitability for the study of social choice in 2007, [4]; he is currently an AI entrepreneur.

2. Research Statement

Algorithm Design research will be undertaken to discover means of aggregating agent preferences using tokenized assets. The basic assumptions are that an agent's influence on collective decision making should depend both on the number of assets held and the time over which those assets have been held. The primary types of attacks we wish to mitigate are collusion and vote buying, in so far as the attacker(s) should not be able to increase the influence of their preferences over the collective decision. Formal mathematical statements of the coordination problem are required to address this further.

The author maintains that game theory based formalisms are insufficient on the grounds that they are not equipped for handling dynamics and uncertainty over time, in a manner similar to which decision theory results built on ensemble probabilities fail due to non-ergodicity, an argument attributed to Taleb, [5].

2.1. **Algorithm Design Research Definitions.** Suppose that we have an algorithm that takes the observable system state x including token holdings, and implicit or explicit preferences, p_t^i for each agent i at time t. Define a local estimator

$$y_t^i = E(x_t, p_t^i)$$

and a global decision function

$$c_t = D(x_t, \vec{y}_t)$$

where the vector notation is used to bundle up any additional dimensions and may have different meanings depending on the specific formulation.

Collectively the functions $E(\cdot)$ and $D(\cdot)$ define the social choice algorithm, but how does one determine if such an algorithm is good? This depends on some underlying assumptions about the existence of ground truth and the nature of the decision variables as shown in Table 1. All network participants are indexed i and may have their own loss functions. Loss functions h compare set based selections and can be thought of as classifier type loss functions in the machine learning literature and loss functions f are arbitrary convex penalty functions, more in line with measures of loss for regression models. For the purpose of this discussion assume that the preferences $p_t^i \in \mathcal{C}$ belong to the same domain as the choices $c_t \in \mathcal{C}$ and in the case that a ground truth optimal does exist, it is denoted $c_t^* \in \mathcal{C}$ and also belongs to the same domain.

Table 1

	Discrete Set	Continuous Parameter
Ground Truth	$\min \sum_t \sum_i h_i\left(c_t, c_t^*\right)$	$\min \sum_t \sum_i f_i\left(c_t - c_t^*\right)$
No Ground Truth	$\min \sum_t \sum_i h_i\left(c_t, p_t^i\right)$	$\min \sum_t \sum_i f_i\left(c_t - p_t^i\right)$

Table 1 shows the primitive problem formulations of interest, described as minimization over the functions $E(\cdot)$ and $D(\cdot)$ of the stated objective functions over time assuming evolution in both x_t and $\vec{p}_t$. These optimization problems require time discounting or windowing in order to ensure the sums are convergent.

Casting the problem as minimizing costs associated with a dynamic process brings us into the regime of sensor fusion. For the examples in the table one cannot compute the sums unbounded in time, fortunately there are well known tools in dynamic programming for handing time discounting, [6]. As this is a research proposal, the mathematical definitions are presented merely as a stub to help anchor the formal approach to the research question presented.

2.2. Preliminary Algorithm Design Research. The formalization of the definition of social choice as sensor fusion has had preliminary exploration. Knowledge of multi-layer evolutionary systems dictates a need for integration operators, whereas blockchain technology provides computational limitations not unlikely those in wireless sensor networks. Early research direction includes exploring *Conviction Voting* which is a continuous voting process derived from the Discounted Integral Priority algorithm presented in [7]. The cited paper involves a local resource routing problem to achieve a global objective, whose coordination problem is most akin to discrete choice with a ground truth which is exists but is unknown. An initial differential equation based model was developed using the Stella Architect modeling software to determine that this is a meaningful direction as shown in Figure 2. Furthermore, some preliminary Agent Based Model simulations were developed in Python for the continuous parameter variant as seen in Figure 3.

The variation of the algorithm implemented in Stella following the assumption that the preferences are one choice c_t^i from a set $\mathcal{C}$ and the conviction for each agent i is

$$y_t^{i,c} = \begin{cases} \alpha \cdot y_{t-1}^{i,c} + x_{t-1}^i & \text{if } c^i = c \\ \alpha \cdot y_{t-1}^{i,c} & \text{if } c^i \neq c \end{cases}$$

where t is block time and x_t^i is the token holdings of agent i at block t and α is the time discounting or forgetfulness parameter. This Estimator $E(\cdot)$ is thus a local discount priority which smooths over variations in preference which come from tokens created or destroyed, changing hands, or agents changing opinions. Given these signals in the dimension of choice by account, a decision can be taken

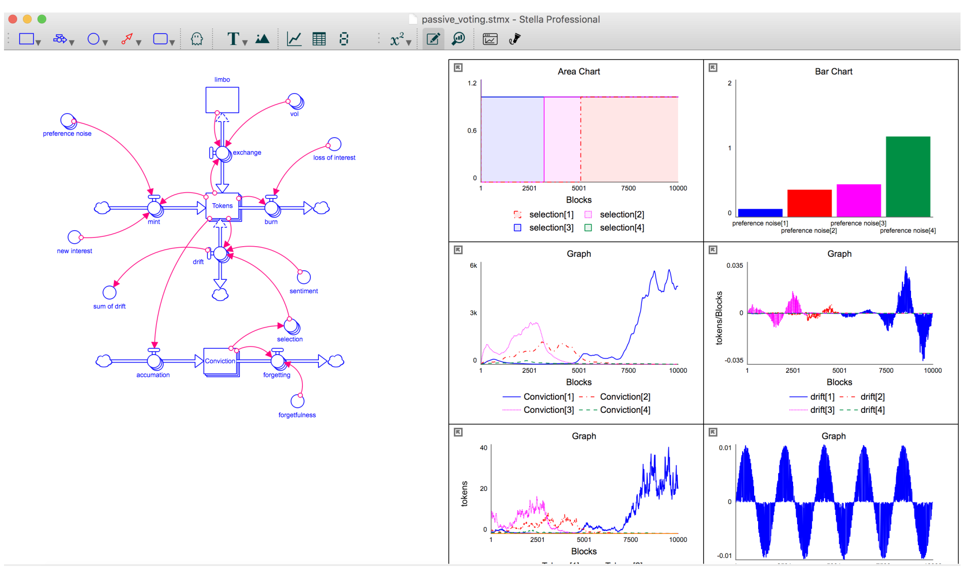


FIGURE 2. Conviction Voting Prototype Simulation in Stella Architect.

dynamically as

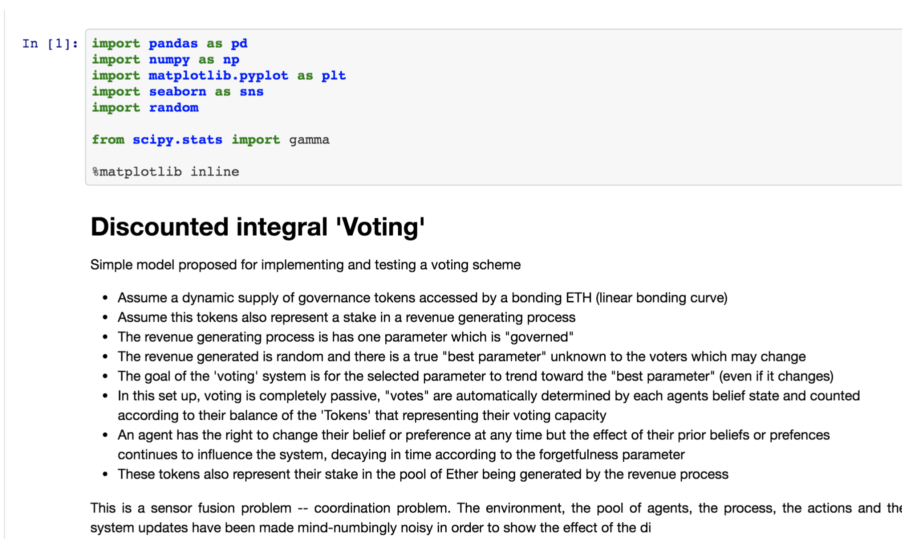
$$c_t = \max_c \sum_i y_t^{i,c}$$

which will shift only when the conviction of the community shifts. Note that the choice may change at any t and thus there is no one short vote for which an attacker can consolidate efforts and force a change on the system. Even if a collusion or vote buying effort were to occur, that effort would need to be maintained to hold the system in the unnatural state of influence. This fundamentally changes the cost profile for attacking the system from the finite cost of launching the attack to the potential infinite cost of maintaining the attack.

This is a very simple variation; there are alternatives which extend to approval voting where agents provide conviction to any choice they approve of. In the continuous choice version, as is the case in the Python simulation, the $D(\cdot)$ function is an average instead of a maximum. More generally however, the fusion algorithm can be designed to correspond to a well defined social utility function following constructs like those in Table 1.

In both cases, this preliminary research was sufficient to establish that this is a fertile research direction. In order to ensure the research achieves the goal of bridging knowledge from many disciplines, the research should continue with a literature review across the related disciplines.

2.3. **Known Economic Challenges.** A critical challenge that arises in any hierarchical evolutionary systems is the effect of changes to the meta-parameters of one system causing unintended effects on the system those parameters govern. This is a known phenomenon both for engineered systems and clearly evidenced in political systems, [8].



In [1]:

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import random

from scipy.stats import gamma

%matplotlib inline
```

Discounted integral 'Voting'

Simple model proposed for implementing and testing a voting scheme

- Assume a dynamic supply of governance tokens accessed by a bonding ETH (linear bonding curve)
- Assume this tokens also represent a stake in a revenue generating process
- The revenue generating process is has one parameter which is "governed"
- The revenue generated is random and there is a true "best parameter" unknown to the voters which may change
- The goal of the 'voting' system is for the selected parameter to trend toward the "best parameter" (even if it changes)
- In this set up, voting is completely passive, "votes" are automatically determined by each agents belief state and counted according to their balance of the 'Tokens' that representing their voting capacity
- An agent has the right to change their belief or preference at any time but the effect of their prior beliefs or prefences continues to influence the system, decaying in time according to the forgetfulness parameter
- These tokens also represent their stake in the pool of Ether being generated by the revenue process

This is a sensor fusion problem -- coordination problem. The environment, the pool of agents, the process, the actions and the system updates have been made mind-numbingly noisy in order to show the effect of the di

FIGURE 3. This is the Jupyter Notebook header for preliminary Agent Based Model simulation found here: `https://github.com/BlockScience/conviction/`

Additional known challenges include "vote-buying" whereby entities with economic power co-opt more influence than they are due in accordance with the governance model stated, and "voter-collusion" whereby entities with social power co-opt more influence that the block of entities would otherwise be due through sub-set coordination strategies at the cost of non-set members. Both of these challenges can be addressed both analytically and numerically with well defined mathematical problem statements.

2.4. **Known Technical Challenges.** When discussing this algorithm with smart contract developers, a common objection is that one can not simply iterate at each block because there is no passive computation. This fact requires that the smart contract based implementation of the discounted sum be implemented differently than it would be in its sensor network counterparts. A variety of strategies may be explored including rewarding the community for calling the update, or forcing every preference update to include an output recompute, among others to be considered.

The author maintains that validation of the suitability of the algorithms as a social coordination mechanism should proceed extensive implementation discussions. That said, a candidate test environment for this algorithm is the ArtDAO: "Artonomous" an open source project being led by Simon De La Rouviere. The BlockScience team has proposed economy design specifications to this initiative and the diagram in Figure 4 indicates how a conviction voting scheme fits into that design.

2.5. **Academic Fundamentals.** In addition to the references throughout the body of this proposal, there are additional critical academic building blocks in both engineering and economics, for the study of: non-linear systems [9], hybrid systems [10], estimation [11, 12], multi-agent robotics [13, 14], stochastic process [15] and risk engineering [16].

Differential games [17, 18] serve as a link between non-linear systems and game theory and System Dynamics serve as a bridge to business operations, [19, 20]. Potential Games [21] serve a critical pathway with convex optimization [22, 23]. When considering game theoretic frameworks it is important to evaluate both cooperative non-cooperative framing [18], in addition to the cooperative framing in [24].

There is Market Design field and experimental economics work, [25]. Game theory, in particular evolutionary [26] and algorithmic game [27] theory are important lines of work to be accounted for, [28]. The field of economics itself is evolving as the lines between physical systems and their social, political, and economic counterparts are blurred by information technology and large volumes of granular economic data become more common, [29, 30, 31]. The author is particularly interested on weakening rationality assumptions while retaining convergence properties in social learning [32, 33] and coordinated decision making.

Finally, a particular important aspect of governance problems is that sufficient abstract characterizations of the problem are required to account for the system itself to evolve; this is more commonly discussed in organizational rather than algorithmic decision making, [34]. These constructs are relatively common in complex systems systems and in controls engineering where system models are known but parameters are unknown or even changing, other disciplines have less mathematical tooling to account for change. In game theory, games where the rules can change are called nomic, as in [35], with [36] referring to system change.

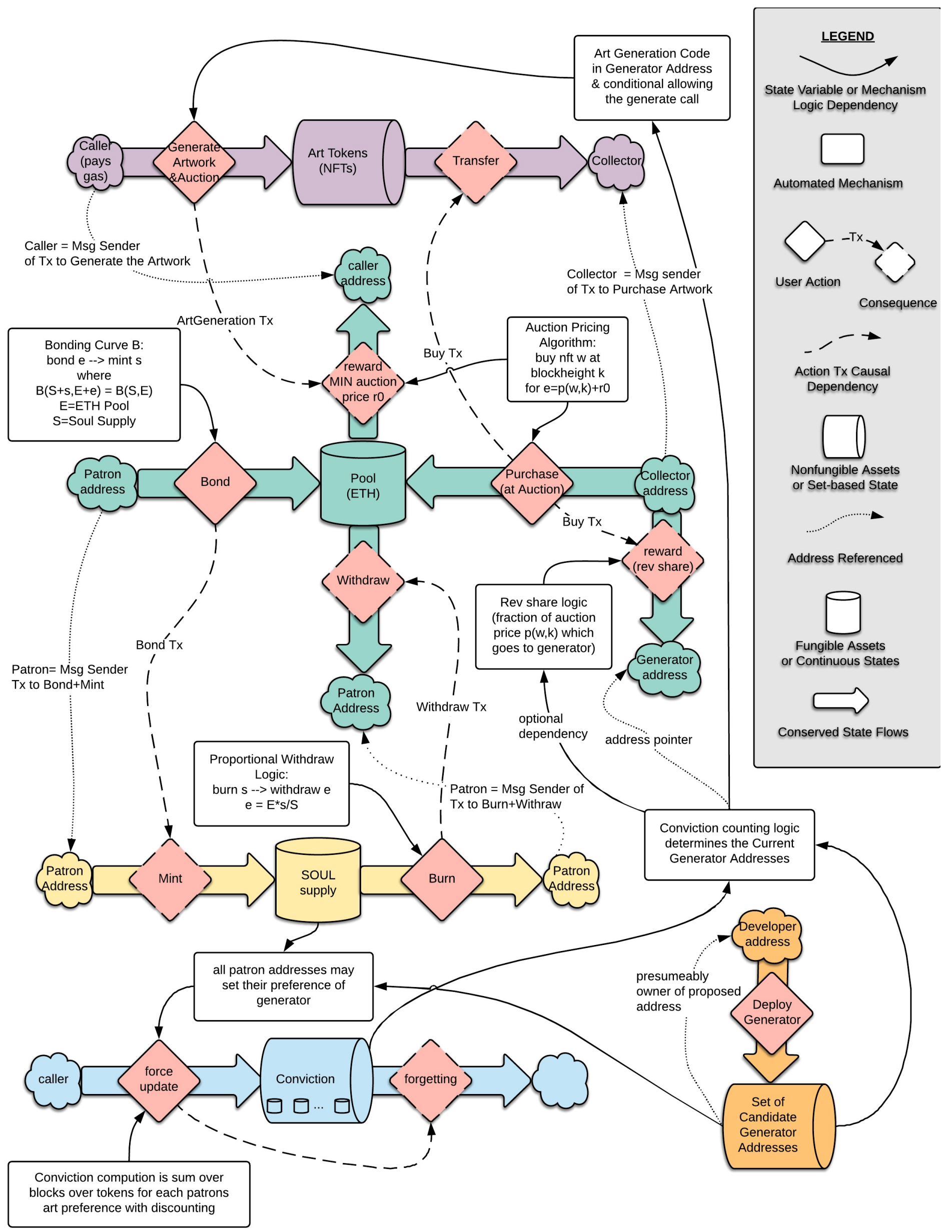


Figure 4. Example of how the conviction voting scheme could be introduced as a subsystem, specifically, a proposed system design diagram for Artonomous, ArtDAO project using conviction voting to select art generator code: `https://github.com/artonomous/artonomous-mvp`

3. Resources

The research outlined requires at a minimum, a lead researcher and project owner who is a qualified academic or industry research engineer with experience in data science, economics and/or estimation in wireless sensor networks as well as fundamental understanding in any of the aforementioned fields in which they are a non-expert. Regardless of domain, the researcher will be trained extensively in complex systems.

The researcher will collaborate with other members of the the BlockScience research team to leverage BlockScience data infrastructure, data science and engineering expertise as well as experience engineering token based economic systems. The research team is collaborative in nature and research project owners contribute to each others projects as the team finds valuable creating a sum that is greater than its parts environment.

The researcher will be provided with a competitive salary, benefits, considerable budget for cloud resources, software licenses as well as both crypto-currency and development resources as needed to proceed with the outlined research. The official goal will be to submit one or more papers to the Complex Systems and token economics focused research communities before the end of the research period, and hopefully more thereafter.

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