A Blockchain-Enabled Participatory Decision Support Framework

Marek Laskowski[1,2,3]

[1] York University, Mathematics and Statistics, Toronto, Canada
[2] University of Guelph, Population Medicine, Guelph, Canada
[3] Seneca College, Information and Computing Technologies, Toronto, Canada
{marek.laskowski@gmail.com}

Abstract. In this "post truth" age of "fake news" and "alternative facts" uncertainty in the provenance of policy makes transparency in decision making increasingly important for evidence-based policymakers. This paper demonstrates how the convergence of Agent Based Modelling, Smart Contracts, Blockchain, and Virtual Reality (VR) technologies make possible the development of participatory decision support frameworks. The concept is demonstrated in a public health context by implementing an Agent Based Model of disease spread within a simulated population (SIR model) as a so-called Smart Contract deployed on a public Blockchain network. We demonstrate that in order to "close the loop" the simulation outcomes can be visualized using commodity VR hardware, and future extensions towards fully interactive simulations are proposed.

Keywords. Blockchain, Participatory Decision Support, Agent Based Model, Data Analysis, Ethereum, Smart Contract, Virtual Reality

1 Introduction

When decisions are made behind closed doors by unknown officials using unseen evidence, there can be a breakdown in communication leading to lowered uptake or acceptance of public policy interventions [1]. As a result, in many developed and developing countries individuals disregard policy (e.g. public health) messages that they do not understand or trust. Furthermore, in recent years there have been increasing calls for transparency and openness in all aspects of public policy decision making processes [2] including the ethical management of individual's data [3].

For applications in public health in particular, the effectiveness of evidence-based decision making relies on not only the compliance of the public, but the availability of highly detailed contact network data and epidemiological surveillance [4] requiring increased trust and buy-in from all stakeholders. We argue that for there to be increased trust between public policy makers and the public, all parts of the decision support phases described by Figure 1 must take into account: fair governance of data and resources, availability of source data and analytics code for all stakeholders, as well as provenance of data and resulting analytic evidence.

The key emerging technologies that enable participatory decision support include:

1) Blockchain - A Blockchain can be said to implement a highly-secure, distributed ledger or database [5][6][7]. Unlike a centralized database controlled by one organization, instead a peer-to-peer network shares responsibility for maintaining the state or integrity of the data contained within. Data stored within a Blockchain is considered immutable, although, in effect, newer records can be created to serve as updates for older records. Value represented as tokens can be transferred using a Blockchain, as demonstrated by networks such as Bitcoin [5] and Ethereum [8].

2) Smart Contracts - The term "Smart Contract" has come to mean a computer program which has its execution carried out on a Blockchain, and furthermore its state and outputs are secured by said Blockchain. A "Smart Contract" can encode complex business logic and allows for highly-structured computations to be carried out without direct human intervention [8][9].

3) Agent Based Models (ABMs), incorporate rules from expert stakeholders, as well as a numerous data streams to parameterize the numerical and statistical parameters that underlie stochastic phenomena in the model [10]. In the resulting model that is both heuristic and data driven in nature, complex behavior emerges from the relatively simple set of rules relating a population of agents to the environment and to each other. Agent Based Modelling is increasingly used for modelling complex social phenomena [10] including the spread of infectious disease [4].

4) Virtual Reality (VR), is a technology that presents realistic 3D highly immersive simulations to users, in which the users can move their bodies to interact with the simulation to varying degrees [11]. In contemporary designs, headgear is used to mount increasingly capable consumer devices (e.g. smartphones) directly in front of the user's eyes showing a different stereoscopic image to each eye.

The remainder of this paper will discuss how each key technology is used in the context of a prototype participatory decision support framework, and evaluate the prototype against the aforementioned principles.

2 Prototype Implementation

An evidence-based decision making process encompassing "from data to knowledge to decision to action" along with the corresponding proposed framework components is shown in Figure 1. In the data collection phase, input data can come from individuals using a Web Browser interface as well as mobile devices including smartphones and Internet of Things (IoT) devices. A Blockchain network client (i.e. geth) is used directly or through an intermediate Javascript/Web layer to deliver data onto the Blockchain.

In the context of this proof-of-concept, anonymous data is aggregated and stored using a relatively simple mechanism within a Smart Contract on the Blockchain network, implemented using the Solidity programming language. The data is combined with expert knowledge encoded within the Smart Contract to implement the Agent Based Model used to model the spread of infectious disease. The disease model here is based on a previously validated model [4]. After simulations are carried out using the computational capacity of the Blockchain network, the relevant simulation logs are extracted using the Blockchain network client. In the "decision" phase, simulation results

can be analyzed using traditional aggregate graphs, charts, and statistics, such as Figure 2. Results can also be visualized using a Virtual Reality "Decision Support Table" implemented using the Google Daydream VR kit[1] and Unity3D[2]. VR represents an intuitive and explicit means of visualizing data and simulation outcomes during the decision phase, and can be used for knowledge translation to convey the nature of simulation based modelling to stakeholders and the public during knowledge dissemination in the action phase.

Within a typical Agent Based Modelling workflow, model refinements are often made by working with the model code, redeploying the code, and re-running simulations. Therefore, at this stage of development some phases of the decision making process understandably involve human intervention, such as deploying or upgrading the Smart Contract, data entry, as well as importing the simulation log into the VR application.

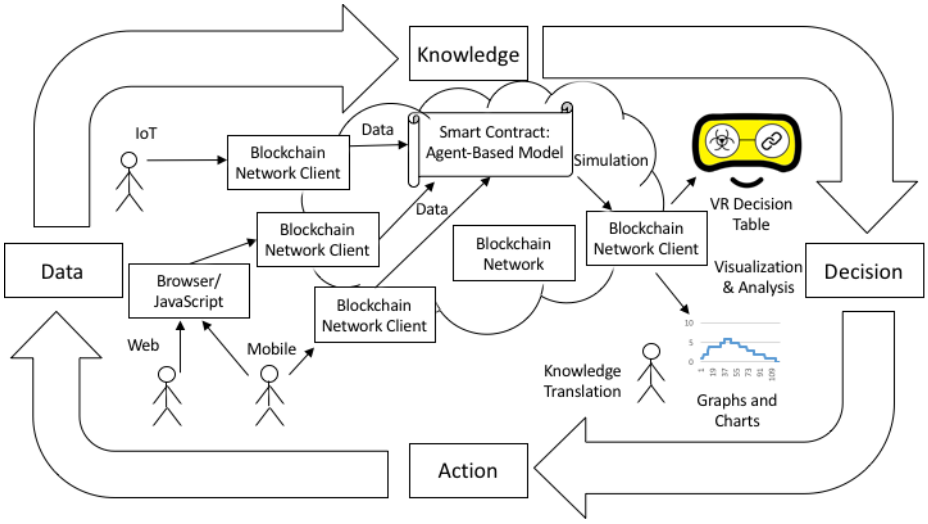

Figure 1. An evidence-based decision support process alongside proposed framework components. Data from a variety of sources including web, mobile, and IoT is collected and stored on a Blockchain network. The data is combined in a Smart Contract with expert knowledge to create an Agent Based Model which can be used to carry out simulations on the Blockchain network. During the decision phase, simulation results can be analyzed using traditional plots or by using a Virtual Reality "decision support table" to assist with knowledge translation leading into the action phase.

For further details, please see the project's Github page: https://github.com/professormarek/Intellichain or [9] for more background on technical implementation. For brevity, screenshots, downloads, and other details concerning the VR decision table demo application are available at: http://www.interllicha.in .

[1] https://vr.google.com/daydream/
[2] https://unity3d.com/

3 Results

A scenario including seven locations, and ten agents, one initially infected was used to demonstrate and test the functionality of the prototype framework; the results of this test run are shown in Figure 2. It was decided to follow the Ethereum community's best practices and carry out tests of the smart contract with the use of a test network. Once preliminary tests were completed, a contract was deployed to the Main Ethereum network at address 0x203028e846f512ef3320c10f0d39739906e65797 - in order to demonstrate the open and participatory features of the framework, anyone can interact with the contract directly using an Ethereum client or using the Application Binary Interface (ABI) published on the project's aforementioned GitHub page.

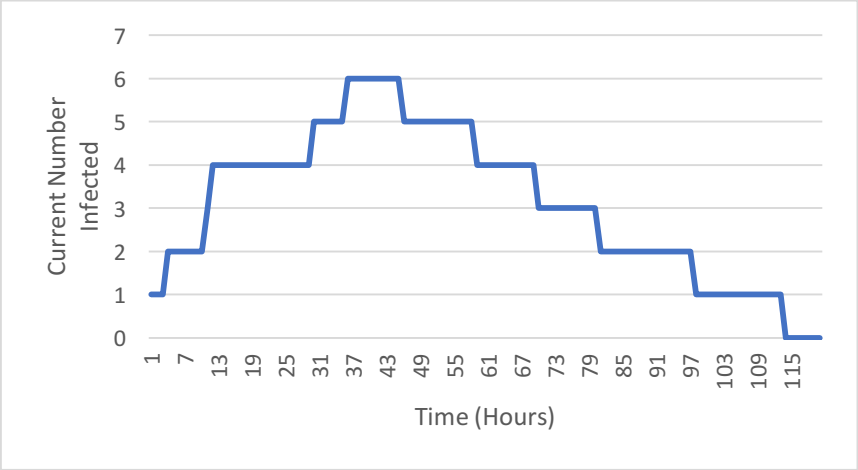

Figure 2. Number of currently infected individuals on each hour of the simulation.

The simulation results can be interpreted using standard analytical tools such as graphs and charts. One such graph is Figure 2 which shows the number of currently infected individuals as a function of time during a simulation with particular initial conditions carried out on the test network. The published VR app demo permits users to experience the simulation carried out earlier on an Ethereum test network, presented as a virtual "decision table". Both Figure 2 and the simulation that plays out in the VR app communicate the important epidemiological principle of a super-spreader infecting several secondary cases early on in the outbreak who in turn infect others later on.

As the purpose of this article is to expound the concept and to demonstrate its viability, a more rigorous study of performance characteristics and analysis of scalability will be the subject of a future publication.

4 Discussion

Regarding the fair use of data and resources, the current iteration of the prototype is focused on the use of open data, as well as anonymized data volunteered by informed participants. However, in general, fairness may imply compensation of participants for the use of their data. Fortunately, the Ethereum Blockchain network has secure value token exchange as a first-class feature of the protocol, making it very easy to compensate participants. Those individuals running nodes that perform calculations and maintain the ledger (i.e. miners) are already rewarded using this concept.

Regarding the participatory and open nature of the framework towards all stakeholders, we argue that this framework is successful in this regard, because all stakeholders including the public are able to access to the same data, results, and tools as experts.

Regarding the clear governance and provenance of data, beyond the aforementioned compensation of participants, the governance of data through the use of smart contracts on a Blockchain, has already been demonstrated elsewhere [12]. Metadata, if available, concerning the provenance of data can be entered into the Blockchain alongside said data. When computation and analytics are carried out using an open Blockchain network, the simulations are verifiable and the provenance of all results are clear owing to the immutability and auditability of the Blockchain [9].

4.1 Future Work

Scientific validation of the model presented here is a priority, however it is a time-consuming process that involves expert stakeholder involvement. Another pressing goal, enabled by advances in mobile Ethereum clients is to make the VR application fully interactive with "live" simulations being executed on the Blockchain from within the VR app. The VR app is also being upgraded to allow multiple users to interact with the simulation and each other in the same shared simulated experience. Now that an initial proof-of-concept has been presented, streamlining of the implemented phases can take place, and increasing the overall automation in the process. As mentioned, extensive performance analysis of the simulation framework will be carried out to better understand scalability and performance limitations.

5 Concluding Remarks

In summary, the framework presented here represents a step forward in participatory decision support, owing to its open design principles as well as advanced analysis and visualization capabilities. The code, data and outcomes are open and the data and simulations are governed by smart contracts on a Blockchain. Experts and the public they serve have access to the same platform where ideas and outcomes can flow freely.

Evidence-based decision support efforts relying on simulation should take into account potentially valuable tradeoffs in being able to substantiate the provenance and quality of the decision support despite any additional overhead incurred. In the near future this may be part of a cost-benefit analysis when deciding on a modelling strategy.

The utility of public Blockchain networks for creating an open, participatory, decision support framework is demonstrated in an epidemiological, public health, context – however, extensions to other domains remain possible. Perhaps one day soon, individuals will run participatory decision support software at home much as they do seti@home or folding@home in the present day.

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