

Introducing the Ω -machine

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ABSTRACT

In this paper, we propose the Ω -machine model for social machines. By introducing a cluster of "oracles" to a traditional Turing machine, the Ω -machine is capable of describing the interaction between human participants and mechanical machines. We also give two examples of social machines, collective intelligence and rumor spreading, and demonstrate how the general Ω -machine model could be used to simulate their computations.

Categories and Subject Descriptors

F.1.1 [Models of Computation]: Bounded-action devices (e.g., Turing machines, random access machines).

H.1.2 [User/Machine Systems]: Human factors.

General Terms

Algorithms, Human Factors, Theory.

Keywords

Social machine, Ω -machine, Turing machine.

1. UNDERSTANDING SOCIAL MACHINES

Social Machines are used to describe the large scale interactions between humans with machines. In social machines, "humans do the creative work, while computers do the intermediation" [4]. Therefore, compared to traditional Turing machines, social machines have got the following characteristics:

- First, the purpose or outcome is not just computation but also impact on society as a whole and on individuals;
- Second, they involve human beings in their operation, whose interaction with machines is a complex process that may not be fully modeled, anticipated or explained. Third, social machines can keep running forever if need be and their mechanisms can evolve over time.

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2. A MODEL FOR SOCIAL MACHINES

Since Turing machines have been proven to be capable of simulating all traditional computing machines, it is intuitive to derive a model for social machines based on Turing machines.

The major difficulty is the probabilistic freewill of human beings, while Turing machines are deterministic. Therefore, we have to employ o-machines [1], a variation of traditional Turing machines plus an "oracle" to introduce probability into the game.

Therefore, an Ω -machine is composed of the following parts:

- A standard Turing machine, which represents the problem itself;
- A set of o-machines representing people involved in the computation, each having their own tape;
- Interactions among humans and machine can be described by the read/write operations on the Turing machine tape when the Turing machine decides to consult the "oracles".

Inspired by the above motivations, we propose a general definition of the Ω -machine in Section 3 which we believe should be capable of simulating the operations of all different classifications of social machines. To demonstrate that, we build specific Ω -machines for two typical cases of social machines, rumor spreading and collective intelligence, in Section 4. Finally, Section 5 concludes the paper and contains some of our discussions on future research directions.

3. A DEFINITION OF THE Ω -MACHINE

We define an Ω -machine as an 10-tuple that can be used to model social machines with the characteristics discussed in the previous sections. The Ω -machine builds on a Turing machine as explained below.

A standard Turing machine can be defined as a 7-tuple as per Sipser [3] $(Q, \Sigma, \Gamma, \delta, q_0, q_{\text{accept}}, q_{\text{reject}})$, where:

1. Q is the set of states
2. Σ is the input alphabet
3. Γ is the tape alphabet (includes the blank symbol and Σ)
4. δ is the transformation function
5. q_0 is the start state

6. q_{accept} is the accept state (which may never be reached in an Ω -machine)
7. q_{reject} is the reject state (which may never be reached in an Ω -machine)

There are many definitions of an oracle machine but it seems that in most cases it includes an *oracle tape* and *oracle head*. They also include:

8. Γ_{ω} (the oracle alphabet which can be different to that of the Turing machine)
9. ASK and RESPONSE states (allowing oracles to be asked questions and provide answers)

We consider Ω -machines with a finite number of oracles (to represent the people), each with their own tape/head.

We assume that the Turing Machine part of the Ω -machine, apart from its *work tape* also has an *output tape*, which can be read by the oracles at any time. This is equivalent to having just one work tape parts of which can be read by the oracles but we introduce this notion for convenience and ease of modeling.

When each oracle (person) enters an ASK state, its response will depend on the Turing machine work tape (as input) and its own tape, and will therefore provide an answer based on a transformation function, which we can call δ_{ω} .

10. δ_{ω} , the transformation function of each oracle, with input $(Q \times \Gamma \times \Gamma_{\omega})$

To sum up, the above elements of an Ω -machine are illustrated in Figure 1.

The Ω -machine

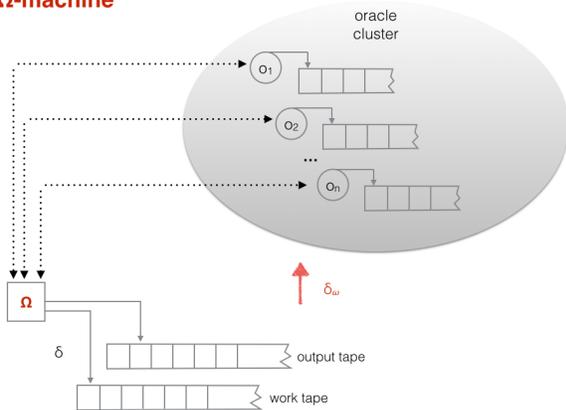


Figure 1: The elements of an Ω -machine.

4. SOME EXAMPLES

4.1 Rumor Spreading

In the example of Figure 2, we demonstrate how an Ω -machine is used to simulate a process of rumor spreading.

We use the output tape of the Turing machine to represent the rumor message, denoted as "B". The oracle cluster represents human who have contact with the rumor by either (i) reading the

rumor from the Web or (ii) learning the rumor from their neighbors. An individual oracle can select to believe it or not based on some probability whose threshold is determined by his own knowledge, his trust on the rumor source, or the society background.

The oracle cluster can instantly access the entire output tape, which simulates their exposed contact with possible rumor sources. The Ω -machine head (indicated with an Ω in the diagram) can consult the oracles and, subject to its transformation function δ , it will compute utilizing its work tape and provide some update on the output tape.

The oracles of the cluster, each one has a symbol on their individual tapes indicating their individual tendency of believing the rumor. When an oracle is asked to provide its answer by the head of the Ω -machine, the YES/NO answer will take into account (i) the contents of the individual tape of itself and (ii) the contents of the output tape of the Ω -machine. If there is a match, it would probably be a YES answer. If the rumor information "B" is against the oracle's background knowledge, as oracle "o₁" in Figure 2, the answer could probably be NO. The Ω -machine does not need to update the output tape since rumor information seldom changes. Individual oracle tapes may change during the computation because some people tend to be influenced by rumors. For example, "o₂" may change its tape from "B" to "A" after a contact with "o₁".

The transformation function for the oracles (δ_{ω}) could be probabilistic and it could take into account network metrics (to reflect social network factors) and potentially the content of the tapes of other oracles. In the example of "o₁" persuading "o₂" to give up believing rumor "B", a link between these two oracles in the underlying social network topology is an implicit assumption.

Ω -machine concept Rumour Spreading

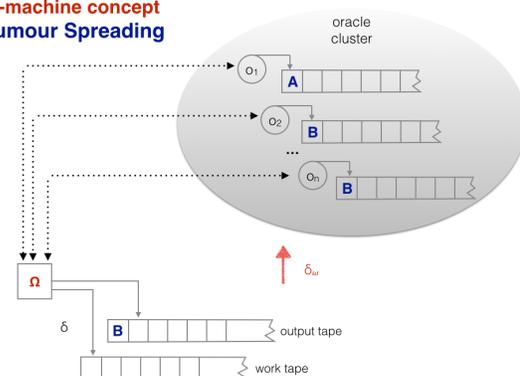


Figure 2: An Ω -machine for rumor spreading.

4.2 Collective Intelligence

In the example of Figure 3, we outline how an Ω -machine could potentially be used to simulate a problem of collective intelligence. That oracle machine does not necessarily have to reach an end-state and complete a computation; the computation is ongoing and its output is displayed in the output tape. The oracle cluster can instantly access the entire output tape. The Ω -machine head (indicated with an Ω in the diagram) can consult the oracles and, subject to its transformation function δ , it will

compute utilizing its work tape and provide some output on its output tape.

The oracles of the cluster, each one has a sequence of symbols on their individual tapes according to the alphabet of the oracles as identified in the Ω -machine; when each oracle is asked to provide its symbols by the head of the Ω -machine each will provide some input that will take into account (i) the contents of the individual tape of each oracle and (ii) the contents of the output tape of the Ω -machine subject to a transformation function δ_o , which can potentially be probabilistic. The Ω -machine at certain stages will update the contents of the output tape based on its input and we can observe the characteristics of that output and how they might change over time for different transformation functions, alphabets and oracle tape contents.

The transformation function for the oracles (δ_o) could be probabilistic and it could take into account network metrics (if we assume that oracles are arranged in a network) and potentially the content of the tapes of other oracles. The purpose of the Ω -machine concept is not to provide a definite model but a way in which we could model such computations.

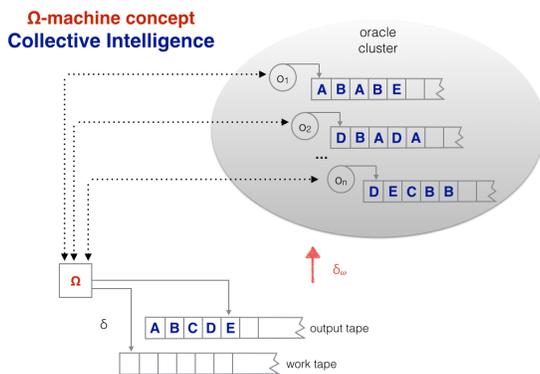


Figure 3: An Ω -machine for collective intelligence.

5. CONCLUSIONS AND DISCUSSIONS

The discussion on whether the human brain is a Turing machine or whether an o-machine can represent the human brain is not yet resolved [1] and it is rather out of the scope of this work. The purpose of proposing the Ω -machine concept is as a means of modeling and simulating interaction among a large number of people (the oracle cluster) where Turing machines are the intermediaries; i.e. interaction in social machines.

We believe that the concept of Ω -machines, where we provide for (probabilistic) transformation functions for the answers of the oracles, along with the transformation function of the Turing machine, could prove to be a powerful tool for the simulation of the operation and of the evolution of social machines and of social machine ecosystems as identified in [2].

In the examples that we provided we outline how basic problems or patterns of social machines could be modeled and potentially simulated by Ω -machines. We showed how elements of collaborative knowledge organization in the context of collective

intelligence could be broken down to Ω -machine computations. We also outlined how rumor spreading could be modeled as an Ω -machine computation.

We believe that the transformation functions of the oracles could be inform by the significant volume of interdisciplinary research that is performed in the context of Web Science and that the outcome of qualitative and quantitative research could be reflected to a satisfactory extent on Ω -machines elements for the purpose of simulation and computation. Finally, we believe that encouraging the research community to focus on modeling efforts such as that of Ω -machines could help further developments on the research roadmap of Web Science.

Since this paper is the first attempt of modeling social machines based on Turing machines, there are still quite a number of open questions that we want to share with interested researchers:

1. Can Ω -machines be used to model all different classifications of social machines?
To answer this question, we need to build specific Ω -machines for each of the classifications of social machines as defined in [2].
2. Can Ω -machines simulate the effect of the society as a whole?

Some social machines, like re-Captcha, have central administrative nodes for task management. Some other social machines, like rumor spreading, can be affected by the society as a whole since the probability of forwarding a rumor is dependent on both the individual's freewill and the outside environment of the whole society.

One possible way of simulating this effect is to introduce another o-machine in Figure 1 to represent outside influence; It is important to note that this o-machine is a single node representing a integrated effect of education, culture, history, language and etc. We can call it the global O; The global O can read and write the tapes of the individual o-machine clusters, simulating the process of administration of the society and other hidden hands.

The introduction of the global O gives rise to another interesting question: Is the Ω -machine with a global O equivalent to a Ω -machines without a global O?

3. Can transformation functions of the Ω -machines, including the basic Turing machine and the cluster of o-machines, change during the computation process?

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