Combining Human Reasoning and Machine Computation: Towards a Memetic Network Solution to Satisfiability*

Daniel S. Farenzena and **Luis C. Lamb**
Institute of Informatics
Federal University of Rio Grande do Sul, Brazil
d.scain.farenzena@gmail.com; luislamb@acm.org

Ricardo M. Araujo
Department of Informatics
Federal University of Pelotas, Brazil
ricardo.araujo@gmail.com

Abstract

We propose a framework where humans and computers can collaborate seamlessly to solve problems. We do so by developing and applying a network model, namely *Memenets*, where human knowledge and reasoning are combined with machine computation to achieve problem-solving. The development of a Memenet is done in three steps: first, we simulate a machine-only network, as previous results have shown that memenets are efficient problem-solvers. Then, we perform an experiment with human agents organized in a online network. This allows us to investigate human behavior while solving problems in a social network and to postulate principles of agent communication in Memenets. These postulates describe an initial theory of how human-computer interaction functions inside social networks. In the third stage, postulates of step two allow one to combine human and machine computation to propose an integrated Memenet-based problem-solving computing model.

Introduction

Recently, Online Social Networks and Internet popularization (Kumar, Novak, and Tomkins 2006) have enabled massive human-aided computation as illustrated by a number of applications (Land et al. 2008; Google Co. 2009). One could think of humans as computational resources as long as one can motivate them to perform useful tasks (von Ahn et al. 2008). Social groups can be seen as networks of agents cooperating towards problem-solving. In such social networks, computers are seen as passive agents that perform specific tasks submitted to human coordination.

In this work, we propose a new model where humans and computers can collaborate seamlessly to achieve general purpose computational problem-solving. In order to do so, we apply a novel network model, namely *Memenets* (from *Meme*tic *Net*works) (Araujo and Lamb 2008), in which human knowledge and reasoning are combined with machine computation through communication evolution. At some point, evolved communication between humans and computers will enable computers to become active, autonomous collaborative computer agents. In addition, no specific Human-Computer interface is used to achieve this interaction between human and computers. Further, the network can provide solutions to problems that currently only human agents compute in a satisfactory way, e.g., decision making or distorted image recognition (von Ahn et al. 2008). The proposed Memenet is a network of agents that interact exchanging and processing *memes*: chunks of data or information that are propagated through copies in a cultural setting, analogous to genes (Dawkins 1990). We construct the proposed Memenet model in three steps:

Step 1: we simulate a computer-only Memenet;
Step 2: we experiment with a human-only Memenet;
Step 3: we analyze Steps 1 and 2, and build a refined model that combines human and computer agents in a Memenet model.

Research done along the lines of Step 1 has verified the ability of a Memenet to solve problems (Araujo and Lamb 2008). Step 2 suggests a possible way of establishing faster peer communication and evolution.

Designing a Human Memetic Network

In order to build and experiment with a network of human computing agents (Step 2 above), we have implemented a web-based application. The Memenet application is fully operational and can be used with a default boolean SAT problem (please see: http://www.inf.ufrgs.br/SatSolverInterface1/Login.aspx).

Human agents participate in a Memenet designed to solve instances of SAT problems (Marques-Silva 2008)[1]. Human agents in the Memetic network exchange memes in the form of a string of "true" or "false" propositional SAT instances assignments. Agents in the memenet can either exchange or construct their own memes (solutions of SAT instances). Memes evolve by selection (possibly by agent interaction) so that they converge to the problem's solution. The interface presents to every agent the number of satisfied clauses, which lead to meme "mutation" towards the correct solution. Agents can only communicate with other agents allowed by the network topology set at the beginning of the experiment. Our experiments with human agents have led us to identify the following principles for building a

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[1]Information about the SAT Memenet are available at: http://www.inf.ufrgs.br/SatSolverInterface1/Main.aspx

memenet. These requirements describe initial principles for memenet communication.
R1 the meme must be human readable;
R2 the meme must be efficiently machine readable;
R3 the meme must be small-sized or have a reduced solution space;
R4 modifications over memes must be performed by operations known by humans and computers.

Analysing the Effects of Human and Machine Readable Memes

R1 states that human-readable memes are required so that humans can effectively collaborate within the network. Together with requirement **R2** we can enable interoperability between humans and computers. There are several data standards for interoperation between computer systems, but they usually do not take into account human readability for problem solving.[2]

We have experienced with 159 subjects, divided into groups of 11, 14, 15, 18 and 26 first and second year undergraduate Computer Science students. We used propositional logic language and the corresponding meme was a "true" or "false" binary vector. As the problem size grew towards industrial size instances, readability became an obvious issue. In addition, agents took too long to read and memorize the problem instance (meme size) with respect to the time agents had to solve the given instance. Each agent is presented with 2 to 6 possible solutions - from their peers - to a given SAT instance. While exchanging memes, 82% of agents used the first meme, among all available to them (from 2 to 6 solutions). Under the current understanding of the SAT problem, there is no compactification of long possible solutions of a SAT instance that is both efficient and precise for human agents. Since industrial size SAT problems can have thousands of variables, visualization techniques and tools are needed (Sinz 2007). However, such techniques have not so far proved to be good representation schemes.

We also use data structures that enable hardware components to operate efficiently avoiding processing and storage overhead. The machine-readability requirement is associated to data formats that can benefit from current hardware architecture and instruction set, including SIMD in GPGPU[3] and SSE[4]. The balance of requirements **R1** and **R2** is thus the first challenge one has to face when modeling and engineering memetic networks.

Solution Space Exploration

From the point of view of optimization, memes are either interpreted as data that are iteratively transformed into a solution, or as chunk of data that contain a solution. For a machine to explore the solution space efficiently, we have to make the solution space as small as possible. In the case of SAT instances, having a Boolean vector is adequate, since it reduces the solution space (operations over binary strings are closed) and humans naturally handle binary vectors. **R4** limits the number of operations that can modify the meme (e.g. in the case of theorem proving, we could name the reduced set of operations as "deduction rules"). Thus, **R4** allows a more human-readable representation while restricting the solution space.
Therefore, the second challenge one faces when modeling and engineering memetic networks is how to follow requirements **R3** and **R4** without contradicting or opposing **R1** and **R2**.

[2]Note, however, that XML and JSON do have the necessary meta-information that enables humans to know more about the data being transmitted. At the same time, they allow for effective machine manipulation of the data and could be an option in future implementations.

[3]General-purpose computation on Graphics Processing Units

[4]Streaming SIMD Extensions

Conclusions and Further Work

We have described the design and application of a Memenet composed of humans and computers. We have defined four basic requirements for the effective construction of such networks. This Memenet is able to compute and communicate memes that are both human and machine readable. Further, the memes represent a problem solution. In order to validate the proposed model, we are currently implementing a Memetic network for SAT solving that will be endowed with memes that are represented in a formal language amenable to human understanding. The construction of such networks, if successful, can lead to a rich computational problem-solving method where humans and computers are fully integrated.

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