When Rationality Entered Time and Became a Real Agent in a Cyber-Society

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Abstract

Since Artificial Intelligence (AI) applications became mature, there has been growing interest in employing them into complex real equipment, especially in order to implement "Cyber-Physical Systems" (CPS). Since its dawn as a discipline, AI focused on simulating and reproducing human-like mental processes using formal structures, chasing the high-quality of reasoning. However, with the challenges posed by CPS, AI needs to take into account concrete real "timing performances" in addition to abstract reasoning about "time". The AI definition of "intelligent agent" seems to perfectly apply to CPS. Nevertheless, to be real, intelligent agents need to deal with, reason about and act in time. This paper motivates such needs by deriving the roots of the definition of Real-Time Agent in Philosophy, Control Theory, and AI. Moreover, some examples are provided to demonstrate why Real-Time agents are required in the "real world" of CPS. The paper concludes listing the desiderata of Real-Time Agents, wishing for the convergence of Multi-Agents Systems and Real-Time Systems.

Keywords: Multi-Agent Systems Real-Time Systems, Artificial Intelligence, Control Theory, Cyber-Physical Agents

1 Introduction

Since Alan Turing's seminal paper [TUR50] Artificial Intelligence (AI) has been conceived as the answer to the fundamental question: *"can machines think?"*. Most of the enormous intellectual effort spent in subsequent decades was on theoretical concepts such as "logical reasoning", "knowledge representation", "machine learning" (even in the architectural framework of "neural networks"), "language understanding", "planning" and so on. However, the original question has been often confused and misplaced with the other one: *"can machines behave intelligently?"* which is well understandable, influential, and impressive for the masses. Brooks [Bro91] noticed that animals exhibit an intelligent behaviour even without an explicit symbolic representation of the world where they live in, thus showing that "reasoning" and "intelligently behaving" are different concepts not necessarily consequential. However, modern Cyber-Physical Systems (CPS) are evolving from the old mathematical notions based on "Control Theory" (CT) towards explicit AI-based techniques, thus conceiving hybrid systems that embody complex reasoning software (produced by the AI community) on the same digital equipment that govern sensors and actuators (which are regarded simply as I/O peripherals of a CPU) through the application of some pieces of software derived from CT. By doing so, CPS becomes nothing more that computing systems running huge AI-based software and some automation firmware over boards where the input devices are defined as "sensors" and the output devices "actuators". However, unfortunately, this evolution remix together concepts that history separated, i.e. "thinking" and "intelligently behaving" thus producing serious design mistakes, especially w.r.t. to the notion of "time". In fact, since the beginnings the AI community very well understood the importance of reasoning *about* time (think for instance of "planning" and "temporal reasoning"), but almost always neglected the importance of reasoning *in* time! On the other hand, CT dealt with timing performances, but never reasoned explicitly *about* anything, notion of "time" included. This paper explores these ideas showing some inherent problems of these new hybrid approaches to CPS.

2 Rationality and Reality

Scrolling the opaque pages of memory and going back to the foundations (Dartmouth workshop - 1956), that saw protagonists such as Marvin Minsky and John McCarthy paving the foundation of Artificial Intelligence, we see that their aim was

> ...to proceed on the basis of the *conjecture* that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to *simulate* it. An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves

It is almost clear that our pioneers' aim was more that of *simulating* humans' mental processes than that of *acting* in the real world; they were more interested in "rationality" (as mental processes) than in "reality" (as processes in the physical world); they (unconsciously?) accepted the ontological distinction between the two and the conjecture that, once precisely defined the descriptions of a certain mental ability, that could as well be implemented into a machine acting in the real world. They didn't considered (or were not aware of) Georg Wilhelm Friedrich Hegel's famous claim [Heg21]:

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What is rational is real;
and what is real is rational.
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i.e. that the two "phases" should better be considered as two sides of the "same" medal. Of course, ignoring Hegel's claim was a pity, but they were completely innocent because for centuries, after Aristotle, "Logic" (hence 'Rationality") limited itself to considering "thought" in its formal structure, making abstraction from every content and, as such, becoming not capable of being "real". This abstract conception of the "Logos" was one of the most influential of the western world philosophy and culture in the last two millenniums, and still pervades our time. To our knowledge, apart from S. John the Evangelist (four centuries after Aristotle) who, in the prologue of his gospel, wrote:

Ἐν ἀρχῇ ἦν ὁ λόγος,
καὶ θεὸς ἦν ὁ λόγος.
οὗτος ἦν ἐν ἀρχῇ πρὸς τὸν θεόν.
πάντα δι´ αὐτοῦ ἐγένετο,
καὶ χωρὶς αὐτοῦ ἐγένετο οὐδὲ ἕν. ὃ γέγονεν

anyone considered "rationality" and "reality" as ontologically different. Back to our era, the queen of sciences for understanding the "real" world is "physics" and in 1905 the most important formula ever written was published [Ein05]

$$Energy = \frac{Mass \times c^2}{\sqrt{1 - \frac{\Delta Space^2}{\Delta Time^2 \times c^2}}} \tag{1}$$

showing that the Universe is not made of five basic elements, as supposed in the ancient China (Fire, Earth, Water, Metal, and Wood), instead "reality" is made of four: $Energy, Mass, Space$ and $Time$. Now, if we accept Hegel's equation $Rationality = Reality$ then we have to conclude that $Rationality$ is a function of $Energy, Mass, Space$ and, in particular, $Time$. In this holistic vision, there is no real difference between the two questions: "can machines think?" and "can machines behave intelligently?", both of them referring to "Rationality" as two sides of the same coin. Being "intelligent", for both a human and a robot, does not implies just reasoning *about* time but also reasoning *in* time, since being "in time" is the only way to *Be* intelligent.

3 Control Theory and Artificial Intelligence

In 1948, Norbert Wiener originated a topic named "Cybernetics" [Wie48] focused on realizing electronic machines able to *replicate* animals behaviors. At that time, computers were not invented yet and electronics were not able to perform any computation (circuits were just analogical). However, the main outcomes of such a discipline were the notion of "feedback" and the mathematical representations of the relations between two temporal functions, Input(t) and Output(t), named "Transfer Functions".

Ten years later, after the first generation of computers, that discipline was named "Control Theory", the Input(t) function was converted into a digital stream, the mathematical "Transfer Functions" started to be "calculated" on a CPU (instead of being just "implemented" into a circuit) and, finally, the digital stream produced by the calculation was converted into an Output(t) function. Few people noticed that this change towards the digital era implied that all the time necessary for the A/D conversion, the calculation and the D/A conversion should be "immaterial" for the process to be correct. Furthermore, the pure material notion of "intelligent behaviour" felt into the pure immaterial notion of "calculation", notion that is deeply entrenched into the Aristotelian and AI's conception of "Logos".

Surprisingly, the CT's notion of a real *embedded system*, today called CPS, perfectly applies to the AI's definition of abstract *agenthood*. Thus, an embedded system can be considered an embodiment of an

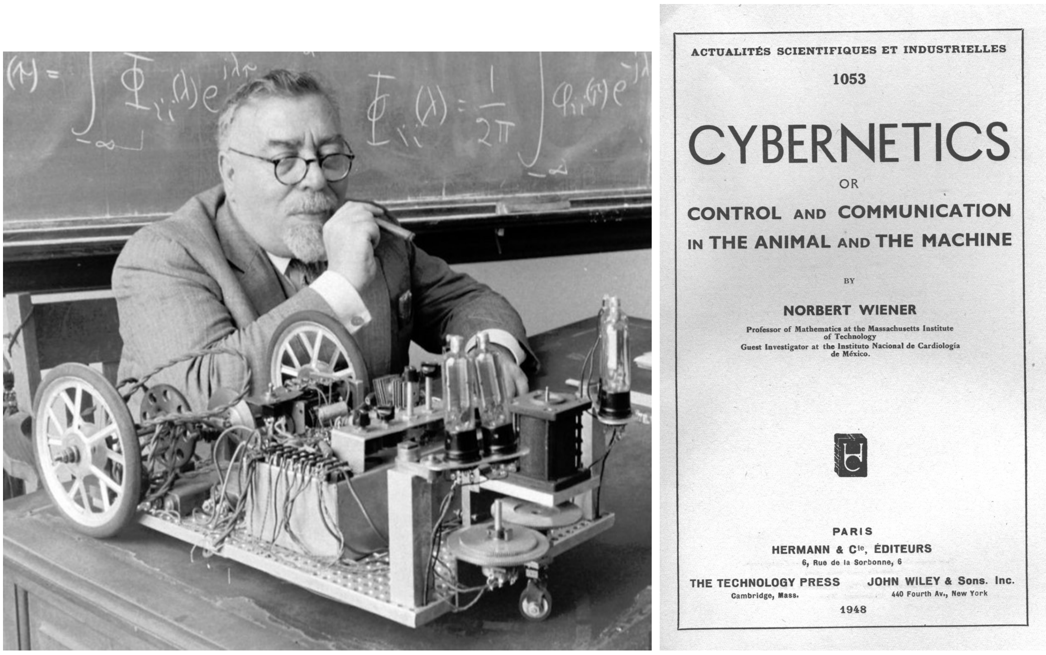

Figure 1: Norbert Wiener and Cybernetics

agent and vice versa. Figure 2 represents a CPS where the yellow box indicates a multi-thread software running on a board which interacts with the environment throughout A/D and D/A converters. If we compare the transfer function of a CPS with that of a pure Computing Systems (CS) we see that there is a difference: in a CS, input and output share the same ontology (both are simple byte streams), while in a CPS the input is a *perception* and the output is an *action*; they exhibit almost the same ontological difference between "read" and "write", the former does not change the real world while the latter definitely does! So, we can learn two lessons here about *Cyber Physical Agents* (CPS+AI):

1. they need *memory*, not just registry, otherwise they could not deal with real byte streams,

2. they need to deal with Energy, Mass, Space and, especially, *Time*, otherwise they could not produce their output (the action in the real world) and remain in the Plato's world of ideas.

4 Real-Time Agent

If an "intelligent agent" would be just a piece of software, then its correctness should be evaluated only in terms of soundness and completeness w.r.t. an I/O transfer function (Aristotle-minded). But if it has to be regarded as a Cyber-Physical Agent (Hegel-minded), than its correctness should be evaluated under a more holistic perspective. The following is to be considered just a step towards that direction.

Definition. A *Real-Time Agent* is a *running process* whose correctness depends not only on the soundness and completeness of its executable (w.r.t. a certain I/O transfer function), but also on the *time* at which the *action* is "performed".

So, while an "intelligent" agent can be thought of as just a smart idea sketched on a whiteboard, a "rational/real" agent is a running process acting in the world that need to perform *in* time, possibly reasoning explicitly *about* time; but if the agent reasons about time then, to be real, it must also possess a sensor to perceive it! Here we learn a third obvious lesson:

3. if a *Real-Time Agent* reasons *about* time then it should embody a clock.

The clock might be just a timer or a hourglass with some kind of sand flowing inside (for instance, electric charge). If the real-time agent reasons about time then, probably, its actions/plans change in function of the current-time/remaining-time. There are two kinds of deadline-related activities for a real-time agent:

1. apply a constant strategy (e.g. A^*) to search for the best action till the current time t reaches the deadline d

2. apply a variable strategy which is a function of the remaining time $d-t$ (e.g. $RTA^*(d-t)$) till $d=t$, where RTA^* is the algorithm $Real-TimeA^*$

4.1 Examples

Let us assume that a vacuum cleaner robot is a simple intelligent real-time agent. Simplifying, it may be pro-

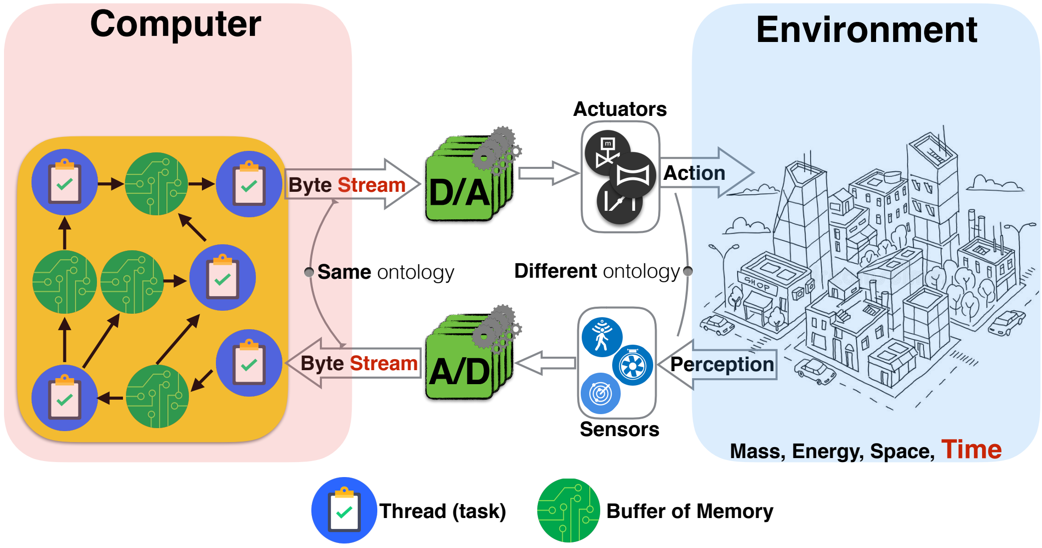

Figure 2: Computer and Environment as CPS.

grammed/trained to clean the room following an optimal path. Nonetheless, it has also to check periodically its remaining charge since its path could change (w.r.t. to the optimal one) in order to reach the docking station in time when needed. A considerably more complex example comes from the stock market, where real-time agents buy and sell huge amounts of shares every few milliseconds. Some of them monitor the market, for instance, every 50ms (those act as "sensors"), while others buy/sell every 350/700ms. The decision about *which* shares sell/buy and *how many* comes from complex criteria that nowadays involve also machine learning, but it is influenced by the remaining time to take it.

5 Real-Time Agency

Looking at Figure2, we might regard each thread as an agent and we might change each memory buffer with a communication channel. By doing so what was a single real-time agent becomes a real-time agency: a real-time multi-agent system. Does it make sense? Is it useful? Is it a real change or just a matter of perspective? In 1986, Marvin Minsky postulated that intelligent behavior is due to the non-intelligent behavior of a very high number of agents organized in a bureaucratic hierarchy - the "Society of the Mind" [Min86]. Such a concept is also known as *swarm intelligence*. Minsky also related the number of agents with their intelligence. The less intelligent the agent are, the more of them we need to produce an intelligent behavior. Each agent's position in the hierarchy and each agent's capacity to access the actuators (and the sensors) is *dynamic* and influenced by stimuli perceived from the environment (*perceptions*): so, the overall external behaviour of the society (*actions*) depends on the effective solutions of the conflicts internal to the agency. For example, during the act of eating, I'm thinking about the pleasant women I met yesterday, nevertheless, I'm still eating, which means that agents responsible for satisfying the stimuli of hunger won any possible conflict with others. However, if that woman appears while I'm eating, some agents in charge of satisfying the sexual and romantic stimulus might prevail and induce me to stop eating. Even at the level of an agency, we cannot avoid to deal with real-time performances. Here is our last two lessons: in a Multi-Agent System (MAS)

4. it does make little sense to talk about agents' interaction protocols without introducing *deadlines*, *precedences* and *resources constraints* among the agents in order to establish their dynamic *priorities* (virtual or real) in order to resolve the conflicts in a "correct manner".

5. agents' behaviors should be regulated by "real-time scheduling" algorithms.

5.1 Examples

In 1977, Randall Smith introduced the Contract Net Protocol (CNP) [Smi77] to enable 1-to-1 interactions in MAS. A first attempt to extend CNP towards real-time performances has been subsequently proposed by FIPA [Fip01], who introduced the concept of "deadlines" (related to the interaction phases) in the CNP. However, as analyzed by Calvaresi et al. [CDB18], the pure notion of "negotiation" is not sufficient to ensure the capability of complying with strict timing constraints. Agents has to take into consideration the time while *(i)* reasoning (e.g., planning and schedulers), *(ii)* when negotiating, and *(iii)* how sending the messages (e.g., communication time delays). The situation gets more and more complex when we consider the contemporaneity of several planning and interactions among the agents. Hence, after receiving a Call for Participation, a candidate Participant should ask itself: “do I have resources to prepare a proposal in the time interval $d - t$?”, “is this CfP worthwhile w.r.t. all the other stuff I'll have *probably* to manage in the time interval $d - t$?” and so on. Of course, the answers to these questions are function of the current time t (d is fixed in the CfP) which should *periodically* checked through the clock.

5.2 Evaluating performances at the Agent's vs. the Agency's level

The last example gives an idea about how much complex are the “Real-Time compliant Multi-Agent Scenarios” [CDB18]. Unfortunately, another difficulty appears when we try to evaluate the real-time performances of the Agency: should we evaluate them from the perspective of each selfish member agent or should we evaluate the overall Agency's performances? Of course, the two perspective are causally independent, as many studies from “economics” and “distributed computing” showed in these decades.

6 Conclusions

We argued the need not only for “time representation” in both single- and multi-agent systems, but also for “timing awareness and performances”. We showed how rooted in the history of philosophy is our perception of time and how much it influences our holistic notion of “Rationality”. Thus, we think it makes little sense to build Cyber-Physical Agents that do not check-and-reason about time. Without this ability, agents are not “real” at all. Summarizing, we learned five lessons: “real agents” need:

1. *memory*
2. to deal with *Time*
3. a *clock*
4. *deadlines*, *precedences* and *resources constraints* in order to establish their dynamic *priorities*
5. “real-time scheduling” algorithms to behave correctly.

We also might express two desiderata for the future:

1. “Real Agents' ” design should be more inspired by “Control Theory”
2. “Multi-Agents Systems” conception should align with “Real-Time Systems” discipline.

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