

# Time Perception: An Indispensable Trait of Robotic Cognition

Michail Maniadakis<sup>1</sup> and Panos Trahanias<sup>2</sup>

**Abstract**—The capacity to experience and process time is fundamental for many of the human daily activities. However, cognition in artificial systems is currently not modulated by temporal features as humans experience them and this fact greatly obstructs robotic agents in developing sophisticated cognitive skills. The current paper focuses on the ability of robotic agents to experience and process the flow of time, arguing that artificial cognitive procedures are necessary to be not only embodied, but also “entimed”, in order to facilitate the seamless integration of artificial agents into the inherently time-structured dynamic world.

## I. INTRODUCTION

The majority of robotic experimentation that is considered today refers mainly to specific behavioral tasks and modes of limited-time interaction between humans and computers. Still, the seamless performance of robots in the real world encompasses an inherent long-lasting temporal dimension that is typically overlooked by contemporary research. In contrast to the human brain, existing intelligent computational systems cannot efficiently handle time, therefore significantly limiting the realm of human robot symbiosis.

Modern computational agents have been greatly motivated from brain sciences, by incorporating a series of different cognitive skills that have been originally explored in humans and animals. The last decade, a significant part of robotic research has been devoted on embodiment and how it facilitates the cheap implementation of situated robots that take advantage of the mind-body-environment interactions to facilitate task accomplishment and the grounding of concepts to the real world. The discussion about embodiment has directed the focus of research on the relationships linking body and environment properties, considering mainly the spatial extent of this information. The unique temporal properties accompanying agent-environment interaction has been a rather minor issue for the existing cognitive systems. Besides the fact that the dynamic cognition approach has considered the spatio-temporal nature of the perception-action loop, emphasis has been mainly given to the integration of information over time and how this can globally advance robotic behavior. Clearly dynamic cognition has not provided robots with any kind of “sense of time” that may be considered in the absence of space.

There has been rather few works discussing the role of time and how it is related to embodied cognition. As it is commented by Wilson one of the “six views of embodied cognition” is time-pressure [1], which suggests that decisions and actions must be understood in terms of the required real-time interaction with the environment. When you are under pressure to make a decision, the choice that is made emerges from the confluence of pressures that you are under and in their absence, a decision may be made completely different. Since there was pressure, the result was the decision you made. In a different direction, Ziemke considers the so called historical embodiment to reflect the history of structural coupling and mutual specification between agent and environment in the course of which the body has been constructed [2]. Finally, Varela and Tani consider the experience/knowledge gained by the interaction with the environment [3], [4]. This has been further extended by our works showing that sense of time may be the key informative parameter for the accomplishment of dual-choice tasks [5], [6]

However, time is involved in a multitude of ways in human daily activities and the independent research directions discussed above are far from describing the complete role of time in cognition. For example, existing works disregard the important role of time in organizing our collaborative and social activities. Every time that we want to meet friends we try to find intersections between our free time and their free time. Rather than isolating specific aspects of how time affects embodied intelligence, it is better to adopt a holistic approach examining all possible roles that time may play in cognition.

In the current article we use Temporal Cognition as an umbrella term describing the set of cognitive functions that support the broad range of our time experiences. Formally speaking, we define TC as follows [7]:

**Definition.** Temporal Cognition encompasses the set of brain functions that enable experiencing the flow of time and processing the temporal characteristics of real world phenomena, accomplishing (i) the perception of synchrony and ordering of events, (ii) the formation of the experienced present, (iii) the perception of different temporal granularities, (iv) the conceptual abstraction and processing of durations, (v) the mental traveling in future and past time, (vi) the social sharing of temporal views about the world.

The current article aims to discuss how temporal information is integrated (complementary to embodiment) into the lower and higher levels of cognition, to reveal the inability of existing artificial systems to efficiently handle time and finally to suggest that it is now high time to direct research

<sup>1</sup> Michail Maniadakis is a postdoctoral researcher with the Computational Vision and Robotics Laboratory, Institute of Computer Science, Foundation for Research and Technology - Hellas, Heraklion, [mmaniada@ics.forth.gr](mailto:mmaniada@ics.forth.gr)

<sup>2</sup> Panos Trahanias is a Professor with the Department of Computer Science, University of Crete, Greece, and the Head of the Computational Vision and Robotics Laboratory, Institute of Computer Science, Foundation for Research and Technology - Hellas, Heraklion, Greece [trahania@ics.forth.gr](mailto:trahania@ics.forth.gr)

efforts on the exploration of the robotic time perception and processing abilities.

## II. COGNITION ENTIMENT

Despite the popularity of robotic cognitive approaches and the bio-inspired capacities that have been introduced in robotics, it is very surprising that little attention has been paid on time and the essential role it plays for the majority of brain processes. This is because our thoughts should not only be situated in space, but also in time. All our decisions and behaviors are modulated by the temporal properties of the world and it is very likely that they would be different if these temporal properties were different. Similar to the well known “embodiment”, we use the term “entiment” to describe the association of cognitive processes with different points or periods in the past, present, or future. Interestingly, modern theories on time processing consider time perception as the integration of ascending interoceptive (i.e. body) signals [8], [9], therefore providing a direct link between embodiment and entiment.

As it is commented by Wilson, time pressure plays a key role in choosing and expressing a given action. If there was no pressure we may have selected a different behavior, or we may have executed the same action differently. This means our decision and final performance are entimed in the world by the given temporal constraints.

Moreover, we often take a particular decision because we expect the occurrence of specific events at specific times in the future. This expands the entiment of our decisions not only in the present but also in the past and future.

In a third example, consider a discussion that we may have with friends about the political events and the music of 60s. In such a scenario, we need to mentally travel back in time, and focus on a particular time period. This means intelligent agents should be able to direct their attention not only in space, but also in time. Continuing on the same example, all persons participating in the discussion need to develop a common understanding about the period we are talking about. If someone will mention by mistake an event of 70s, we will most likely identify this conflict, correcting our partner that his mind has moved outside the period of interest (i.e. outside of the 60s decade). Therefore, we not only situate our thought in time, but in order to efficiently communicate and socialize we perceive the entiment of others thoughts and activities.

Overall, time processing and the entiment of cognition seems to be key ingredients for human cognition and if we are going to ever implement intelligent robots seamlessly interacting with humans, such robots will be equipped with advanced, human-like TC.

## III. ENTIMENT COMPLEMENTS EMBODIMENT

The current inability of artificial agents to perceive and process time, significantly obstructs their integration into the human daily life. The present paper argues that, complementary to embodiment, the entiment of artificial cognition to the

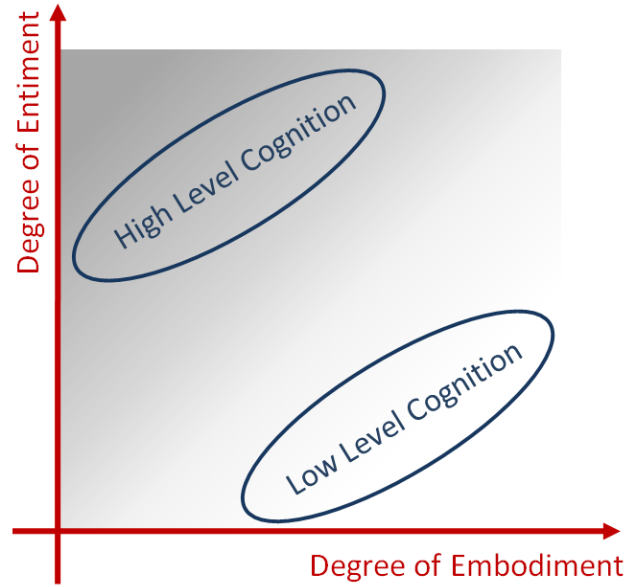


Fig. 1. The passage from embodiment to entiment, related to the different levels of cognition.

past, present and future is essential for incorporating robotic systems in the real world.

This is because time is crucially involved in all levels of cognition. Even simple actions such as object grasping include a critical when component [10] that links a given behavior with the ongoing real world processes. Notably, high-level cognitive skills that are typically less related with the here and now of the world are significantly more correlated with TC and the relevant cognitive processes may be entimed in a multitude of ways. In particular, high level skills such as theory of mind, strategy implementation, prospective memory require the association and reasoning on events that occurred, or will occur at different times (e.g. theory of mind links past knowledge with future actions). The role of TC is essential in this direction, because it may implement and provide the framework that enables to mentally associate asynchronous events.

Therefore, it seems that when we move from the lower to the higher levels of cognition, i.e. when our thoughts are less related to the here and now of the world, cognition becomes less embodied but more entimed and the other way around. This view on cognition is depicted graphically in Fig 1. For example, when we design plans aiming to achieve certain goals in the future it is more important to consider the ordering of subgoals rather than the sensory-motor details of our actions (but still considering how our body is related to the physical properties of the environment remain an issue). On the other side, when we react on a given environment stimulus it is more important to fit the physical properties of our body on the environment and then consider what will be the consequences of our current actions to the future.

This view clearly suggests that the equipment of robots with TC is a critical milestone for for implementing in-

telligent robots that think, operate and socialize in a way comparable to humans.

#### IV. A CRITICAL COGNITIVE CAPACITY

The lack of time processing capacity in existing artificial systems diminishes their ability to perceive the world in a complete and meaningful way which in turn impedes the seamless integration of robots in human daily activities. This does not mean that the robots are unable to accomplish a specific type of tasks. However, to better appreciate current robot abilities we need to consider that most of the problems examined in the field of robotics are considered in a limited-time domain (in lab experiments or carefully set demos). Therefore many real world temporal properties of the task are artificially eliminated (e.g. object grasping is fast when we are in rush, but slow when we are bored).

Let us slightly shift the discussion on embodiment that has been now established as one of the fundamental properties in the pursuit of robotic intelligence, and try to reveal the unique features it endows to robotic intelligence. It is rather difficult to identify a category of problems that can not be solved without embodiment. The old-fashion disembodied approaches seem capable to solve any specific single task. That is, with a first rather superficial consideration, embodiment does not look critical and may not be considered as a prerequisite for robotic intelligence. However, after careful consideration, it is now well established that cognition is not a phenomenon that can be successfully studied while marginalizing the roles of body, world and action (Clark 1999). In biological systems, cognitive mechanisms are coupled with the bodily characteristics of the performing agents as well as the environment properties. Therefore, even if it is possible to solve the all single robotic tasks by following a disembodied approach, cognitive robotics community considers embodiment as a highly desirable property with a key role in the development of robotic cognitive systems. In a broader context, people often raise similar questions regarding the value of bio-inspired cognition and how it compares to the ordinary algorithmic approaches. Is there any type of problems that cannot be solved by following the ordinary algorithmic approach? Since cognitive robots remain typically less skilled than algorithmic implementations, why do we need a bio-inspired approach in robotics? The answer on these questions is that we need to proceed along the directions of bio-inspired cognition because this looks the most promising way to bring artificial cognitive capacities closer to human intelligence.

Directing again our focus on time, the ordinary robotic approach until now, has been to isolate specific tasks and examine them in a limited time domain (therefore eliminating most of their real world time-relevant dimensions). The significant progress accomplished so far does not mean that the approach followed is optimal for endowing robots with high-level intelligence accomplishing effective human-robot cooperation. By disregarding the temporal dimension of tasks the relevant artificial actions and cognitive units can not easily coalesce into the inherently temporal real world.

The equipment of artificial cognitive systems with a time experiencing and time processing capacity will enable robots to consider aspects of the real dynamic world that have been largely disregarded until now. Moreover, the entiment of cognitive modalities will provide a powerful basis for the subsequent development of gradually more complex cognitive skills that require the processing of temporal information. Overall artificial TC will be the key ingredient for integrating robotic cognition and activities into the real world in a continuous and long-term basis.

#### V. A CHALLENGING TASK

Despite the fact that describing a class of problems that can hardly be solved without considering time is out of the scope of the present paper, there are some challenging real life tasks where the entiment of cognition seem to play a very critical role. For example these may be related to the sense of presence, a concept that is dynamically specified by humans depending on the context of their activities. This capacity is very critical for the unobstructed cooperation of robots with humans.

As an example case, let us consider a robot that operates as assistant for people in home environments. The robot helps with cleaning the house and when it is close to finishing the job, the person controlling the robot requests: Since you are almost done with dusting the furniture lets have now a chess game. Obviously, in the current context, now means in the next few minutes (i.e. it is in fact the future that is referred as present). The robot has to first finish with cleaning and then setup the chess game. During chess playing the person may come up and say: I really feel bad with my stomach-ache; I need my medicine now. This time, the robot has to understand that now corresponds to an urgent situation, stop playing chess and bring medicine as soon as possible. At the end of the day, the person is ready to go to bed, saying the alarm system is installed in the house, now you should observe the indicator light to make sure that access to our house is not violated. Noticeably, in the latter case now means for the whole night period and actually for every night from now on.

Clearly, humans have a very flexible way of considering present and implement entiment of the relevant information. The human sense of present depends on the context of a given task, and it is currently particularly difficult to develop a similar capacity for artificial agents. Note that the definition of present affects also other important aspects of TC such as past-present-future distinction or synchrony (i.e. it is different to synchronize in a 10 minute cooking task, than synchronizing in a 2 year book writing task). To the best of our knowledge there is no such artificial system today that flexibly perceives present in a way comparable to humans.

#### VI. TIME AND BRAIN FUNCTIONING

The interaction of humans and animals with the environment is supported by multiple sensory modalities such as audition, vision and touch, each one mapped on a specific region of our brain. Interestingly, our sense of time relies on

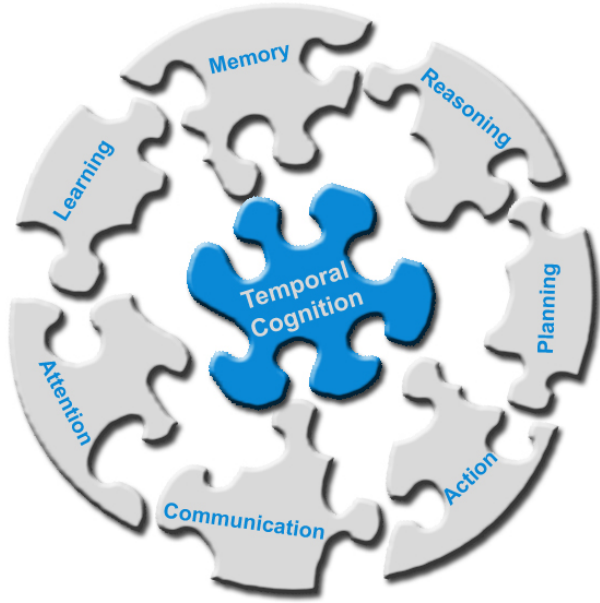


Fig. 2. TC regarded as the cognitive glue that integrates various cognitive skills, effectively accomplishing high-level intelligence.

radically different working principles breaking the rule of using a dedicated brain region for processing. Humans and animals lack “time sensors”, as well as a primary sensory brain area devoted explicitly to the sense of time [11].

Time experiencing has attracted significant research interest in brain science, with several works considering where and how time is processed in our brain [12], [13]. An extensive number of brain areas have been reported to contribute in the entiment of our sensory-motor experiences such as the cerebellum [13], the right posterior parietal cortex [14], the fronto-striatal circuits [15], the insular cortex [9] and the medial temporal lobes [16].

The combination of the extensive network of brain areas supporting TC, in conjunction with the non-existence of a sensory system dedicated exclusively to time [17] suggests that the sense of time relies on, and possibly emerges from, multi-modal cortical interactions. This implies TC as the cognitive glue capable of integrating various cognitive skills (see Fig 2) and additionally points out that entiment is crucial for a wide range of cognitive capacities. This is because TC supports making sophisticated thoughts that may span in a wide period of time, paving the way for high level cognition.

Overall, time plays an important role in binding our experiences, mental states, goals and behaviors, significantly supporting our daily activities.

## VII. ENTIMED ROBOTS

The development of natural, human-like cognition in artificial agents requires incorporating fundamental capacities of biological cognition in artificial agents. It is now known that apart from humans, many animals such as monkeys [18], [19], rats [20], even zebra-fish [21], are capable of processing time. Therefore, it seems likely that time processing is an

essential capacity of biological agents and it is a prerequisite for the development of intelligence.

Despite the fundamental role of time in natural cognition, current endeavors in the development of robotic systems are by no means directed towards encompassing TC in the systems repertoire of capacities [5]. This results into a kind of paradox, because robots that have perfect time sensors (i.e. computer clocks) exhibit poor TC capacity, while humans that have no time sensory system and measure time inaccurately, develop very efficient TC skills.

The fact that robotic systems are already equipped with clocks occasionally makes robotists believe that TC can straightforwardly be implemented, rendering time perception and processing an exception to the well known no free lunch theorem [22]. Evidently, this is far from reality, in the same way that getting spatial information was far from achieving efficient robotic navigation in human environments (it took more than a decade of intense research to implement robust navigation methodologies). In other words, getting a bunch of measurements from a robots clock is far from efficiently incorporating time in the cognitive loop of artificial agents.

The latter suggests that adopting traditional artificial intelligence approaches such as temporal logic or event calculus [23], [24] for implementing a dedicated time processing component that operates in isolation from other cognitive processes can hardly parallelize with the known TC brain processes where there is no time dedicated region and time experiencing emerges from the interaction of sensory, motor, cognitive and emotional modalities [11].

It seems more likely that the fruitful exploration of artificial TC will come by means of bio-inspired cognitive approaches that will share common characteristics with the TC mechanisms of the human brain. Interestingly, the strong coupling between TC and the already investigated cognitive modalities, i.e. their entiment in past, present and future, will provide added value to the composite cognitive system, significantly improving robots’ performance. For example, this may result in new learning algorithms that consider the details of past events when adjusting decision making procedures, new time-based association mechanisms that accomplish future conflict prediction, and a new attentional mechanism that may be shifted on multiple points in time enabling artificial agents to consider relations between asynchronous events.

This view supports further our argumentation in section III regarding fundamental role of entiment in accomplishing high-level cognition.

## VIII. CONCLUSIONS

As it is argued throughout the paper, temporal cognition is not an optional extra but a necessity towards the development of truly autonomous and intelligent machines. Temporal cognition is a vital capacity that enables the processing of the well defined physical concept of time and additionally the entiment of other cognitive modalities into the real world. The latter facilitates the binding of cognitive modalities into

a complex whole that effectively accomplishes high-level cognition.

However, in the field of robotics, the key role of time in cognition is not adequately considered in contemporary research, with artificial agents focusing mainly on the spatial extent of sensory information, almost neglecting its temporal dimension. Surprisingly, robots have perfect time sensors (i.e. computer clocks) but poor TC capacity, while humans that have no time sensory system and measure time very inaccurately develop very efficient TC capacity.

Without any doubt, it is now high time to direct research efforts on the exploration of robotic time perception and processing abilities. This will be a significant milestone in bridging the gap between human and artificial cognition. Due to the central role of time in human daily activities, the integration of TC in the perceptual, behavioral, emotional and communicative processes of computational systems has the potential to significantly contribute in achieving the long term goal of human-machine symbiosis.

## REFERENCES

- [1] M. Wilson, "Six Views of Embodied Cognition," *Psychonomic Bulletin and Review*, vol. 9(4), pp. 625–636, 2002.
- [2] T. Ziemke, "Are robots embodied?" in *In: Balkenius, Zlatev, Dautenhahn, Kozima, Breazeal (eds.) Proceedings of the First International Workshop on Epigenetic Robotics - Modeling Cognitive Development in Robotic Systems*, 2001, pp. 75–83.
- [3] F. Varela, E. Thompson, and E. Rosch, *The Embodied Mind: Cognitive Science and Human Experience*. Cambridge, MA: MIT Press, 1991.
- [4] J. Tani, "The Dynamical Systems Accounts for Phenomenology of Immanent Time: An Interpretation by Revisiting a Robotics Synthetic Study," *Journal of Consciousness Studies*, vol. 11, no. 9, pp. 5–24, 2004.
- [5] M. Maniadakis, P. Trahanias, and J. Tani, "Explorations on artificial time perception," *Neural Networks*, vol. 22, pp. 509–517, 2009.
- [6] M. Maniadakis and P. Trahanias, "Experiencing and processing time with neural networks," in *accepted for presentation in the 4th International Conference on Advanced Cognitive Technologies and Applications (COGNITIVE)*, Nice, France, 2012.
- [7] —, "Temporal cognition: a key ingredient of intelligent systems," *Frontiers in Neurorobotics*, vol. 5, 2011.
- [8] A. Craig, "Emotional moments across time: a possible neural basis for time perception in the interior insula," *Phil. Trans. Royal Society B*, vol. 364, pp. 1933–1942, 2009.
- [9] M. Wittmann, "The inner experience of time," *Phil. Tran. Royal Soc. B*, vol. 364, pp. 1955–67, 2009.
- [10] L. Battelli, V. Walsh, A. Pascual-Leone, and P. Cavanagh, "The when-pathway explored by lesion studies," *Curr.Opin.Neurobiol.*, vol. 18, pp. 120–126, 2008.
- [11] M. Wittmann and V. van Wassenhove, "The experience of time: neural mechanisms and the interplay of emotion, cognition and embodiment," *Phil. Trans. Royal Society B*, vol. 364, pp. 1809–1813, 2009.
- [12] W. Meck, "Neuropsychology of timing and time perception," *Brain & Cognition*, vol. 58, no. 1, 2005.
- [13] R. Ivry and J. Schlerf, "Dedicated and intrinsic models of time perception," *Trends in Cogn. Science*, vol. 12, no. 7, pp. 273–280, 2008.
- [14] D. Buetti, B. Bahrami, and V. Walsh, "The sensory and association cortex in time perception," *Journal Cognitive Neuroscience*, vol. 20, pp. 1054–1062, 2008.
- [15] S. Hinton and H. Meck, "Frontal-striatal circuitry activated by human peak-interval timing in the supra-seconds range," *Cognitive Brain Research*, vol. 21, pp. 171–182, 2004.
- [16] A. Botzung, E. Denkova, and L. Manning, "Experiencing past and future personal events: functional neuroimaging evidence on the neural bases of mental time travel," *Brain and Cognition*, vol. 66, pp. 201–212, 2008.
- [17] R. Ivry and R. Spencer, "The neural representation of time. Current Opinion in Neurobiology," *Current Opinion in Neurobiology*, vol. 14, pp. 225–232, 2004.
- [18] M. Leon and M. Shadlen, "Representation of time by neurons in the posterior parietal cortex of the macaques," *Neuron*, vol. 38, no. 2, pp. 317–327, 2003.
- [19] J. Medina, M. Carey, and S. Lisberger, "The representation of time for motor learning," *Neuron*, vol. 45, no. 1, pp. 157–167, 2005.
- [20] P. Guilhardi, R. Keen, M. MacInnis, and R. Church, "How rats combine temporal cues," *Behavioural Processes*, vol. 69, no. 2, pp. 189–205, 2005.
- [21] G. Sumbre, A. Muto, H. Baier, and M. Poo, "Entrained rhythmic activities of neuronal ensembles as perceptual memory of time interval," *Nature*, vol. 456, pp. 102–106, 2008.
- [22] D. Wolpert and W. Macready, "No Free Lunch Theorems for optimization," *IEEE Trans. Evol. Comput.*, vol. 1, pp. 67–82, 1997.
- [23] M. Fisher, D. Gabbay, and L. Vila, *Handbook of Temporal Reasoning in Artificial Intelligence*. Amsterdam: Elsevier, 2005.
- [24] S. Brandano, "The event calculus assessed," in *IEEE TIME Symposium*, 2001, pp. 7–12.