Levels of Networked Self-awareness

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***Abstract*—Attempting to achieve self-awareness in computerised systems promises improvements in autonomous behaviour. Since SISSY systems have to integrate with other systems at runtime, self-awareness alone may not be enough. Humans become better at cooperative work once they become aware of the self-awareness of others. When we have integrating systems, they have to also be aware of the ongoing interactions between other sub-systems and how their own interactions will influence the behaviour of the entire system. We propose levels of networked self-awareness to model these networked interactions.**

I. Introduction

Introducing self-awareness to computing systems is intended to increase their usability by making them more efficient, resilient, and flexible. This would enable them to overcome one of the main issues addressed by SISSY systems: coping with situations for which they have not been explicitly designed [1], [2], [3]. We suggest that introducing the 'awareness that others are also self-aware' to computing systems might increase their potential for collaborative effort as it does in humans; further enhancing their ability to adapt to new, unanticipated situations.

In humans, self-awareness is not the end of a process. It is one step along the path towards a sense of the self-awareness of others [4]. This process takes place over years in the natural development of children, and can be seen as they begin to understand that the world contains sentient beings, distinct from oneself and from other non-sentient artifacts [5]. An understanding that other sentients are of equal value to ourselves is a natural step in cognitive development that is not always achieved [6]. The current concept of computational self-awareness is heavily based on the work of Neisser [7]. Neisser proposes five levels of self-awareness in humans which, rather than built atop each other, are developed in parallel from earliest infancy. Lewis et al. [8] and Kounev et al. [3] apply these five levels of self-awareness to computational systems. However, current work towards self-awareness in psychology investigates the importance of interactions within a social system [9], [10]. In order to perform the social interactions that would facilitate the development of self-awareness, each system would benefit from awareness that each other system is also self-aware. In order to ensure, that we can overcome SISSY problems, we have to make sure systems are aware of the impact of their actions on the environment, whether this is due to direct or indirect interaction or through alignment of goals. In this work we follow Neissers, Lewis and Kounevs steps from a psychological, philosophical and anthropological point of view in order to identify blind spots that require further investigation.

II. Discovering the World

As the tools of self-awareness develop; as perceptions lead to theories that are tested, proven and disproven in ways that lead to new theories in a rapid and iterative cycle, humans move naturally from superstition towards logical thinking, and their mental map of the world around them and their place in it changes accordingly. The infant in utero knows nothing but being. Upon birth, the infant experiences fluctuations of cold and hunger. It is only natural to assume that the infant would build a theory of a causal relationship between itself and these sensations in the world: "If I just kick my leg like this and shake my head, and make that screaming sound, then warmth presses against my face, sensation floods into my mouth, and the hunger goes away." This must be an early form of superstition. If I do this and that, then forces beyond my control show mercy and deliver me from hunger. These beliefs eventually succumb as the baby's model of the universe becomes more detailed and accurate through repeated testing. The world has other agents, playing different roles. They can take away hunger or cold. The agent that takes away cold if you pull it over your shoulder and snuggle down into it is not the same agent who takes away cold by picking you up and carrying you across what you will someday call "the room". Perhaps there are multiple agents who pick you up and carry you around. All of them can take away cold and loneliness, and all of them can hug you and press themselves against your face, but only one of them presses your face in the way that takes away hunger. Thus, the categorization of these entities becomes increasingly complex, going from Me as the World to Me and the World, to Me and the World with others, to Me and the World with Mommy and Other Agents, and on to Me and the World with Mommy and Daddy and Dog in it. And then the classification changes again, because, while Mommy and Daddy are different, Dog is vastly more different than either of them, and a chair even more. And we only learn later that a chair is inanimate and 'responds' differently. We see this in children who attribute volition to the inanimate objects in their lives, e.g. when they bump into a chair, until they learn not to [5]. Later on, we understand that others have a similar, or even bigger, understanding of the world. We start to attributed intentions in their behaviour and interactions. We learn to distinguish between intended and coincidental interactions. And we realise that our actions have an impact on the behaviour, interactions and the general state of the environment and *vice versa*. The understanding of the others self-awareness defines but also improves the interaction among us.

In computational systems, previous work minimizes or ignores the importance of recognizing that other systems are also self-aware. We believe this is key, whether in developing own self-awareness, cooperating towards common goals, or in optimising own performance in order to achieve Pareto-efficient outcomes in competing situations. Therefore we define levels of networked self-awareness for interacting systems that allow for better system integration at runtime through mutual understanding of actions.

III. Levels of Networked Computational Self-Awareness

Given the nature of interaction among different devices, entities, and systems, individuals need to be aware of more than just themselves and their own immediate environment. They also need to have an understanding of the impact of their own actions on others. We call this extension to computational self-awareness *Networked Computational Self-awareness*. Similar to the original self-awareness as defined by Lewis et al. [2] and Kounev et al. [3], we utilise different levels of self-awareness in a networked environment. In this section we shed light on the requirements of the different levels, in terms of both increased understanding the environment, and the impact of their existence. Importantly, systems must be at least interaction-aware in order to be able to exhibit and implement networked self-awareness levels.

1) **Networked Stimulus-awareness:** Stimulus-awareness allows a system to recognise stimuli, whether coming from itself or from the environment. *Network stimulus-awareness* allows the system to identify how stimuli impact the environment. Importantly, the system does not know, whether the stimuli comes from itself or the environment.
2) **Networked Interaction-awareness:** When exhibiting interaction-awareness, a system can distinguish where stimuli are coming from. *Networked interaction-awareness* models the effects of interactions of others on itself. The main idea is that a system can observe the interactions of others and reason about the possible effects that these interactions will have on it. Reliably knowing the state of the environment allows the system to minimise the probability of a misinterpretation of environmental changes and their impact on the interaction between others.
3) **Networked Time-awareness:** A system exhibiting *networked time-awareness* is able to keep information about past stimuli, and potentially predict future stimuli and their respective effect on others. Acquiring an understanding of ones own actions on others also requires a comprehensive model of the environment, in order to minimise the probability of 'noise' being responsible for an action response.
4) **Networked Goal-awareness:** A goal-aware system knows about its own goals and is potentially able to adjust them according to the current situation. Understanding and knowing the goals of others, how they are pursued, and how this affects oneself, is considered *networked goal-awareness*. This awareness combines multiple challenges. First, we need to reliably identify the goals of others. Second, the system needs to understand who is involved in achieving those goals. Third, the system requires a comprehensive model of the environment in order to ensure that environmental conditions are considered when deciding on which actions to take in order to achieve goals.
5) **Networked Meta-self-awareness:** is a systems, as in *standard* self-aware systems, that is able to determine its own level of networked self-awareness.

It becomes apparent that it will be most important for each system to have a clear model of the environment in order to to reliably identify the origins of stimuli and interactions. We speculate, that *a priori* information in combination with online, non-supervised learning techniques will be most efficient for this task.

IV. Conclusion

Future self-integrating systems will interact with and incorporate with other, interacting systems. It will be vital to enable each individual to understand the goals of the others, the interactions among various other systems, and the impact of it all. We presented different levels of *networked self-awareness* that should, upon implementation, bring us closer to systems that are able to self-integrate and potentially even disintegrate at runtime without the assistance of a human operator.

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