# Personal Partner Agents for Cooperative Intelligence

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*Abstract*—We advocate cooperative intelligence (CI) that achieves its goals in cooperating with other agents, particularly human beings, with limited resources but in complex and dynamic environments. CI is important because it delivers better performances in achieving a broad range of tasks; furthermore, cooperativeness is key to human intelligence, and the processes of cooperation can contribute to help people gain several life values. This paper discusses elements in CI and our research approach to CI. We identify the four aspects of CI: adaptive intelligence, collective intelligence, coordinative intelligence, and collaborative intelligence. We also take an approach that focuses on the implementation of coordinative intelligence in the form of personal partner agents (PPAs) and consider the design of our robotic research platform to physically realize PPAs.

*Index Terms*—Coordination; Collaboration; Symbiosis

## I. COOPERATIVE INTELLIGENCE AND THE FOUR ASPECTS

When hearing the word "cooperation," most people imagine people sharing normal, everyday tasks. Orientation towards cooperation is considered to be the origin of human intelligence [15]. On the other hand, it is also widely known that even insects such as ants and bees exhibit cooperative behaviors within a colony. Furthermore, we can observe some essence of cooperation even in the interactions between an agent and its environment. As such, the notion of "cooperation" or "cooperativeness" is wide and therefore vague. Here, we identify the four aspects of cooperativeness, each of which contributes to CI as different fundamentals. These four aspects could be regarded as the layers in a hierarchy, but it would be more appropriate to deem the interfaces between them as fused rather than as clearly separated.

*a) Collective Intelligence:* The first aspect is the primitive and genetically encoded cooperation within a group of the same species, such as fish and insects. Even in humans, so called *intersubjectivity* or *intercorporality* is achieved given a biologically shared oneness. Research on cooperation in evolutionary robotics (e.g., [5]) tackles such a factor of intelligence. Common sense [10] also rests on this aspect.

*b) Coordinative Intelligence:* Coordination is strongly connected to both non-verbal and verbal communication. The non-verbal side seems to get close to collective intelligence, and the verbal side seems to get close to following collaborative intelligence.

Coordination or synchronization among interacting humans is called "entrainment" or "resonance." Such synchronization is observed in a variety of phenomena, including those of heartbeats and nodding (e.g., [17]). Empathy is also a kind of coordination, which is observed in both humans and other mammalian species [3]. Such factors form the basis of verbal communication as the general interaction abilities of humans [7].

Language is at the heart of human communication. Language relies heavily on conventions [8], and using conventions is resolving a coordination game [12]. Through his analyses, Clark [2] identifies that using language, that is, doing a conversation, consists of coordinated joint actions simultaneously implemented at multiple levels, from the signal level to the intentional level.

*c) Collaborative Intelligence:* Humans can collaborate with others to achieve a shared goal under *we-intention* [13]. According to [14], humans are different from other primates in that they can recognize others as intentional actors and can separately consider means and ends. In this way, humans can collaborate with others by coordinating means and ends.

*d) Adaptive Intelligence:* Last not but least, adaptation at the level of individuals is essential for living things, while collective intelligence is accumulated over several generations. Animals that have a brain predict changes in the environment and adapt to (or learn from) the environment by minimizing prediction errors [4]. Such adaptation supports the other three aspects of CI.

## II. PERSONAL PARTNER AGENTS

As we saw in the previous section, the range of CI research is vast and the phenomena/elements mentioned above are only a part of it. To shape our project to embrace various aspects of CI and establish a focus for our research project, we pose the concept of "personal partner agents (PPAs)" as our research target. We approach PPAs with particular emphasis on coordinative intelligence.

PPAs are roughly defined as an agent that:

- Is autonomous with its own intention and independence but always accompanies the owner.
- Needs to be supported by its owner to support the owner.
- Develops with the owner and will be loved by the owner more than pets like cats and dogs.

In short, PPAs are somewhere between pets that are cherished and friends that influence. Many people love either dogs or cats. The preference for dogs or cats is determined by a person's personality or sense of value [6]. Thus, to be loved more than a dog or cat, a PPA must coordinate with its owner's sense of value.
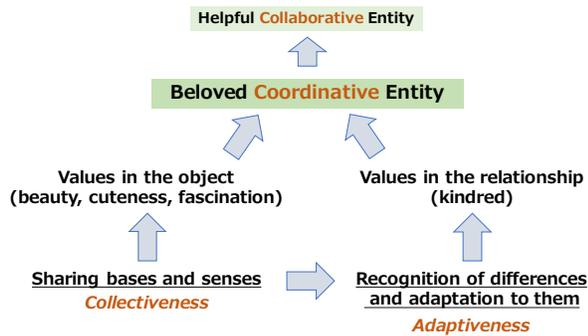
Fig. 1. Our approach to CI and links to the four aspects in CI.

We believe that PPAs must be equipped with two kinds of values. One is the values that a person, or the subject, recognizes in a PPA, or the object, independent of the subject, such as beauty, cuteness, or fascination. The other is the values that the subject recognizes in its relationship with the object, such as being able to understand it, being understood by it, or being identical to it. The former solicits the motivation of the subject to interact with the object. The latter maintains and buoys the motivation. In our view, the former is based on the collective aspect of CI, and the latter is achieved by the adaptive aspect upon the collective aspect. And these two aspects and values establish the coordinative aspect and co-ordination of values. The collaborative aspect, which impacts effectiveness or usefulness, will be better established when the coordinative aspect is firmly settled (see Fig. 1). In our eyes, most past approaches to useful interactive machines seemed to focus impetuously and narrowly on the collaborative aspect and pay little attention to the underlying aspects.

## III. BLIMP DRONES AS PPAs

We need an embodied autonomous agent to conduct inter-action research. Among various conceivable forms, we find blimps or balloon-like robots (such as [9], [18]) best exemplify the concept of PPAs. The importance of "being supported" has already been indicated by [11]. The concept of "always being together" has already been examined by [16]. However, the difficulty of the former is in always being together as a ground robot, and the difficulty of the latter is in being autonomous and independent. A flying drone can take a position from its own motive based on its understanding of the owner's mental/physical state and environment.

Although popular quadcopter-style drones have critical is-sues with safety, battery-life, and noise level, a blimp-based design can resolve these issues [9]. By leading the drone with a hand rope like a balloon, the owner can support the travel of the drone in open air. The lead enables physical interaction between the owner and the drone, like that between a human and a dog or horse. It also enables hours-long interaction by supplying electrical power through the lead. Even while it is led, it still maintains its own freedom in the space.

Not limited to being a basic research platform for CI, such a blimp-style PPA will implement some useful applications even before tackling the collaborative aspect. First, it can be a minder for children. It can look around from a higher viewpoint and warn them about potential dangers. When it achieves the collective and adaptive aspects of CI, it will be able to identify the people, things, and events that are important to the owner and autonomously record the valued moments to compose smartly personalized photo albums. When it achieves the coordinative aspect of CI, it will be able to establish an attachment [1] to lonely kids and elders to support their mental health. It will be able to make ordinary lives more enjoyable and memorable as companions sharing time and experience even if it does not speak.

## IV. CONCLUSIONS AND PROSPECTS

We have described an overview of CI research based on the four aspects of CI and have introduced the concept of personal partner agents (PPAs) as our approach to CI with emphasis on the coordinative aspect. We have determined blimp-like drones to be the best embodiment of PPAs. We are currently designing our original drone hardware as a research platform. This platform consists of hardware design (including 3D-printable frames and electric circuit boards) and open source-based driver software of motors and sensors.

The platform will be publicly available in the near future. Although this paper mostly discussed a focused, one-to-one interaction, this platform will also enable large-scale many-to-many interaction research, as the hardware is quite affordable.

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