Towards the Identification of Emergent Strategies for Interdependent Collaboration in Complex Tasks

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Abstract: In this study, we describe a pilot investigation of the strategies and behaviors that small groups learn to use to collaborate on a technology-mediated task. Four subjects independently controlled the wheels of a remote-controlled car, and were tasked with driving it through a simple course. Results suggest that effective solutions often involve isolating repeatable behaviors within the system to reduce the complexity and challenge of their task.

Introduction

Networked computational technologies are an ideal research tool to investigate the dynamics of collaboration. While computers are typically viewed in education as pedagogical tools, communication systems, and media for productive work (Lonchamp, 2007; Çakır, Zemel, & Stahl, 2009), they are also useful for collecting data on student behavior patterns, alone and in groups (e.g., Learning Analytics: Blikstein and Worsley, 2011). In this study, we use a technology-mediated learning environment to collect data on subjects' interaction patterns. Collaborative behavior can also be simulated using agent-based modeling (ABM). ABM has been used by scientists to study phenomena such as the interactions of species in an ecosystem, the collisions of molecules in a chemical reaction, and the food-gathering behavior of insects (Bonabeau, Dorigo, & Theraulaz, 1999; Troisi, Wong, & Ratner, 2005; Wilensky & Reisman, 2006). Agent-based models have also been used in social simulations in which humans are the agents, such as voting, segregation, and the spread of a rumor. Participatory simulations, in which real humans play the role of virtual agents, point to ABM's usefulness as a tool for extracting agent-like behaviors from human participants (Wilensky & Stroup, 2002). This work builds on our previous work on a strategy known as Human, Embedded, and Virtual agents in Mediation or HEV-M (Blikstein, Rand, & Wilensky, 2007). HEV-M uses sensory-enabled robotics as the common medium for the interaction of humans and autonomous virtual agents. This research agenda purports to observe the side-by-side interactions of humans and virtual agents in order to understand, model, and improve the performance of both on real-world tasks.

As a first step in this direction, the collaborative task designed for this study used a robotic car only controlled by humans. Four subjects sat side-by-side and *each controlled one wheel* of a small robot car. All were free to observe the car and communicate with each other. Our guiding questions for this study were the following: What would the biggest challenges be for emergent collaboration in very unfamiliar tasks? What would the most effective individual and group strategies be to respond to those challenges, and why? And finally, what can the nature of the challenges and techniques of collaboration tell us about the possibility of the design of virtual agents to emulate collective human behavior?

Method

We constructed a pilot experiment to explore these questions. One group of four graduate student volunteers (two male, two female; ages ranged from 25 to 40) used a set of four laptops running a software platform that wirelessly controlled individual wheels on a robot car. The wheels can rotate forwards or backwards, but they have no ability to steer left or right. Therefore, users can make turns by rotating one or two same-side wheels in the same direction, and the turns can be made sharper by rotating the opposite-side wheels in the opposite direction. To allow for multiple combinations of interactions, the system has built-in redundancy - i.e., *there are several ways to achieve a right or left turn*. Finally, driving the car in a straight line requires at least two wheels on opposite sides turning at the same time.

Our experimental session lasted approximately 40 minutes, and consisted of three parts. First, the subjects were instructed very briefly in the interface and allowed to determine which wheel they controlled. They were then given 20 minutes to drive the car in an S-curve around three obstacles spaced several feet apart. All subjects could see the car at all times. After the task, a short group interview was conducted in which we asked the subjects about their changing strategies over time. Simultaneous video and audio was recorded for the subjects and the car, and all keystrokes and mouse clicks were logged through a central server.

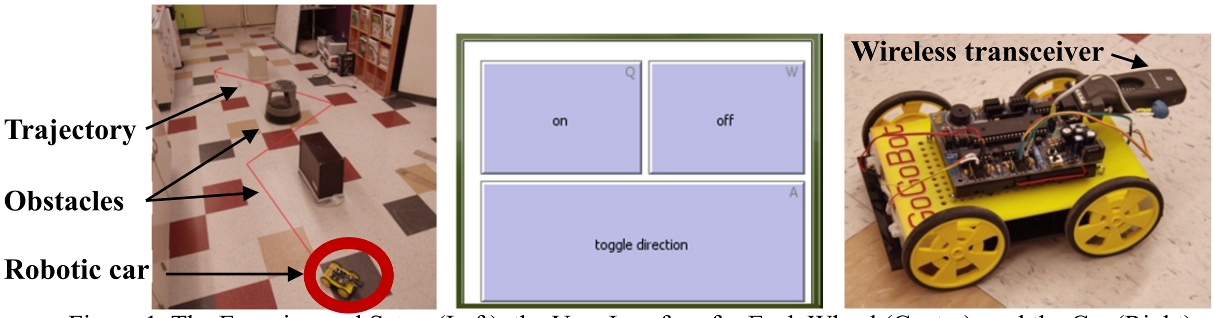

Figure 1. The Experimental Setup (Left), the User Interface for Each Wheel (Center), and the Car (Right).

Analysis and Conclusions

Our analysis identified characteristic challenges created by the nature of the task, the technology used, and the limits of human performance. The primary task challenge was that moving the car in a predictable way required control of multiple wheels. The technology offered a limited interface with a small time delay and inconsistent wheel traction. These challenges were made relevant by the subjects' limited abilities to synchronize their actions, to react quickly, to use the interface, and to remember the orientation of the car.

The solutions and collaboration methods devised by the group also addressed these challenges primarily by grouping and isolating particular sub-goals. For example, the group switched the physical location of two computers at the start of the study, grouping the left and right sides on the left and right side of the table. This would make no difference to a disembodied virtual agent, but it allowed the subjects to devote less working memory to remembering who controlled each wheel. The use of key words like "kill it" and "ready, set, go" also helped the group compensate for technology delays and poor human timing by stopping and starting their input as a team. The overall route planned out by the subjects also reflected a conscious response to the challenges of coordination. The group intended to drive the car in a zig-zag pattern, alternating between periods of traveling straight and turning rather than adjusting on the fly. By simplifying and separating the two components of the car's movement – traveling straight and turning – the group attempted to pull apart the complex system of the car into something more manageable. Overall, we noticed that the subjects' response to a highly dynamic and unpredictable system was not to create complicated coordination schemes or scripted routines, but to identify a very small number of easy-to-execute core behaviors (such as turning off a group of wheels) and dynamically sequence them as needed.

Our findings suggest that collaborative tasks are made easier by the dynamic segregation and organization of work into independent sub-tasks, a principle that is foundational in cognitive science at the individual level (Simon, 1962), and in industrial management at the social level. In other words, subjects' response to the complexity of the task was not to increase complication, but simplicity. It also suggests that realistic virtual agents could be designed by a collection of those simple behaviors, and calibrated with data extracted from networked experiments such as the one we utilized. Future work will continue to reveal the degree to which humans and virtual agents can cooperate in real time in environments with high degrees of complexity and unpredictability.

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