Advances in Developing Physical and Cognitive Surrogates for Remote Operations—The Mars Exploration Rovers as Collaboration Tools

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Topic Description

This presentation draws primarily from the author's book (Clancey, 2012)—which recently received the AIAA 2014 Gardner-Lasser History Literature Award—about the MER scientists' experience in their "voyages of discovery" exploring the surface of Mars, as well as related studies by Vertesi (2012), Cohn (2013), and Mazmanian (in press). Because of the infrequency of planetary missions the opportunities for study are few, however lessons learned could have a fundamental, broad effect on how we conceive of the role of robotic surrogates of teams on Earth in scientific and military field operations, hospitals, factories, etc.

During the past two decades, technologies for packaging and delivering miniature, low-power scientific instruments to other planets, along with AI tools for operating these systems remotely, have radically transformed our ability to conduct planetary science. Most notably, constraint-based planning (Aghevli et al. 2006; 2010), image processing (Estlin et al. 2012), and robotic navigation (Bajracharya et al. 2008) have enabled conducting field science on Mars using mobile programmable laboratories—Sojourner (1997), the dual Mars Exploration Rovers Spirit and Opportunity (2004–present), and the Mars Science Laboratory (MSL), Curiosity (2012–present)—the first overland expeditions on another planet.

The scientists originally conceived of the MERs as "robotic geologists," though in practice they have become tools that facilitate and promote collaboration across the scientific disciplines. Following the design principle of "one instrument, one team," the sensor fields of MER's instruments were integrated and the science theme groups organized so scientists were encouraged to work together to develop a holistic model of the planet's geology, biology, and climatology. The MER mission's design also exemplifies physical embodiment and social participation aspects of situated cognition. Projecting oneself into the rover and remote terrain through virtual reality tools provides situation awareness (e.g., knowing what can be sensed or manipulated). Daily commanding enabled by scheduling/planning tools keeps individuals engaged in an often tedious, multiyear consensus-based investigation.

Technology, organizations, and operations are contexts for defining and shaping each other; the mutual effects can produce very different designs. One principal investigator led the MER science team, but JPL has organized MSL and most flyby and orbital missions (notably Cassini) in instrument "payload" silos, each with its own PI. A recent study of Cassini focuses on technological change occurring during the mission in the "regimes" of international interaction, "aging spacecraft, and increasingly obsolescent software infrastructure" (Cohn 2013). By comparison, teams conducting deep water investigations on Earth can teleoperate submersibles they may maintain daily—these scientists may be shore-bound (e.g., NSF Ocean Observatories Initiative) or at sea (Mindell & Croff 2002). The DARPA Robotic Challenge is another example of how multidisciplinary teams may soon carry out complex operations in extreme environments (e.g., a highly radioactive power plant) through a "supervised autonomy" surrogate.

This emerging relation among technology, organization, and domains of investigation (Clancey 2010), prompted by the capability to work remotely that AI and robotics have enabled, reveals that the particular design of an *exploration system* may either limit or amplify the collective intelligence of human teams coupled with robotic surrogates. For example, a recent DoD report (DSB 2012) concluded that AI studies describing "levels of autonomy" have been "counterproductive [for design] because they focus too much attention on the computer" rather than on the joint work between the people and automated systems.

Robotic systems for planetary science and on Earth will likely be given capabilities to be more capable cognitive surrogates, to the point of selecting targets to image and sample, as well as perhaps analyzing data. However, except when intended for systematic reconnaissance/survey, their design will be oriented to the continuously developing interests and practices of the organizations who own and operate them. Improving autonomy will enable fewer engineers to operate a planetary rover or spacecraft; but with costs exceeding more than $2 billion as for MSL, our technical focus will also be on *how more scientists can be fruitfully engaged during a mission—increasing collective intelligence*. For example, we've learned that constraint-based planning tools that make daily commanding possible and sequencing architectures that make recovery from execution failures more reliable have lessened the daily work required of engineers—while enabling control sequencing to be moved earlier in the process, into the tools used by the scientists. In this respect, AI methods the current rovers exploit illustrate that what autonomy is desirable, which may change during a mission, depends on the relation between what people are trying to do collaboratively and what operational logistics afford and require.

Presenter's Contributions

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