Modeling and Simulation of Work Practices on the Moon

Maarten Sierhuis
RIACS
NASA Ames Research Center
Moffett Field, CA
msierhuis@mail.arc.nasa.gov

Introduction

At NASA we develop new work systems for exploring extraterrestrial bodies, and scientific research in space. The work performed during a Space Shuttle flight is the result of a developed work system. The International Space Station will need a new and different work system, not yet fully developed. When eventually we will go to Mars we need a totally different type of work system. A small group of humans will work together with sophisticated autonomous and semi-autonomous robots. Collaboration between the people on Earth and the people on Mars will be of a different order than what we have been used to. A forty-minute communication delay will change the nature of this collaboration significantly.

In designing and implementing collaborative work places we need to understand the way people work together, and analyze work practices in order to design improvements or changes. The way people collaborate, as well as the culture of an organization is encompassed in the communities of practice of an organization—the work practices of people (Wenger 1997).

Work practice analysis, design methods and tools need to be developed that allow us to understand not only the work process, but also the work practice of an organization. In order to have a computer model that allows us to model the situated work activities and collaboration of people in a work process, we first need a theory and modeling language that incorporates the aspects of work practices of people in an organization.

A theory of modeling work practice

Representing how people do work can be done at many different levels. In the knowledge engineering and AI world, people's work has been described in terms of their problem-solving expertise. The theory is that we can model people's problem-solving behavior by representing this behavior in a computational model that is able to duplicate some of this behavior. Work process models, such as Petri-Net models of a work process, describe what tasks are performed and when. In workflow models we describe how a specific product "flows" through an organization's work process. This describes the sequential tasks in the work process that "touch" a work-product. All these modeling approaches describe the work in an organization at a certain level of detail. However, what is missing from all these types of modeling approaches is a representation of how work gets done. What is missing is a description of the work at the work practice level.

Work practice includes those aspects of the work process that make people behave a certain way in a specific situation, and at a specific moment in time. To describe people's situation-specific behavior we need to include those aspects of the situation that explain the influence on the activity behavior of individuals (in contrast with problem-solving behavior). The important aspects that determine work practice are the individual *agents* and their *activity behavior*, the *context* in terms of artifacts and tools used, and location and movement of objects and agents as *facts* in the world, the interpretation of the facts into individual *beliefs* on which the agent's decision to act are based, the *communication* between agents, as well as the *communication tools* that are used to communicate.

We have implemented our theory in a modeling and simulation environment called Brahms. Brahms consists of a multi-agent language, a discrete-event simulator, a history database of the simulation runs, and a tool for viewing the activity-behavior of and communication between agents, artifacts, as well as geographical location and movement.

Brahms Agents

An agent is a construct that generally represents a person or robot within a workplace or other setting being modeled. Agents have a name and a location. To specify what an agent does the modeler defines *activities* and *workframes* for the agent. The key properties of agents are group membership, beliefs, activities, workframes, thoughtframes, and location. The simulation engine schedules the constrained activities of agents (Clancey et al. 1998).

A group can represent one or more agents, either as direct members or as members of subgroups. Typically, a modeler would associate descriptions of activities with groups, so that a group represents a collection of agents that perform similar work and have similar beliefs. Depending on the purpose of the model, agents in a model may represent particular people, types of people, or pastiches. Each agent and group can be a member of any number of groups, providing that no cyclic membership results.

Agents can get beliefs. A belief is a first-order predicate statement about the world. Beliefs are always local to an agent. This allows us to represent how a specific agent "views" the state of the world (Hintikka 1962). Agents act based on their beliefs, which are the "triggers" of agent’s activities.

Activities in Brahms take a certain amount of time, either derived or defined. Even though an activity has a pre-specified duration (fixed or random), the actual duration of an activity depends on the context in which the agent performs the activity (Agre and Chapman 1987). An activity can be interrupted or impassed based on the detection of facts in the world, communication, or reasoning. There are a number of types of activities that are defined for the Brahms language (primitive, communicate, move, create-object, composite) and can be executed by workframes.

Workframes are rule-like constructs with preconditions constraining the execution of activities for an agent. The preconditions in a workframe are matched against the belief-set of the agent. The body of a workframe can contain consequences and activities. Consequences create new beliefs and/or facts in the world. The creation of beliefs and facts can be controlled with certainty factors. The body of a workframe is executed sequentially. Workframes can be interrupted, which means that the workframe execution is suspended, and its context saved. At continuation of the workframe the context is restored and execution continues where it was interrupted. The execution of workframes is also controlled by their priority. The available workframe (i.e. all preconditions match beliefs of the agent) with the highest priority is the current workframe being executed.

Thoughtframes are forward chaining production-rules. Thoughtframes are different from workframes in that they cannot contain any activities, and therefore do not take any time. Thoughtframes can only create new beliefs, and are thus used to model reasoning behavior of the agent.

Reactive Behavior

To model humans, we need to allow for both deliberative as well as reactive behavior. Brahms combines both of these types of behaviors. Deliberative behavior of an agent is modeled using a combination of workframes and thoughtframes, as described in the previous section. Reactive behavior of agents is modeled through a construct called a *detectable*. A detectable is a mechanism by which, whenever a particular fact occurs in the world, an agent may notice it. The noticing of the fact may cause the agent to stop or finish the activities in a workframe.

Two things can occur in a detectable. First, the agent detects the fact and the fact becomes a belief of the agent. Second, the beliefs of the agent are matched with the condition in the detectable, and if there is a match the action-part of the detectable is executed, which may continue, abort, complete, or impasse the workframe. With a detectable, an agent may notice passive observables, such as when someone shouts, a door opens, a phone rings, a fax arrives, or an agent is present vying for attention.

Modeling the Apollo ALSEP Deployment

In the sixties and early seventies, during the Apollo project, NASA developed a work practice for a small number of people on the Moon. Until we will go to Mars this is the only real data we have in understanding how people work on extraterrestrial planets. To understand how to design the collaboration between humans and robots in deploying scientific instruments on Mars, we are investigating the work practices of the Apollo astronauts during the Apollo Lunar Surface Experiment Package (ALSEP) deployment.

We are developing three types of work practice models. The first model is a *descriptive* model of the ALSEP package offload from the lunar module. This model is developed to determine if the Brahms language is powerful enough to model and simulate the astronauts' work practices, including the communication delay to Earth. The second model is a *predictive* (or planning) model that can simulate the deployment of the Heat Flow Experiment (HFE) based on the Apollo 16 lunar surface procedures (Kain et al. 1972). This model not only predicts how to deploy the HFE, but also the voice data communication, using a description of a question and answer conversation policy (Holmback et al. 1999), as well as error-recovery activities, based on the errors from Apollo 15 and 16. The third model is a *prescriptive* (or design) model of the HFE deployment for a future mission where a semi-autonomous rover will explore the poles of the Moon and deploy several HFE instruments.

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