Subsumption and Cognitive Workflow

Introduction

Subsumption is a hierarchical structure in which activities at a subordinate level are subsumed under a super-ordinate activity. The relationship between the super-ordinate and subordinate activities is one of supervisory management; the super-ordinate activity initiates, monitors and terminates the subordinate activity but beyond that, the subordinate node is autonomous (management, not control).

- The subsumption architecture may extend over several levels, with the supervisory management relationship, always flowing between adjacent levels from super-ordinate to subordinate.
- Adjacent levels require two-way communication; management flows from super-ordinate to subordinate and status updates and product delivery flows from subordinate to the super-ordinate.
- One super-ordinate node may manage many subordinate nodes.

The essential character of Subsumption

Subsumption depicts workflow as a composition (performance) versus a causal sequence. It depicts concurrent behaviors acting independently but orchestrated as a coherent performance on the basis of supervisory priorities (those who plan do not necessarily execute). Subsumption permits a meaningful representation of distributed supervisory management and can capture essential elements of both individual and team (distributed behavior).

A multi-course meal is a composition, not a causal sequence, because completion of one course is not required to proceed to the next (the first does not enable the second). Many work processes (e.g., a design flow) might appear from a rational perspective to be a causal series of an enabling flow, but are (in practice) compositions as can be depicted by a subsumption representation.

Subsumption depicts a model of management versus micromanagement – it can represent a system in which those who execute are given the freedom to exploit their strengths as they contribute to the common goal. It depicts how supervisory management can communicate with subordinate entities and how it can coordinate their efforts; an issue for all distributed cognition and the essence of teamwork

The theory of Situated Cognition (Clancey, 1997), on which the Brahms simulation environment is based, assumes that human activity is subsumed within and shaped by context and that most activity is shaped by loosely coupled constraints between several levels of hierarchically nested contexts (Figure 1). The Brahms simulation environment instantiates this assumption as a hierarchical subsumption architecture of work frames and activities (Clancey, Sachs, Sierhuis, van Hoof, 1998).

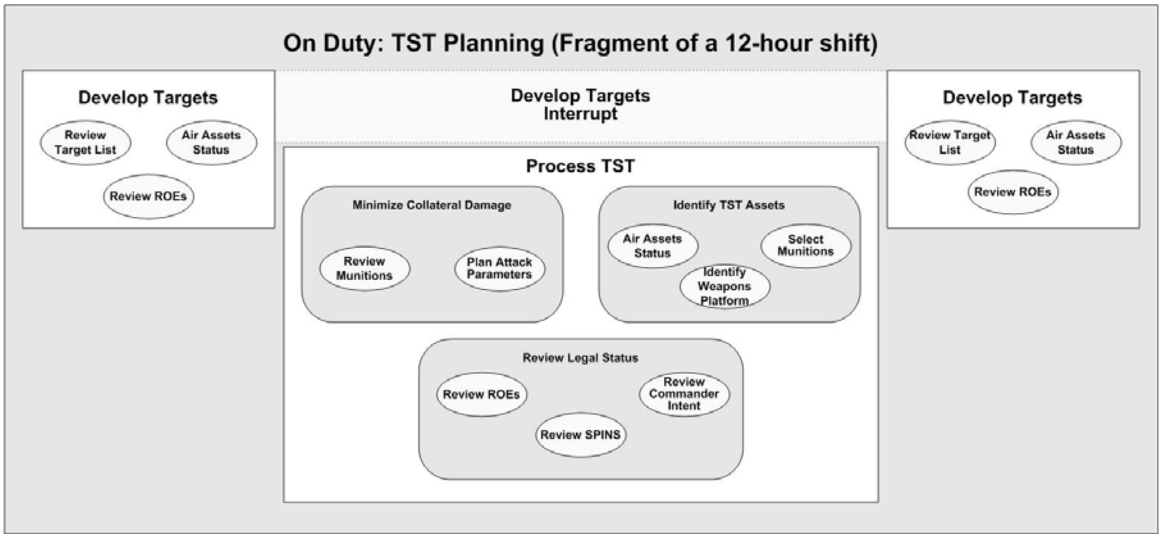

Figure 1: A subsumption diagram of planning for Time Sensitive Targeting: within the context of being on duty, this agent is generally in the subsumed, generic context of target development but will transition to a target processing context on demand and, within that context, will execute the required activities

The important modeling capabilities of Brahms are:

- Workflow interruption. As is common in normal work, a high priority event can interrupt ongoing work. The interrupted work may be aborted or it may be suspended and then resumed once the higher priority demand has satisfied.
- Communication. Human agents and information objects can communicate with each other to guide, inform or alert.
- Record creation. Information objects can be created and then updated by various agents.
- Decisions. Human agents can make decisions based on information they receive and on the information sources they review.
- Contingent action. Human agents react to the decisions they make and also to information they receive from other sources.

In the next section of this paper I discuss how these capabilities were used to model cognitive workflow for Time Sensitive Targeting.

Cognitive Workflow Illustration: Time Sensitive Targeting

Time Sensitive Targeting is a real-time planning and targeting function that is located in the Offensive Operations Unit within the Combat Operations Division of an Air Operations Center. The existing organizational structure of the Air Operations Center is shown in Figure 2. The Time Sensitive Targeting cell is staffed by a Cell Chief, a Targeteer, a Rerole Coordinator, an Attack Coordinator and a representative of the Judge Adjutant General (JAG). The scenario modeled here also involves a Targeting Officer located in the Intelligence Surveillance and Reconnaissance (ISR) Division and an information system, the Automated Deep

Operations Coordination System (ADOCS). Although Brahms can model the properties of diverse communications systems, a generic communications net was used to simulate communications flows in this model.

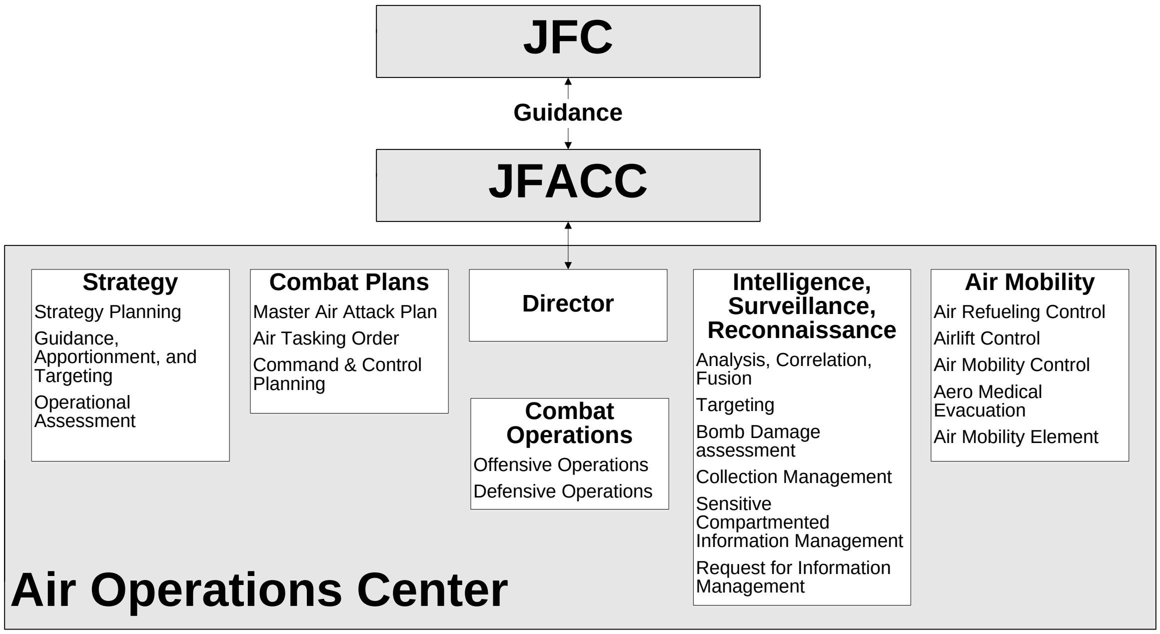

Figure 2: Functional organization of the Air Operations Center

A 12-hour work shift is modeled. Each agent on the modeled shift has a contemporary from whom they accept the shift. A shift transfer is modeled as a series of information exchanges on different topics (Science Applications International Corporation, 2001) and ends with a communication exchange between the two agents (Figure 3). The next task for the agent taking over the shift is to build situation awareness related to current operations. Once an agent is satisfied with her/his level of situation awareness, s/he engages in generic activities.

Information about potential Time Sensitive Targets arrives at the Air Operations Center at irregular intervals. The entry of a Time Sensitive Target to the system initiates a series of identification and planning activities, some undertaken sequentially and others in parallel, by various members of the ISR and Operations Divisions.

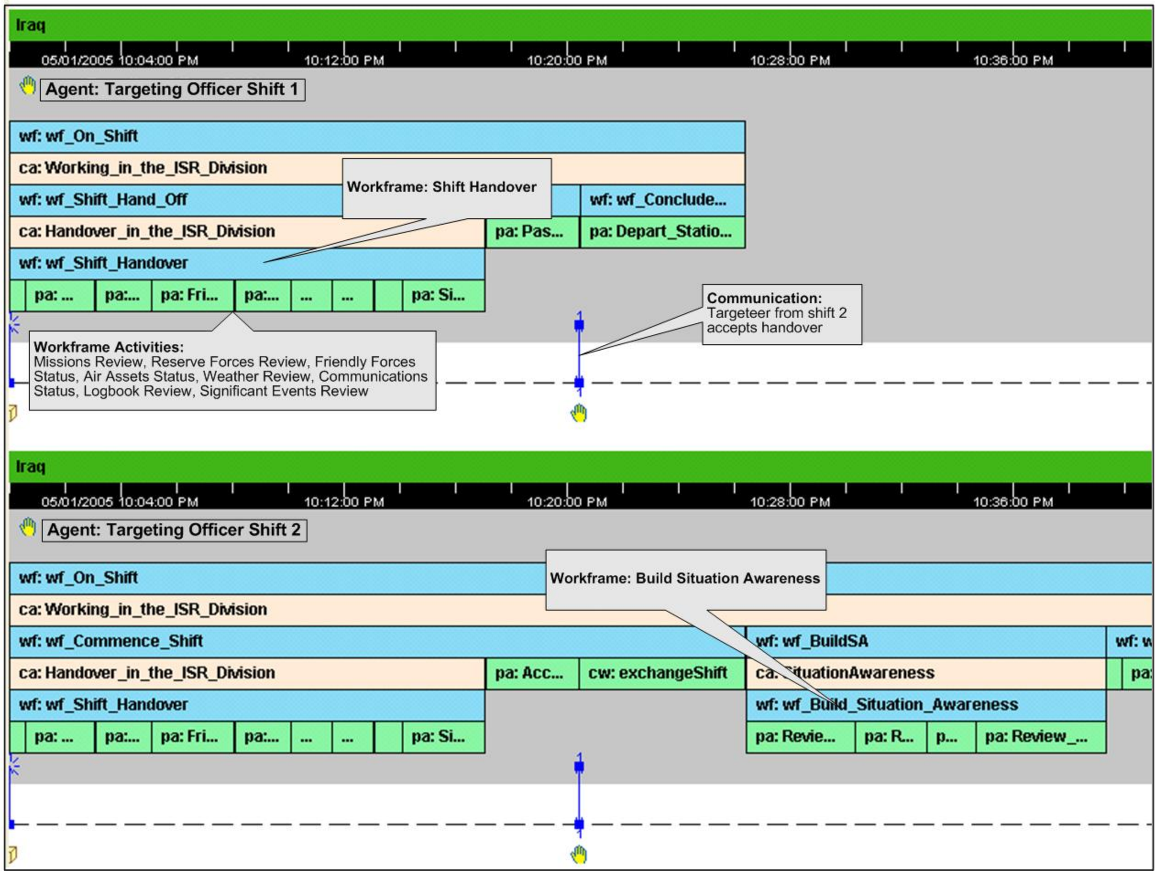

Figure 3: A section of the timeline produced by Brahms for two agents, the Targeting Officer for the old shift and the Targeting Officer for the new shift (callouts added to the figure to identify Brahms output features)

Processes for identifying Time Sensitive Targets in the Theater of Operations and then transmitting information about them to the Air Operations Center are not represented in this model. That information is created by a generic Field Agent to seed the modeled workflow. Incoming information specifying target type and location described in terms of proximity to well known physical features is recorded in a field report and assigned to a vacant target slot in the information system. Targets are subsequently identified by the numerical designation for their respective slot. Each slot has the capacity to record a pre-specified set of target attributes, all of which are set as *unspecified* or *unknown* at the initiation of the simulation. Thereafter, these attributes are converted by the different agents into values specific to the particular target allocated to that slot.

The ISR Division Targeting Officer is notified (in this simulation, by the generic Field Agent) via ADOCS that a record of a Time Sensitive Target has been created and is available for processing (Figure 4). The Targeting Officer confirms the target identity and identifies its mensurated coordinates. S/he identifies its priority as previously established by instructions from the Joint Forces Air Component Commander and records that information in the ADOCS target record (Figure 5). S/he then advises the Targeteer in the Time Sensitive Targeting cell of the Operations Division that the record is available for targeting.

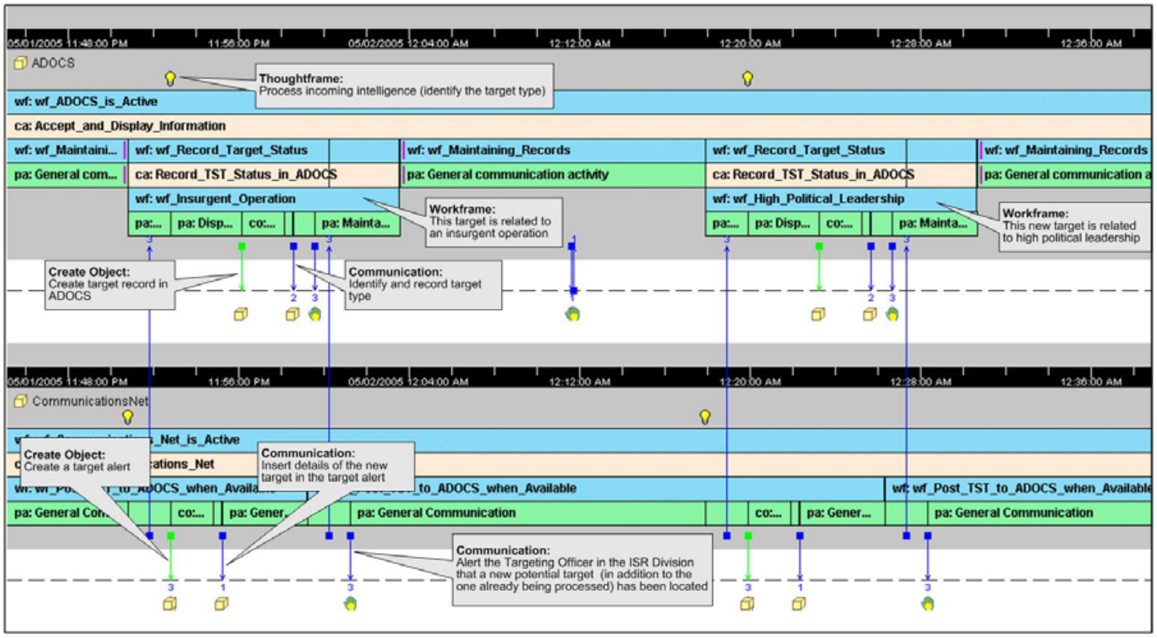

Figure 4: A section of the timeline produced by Brahms for two information systems, the Automated Deep Operations Coordination System (ADOCS) and a generic communications net (callouts added to the figure to identify Brahms output features)

Figure 5 illustrates the workflow interruption feature of Brahms. The Targeteer is routinely engaged in developing generic targets except when dealing with a Time Sensitive Target. In the modeled scenario, s/he stops work on generic target development immediately s/he is alerted to the Time Sensitive Target but returns to generic target development once the higher priority demands associated with the Time Sensitive Target have been satisfied.

The Attack Coordinator schedules the mission, paying attention to such things as air refueling needs and locations of enemy air defenses. The Attack Coordinator will plan the electronic footprint required to suppress enemy radar threats and will normally need to schedule two to three aircraft with electronic suppression capability for that task. S/he will also take account of collateral damage issues and will plan attack run-in lines and attack angles accordingly. After recording that information in ADOCS, s/he will take the plan to the TST Cell Chief for approval.

The TST Cell Chief will review the plan and may consult the JAG representative to confirm its legality. The target plan is then posted to ADOCS and is now ready for execution.

The timeline shown in figures 2 to 4 is the primary output of Brahms but other output capabilities are available to examine the progress of events. Figure 6 shows the flow of Time Sensitive Targets through ADOCS. This record reveals the times at which different targets enter the system. Once a target has been passed on or a permanent record created, the system is set to “standby” in readiness for another target.

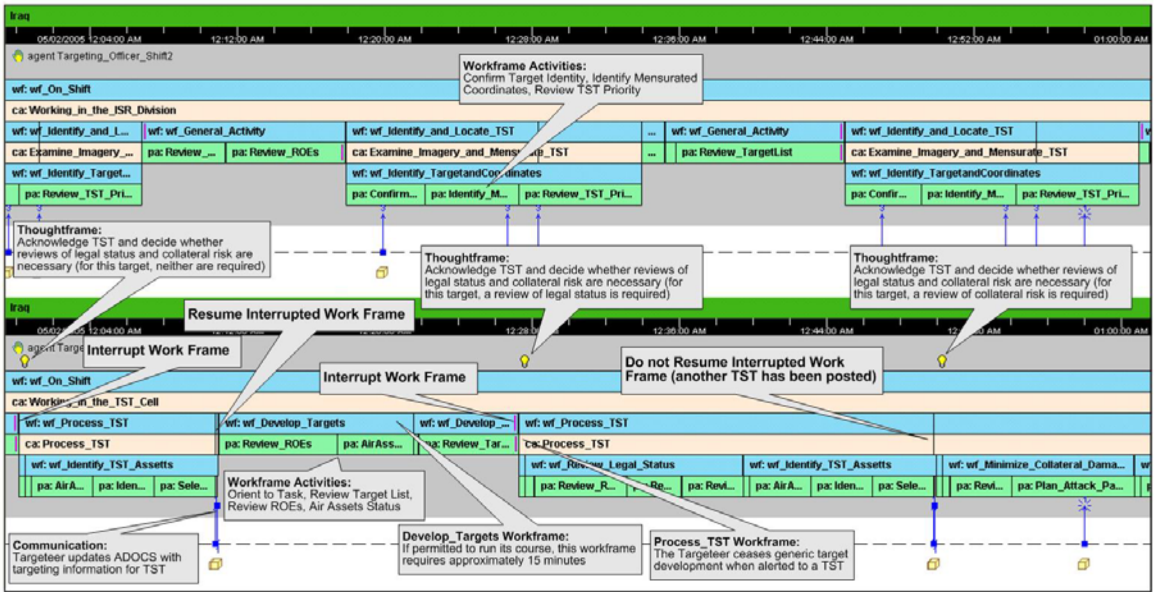

Figure 5: A section of the timeline produced by Brahms for two agents, a Targeting Officer and a Targeteer (callouts added to the figure to identify Brahms output features)

Further Brahms Development

While the Brahms modeling environment, in itself, is structurally compatible with the requirements for the design of complex, socio-technical systems, there are a number of improvements that would increase its usefulness. Many of these are relatively trivial; for example, the suite of communication modes that can be supported is limited. However, the form of the simulated output requires further development. At this stage, the primary output form is a timeline that shows activities, work frames, thought frames and communications. This output timeline is created in batch mode although the developers are currently working on a virtual animation of work activity. An enhanced set of output representations that depict how cognitive processes unfold over time and that direct attention to possibilities for redesign, would be useful. In particular, a dynamic simulation of communication sequences, programmed to unfold over compressed time, would be invaluable. Work has been proposed but not yet funded to proceed in this direction.

Summary

Brahms is a prototyping tool that can be used to develop a computer model of a socio-technical system. The modeling process links tasks to work requirements and to functional structure. The subsumption architecture of Brahms, in which activities are executed and beliefs modified contingent upon satisfaction of conditions, supports a modeling strategy of super-ordinate guidance acting as selective constraints on subordinate activity as is consistent with normal work practice.

Time	Belief/Fact
21920	belief: (ADOCS.TST_Description = "Standby")
21515	belief: (ADOCS.TST_Description = "Weapons of Mass Destruction")
21455	belief: (CommunicationsNet.TST_Description = "Weapons of Mass Destruction")
20335	belief: (CommunicationsNet.TST_Description = "Standby")
20295	belief: (ADOCS.TST_Description = "Standby")
19890	belief: (ADOCS.TST_Description = "Insurgent Operation")
19830	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
18710	belief: (CommunicationsNet.TST_Description = "Standby")
18670	belief: (ADOCS.TST_Description = "Standby")
18265	belief: (ADOCS.TST_Description = "Insurgent Operation")
18205	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
17085	belief: (CommunicationsNet.TST_Description = "Standby")
17045	belief: (ADOCS.TST_Description = "Standby")
16640	belief: (ADOCS.TST_Description = "Insurgent Operation")
16580	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
15460	belief: (CommunicationsNet.TST_Description = "Standby")
15420	belief: (ADOCS.TST_Description = "Standby")
15015	belief: (ADOCS.TST_Description = "Insurgent Operation")
14955	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
13835	belief: (CommunicationsNet.TST_Description = "Standby")
13795	belief: (ADOCS.TST_Description = "Standby")
13390	belief: (ADOCS.TST_Description = "High Political Leadership")
13330	belief: (CommunicationsNet.TST_Description = "High Political Leadership")
12210	belief: (CommunicationsNet.TST_Description = "Standby")
12170	belief: (ADOCS.TST_Description = "Standby")
11765	belief: (ADOCS.TST_Description = "Insurgent Operation")
11705	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
10585	belief: (CommunicationsNet.TST_Description = "Standby")
10545	belief: (ADOCS.TST_Description = "Standby")
10140	belief: (ADOCS.TST_Description = "Insurgent Operation")
10080	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
8960	belief: (CommunicationsNet.TST_Description = "Standby")
8920	belief: (ADOCS.TST_Description = "Standby")
8515	belief: (ADOCS.TST_Description = "Insurgent Operation")
8455	belief: (CommunicationsNet.TST_Description = "Insurgent Operation")
7335	belief: (CommunicationsNet.TST_Description = "Standby")
7295	belief: (ADOCS.TST_Description = "Standby")
6890	belief: (ADOCS.TST_Description = "Weapons of Mass Destruction")
6830	belief: (CommunicationsNet.TST_Description = "Weapons of Mass Destruction")
5710	belief: (CommunicationsNet.TST_Description = "Standby")
5670	belief: (ADOCS.TST_Description = "Standby")
5265	belief: (ADOCS.TST_Description = "High Political Leadership")
5205	belief: (CommunicationsNet.TST_Description = "High Political Leadership")
4085	belief: (CommunicationsNet.TST_Description = "Standby")
4045	belief: (ADOCS.TST_Description = "Standby")
3640	belief: (ADOCS.TST_Description = "Standby for incoming intelligence on TST")

Figure 6: A chronology of target flow through the communications net and through the Automated Deep Operations Coordination System (ADOCS)

Because development of a Brahms workflow model is actually a design activity, the modeling process in itself will help us understand a good deal about how to design a physical system. However, prototyping has an additional and unheralded contribution to the design of complex, socio-technical systems. Cognitive Engineers rarely have the opportunity to build anything and thus remain separated from the fabrication process even when they are involved with systems under development. Because we never have an opportunity to build anything, we never have an opportunity to confirm the value of our analytic products firsthand. Rapid prototyping has value for Cognitive Engineering, far beyond that of demonstrating the viability of a design, by allowing us to be fully involved in prototype development and thereby permitting us to evaluate our own design methodologies in practice.

References

Clancey, W. J. (1997). *Situated Cognition: On Human Knowledge and Computer Representations.* Cambridge. Cambridge University Press.

Clancey, W.J., Sachs, P., Sierhuis, M., & van Hoof, R. (1998) Brahms: simulating practice for work systems design. *Int. J. Human-Computer Studies*, 49, 831-865.