BrahmsVE: from Human-Machine Systems Modelling to 3D Virtual Environments

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ABSTRACT

Since the early Nineties there has been a requirement at the European Space Agency for a crew activity analysis methodology and tools in support of this methodology. Early efforts were confined to human missions, and were mainly concentrated on the Columbus project. A further constraint was the state of development in computer systems required for real-time analysis and 3D simulation. In addition, the crew activity analysis efforts were seen as separate from the development of simulators for space missions, with parallel but different approaches for human vs. robotic spaceflight. Since then the technology required has developed exponentially, and a more integrated approach to space exploration has been adopted by the Agency, as exemplified by the Aurora programme.

In this paper we describe BrahmsVE, a methodology that introduces a new approach: holistic, agent-based human-machine systems modeling linked to state-of-the-art, distributed 3D simulation techniques. People, machines, and the environment are modeled. Daily activities of individuals and groups are modeled in great detail, including movements, use of tools, and inference. A virtual environment by itself is of little use without a powerful back-end architecture that can represent the complexity of human-machine systems. For over a decade, teams at NYNEX, the Institute for Research on Learning and now. NASA Ames and RIACS, have been developing Brahms, an intelligent multi-agent environment used for modeling, simulating and analyzing work practice. Brahms is a data-driven (forward chaining) discrete event environment, usable for simulation purposes as well as agent-based software solutions requiring the use of "intelligent agents."

Prior to the partnership with DigitalSpace, Brahms models could only be viewed in execution using a timeline bar chart-style interface. Brahms becomes a more effective tool through an interface that enables realistic reconstruction and interaction with 3D scenes representing the real world people and systems being modeled.

Three years of development have resulted in the architecture presented in this paper connecting Brahms with DigitalSpace's OWorld platform, the Adobe Atmosphere 3D web browser component and many additional subsystems. The combined environment allows researchers to assemble and operate networked simulations within a standard web browser on ordinary consumer personal computers with no special equipment. The entire BrahmsVE package is therefore easier and much lower cost to operate, develop models and introduce into geographically separated teams.

In this paper, examples are given from human and robotic missions where BrahmsVE has been applied. Suggestions for future use by the Agency are also provided.

INTRODUCTION

Since the early Nineties there has been a requirement at the European Space Agency for a crew activity analysis methodology and tools in support of this methodology [1,2]. Early efforts were confined to human missions, and were mainly concentrated on the Columbus project. A further constraint was the state of development in computer systems required for real-time analysis and 3D simulation. In addition, the crew activity analysis efforts were seen as separate from the development of simulators for space missions (tools such as SIMSat and Eurosim), with parallel but different approaches for human vs. robotic spaceflight. Since then the technology required has developed exponentially, and a more integrated approach to space exploration has been adopted by the Agency, as exemplified by the Aurora programme.

In this paper we describe Brahms and BrahmsVE, tools rooted in a methodology that introduces a new approach: holistic, agent-based human-machine systems modelling linked to state-of-the-art, distributed 3D simulation techniques. [3].

THE BRAHMS LANGUAGE

In a Brahms model people, machines, and the environment are modeled. Brahms is a data-driven (forward chaining) discrete event environment, usable for simulation purposes as well as agent-based software solutions requiring the use of "intelligent agents." Daily activities of individuals and groups are modeled in great detail, including movements, use of tools, and inferences. Brahms models may be thought of as statements in a new formal language developed for describing work practice. The language is domain-general in the sense that it refers to no specific kind of social situation, workplace, or work practice; however, it does embody assumptions about how to describe social situations, workplaces and work practice.

Brahms can model and simulate work practices. Brahms models are written in an agent-oriented language. The run-time component - the simulation engine - can execute a Brahms model, also referred to as a simulation run. A Brahms model can be used to simulate human-machine systems for what-if experiments, for training, for 'user models', or for driving intelligent assistants and robots. A traditional task or functional analysis of work leaves out the logistics, especially how environmental conditions come to be detected and how problems are resolved. Without consideration of these factors, we cannot accurately model how work and information actually flows, nor can we properly design software agents that help automate human tasks or interact with people as their collaborators. What is wanted is a model that includes aspects of reasoning found in an information-processing model, plus aspects of geography, agent movement, and physical changes to the environment found in a multi-agent simulation. A model of work practice focuses on informal, circumstantial, and located behaviors by which synchronization occurs, such that the task contributions of humans and machines flow together to accomplish goals.

Brahms makes this kind of models possible. Brahms relates knowledge-based models of cognition (e.g., task models) with discrete simulation and the behavior-based subsumption architecture. Brahms is centered on the concept of 'agents'. Agents' behaviors are organized into activities, inherited from groups to which agents belong. Most importantly, activities locate behaviors of people and their tools in time and space, such that resource availability and informal human participation can be taken into account. A model of activities doesn't necessarily describe the intricate details of reasoning or calculation, but instead captures aspects of the social-physical context in which reasoning occurs. Thus Brahms differs from other multi-agent systems by incorporating chronological activities of multiple agents, conversations, as well as descriptions of how information is represented, transformed, reinterpreted in various physical modalities.

The Brahms language is structured around the following concepts:
· Agents and Groups
· Objects and Classes
· Beliefs and Facts
· Workframes
· Activities
· Thoughtframes
· Geography

which can be related one to the other in the following way:

Groups contain
agents who are located and have
beliefs that lead them to engage in
activities that are specified by
workframes that consist of
preconditions of beliefs that lead to
actions consisting of
communication actions
movement actions
primitive actions
other **composite activities**
consequences of new beliefs and world facts
thoughtframes that consist of
preconditions and
consequences

At the core of Brahms there is thus the concept of agent. An agent represents an interactive system, a subject with behavior interacting with the world. An agent can for example represent a person in an organization, but could also represent an animal in a forest. A Brahms model is always about the activities of agents in a work process, and agents engage in activities depending on facts as well as the beliefs they have about facts in the world. Mapping a scenario into Brahms, therefore, means that the modeler must adopt an holistic approach to modeling, trying to explain and simulate individual behavior through actions and decisions, and selecting what to keep inside the picture and what to take out. There is a deep conceptual difference between the way a scenario can be dealt with in Brahms and the object-oriented approach. To write a proper Brahms model, you will have to think about the why of the various things agents and objects do. This is a more complete and more holistic approach. It is a human centered computing (HCC) view as opposed to the software engineering view. The latter might be satisfied with focusing on use cases; the HCC view instead studies why and how the human is using a machine, before designing the machine itself. This also translates in language differences between Brahms and other object-oriented languages: Brahms is an agent-oriented language with elements of rule-based languages, where activities are not the same things as methods, and rules are not the same as if..then constructs of imperative languages. It is important to keep this in mind while modeling in Brahms in order to avoid errors and misunderstandings.

3D VISUALISATION OF BRAHMS MODELS

A Brahms model can be described as a virtual representation of the actual work situation, including human and machine agents cooperating in a virtual environment. However, a virtual environment by itself is of little use without a powerful back-end architecture that can represent the complexity of human-machine systems.

Prior to the partnership with DigitalSpace, Brahms models could only be viewed in execution using a timeline bar chart-style interface. Brahms becomes a more effective tool through an interface that enables realistic reconstruction and interaction with 3D scenes representing the real world people and systems being modeled. [4]

Three years of development have resulted in the architecture presented in this paper connecting Brahms with DigitalSpace's OWorld platform, the Adobe Atmosphere 3D web browser component and many additional subsystems. The combined environment allows researchers to assemble and operate networked simulations within a standard web browser on ordinary consumer personal computers with no special equipment. The entire BrahmsVE package is therefore easier and much lower cost to operate, develop models and introduce into geographically separated teams. Figure 1 shows the overall architecture of BrahmsVE:

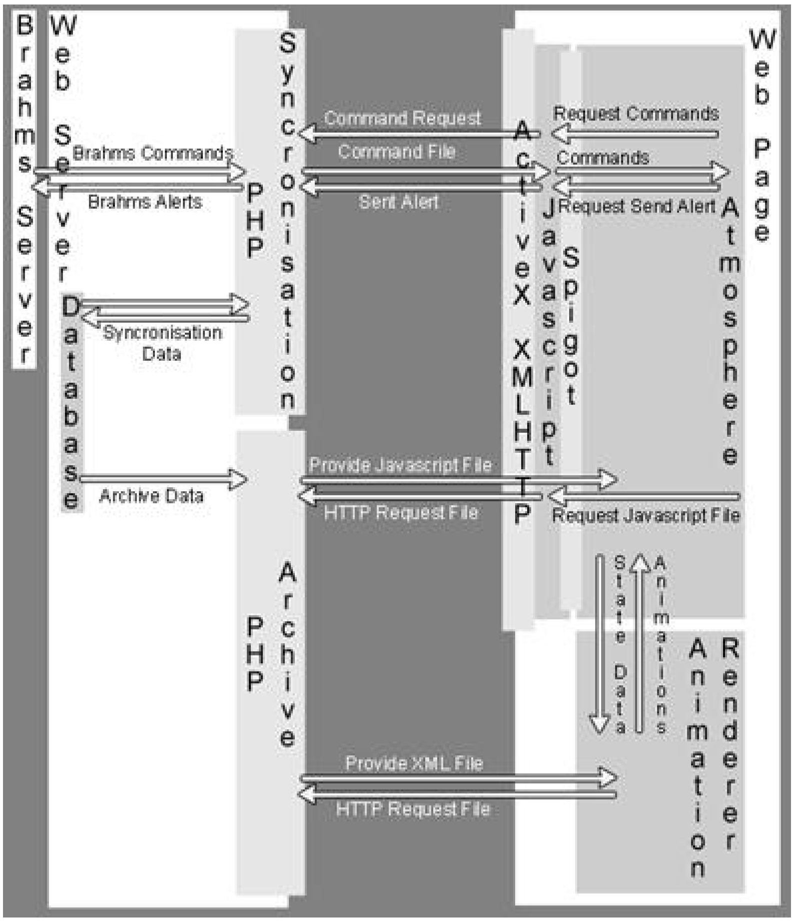

Figure 1

BrahmsVE is constructed out of lightweight web-deployable components. The Atmosphere 3D web-based player component is used in conjunction with OWorld, DigitalSpace's platform for driving multi-threaded simulations in a 3D space supporting two-way communications with two servers:

1. Brahms, running server-side, is generating the initial setup of the 3D simulation and thereby executing agents with "beliefs" to take actions that are mirrored in the virtual environment and
2. The DigitalSpace BrahmsVE server, a MySQL/PHP based server which supplies web page delivery, configures the initial state of the simulation, builds the scene graph from existing 3D components and scripted animations, and then operates as the synchronization and reporting mechanism during server operations

The DigitalSpace BrahmsVE server has a key role in reporting information and exceptions back to Brahms such that Brahms agents receive "real world" input from the 3D environment. Some of this real world information includes collisions, which are reported when geometric volumes intersect in the 3D Atmosphere scene. Atmosphere uses the built-in Havok physics engine to report collisions to OWorld, which communicates these events via PHP to MySQL and the MySQL database then updates a table available to Brahms, thereby reporting this exception. Brahms may then alter its action frames or generate new frames to deal with the exception and then restart or continue the simulation. Throughout this entire process a system clock is employed to synchronize the activities within the scene graph and across multiple browser views.

FROM HUMAN-MACHINE SYSTEMS MODELLING TO 3D SIMULATION: TWO EXAMPLES

As mentioned above, BrahmsVE is the result of several years of intense work among the Brahms teams at RIACS, NASA, and DigitalSpace, beginning in 2000, continuing with work to model EVA and day to day operations aboard the FMARS/Haughton-Mars Project analog habitats. This lead to a specification for the OWorld and Brahms interface [5].

An early application of this methodology will now be described. In 2002 DigitalSpace completed several "day in the life" scenarios aboard FMARS in the project called SimHab as well as a concept project for NASA ARC and MER outreach for presentation at JPL. Finally in 2003, BrahmsVE was developed further to support simulation of the Personal Satellite Assistant (PSA) aboard ISS and an extensive water tank filling simulation for FMARS.

Many sources were employed to assemble and operate the 3D scene graphs for BrahmsVE/SimHab and other applications:

- Brahms Models developed in the Brahms development environment and AgentViewer;
- Still images of FMARS and MDRS crew activities;
- Documents detailing the layout of FMARS, MDRS, ISS/PSA and MER;
- Video from FMARS showing astronauts in routine activities (this was our primary source for the "day in the life" series);
- Written notes detailing crew activities (logs);
- Rendered computer graphics for concepts of the PSA in flight aboard ISS.

Current development of the SimHab application concentrates on the delivery of a fully tested two-way synchronous interface between the scene graph and Brahms such that Brahms agents will be rendered with a real-time synchronized clock in the 3D scene graph. Therefore, a robot or human agent moving through steps in the Brahms model will have a synchronized view in the 3D scene. This 3D representation will be subject to exceptions, such as collisions, which will be reported back to Brahms in real-time, permitting a modification of the subsequent Brahms actions (such as an astronaut stepping around an obstruction). By the conclusion of the project, the full BrahmsVE environment will be packaged and delivered as an end-user product for use throughout NASA, other government agencies and commercial enterprises.

- In our second experience case study, we will examine the recently undertaken SimStation Online project, being performed in collaboration with the SimStation team at Ames for customers at NASA's Johnson Space Center. SimStation Online is a new project that employs similar modeling sources used for several years on the SimHab project outlined above, with a few additional inputs.

The immediate goals of the SimStation Online (SSO) project are to supplement the current SimStation efforts at NASA's Ames and Johnson Space Centers with an online rendition of the 3D component structure of current and future configurations of the International Space Station (ISS). The SSO application interface is presented within a web interface using the Adobe Atmosphere player, and DigitalSpace OWorld framework and can be shared and synchronized via an SQL database with a group to permit collaboration. A key element of SSO is that by selecting a 3D component in the scene graph a database call is initiated that brings up documents, database queries, close-out photographs (photographs of components taken just before launch), video and notations.

SSO models are created from:

- Provided DirectX and VRML models of ISS exterior, shuttle, suits and parts (from Boeing and JSC)
- XML descriptions of ISS configurations
- Documents and web-site data detailing the currently deployed ISS and future configurations.

Therefore, in a group setting, users can select a component, bring up common documents, associate new documents, images, and video notations and store these associations with a particularly 3D ISS configuration. Future goals for SSO include visualizations of the assembly sequences, EVA (extra vehicular activity) procedures and computational capabilities such as estimates of the length of cabling and inventories of parts.

Future work on SSO will derive 3D modeling data and activities from the following sources:

- Video from ISS, NASA's JSC Neutral Buoyancy Laboratory and other sources
- Still photos from NASA training, contractors, and close-out photography
- Written EVA checklists and procedural guides to operations
- Brahms models of human/systems activities surrounding ISS simulation scenarios.

SimStation Online is built on the BrahmsVE architecture described above. SSO has required us to make several important extensions to BrahmsVE including:

1. Full assembly of a 3D virtual environment component-by-component using a MySQL database driven by PHP commands from a web component. This web component, known as the OWorld Information Broker (OWIB) is able to assemble any configuration of a virtual ISS model drawing its sources from arbitrary we locations of locally from a file store or distributable storage medium such as CD or DVD. Figure 20 below illustrates the content assembly architecture for SSO. A variety of protocols are used to set up and operate layers of interfaces including a database-driven web site with various levels of user access, and web-embedded BrahmsVE applications for the virtual environment itself.

2. Also utilising the OWIB, we are employing an extended variety of communications protocols to enable communications with Brahms, Atmosphere, and Talkspace, a voice over IP technology developed by DigitalSpace. Talkspace will facilitate the triggered playback of voice loops commonly heard as part of EVA and ISS assembly operations.

As the SSO project is strong driver for BrahmsVE development, continued support for SSO development would permit us to provide a detailed 3D simulation of the above operation, which could be shared via the web with the engineering team and for use in astronaut refresher training. One key element of this operation is that the geometry of the modules and interface adapters must be well known as each step involves cabling (temporary and permanent) between modules. If at any step the cabling is of insufficient length, this could lead to serious problems during the operation. We would hope that SSO would augment SimStation, the Neutral Buoyancy Laboratory and the other visualization and training systems in use at JSC and NASA to permit safe completion of such complex on-orbit operations.

Other areas that will need to be addressed in the future for SSO include connection of the platform with other efforts at NASA and elsewhere. Further assessment of the platform is required: this includes training effectiveness evaluation, knowledge capture through sensored objects and activities, and comparison of simulation versus on-orbit operations.

Experience in developing SimStation Online provides yet more justification why databases are integral to the creation of useful applications that employ 3D scene graphs. Effectively acting a 3D interface for access to and sharing of web-based and database-sourced documentation, SSO is an example of a 3D virtual environment acting as an exotic database search and updating interface.

In the case of both SimHab and SimStation Online, development is in a very early stage with focus on enabling and validating platform capabilities. The viability of both applications and their underlying architecture in supporting real mission goals has yet to be tested. Well-established methods from previous virtual environment simulation platforms have been used and close consultation with the end customers of the applications has been made a priority. Within a few years we hope that this synergy of databases, agents, 3D virtual environments, and collaborative web delivery will provide NASA and other end-users a capable platform to meet design, training and public outreach missions.

THE FUTURE: SIMSPACE

The work done within the SimHab and SimStation projects led to the definition of a multi-purpose simulation tool, SimSpace [6]. The open methodology of SimSpace enhances these two platforms, and any future platform with the following unique and novel features:

- Real-time 3D through the internet using a variety of 3D rendering technologies (commercial and open source engines).
- Rapidly developed models and animation lower costs (employing a model repository which is the subject of a full Phase II development proposal).
- Multi user interaction to permit shared presence in the simulations.
- Collaborative database to associate existing vehicle databases with 3D scenarios.
- Web-accessibility permitting universal access to the environments even employing computers in vehicles in flight.
- Open scripting component architecture to permit physical and haptic device interfaces (planned).

SimSpace thus combines 3rd party Foundation elements (Brahms, SimStation, shared models and any other open system) within a common Simulation layer (SimSpace including the BrahmsVE interface, Oworld Agent Information Broker (OWIB) and OWorld engine). This drives a flexible Presentation layer (commercial or open source 3D engines) enabling a much larger range of Applications than would be possible with a monolithic system. See figure 2 for the SimSpace architecture:

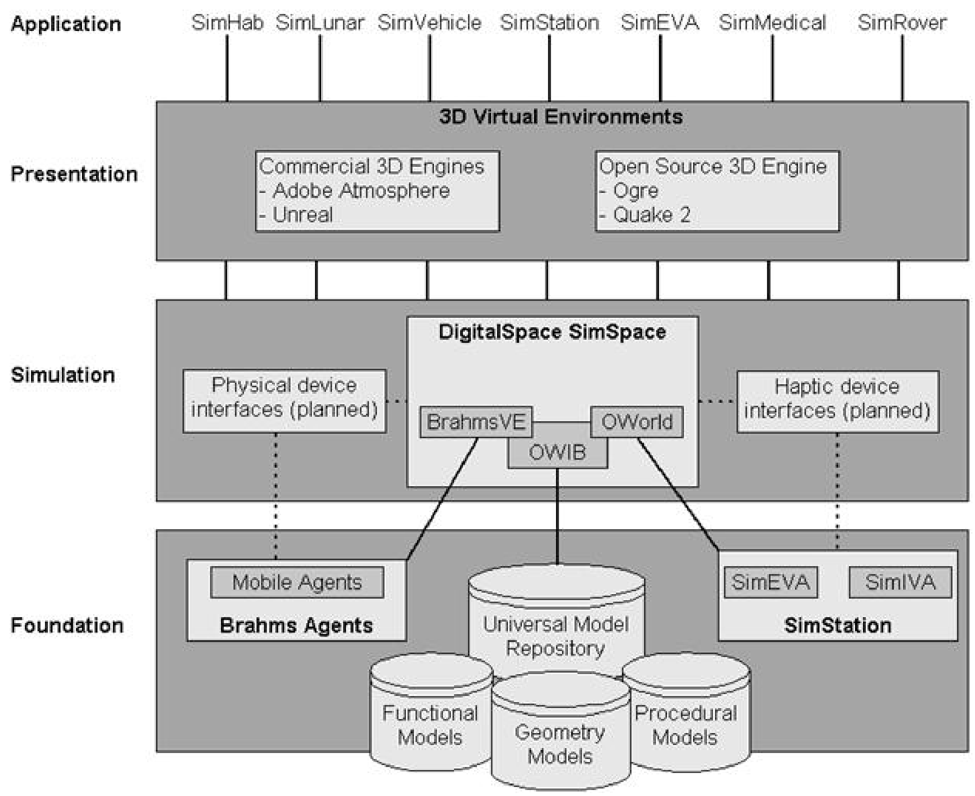

Fig 2

The approach has proven successful as SimSpace has begun to gain wider acceptance across NASA centers and within the contractor community. The following applications have been built on SimSpace and delivered to customers:

- SimHab: FMARS and Mars Desert Research Station Analog Habitats.

- SimRover: 3D scenarios of Mobile Agents work practice (current summer 2004) (Brahms from ARC and rovers from JSC). MER Rover surface operations reconstruction prototype in "Drive On Mars" (ARC VizOpps group, JPL surface data).

- SimStation: Web-based collaborative rendering of SimStation application including exterior 3D ISS configurations with linked in photography and database documents (SimStation group at ARC, JSC, Langley)

- SimEVA and SimIVA: EVA training prototype for Neutral Bouyancy Laboratory/Raytheon including CMG changeout for STS-114 and RPCM changeout on the ISS (SimStation group at ARC). Simulation of Personal Satellite Assistant in ISS IVA operations (ARC). Simulation of EVA on Mars for BrahmsVE application (ARC).

- SimMedical: VAST project for ISS crew medical training on CHeCS rack procedures (Lockheed Martin, ARC, JSC, Langley). National Institutes of Health project for childhood autism, safety learning game (DoToLearn).

- SimVehicle and SimLunar: 3D simulations for Boeing of Lunar base and Crew Exploration Vehicle (CEV) concepts. Prototypes for Space Exploration Online (SEO), initiative for a massively multiplayer space oriented Lunar base reality game (Boeing CII project, ARC, JSC, MOVES Institute, Arsenal Interactive).

CONCLUSIONS AND RECOMMENDATIONS

For the upcoming new exploration initiative to the Moon, Mars and beyond, this platform will support concept design for long duration missions, Lunar and Mars surface operations as well as just-in-time crew in situ training and evaluation of safety and crew health. Prior to new missions, the platform is of relevance to safely completing the build-out of ISS. Mobile agents and Mars analog habitat studies will be empowered by the platform's ability to represent human and machine agents working together.

BrahmsVE (through SimSpace) has also been used in a project for the teaching of safety practices to children with Autism in a controlled study funded by the National Institutes of Health at Emory University in Atlanta. Other applications include the design of factory floors where people work in concert with robots, surgical theaters where physicians and staff need to optimize the utilization of space, time and equipment, and as an engine for battlefield training where agents represent combatants and geometry of vehicles and terrain is served out by the database and agent broker.

Within the context of current and planned ESA projects (especially within the Aurora framework, with its mixture of human and robotic missions), and given the requirements set out in [1] and [2], it would seem clear to us that ESA also has a requirement for the methodology and tools outlined in this paper. BrahmsVE should be seen as complementary to ESA simulation tools for spacecraft and other hardware such as SIMSat and Eurosim. We would therefore like to present BrahmsVE and SimSpace to the Agency for use in future missions.

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