LECTURES ON WORK SYSTEMS DESIGN

William J. Clancey
NASA Ames Research Center

This series of lectures, including a public and a school talk, reveal how computer technology development and achievements in the past few decades, relate to a paradigm shift in understanding human thinking. The practical implication is that research for developing useful and innovative technologies is necessarily multidisciplinary—building useful computer technologies benefits from the knowledge and methods of mathematicians, cognitive scientists, and social scientists working together. This series of lectures will illustrate with many examples new ways of analyzing the work that people do everyday, with methods for identifying opportunities for innovative automation and collaborative technologies. The public talk will give the audience a view of an example of a frontier technology now in use on Mars, developed by NASA, that has the potential to radically change how scientists and engineers collaborate across international borders.

In the first week of lectures, participants will be introduced to human-centered computing technologies being developed at NASA. One highlight is technology that automates how Mission Control in Houston supports with astronauts onboard the International Space Station. In the second week of lectures, participants will learn and exchange knowledge about the technology design concepts and principles that sit at the heart of building these human-centered computing technologies. One highlight is how social networking is changing how computer scientists' view "artificial intelligence."

Participants who attend this series of lectures will learn why it is important to understand how human knowledge, memory, and learning are radically different from model-based computer programs. They will learn how researchers from various scientific disciplines, applying this paradigm shift in cognitive science, can collaborate to develop innovative technologies that help people and make new kinds of human endeavors possible. In particular, you will learn:

- different ways of viewing human behavior and describing how people work in any type of organization;
- how to know what technologies to build using the concepts of participant observation, participatory design, and work practice analysis;
- a practical methodology for simulating how people work in organizations and developing prototypes; and
- software architectures that enable human creativity and responsibility, hardware and software systems integration, and software reuse.

DATE	Monday 6/6	Tuesday 6/7 Morning	Tuesday 6/7 Afternoon	Wednesday 6/8	Thursday 6/9	Friday 6/10	Evening Public presentation
TALK TOPIC/TITLE	**"Designing Work Systems at NASA"**	**"Brahms I: The Brahms Multiagent Work Practice Simulation System"**	**Brahms II: "Brahms: A multiagent modeling environment for simulating work processes and practices"**	**"Agent-Based Systems Integration"**	**"OCAMS: Multi-Agent Simulation to Implementation: A Practical Engineering Methodology for Designing Space Flight Operations"**	**"Situated Cognition I: Origin, Concepts, and Applications"**	**"Voyages of Scientific Discovery with the Mars Exploration Rovers"**
Software Design Concepts and Principles	• Total System Design • Work System vs. Software System • Design in the Context of use • Participatory Design • Participant Observation • Iterative Prototyping • Human-centered vs. technology-driven • Software reuse with agent workflow backbone • Applied Research	• Social vs. Cognitive Models of Work • Modeling People, Environment, & Interactions • Activity vs. Task (Function) Analysis • Practice vs. process • Models of Behavior vs. Knowledge & reasoning • Multiagent System Architecture • Integrating Simulations: Work, VR, & subsystems • Developing tools that fit work practice	• Activity vs. Procedure • Subsumption Architecture • Workframe vs. Inference Rule • Forward Inference (Thoughtframes) • Discrete Event Simulation • Agent Groups & Inheritance	• Open Architecture • Interoperability • Workflow Agent Architecture • Service-Oriented Architecture • End-to-End System Design • Empirical Requirements Analysis • Incremental System Buildup	• Simulation-Based Design, Development, & Testing • Formulating metrics to answer design questions • Participatory Design • Research-Operations Partnership • Respecting Security & Privacy Policies • Human-System Role Interactions	• Scientific Antecedents: Complex Systems • Systems Thinking • Human Knowledge vs. Computer Models • Ontological Limitations of Computer Models • Contextual Design • Transactional Analysis • Human-Centered Roles for Model-Based Systems • Functional vs. truth-based evaluation • Systems for Experts vs. Expert Systems • How automation embodies theory of knowledge & practice	• Total System Design • Nature of a Robotic Laboratory • Virtual Presence • Design for Multidisciplinary Collaborative Engineering • Training Simulation-Based Design
Afternoon				Assist Brahms setup and/or individual mtgs	Individual & small group discussions	*Discussion about Sit Cog- Why did psychology & automation lag behind the other sciences in the 20th century?*	

DATE	Monday 6/13	Monday 6/13 Evening School presentation	Tuesday 6/14	Wednesday 6/15	Thursday 6/16	Friday 6/17
MORNING TALK TOPIC	**"Situated Cognition II: Conceptualization, Consciousness, & Identity"**	**"Voyages of Scientific Discovery with the Mars Exploration Rovers"**	**"Situated Cognition III: Relating Modes of Thought"**	**"Being Scientific on Mars: The Challenges and Accomplishments of the Phoenix Lander Mission"**	**"Empirical Requirements Analysis for Mars Surface Operations Using the Flashline Mars Arctic Research Station"**	**Discussion about Innovative R&D**
Software Design Concepts and Principles	• Semantic Network vs. Conceptualization • Motives vs. Goals • Role of Values in System Analysis • Role of Participation & Identity in Work Systems • Coordination & Cooperation vs. Collaboration		• Logicist/Technologist Perspective • Multidisciplinary Design Teams • Codifying vs. Facilitating Communication & Learning • Identity & Role for Software Engineers • Models based on Objectivity vs. Pluralism • Design as Conversation with Materials • Common Pitfalls in Problem Framing	• Cost and Risk Tradeoffs in Automation Design • How automation changes work practices • Regimented Work vs. Creative Exploration • Multidisciplinary Communication & Decision Making	• Empirical Requirements Analysis • Data Collection & Analysis for Work System Design • Participant Observation • Quantitative Ethnography • Exploratory Research	
Afternoon Activity	Individual & small group discussions		Individual & small group discussions	Individual & small group discussions	*Discussion about Brahms (Tutorial Review)*	*Discussion: What is a Researcher? How do you become a researcher and what is your role?*

Designing Work Systems at NASA

William J. Clancey, PhD

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Intelligent Systems Division
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Florida Institute for Human and Machine Cognition

November 4, 2010

Human-Centered Computing...

- A **software engineering methodology,**
- Based on the **scientific study of cognition** in people and machines, especially understanding the differences between perceptual-motor/cognitive/social aspects of people and present-day computer systems,
- With the objective of developing computer **systems that fit** human capabilities and practices by **exploiting and improving AI** programming methods.

We know how to teach people how to build ships,
but not how to figure out what ships to build.

—Alfred Kyle, quoted by Donald Schön

Human-Centered Computing defined by analogy...

HCC is to the rest of software engineering as

Architectural Design is to structural engineering

Specializing in working with users for requirements analysis, generating new kinds of computer system designs, and evaluating systems in the context of use.

Automating Capcom

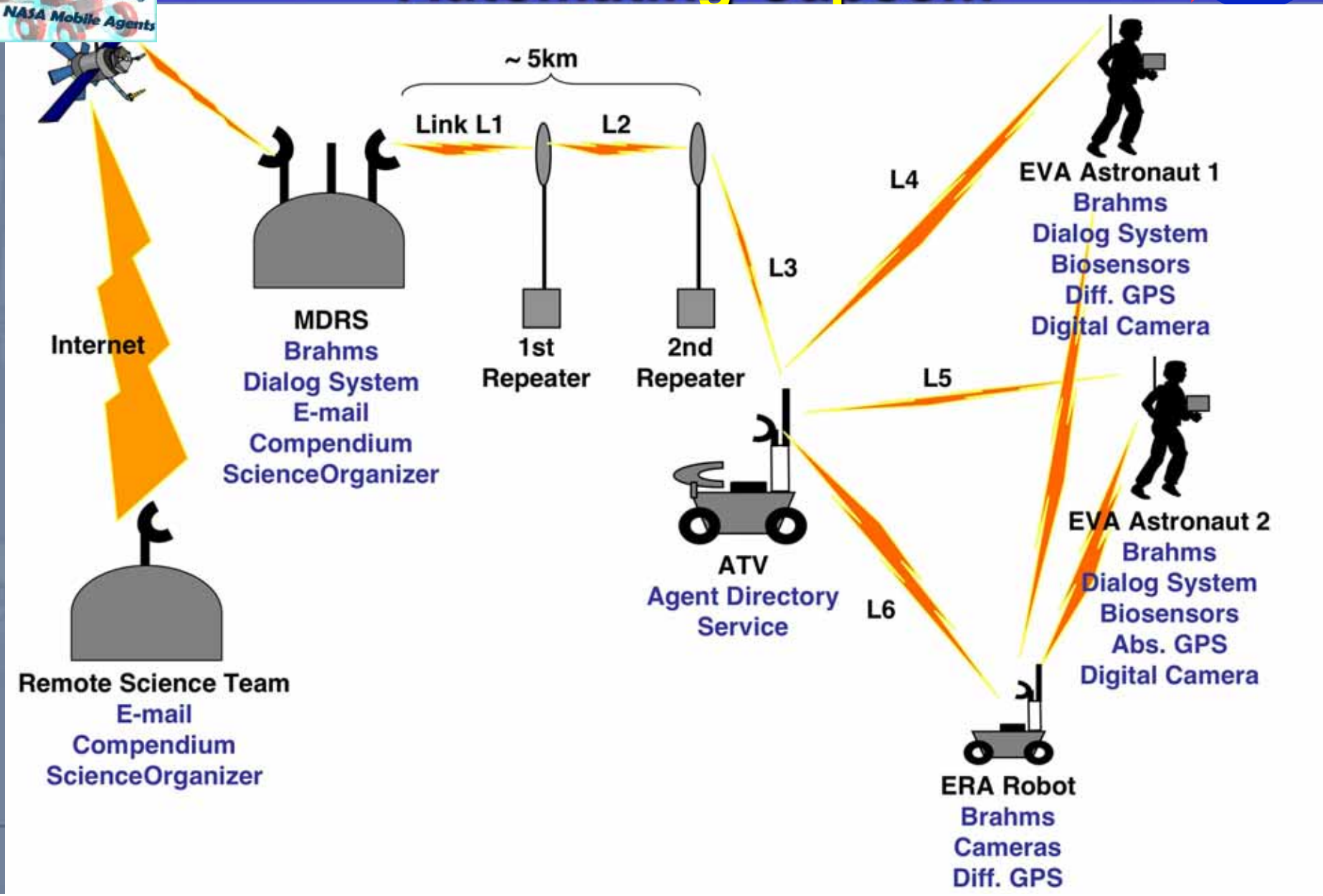
Apollo 17 Moon 1972

Mobile Agents UT 2005

Mission Control's Role in Apollo:
Monitoring and directing all aspects of the mission

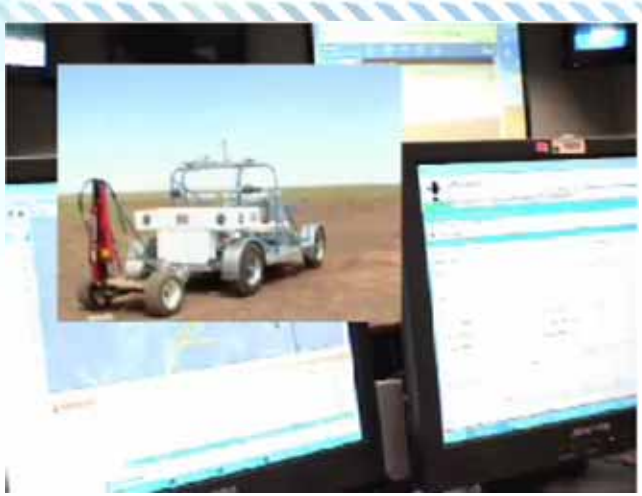
Navigation, schedule, logging of observations, monitoring astronaut health, managing vehicle health, resource management

Mobile Agents
"Automating Capcom"



Astros can work fully in parallel, talking to personal agents
Robot on ledge tracks Astronauts & takes photos when commanded
Mars Desert Research Station
2004
Rotation 29
Brahms
RIALIST
ERA
MEX
NREN
SciOrg
NASA Mobile Agents
Voice annotation is recorded and transmitted to database in habitat & to RST on earth
Robot in "follow me" mode

Mobile Agents Experiments

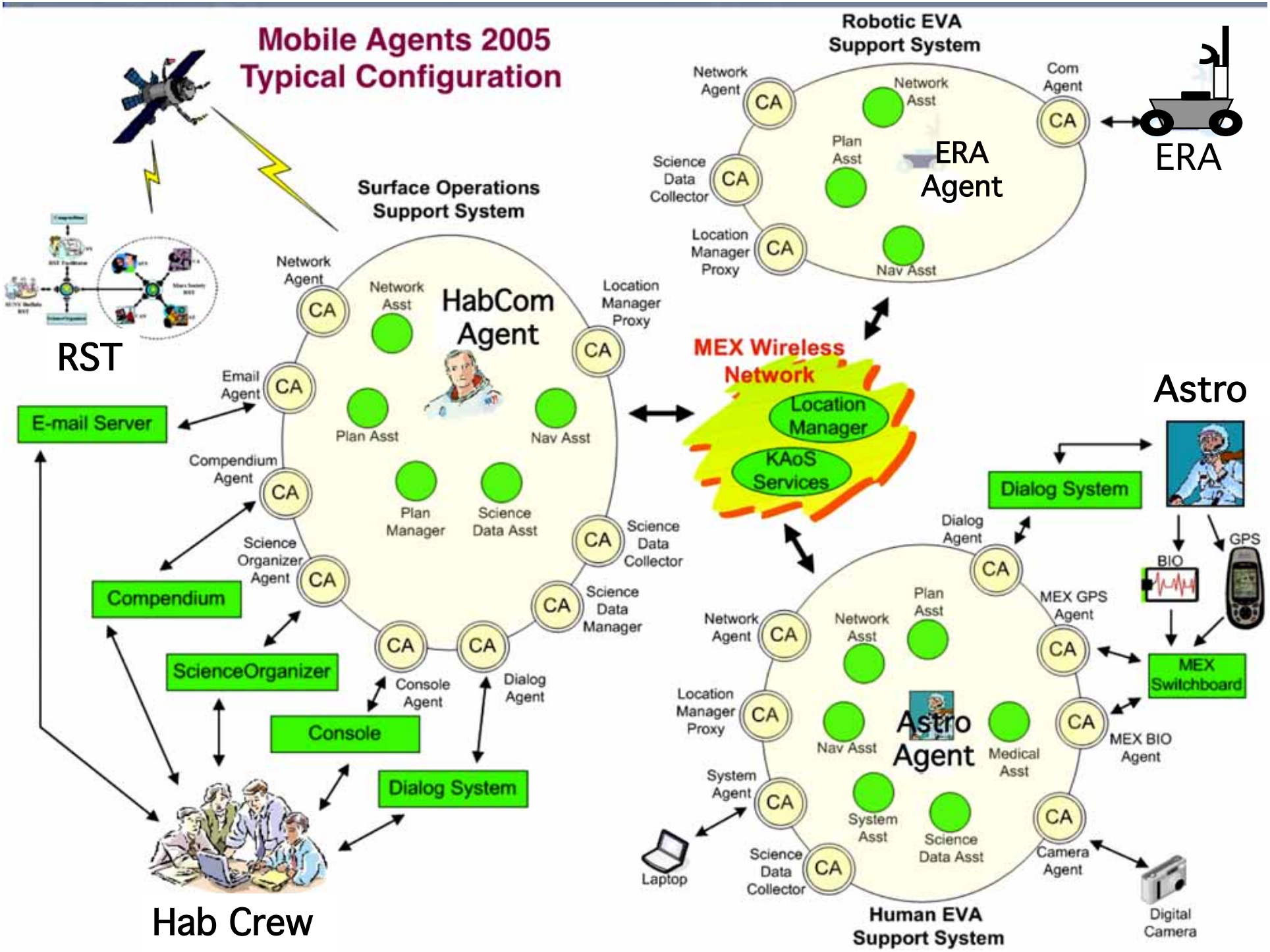


ExPOC-Scout TX/AZ 2006

iMAS NM 2008

Power Agents UT 2006

MMAMA BZE 2008


Mobile Agents 2005
Typical Configuration
Robotic EVA
Support System
Network
Agent
CA
Network
Asst
Com
Agent
Plan
Asst
ERA
Agent
Science
Data
Collector
Location
Manager
Proxy
Nav Asst
ERA
Surface Operations
Support System
RST
Network
Agent
Network
Asst
HabCom
Agent
Location
Manager
Proxy
Email
Agent
E-mail Server
Plan Asst
Nav Asst
MEX Wireless
Network
Location
Manager
KAoS
Services
Astro
Compendium
Agent
Plan
Manager
Science
Data Asst
Dialog System
Science
Organizer
Agent
Science
Data
Collector
Compendium
Science
Data
Manager
Dialog
Agent
BIO
GPS
Console
Agent
Dialog
Agent
ScienceOrganizer
Console
Dialog System
Network
Agent
Network
Asst
Plan
Asst
MEX GPS
Agent
MEX
Switchboard
Location
Manager
Proxy
Nav Asst
Astro
Agent
Medical
Asst
MEX BIO
Agent
System
Agent
System
Asst
Science
Data Asst
Camera
Agent
Laptop
Science
Data
Collector
Digital
Camera
Hab Crew
Human EVA
Support System

EVA Data Shared on Interplanetary Internet

ScienceOrganizer: An Information-Sharing Tool for Mobile Agents — NASA Ames

New Item | Search | Home | Go To | Logout | Help

View Links | Edit Links

- WorkStation9 (open all | close all)
  - **EVA** *(1 EVAs)*
    - Day_5_Beyond_Poohs_Corner_2_EVA
  - **Eva Plan** *(1 EVA Plans)*
    - Day_5_Astro_EVA_2_To_Beyond_Poohs_Cor
  - **Gps Location** *(1 GPSData)*
    - AstroOneModel_GPSDATA_9
  - **IsAssociatedWithImageFile** *(4 Image Files)*
    - image_collection6
  - **IsAssociatedWithVoiceAnnotation** *(2 Voice Ann*
    - voicenote_2
    - voicenote_4
  - **Plan Activity** *(1 MA Activites (Planned))*
    - WorkInRavine

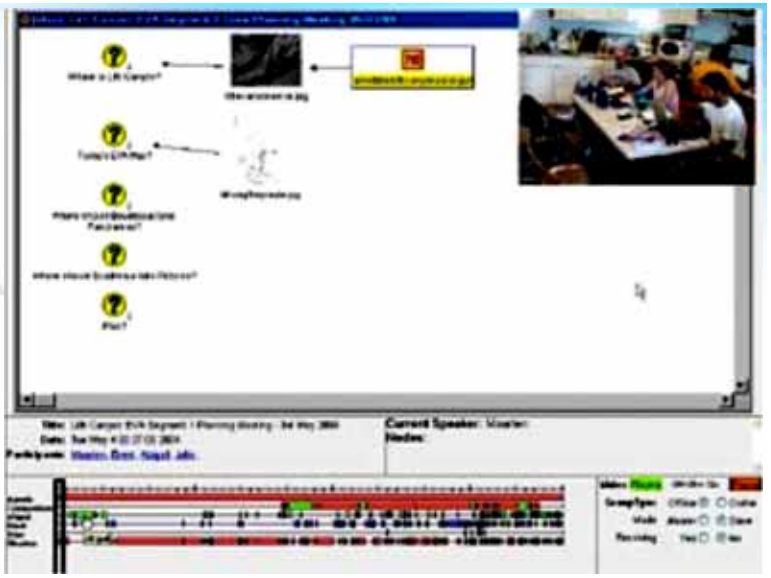
Modify | Permissions | Delete | Duplicate | Put in a Folder

MapLocation: WorkStation9

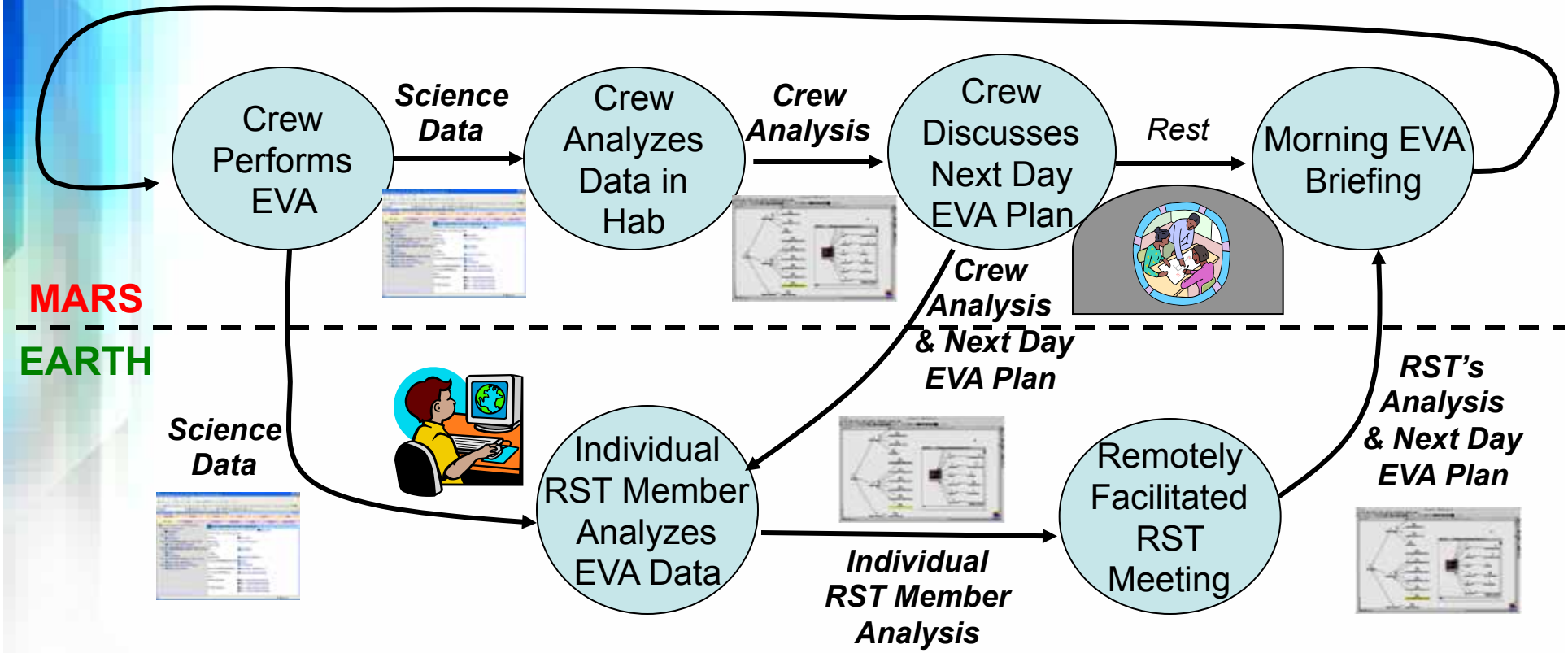
Item ID# 183961 updated 2005/04/15 05:25PM PDT by ScienceOrganizer Com Agent (SOCA)
Send this Item's web address via Email

Radius	0.0 meters
Creator	
Timestamp	2005-04-16 01:07:09.0
Gps Location	AstroOneModel_GPSDATA_9
Eva Plan	Day_5_Astro_EVA_2_To_Beyond_Poohs_Corner_Plan
EVA	Day_5_Beyond_Poohs_Corner_2_EVA
Plan Activity	WorkInRavine
IsAssociatedWithImageFile	image_collection6
IsAssociatedWithSampleBag	
IsAssociatedWithVoiceAnnotation	voicenote_2 voicenote_4
Notes	
Write Permission	Mobile Agents Architecture (MAA -- Entire)
Read Permission	Mobile Agents Architecture (MAA -- Entire)

Collaborative Design of Operations with Remote Science Team



Revised Long-Term Plans



HCC Analysis Heuristics

- Start by ***studying what people do,*** not only technological possibilities.
- Follow ***conversations.***
- Focus on ***interactions across organizational boundaries.***
- Enable ***participation.***

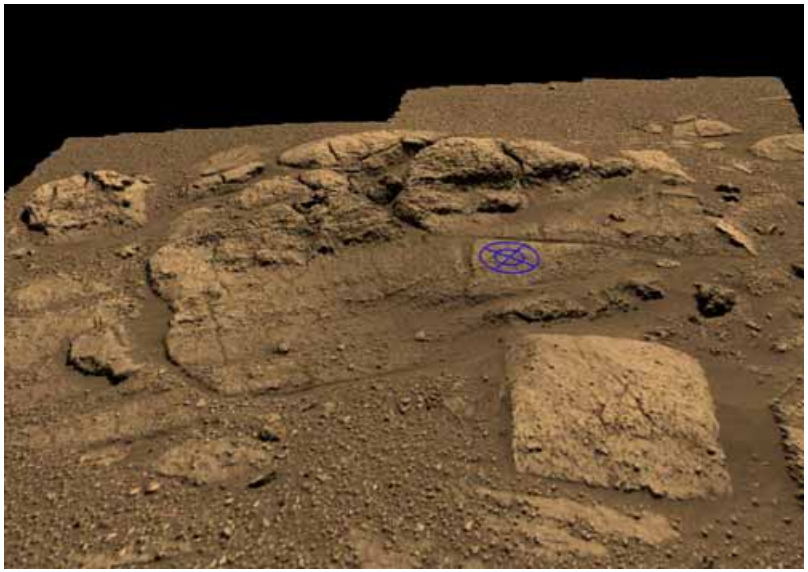
Field Science on Earth: Opening a Rock

A geologist on Earth may hit any rock he fancies, just out of curiosity, and privately share his interpretations while making observations…

Biologist and geologist, Haughton Crater, Devon Island, July 1999

Human-Robotic Interaction: A New Way of Being a Scientist

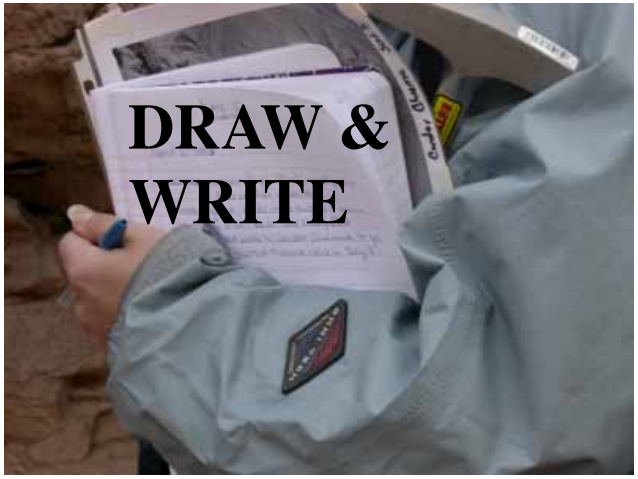
"… don't say let's RAT here to reveal this and let's RAT here to reveal that, let's talk it through in terms of the specific scientific hypotheses that we're trying to test."



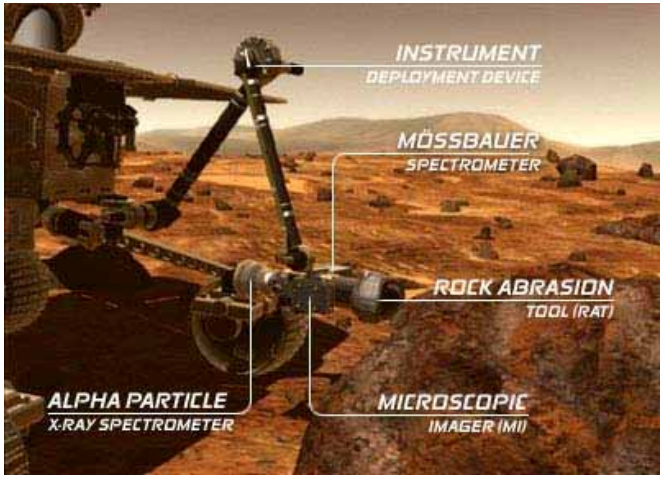
After hours of discussion, X marks the spot.

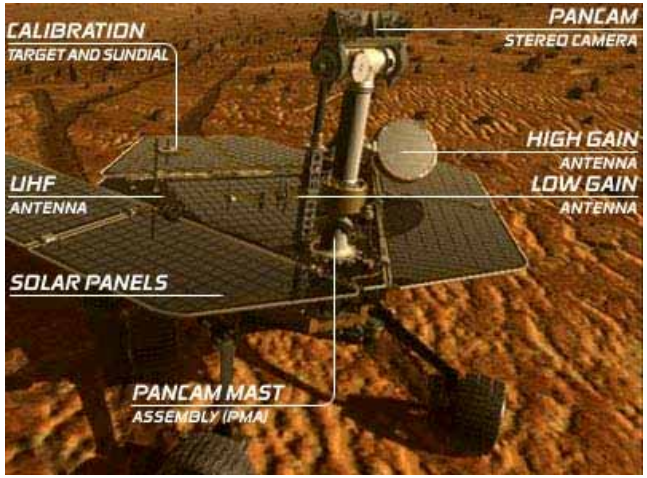
Public, communal exploration requires conforming to text-book norms of science… what work systems can facilitate individual-group-team identities & projects?

What Geologists Do in the Field



MER: Scientific Laboratory on Mars

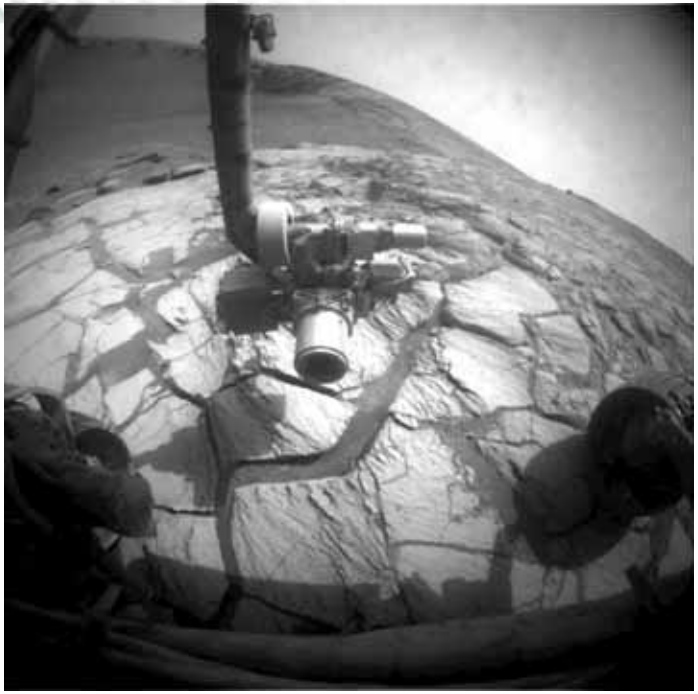




Computer-controlled (robotic) system for doing field science, programmed on Earth every day:

- **NAVIGATE**
- **SCRAPE: RAT**
- **PHOTOGRAPH: PanCam, MI**
- **DETECT CHEMICAL COMPOSITION: APXS, MB, MiniTES**
- **CHARGE BATTERIES**
- **RECEIVE PROGRAMS & TRANSMIT DATA**

“We’re on Mars!”



Virtual Presence: Seeing & Touching

“We realized *we had landed in a crater*, probably Eagle Crater, and that’s where we were. And then *we noticed, 800 meters away*—which is more than our 600 meters, but *maybe we can make it*—there’s Endurance Crater. We’re talking about that, “Wouldn’t it be great to actually get there!”

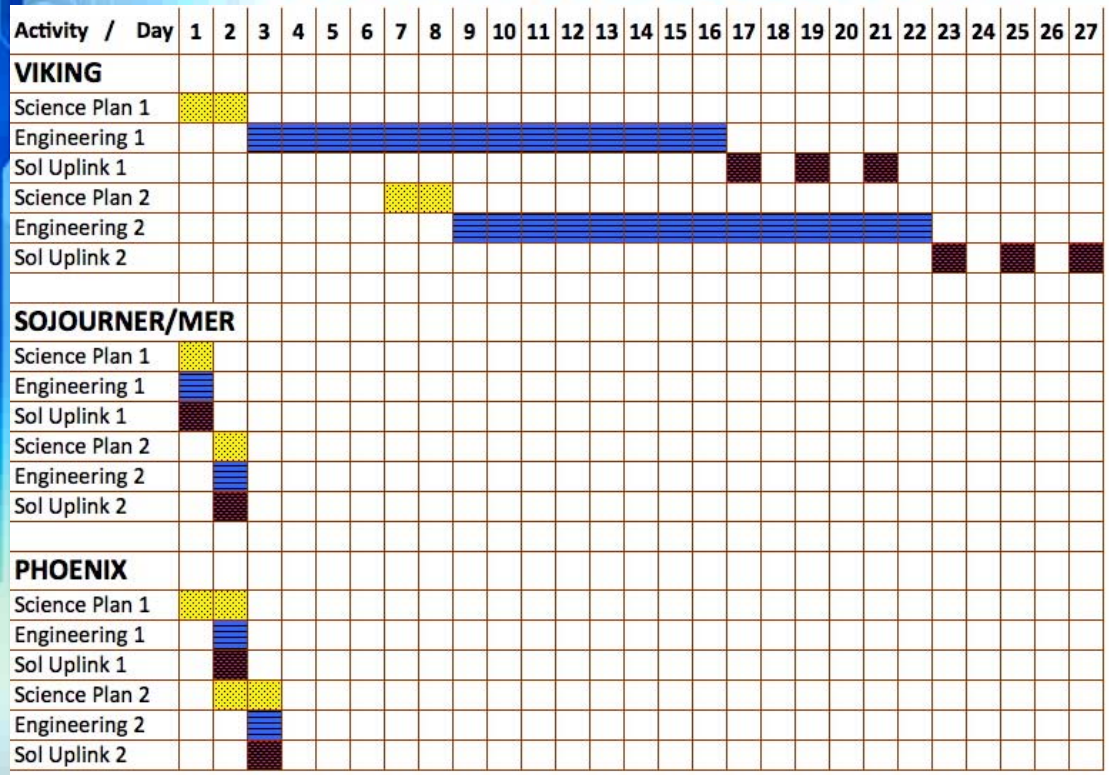
Steve Squyres, MER PI, 2007

The Pivotal Design Principle: "One Instrument, One Team"

"You've got these sensors and each of them provides complementary bits of knowledge, so that the totality is more than the sum of the individual parts. *You're going to use the payload to fullest advantage, if people look at it as being entirely at their disposal*. . Everything works together."

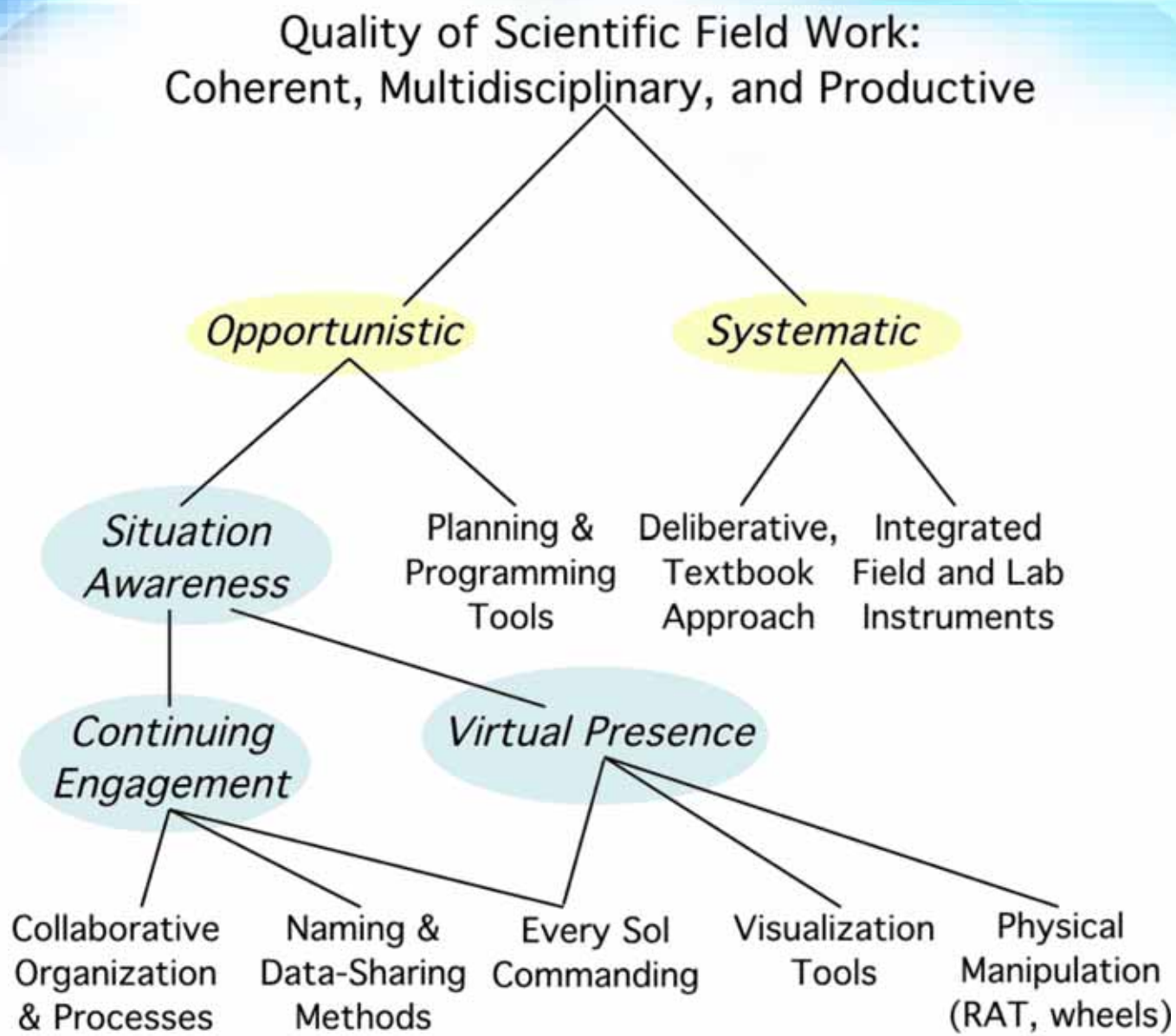
Steve Squyres, *MER PI*

Serendipitous Benefits of Daily Commanding



Viking veterans were skeptical; mission design presentations did not mention cognitive or social benefits

- Intensive daily activity, with sufficient feedback to assess the previous day's results
- Significantly increased the scientists' creative engagement of "being on Mars" (virtual presence)
- Enhanced conflict resolution, collaboration, and productivity, and hence quality of the field work



Design Framework for Scientific Exploration Systems

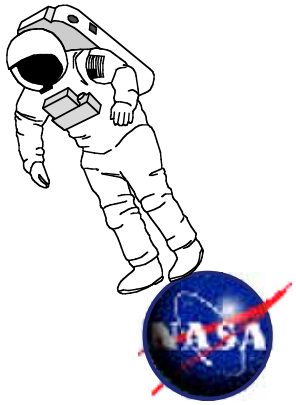
Think Differently:

"Participatory" "Design" of "Computer Tools"

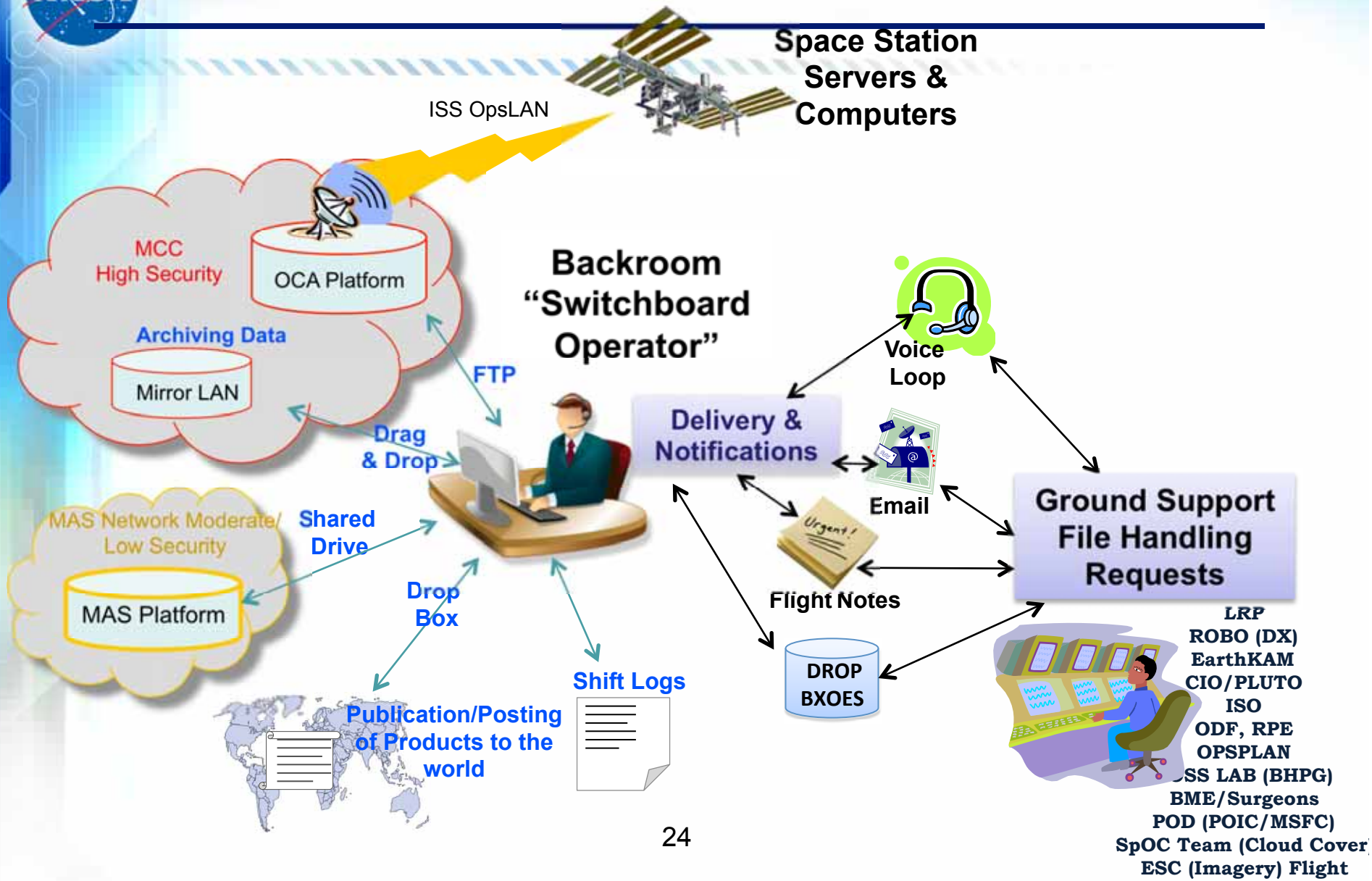
@ DESIGN TIME: **A different view of collaboration ← a different view of problem framing ← a different view of knowledge.**

@ WORK: **A different view of tools ← a different view of the relation of plans/designs and action ← a different view of knowledge.**

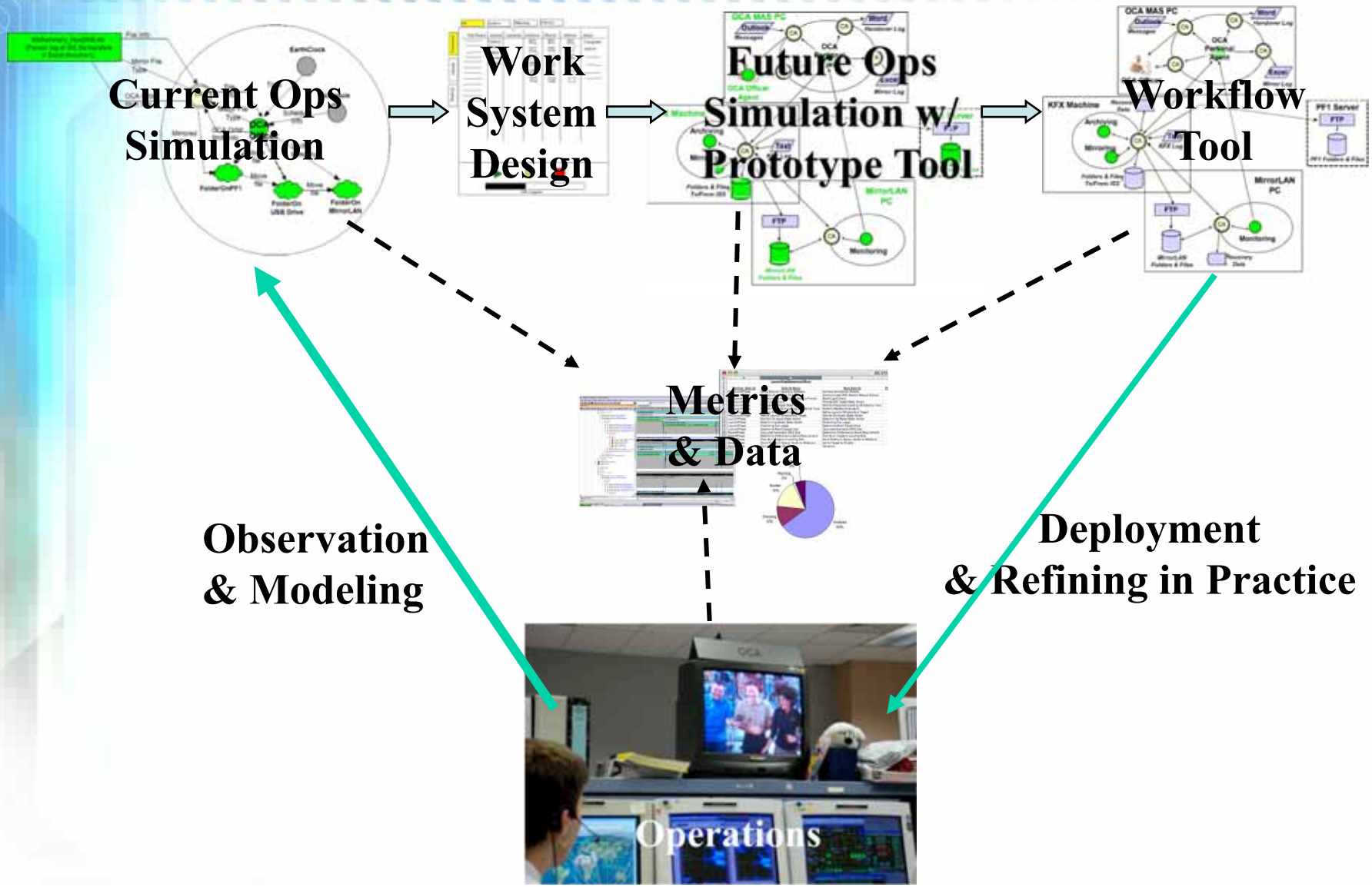
The essence of problem solving is not just "finding out the truth" and "path optimization" but ***dynamically finding new paths****.*



The ISS File Management Problem



OCAMS: Simulation-to-Implementation Methodology

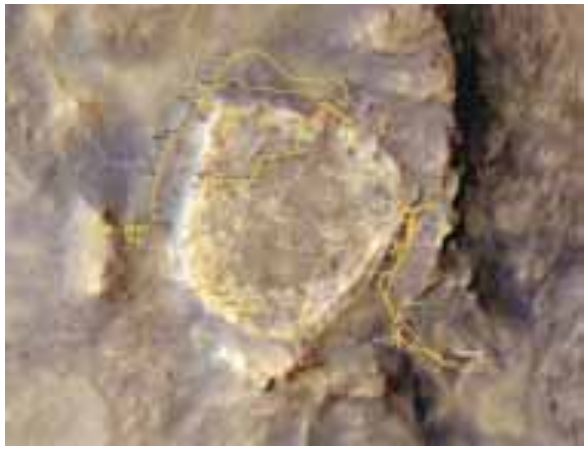


HCC Methodology = Design in the Context of Use

- **Participatory design,** with incremental value
- **Participant observation,** ethnography, video interaction analysis
- **Total systems perspective** (process, tools, organization, facilities), integrating multiple views: Workflow, information processing, reasoning, situated action
- **Organizational learning**/developmental perspective
- ***In situ* evaluation,** uncover broader effects

For more information…

- Field experiments: www.NASA.Gov/exploration/analogs
- Papers & videos: http://bill.clancey.name
- Brahms: www.agentsolutions.com



The Brahms Multiagent Work Practice Simulation System

William J. Clancey, PhD

NASA/Ames Research Center &
Florida Institute for Human & Machine Cognition

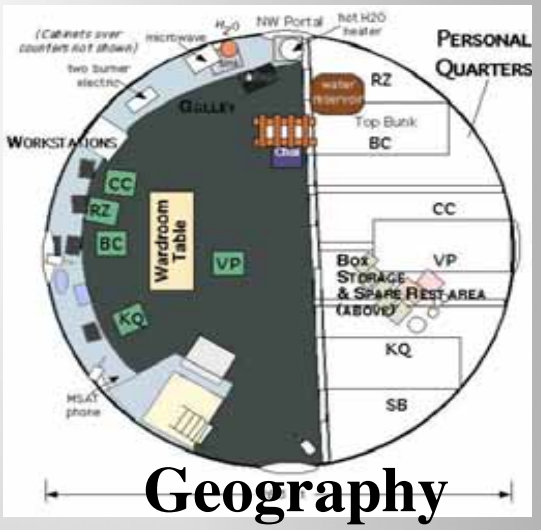
TOPICS

- Nature & Origin of Activity-Based Multiagent Simulation
- History
- Tool & Language Overview
- Examples:
  - Mission Operations Simulations
  - Coupling to Animation & Control Systems
  - Workflow Automation
- Lessons Learned

Acknowledgements

- Patent authors: Clancey, Sachs, Sierhuis, Torok, van Hoof
  - Institute for Research on Learning collaborator: Jordan
  - IRL & NYNEX supporters: Stucky/Henschel, Euchner/Thomas
- Maarten Sierhuis, Co-PI (1992-2010)
- Ron van Hoof, system czar (1995-)
- Mike Scott, modeling tools (1998-)
- Chin Seah, modeler (2001-)

Brahms View of the World



Brahms: A Response to Business Process Modeling (circa 1992)

- **Provide a work systems design tool that the people we are trying to help can use:** Not something else that needs to be learned and fit into the work process
-
- **Make Social Processes Visible**
  - How **people participate** to get jobs done
  - How the **environment** and use of space affects work
  - How **communication** happens
  - What **tools and artifacts** are used/created
  - What **informal methods & tools** resolve breakdowns (workarounds)
- **Activity perspective:** People conceptually situated—in groups, interacting with each other, their tools, and the environment
- **Human-Centered Design:** Look beyond job functions and interfaces to grasp the *total work system*

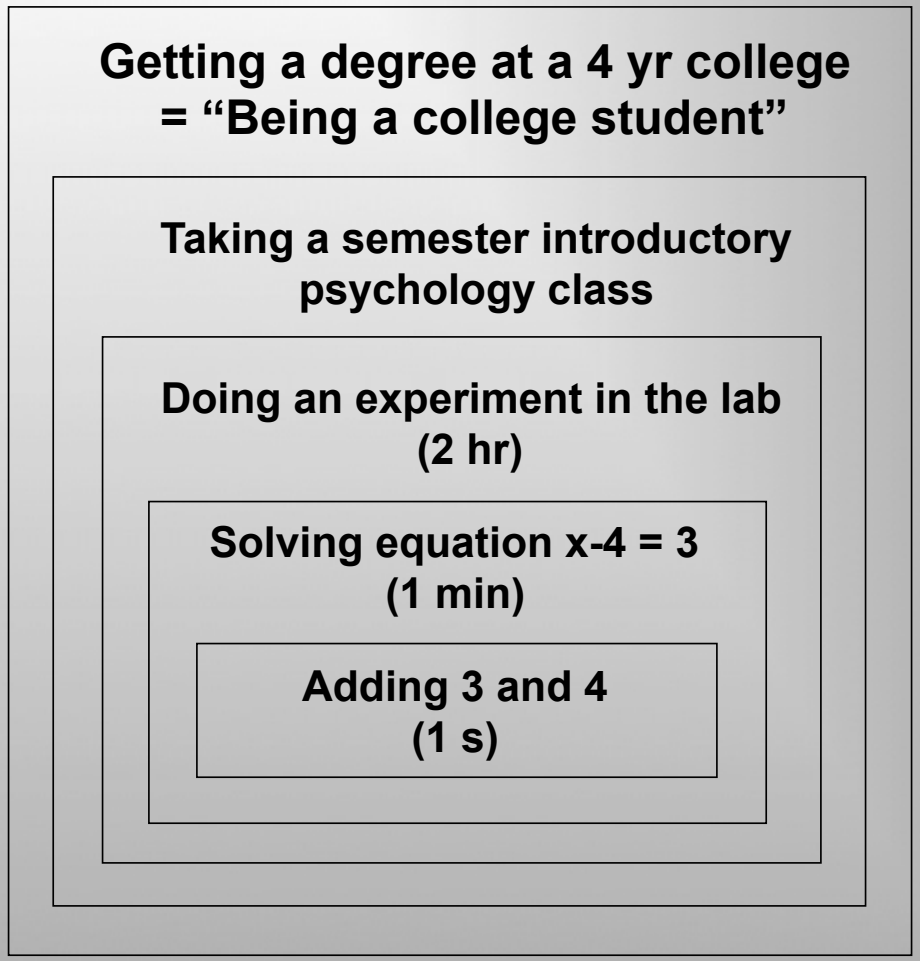
Tasks vs. Activities

Problem-Solving Perspective

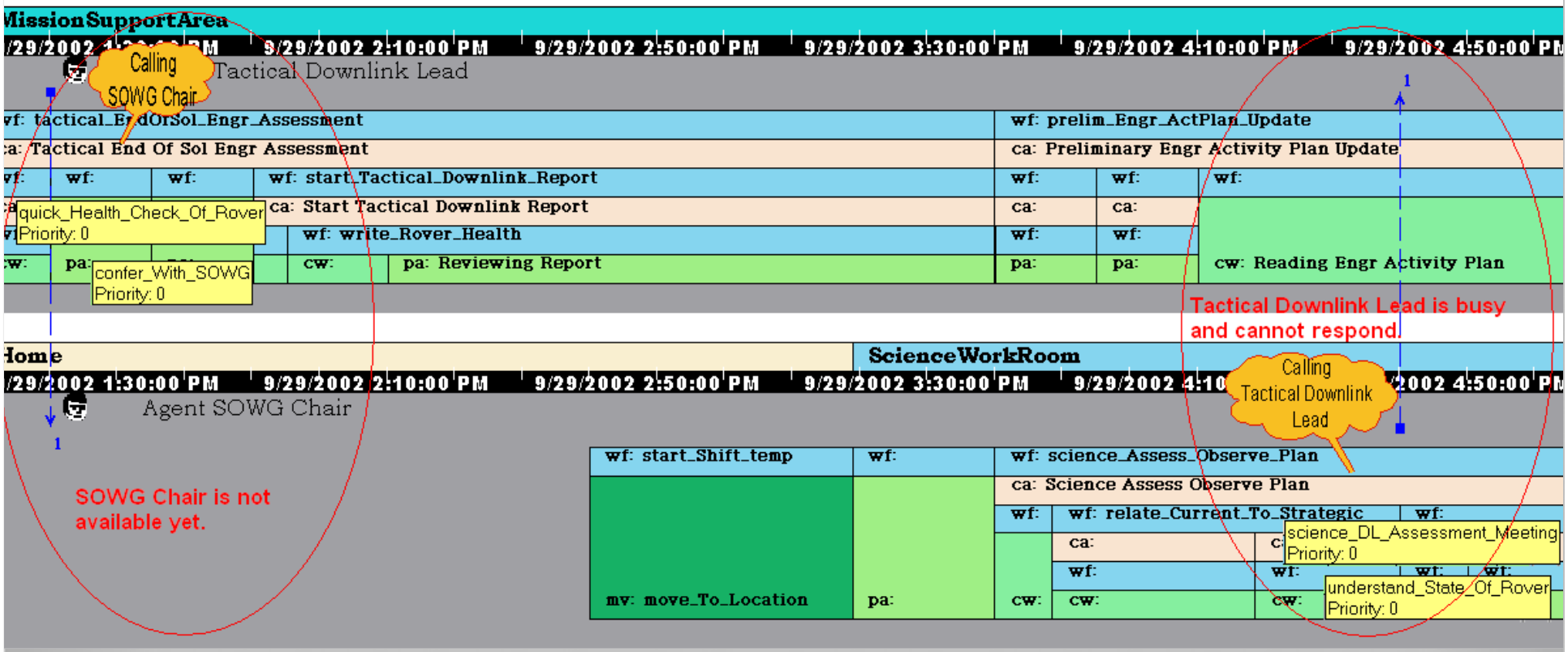
Goal Stack

6. Add 3 and 4
5. Solve x-4 = 3
4. Solve equation on screen
3. Get experiment credit
2. Pass introductory psychology
1. Get college degree

Activity Perspective



Brahms Agent Viewer Timeline



Brahms History

2001-2006 **NASA Intelligent Systems Program:**

- Mission operations simulations: FMARS, MER, Victoria, ISS
- BrahmsVE (DigitalSpace)
- Real-time Distributed Agent Execution engine (VM)
- Mobile Agents: "automating CAPCOM" for Mars surface EVAs

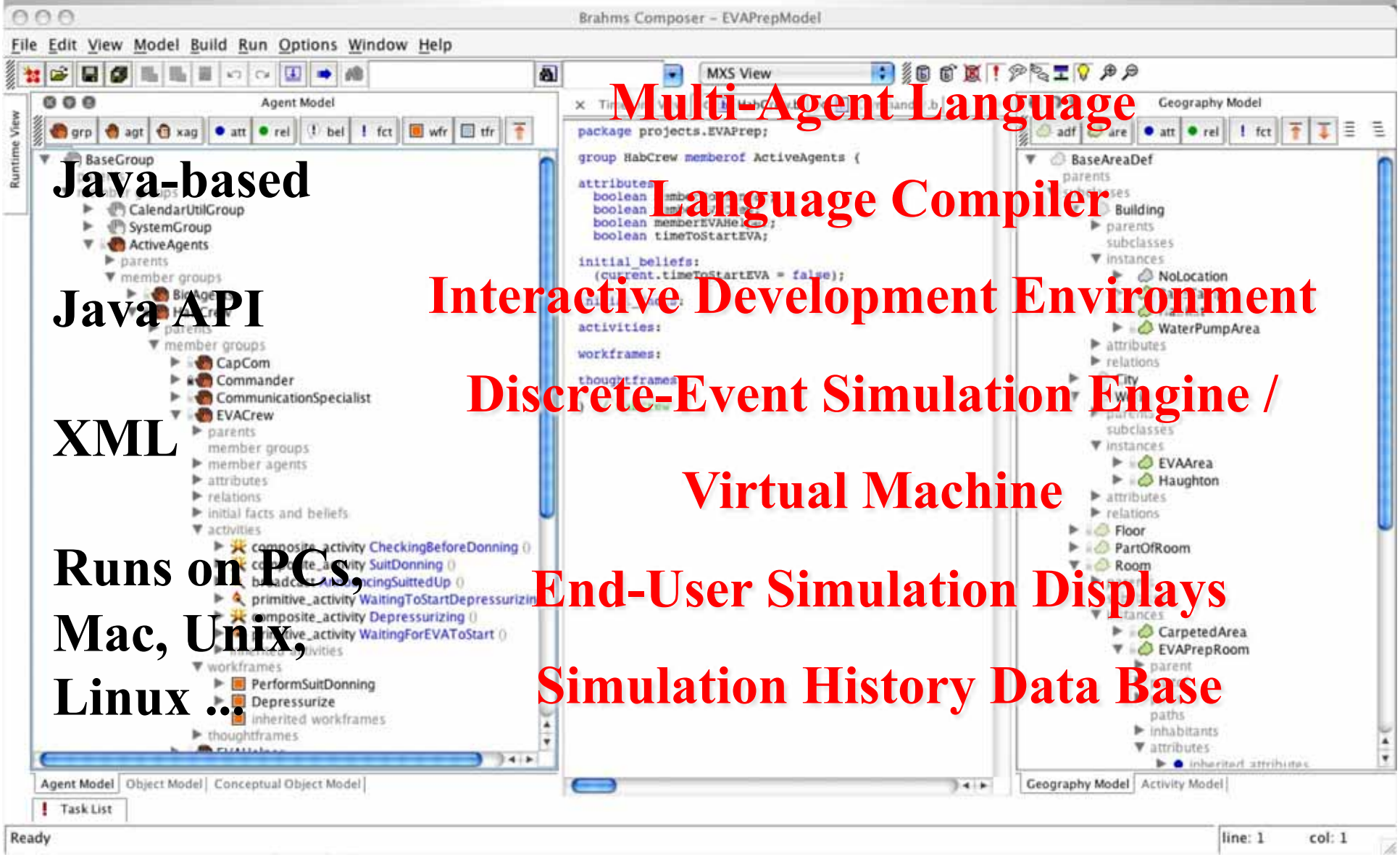
2005 **NASA ESAS Program:** CEV & robotic simulation (6 months)

2006-2011 **JSC-Ames Partnership:** mission support automation

- "Simulation to Implementation" methodology
- OCAMS: routine file management between ground support and ISS crew (JSC Exceptional Software Award)

2011 **Air Traffic Control:** Protocol simulation & model checking

The Brahms System



Multi-Agent Language

Language Compiler

Interactive Development Environment

Discrete-Event Simulation Engine / Virtual Machine

End-User Simulation Displays

Simulation History Data Base

Java-based

Java API

XML

Runs on PCs, Mac, Unix, Linux ...

Brahms Model Constructs

The world is modeled as a **Geography** (*consisting of* **Areas** & **Paths**) *containing…*

- **Agents**
  - *belong to* **Groups**
    - *which may have* **Beliefs & Activities** *and contained sub-*Groups
  - *have* **Facts** *describing them (e.g., physiology)*
  - *have* **Beliefs** *about the world (uncertain propositions)*
    - *which may lead them to engage in interactive behaviors, modeled as…*
  - **Activities**
    - *specific to the agent or inherited from groups*
    - *may be composite, consisting of collections of prioritized…*
    - **Workframes**
      - *with* **Conditions** *satisified by an agent's beliefs,*
      - *entailing* **Actions** *such as communication, movement, and primitive or composite activities,*
      - *during which* **Detectables** *model the agent's perception of* **Objects** *as changed beliefs*
      - *having* **Consequences** *that change…*
        - » *the agent's* **Beliefs**
        - » *facts about* **Objects**
    - *And anytime during an activity, changed beliefs may trigger…*
    - **Thoughtframes**
      - *with* **Conditions** *and* **Consequences** *(again changing the agent's beliefs)*
- **Objects**
  - *are instances of* **Classes**
  - *have properties (attribute-values) called* **Facts**
  - *may have interactive behaviors modeled as* **Activities.**

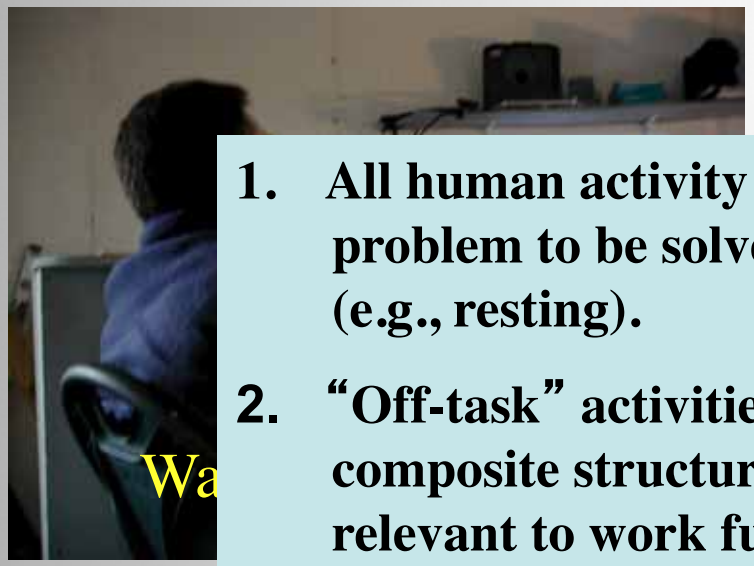
Activity as Unit of Analysis

- Activities are consciously choreographed behaviors in the world
- “What am I doing now?” = “Who am I being now?”= “How am I behaving now?”
- Social, i.e., realizing norms of appearance, speech, action
- Define/Determine roles, communications, schedules, methods, tools
- Frames how problems are described and approached
- Focuses modeling on interactions & modes

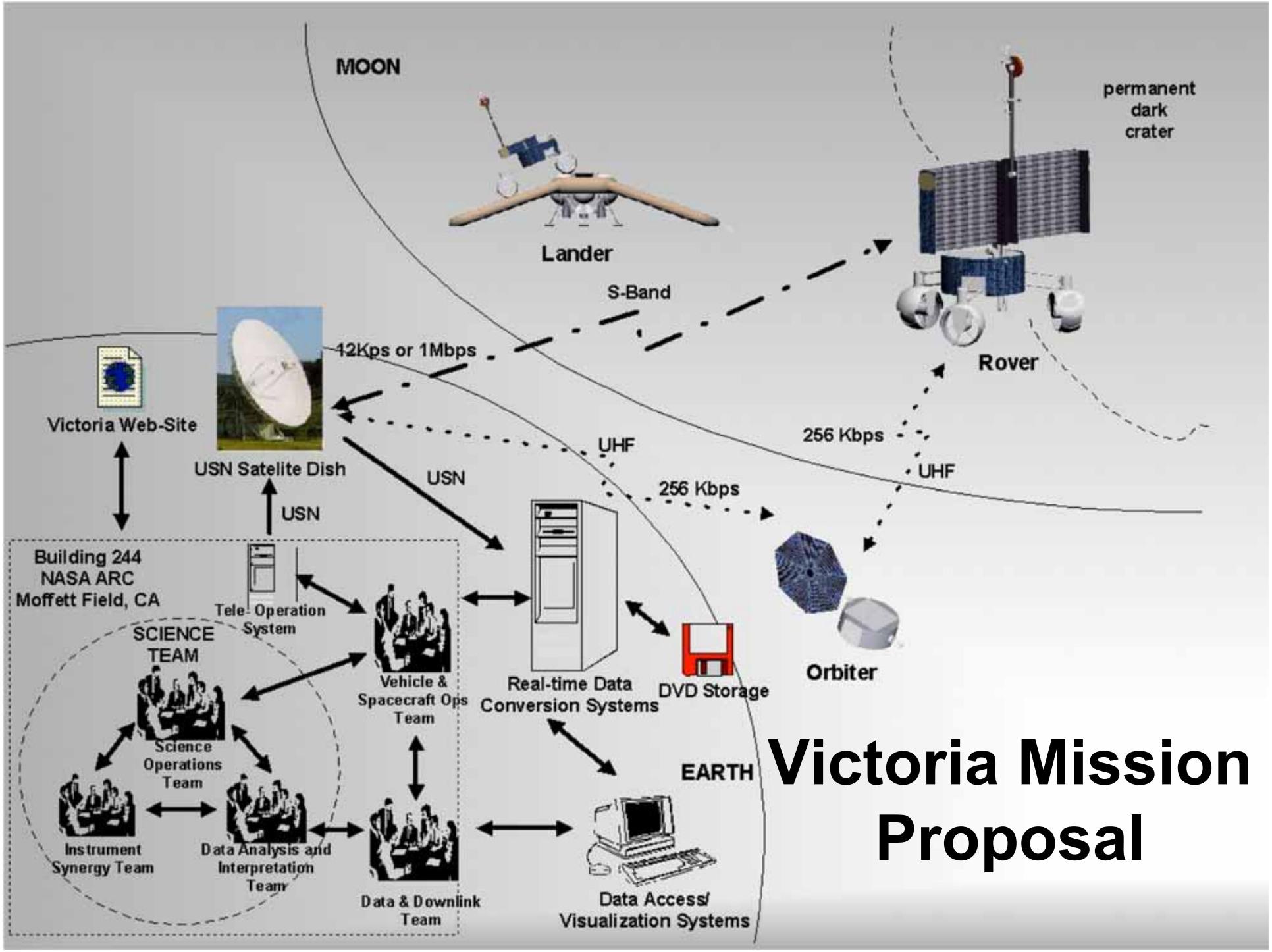
Working Alone Together

A group activity that is not collaborative

Modeling Activities
Describing & Explaining Behavior

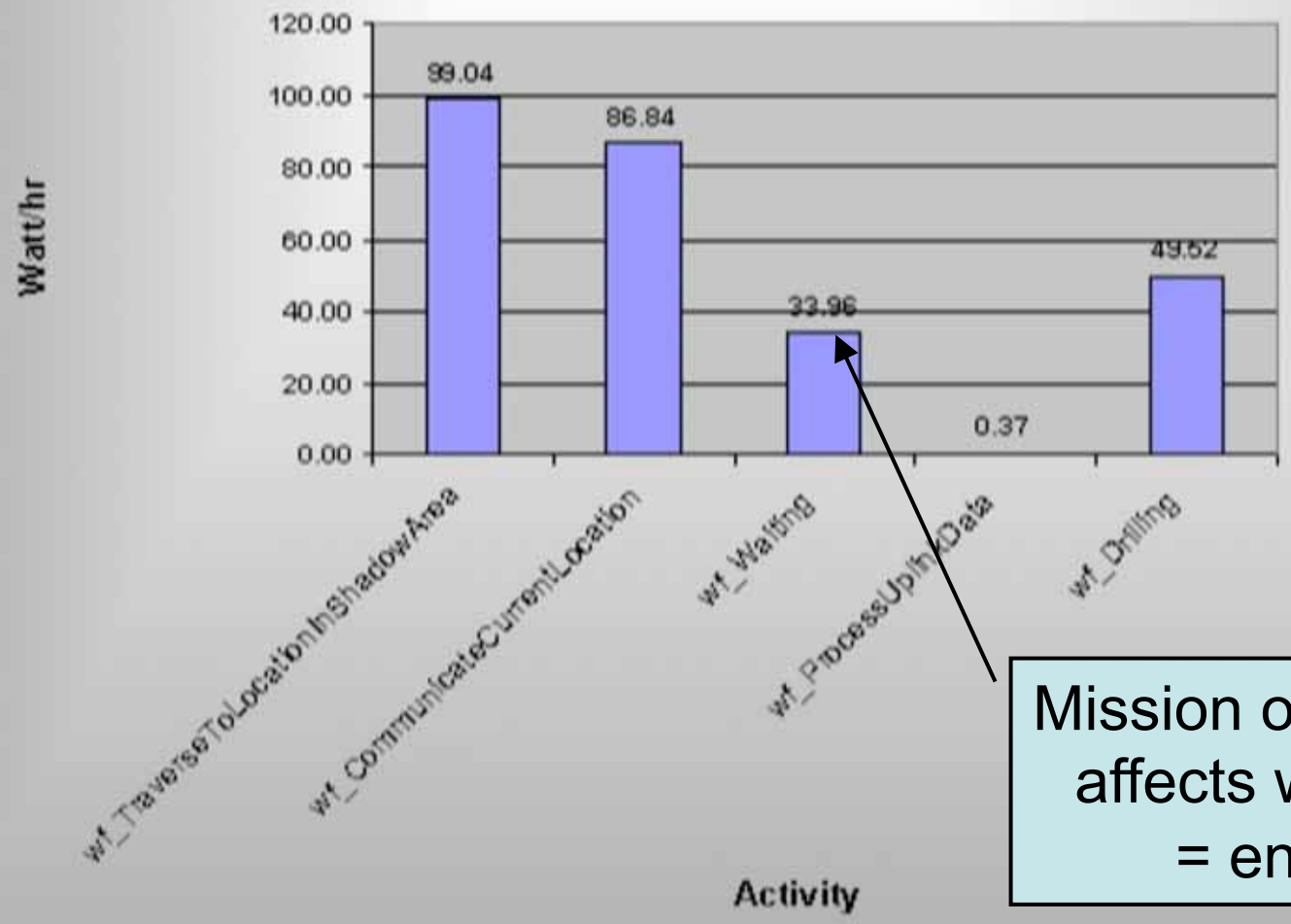


1. **All human activity is purposeful, but not every goal is a problem to be solved and not every activity performs a task (e.g., resting).**
2. **"Off-task" activities (waiting, talking, playing) have composite structure, norm-based variations, and purposes relevant to work functions.**
3. **Some goals are states to *sustain*, not requiring search or pathfinding (e.g., brainstorming).**
4. **Includes physiological & regulatory goals (e.g., a relaxing change of pace)**



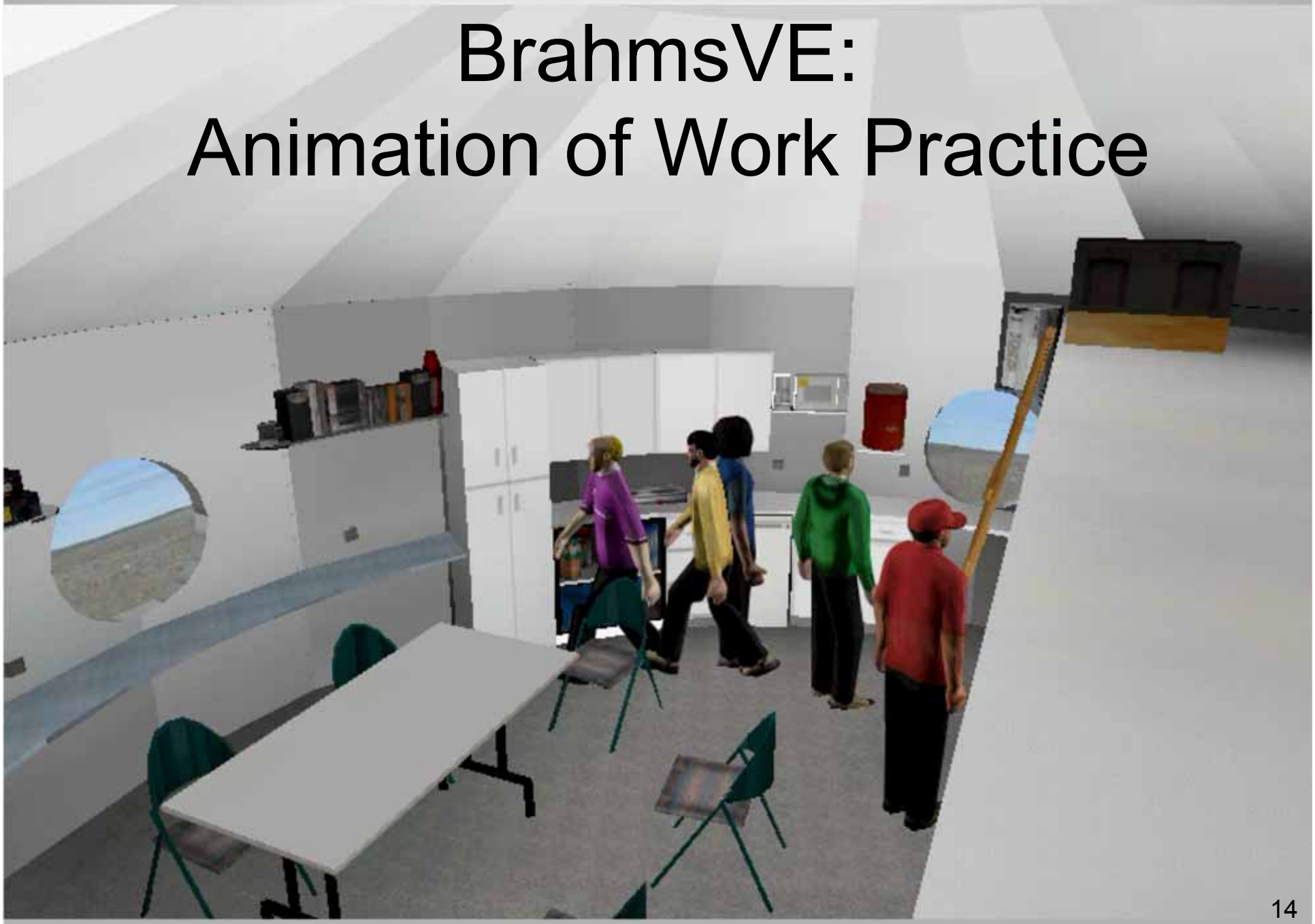
Victoria Mission Proposal

Victoria Rover Energy Used in Drilling Activity *(Brahms output)*

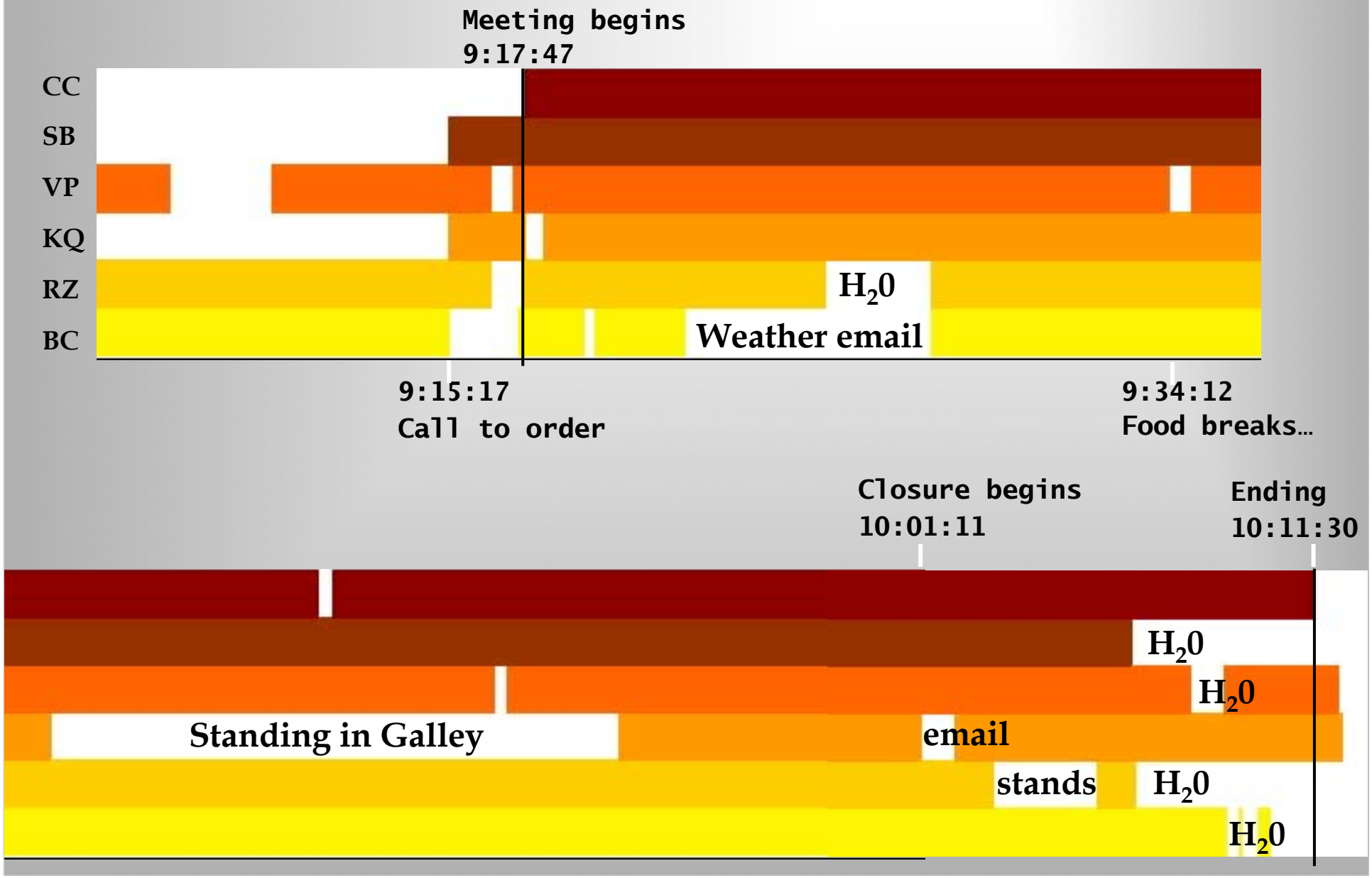


Mission ops design affects wait time = energy

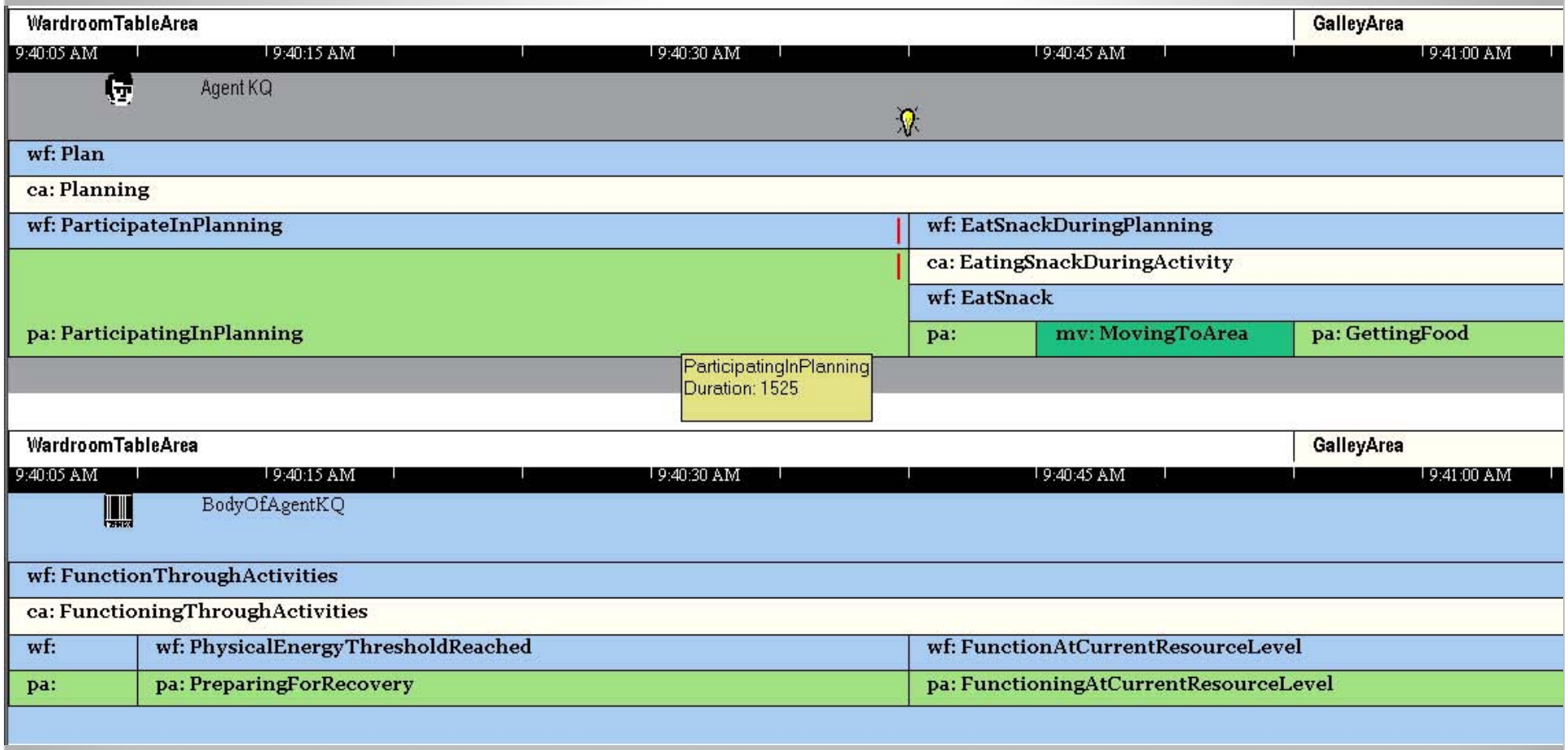
BrahmsVE: Animation of Work Practice



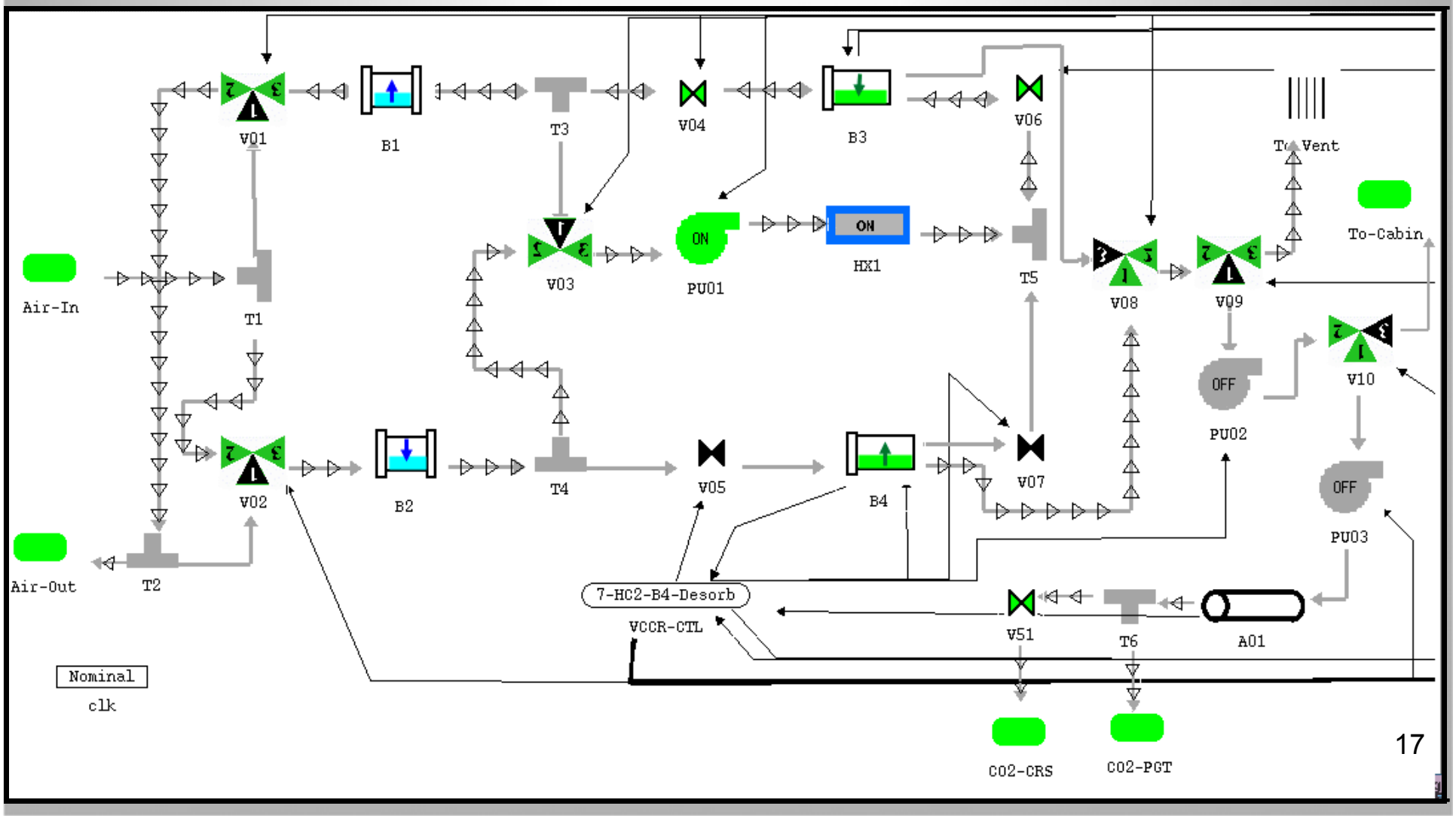
Patterns: Norms of an Ensemble



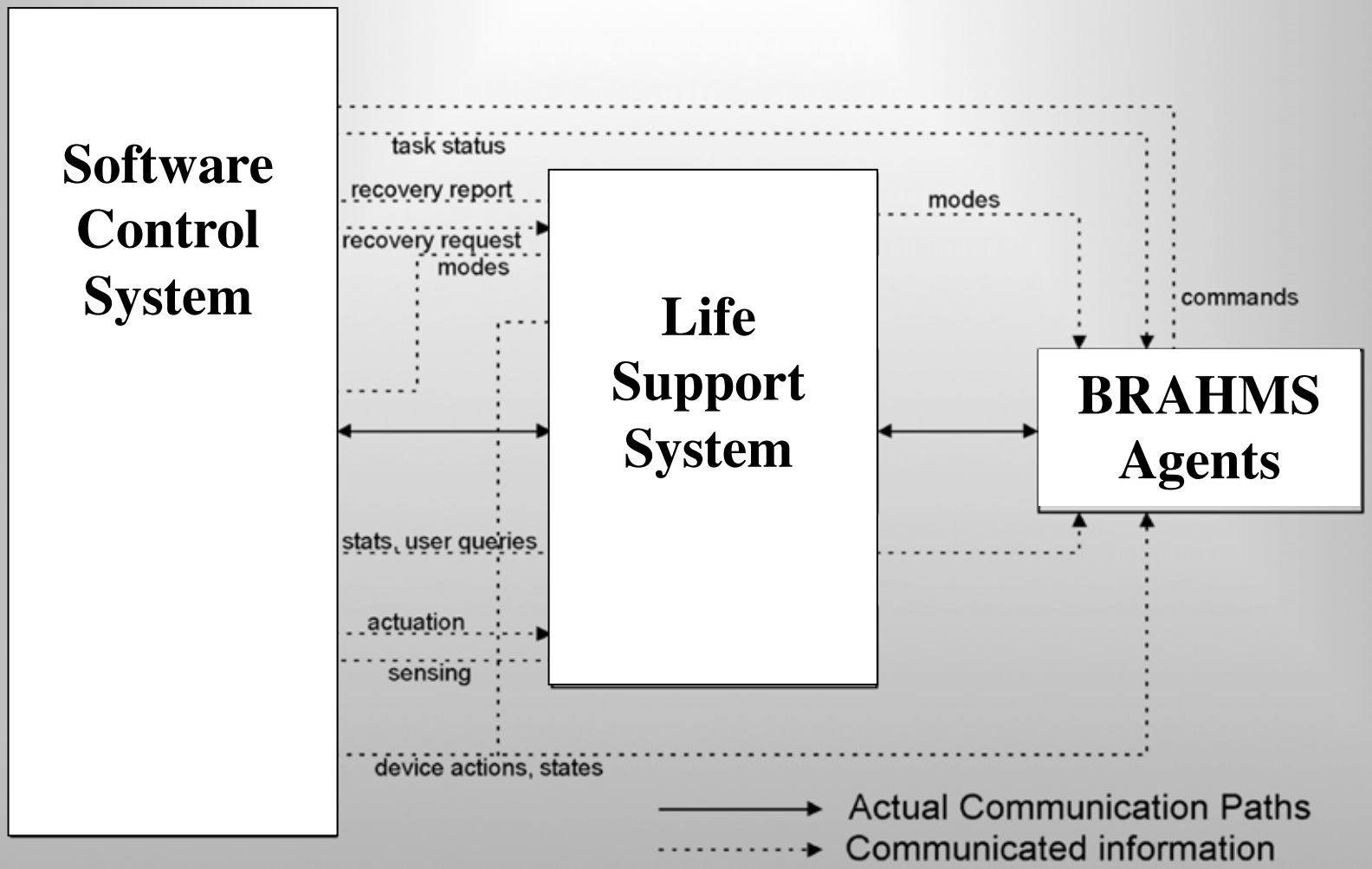
Modeling Biological Motives



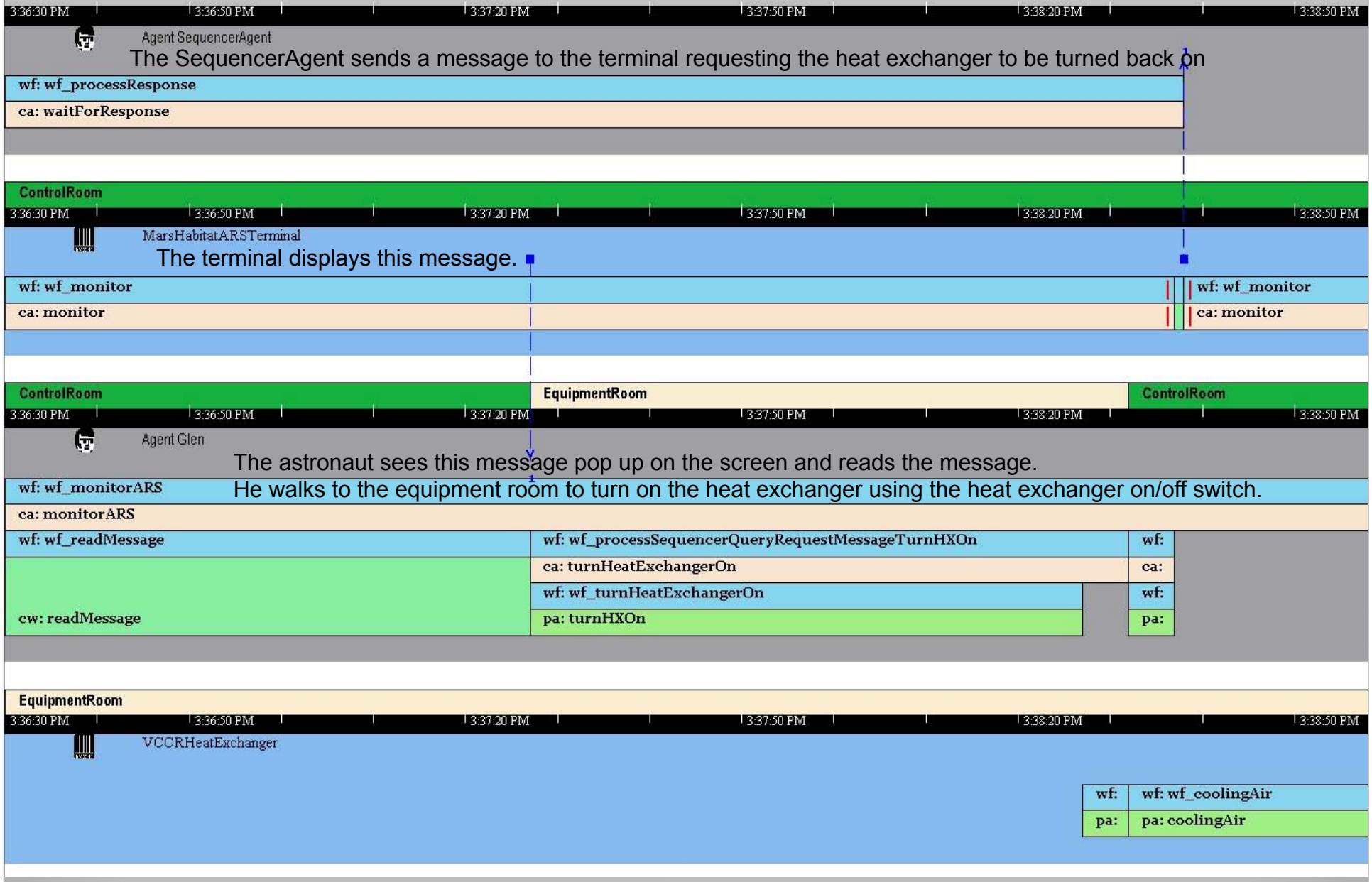
CONFIG Model: CO_2 Recovery System



Brahms-CONFIG:
Coupled Human-Systems Simulation



Brahms-CONFIG Output: Crew member processes request by life-support software



The heat exchanger powers on and starts cooling air. He waits until he sees that the heat exchanger indeed starts cooling air. He walks back to the control room and presses the Yes button on the screen to confirm that the heat exchanger is on again. The terminal processes this answer and sends the results back to the SequencerAgent.

Brahms Characteristics

- **Modeling Language & Architecture**
  - Behaviors (vs. tasks/functions & inferences)
  - Subsumption activation (vs. procedure stack)
  - Perception scoped by activity (vs. unbounded awareness)
  - Dual-API method for integrating agents & external systems
- **Content**
  - Focus on located, circumstantial interactions (vs. idealized flows & prescribed processes)
  - Variable detail: Sketch practice or *how* connectivity happens
  - Design questions answered by metrics => scope
- **Applications**
  - Oriented to social conception of role, participation factors: Whose knowledge is called into play? How?
  - Integrated Systems: Hardware, control systems, voice commanding, other simulations, VR

Limitations

- **Our theory of practice exceeds what we can model**
  - Omits learning within work practice (e.g., improvisation)
  - Emotions & Activity (e.g., recuperation by reading newspaper)
  - Reflection on quality of group dynamics (e.g., confrontations)
  - Blending of identities/priorities (adapted methods)

- **Modeling tools perennially underfunded**
  - Need libraries, drag and drop agents, geography editor
  - Simulation-to-implementation requires handcrafting
  - Need model validation methodology

- **What we're working on next..**
  - Brahms compiler for model checking (and efficiency?)
  - Simulating air-traffic control failure scenarios to push fidelity of modeling communications across organizations

For more information…

- Brahms: http://www.agentisolutions.com
  - Download available for academic research
  - Language definition
  - Tutorial
- Publications & Photos: http://Bill.Clancey.name
- Key papers:
  - *Simulating activities*
  - *Cognitive modeling of social behaviors*
  - *Multiagent modeling and simulation in human-robot mission operations work system design*
  - *BrahmsVE: From human-machine systems modeling to 3D virtual environments*
  - *Multiagent Simulation to Implementation: A practical engineering methodology for designing space flight operations*

Modeling in Brahms: Agents Facts & Beliefs Objects

William J. Clancey, PhD

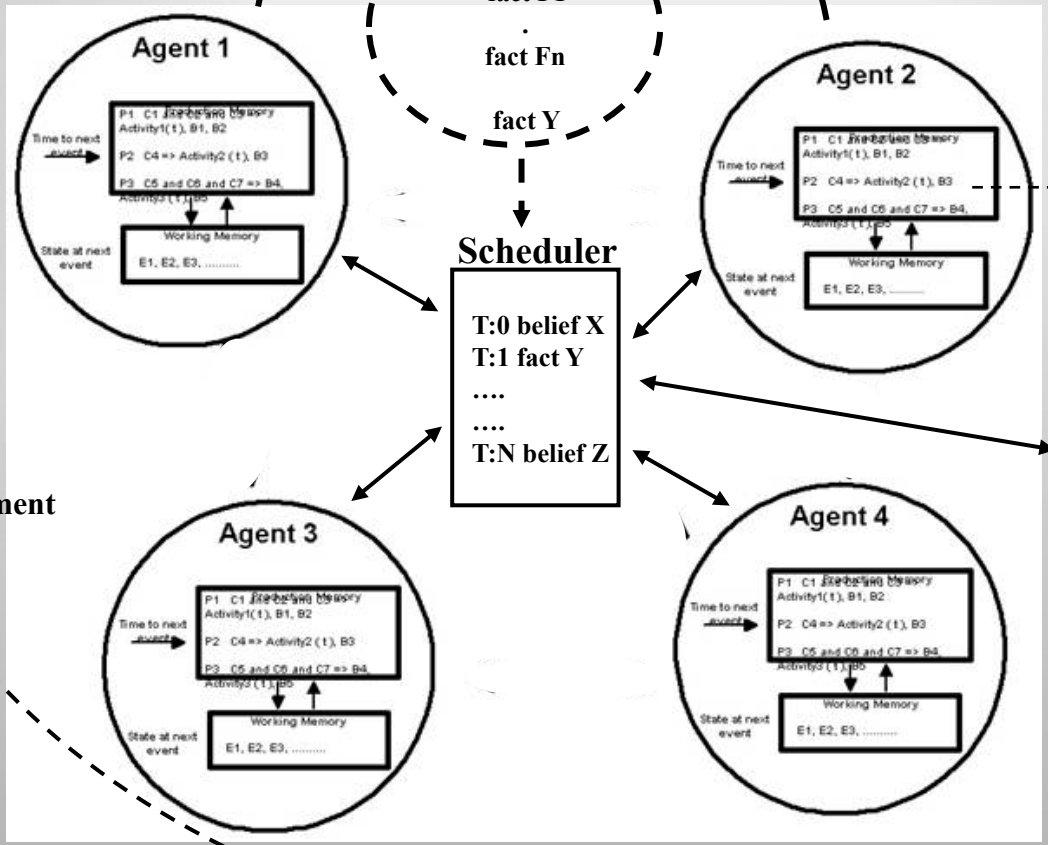
Florida Institute for Human and Machine Cognition
NASA/Ames Research Center

Multiagent Modeling Language

BRAHMS

Virtual Machine

Integrate:
Other Simulations
Devices & Systems
People



Java

class Activity2 extends
AbstractExternalActivity
{ .... }

Java Agent 5

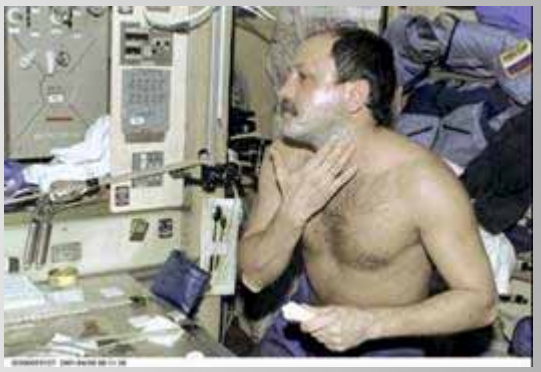
class Agent5 extends
AbstractExternalAgent
{ .... }

World environment

Brahms Agents

- People or Interactive Systems (e.g., robots)

- Characteristics:
  - Located & Mobile
  - Have behaviors
  - Communicate
  - Sense/Interpret Objects
  - Capable of inference

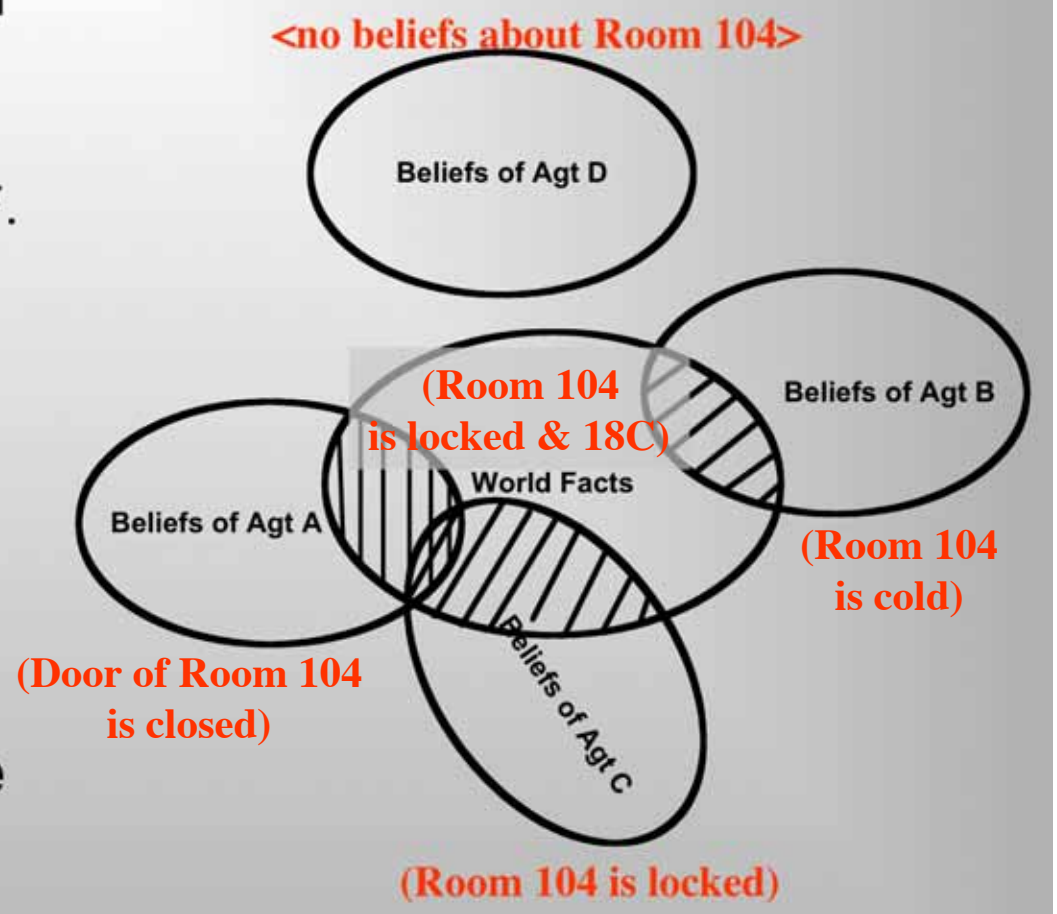


- Inherit facts, beliefs, activities from one more more {organizational, social, functional} groups

E.g., agent Dick_Gordon memberof CommandModulePilot { … }

Facts & Beliefs

- **Facts represent physical states of the world (objective)**
  - Alex's temperature is 98.0F.
  - Alex is located in room 104.
  - Room temperature is 18C.
  - Time is 10:40 AM.
- Agents can **detect facts,** forming beliefs (modeling human perception and system sensing).
- Agents can **communicate** their beliefs (Ask & Tell) & **make inferences** (Thoughtframes).

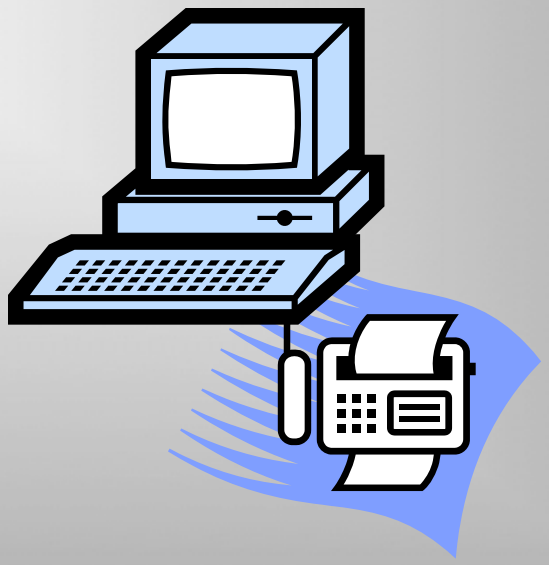


Example Beliefs

- **Represents an agent's interpretation of a fact**
  - *Alex believes "The temperature of Room 104 is cold."*
- **Represents an agent's conception of identity/activity**
  - *"I am a student at University of California, Berkeley."*
  - *"I am working on tomorrow's homework."*
- **Represents an object's world model:**
  - *E.g., represented in a computer program: "Alex's bank account balance is $454.23."*
  - *E.g.,written in a document: "Total = $454."*

Brahms Objects

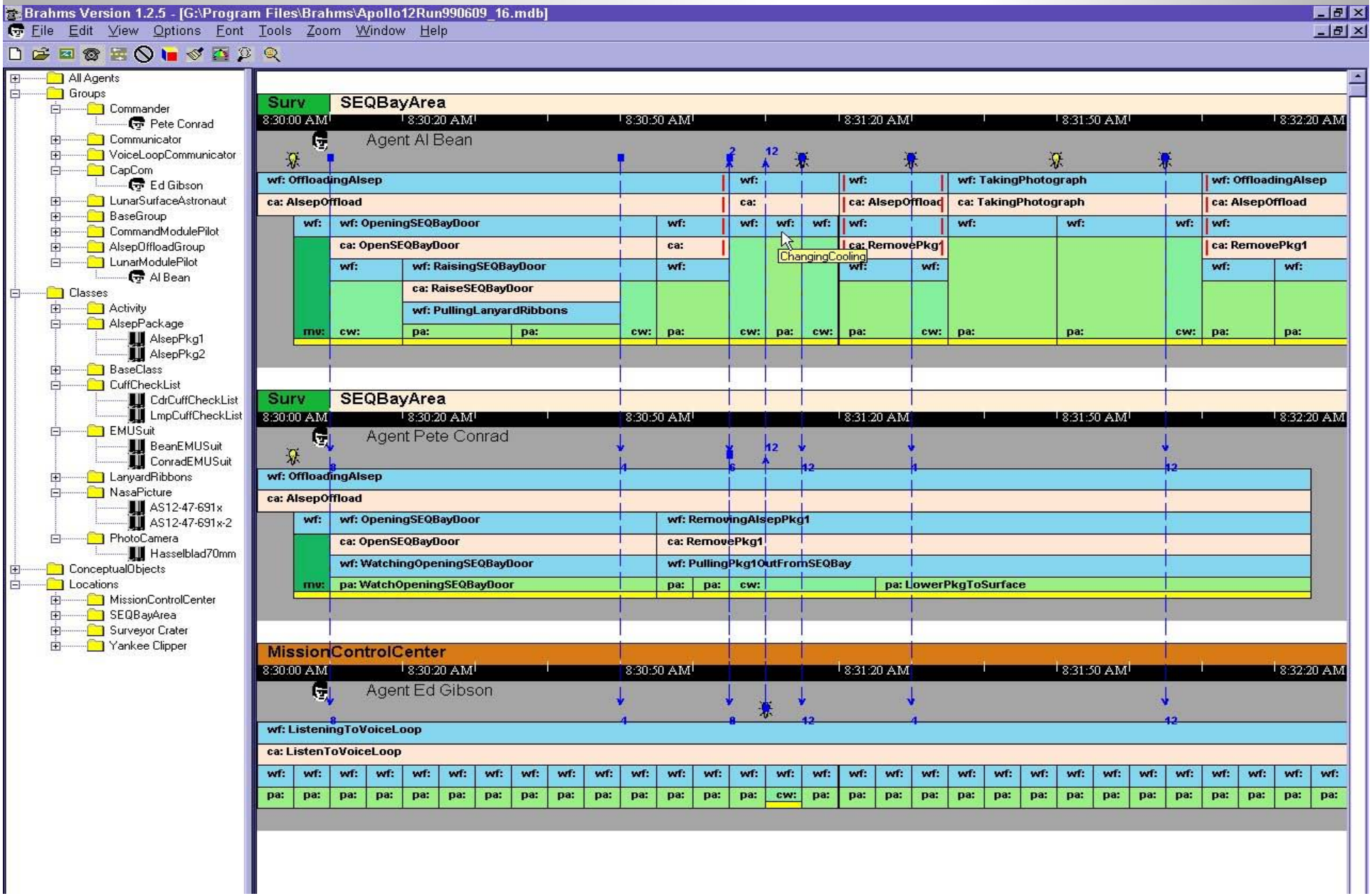
- Objects may be **conceptual** (e.g., jobs, computational data sets) or **physical** (e.g., inanimate artifacts, tools)
  - *Conceptual objects do not have behaviors.*
- Whether to categorize physical objects with behaviors as agents is a convention of particular work situation.
  - *Robots are Agents; Databases are objects*
- *Physical Object Examples:*
  - Computers
  - Instruments
  - Rock samples
  - Cameras
  - Space suits
  - ATM



Brahms Activities:

Composite Activity
Communication
Movement
Primitive (Action)

Brahms Agent Timeline



Communication Examples

Group Student:

```
communicate communicatePIN(Atm at3) {
    max_duration: 1;
    with: at3;
    about:
        send(current.pinCommunicated = unknown),
        send(current.believedPin = unknown);
    when: end;
}
```

Communications *—* ***activities*** *that* ***transfer beliefs*** *from one agent to one or more agents, or to/ from objects that include data*

Class Bank:

```
communicate replyAtm(Atm at3, Account bka) {
    max_duration: 1;
    with: at3;
    about:
        send(current.correctPin =  unknown),
        send(current.enoughBalance = unknown),
        send(bka.balance = unknown);
    when: end;
}
```

Examples:

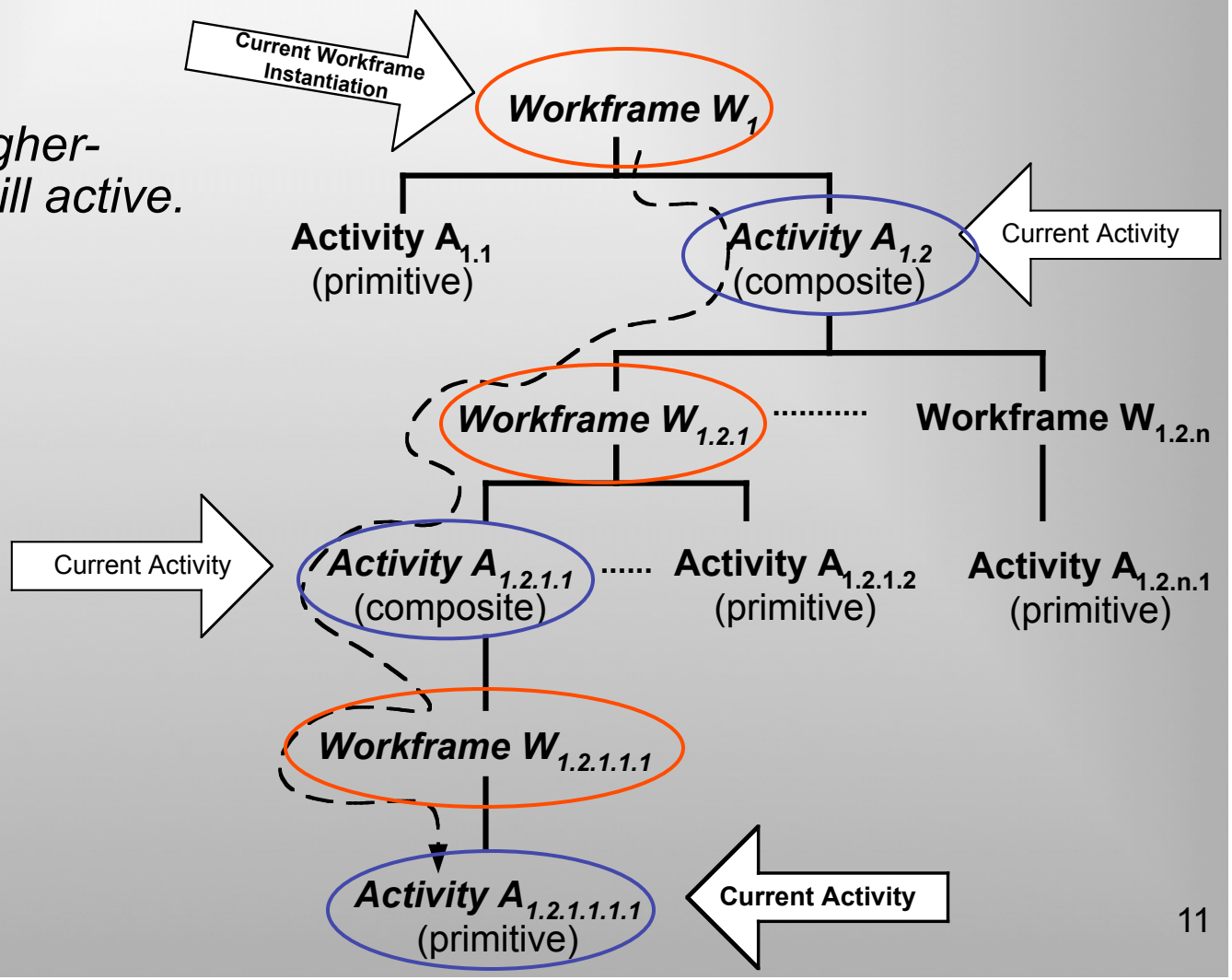
- *Face-to-face conversations*
- *Reading or writing document/interface*
- *Software agent communications*

Composite Activity: Study( )

- Student
  - parents
  - member groups
  - member agents
  - attributes
  - relations
  - initial facts and beliefs
  - activities
    - composite_activity study ()
      - parameters
      - detectables
      - activities
        - primitive_activity reading ()
      - workframes
        - wf_readingWhileStudying
          - variables
          - detectables
          - preconditions
          - body
            - reading()
      - thoughtframes
        - tf_needCashToEat
        - tf_enoughCashToEat
        - tf_HowMuchMoneyToGet_HungryEQhigh
        - tf_HowMuchMoneyToGet_HungryEQlow
        - tf_HowMuchMoneyToGet_HungryEQmedium
        - tf_Hungriness_High
        - tf_Hungriness_Low
        - tf_Hungriness_Medium

Workframe-Activity Subsumption Hierarchy

While "in" an activity higher-order activities are still active.

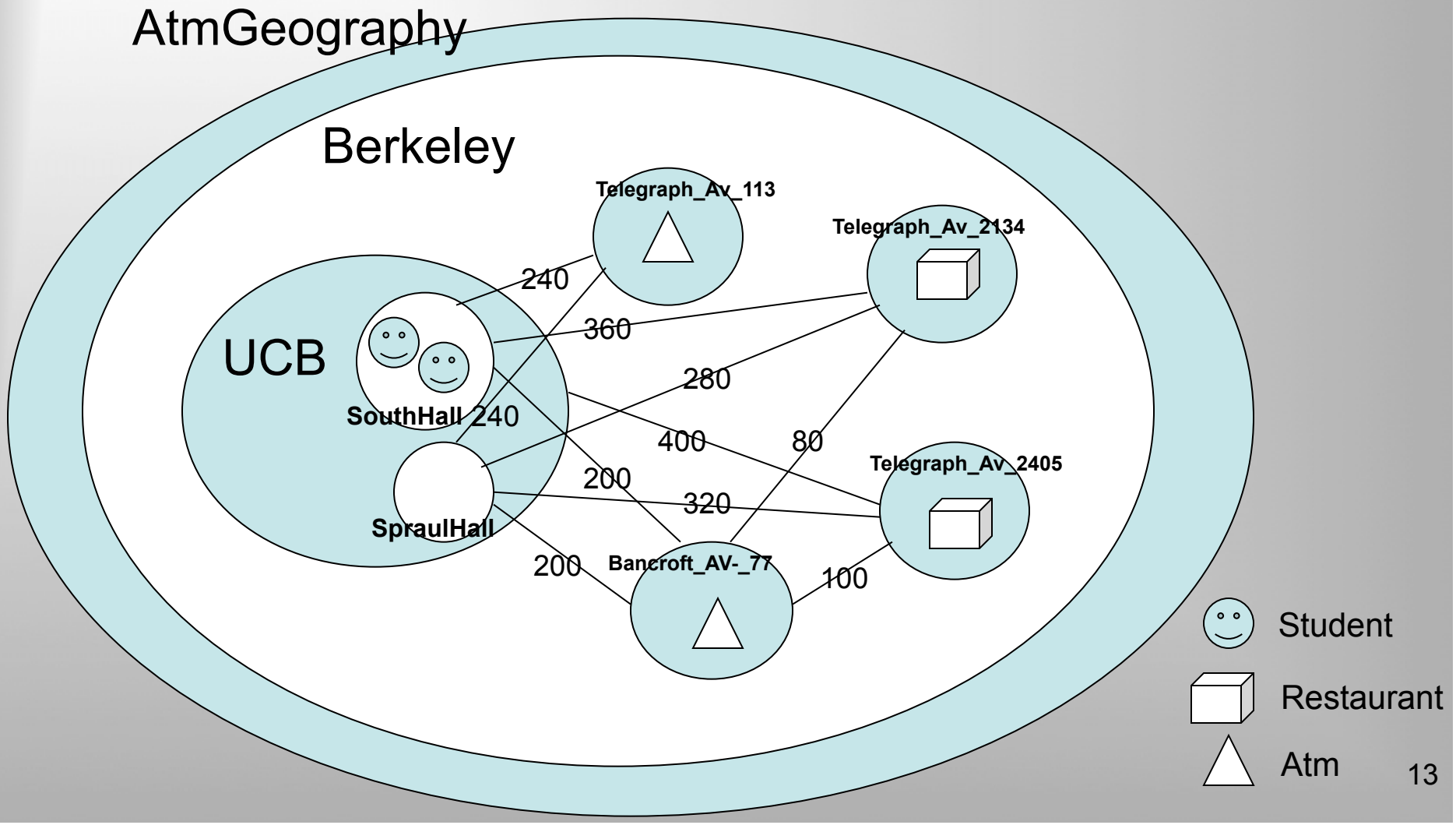


Brahms Geography

Example Geography Model

```
//paths to and from banks from
spraul and south halls:

path SpH_to_from_WF {
        area1: SpraulHall;
        area2: Bancroft_Av_77;
        distance: 200;}
```



Some Geography Details

- Agents/Objects have **initial locations**.
- **Duration** of move action is specified by modeler.
- Agents know where they are and **notice** others:
  - When agents come into a location, the Brahms automatically gives the agent…
    - a belief about its new location
    - a location belief for all other agents and objects currently in that location.
- Agents and objects can **carry** other agent/objects.
  - Built-in *containment* relation
  - Contained objects are not noticed until they are *put* into the area.

BrahmsVE

```
workframe CheckWaterLevel
when (unknown
    (current.timeToFillWaterTank))
detectable DetectWaterLevel {
    detect((WaterTank.waterLevel = 0))
    then continue;}
```

```
do {Getup();
    Walk(GalleyLadderArea);
    Upladder(WaterTankArea);
    CheckWaterLevel();
    Downladder(GalleyLadderArea);
    Walk(WardroomTableArea);
    conclude((current.waterLevelChecked
    = true));
```

BrahmsVE
Animates Simulation Events

- **Brahms model definition:** move Upladder(BaseAreaDef loc) {max_duration: 5; location: loc;}
- **OWorld Service converts event:** activity|move|164|169|projects.fmarsvre.RZ|Upladder||projects.fmarsvre.GalleyLadderArea|projects.fmarsvre.WaterTankArea
- **OWorld Parser** (Javascript in Adobe Atmosphere) sends scheduled animation to agent object queue
- RZ agent's Upladder ***action script*** executes movement details

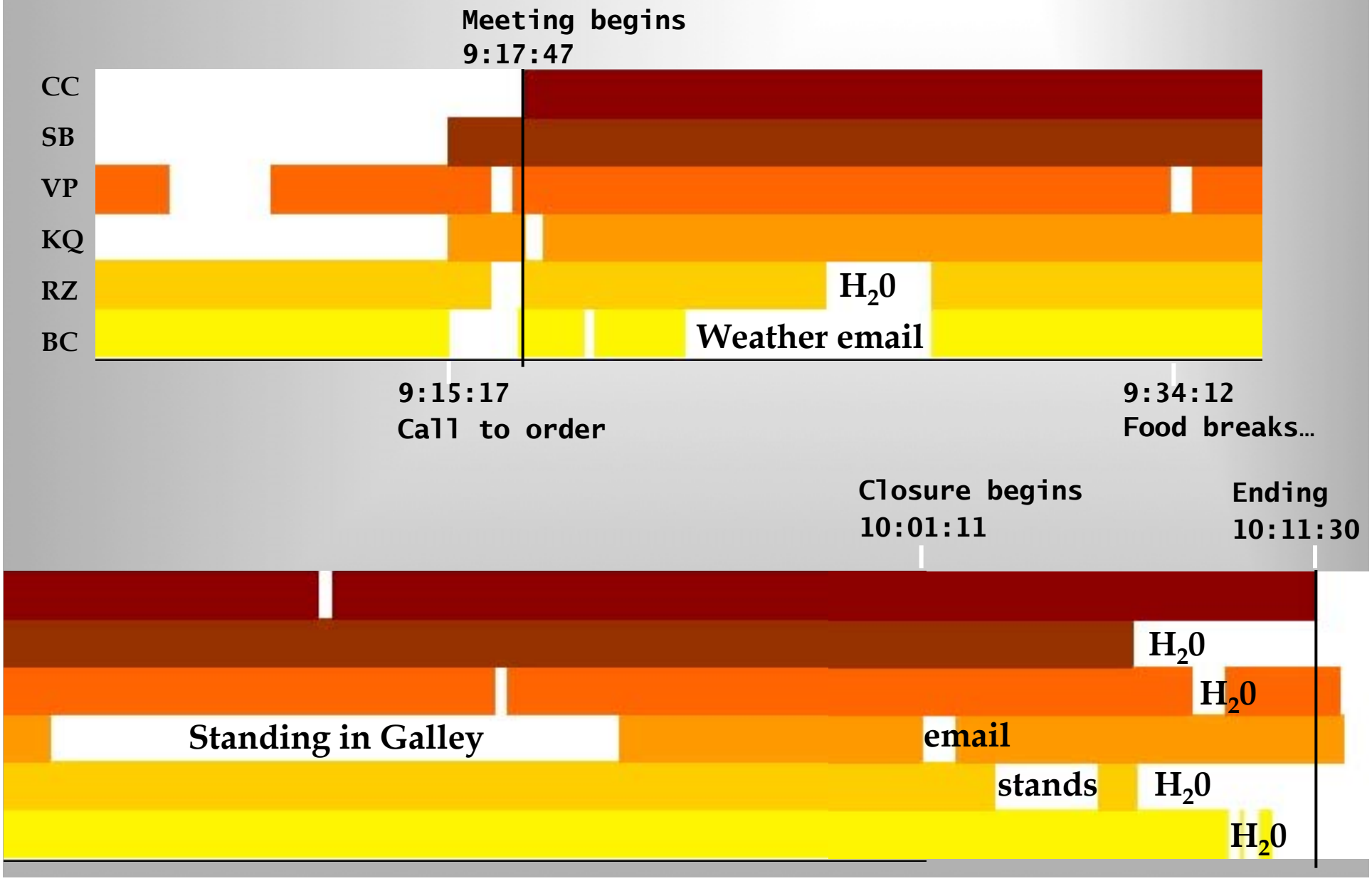
Camera angle changed dynamically by viewer running Adobe Atmosphere plug-in

BrahmsVE 2003 Status

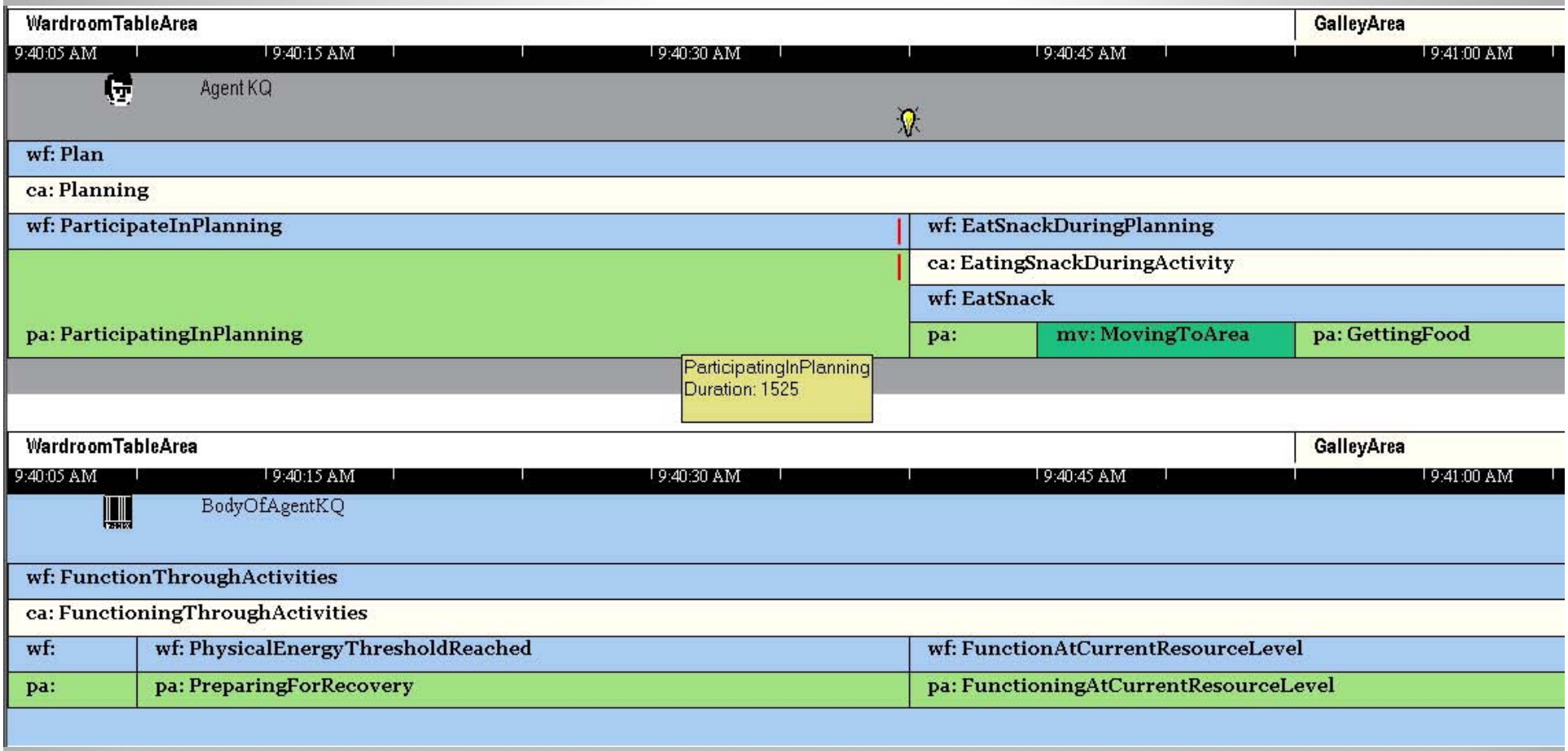
- Depicted three scenarios in Atmosphere action scripts (planning 200 scripts, water fill 67, EVA Prep 423).
- Not coupled real-time: Hard-coded timing and waypoints, so agents don't run through objects and each other
- Next: Co-Processing relation with Brahms engine (e.g., “Move” interruptible; dynamic paths)

Example: FMARS Planning Meeting Simulation

Patterns: Norms of an Ensemble

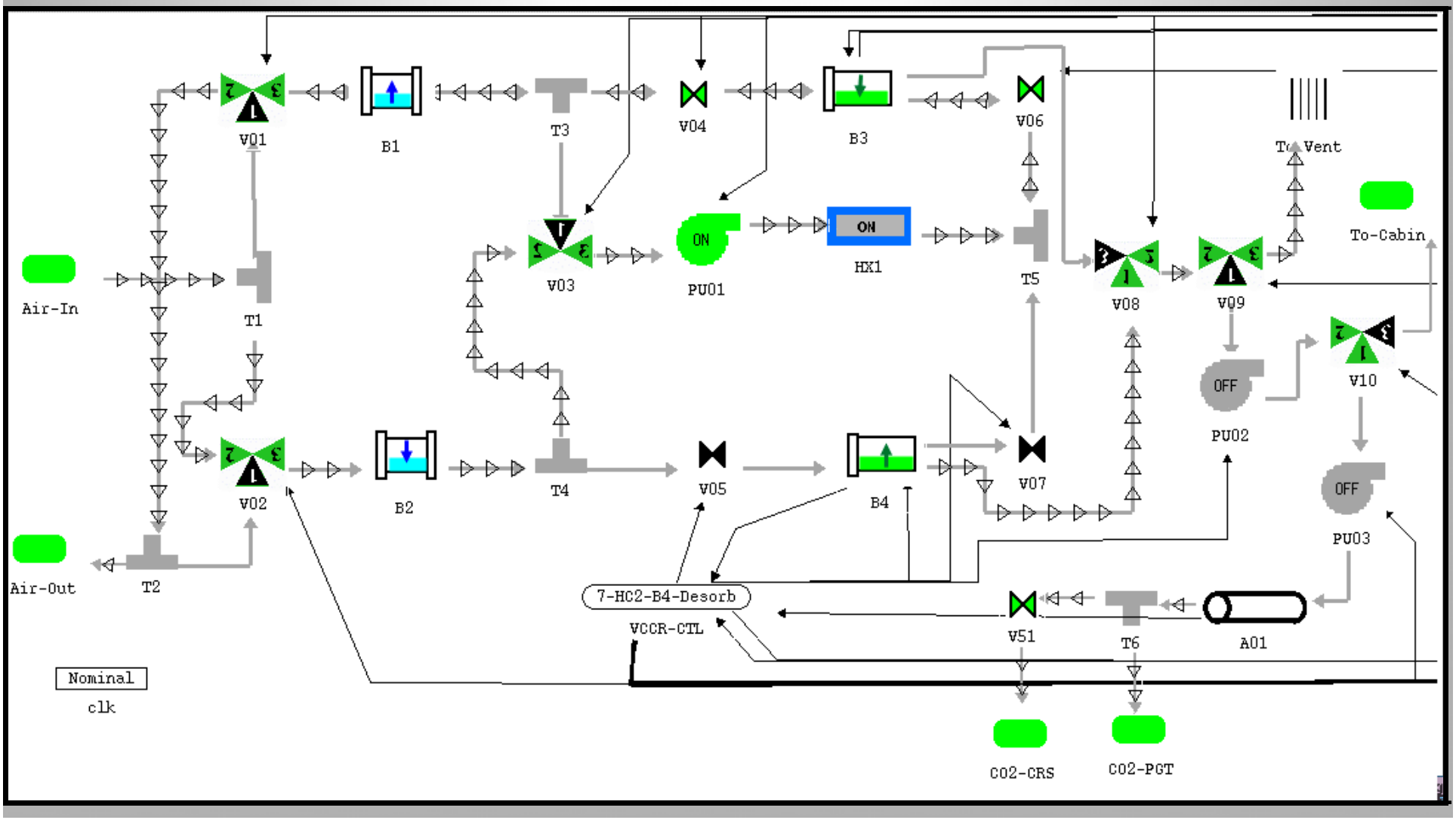


Modeling Biological Motives

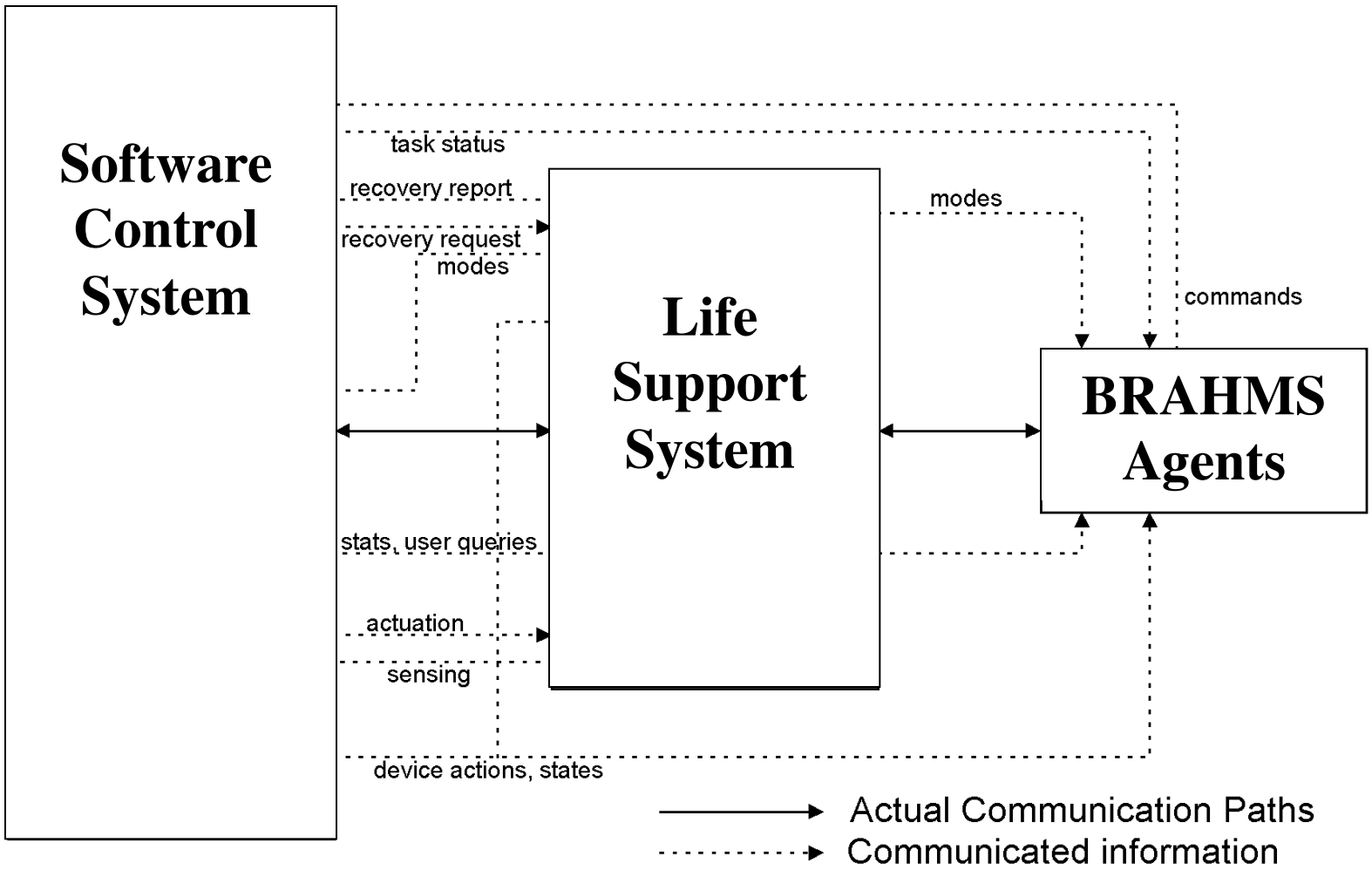


Example: Integration with CONFIG Systems Simulation

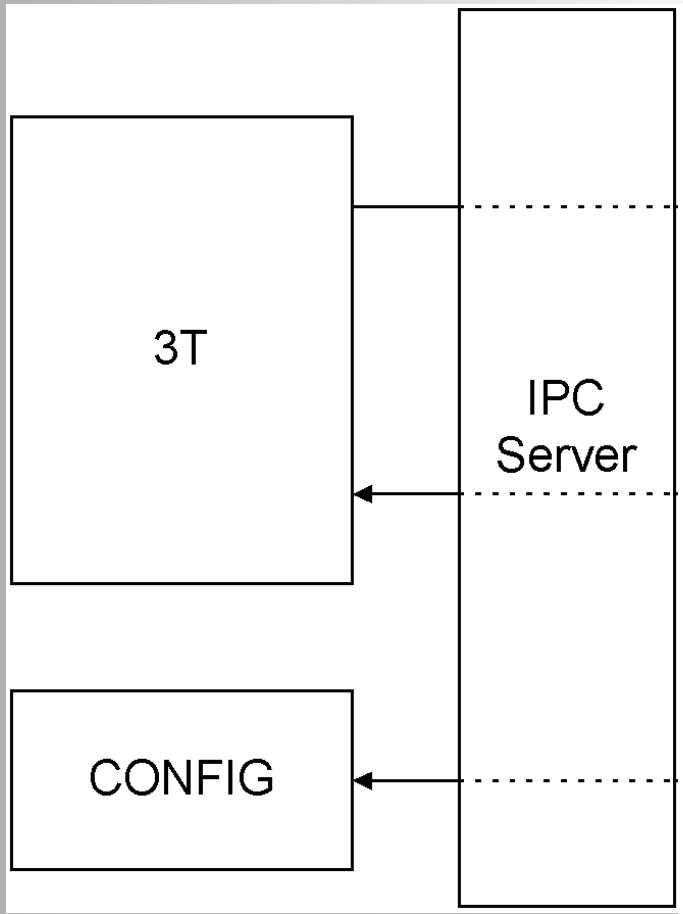
CONFIG Model: CO_2 Recovery System



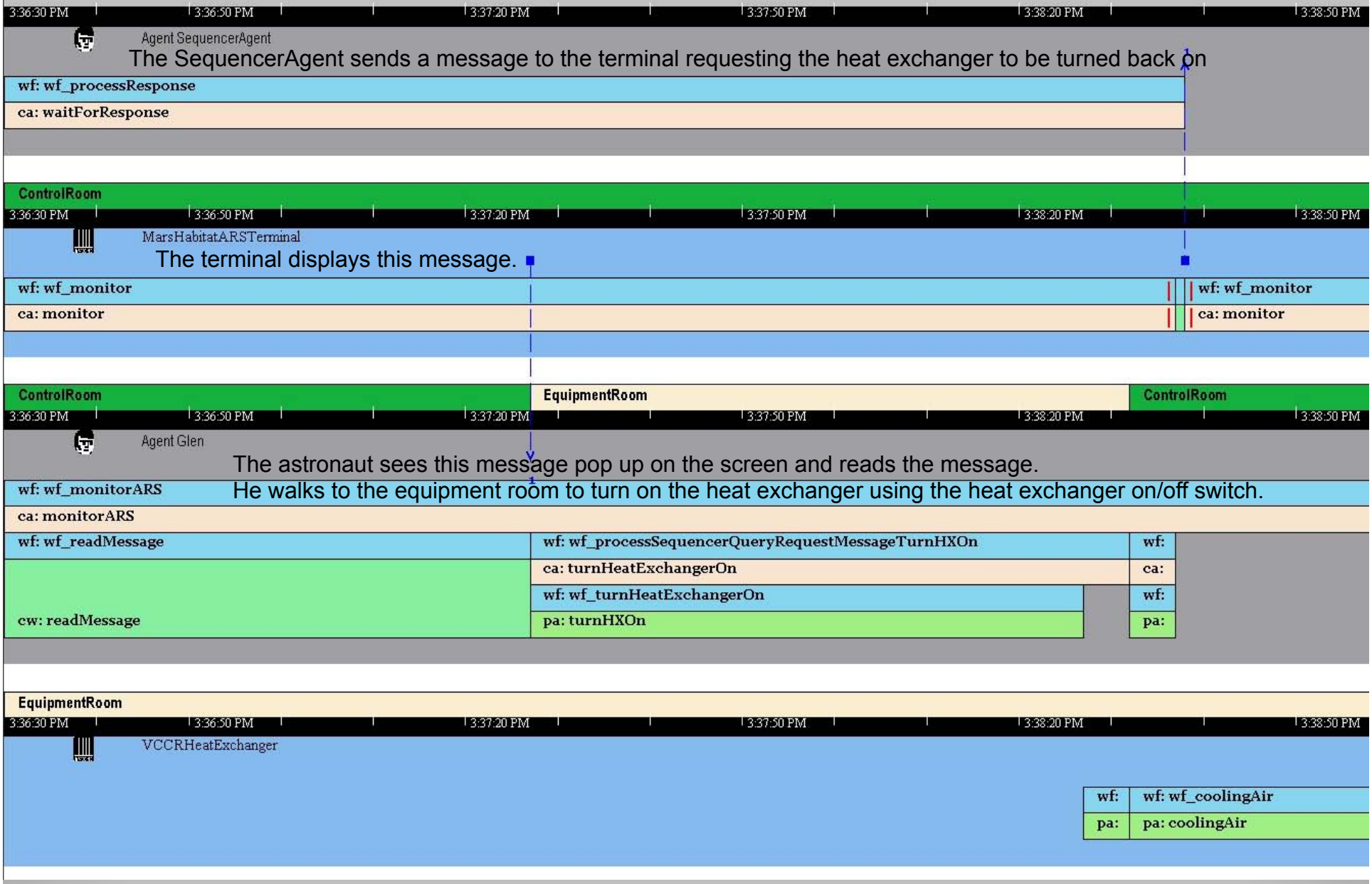
Brahms-CONFIG



Brahms Proxy Agents



Brahms-CONFIG Output: Crew member processes request by life-support software



The heat exchanger powers on and starts cooling air. He waits until he sees that the heat exchanger indeed starts cooling air. He walks back to the control room and presses the Yes button on the screen to confirm that the heat exchanger is on again. The terminal processes this answer and sends the results back to the SequencerAgent.

For more information…

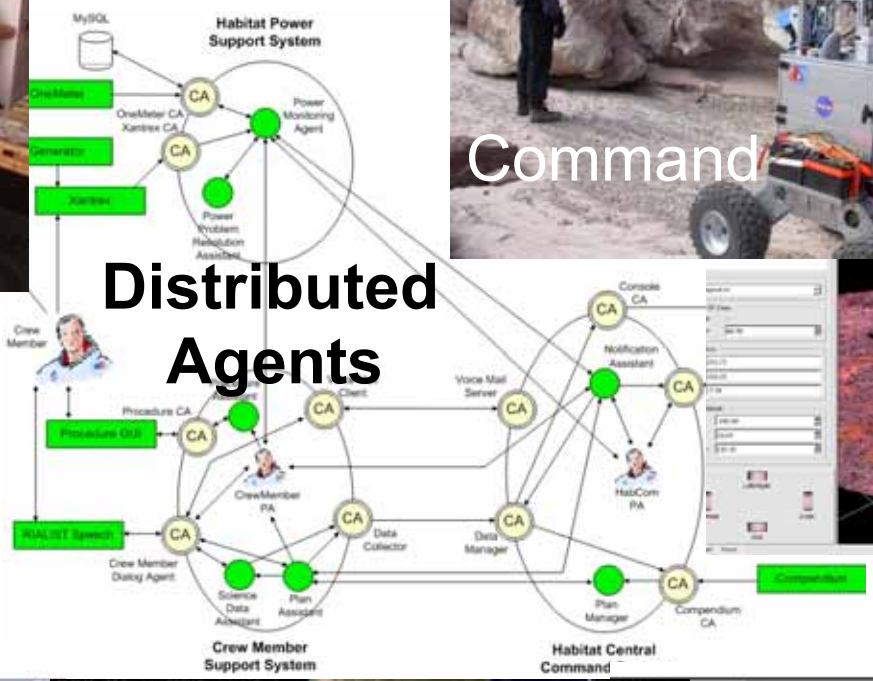
- Brahms: http://www.agentisolutions.com
  - Register to download software
  - Language definition
  - Tutorial
- Publications & Photos: http://Bill.Clancey.name
- Key papers:
  - Simulating activities
  - Cognitive modeling of social behaviors
  - Multiagent modeling and simulation in human-robot mission operations work system design
  - BrahmsVE: From human-machine systems modeling to 3D virtual environments

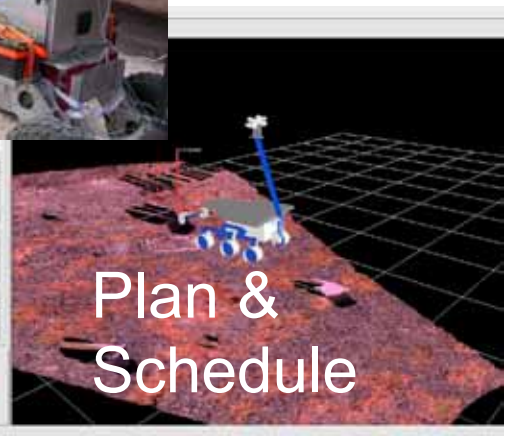
Brahms/Mobile Agents: Human-Systems Integration

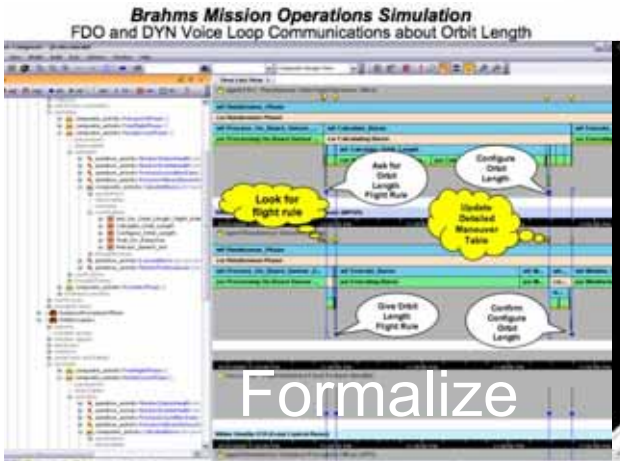
William J. Clancey, PhD
Chief Scientist, Human-Centered Computing
Intelligent Systems Division
NASA Ames Research Center

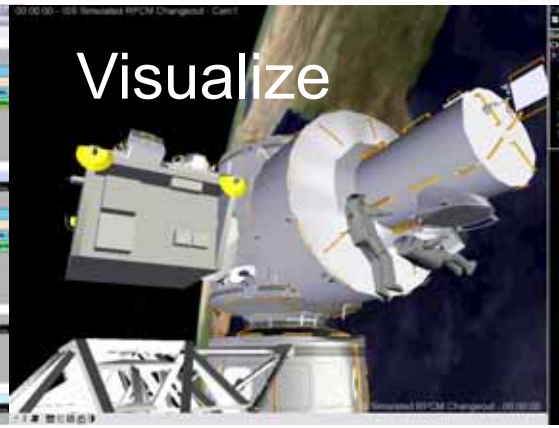
June 23, 2006

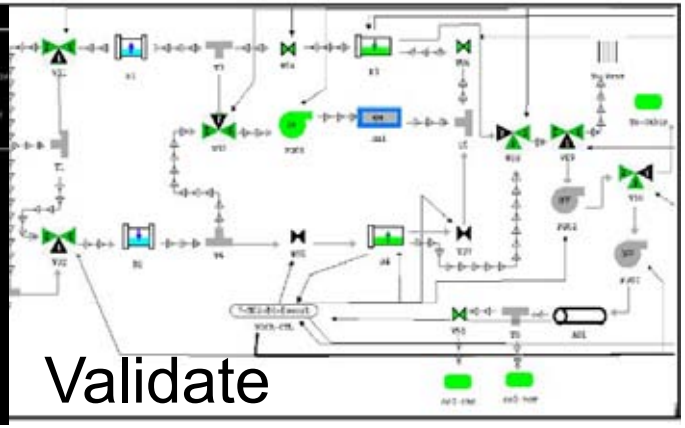
Integrating People, Systems, & Simulations











Agent-Based Systems Integration

- Method:
  Proactive, model-based data exchange layer between applications and networks
  - Dynamically reconfigurable
  - Activity-based (context-sensitive) protocols
- Projects:
  - Human-Systems Integration for CEV (ESAS 6E) ("Collaborative Infrastructure" or Transport layer)
  - Human-Systems Integration for surface EVAs (ESAS 12) involving robots, instruments, etc., including coordination with remote support teams
  - Mission Operations Design & Analysis Tool (CDDF)

Software Engineering Architecture

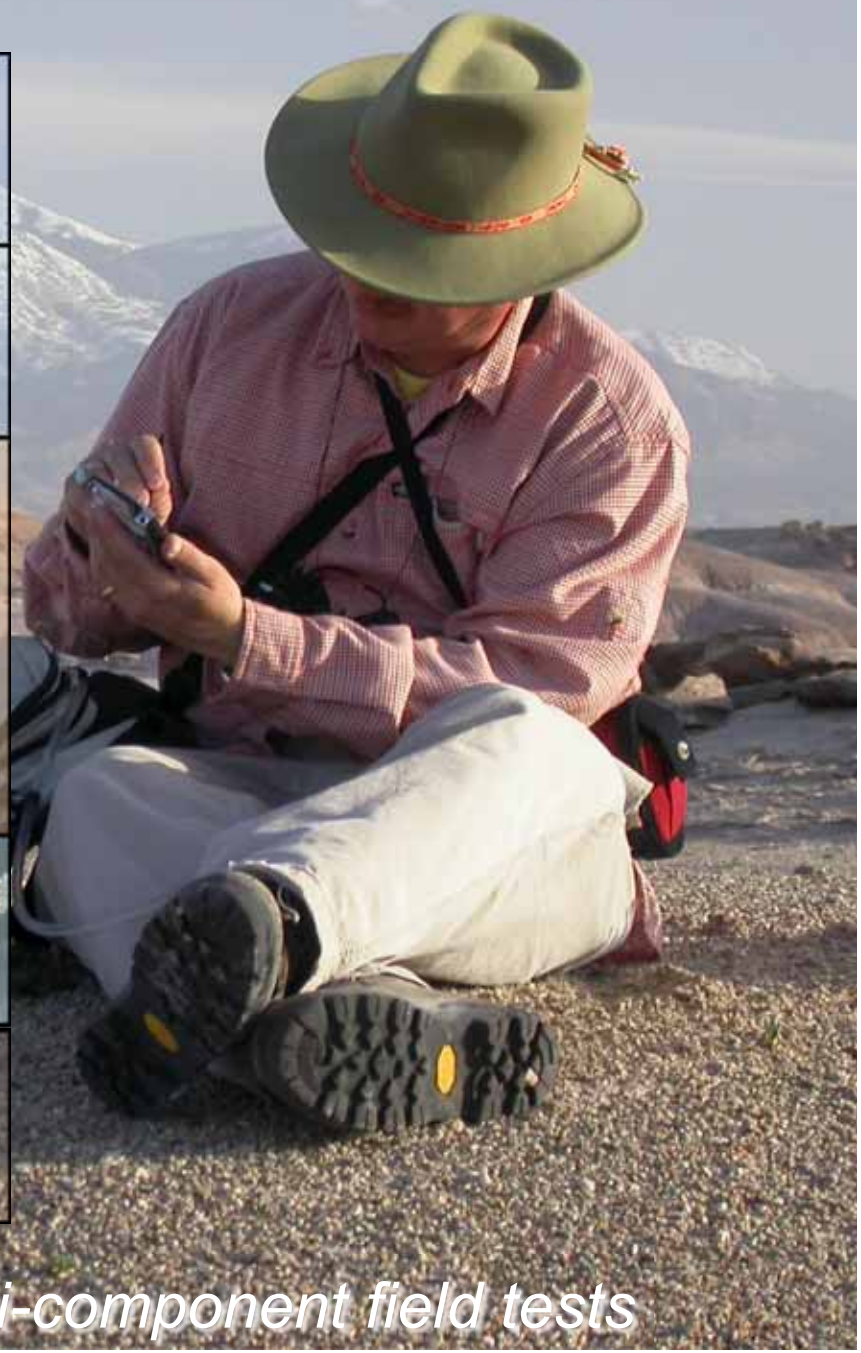
Communication Protocols
(commands, confirmation, alerting, etc.)

Agent-Based Integration
(Personal, Comm, Functional)

Activity Modeling Language
(Groups, Agents, Activity, Workframes, Thoughtframes, Detectables, Beliefs, Facts, Propositions, Objects, Classes, etc.)

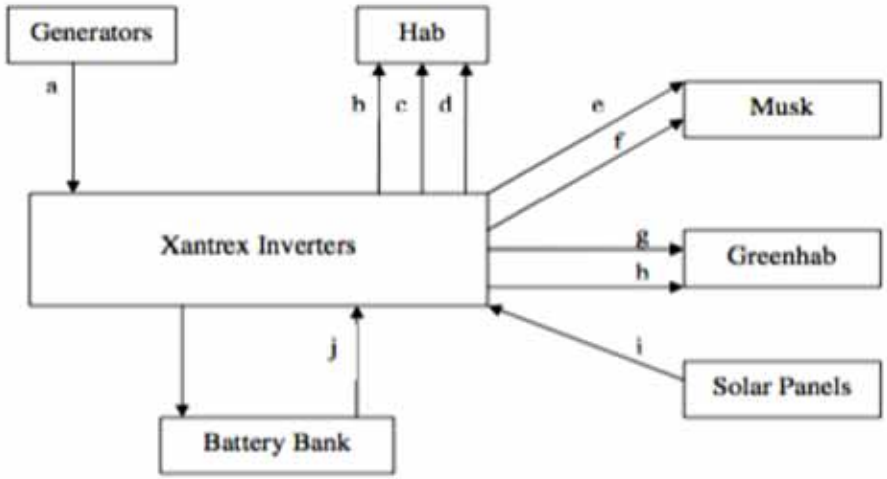
BDI Framework
(agents: Beliefs, Desires, Intentions)

Interoperable Programming
(Java, XML, CORBA, etc.)



50+ person-years R&D; 7 multi-component field tests

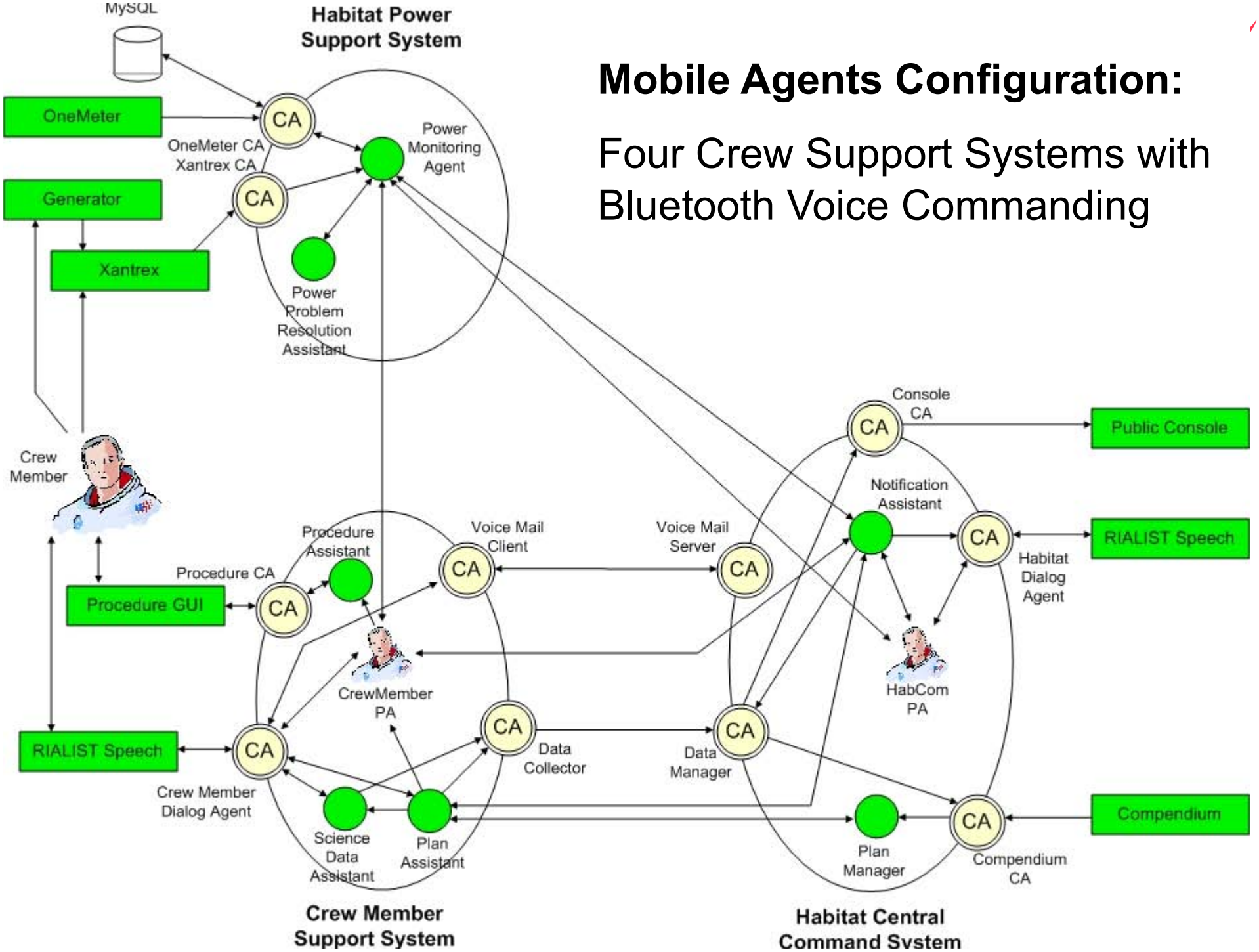
MDRS Power System I/F



- Multi-Channel Telemetry
- Logged & Analyzed by Agent System
- Current & Historical Voice Inquiries via Personal Agents
- Wireless Access (Bluetooth)
- Procedural Advice
- Activity Tracking

Mobile Agents Configuration:

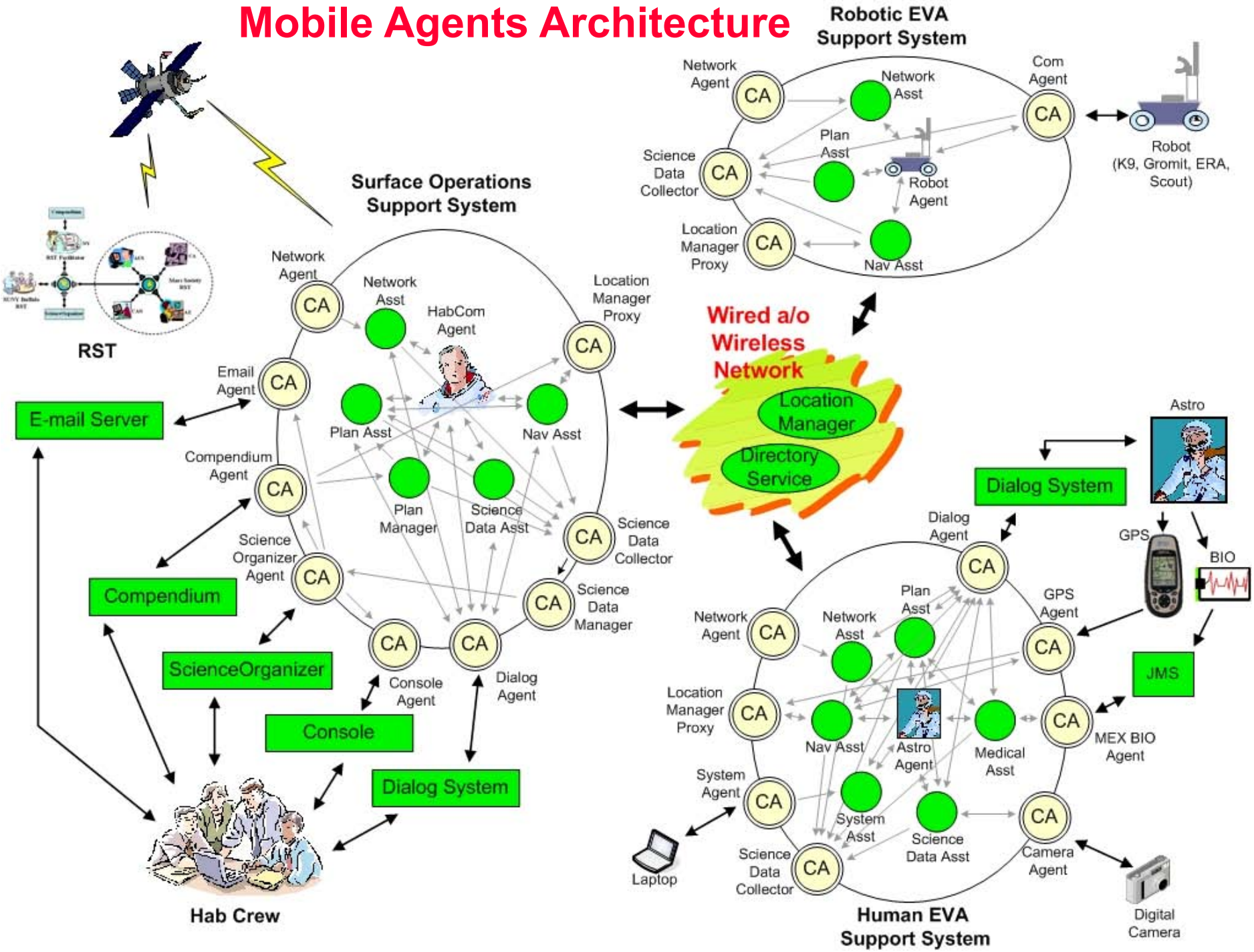
Four Crew Support Systems with Bluetooth Voice Commanding



Power Agent Voice Commands

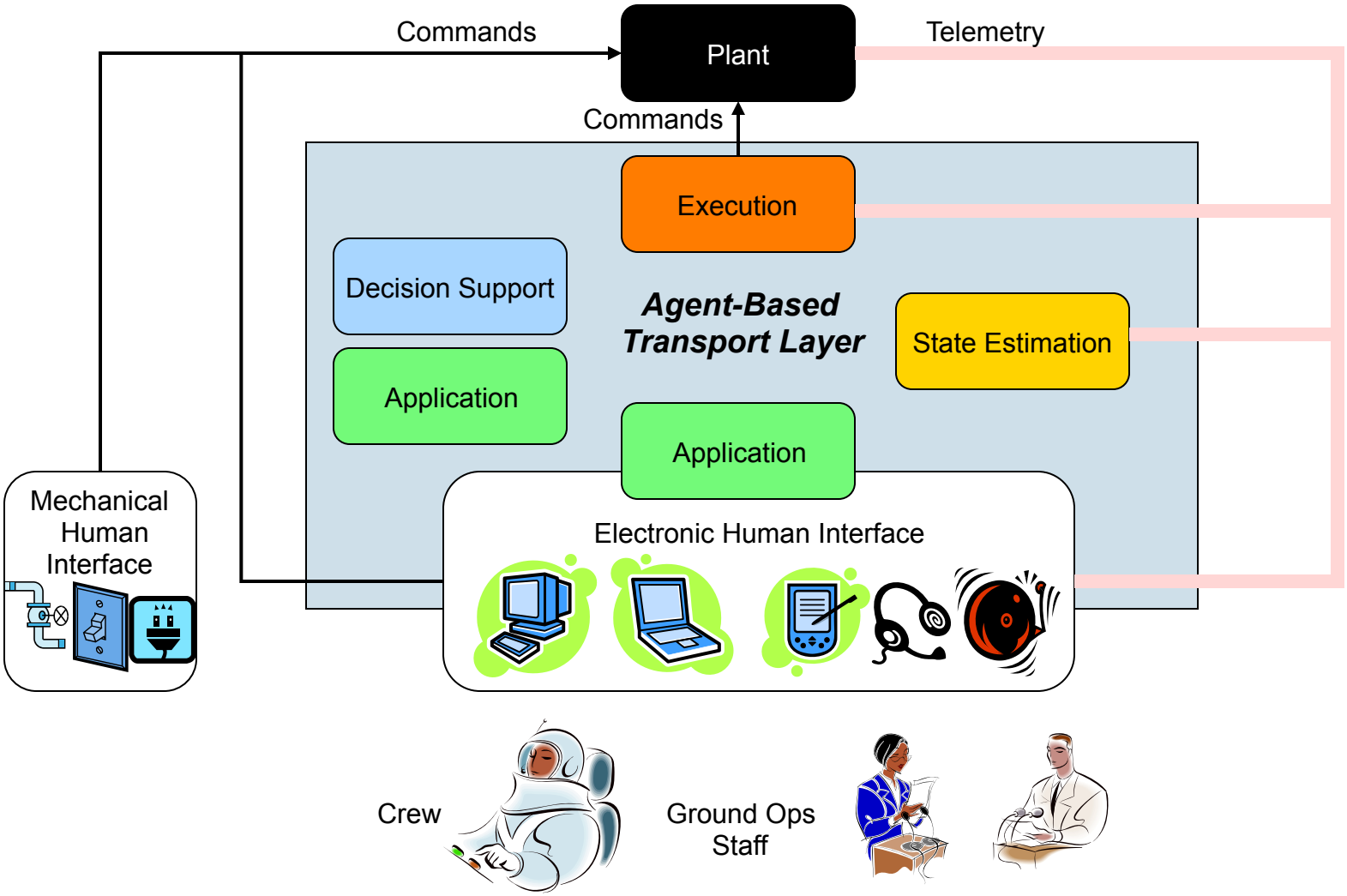
- What is the {battery | generator} {volts | amps | volts and amps}?
- What is the status of the {generator | inverter | battery | solar panel}?
- Are the batteries charging?
- What is the hab{itat} {power usage | volts | voltage | amps | volts and amps}?
- What is the low battery cut {off | out voltage}?
- What was the average hab{itat} {amps | volts | voltage} since <#> {AM | PM}?
- When did the {generator | batteries} change status?
- When did the batteries start {dis}charging?
- What was the {hab{itat} | battery} {amps | volts | voltage} at <#> {AM | PM}?
- What was the maximum hab{itat} {amps | volts | voltage} {today | this morning | this afternoon | this evening | yesterday | last night}
- Tell {me | <person> | everyone} when{ever} the generator goes offline.
- Tell {me | <person> | everyone} when the hab{itat} {amps | volts | voltage} {exceeds | drops below} <#>.
- {Send | Take | Record} {a} voice note {{for | to} <person>}
- Send voice note <#> to <person> {at <time>}

Mobile Agents Architecture

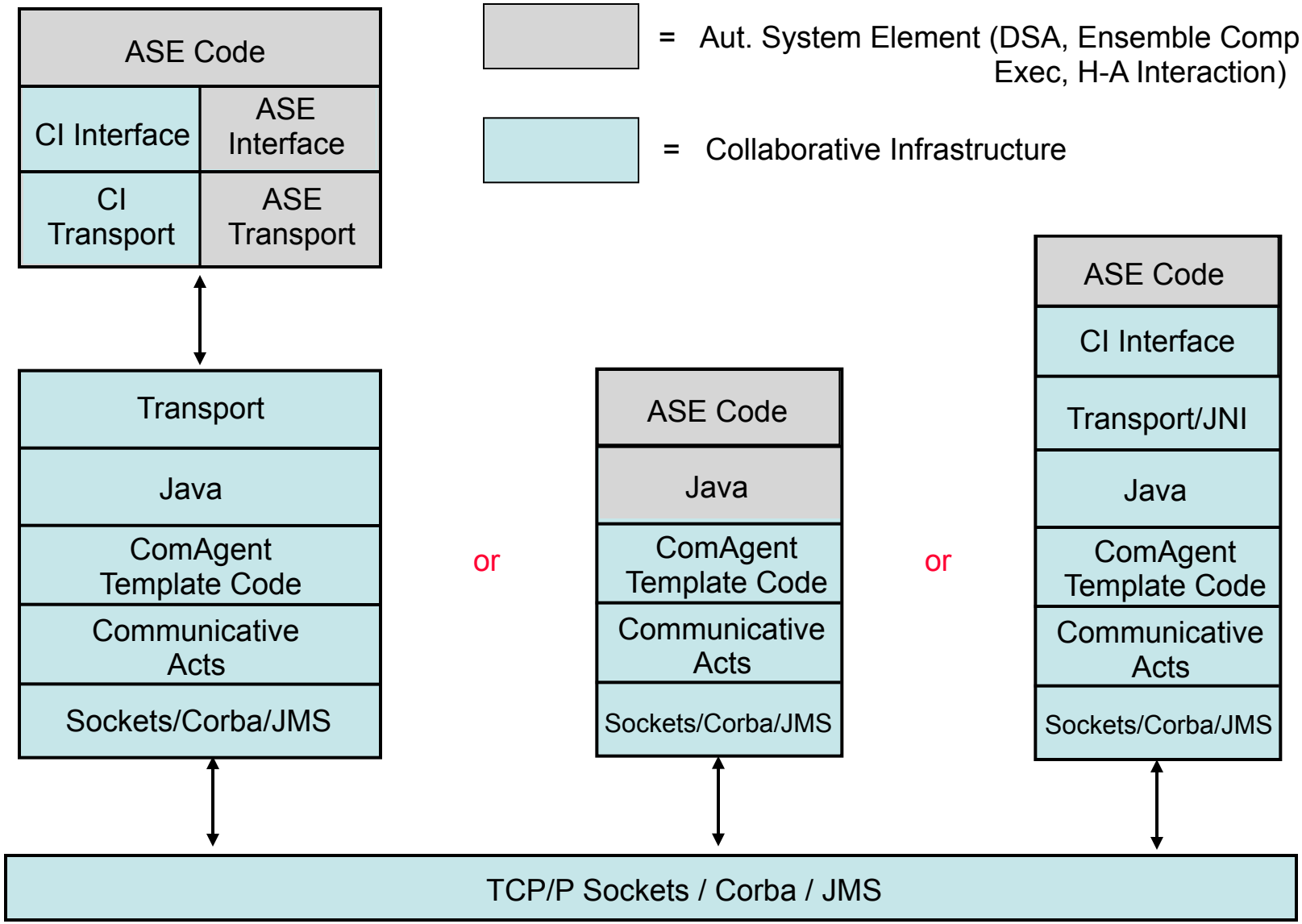


Spacecraft Autonomy for Vehicles and Habitats

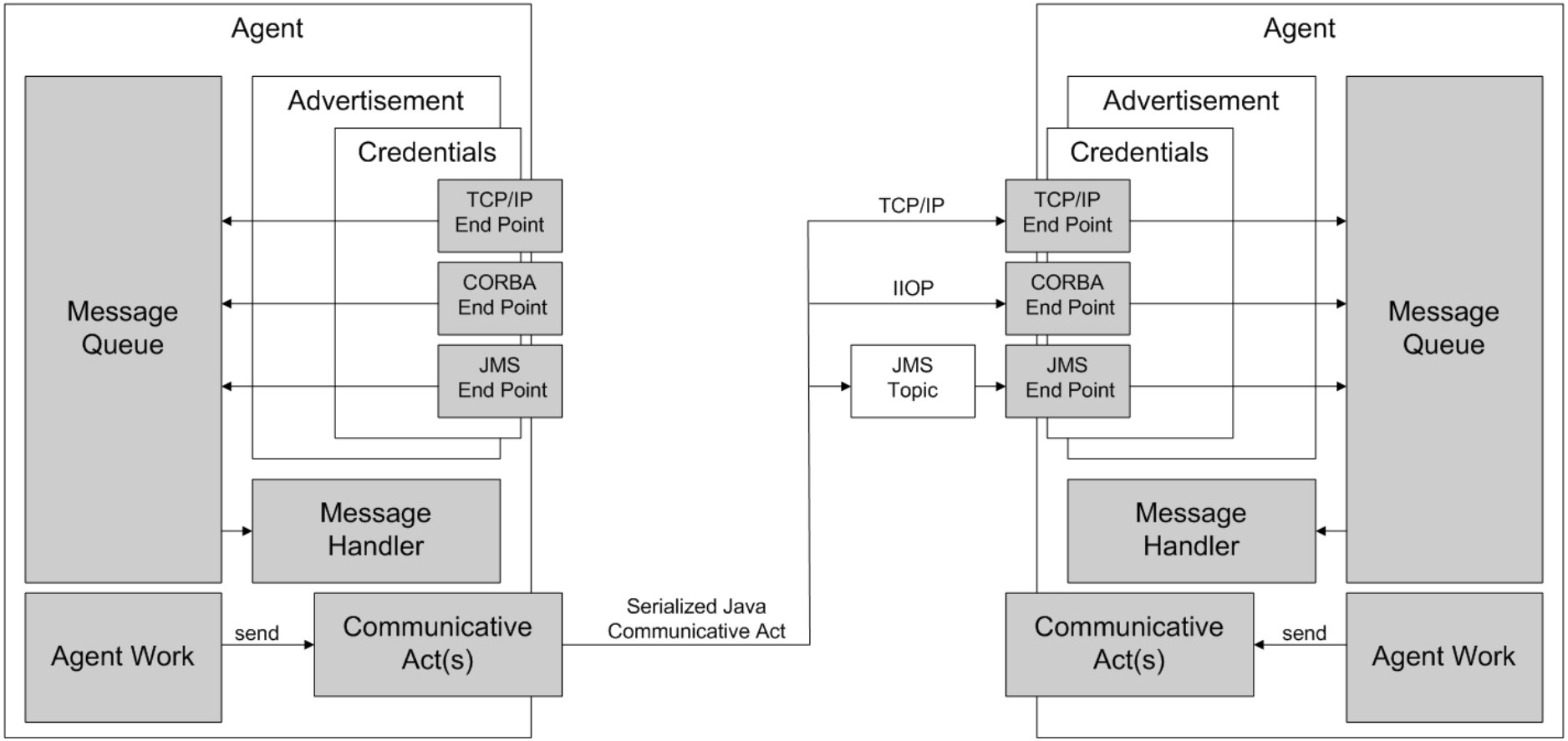
Architecture Schematic



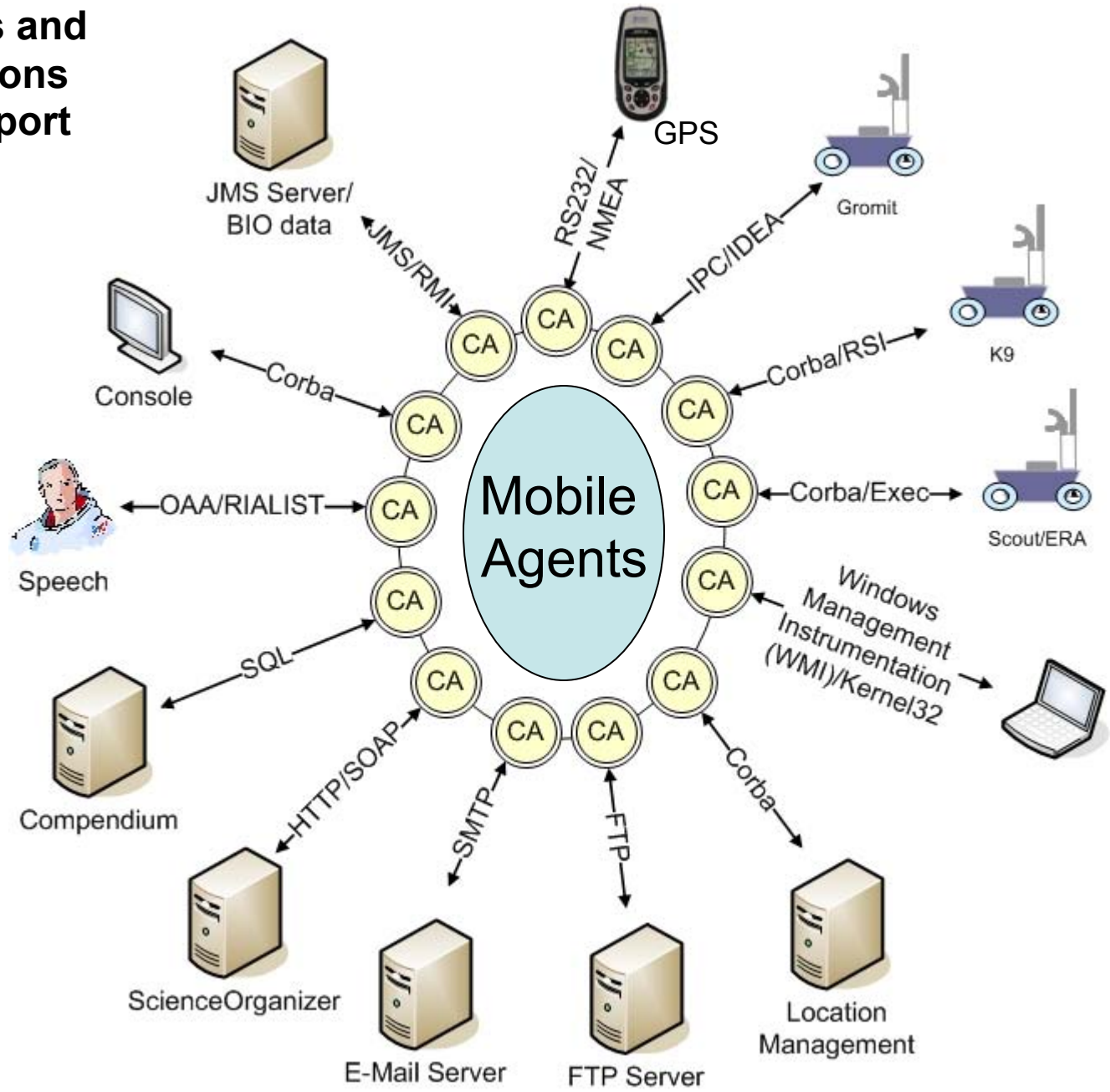
ESAS 6E: Collaborative Infrastructure



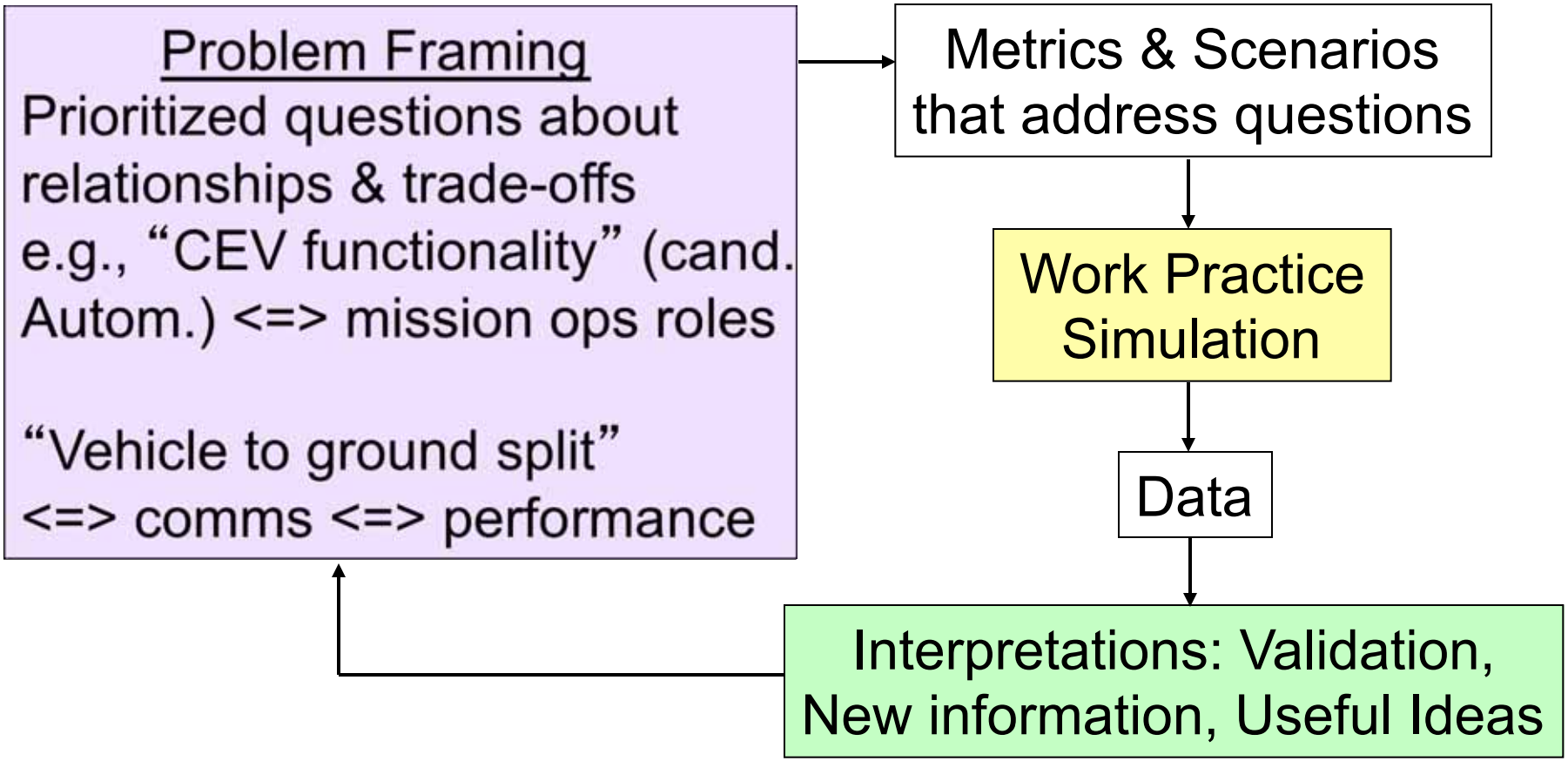
Agent Transport Layer



Implemented Brahms/ MA Interfaces and Communications Protocol Support

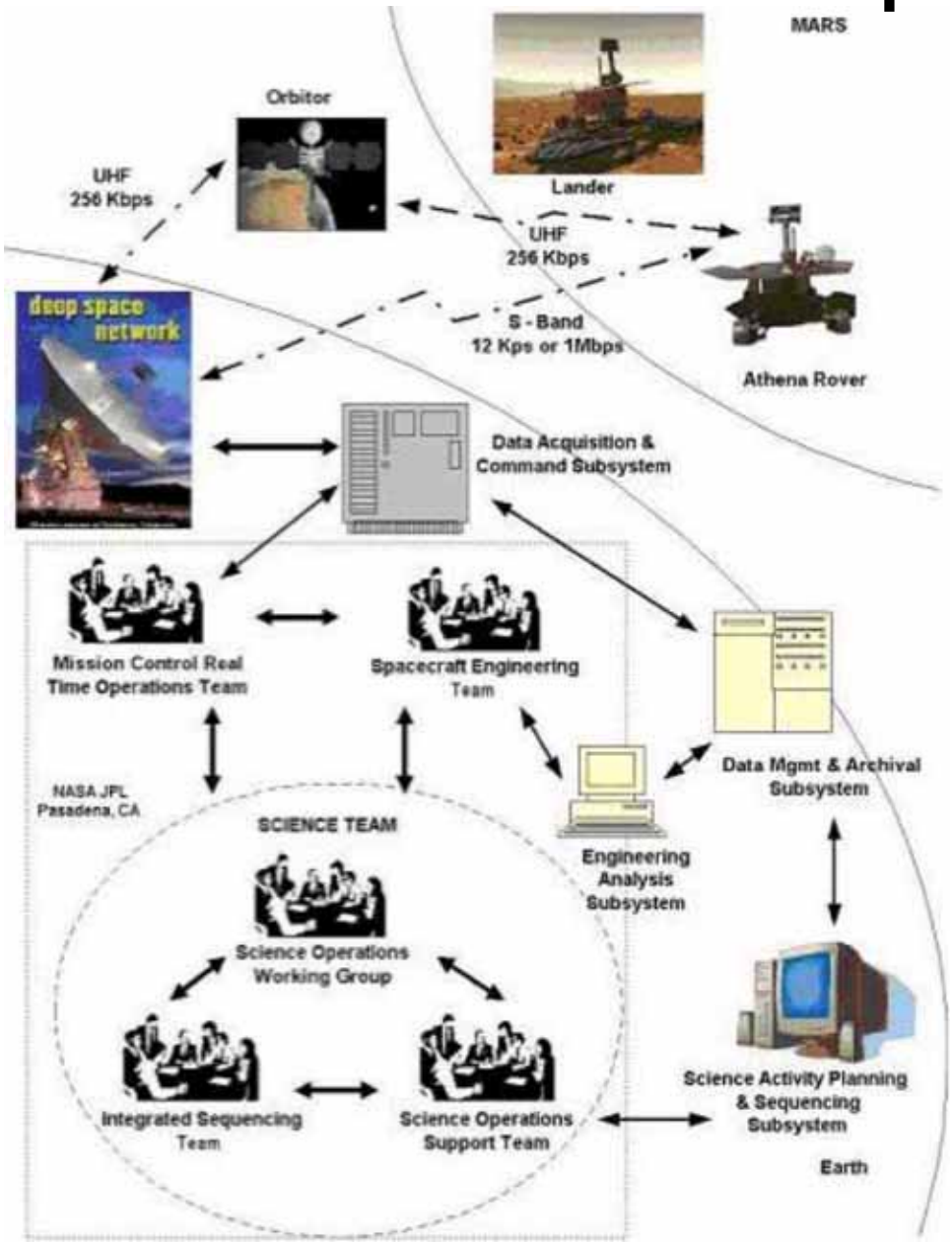


Simulation-Based Mission Operations Design



Participants: Flight Controllers & other stakeholders, operations designers, work systems analysts

Application of Work Practice Modeling for Mission Operations Design

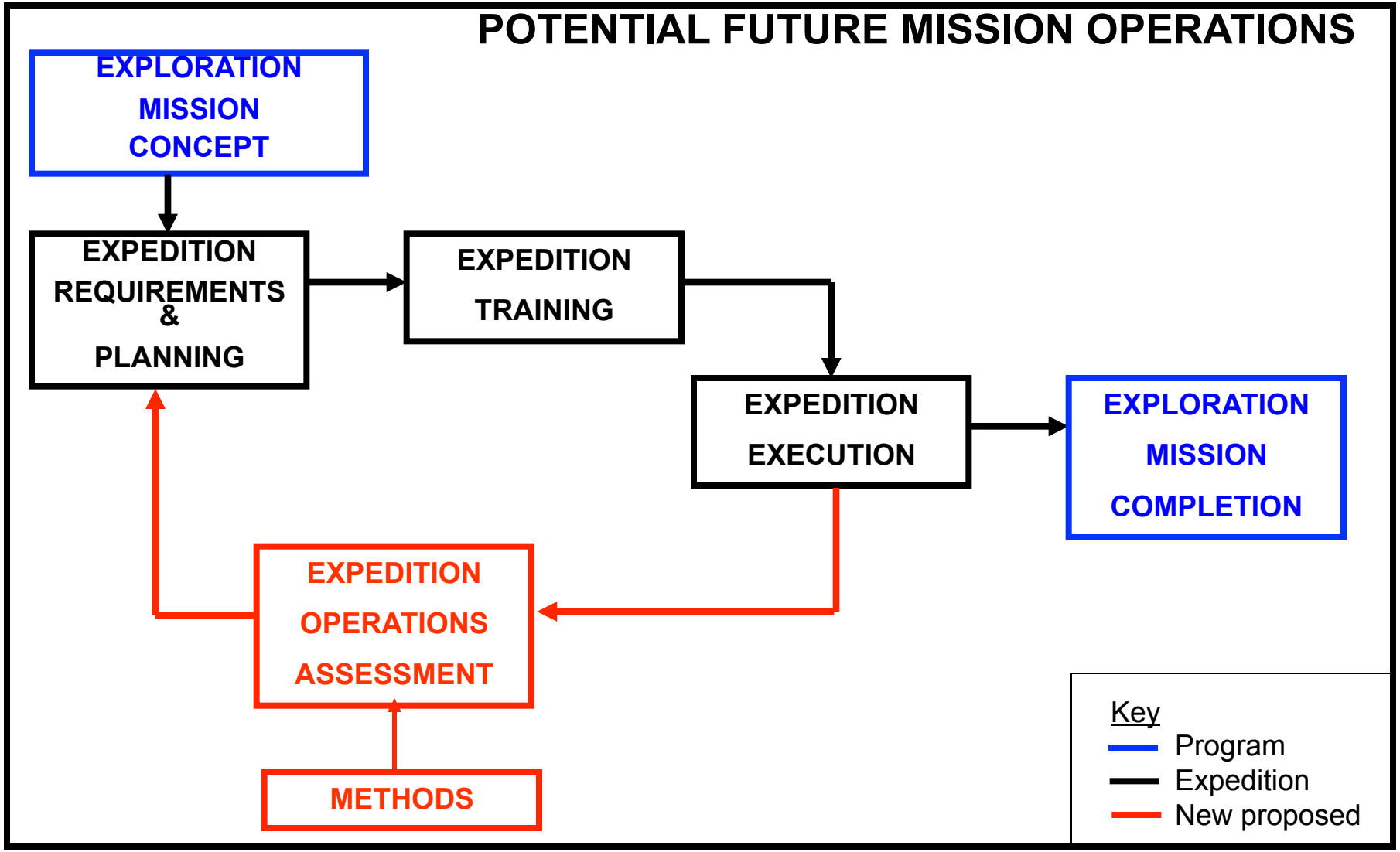


- Design Approach:
  - Facilities & Organization
  - Processes & Tools
- Complex Work System
  - Scientists and Engineers
  - 24*7 (3 shifts)
  - Two Rover Time Zones
  - Mars sol ≠ Earth day
  - New & Legacy Systems
- Iterate by trial and error during operational readiness tests (ORTs) —6 months after launch

Q: WHAT IS THE GOAL OF THE MODAT PROJECT?

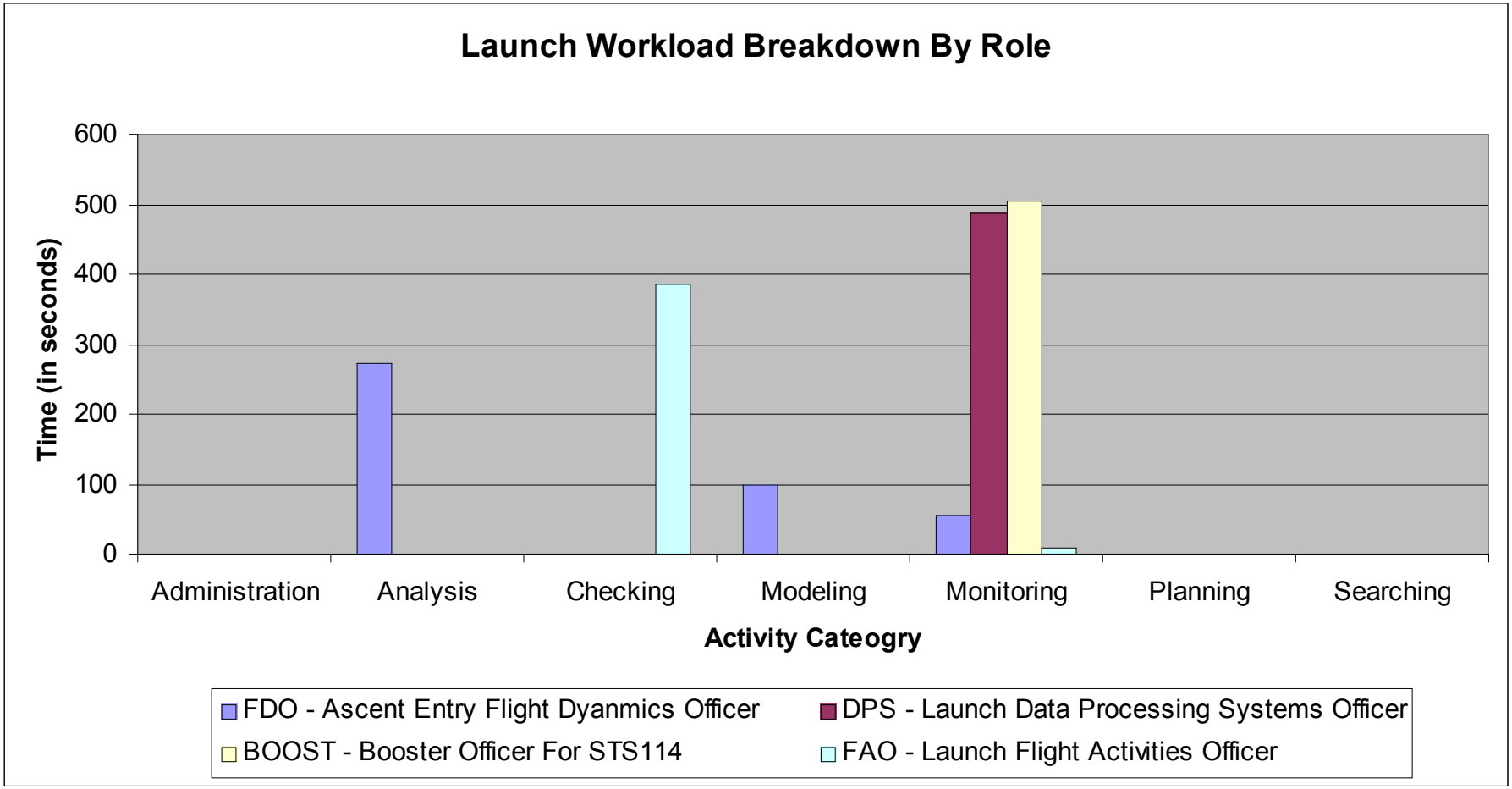
A: CONTINUOUS IMPROVEMENT / WORK EVOLUTION FOR COST EFFECTIVENESS

HOW?: DECISION SUPPORT PROCESS FOR OPERATIONS ASSESSMENT



Results: Assessment of Simulated Work Process

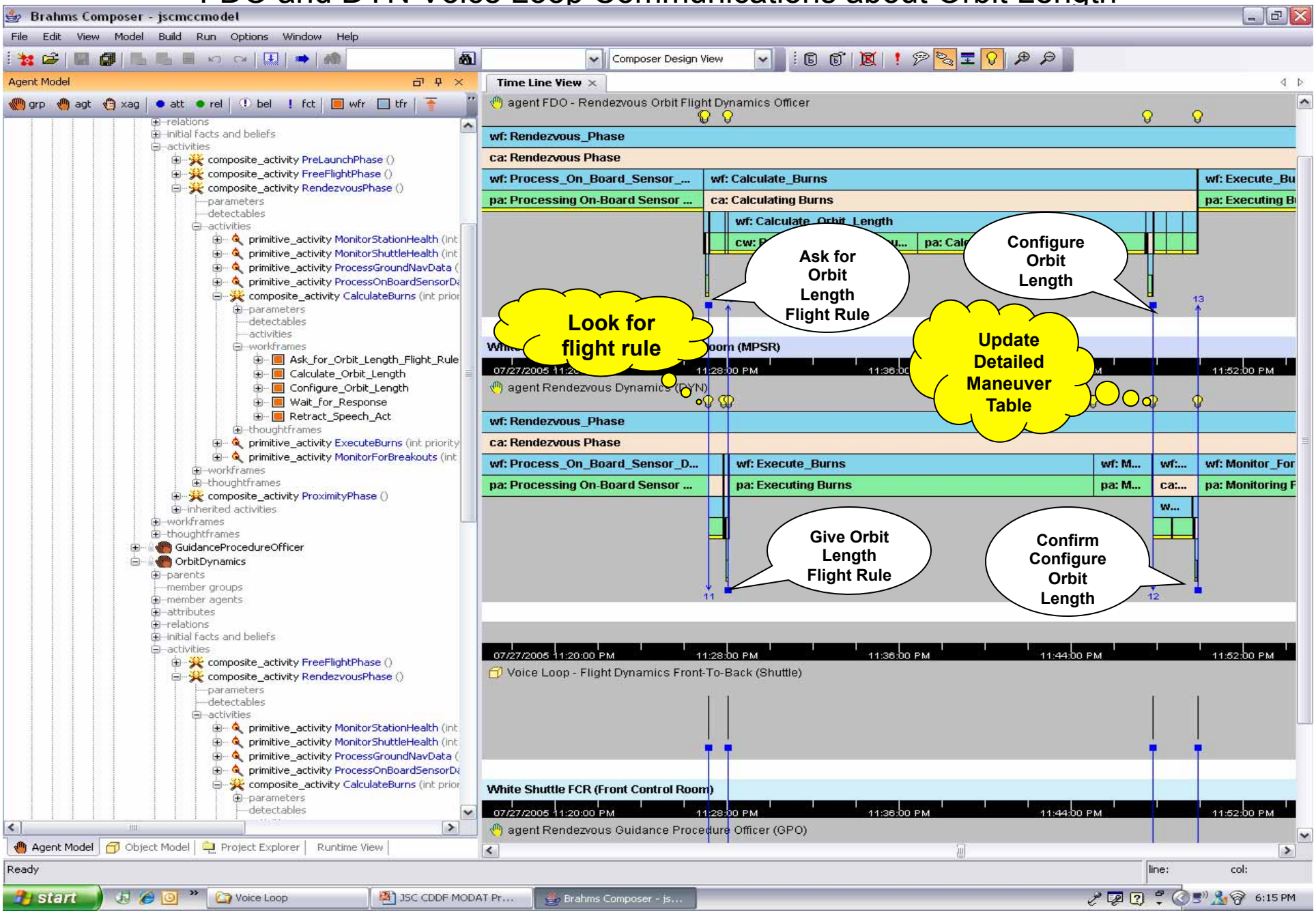
Metrics of Flight Controllers Workload



Simulation output validates intuition from ethnographic observations that FDO has a “heavy” workload (multiple activity categories) compared to other roles during the short launch period.

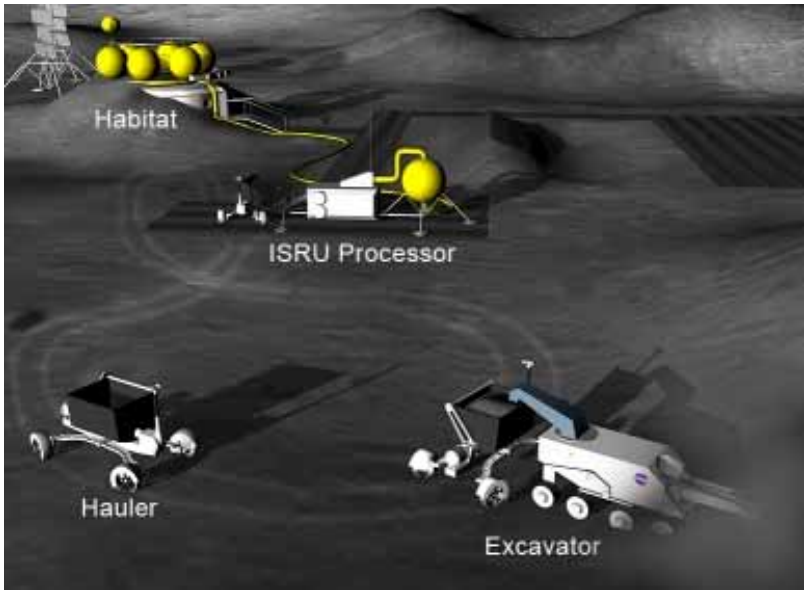
Example 2: Representation of Current Operations

FDO and DYN Voice Loop Communications about Orbit Length



Applications of Integrated Work System Simulations

- Space Habitat & Vehicle Design
- Remote support-space ops integration
- Simulating & testing automated systems (e.g., robots, agents)
- Crew scheduling & replanning
- Tool & Procedure Design (e.g., human-robot interaction)
- Procedure change evaluation
- Communication-coordination planning
- Flight controller & crew training



Multi-Agent Simulation to Implementation: A Practical Engineering Methodology for Designing Space Flight Operations

NASA Ames Research Center, CA
& Johnson Space Center, TX

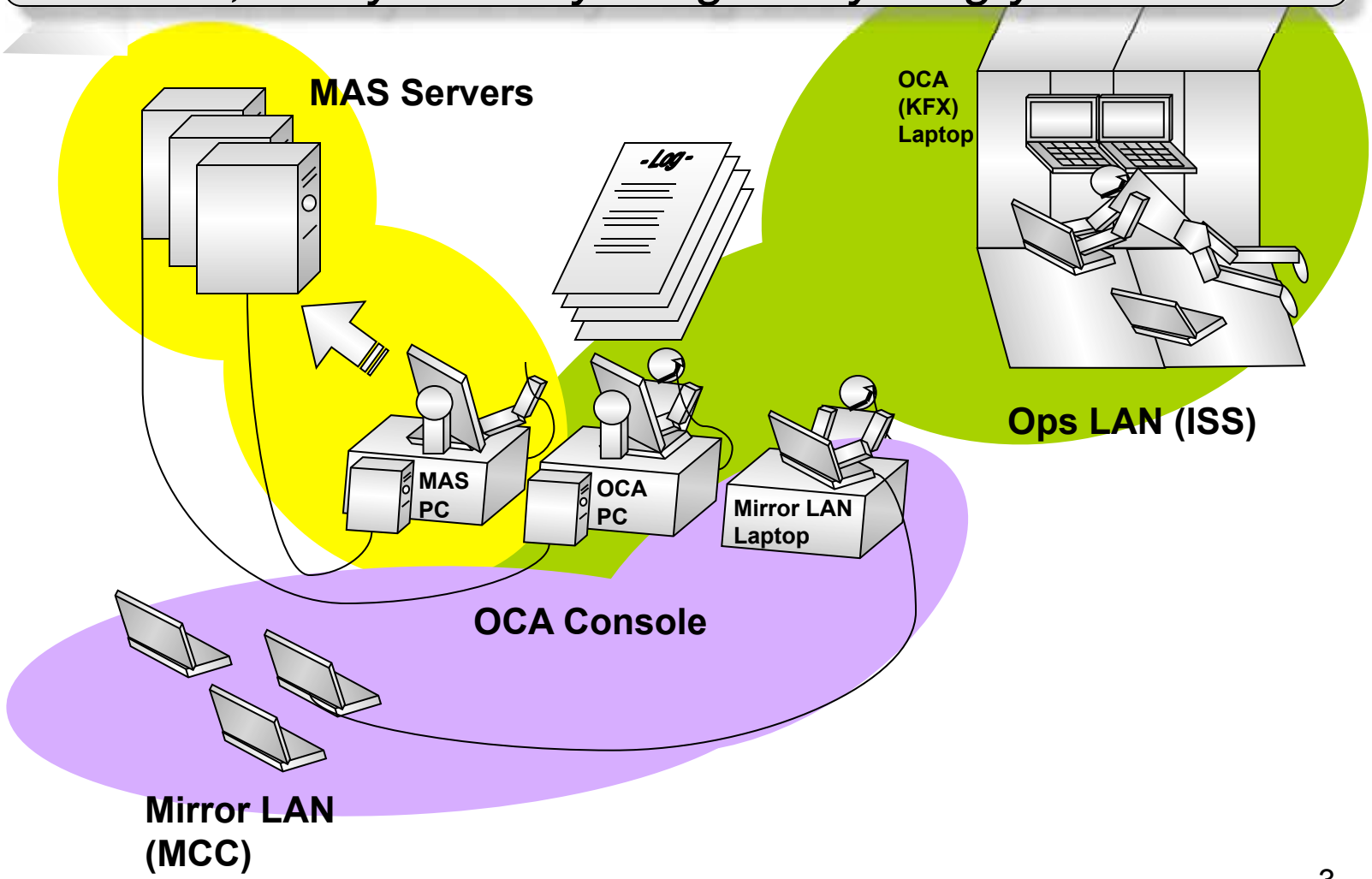
William J. Clancey, Maarten Sierhuis, Chin Seah,
Chris Buckley, Fisher Reynolds, Tim Hall, Mike Scott

Talk Outline

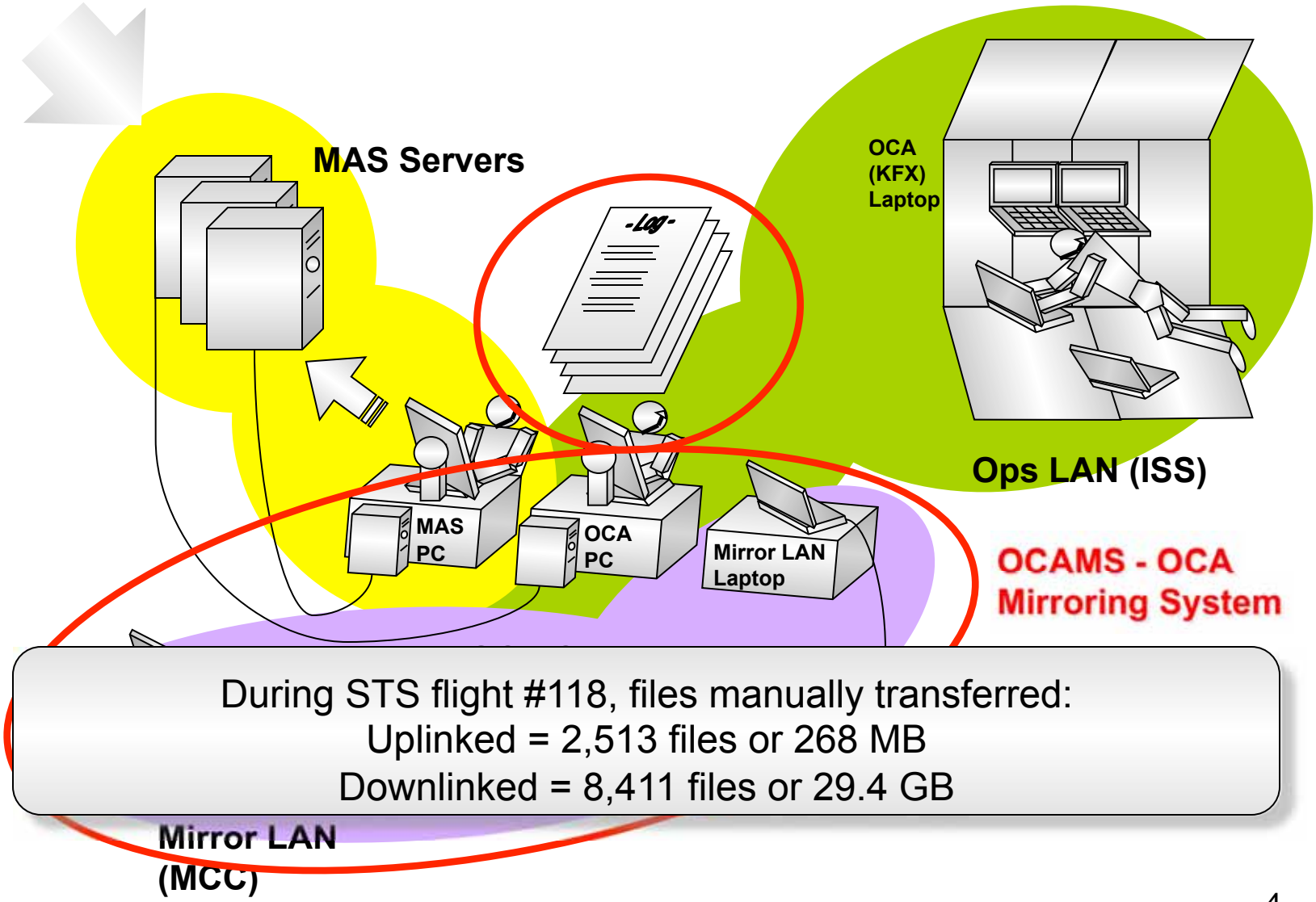
- Problem: Earth-Orbit Communications
- Approach: Simulation-to-Implementation
- Model of Current Operations Work System
- Model of Future Operations Work System
- Related Work
- Implications for ESAW

Problem: OCA Console Operations

And, oh by the way…log everything you do!!!



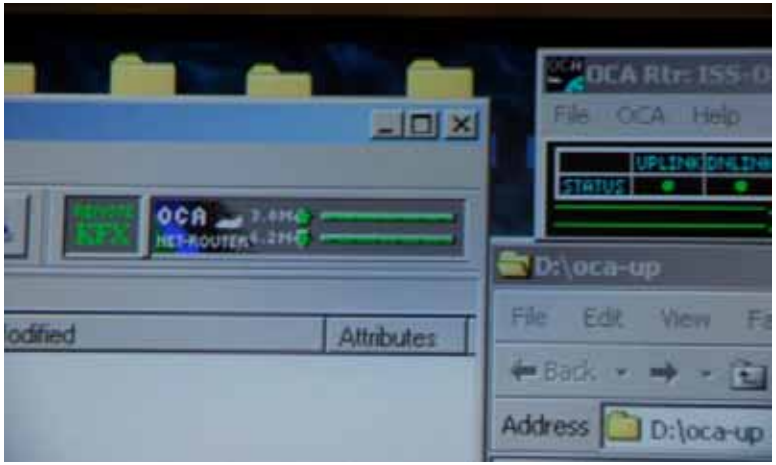
Solution: OCAMS – OCA Mirroring System



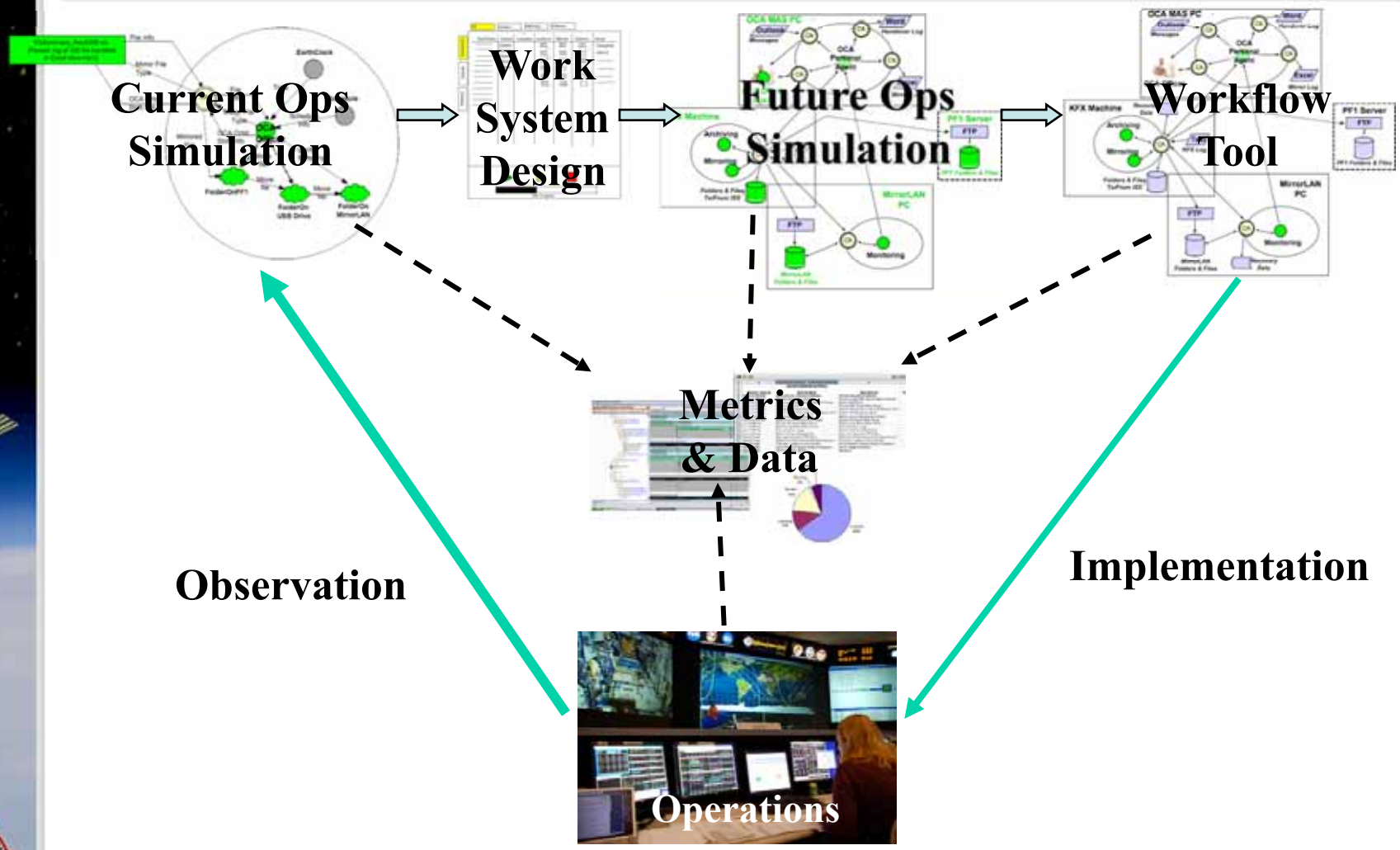
During STS flight #118, files manually transferred:
Uplinked = 2,513 files or 268 MB
Downlinked = 8,411 files or 29.4 GB

Complex Work System

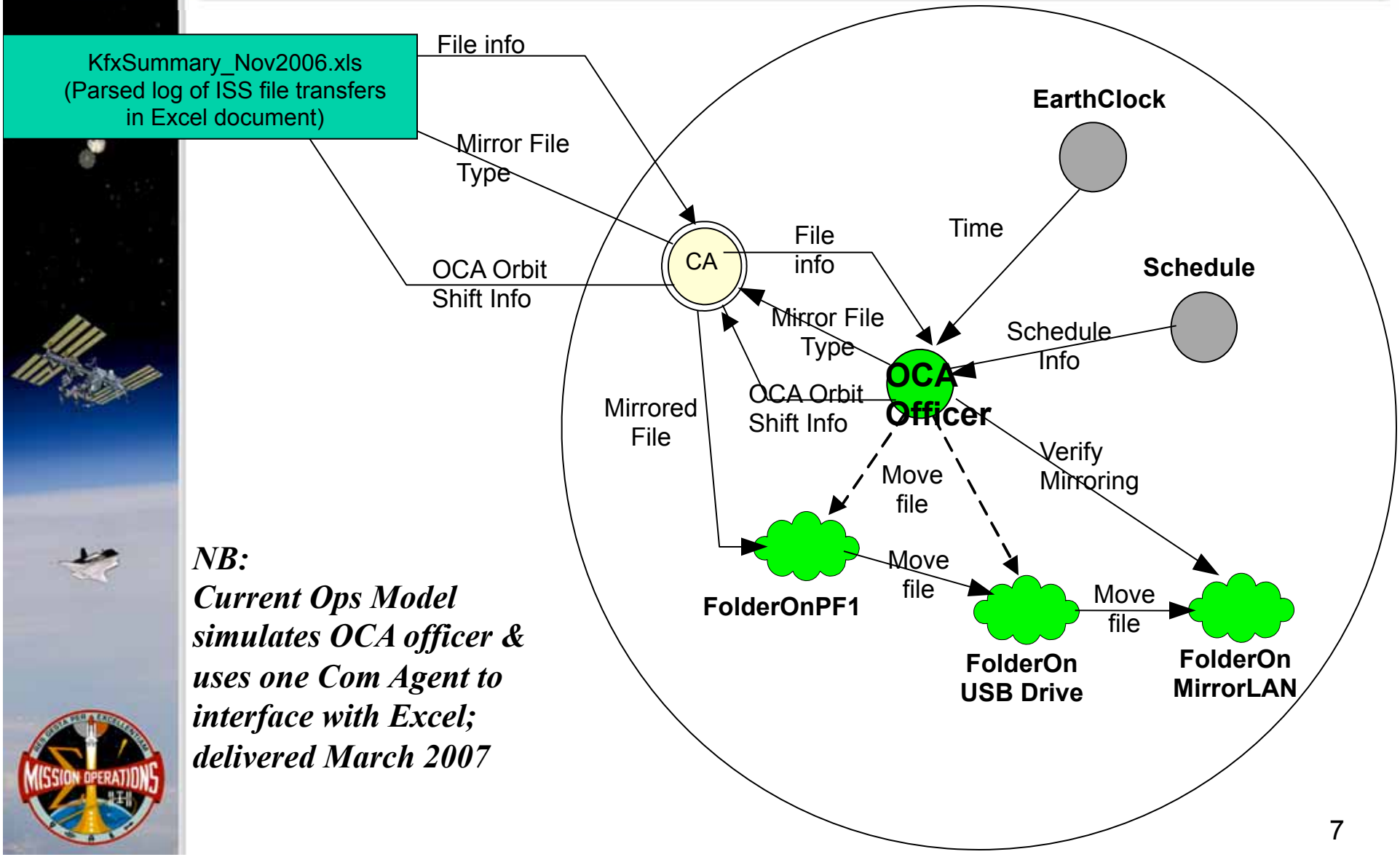
- People & Organizations
- Computer Systems
- Communication Media
- Space Comm Network
- Geographic Distribution
- Regulations
- Work practices & protocols



Approach: Simulation to Implementation

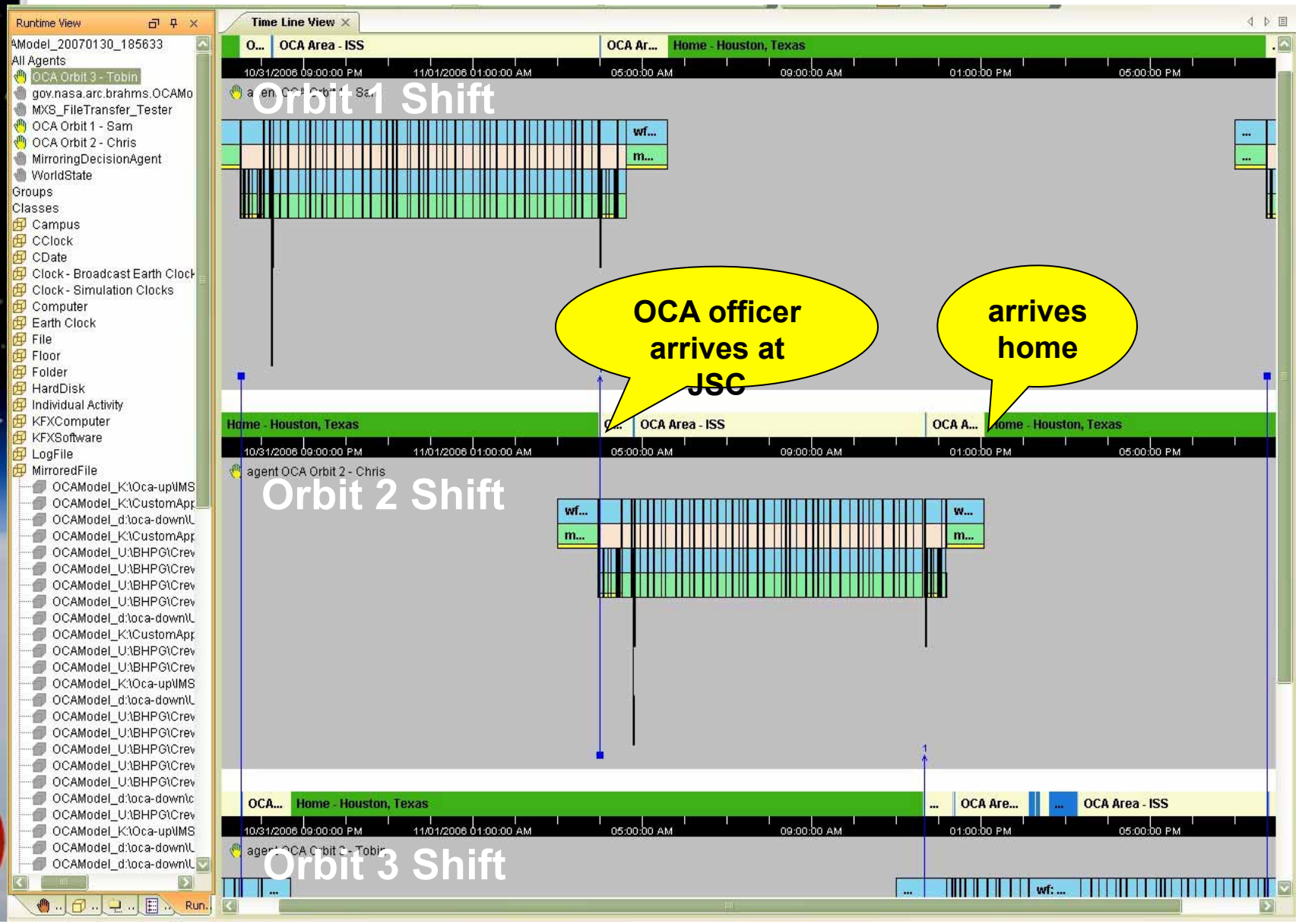


OCA Current Operations Model

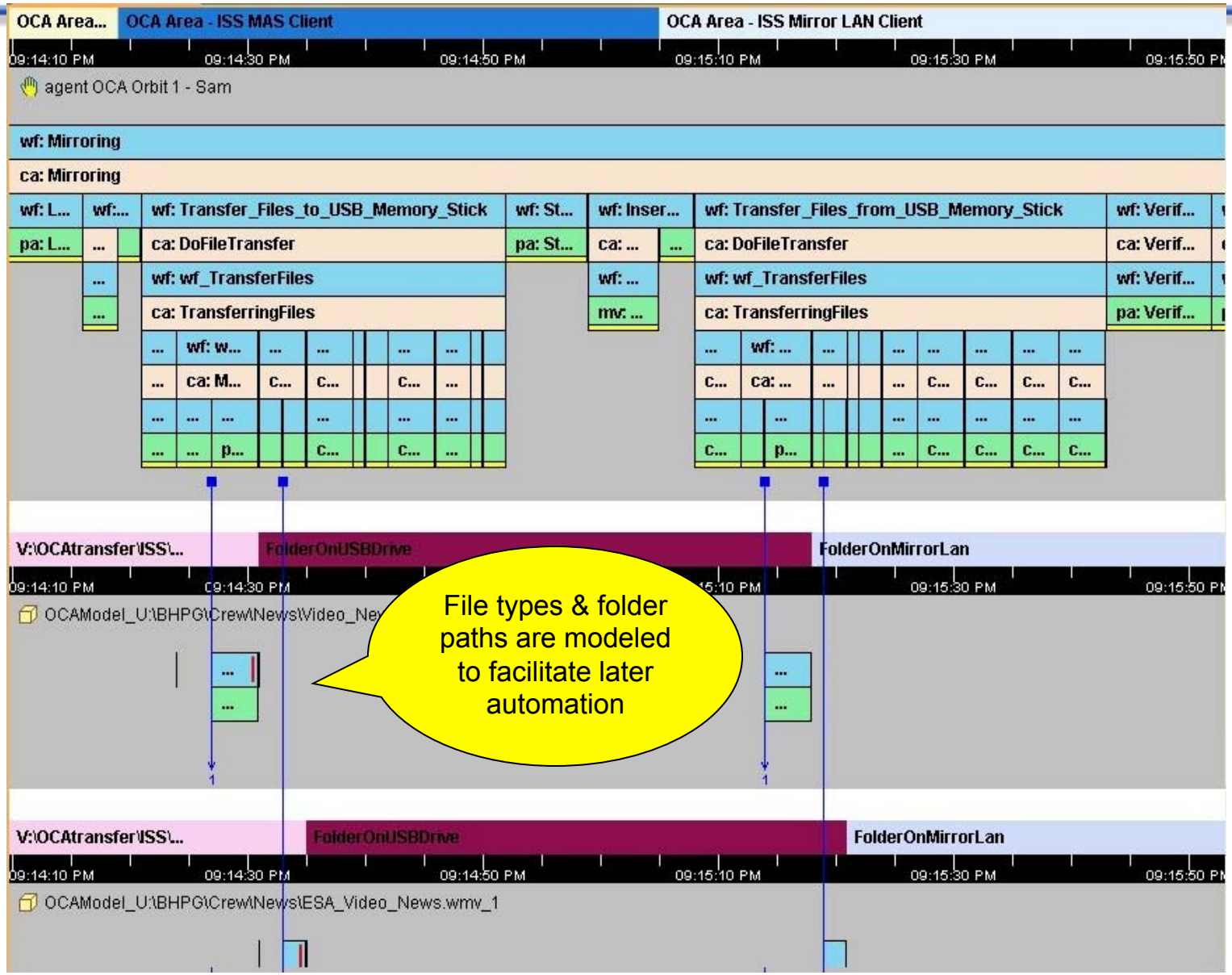


NB:
Current Ops Model simulates OCA officer & uses one Com Agent to interface with Excel; delivered March 2007

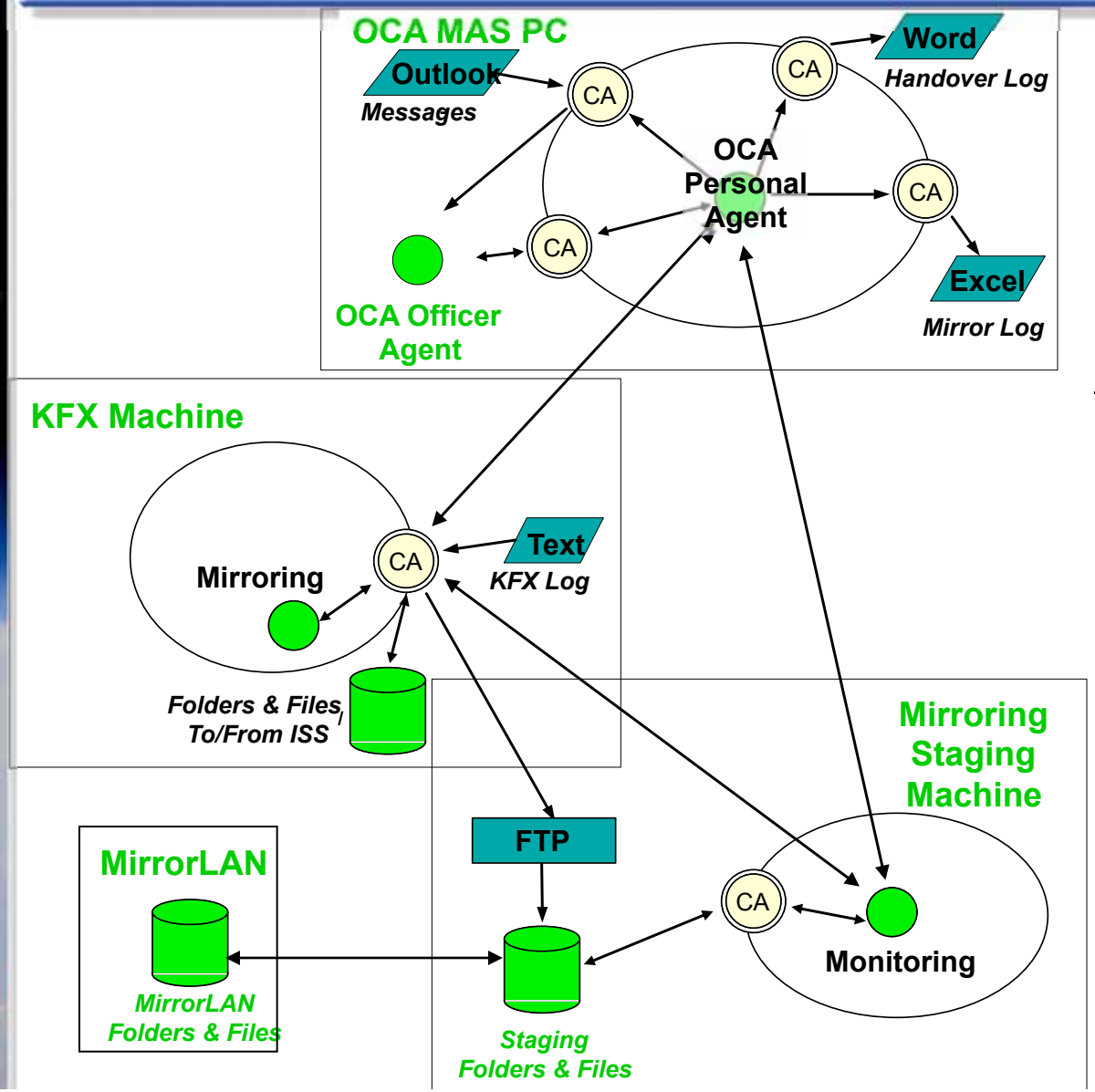
Current Ops: A Full Day Simulation



Current Ops: Mirroring Simulation



Future Ops Simulation: OCAMS Prototype Tool



NB:
Future Ops Model runs on one laptop; delivered October '07

LEGEND:

- = Brahms Agent
- CA = Communication Agent (Java)
- = External System or Document
- = Simulated File System

Future Ops: Simulation GUI (OCAMS Prototype Tool)

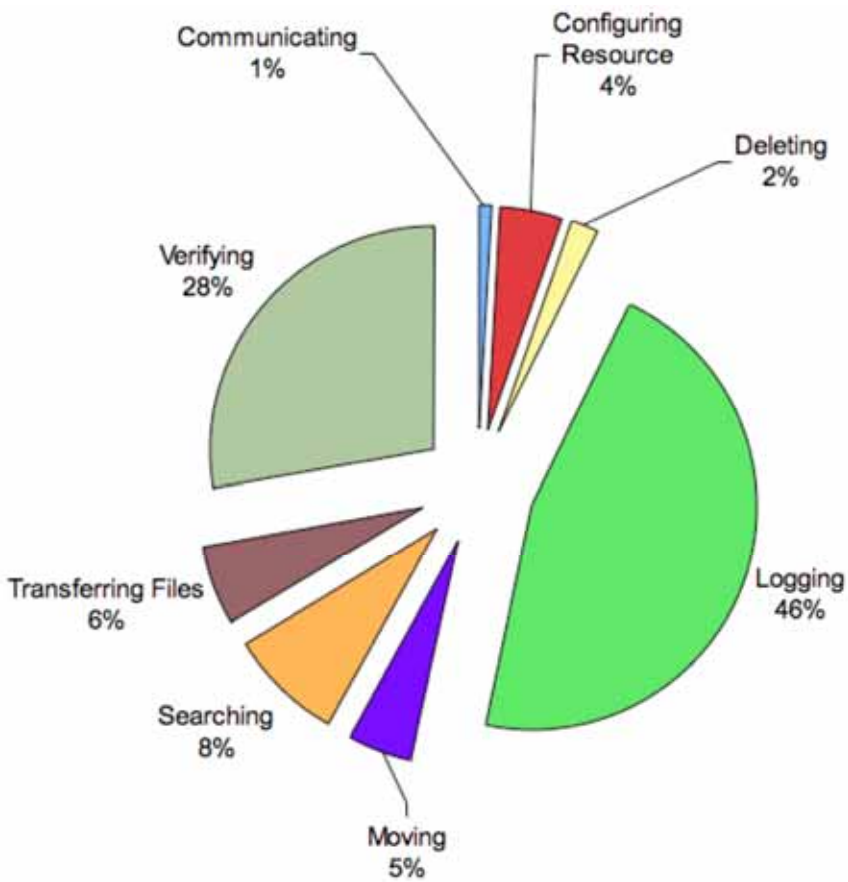
OCAMS KFX Activity

KFX Activity for [GMT] 248/16:26:38 through [GMT] 248/17:36:41

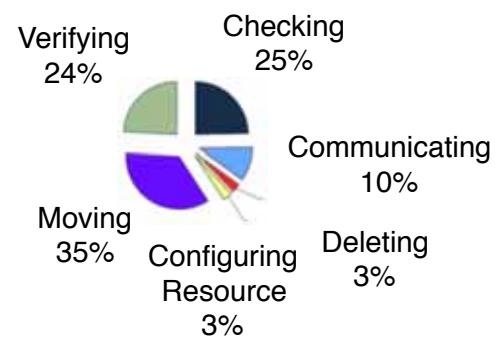
Date	File Name	Action	Location	Archive	Mirror	Deliver	Status
[GMT] 248/16:26:38	distsite.bat	Uplink	k:\oca-up\		X		FTP Permission Granted
[GMT] 248/16:26:38	distsite.pif	Uplink	k:\oca-up\		X		FTP Permission Granted
[GMT] 248/16:26:42	msgs.zip	Uplink	k:\oca-up\		X		FTP Permission Granted
[GMT] 248/16:26:45	web.zip	Uplink	k:\oca-up\		X		FTP Permission Granted
[GMT] 248/16:27:58	Updates.log	Downlink	d:\oca-down\				
[GMT] 248/16:27:58	Updates.xml	Downlink	d:\oca-down\		X		FTP Permission Granted
[GMT] 248/16:28:06	Updates.log	Delete	K:\CustomApps\Ostpv\WebData\ISS\Export\				
[GMT] 248/16:28:06	Updates.xml	Delete	K:\CustomApps\Ostpv\WebData\ISS\Export\				
[GMT] 248/17:29:21	22P_unpack_GMT 205start_a14c5963-0fab-4418-9d8d-967...	Downlink	d:\oca-down\				
[GMT] 248/17:29:22	22P_unpack_GMT246_start_13-0525e.xls	Downlink	d:\oca-down\				
[GMT] 248/17:30:23	Updates.log	Downlink	d:\oca-down\				
[GMT] 248/17:30:23	Updates.xml	Downlink	d:\oca-down\		X		FTP Permission Granted
[GMT] 248/17:30:31	Updates.log	Delete	K:\CustomApps\Ostpv\WebData\ISS\Export\				
[GMT] 248/17:30:31	Updates.xml	Delete	K:\CustomApps\Ostpv\WebData\ISS\Export\				
[GMT] 248/17:36:28	2006-248_17-34-20_Snapshot.zip	Uplink	K:\CustomApps\Ostpv\WebData\ISS\		X		Completed
[GMT] 248/17:36:41	2006-248_17-34-20_Snapshot.zip	Move	K:\CustomApps\Ostpv\WebData\ISS\				

Parse the KFX Activity Log | Process the Current List of Files | Clear Processed Files

Statistics: Manual (current) vs. Automated (future) OCA Mirroring



Current Operations:
Mirroring Activities
≈ > 5% shift time



Future Operations (with OCAMS):
Mirroring Activities
≈ < .5% shift time

Next: Implementation & Extension

- FY 2008
  - Now: Transfer OCAMS simulation to multiplatform implementation
  - Automated file archiving and customer notification
  - OCA officer capability to modify mirroring/file transfer rules
- Beyond 2008
  - Interactive query & notify via synthetic voice communications on voice loop (agents <-> people)
  - Apply OCAMS to OCA ISS uplinks
  - Identify other target processes for Mission Operations and Design Tool in MCC operations

Related Work

- Workflow Management Tools
  - Unit of Analysis: Activity vs. Task
  - Run-time Process: Identity vs. Function
  - Simulation fits Implementation-in-Practice
- Agent-Based Modeling & Simulation
  - Cognitive Agents
    - Beliefs, Multiple Groups/Roles
    - Subsumption vs. Procedural Stack
  - Contextual Behavior fits Distributed Work System

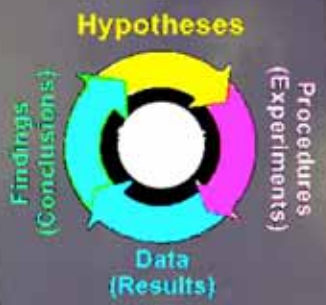
Implications for Engineering Societies of Agents

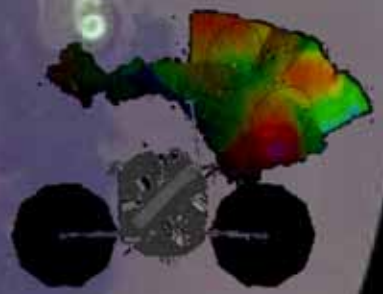
- Highly interdisciplinary methodology for engineering complex distributed applications
  - Ethnography, Flight Ops (Aeronautics), Computer Science/Networking, Space Science
- Simulation-to-Implementation: Analysis, design, development & verification of agent system
- Agent-Based Systems Integration: Middleware infrastructure for agent societies

For More Information…

- NASA.gov
- www.AgentISolutions.org
- Bill.Clancey.name
- homepage.mac.com/MSierhuis

Being Scientific on Mars: The Challenges and Accomplishments of the Phoenix Lander Mission



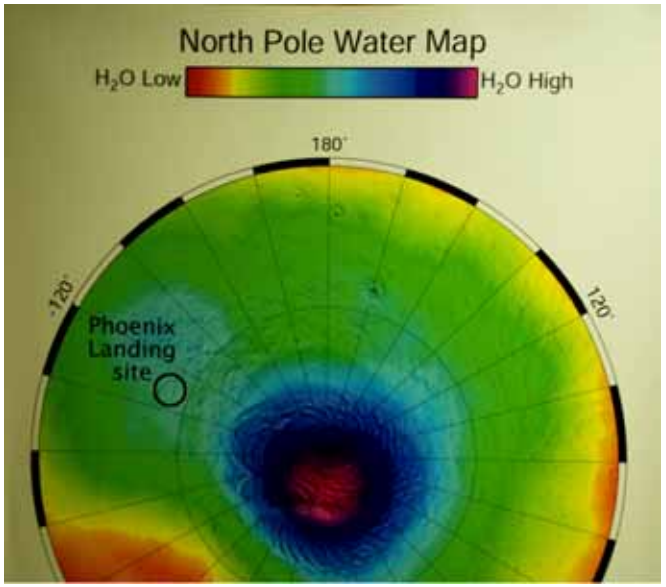


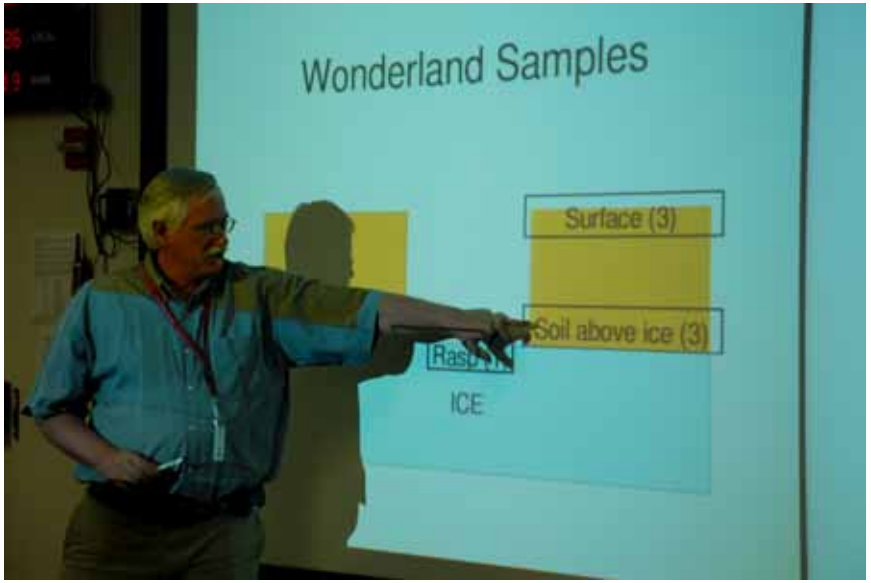
William J. Clancey

Chief Scientist, Human-Centered Computing
Intelligent Systems Division

NASA Ames Research Center

Phoenix SOC 2008

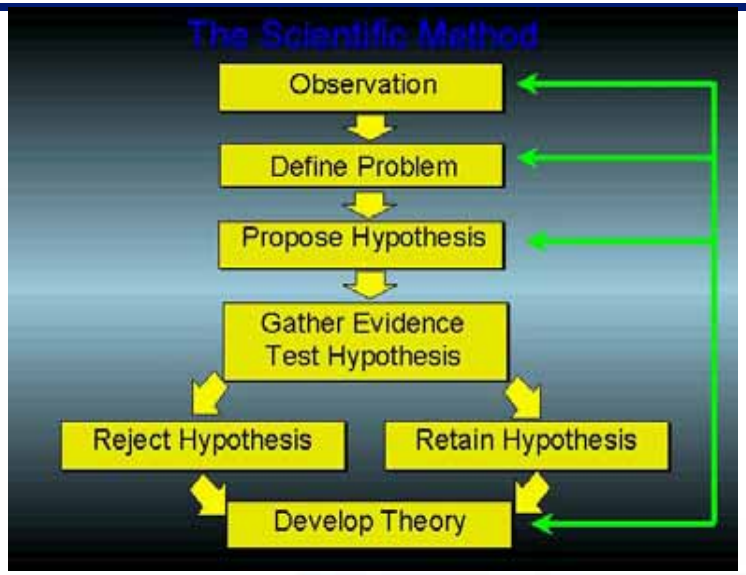


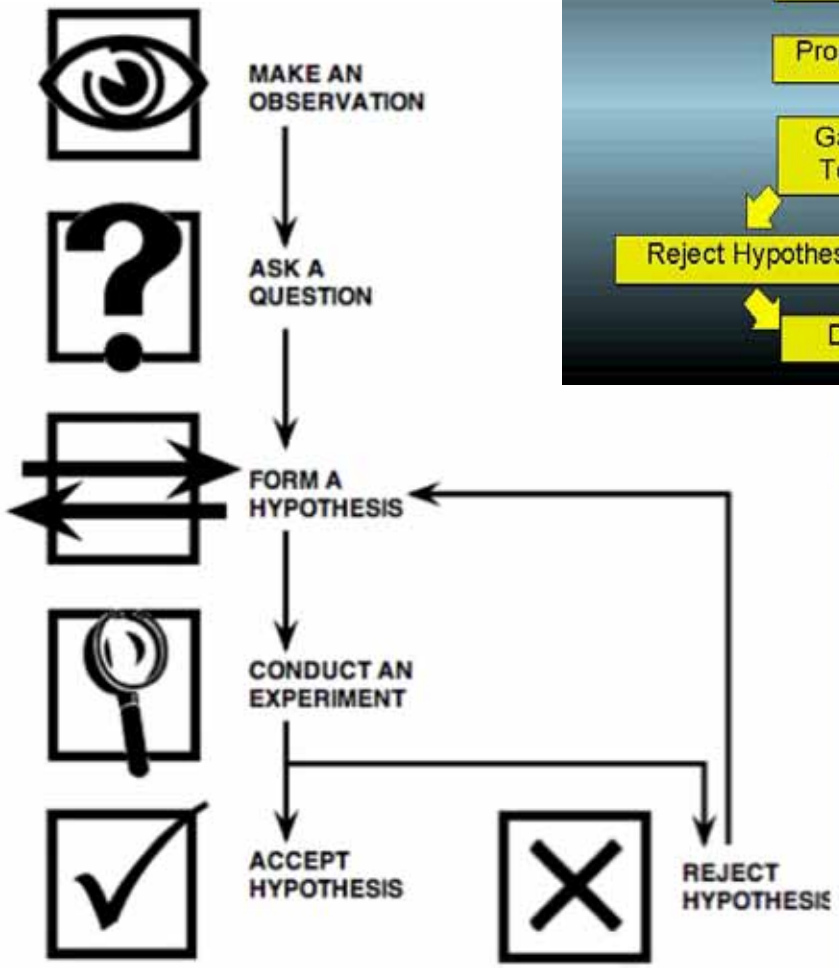


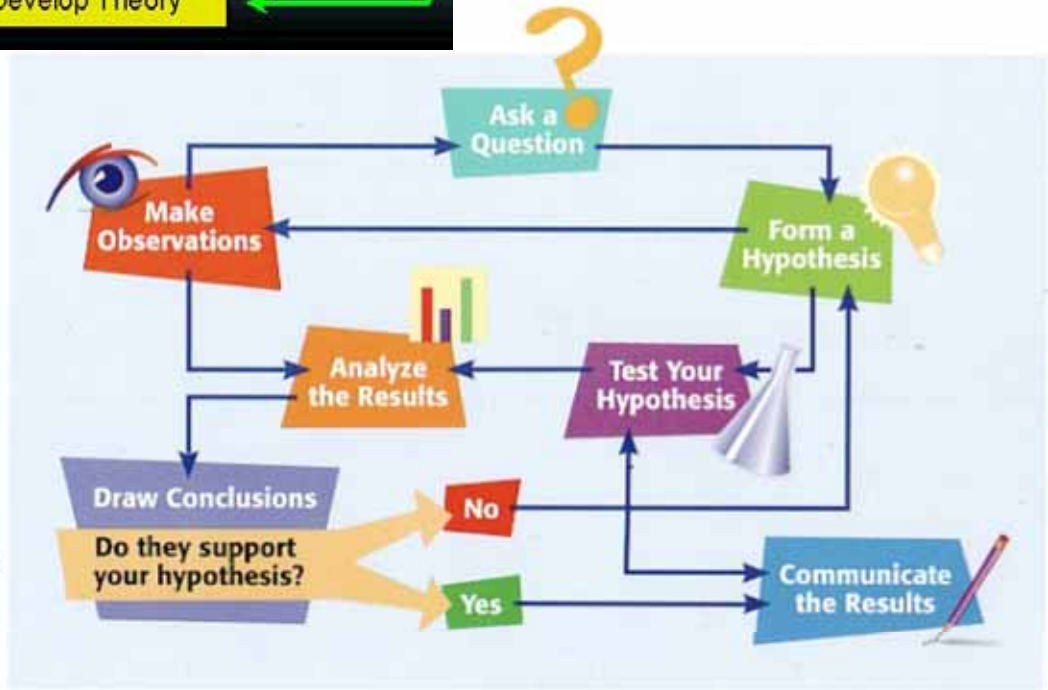
Phoenix Lander

“The Scientific Method”

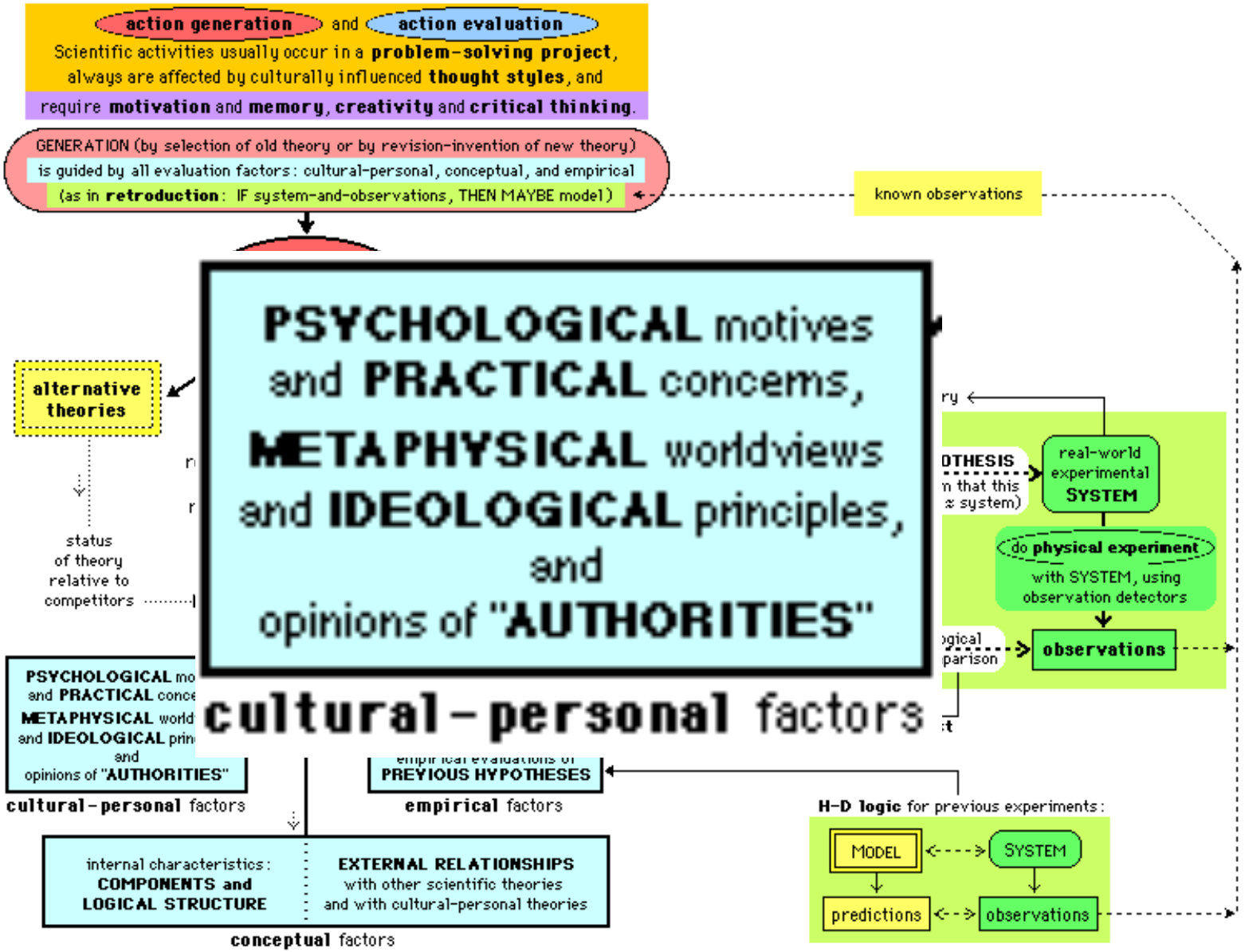
More Scientific Methods







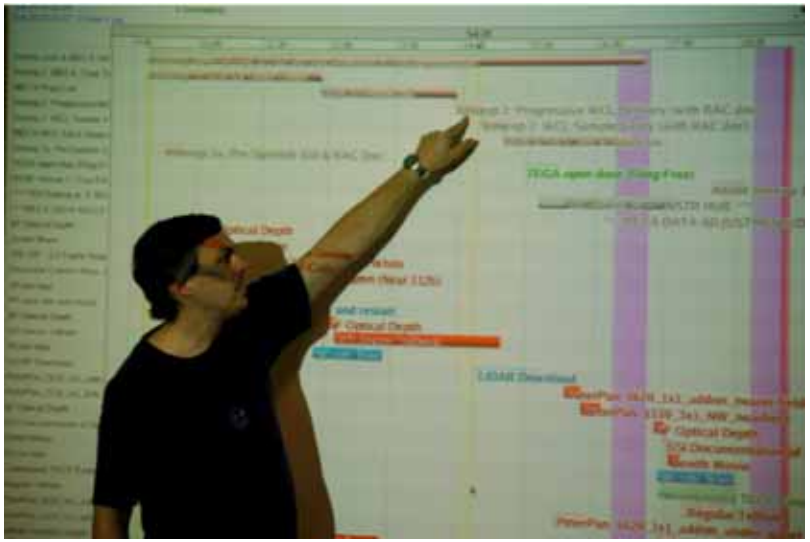
A Scientific Methodology?

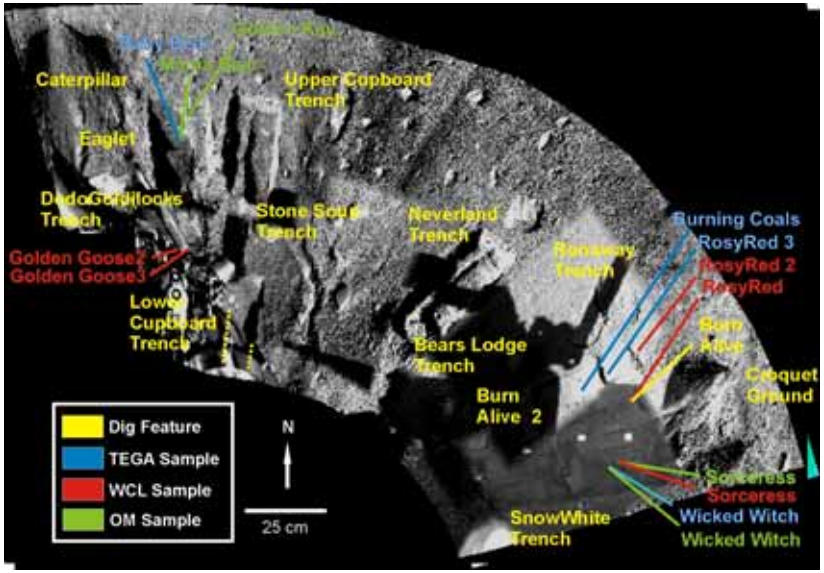


Phoenix: Being Scientific

Challenges & Accomplishments

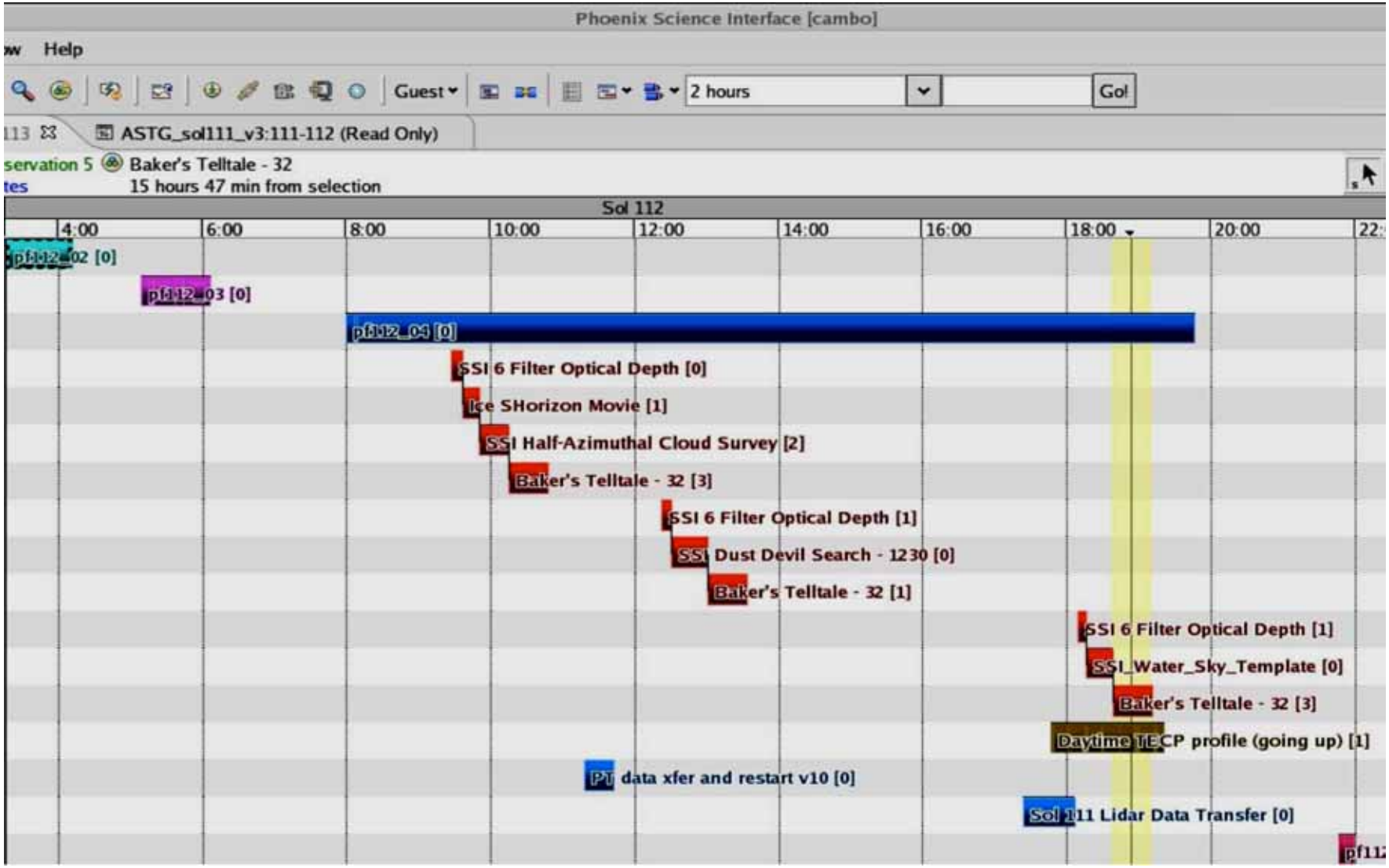
- Available tools (TEGA, WCL, OM…) → definition of "evidence"
- Publication genre (e.g., *Science*) → data gathering
- Public expectations & blogs →announcements
- Mission Success Criteria ≠ scientific objectives (like MER)
- Fixed workspace → requires consensus for defining systematic study (vs. MER)
- Complex daily multi-level engineering process → science proceeds at the pace of the total system (comms, power, memory, programming/OS, instrument interactions, roles & schedules)





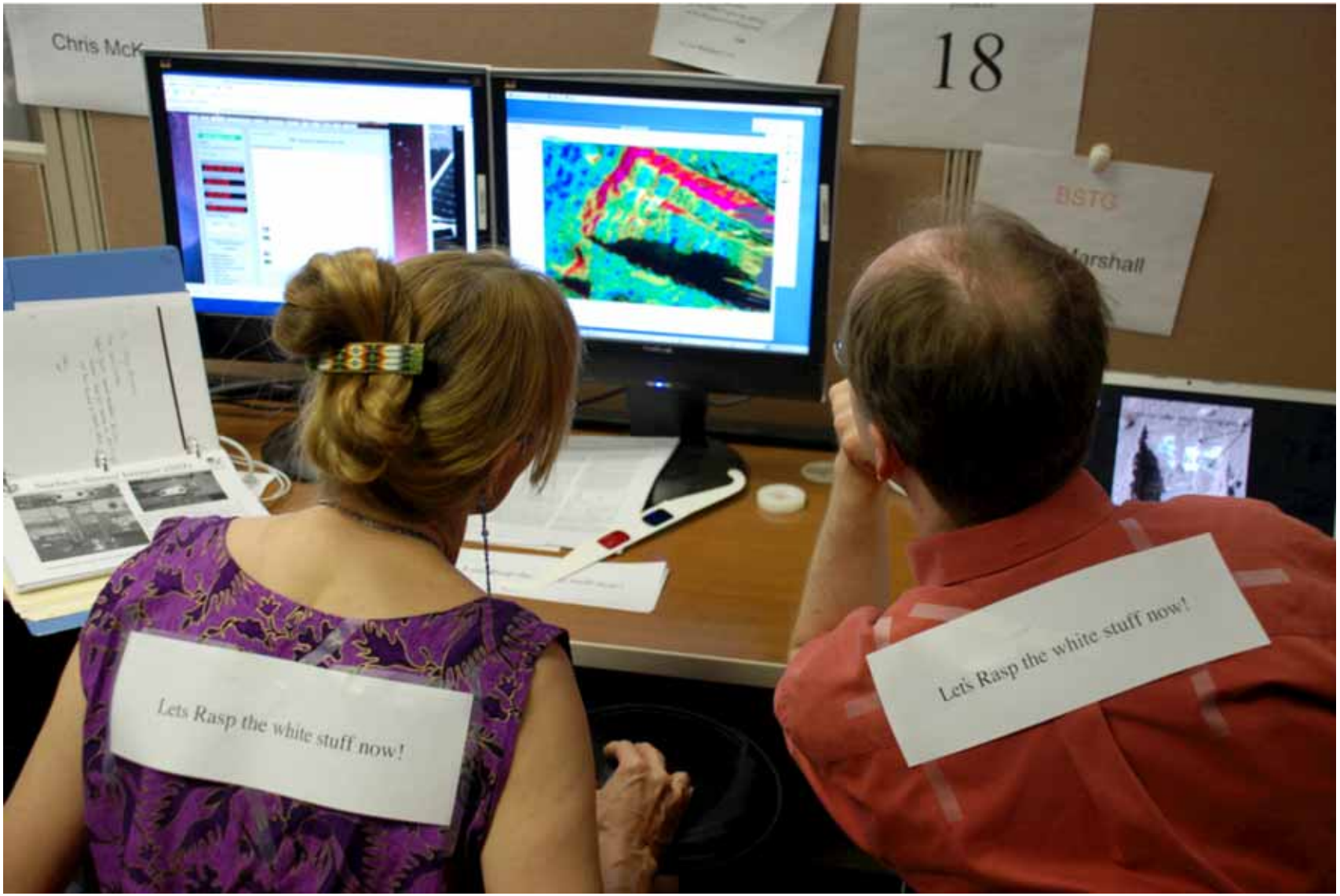
Phoenix: Being Scientific

Planning & Documenting with Engineering Tools



Phoenix: Being Scientific

Opportunistic Practicality vs. Principled Strategy



Phoenix: Being Scientific

Managing Programmatic Requirements

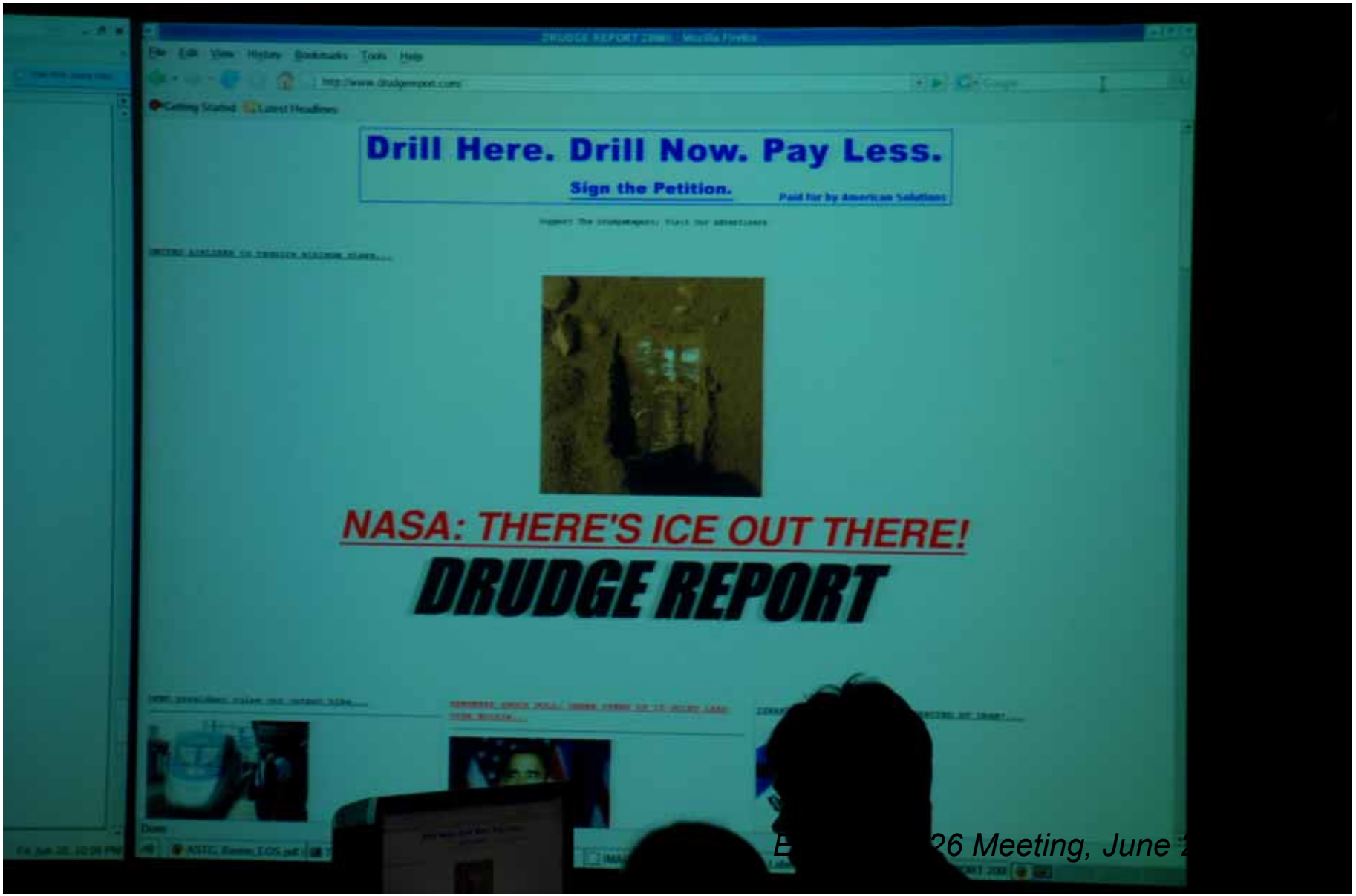
Landing Scorecard					
EXPECTED MISSION	**FULL MISSION SUCCESS**	**MINIMUM MISSION SUCCESS**	**MINIMUM ACHIEVED**	**FULL ACHIEVED**	**ISSUES**
Land successfully on the surface	Same	Same	DONE	DONE	NONE

Sample Analytical Analysis Scorecard					
EXPECTED MISSION	**FULL MISSION SUCCESS**	**MINIMUM MISSION SUCCESS**	**MINIMUM ACHIEVED**	**FULL ACHIEVED**	**ISSUES**
Samples of the surface soil and **three depths** to both TEGA and MECA.	Samples of the surface soil and **two depths** to both TEGA and MECA.	Samples of the surface soil and **one depth** to either TEGA or MECA.	50%	33% (TEGA and WCL suface sample delivered)	
Use TEGA to analyze **8 soil samples** for H2O profiles and **4** atmospheric samples in its mass spectrometer	Use TEGA to analyze **3 soil samples** for H2O profiles and **an atmospheric sample** in its mass spectrometer	If TEGA, analyze **at least 2 soil samples** for H2O profiles and **an atmospheric sample** in its mass spectrometer	66%	50%	
Use MECA to analyze the wet chemistry of at least **4 soil samples**	Use MECA to analyze the wet chemistry of **at least 3 soil samples**	If MECA, analyze the wet chemistry of **2 soil samples.**	50%	33%	
Use MECA to analyze **10 samples** in its microscopy station.	Use MECA to analyze 3 samples in its microscopy station.	--	--	50% (Part A of 3 OM samples)	
Provide MECA/TECP soil conductivity measurements for a diurnal cycle 3 times and up to 3 depths beneath the surface	--	--	--	--	

Terrain, Rock, and Soil Remote Sensing Characterization Scorecard					
EXPECTED MISSION	**FULL MISSION SUCCESS**	**MINIMUM MISSION SUCCESS**	**MINIMUM ACHIEVED**	**FULL ACHIEVED**	**ISSUES**
Full RGB panorama of the landing site	Same	Partial monochromatic panorama of the landing site	DONE	55%	
Calibrated optical spectra of at least 3 locations	Same	--	--	DONE	NONE

Phoenix: Being Scientific

Managing the Public's Publications – part 1



Phoenix: Being Scientific

Managing the Public's Publications – part 2

Let's go for Broke?

- Without hard evidence that we have ice, the perception will be that the mission is failing
- With quantitative evidence of ice, and evidence of ice melting, the perception will be that we have a successful mission
- **Let's RASP the ice now!**
  - Even without analysis this could provide hard evidence that we have ice.

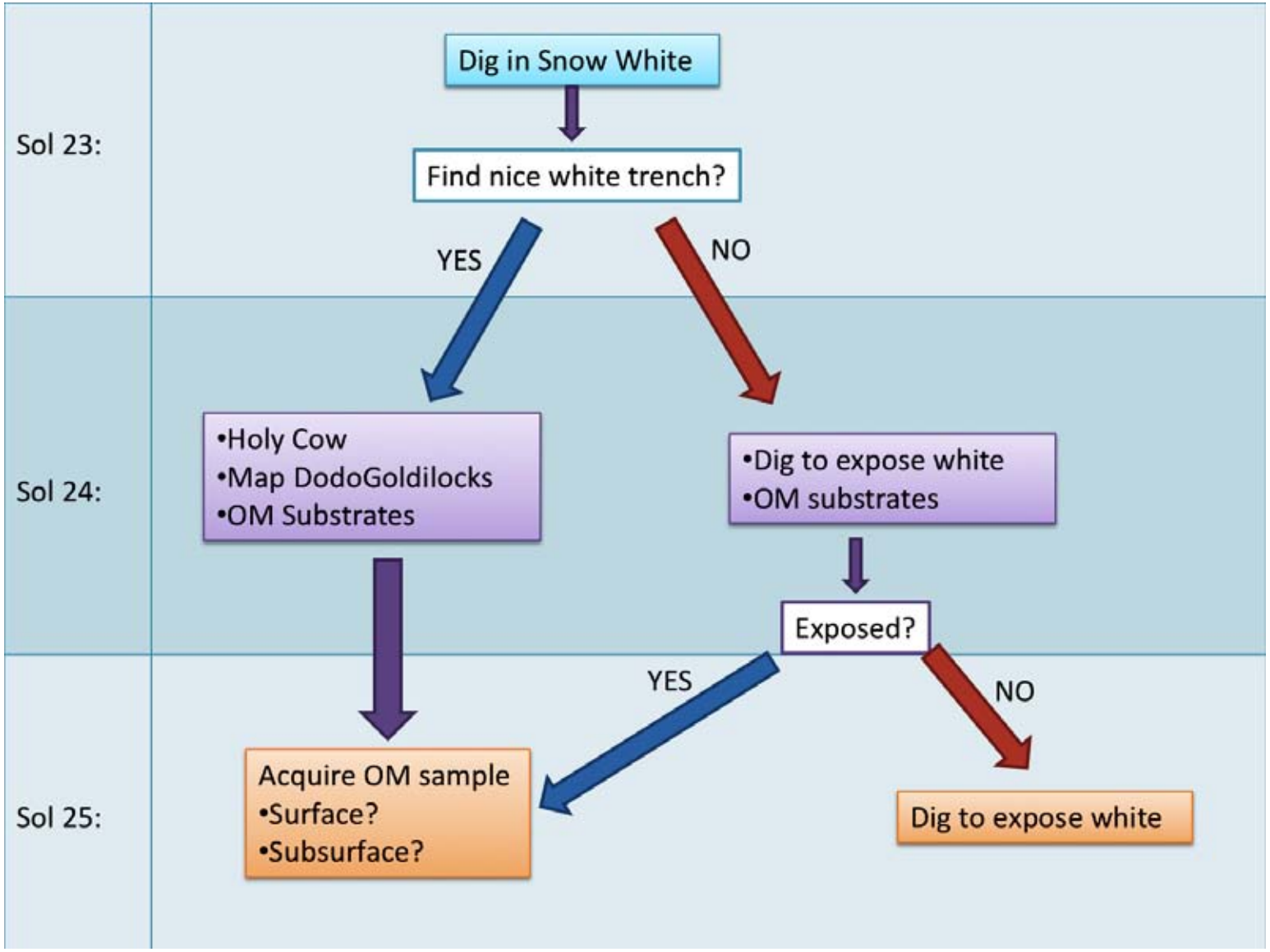
End of Sol 26 Meeting, June 20, 2008

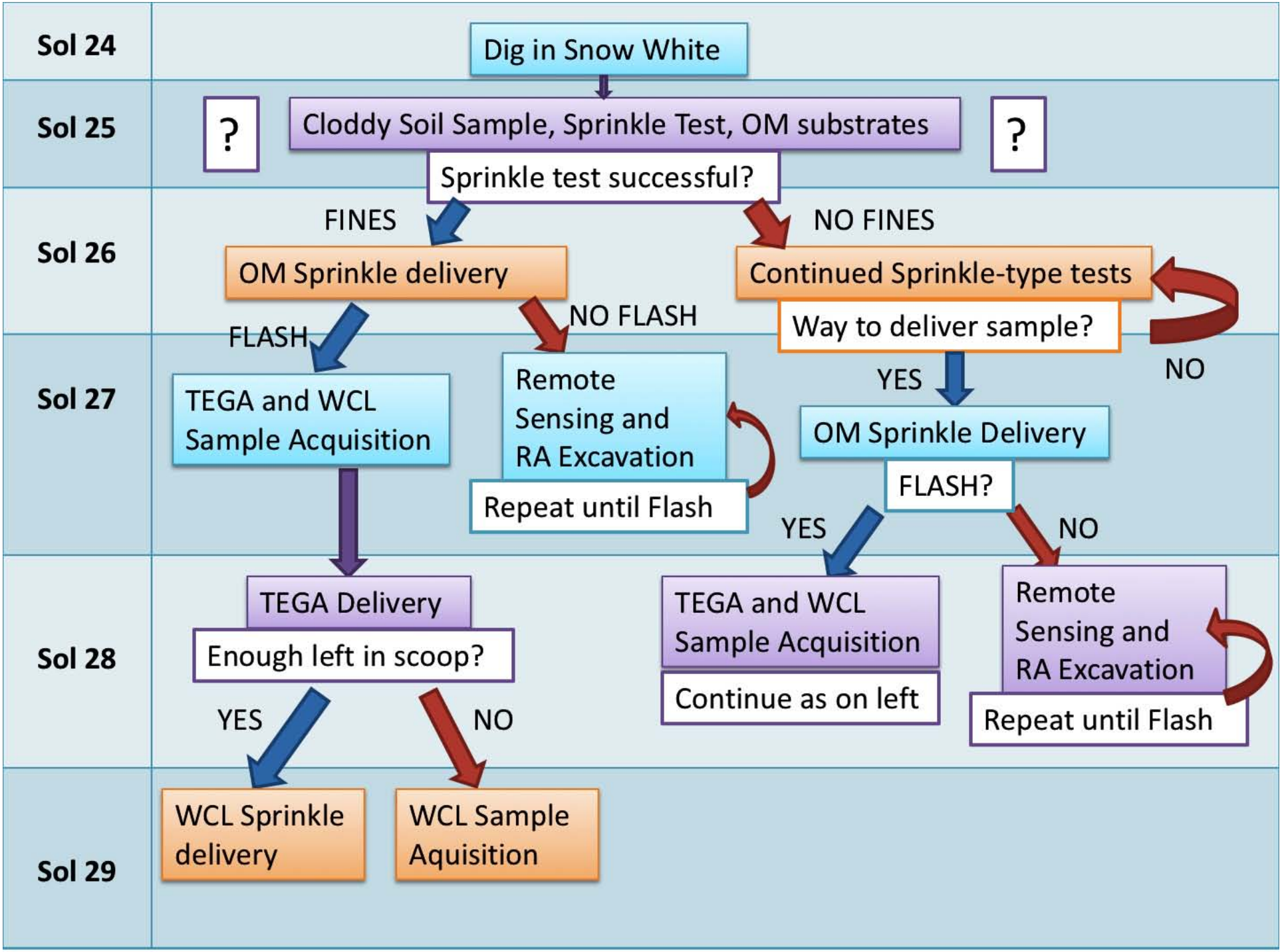
Phoenix: Being Scientific

Working with a Blind Robot

Phoenix: Being Scientific

Managing Contingencies on a Timeline

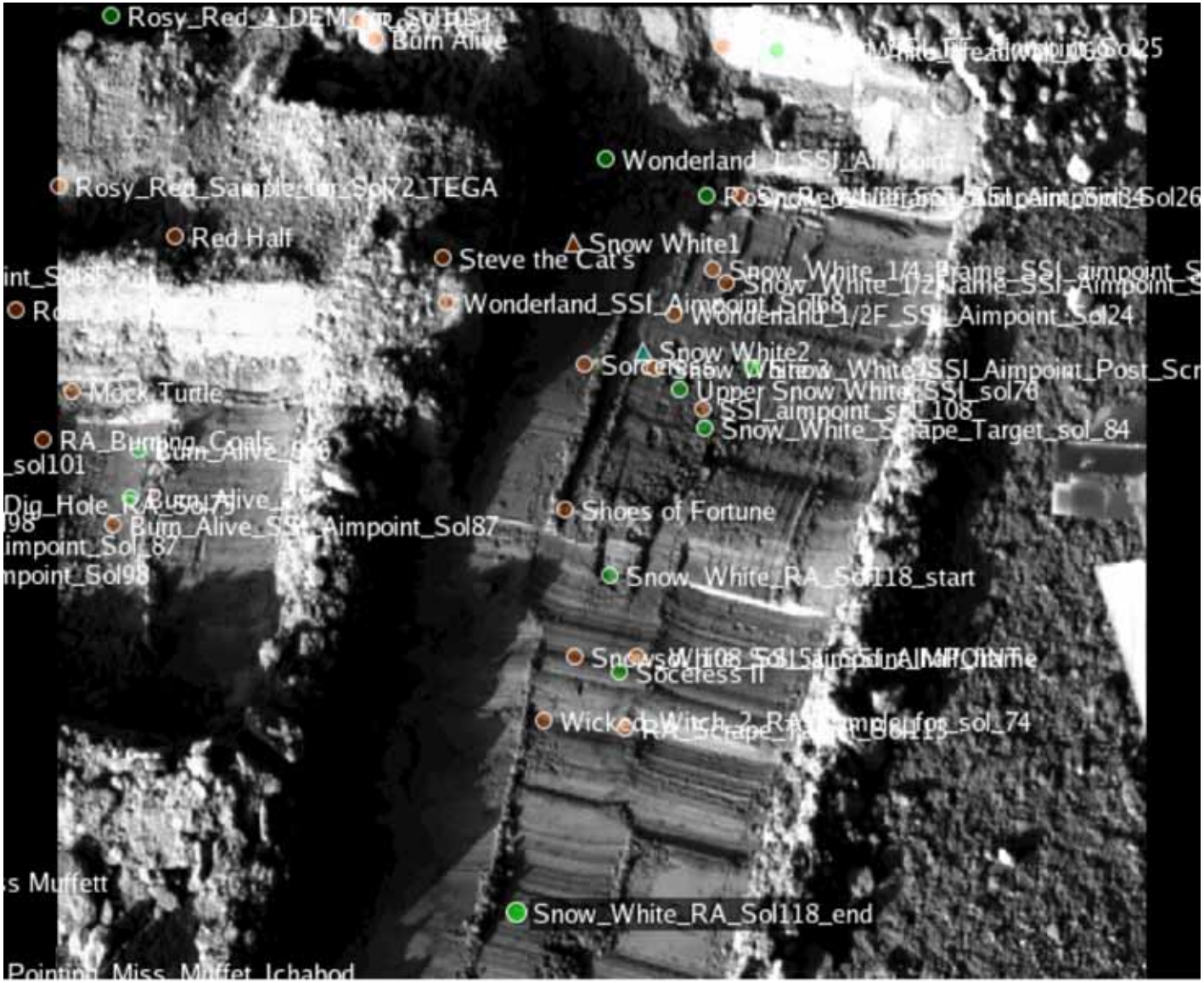



Sol 24
Dig in Snow White
Sol 25
?
Cloddy Soil Sample, Sprinkle Test, OM substrates
?
Sprinkle test successful?
Sol 26
FINES
NO FINES
OM Sprinkle delivery
Continued Sprinkle-type tests
Way to deliver sample?
NO
FLASH
NO FLASH
Sol 27
TEGA and WCL Sample Acquisition
Remote Sensing and RA Excavation
Repeat until Flash
YES
OM Sprinkle Delivery
FLASH?
YES
NO
Sol 28
TEGA Delivery
Enough left in scoop?
YES
NO
TEGA and WCL Sample Acquisition
Continue as on left
Remote Sensing and RA Excavation
Repeat until Flash
Sol 29
WCL Sprinkle delivery
WCL Sample Aquisition

Tactical Planning sol# / Day of Week / Strat Sci Planning / Strat Eng Planning	Sol 23 6/17 LTP B	Sol 24 6/18 LTP C	Sol 25 6/19 LTP C	Sol 26 6/20 LTP D SCAM	Sol 27 6/21 Margin	Sol 28 6/22 LTP A
Sampling Interop	Engineering Day	Continue trench in Wonderland	Acquire sample for OM, sprinkle clods (de-lump)	Xfer sample to OM (a.k.a. sprinkle test)	Acquire (or move) sample for TEGA	Xfer sample to TEGA
Surface Imaging		Mission Success		Change Monitoring polarization DodoGoldi	Mission success	Change Monitoring
RAC			RAC doc TEGA open door			
TEGA			TEGA high-temp ramp 2, open door	EEPROM update, bake	Update param. table, EGA prep, TA ramps, DSC	TEGA acquire sample, low-temp ramp
MECA- OM		Stage diagnostic	Pre-delivery imaging			Microscopy A
MECA- WCL					WCL Test thaw diagnostic	
MECA- TECP		TECP extended				
MET		Regular ATM	Regular ATM	Regular ATM	Regular ATM	Regular ATM
Coordinated Science					Water vapor 22:01, 1:38, 7:04	
Nighttime Science					Coordinated + 1:00am	22:00, 0:45, 3:30, 6:15

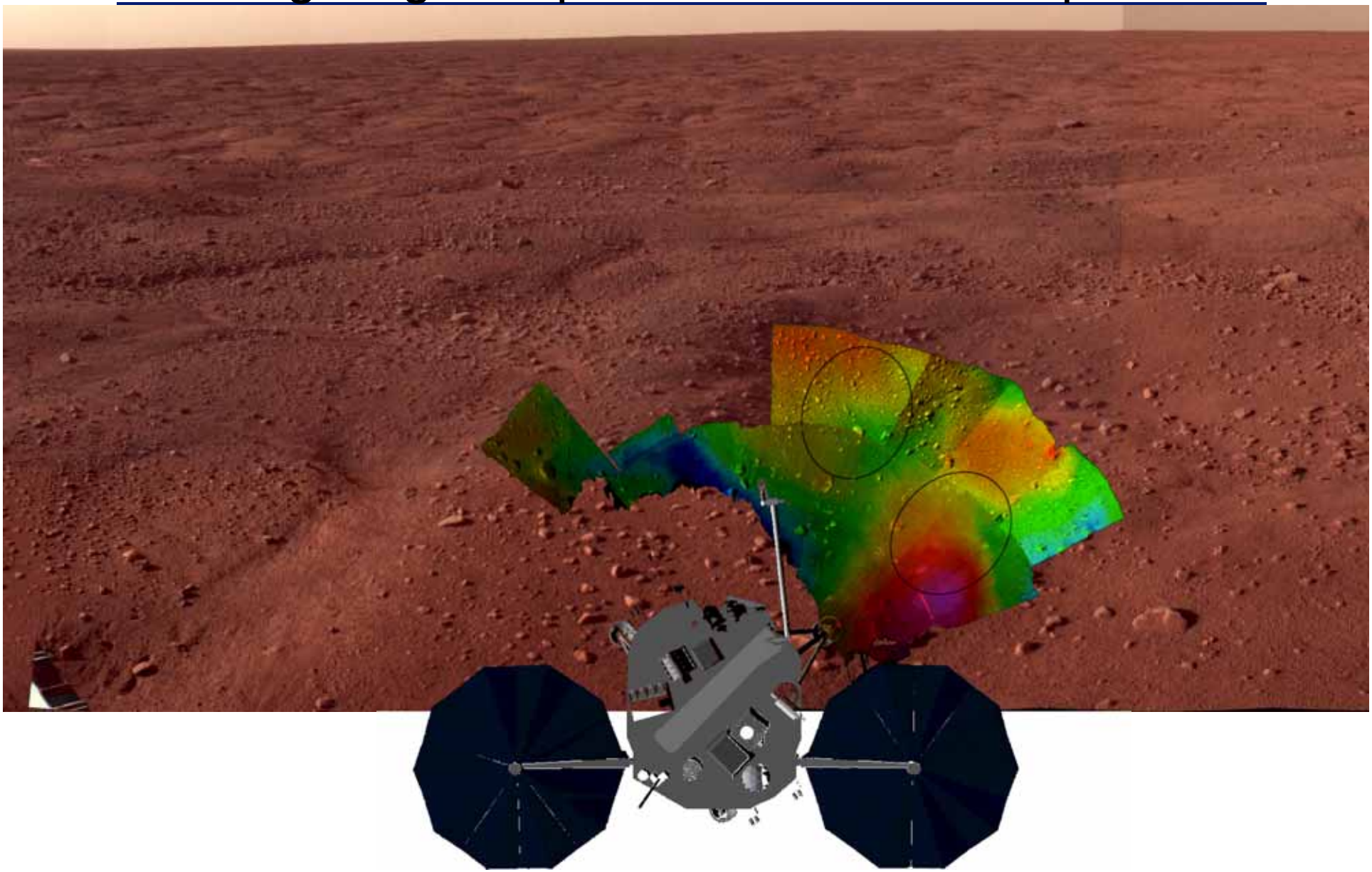
Phoenix: Being Scientific

Targeting Samples in Shared Workspace



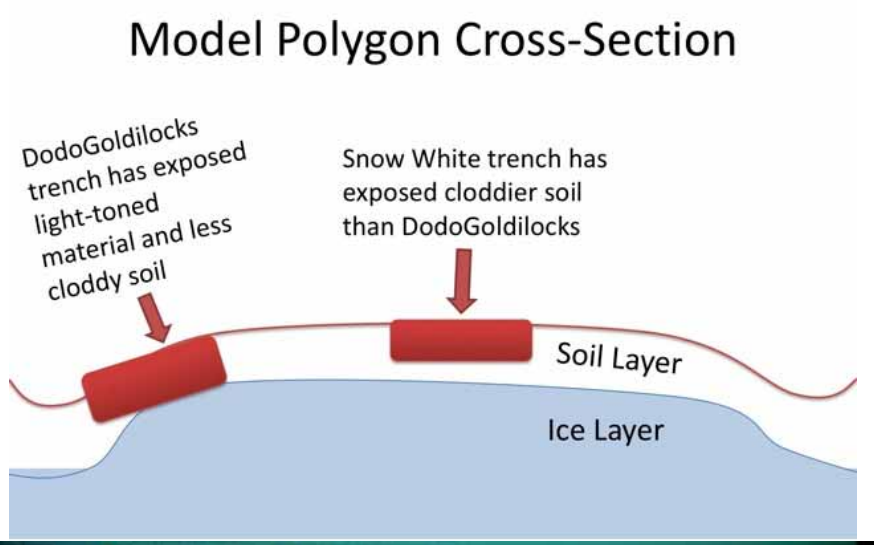
Phoenix: Being Scientific

Targeting Samples in Shared Workspace



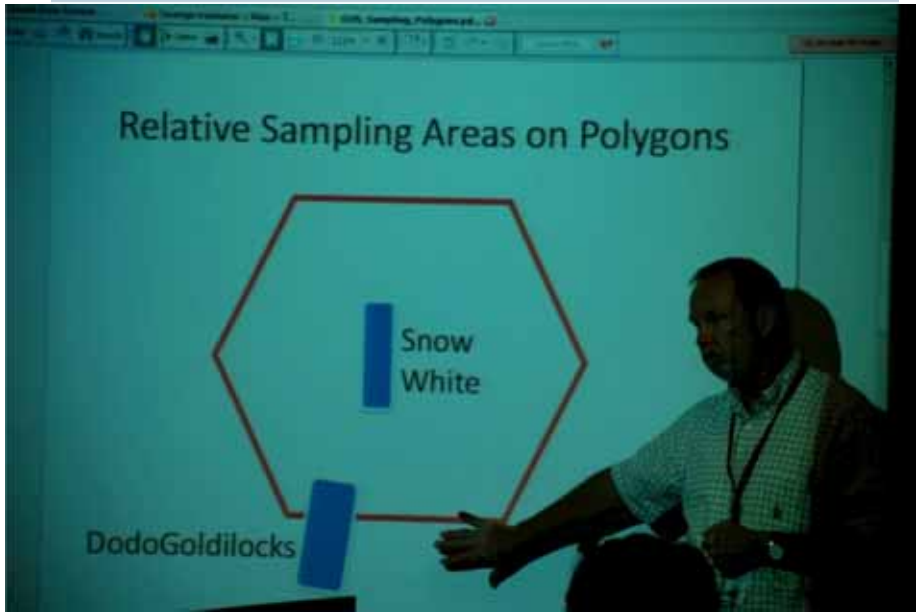
Phoenix: Being Scientific

Model-Based Data Gathering



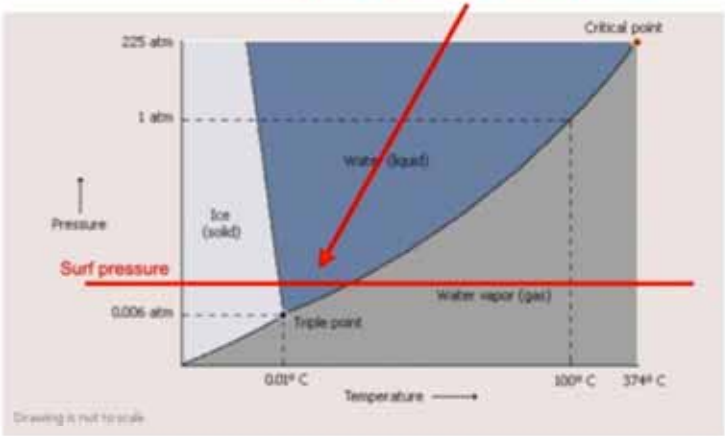
Profile Icy Polygon

Use Instruments ⟷ Confirm Subsurface H20 Ice



Melting Ice?

We need the soil temperature



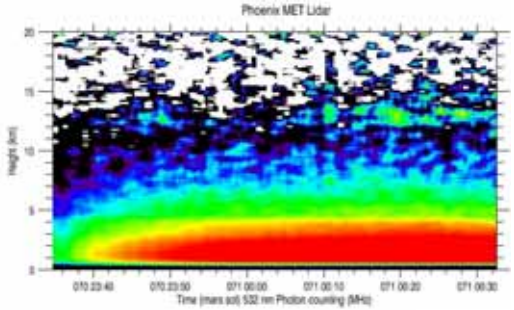
The Scientific Method Revisited

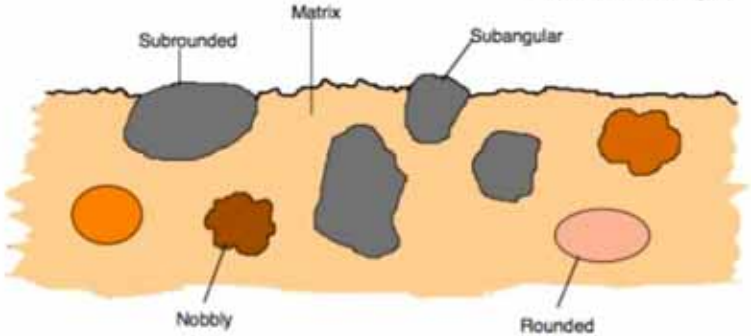
Beyond Observing, Hypothesizing, Experimenting

- Informed exploration
- Schedule & work plan prioritization
- Modeling: Not just isolated hypotheses
- Strategic sampling & test allocation
- Experimentally testing instruments to calibrate
- “Doing” the story you want to tell or need to publish

“Good science is simply not trying to be tricked into the wrong answer by the evidence.”

08:15 MST	74 minutes ago	End-of-Sol Science Meetir
10:30 MST	61 minutes from now	Activity Plan Approval Meetin
09:20 MST	**9 minutes ago**	**Upcoming Sol Planning**
10:15 MST	**46 minutes from now**	**Short-Term Planning**
11:15 MST	2 hours from now	Long-Term Planning
12:30 MST	3 hours from now	Sequence Walkthrough
12:30 MST	3 hours from now	Shift 1 End
13:45 MST	4 hours from now	Final Sequence Integration

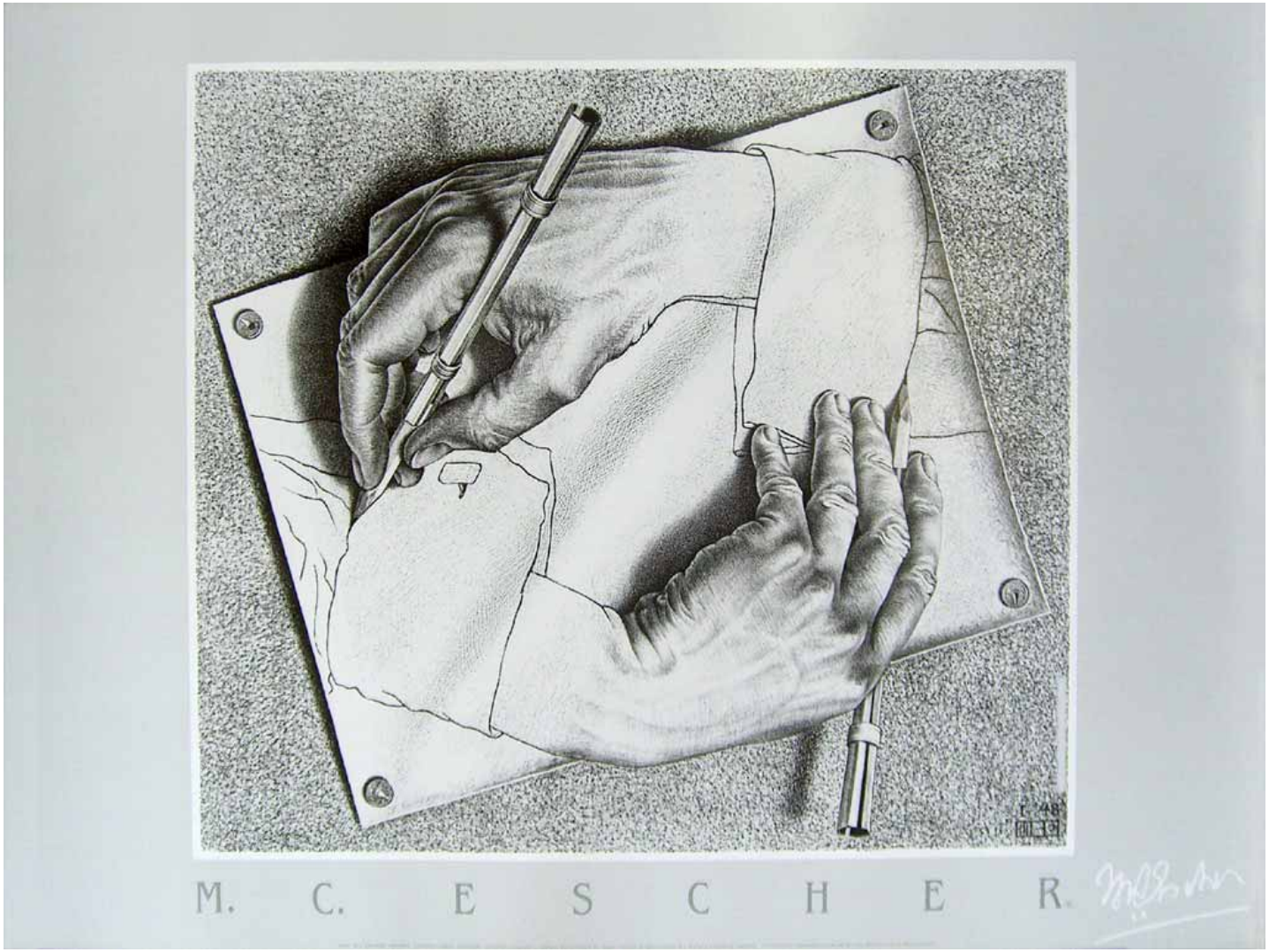




Being Accountably Scientific

Responsive to peers, program managers, publishers, and public interest in a principled, coherent manner

Constructing an orderly image of the world … that includes your visible actions.



Creating knowledge in visibly knowledgeable ways…

The plumes of Phoenix seemingly etched its own image as it launched to Mars…

SITUATED COGNITION:

Part 1
A Transactional View of Knowledge

Part 2
Implications for Design

William J. Clancey

Senior Research Scientist
Institute for Research on Learning

Canberra, Australia @ 1997 WJ Clancey

The Holistic View of Knowledge

- **Interactive** — created within coordinated activity
- **Interpretative** — enables giving meaning to descriptions
- **Collaborative** — oriented within shared activities and methods
- **Developmental** — always changing in activity
- **Emergent** — transcends individual control
- **Participatory** — develops through interactions between communities of practice

Where a Psychological Perspective is Helpful...

"Social construction... sees our understanding of the world as generated by people...rather than as a set of fixed, immutable facts." (p. 12)

"Skill and expert performance cannot be captured as a set of formal rules... skills are performed in the context of specific situations." (p. 13)

"A strict model of human action in most work situations is not possible or appropriate; rather, human action is driven by the concrete situation that exists at any moment and is constantly changing. This implies that we should *support office workers in their activities*, rather than *building office automation systems*." (Bannon, p. 35)

"It is the community rather than the individual, that defines what a given domain of work is and what it means to accomplish it successfully." (Suchman and Trigg, p. 73)

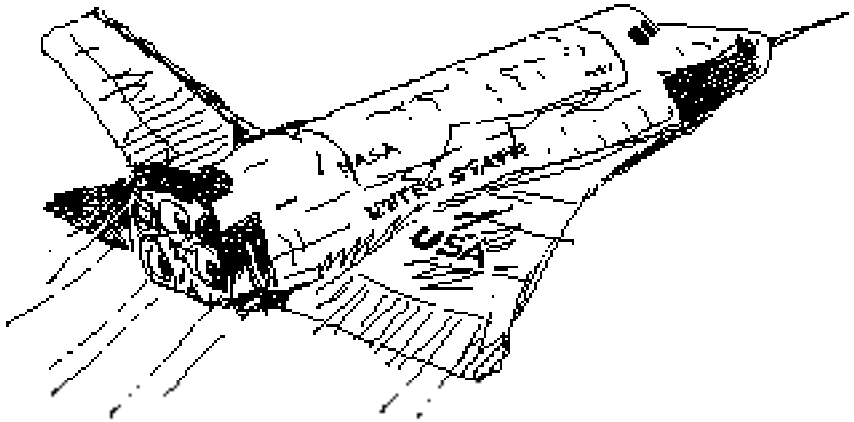
"The members of the team go rapidly into position which they did not foresee, plan, or even immediately envisage, any more than the bits of a glass in a kaleidoscope think out their relative positions in the patterns which they combine to make." (Bartlett, 1932)

Generated by people vs. fixed? Cannot be captured? Possible or appropriate? Who has ideas, a person or a community? People are like randomly moving bits of glass?

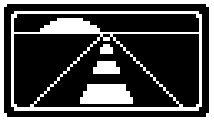
From Social Science to Neuropsychology

1st Order (External View)	2nd Order (Internal View)
1) **Social Science:** Interactive view of everyday practice. *Distinction between practice and theory; culture not reducible to lists of beliefs, conventions, rules.*	4) **Neuropsychology:** Cognitive processes in the brain. *Distinction between deliberation and coordination.*
2) **Situated Cognition:** How representations are created and used. *Distinction between representations we can perceive, representing to ourselves, and neural structures.*	3) **Philosophy:** Foundational analyses of concepts, meaning, and models. *Distinction between models and knowledge.*

What is the ontological difference between piloting an aircraft



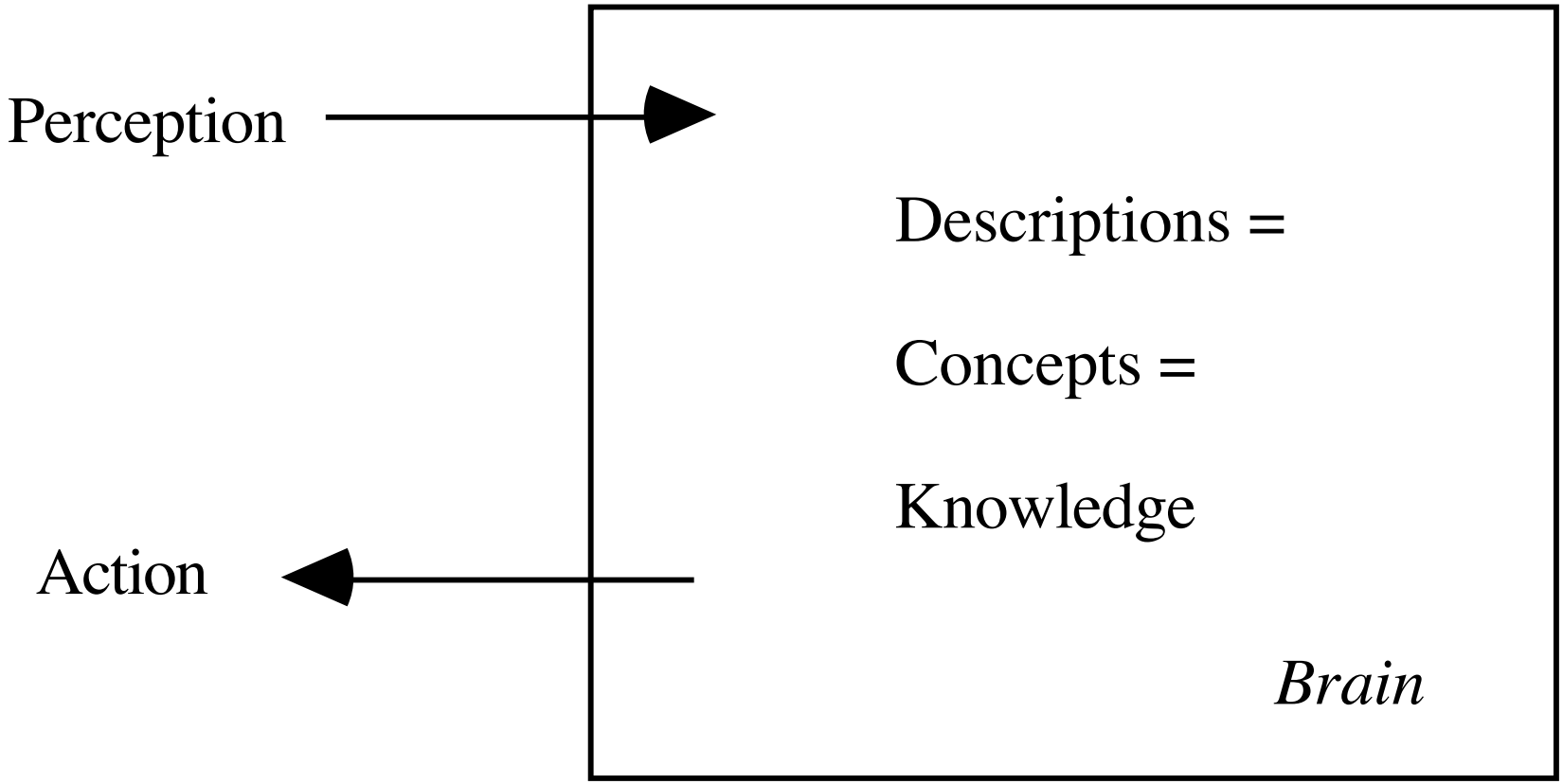
using a flight simulator (as in virtual reality)



and manipulating a fully-computerized simulation?

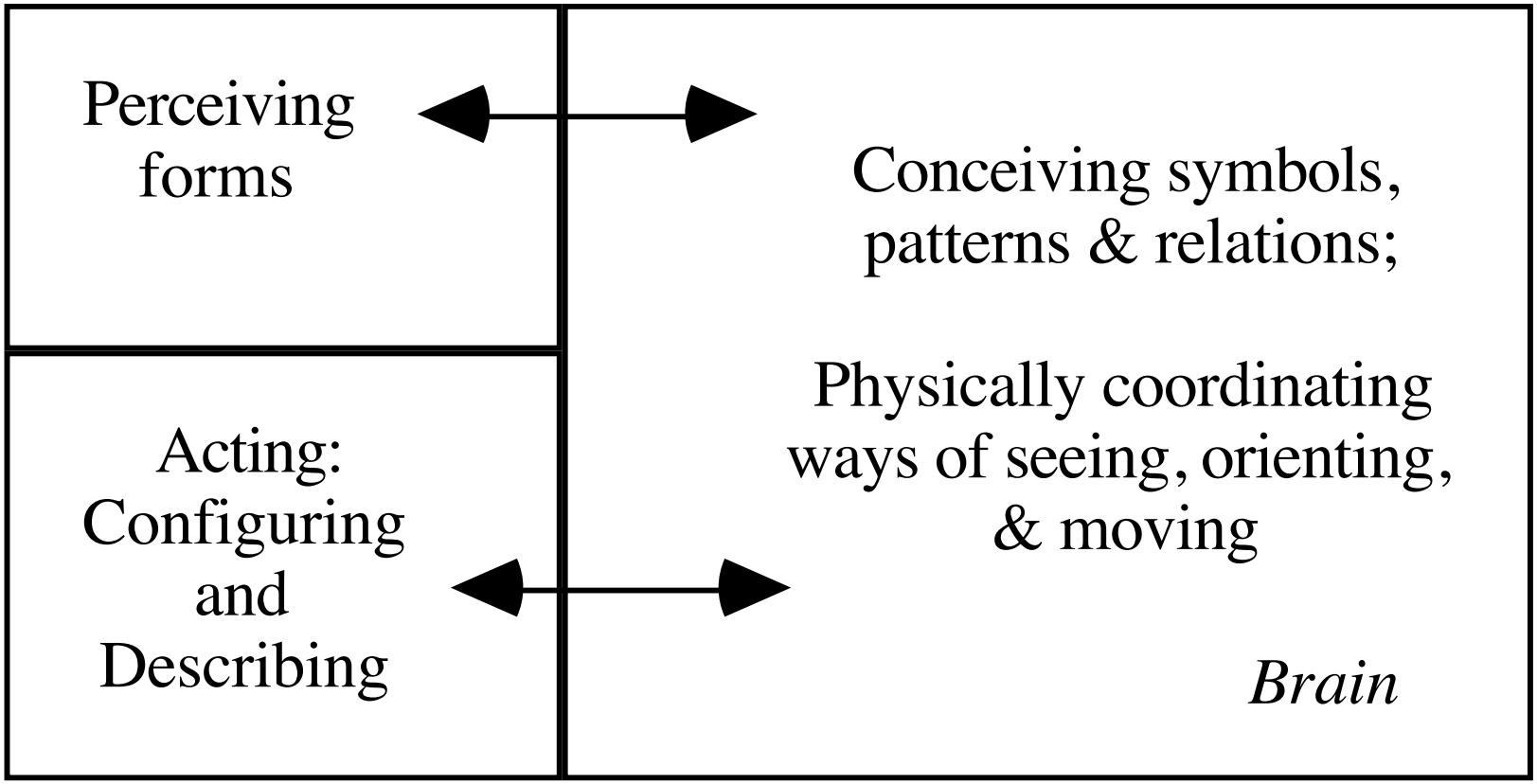
Situated Cognition -- Main points

1) Every thought, perception, and action is a generalization.
2) Human memory is not a storage place.
3) Experienced representations (whether imaginary or physical forms in the world) are created and given meaning perceptually.
4) Rules and scripts represent historical trends and patterns of interaction relative to an observer.
5) "Reality" cannot be objectively described or modeled.
6) Laws and grammars descriptions don't generate behavior patterns except in formal systems.
7) Simple mechanisms in complex environments can produce complex-appearing behaviors.



Traditional, Parallel-Independent View of Perceiving and Acting

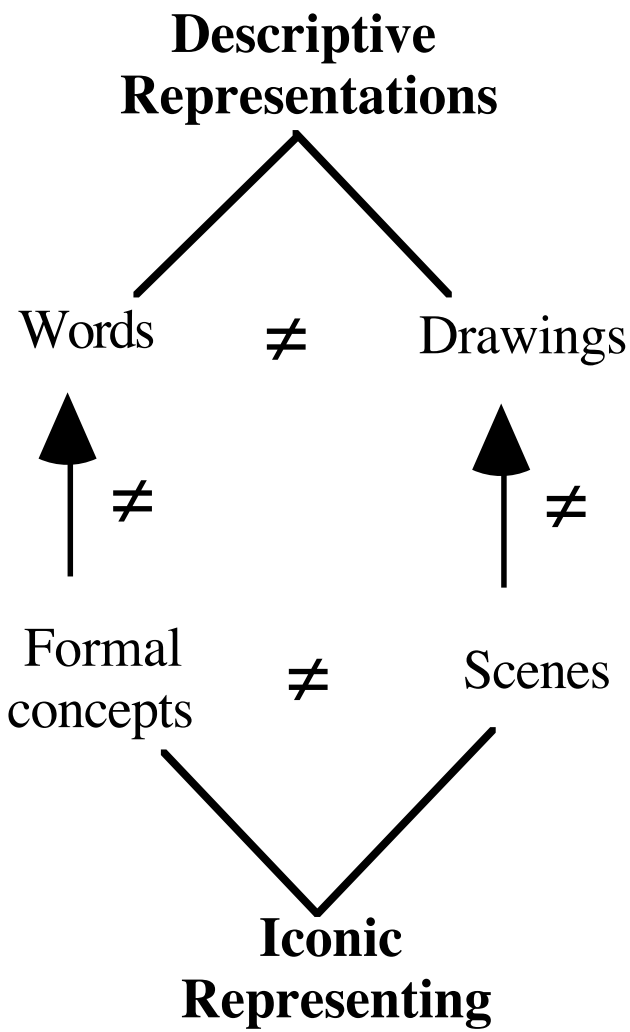
(Descriptions mediate behavior internally)



Simultaneous, Co-Dependent View of Perceiving and Acting

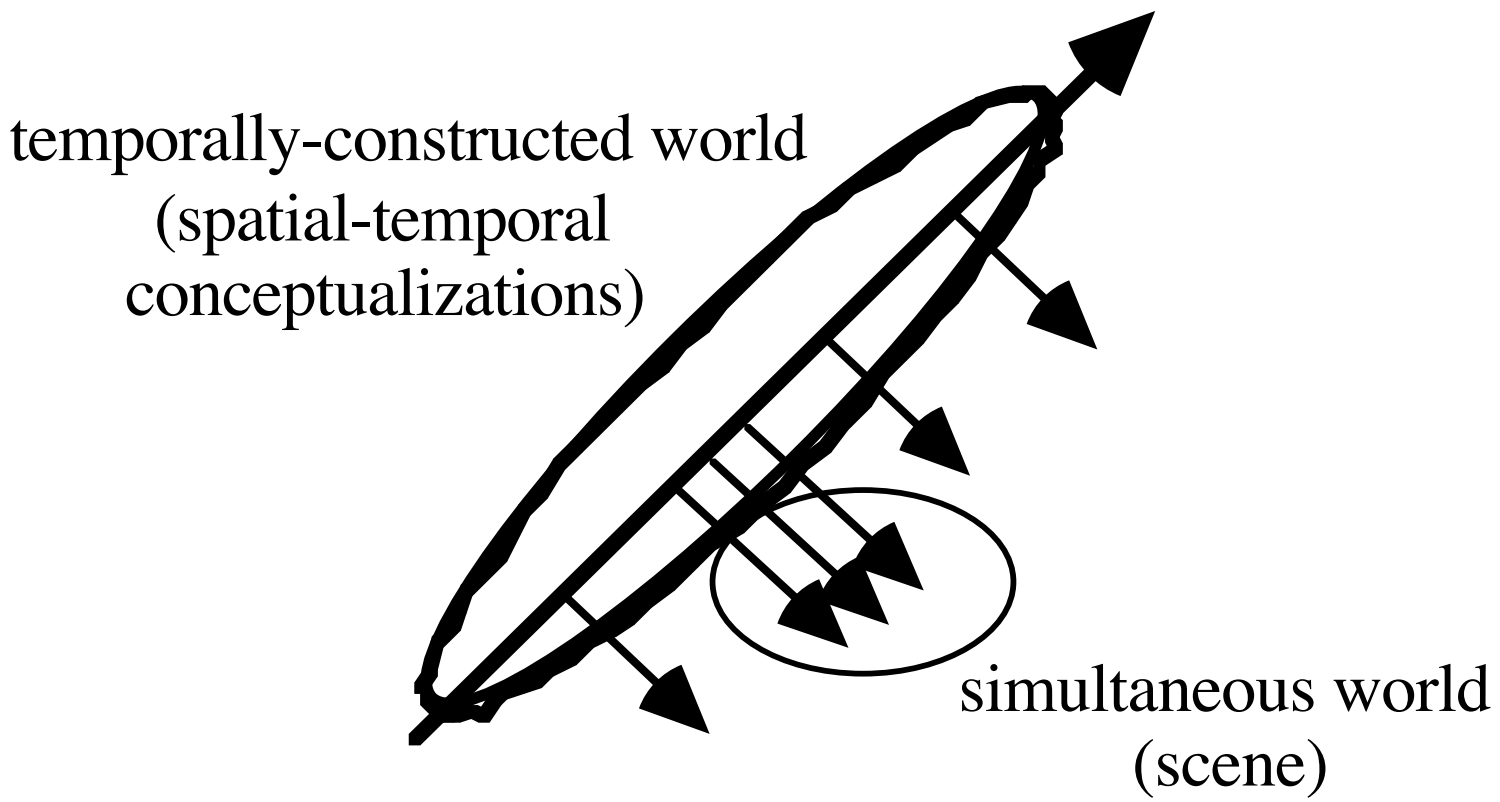
(Perceiving and describing are *behaviors;* descriptions are *artifacts*.)

Representational Artifacts and Modes of Representing



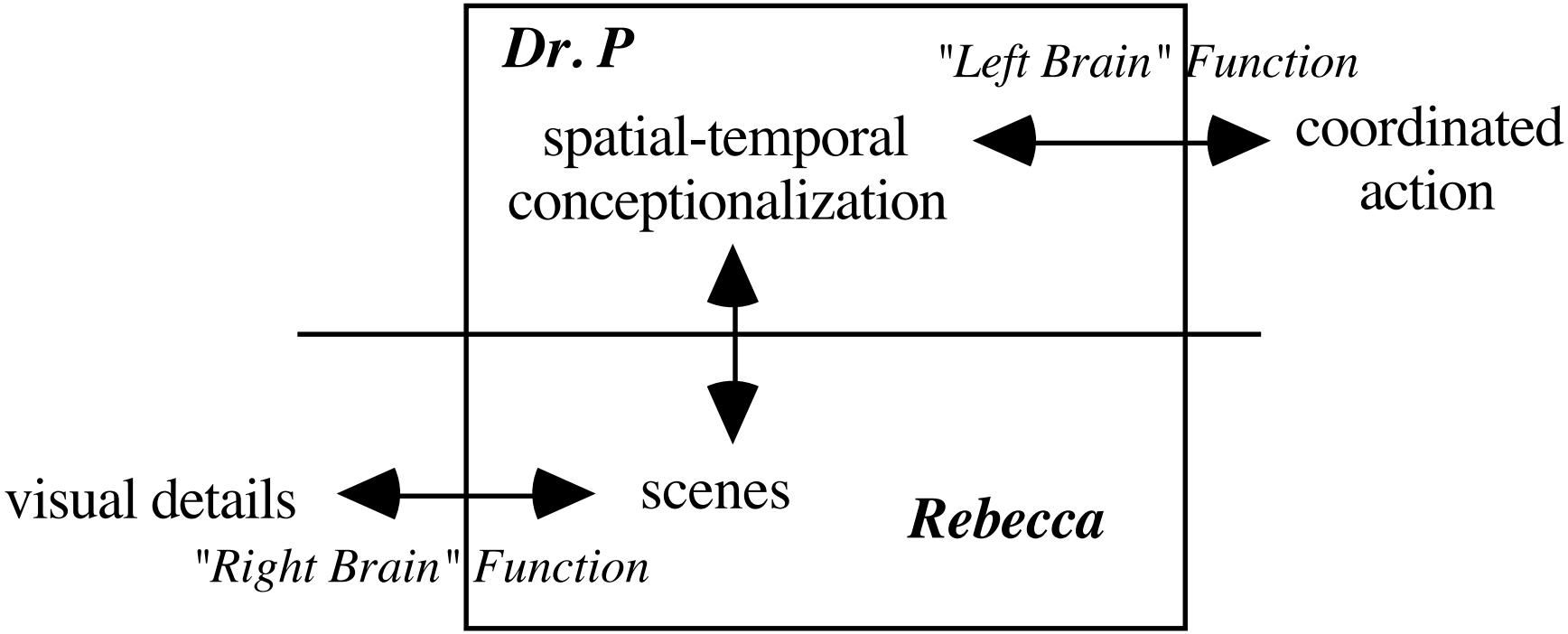
Two Modes of Higher-order Categorizing:

Sensorimotor Sequences (serial) &
Simultaneously-Perceived Details (parallel)

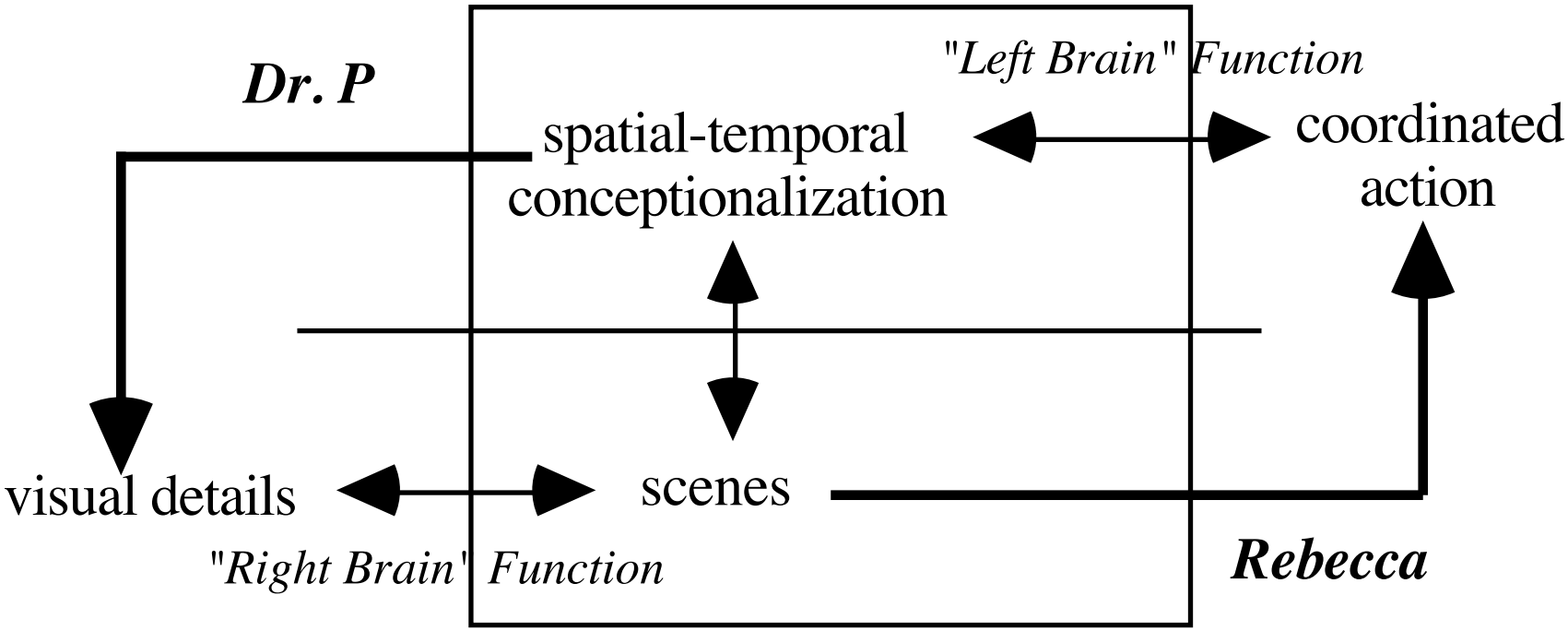


Dependencies of Perceiving, Conceiving, and Coordinating Action

(revealed by the experiences of Dr. P and Rebecca)



Conceptual Strategies of Dr. P and Rebecca to Coordinate Activity



SINGLE-MOST COMMON CONFUSION IN AI

Equating:

"knowledge"
"knowledge representations"
"representations"
"mental models"
"knowledge base"

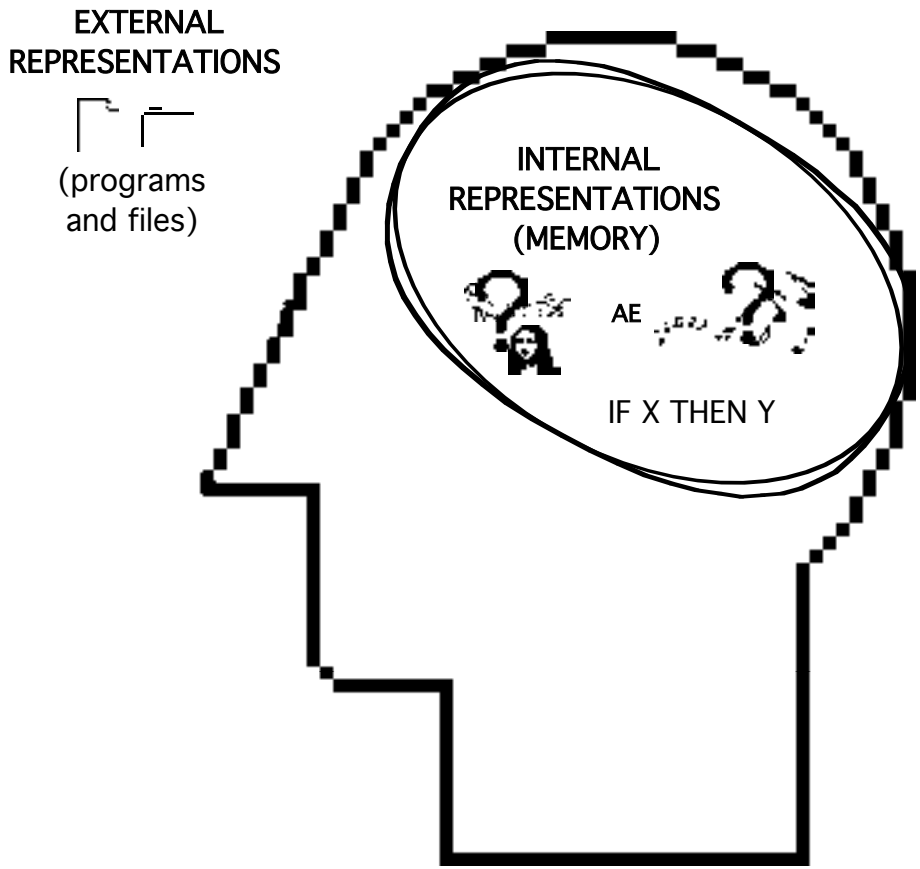
Often leads to interpreting situated cognition to mean that there are "no internal representations" or "no concepts in the mind."

Rather, the claim is that "knowledge" is an analytic abstraction, like energy, not a substance that can be in hand. You cannot inventory what someone knows.

Knowledge representations (e.g., textbooks, expert systems) are descriptions, which are tools, not knowledge itself. "The map is not the territory."

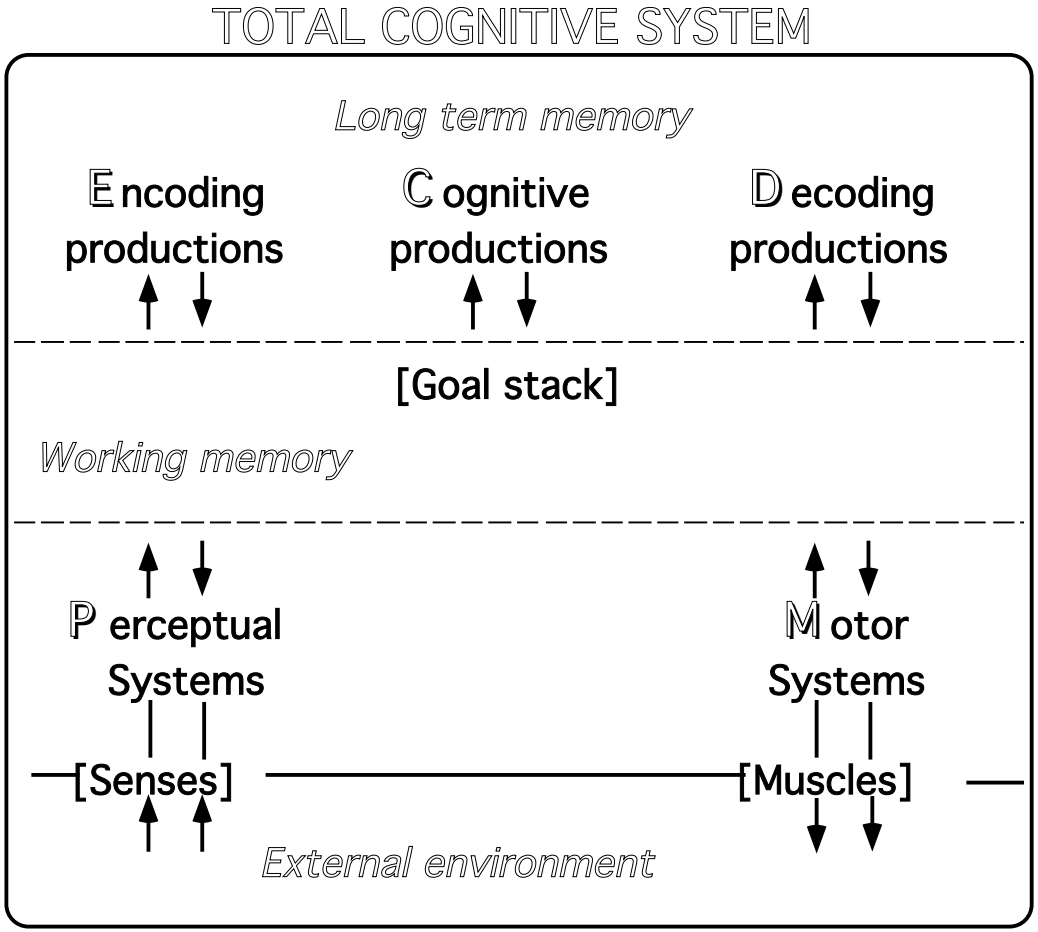
Taking what is already known or pointing to it is no more a case of knowledge than taking a chisel out of a toolbox is the making of the tool.

John Dewey, *The Quest for Certainty*, 1929



"Much of what constitutes domain-specific problem-solving expertise has never been articulated. It resides in the heads of tutors, getting there through experience, abstracted but not necessarily accessible in an articulatable form."

(Sleeman and Brown, 1982, p. 9)



Performance:
[P ---> E] ---> C ---> [D ---> M]
Structure and Learning:
[P] ---> [E ---> C ---> D] ---> [M]

Newell, *Unified Theories of Cognition,* 1990, p. 195

The Cottage Cheese Example

Information and procedural knowledge accessed by eye, hand, or transformed in activity, make possible a move toward the solution or suggest a change in the solution shape that draws it closer to the information at hand... It may be difficult, even, to distinguish the problem from its resolution...

Another problem posed to new members of the Weight Watchers in their kitchens provides a further illustration... In this case they were to fix a serving of cottage cheese, supposing that the amount allotted for the meal was three-quarters of the two-thirds cup the program allowed.

The problem solver in this example began the task muttering that he had taken a calculus course in college (an acknowledgment of the discrepancy between school math prescriptions for practice and his present circumstances). Then after a pause he suddenly announced that he had "got it!" From then on he appeared certain he was correct, even before carrying out the procedure.

Cottage cheese example (continued)

He filled a measuring cup two-thirds full of cottage cheese, dumped it on a cutting board, patted it into a circle, marked a cross on it, scooped away one quadrant, and served the rest.

Thus, "take three-quarters of two-thirds of a cup of cottage cheese" was not just the problem statement but also the solution to the problem and the procedure for solving it. The setting was part of the calculation process and the solution was simply the problem statement, enacted with the setting.

At no time did the Weight Watcher check his procedure against a paper and pencil algorithm, which would have produced 3/4 cup x 2/3 cup = 1/2 cup. Instead, the coincidence of problem, setting, and enactment was the means by which checking took place." (p. 159-165)

Cottage cheese example (continued)

"[He] appeared certain he was correct, even before carrying out the procedure" —> *Internal experience of representing*, never discussed by Lave, et al.

"...the solution was simply the problem statement, enacted with the setting" —> No, the setting isn't given, but is perceived in a certain way, as affording a certain kind of activity.

Subject's certainty is evidence for conceptual understanding, which coordinated the activity as a procedure; this was not carried out in the manner of executing a program, but enacted.

Besides contrasting the enactment with the calculation on paper, we must also draw out the psychological aspects, which themselves contrast with symbol manipulation on paper.

Conceptualizing <—> Interacting <—> Symbolically Manipulating

Deficiencies of Cognitive Studies of Learning (re: Transfer)

(from Jean Lave, Cognition in Practice)

— Devalues knowledge of "just plain folk" (JPF), misconstruing relation of practice & theory.

— Reduces culture, meaning, knowledge, & context to descriptions.

— Problem-solving experiments restrict reasoning to symbol manipulation in a given, fixed language ("characterize on *a priori* grounds the structure of 'correct knowledge'")

— Reduces "using a theory" to instantiation & mapping vs. interpretation, reconceptualization, reperception & interactivity.

Pam and Sarah Using the Grapher Program

As you may have noticed, the graphs of these equations are straight lines... We're going to try to make some sense out of why different numbers produce different lines...

Your equations	Your discoveries
Y = 4X +3	When you try an equation with smaller numbers the line gets straighter.
Y= -1X + 10	
Y = 5X+5	
Y=5X+7	
Y=10X +9	When you type higher numbers the line gets thicker.
Y=30X+10	
Y=50X+50	

Clear the screen and type in these equations, one at a time:

Y = 2X + 1

Y = 3X + 1

Y = 4X + 1

What do you notice? The lines are not very straight.

How are these lines similar? They are

How are they different? Each one is thicker than the other one.

What do you think will happen if you type in Y = 5X +1? That the equation is not going

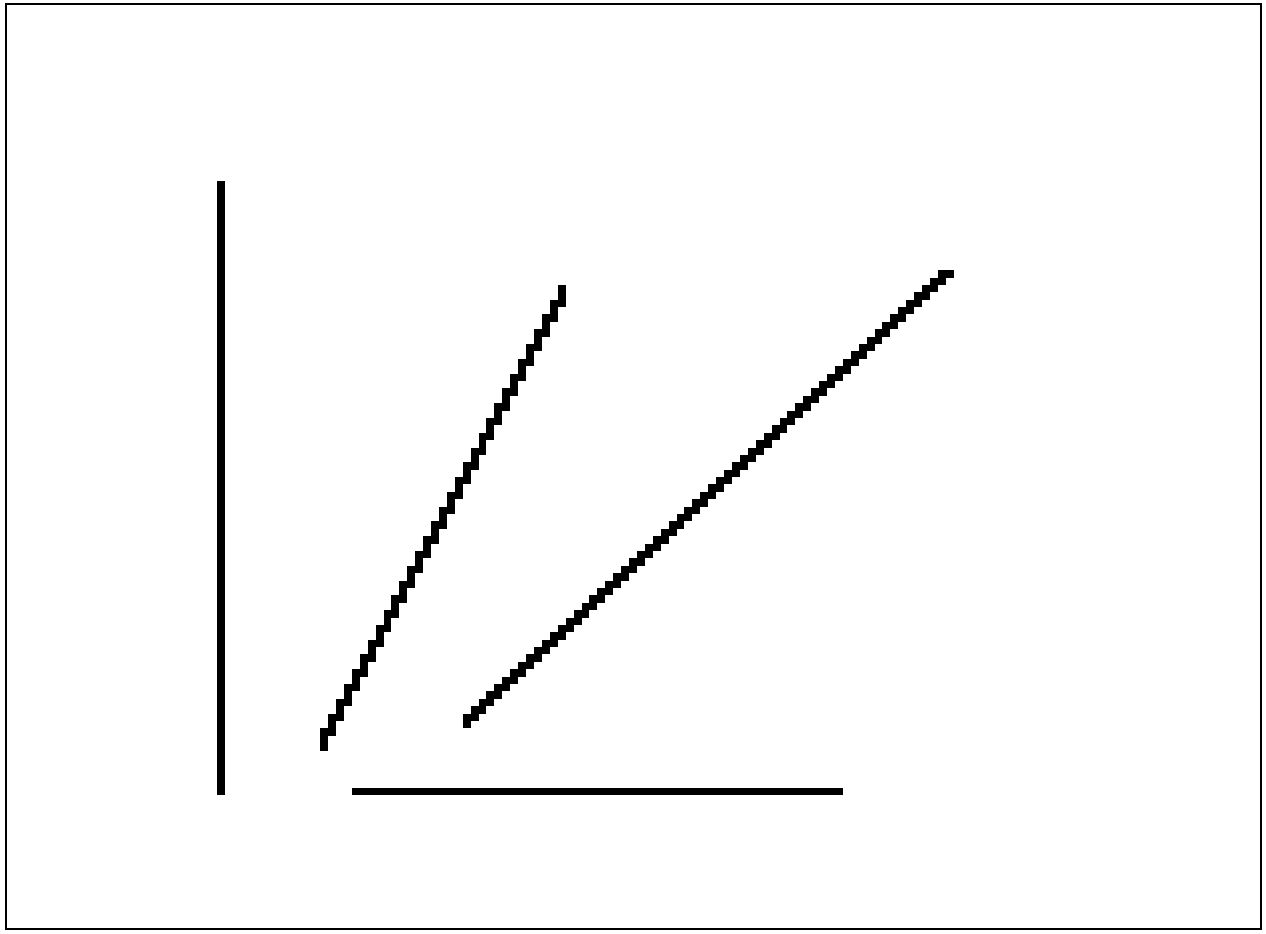
Sketch your prediction on this empty graph and then try it on the computer. to get ~~thicker~~

straight.

What do you think will happen if you type in Y = 1X +1? The line is

going to get straighter.

Sketch your prediction on this empty graph and then try it on the computer.



Effect caused by pixel visibility on computer screen:
Only the horizontal and vertical lines are "straight."

Which Symbols are GIVEN in this Problem?

POINT, STRAIGHT LINE

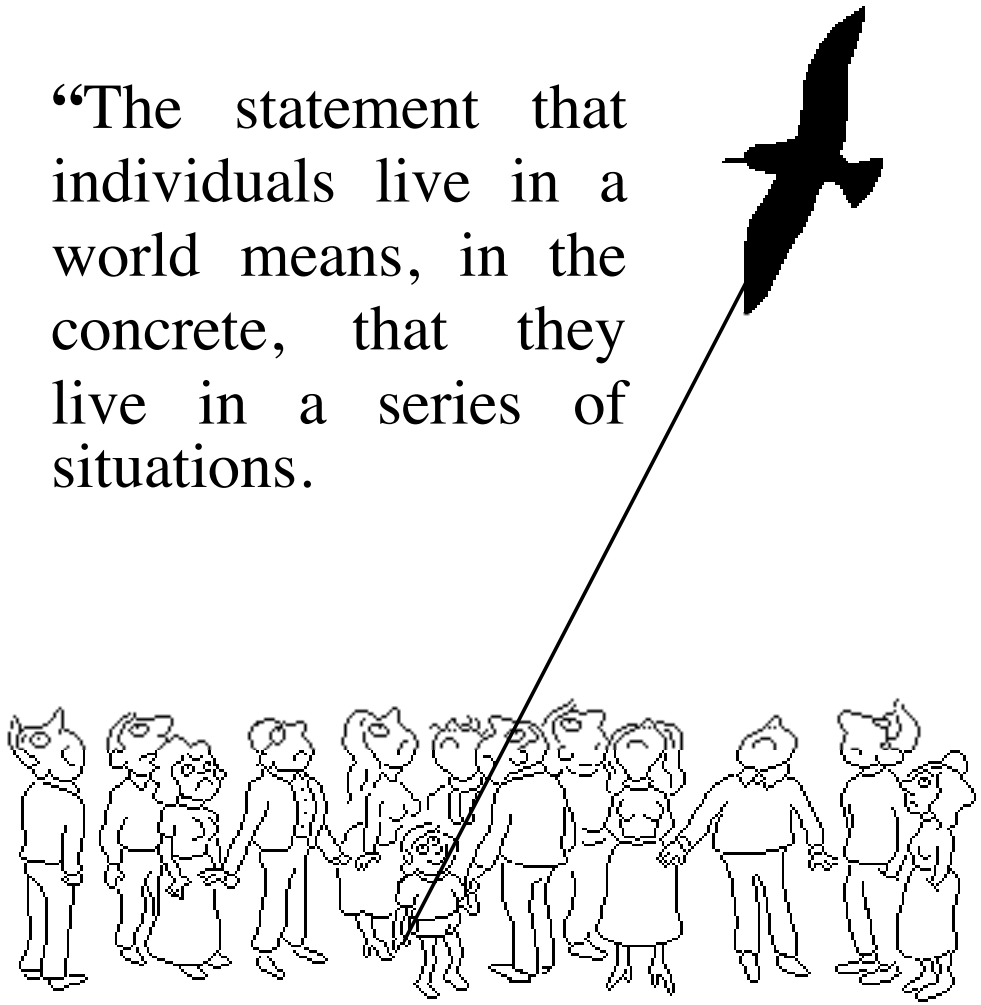
THE LITTLE DOTS
THESE LITTLE LINES

STRAIGHT

THICKER
BIGGER

The words are grounded in the activity of seeing (grainsize, segmentation, alignment), orienting the paper, & gesturing -- and this activity is conceptually constrained by an understanding of the experimental activity, what they are supposed to be doing and how they are supposed to do it.

"The statement that individuals live in a world means, in the concrete, that they live in a series of situations.



The meaning of the word 'in' is different from its meaning when it is said that pennies are 'in' a pocket or paint is 'in' a can.

It means ...
that interaction is going on between individuals and objects and other persons.

The conceptions of *situation* and of *interaction* are inseparable from each other."

(Dewey, The Child and the Curriculum, 1902)

Dewey: *The Reflex Arc Concept of Psychology*

"The older dualism between sensation and idea is repeated in the current dualism of peripheral and central structures and functions; the older dualism of body and soul finds a distinct echo in the current dualism of stimulus and response.

Instead of interpreting the character of sensation, idea, and action from their place and function in the sensorimotor circuit, we still incline to interpret the latter from our preconceived and preformulated ideas of rigid distinctions between sensations, thoughts, and acts. The sensory stimulus is one thing, the central activity, standing for the idea, is another thing, and the motor discharge, standing for the act proper, is a third.

As a result, the reflex arc is not a comprehensive, or organic, unity, but a patchwork of disjointed parts, a mechanical conjunction of unallied processes...

What is wanted is that sensory stimulus, central connections and motor responses shall be viewed, not as separate and complete entities in themselves, but as divisions of labor, functioning factors, within the single concrete whole, now designated the reflex arc....

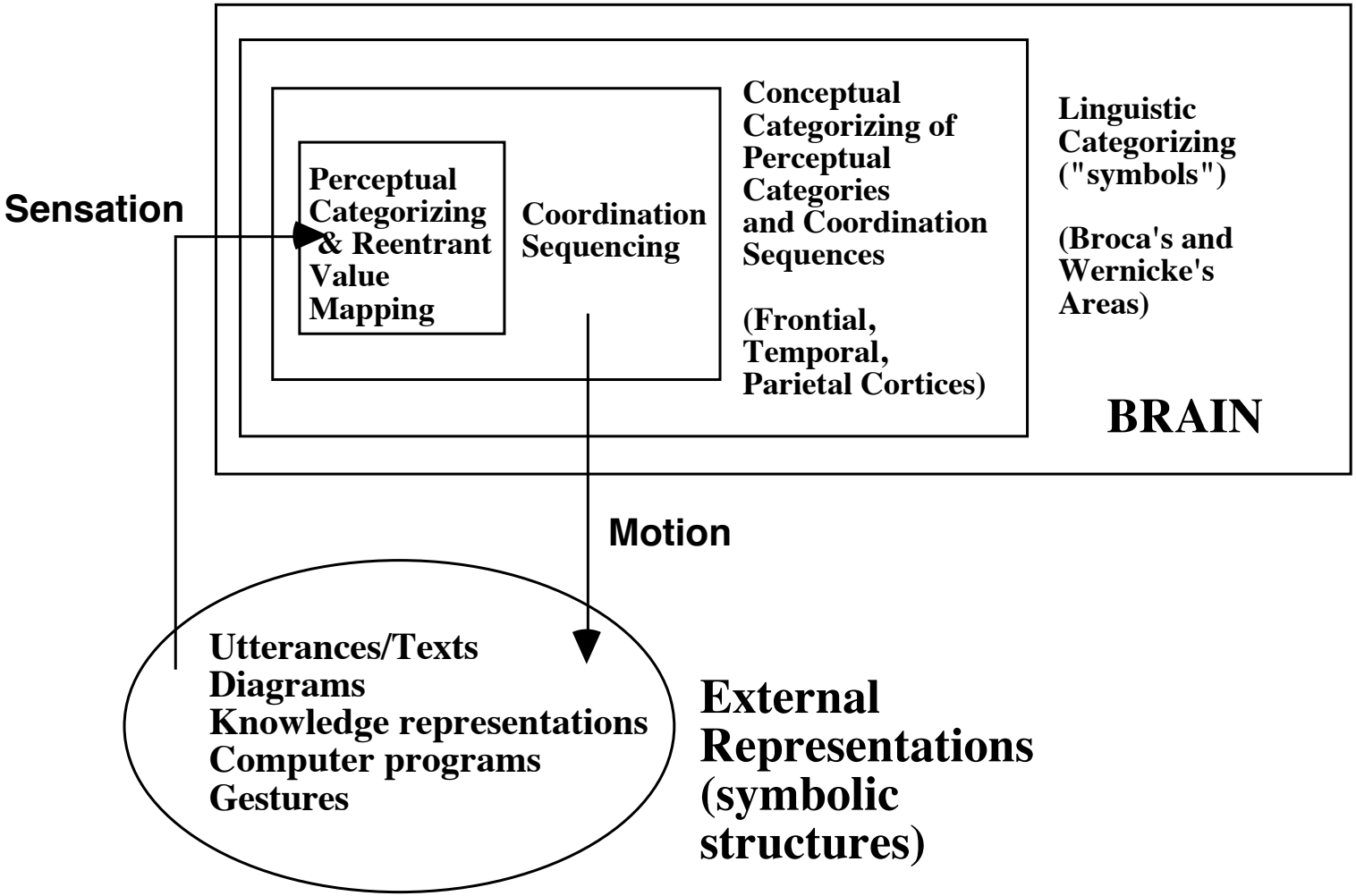
What shall we term that which is not sensation-followed-by-idea-followed-by-movement...?

Stated on the physiological side, this reality may most conveniently be termed co-ordination.

(Dewey, *The reflex arc concept of psychology*, 1896, p. 137)

Situated View of Sensorimotor Coordination

(adapted from Edelman, *Bright Air, Brilliant Fire*, 1992)



Physical Symbol Systems

The most fundamental contribution so far of artificial intelligence and computer science to the joint enterprise of cognitive science has been the notion of a physical symbol system,

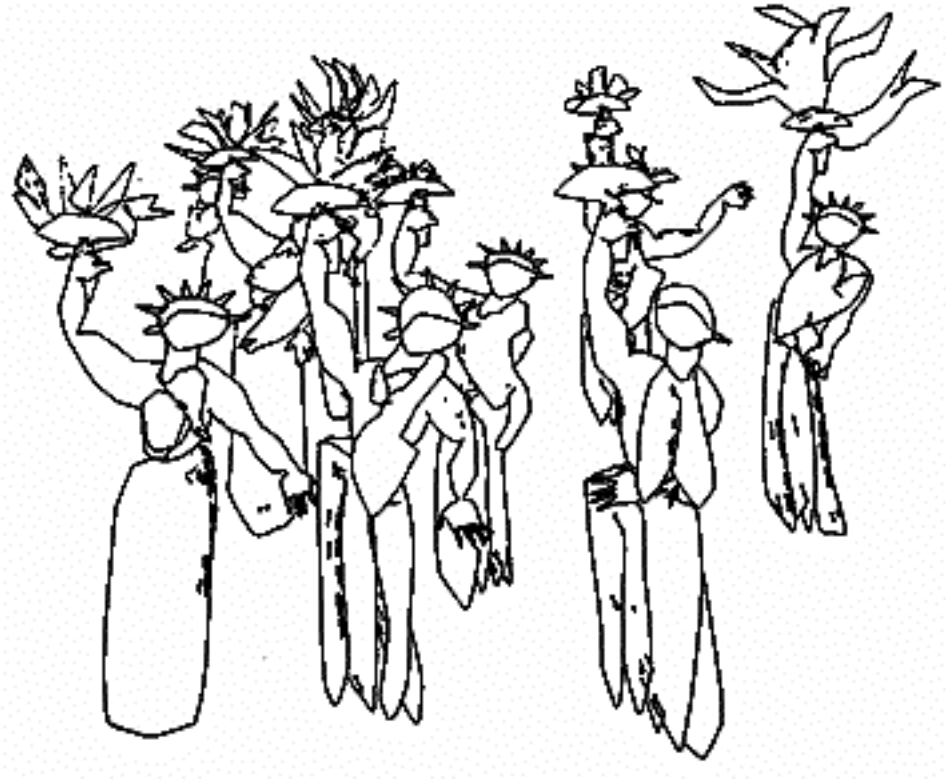
i.e., ... systems capable of having and manipulating symbols, yet realizable in the physical universe.

It becomes a hypothesis that this notion of symbols includes symbols that we humans use everyday in our lives.

Allen Newell, *Cognitive Science*, 1980

Aaron: Representations and Experience

(from Aaron's Code, Pamela McCorduck, 1991)



To be truly artistic, a work must also be esthetic–that is, framed for enjoyed receptive perception. Constant observation is, of course, necessary for the maker while he is producing. But if his perception is not also esthetic in nature, it is a colorless and cold recognition of what has been done, used as a stimulus to the next step in a process that is essentially mechanical. . . . Mere perfection in execution, judged in its own terms in isolation, can probably be attained better by a machine than by human art. . . . The doing or making is artistic when the perceived result is of such a nature that its qualities as perceived have controlled the question of production. . . . **If the artist does not perfect a new vision in his process of doing, he acts mechanically and repeats some old model fixed like a blueprint in his mind.**

John Dewey, *Art as experience: Having an experience*, 1934.

Example: Coupling of Perception, Meaning, and Conception of Activity

A

DATE 20/3/89 HEURE

En Votre Absence

MR. CLANCEY

DE

TEL

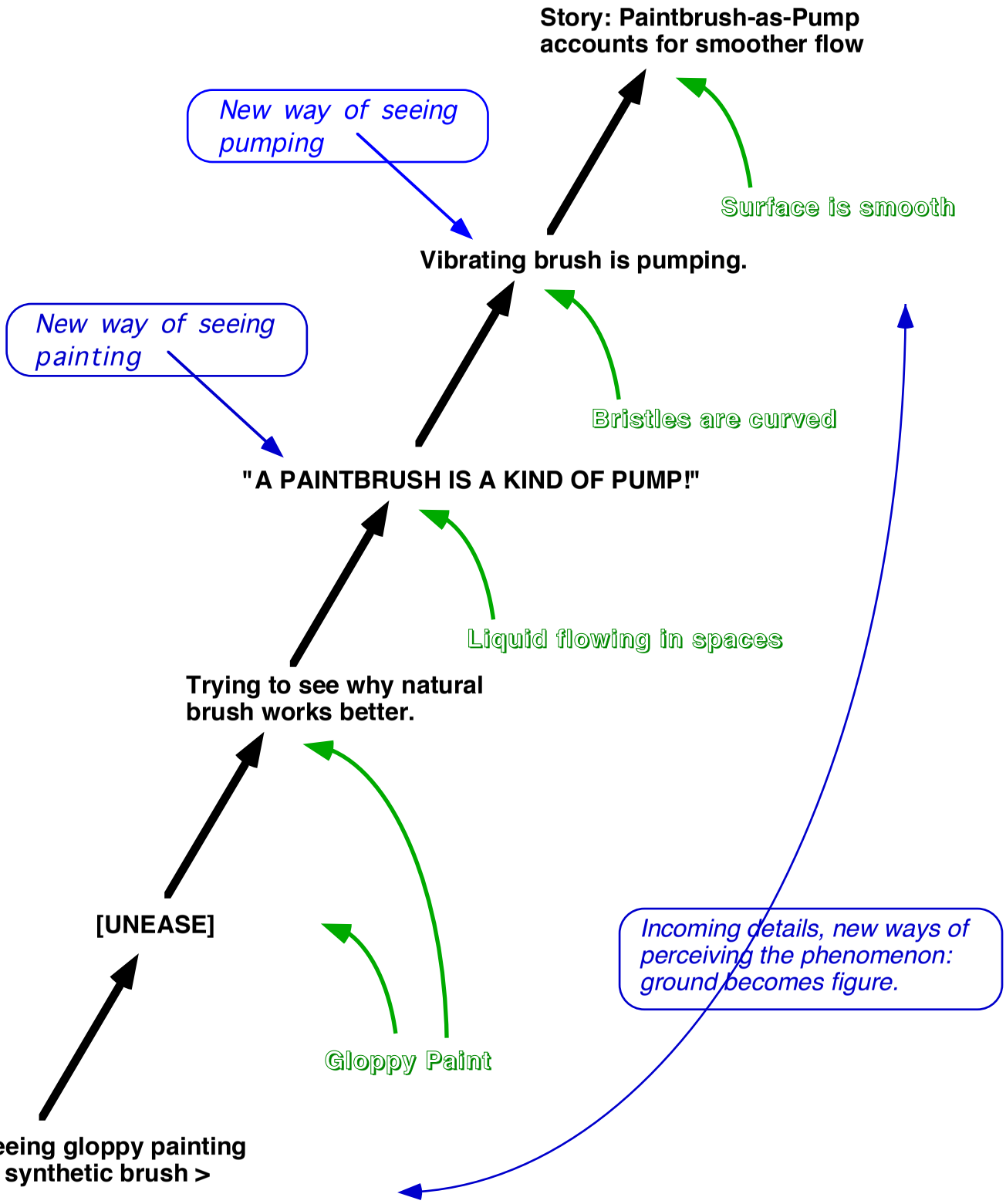
Indicatif Numéro Extension

A téléphoné ☒ Vous a rappelé ☐
Retéléphonera ☐ Urgent ☒
Veullez rappeler ☐ Amerait vous voir ☐

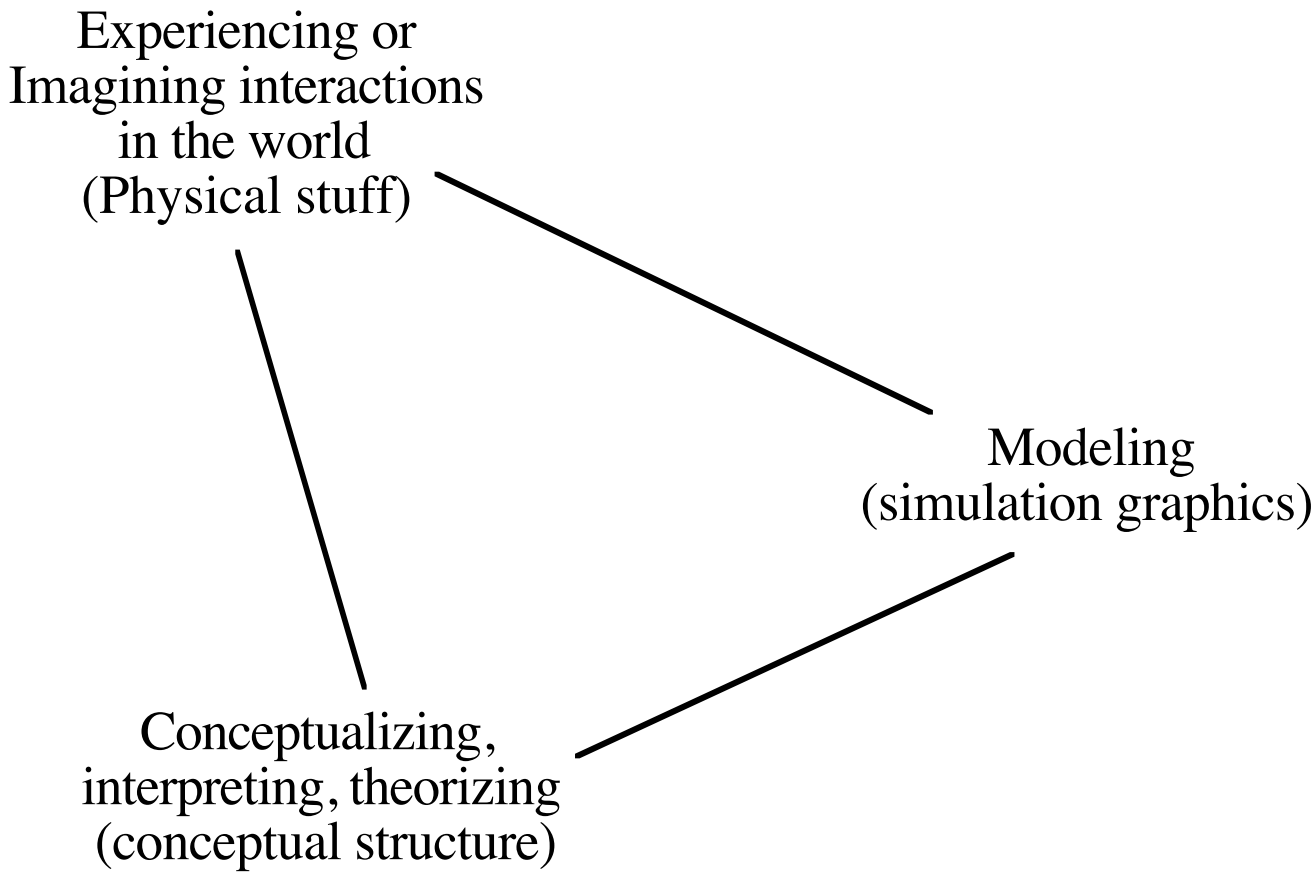
MESSAGE You must be at the train station as soon as possible --6:30 at the later.

Reçu par Monique

Generative Metaphor: Schön's Paintbrush Example



Interacting Tool-Use Activities



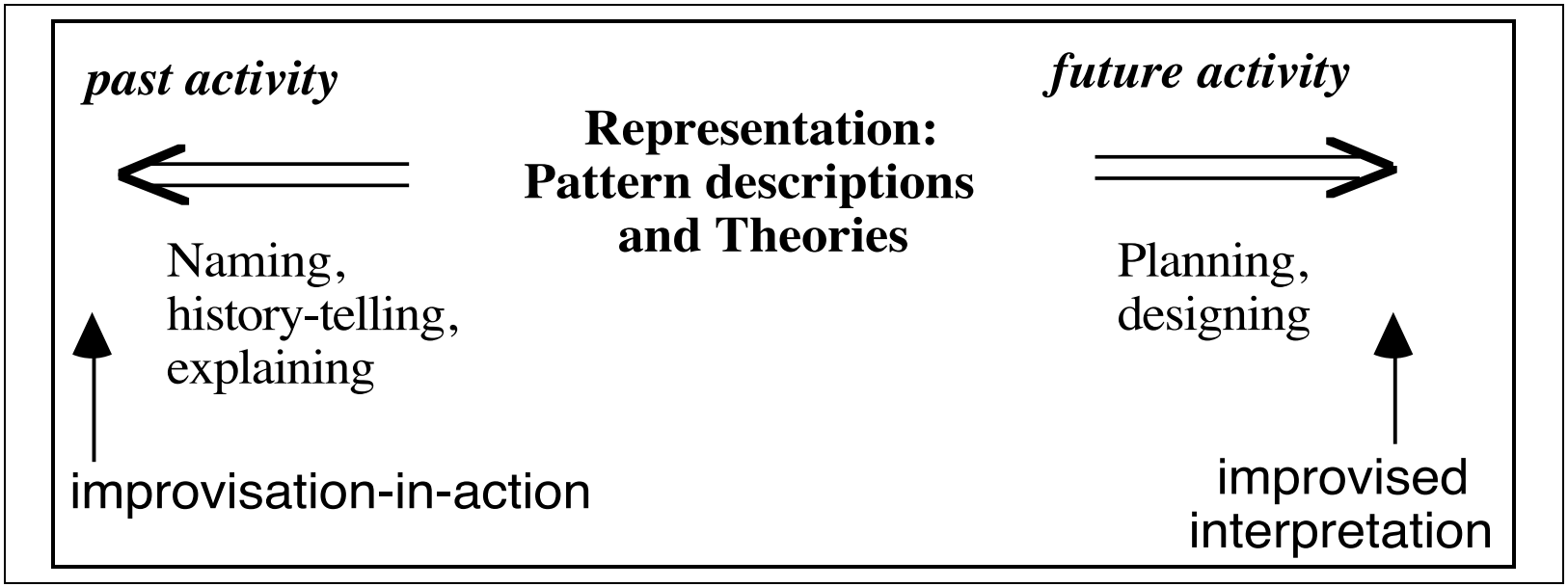
Learning new ways of ***seeing*** *&* ***coordinating action****, new ways of* ***talking****, new* ***interpretations*** *of practical constraints.*

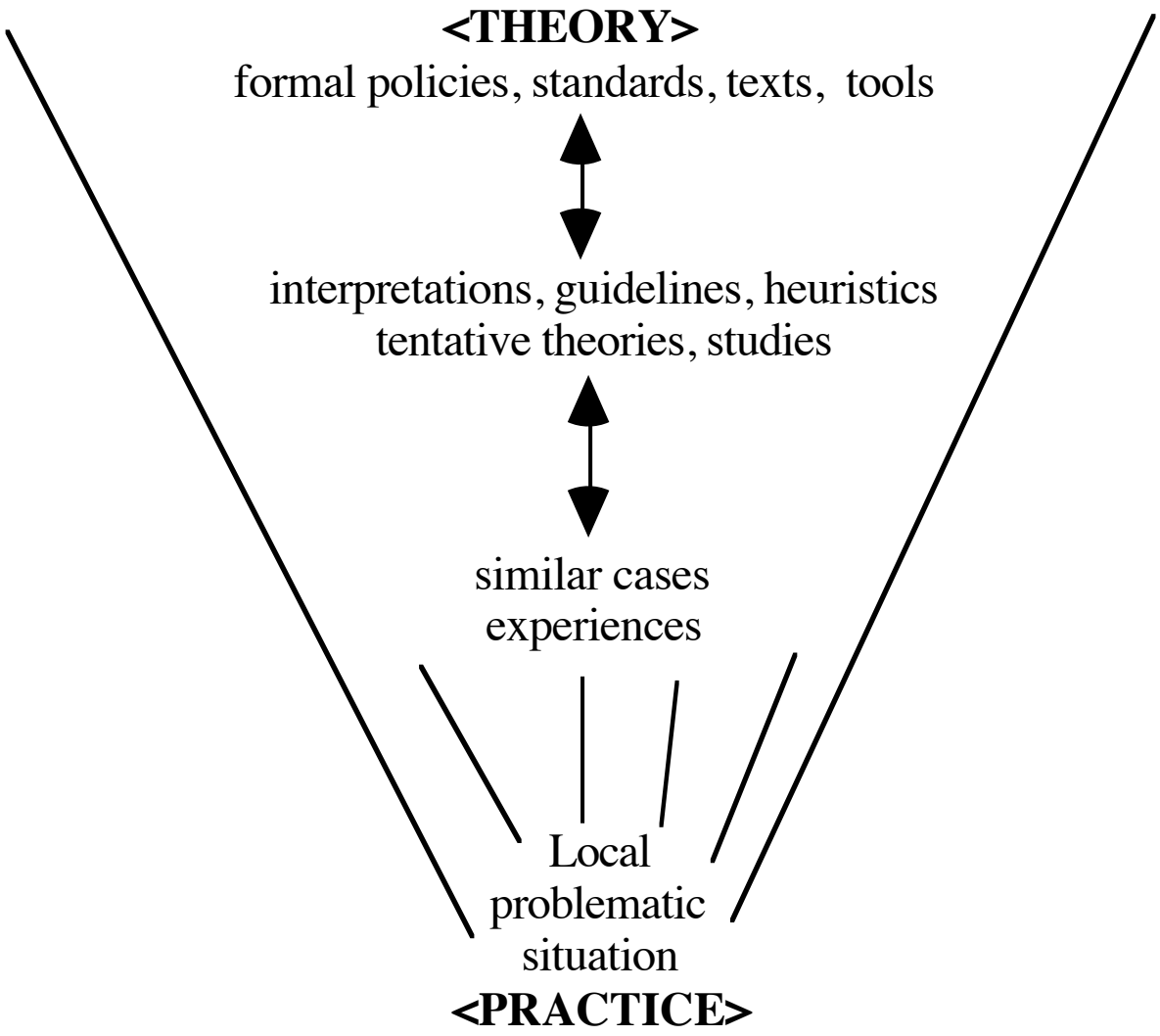
Plans are Descriptions of Activity

One kind of activity is an essentially situated and *ad hoc* improvisation—the part of us, so to speak, that actually acts. The other kind of activity is derived from the first, and includes our representations of action in the form of future plans and retrospective accounts. Plans and accounts are distinguished form action as such by the fact that, to represent our actions, we must in some way make an object of them. Consequently, our descriptions of our actions come always before or after the fact, in the form of imagined projections and recollected reconstructions.

(G.H. Mead, *Mind, Self, and Society*, 1934)

Theoretical Descriptions Lie Between Performances





Relation of Descriptions to Practice

Human Learning

More than just accessing and manipulating facts and theories, but also perceiving, conceiving, coordinating, participating, and conversing in new ways.

Changes *activities—the choreography,* not just facts, models, and tools.

Changing How We Talk about Knowledge

What is potentially misleading about these statements?

"They have knowledge but cannot act."

"Knowledge should be stored before it gets lost."

"Mental models are in the head of the user."

"Perception is controlled by theory."

"Learning is an individual, knowledge-based process and a social communication process."

"Expert systems don't learn from experience."

Example: Constructing "The Ontology" Of Medical Knowledge

One View: "The real question is whether a coding system like SNOMED is sufficient to represent medical concepts."

Better View: "Sufficient" as a map, a tool, not to "capture" & store.

SNOMED = MEDICAL VOCABULARY (WORDS) ≠ MEDICAL CONCEPTS

Cannot represent "all the details"; cannot anticipate "every useful point of view."

The map is not the territory.

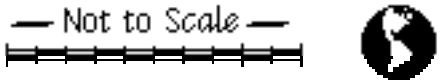
"The map orders individual experiences, connecting them with one another irrespective of the local and temporary circumstances and accidents of their original discovery...

The map is not a substitute for a personal experience. The map does not take the place of an actual journey. The logically formulated material of a science or a branch of learning, of a study, is no substitute for the having of individual experiences...

The map, a summary, an arranged and orderly view of previous experiences, serves as a guide to future experience; it gives direction; it facilitates control; it economizes effort, preventing useless wandering, and pointing out the paths which lead most quickly and most certainly to a desired result...

There is, then, nothing final about a logical rendering of experience. Its value is not contained in itself; its significance is that of standpoint, outlook, method."

(Dewey, The Child and the Curriculum, 1902)



Requirements for a Tool for Medical Inquiry

Despite the fact that the Weed [PROMIS] system was designed precisely to promote a synthesis of scientific and practical thinking, its automated form was not open and it **did not leave enough room for the frequent tentative rearrangement of facts and hypotheses that are part of cognition in real world problem solving.** [Lincoln, p. 164]

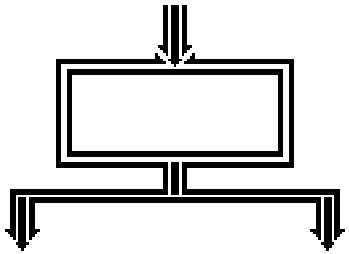
- **Notational Structure** — not just recording transactions

What MUMPS could not do, and the industry failed to do, was to provide an adequate platform that would address the interactive needs of top professionals properly: to be able to enter their own data and to navigate through a context rich data base with the express purpose of solving clinical problems.... **These records do no more than document a series of specific transactions. They do not support spreadsheet-like interactions that deal with tentative inference and with volatile, revisable situations.** (p. 178)

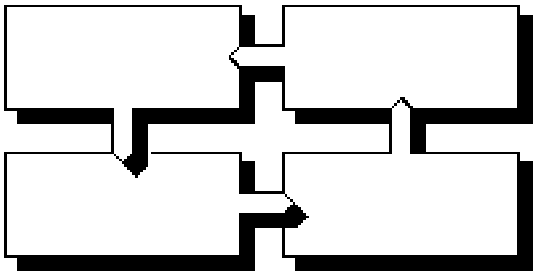
- **Narrative Structure** — story of the patient, story of the encounters, story of the disease

Judgment will only return to its own if the logic behind it is captured and becomes subject to review, personal improvement, and teaching by better example. **For clinical experience to be self-correcting, data must be approached in a manner similar to research: hypotheses must be recorded, together with actions taken in response to each, and the expected outcome predicted**—all in sufficient detail (as a part of the patient chart)—**to be the equivalent to a laboratory notebook.** Only then will it be clear why a particular care policy succeeded or failed in a given circumstance, and whether the logic that was used was appropriate. (p. 173)

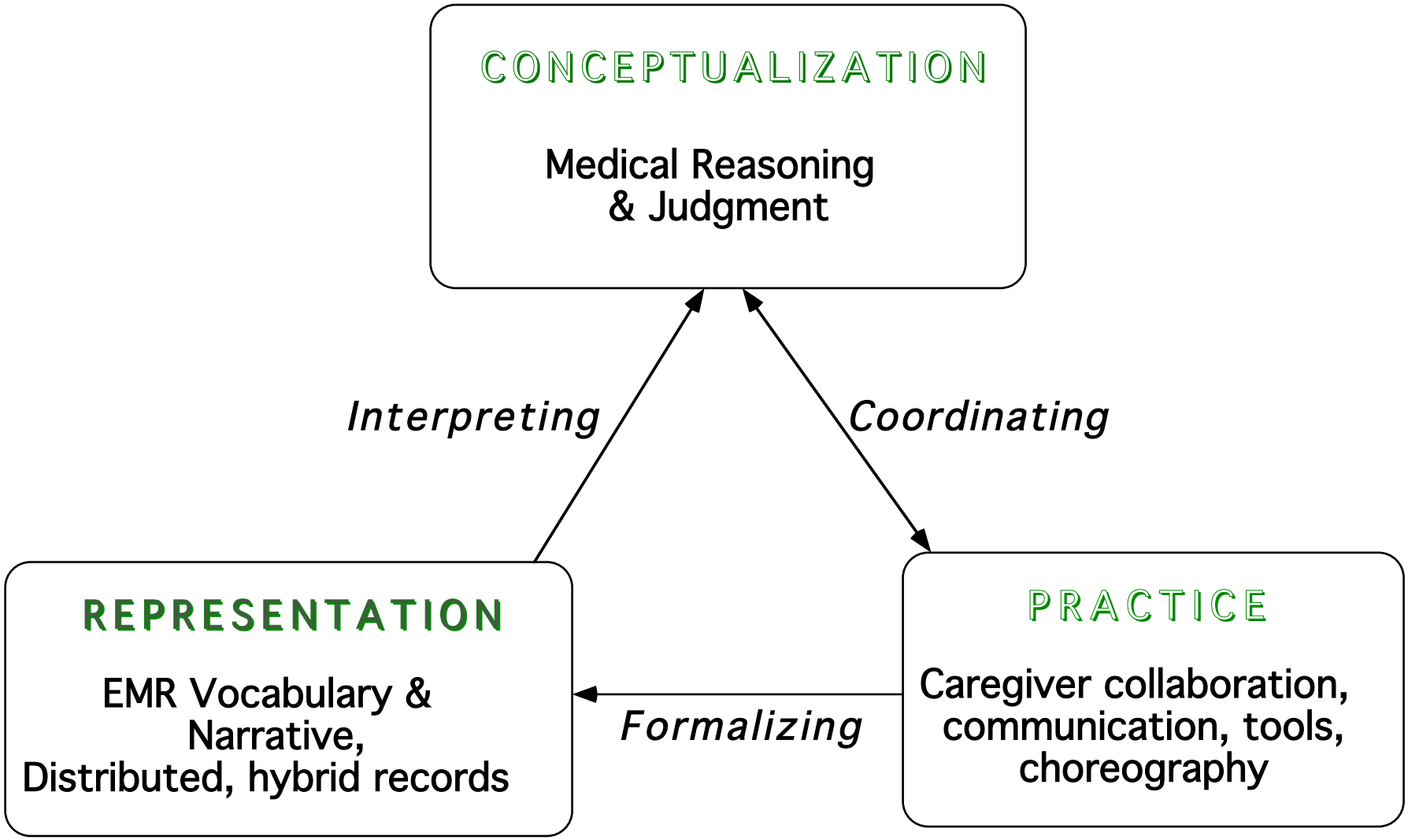
Not just a "Computerized Patient Record"



Members of a team are not merely exchanging medical descriptions ("it's negative") but cross-checking each other's work and examining primary data from different perspectives.



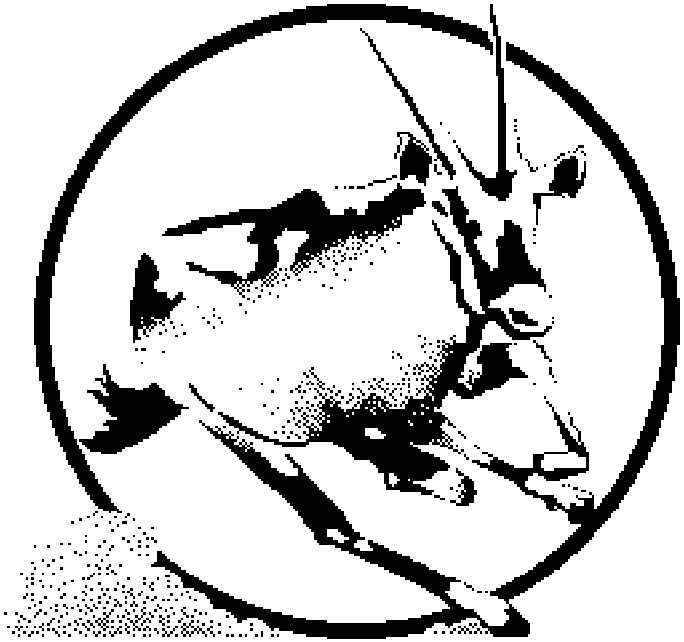
"Components" of Medical Knowledge



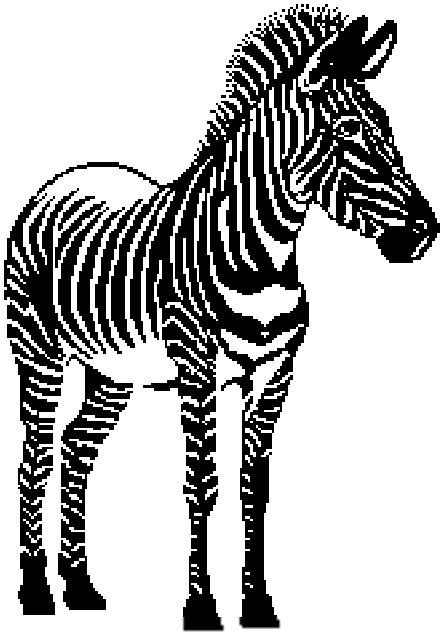
Problem Framing

(Schön, *Educating the Reflective Practitioner*, 1987)

"The problems of real-world practice do not present themselves to practitioners as well-formed structures."



"When a practitioner sets a problem, he chooses and names the things he will notice. In his road-building situation, the civil engineer may see drainage, soil stability, and east of maintenance; he many not see the differential effects of the road on the economies of the towns that lie along its route."



"Conflicting frames pay attention to different facts and make different sense of the facts they notice... it is through naming and framing that technical problem solving becomes possible."

"A problematic situation presents itself as a unique case, or causally uncertain, or framed by conflicting values... To deal with it competently, she must improvise, invent, and test in the situation strategies of her own devising."

“The construction of a well-formed problem is not a technical task.”

Generative metaphor.
Putting representations into the environment.

Generative Metaphor

- Perceiving, naming, and differentiating patterns.
- Commenting on the meaning of patterns.
  "What is this? How have I been thinking about this?"
- Constructing a narrative, attributing causality, rationalizing.
  "How did this begin? What happens next? Why?"
- Setting subproblems, experimenting.
- Making new, perceptually-coherent figures.

“On the objectivist view,
facts are what they are,

and the truth of beliefs is strictly testable
by reference to them.

All meaningful disagreements are resolvable,
at least in principle,
by reference to the facts.

And professional knowledge rests on a foundation of facts.”

“We know how to teach people how to build ships, but not how to figure out what ships to build.”

(Kyle, quoted in Schön, p. 11)

The Meaning Of Designs

"Those of us who are concerned with buildings tend to forget too easily that all the life and soul of a place, all of our experiences there, depend not simply on the physical environment, but on the patterns of events which we experience there."

(Christopher Alexander, 1979)

Generic Form of Design Patterns

CONTEXT

⇨ **SYSTEM OF FORCES (conflicts)**

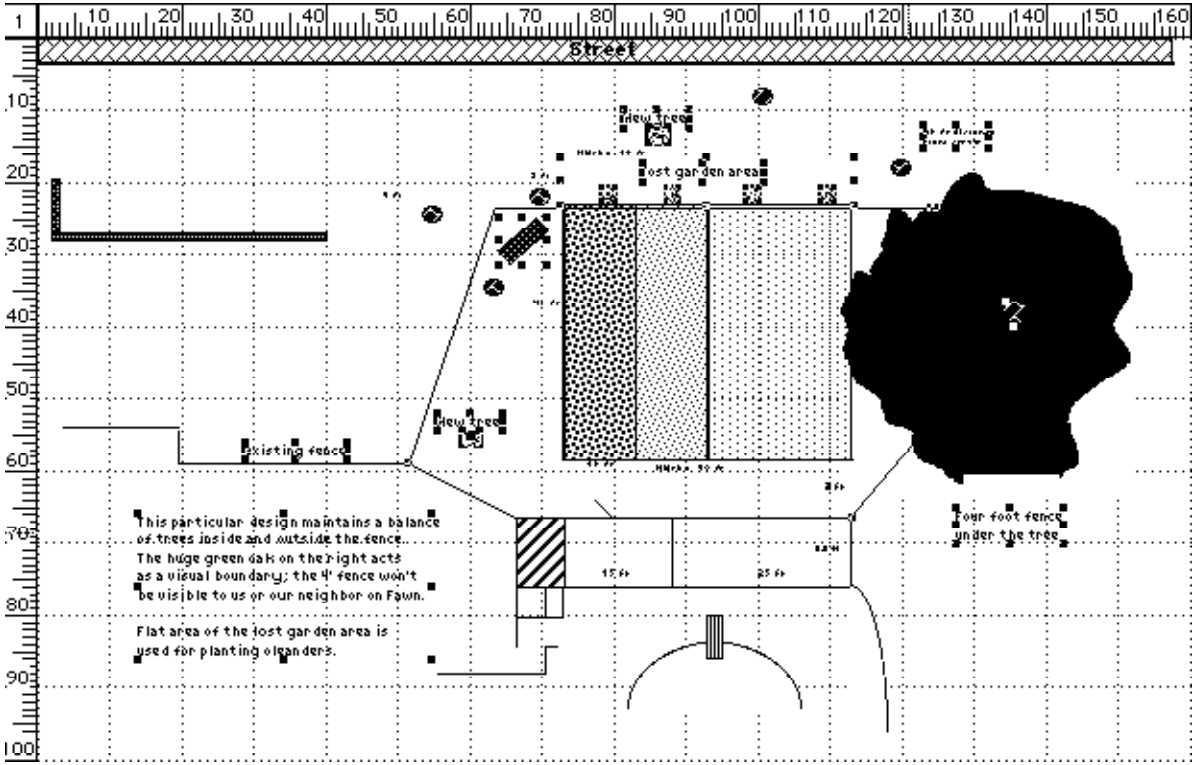
⇨ **CONFIGURATION**

A design pattern is "an attempt to discover some invariant feature which distinguishes good places from bad places with respect to some particular system of forces."

(Alexander, 1979)

Examples of good classroom patterns:

Door in the back of the room.
Unanchored chairs on wide terraces.
Stacking blackboards.
Exits on both sides.



"In the constructivist view, our perceptions, appreciations, and beliefs are rooted in worlds of our making that we come to *accept* as reality."

private terrace on the street
outdoor room
hierarchy of open space
south-facing outdoors
something roughly in the middle
roof edges you can touch

Implications of Situated Cognition for Socio-Technical System Design

1) **Practices can be described, but are not equivalent to laws, rules, grammars.**
2) **Socio-technical systems must evolve; they cannot be strictly controlled.**
3) **Don't just deliver technology; collaborate with users on site in tightly incremental designs.**
4) **Design to facilitate, don't just automate conversations.**
5) **Design for innovation, multi-role jobs, nonroutine problem solving.**

Reconceiving the Role of Formal Modeling

- **Process-modeling language**
  is required for describing work processes
  (e.g., scripts, transition nets).

- **What coordination accomplishes, not individual "reasoning"**
  (i.e., transcends individual point of view).

- **Patterns of interaction,**
  not templates stored in individual brains
  (i.e., a representation, not knowledge itself).

➘ *We can use formal techniques to analyze and share data—to model workplace interactions—without making commitments to putting models in computer tools for workers.*

Design for Learning (Work as Design)

- Adopt a *holistic epistemology*:

  —Knowledge is the capacity to adaptively recoordinate past ways of seeing, talking, and interacting.

  —Information representations are created and (re)interpreted within inherently social activities.

  —Meaning ≠ semantic representations.

- If learning is reduced to *storage of descriptions* (theories, models, data), technology will be inadequately exploited and glaring problems will remain.

Dynamic View of Tool Creation & Use

- **Projecting** future interactions via imagination & mock-up trials.

- **Reconceptualizing or interpreting theory** (creating new vocabulary for describing spatial-temporal interactions, e.g., "work triangle" in kitchen design).

- **Negotiating** with clients, suppliers; getting advice from the community of practice.

- **Correlating** rules of thumb, regulations (global standards, prone to change or highly complex), and new articulations from personal experience.

Relating formalized constraints to other physical, tacit, relational sources of information.

Design Ideas from Workplace Studies

Enable Forms of Sharing

- make resources (human and artifacts) more available;
- see, copy/incorporate, possess, modify, "become responsible for"

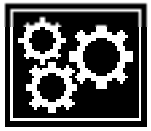
Make Tools Accessible to Everyone in the Group

- support overlapping responsibilities;
- relate contributions, not isolate jobs;
- accommodate novices & experts, people familiar or not with situation

Map to Activities of Problem-Solving

- orientation, exploration, collaboration, coordination, taking action;
- allow non-routine processes to remain ad-hoc

LIMITATIONS IN ANALYSIS OF COMPUTER-HUMAN INTERACTION



Emphasis on automation, objectivist view of knowledge.

Systems analysis functionalism (building tools around formal descriptions of production) vs. facilitating innovation.

How are representations created? How are categories given meaning in activity?

Emphasis on individual, workstation view of reasoning.

Describing people one-dimensionally as rational information processors, vs. problems of identity and conflicting values influencing roles, rights, and access to information.

What interactions occur outside the web of information-processing computers and telecommunications links?

The "cooperative approach" must *include* the "traditional approach."

(Greenbaum and Kyng, 1991, p. 16)

"It is easier to see the conditions in their separateness, to insist upon one at the expense of the other, to make antagonists of them, than to discover a reality to which each belongs....
When this happens a really serious problem—that of interaction—is transformed into an unreal, and hence insoluble, theoretic problem." **(Dewey, The Child and the Curriculum, 1902)**

TRADITIONAL APPROACH *focus is on*	**COOPERATIVE APPROACH** *focus is on*
problems	situations and breakdowns
information flow	social relationships
tasks	knowledge
describable skills	tacit skills
expert rules	mutual competencies
individuals	group interaction
rule-based procedures	experience-based work

SOME CONCLUSIONS ABOUT TECHNOLOGY

What are knowledge bases?

Qualitative models, used by people to design, audit, repair, predict, and control systems in the world.

How are "intelligent systems" different from people?

As different as the carpenter from a chisel:
Human knowledge & culture cannot be inventoried;
Learning occurs with every human action;
Human memory is not a place where representations are stored.

How can we develop tools that people want to use?

Multidisciplinary, participatory, iterative, design in the context of use; facilitate human interaction & creativity.

“The road to technology-centered systems is paved with human-centered intentions.”

David Woods, Ohio State University

BASIC READING ON SITUATED COGNITION

Bamberger, J. 1991. *The mind behind the musical ear*.

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Clancey, W.J. 1993. Situated Action: A neuropsychological interpretation (Response to Vera and Simon), *Cognitive Science*, 17(1), Jan-Mar.

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Gardner, H. 1985. *The Mind's New Science*.

Gregory, B. 1988. *Inventing Reality: Physics as Language*.

Lakoff, G. 1987. *Women, Fire, and Dangerous Things: What Categories Reveal about the Mind*.

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Lave, J. and Wenger, E. 1991. *Situated Learning: Legitimate Peripheral Participation*.

Schön, D.A. 1979. Generative metaphor: A perspective on problem-setting in social policy. In A. Ortony (ed), *Metaphor and Thought*. p. 254-283.

Suchman, L.A. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication*.

Winograd, T. and Flores, F. 1986. *Understanding Computers and Cognition: A New Foundation for Design*.

Wynn, E. 1991. Taking Practice Seriously. In J. Greenbaum and M. Kyng (eds), *Design at Work: Cooperative design of computer systems*. p. 45-64.

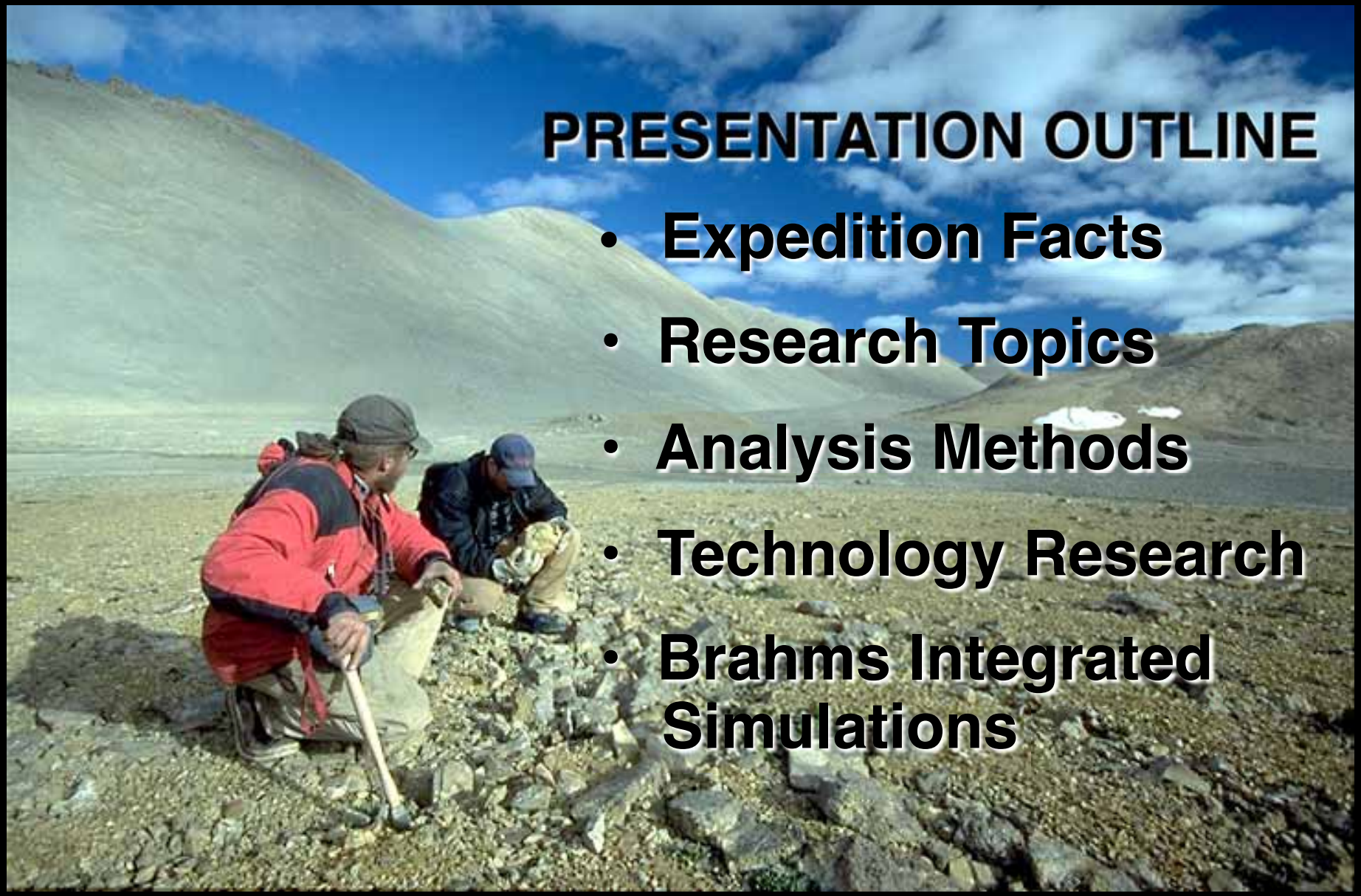
Empirical Requirements Analysis for Mars Surface Operations Using the Flashline Mars Arctic Research Station

William J. Clancey, Ph.D.

Chief Scientist, Human-Centered Computing

NASA/Ames Research Center

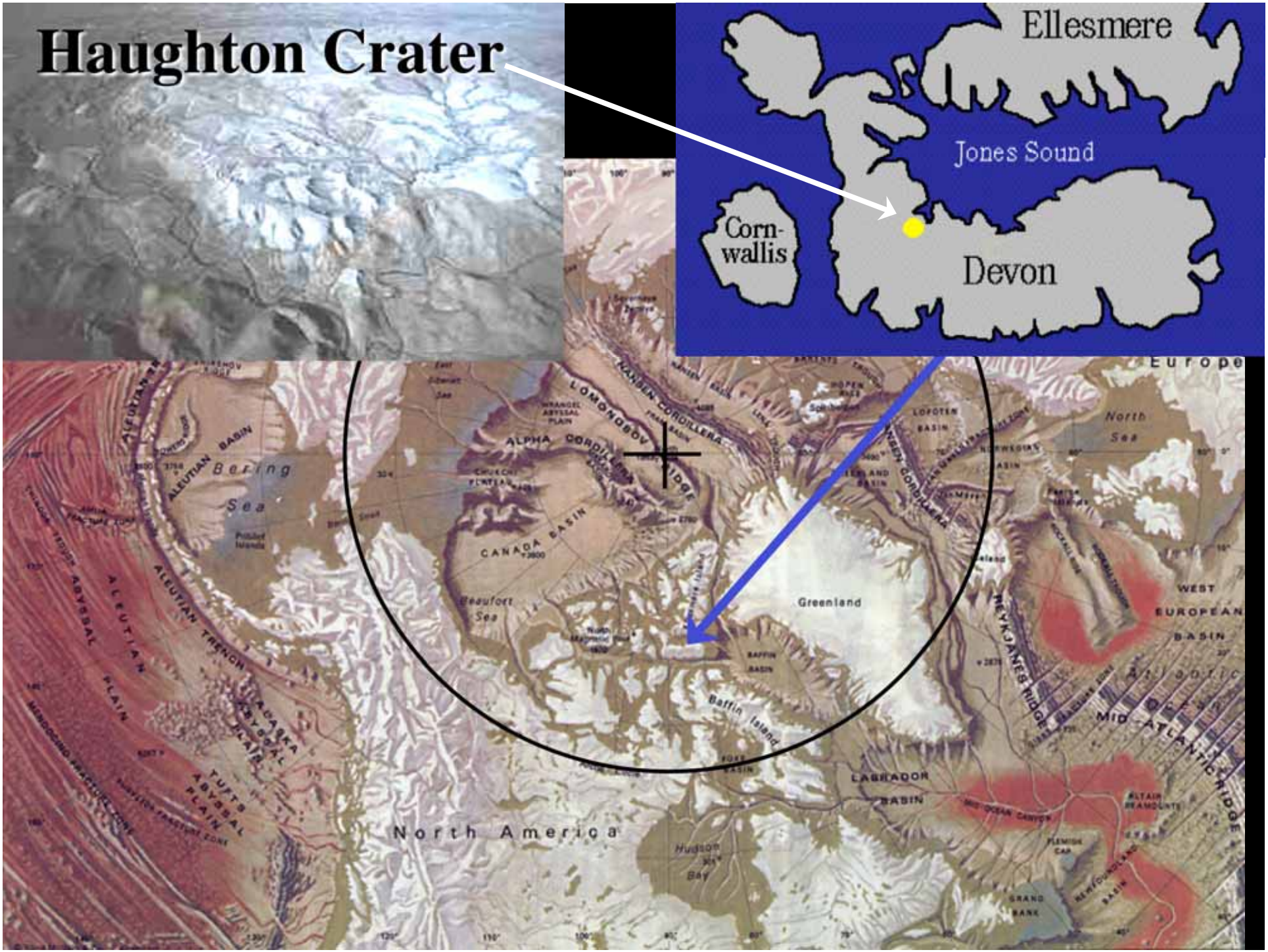
University of West Florida



PRESENTATION OUTLINE

- Expedition Facts
- Research Topics
- Analysis Methods
- Technology Research
- Brahms Integrated Simulations

Haughton Crater

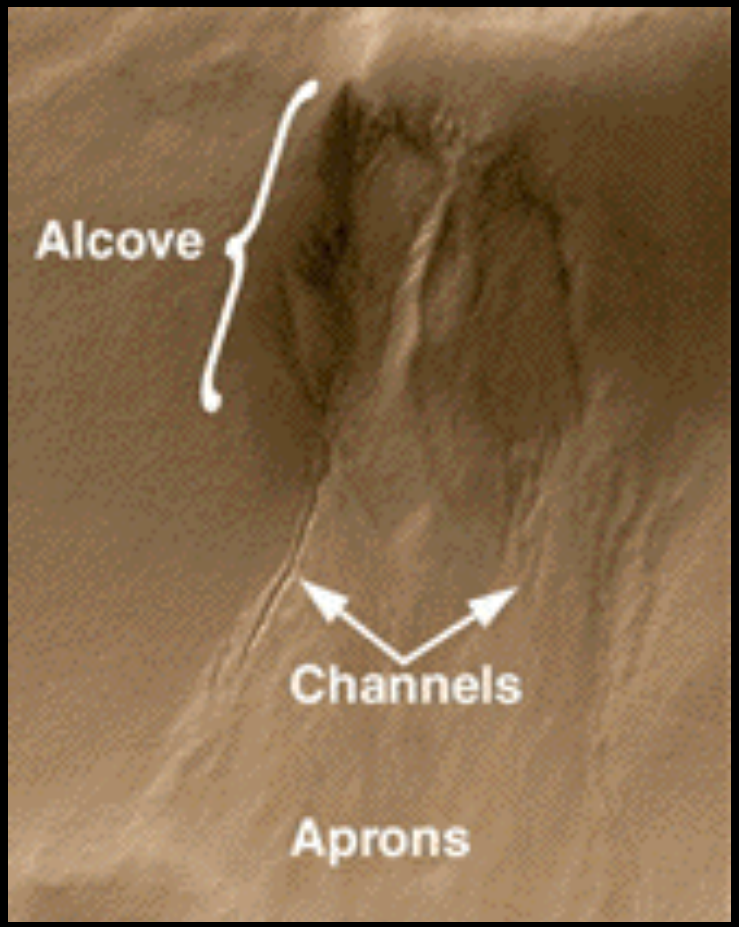


Camping on a 320 mile-wide island

Why Go to Devon Island?

- **Authentic work environment**
- **Real logistics and safety problems**
- **Evocative, appropriate landscape**

Mars Geology Analogs



Mars Global Surveyor Photo

Permafrost alcove in Haughton Crater

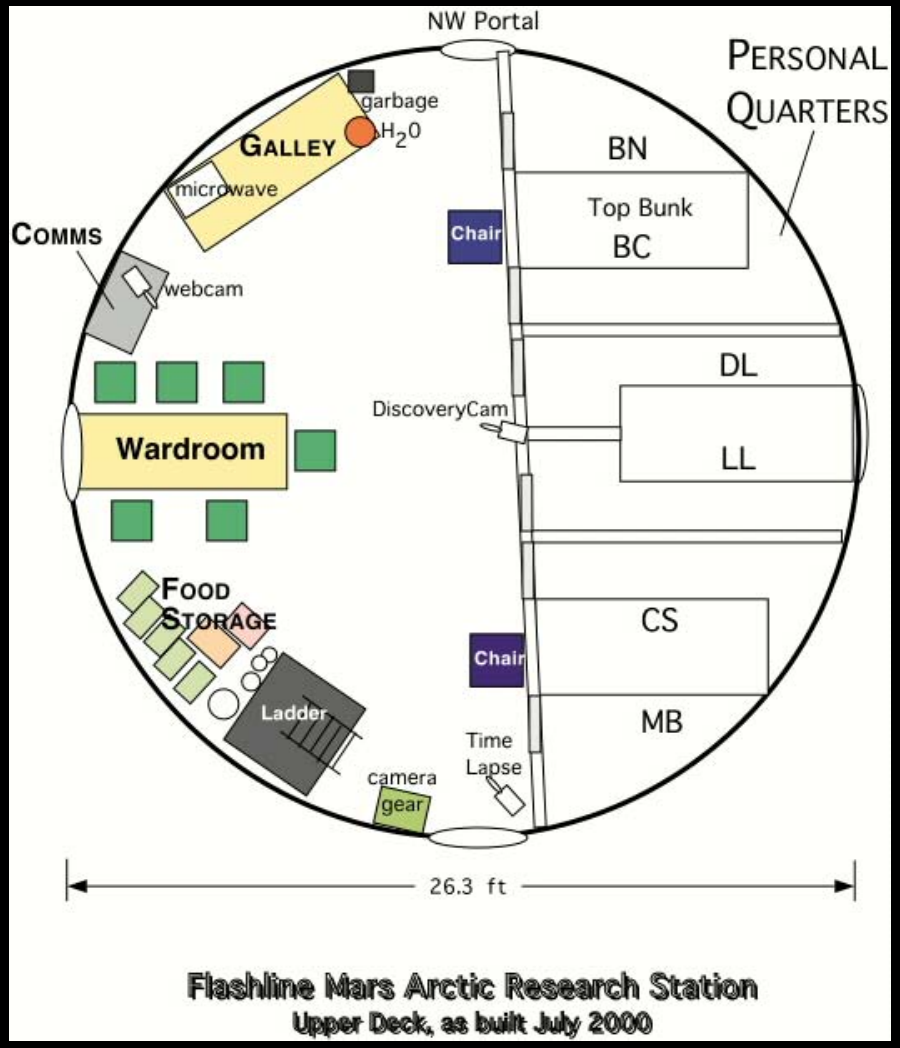
Flashline Mars Arctic Research Station

FMARS April 2001, Devon Island

- NASA/SETI & Mars Society: Promotion plus Research
- Authentic work site: Geology, biology, computing, medicine,…
- Investigate how we will live & work on Mars
- Six-person crew
- Six rotations June-Aug 2001

FMARS Research Topics

- Hab design
- Daily life schedules & procedures
- Communication protocols



Learning in the Field

"It's like a mixture of breccia and algae nodules…"

"We found another lake...that has microbial mats.."

Fidelity Characteristics

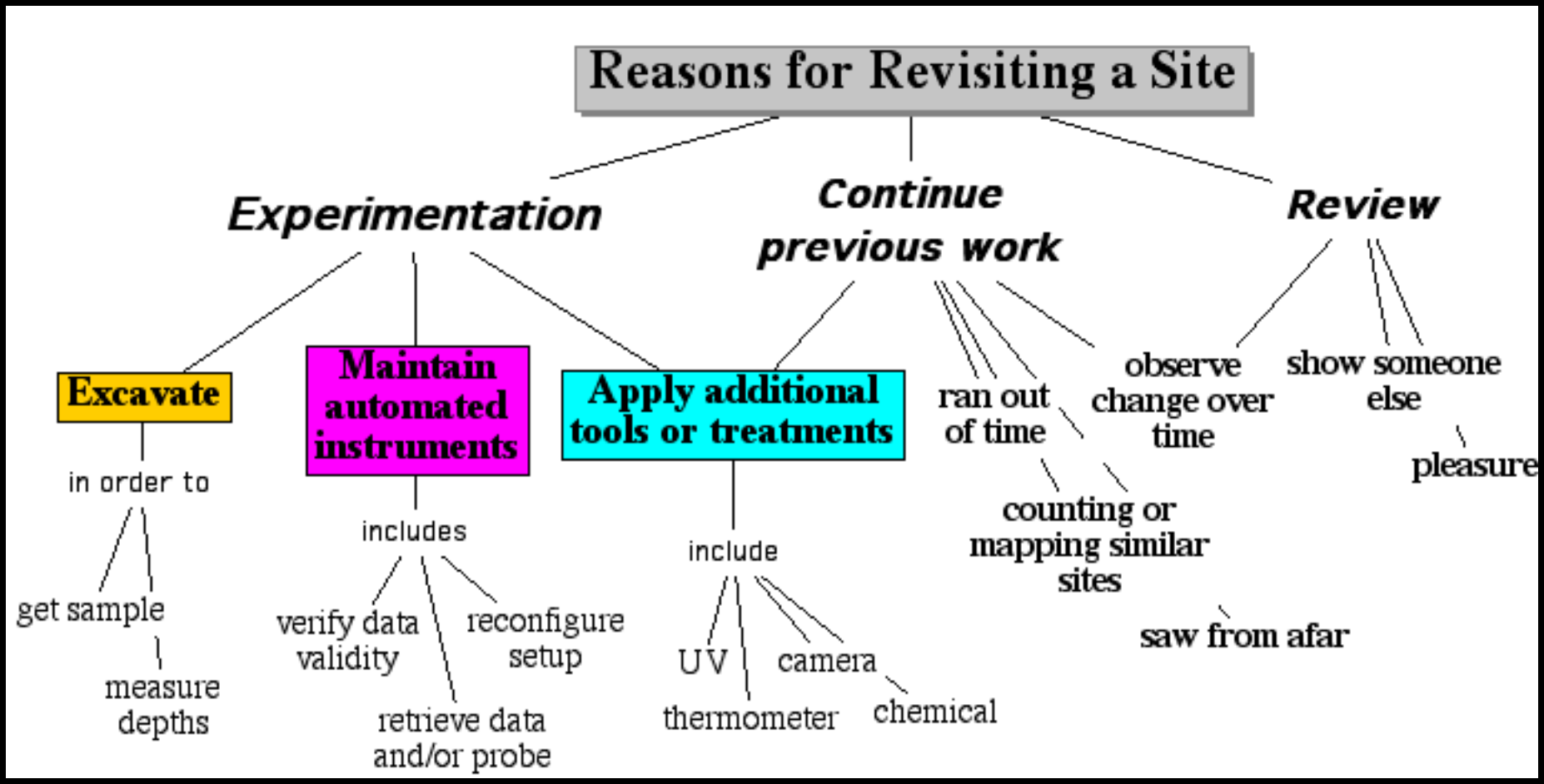
- **Inherent high-fidelity** (e.g., authentic work to be performed and time constraints on being outdoors)
- **Imposed experimental** (e.g., wearing realistic gloves and coordinating with off-site investigators)

Domain Analysis: Stages in a Traverse

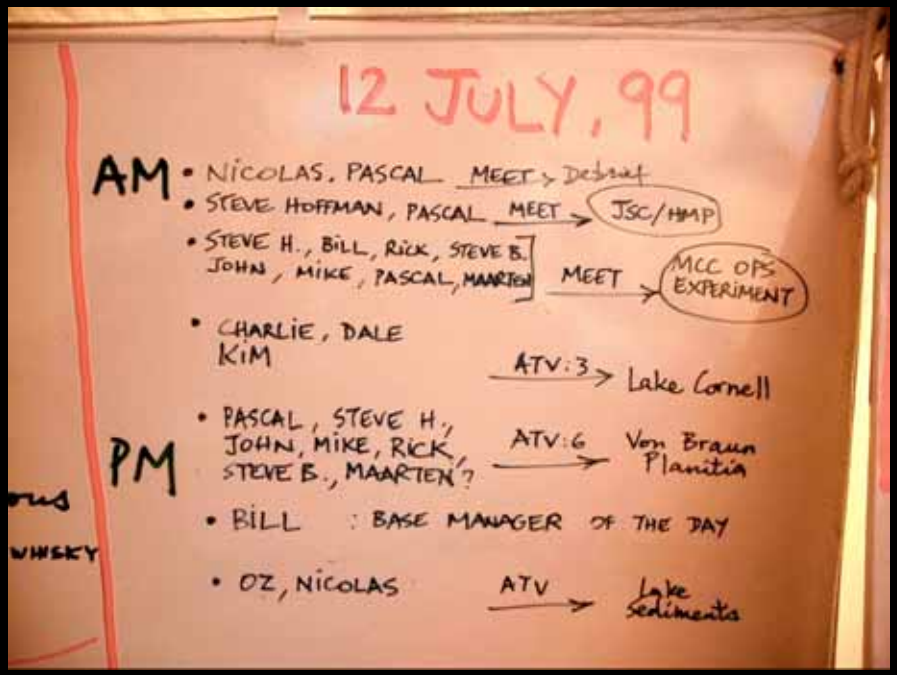
Robotic assistants will need to understand the context, how work flows develop in practice

- ***Planning*** the activity
- ***Organizing*** at start (e.g., gathering at the ATVs)
- ***Launching*** into the activity (e.g., leader departs, others follow)
- ***Punctuated events*** (e.g., full stops)
- ***Regrouping*** (bringing the group back together)
- ***Ending*** the activity
- ***Following-up*** (action items)

Towards a Theory of Human Exploration



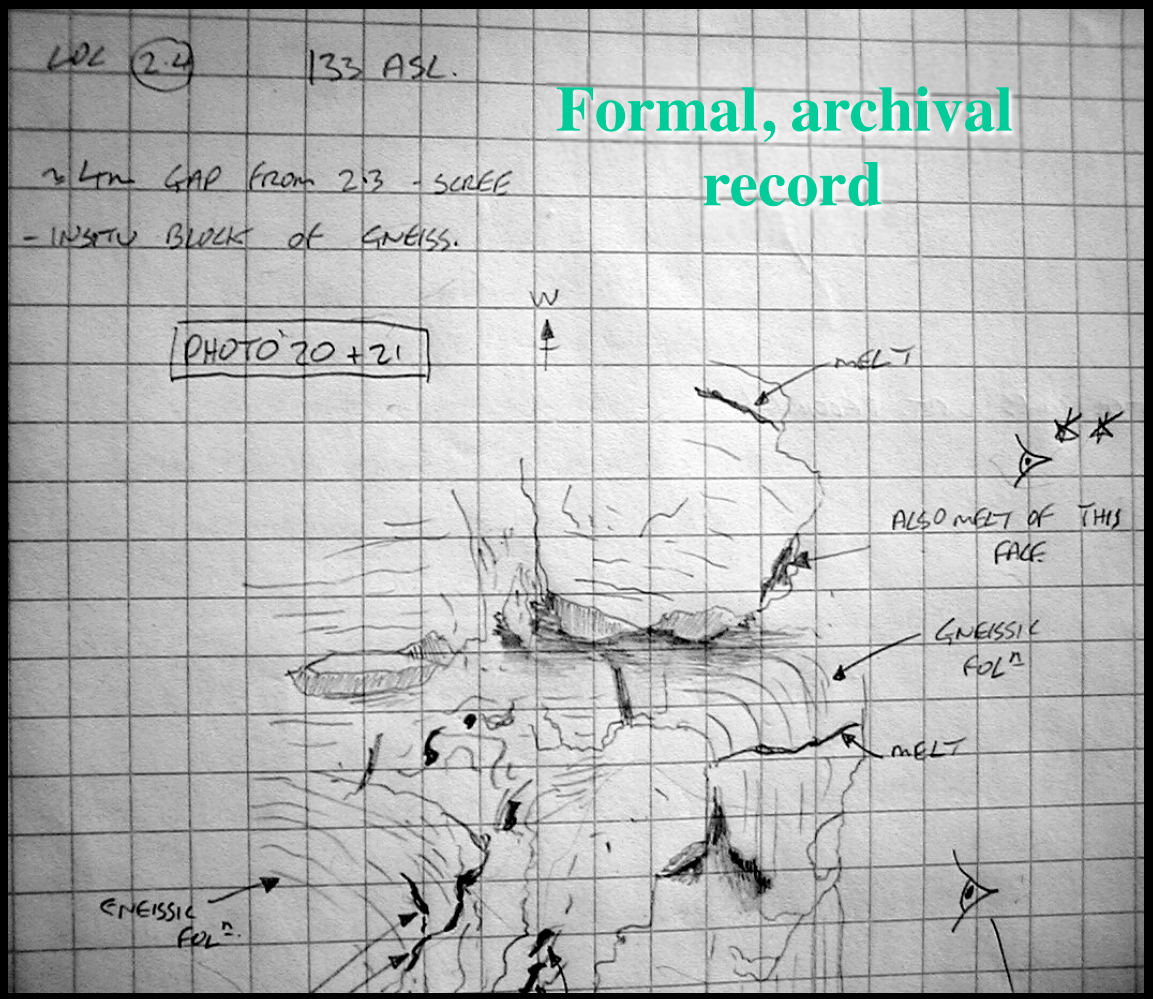
Disciplinary Differences



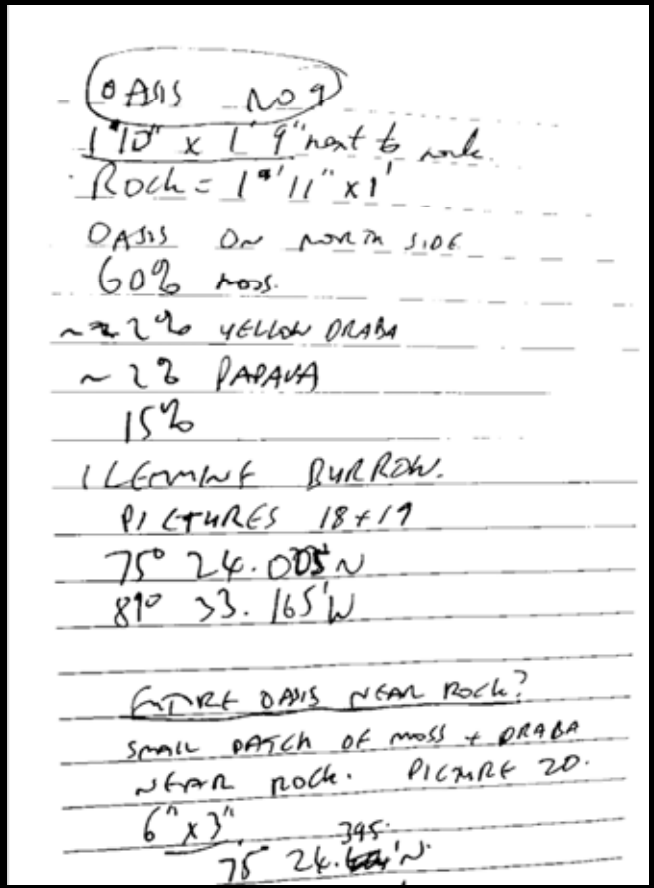
Whiteboard plan in dome tent

- 23 people, 18 days, 27 locations, 58 traverses
- 3.5 people/traverse, 7.3 days out/person
- Geologist & Biologist had 21 traverses each
- But geologist visited 14 sites once, biologist only 3
- Geologist visited 13 sites not visited by the biologist

Kinds of Notebooks



Formal, archival record

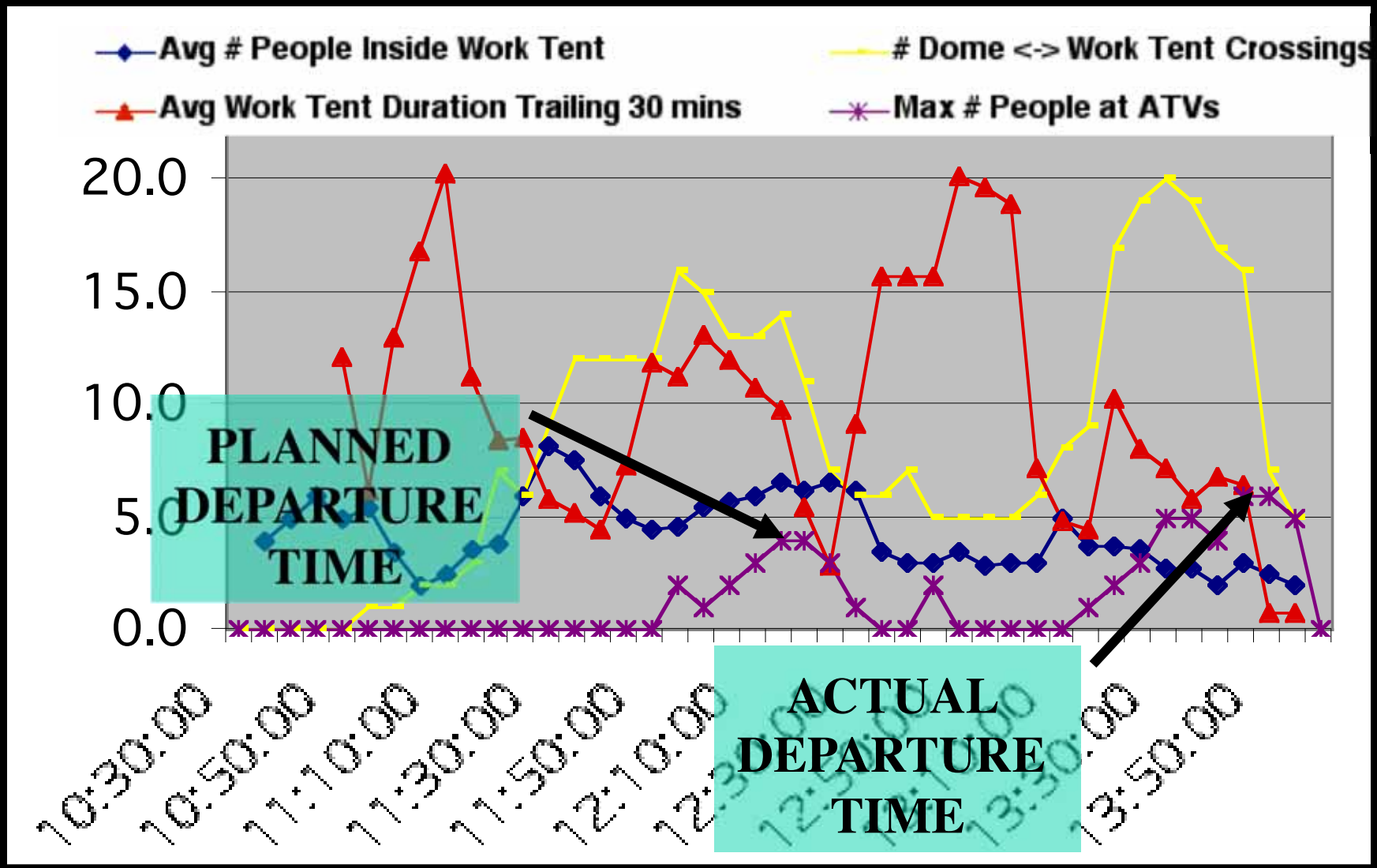


Factual notepad

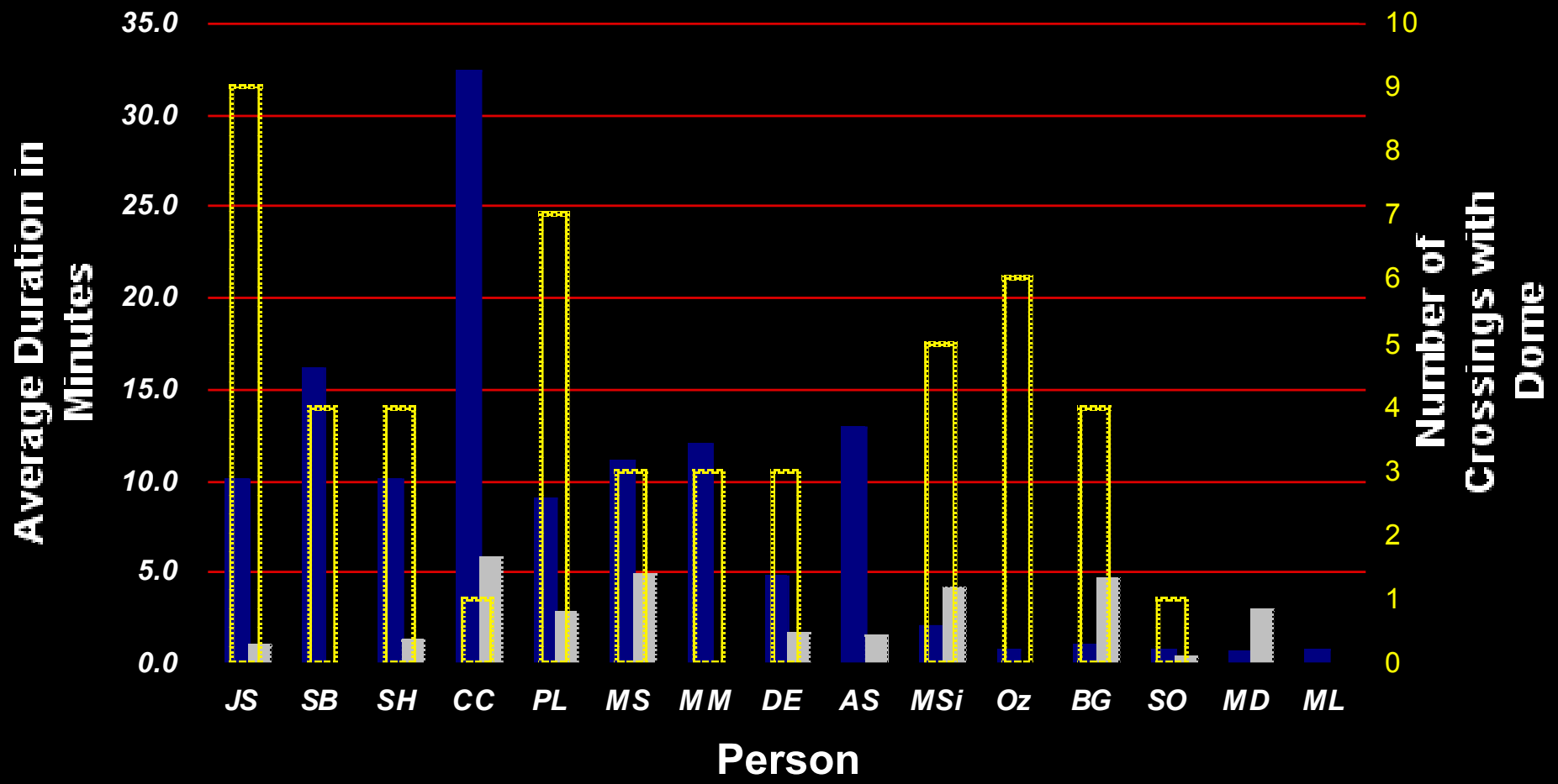
Time-Space Interactions

- Time lapse 3 hrs (11am-2pm)
- 3600 frames
- Movement between ATVs & shared tents
- Corresponds to two floors of habitat
- Shows effect of schedule changes on resources (ATVs)

Time Lapse Analysis



Average Duration by Person
(with number of crossings)



■ *Avg Duration Inside Work Tent* ■ *Avg Duration ATV*

□ *# Crossings Between Dome and Work Tents*

Work Tent Visit Durations

First row has been cut in half to fit

0	1 2 0 2 2 1 0 0 0 1 0 0 1 0 0 1 0 0 0 1 0 0 7 1 1 4 7 0 0 0 0 0 2 3 4 0 1
1	4 0 4 6 6 2 8 1 2 2 0 1 2 4 1 1
2	6 2 8 6 0
3	0 1 7 0 8
4	7 7
5	4 0 6
6	6 3 0 6
7	8
8	4
9	
10	8
11	
12	
13	
14	3

July 11, 1999 — 3:26 - 1130 PM

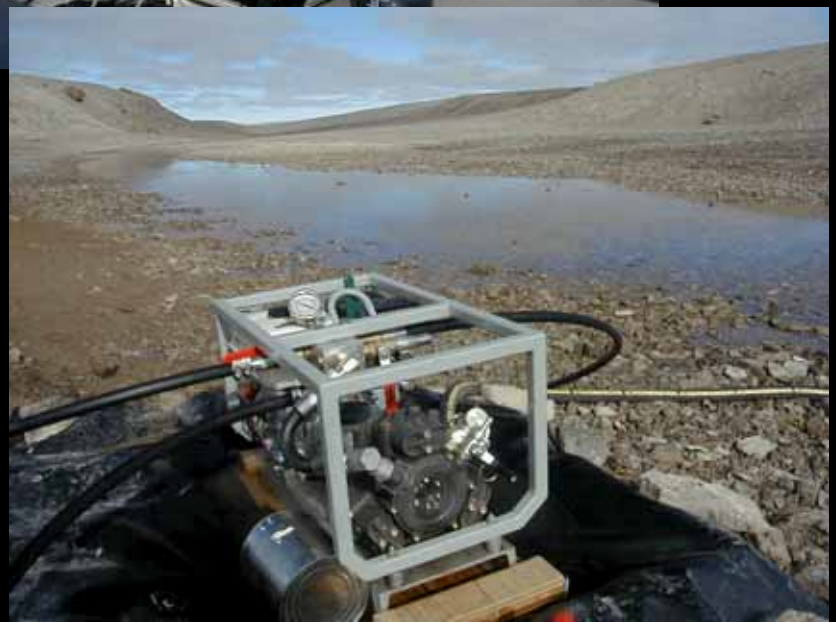
Duration in minutes, e.g., 14 | 3 = 143 mins

(after Tufte, split line chart)

Frequency and order of visits —50% under 10 minutes => storing & retrieving things

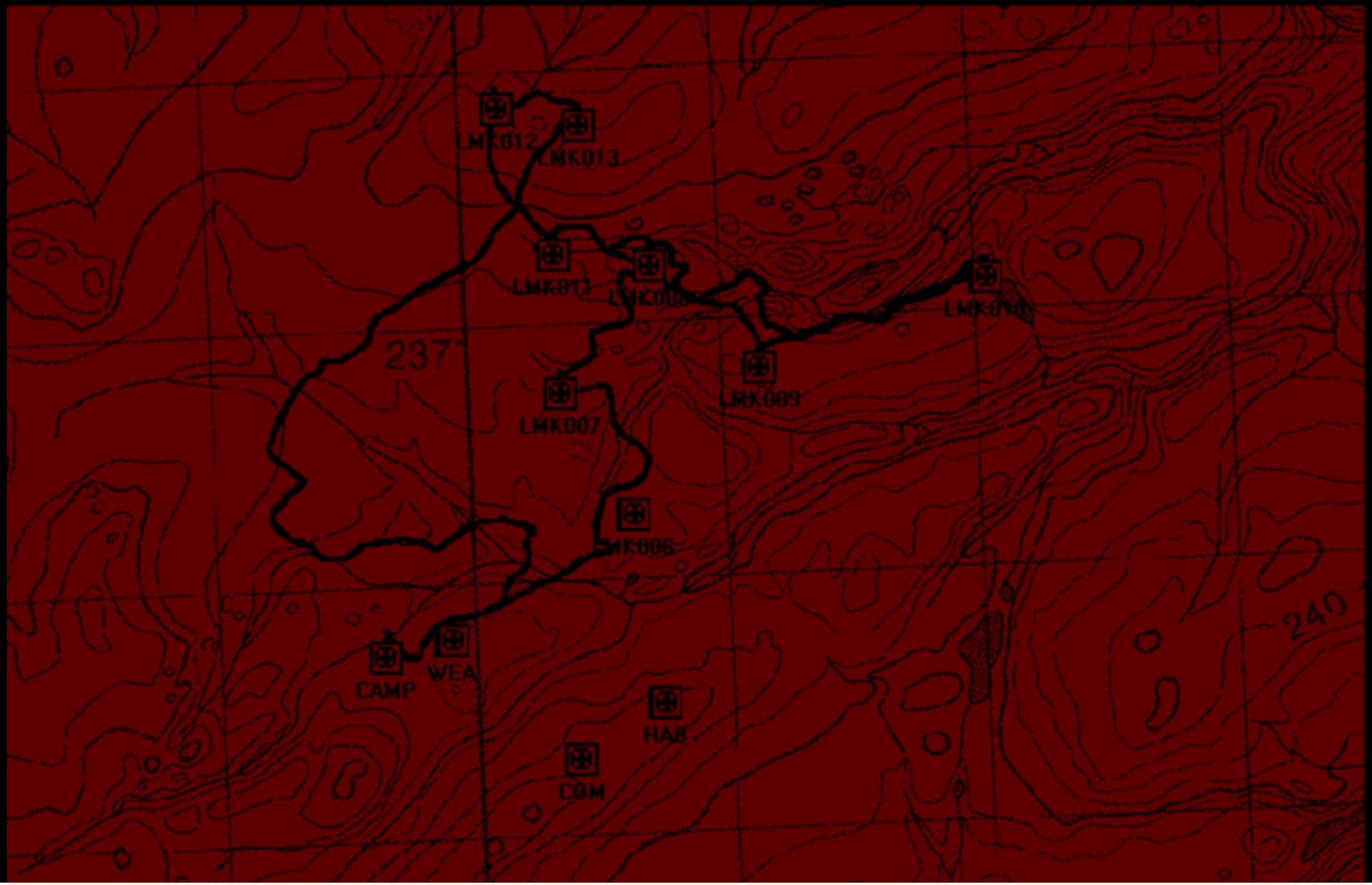
FMARS Computing Research Topics

- **Computing & Communication Infrastructure**
  (hab-rover-suit, telemetry, satellites, …)
- **Scientific instruments**
  (deploy, maintain, reprogram, …)
- **Automation**
  (scheduling, life support, robots, mobile agents, …)
- **Telescience, medicine, instruction**

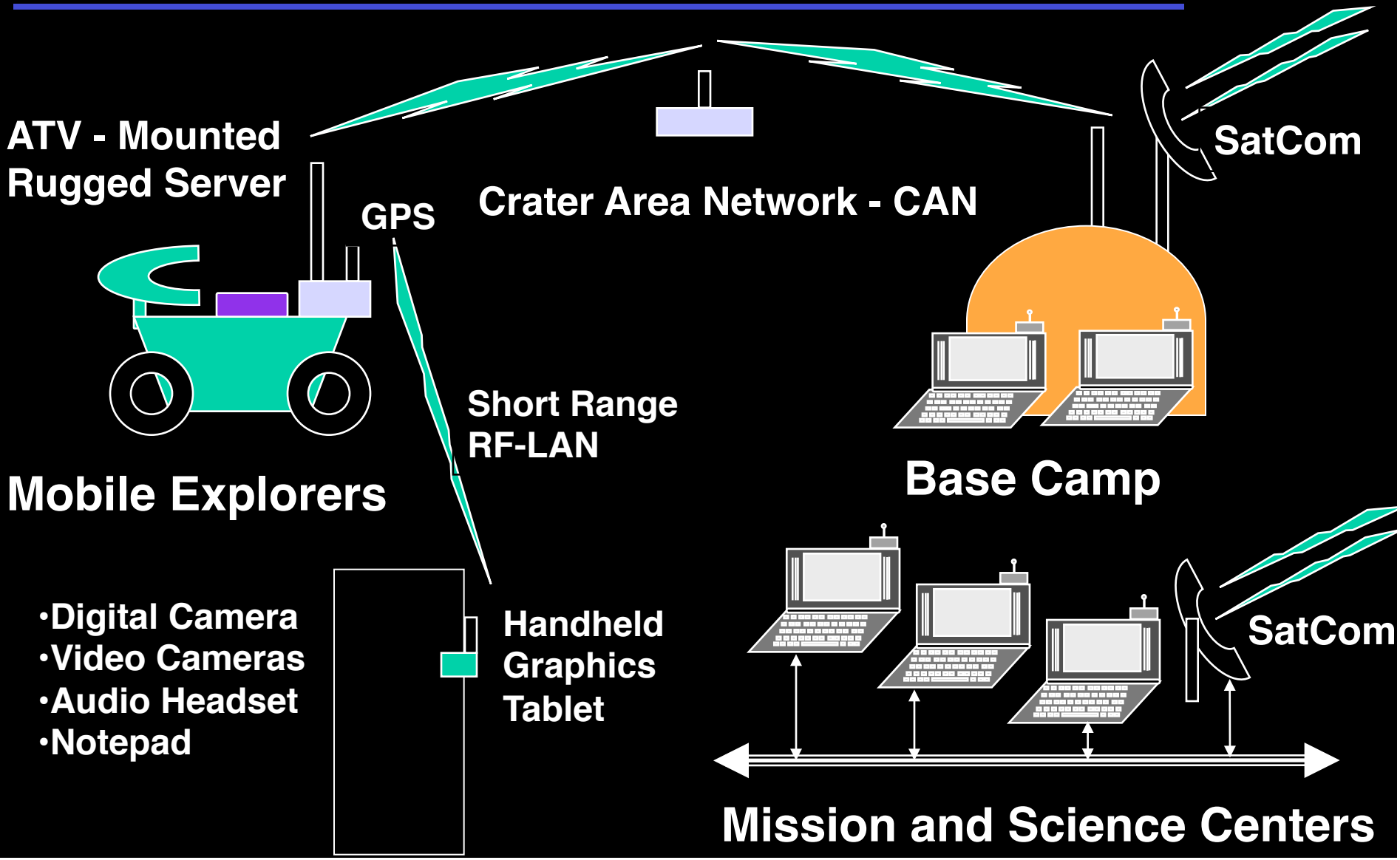


Mobile Computing HMP 2000

Traverse July 18, 2000



Mobile Exploration System



Multimedia Records

Expedition Memory

Crater Rim

WHERE

WHEN

7/20/98 5:35 PM

GPS

75 20.31N 89 49.82W

WHO

CMD, MS1

SITE

S10832

VIDEO

RIM PAN

SAMPLES

WATER S27

FLORA

PLANT S35

NOTES

OVERVIEW VIDEO

MONOMICT BRECCIA

COMMENT VIDEO

Telemetry Processing

Weather station at airstrip

Store and analyze data in Hab

Share with local and remote mission support

Crew Reporting Problem

Interacting with "Devon Support" involved 2 or more people, about 2 hrs/day

- Full-time job to record & format "captain's log"
- Better for individuals to audio log activities
- Transcribe & format on Earth (MCC)
- What can be tracked automatically?

Computer Use Survey

- > 90% used a computer
- About 60% browsed web, used e-mail daily, and informed colleagues or sought advice
- 1/3rd downloaded software!
- > 50% learned to use new software!
- 75% watched a full DVD movie
- 64% used a digital camera (137 photos avg.) & most of these e-mailed photos
- 4 people used computer outside or in personal tent

Computers & Internet access were central to expedition life (N=25, year 1999)

How the Internet Affects Field Science

"You might want to read John Spray's e-mail…"

Hypotheses Under Investigation

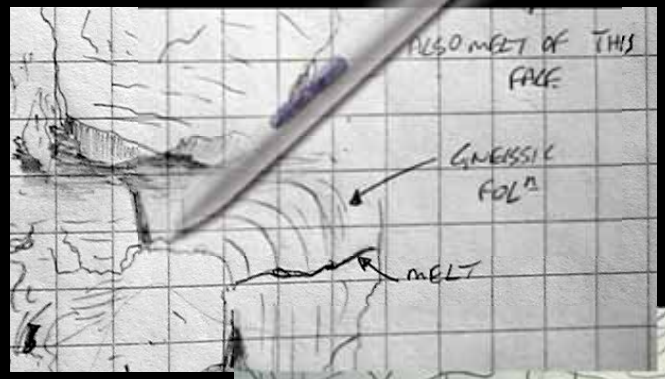
Exploration is not just about covering the most area in the most time; continuously *revisiting places* is essential.

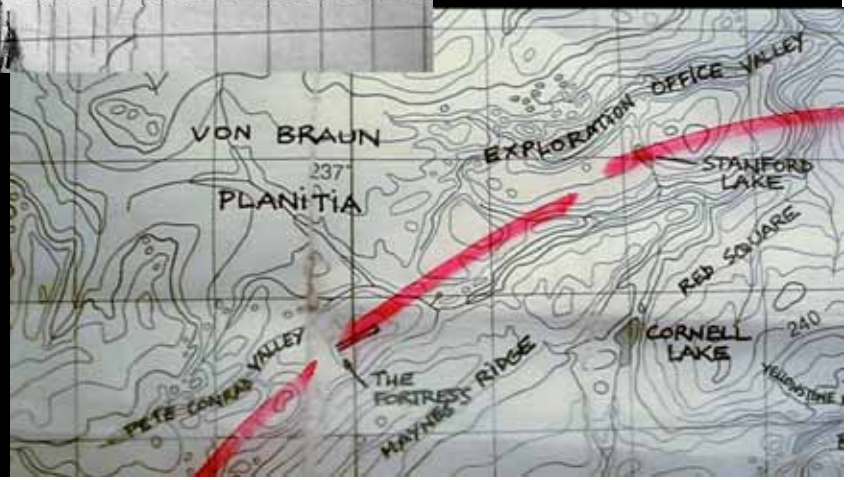
Hypotheses Under Investigation

Living on Mars will *change scientific practice*, physically constraining how the work is done and how analysis and publication are coordinated.

Hypotheses Under Investigation

Observing scientists at work — *before deciding what to build* — can improve designs of facilities and tools.





Draw directly on camera LCD & link to a map database image stored in the camera

Hypotheses Under Investigation

An important use of computers will be *life support automation and mediating communication* with Earth.

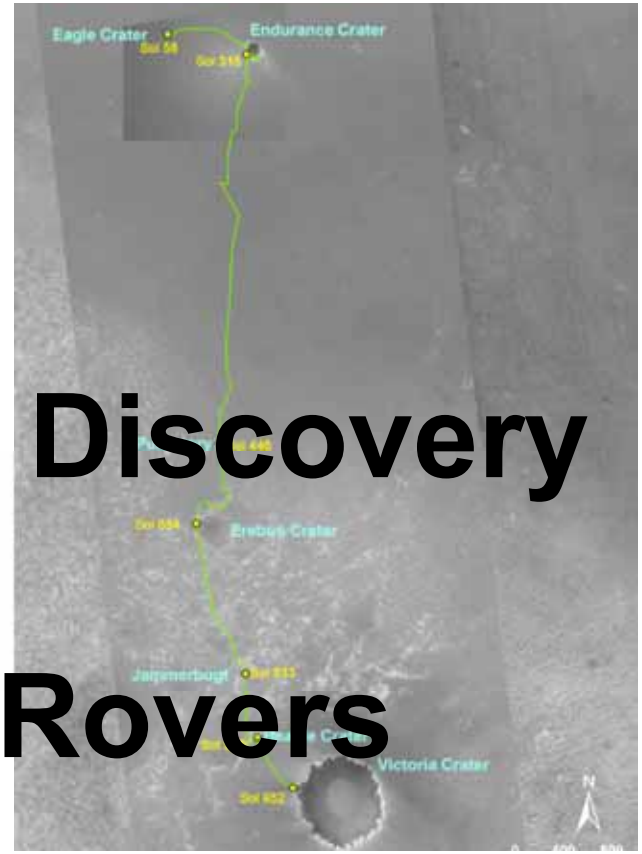
Hypotheses Under Investigation

Mission Control must learn about *human activities on Mars* and adjust its support role as surface practices develop.

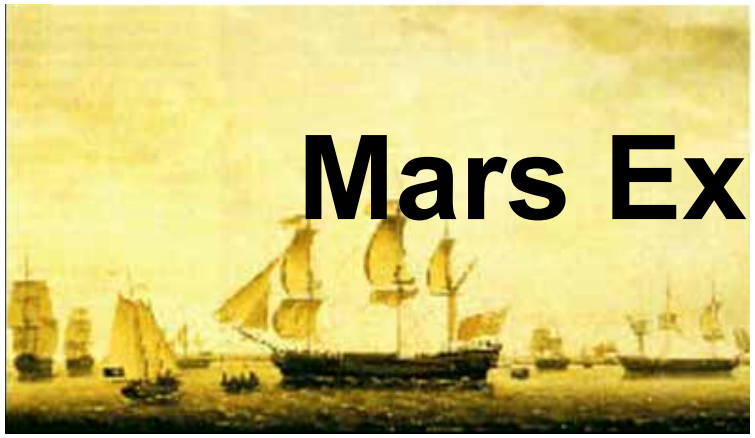
For more information...

- *National Geographic* (July 99)
- WJClancey.home.att.net
- Visualizing Practical Knowledge (1998)
- Human Exploration Ethnography (1999)
- www.MarsSociety.org
- Mars Society Meeting @ Stanford, August 2001

Exploration: Another kind of cognitive activity



Voyages of Scientific Discovery with the Mars Exploration Rovers

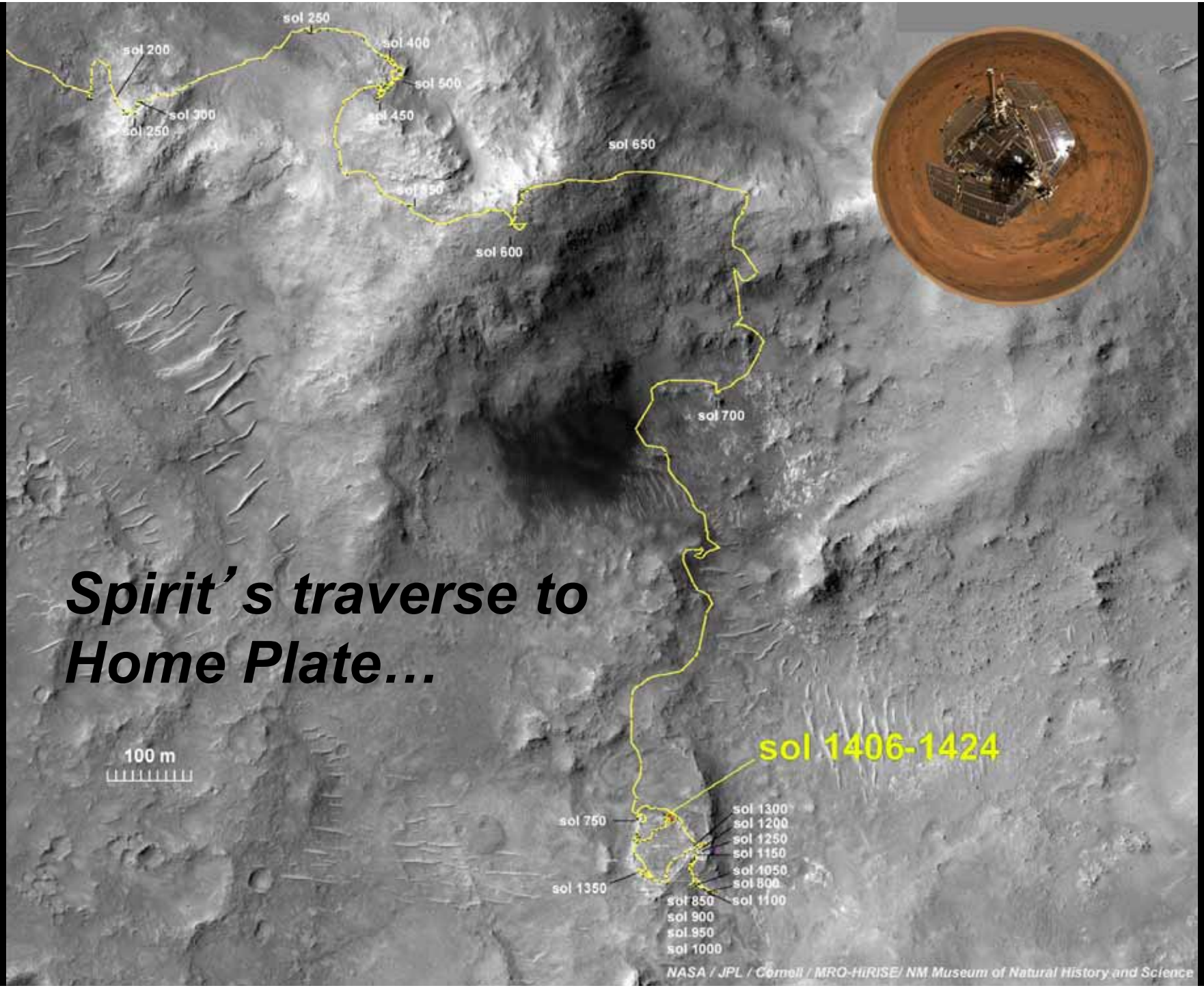


William J. Clancey

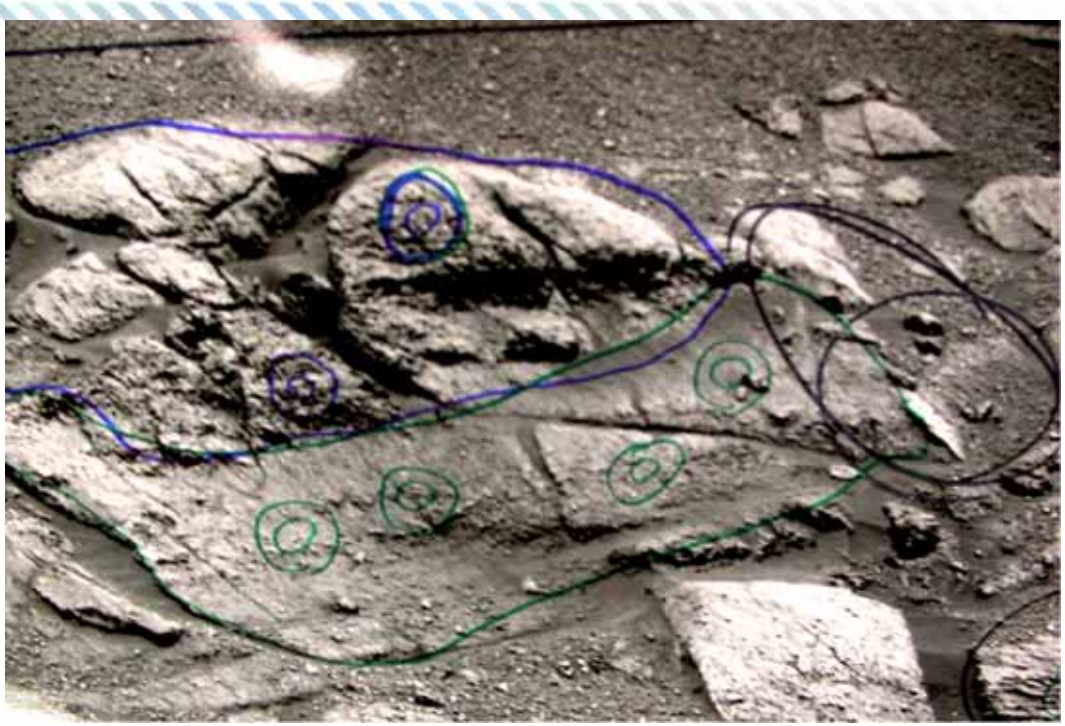
Chief Scientist, Human-Centered Computing

Intelligent Systems Division

NASA Ames Research Center


sol 250
sol 200
sol 400
sol 500
sol 300
sol 250
sol 450
sol 650
sol 550
sol 600
sol 700
Spirit's traverse to
Home Plate…
100 m
sol 1406-1424
sol 750
sol 1300
sol 1200
sol 1250
sol 1150
sol 1050
sol 800
sol 1350
sol 850
sol 1100
sol 900
sol 950
sol 1000
NASA / JPL / Cornell / MRO-HiRISE/ NM Museum of Natural History and Science

Surprise #1: Textbook Method



"… don't say let's RAT here to reveal this and let's RAT here to reveal that, let's talk it through in terms of the specific scientific hypotheses that we're trying to test."

Surprise #2: Rover as Hero

IMAGES | MULTIMEDIA | NEWS | MISSIONS | EVENTS | KIDS | EDUCATION | SCIENCE & RESEARCH | ABOUT JPL

- PRESS RELEASES
- SPOTLIGHT FEATURES
- PROFILES
- E-NEWSLETTER
- JPL ANNUAL REPORTS
- EMPLOYEE NEWSPAPER
- FOR MEDIA PROFESSIONALS
- MEDIA CONTACTS
- MEDIA VISITS
- IMAGES/MULTIMEDIA CONTACT

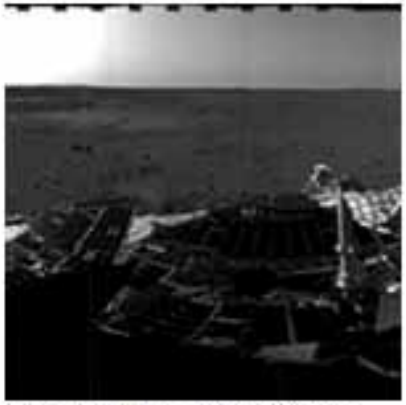
2004 News Releases

Spirit Lands on Mars and Sends Postcards
January 4, 2004

A traveling robotic geologist from NASA has landed on Mars and returned stunning images of the area around its landing site in Gusev Crater.

Mars Exploration Rover Spirit successfully sent a radio signal after the spacecraft had bounced and rolled for several minutes following its initial impact at 11:35 p.m. EST (8:35 p.m. Pacific Standard Time) on January 3.

"This is a big night for NASA," said NASA Administrator Sean O'Keefe. "We're back. I am very, very proud of this team, and we're on Mars."

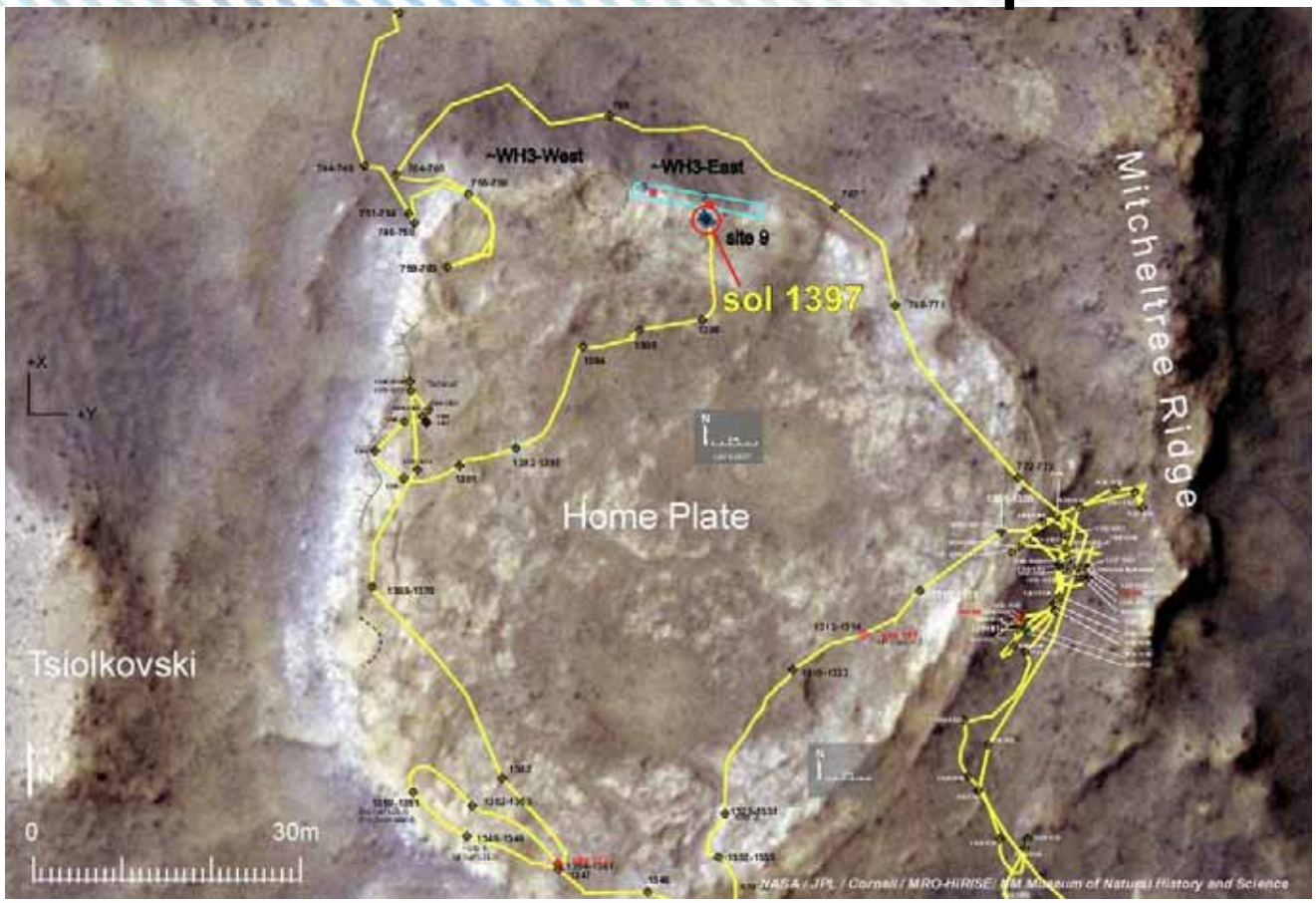


Mosaic image taken by the navigation camera on the Mars Exploration Rover Spirit.

Related Links:
+ Spirit's First Images from

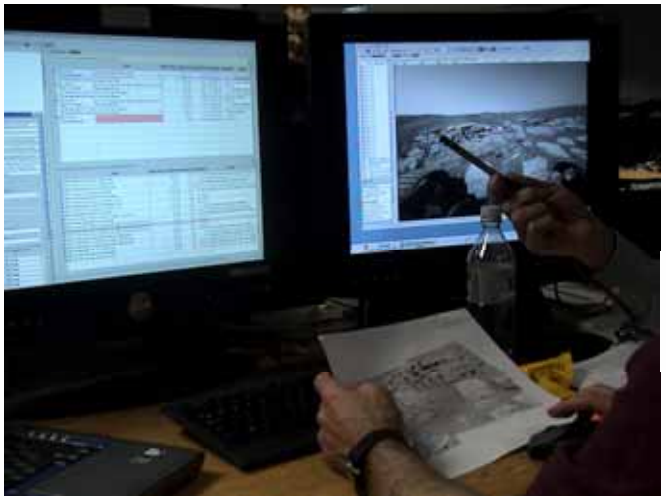
"The first ever *robot field geologist* on Mars…"

Surprise #3: Analyzing a Planet with a Microscope



150 scientists & engineers have investigated 100m² for over 2 years, with 1 robot (Spirit)

A New Practice of Field Science:
Communal, Deliberative, Public, Virtual



Types of Scientific Exploration

Type	Setting	Domains	Tools	Scale
Voyages of Discovery	Extreme	geography, bio, anthro	Hand	10s - 100s
Laboratory Science	In a building	bio, chem, physics	Lab	Few
Field Science	Isolated or Mundane	bio, geology, social	Hand	One - few
Modern Expedition	Base camp; usually extreme	archaeology, geo, bio, robotics	Hand + Lab	Few - 10s
Big Science	Isolated site	physics, astro, ocean	Huge machines	100s - 1000s
Planetary Missions	Extreme	astro, geo, bio, physics	Robotic spacecraft+	1000s

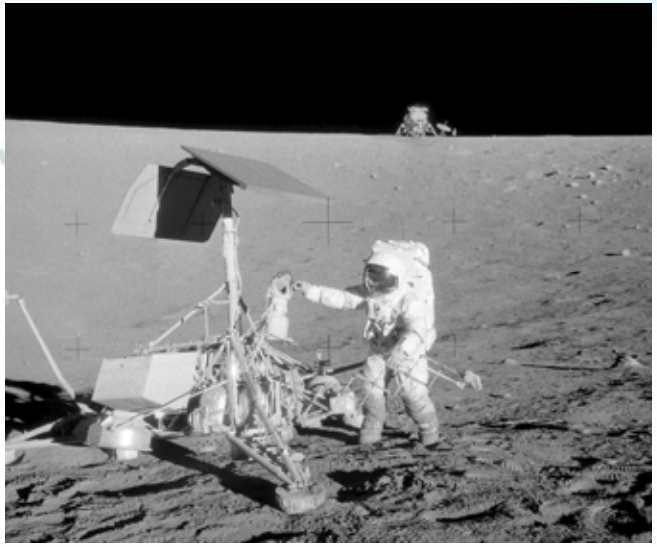
TIME

Same | Different

PLACE

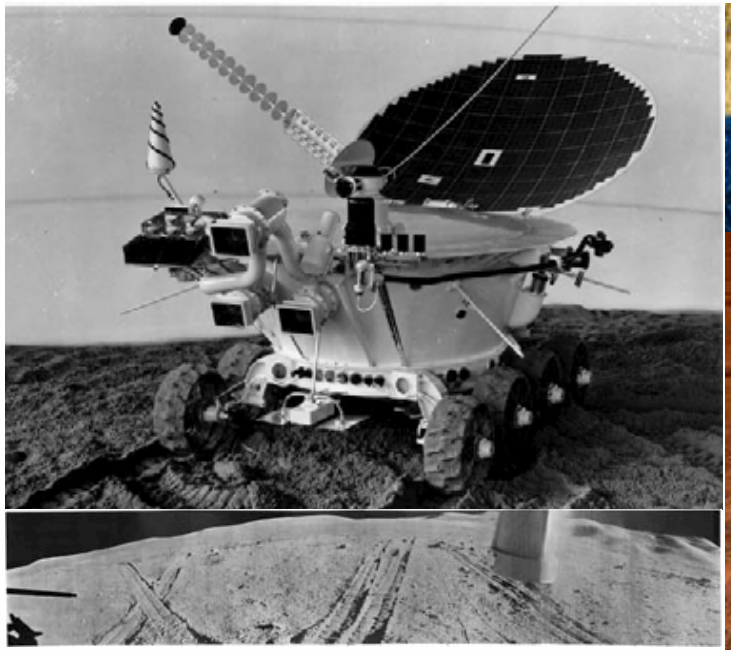
Same

Mobile Agents

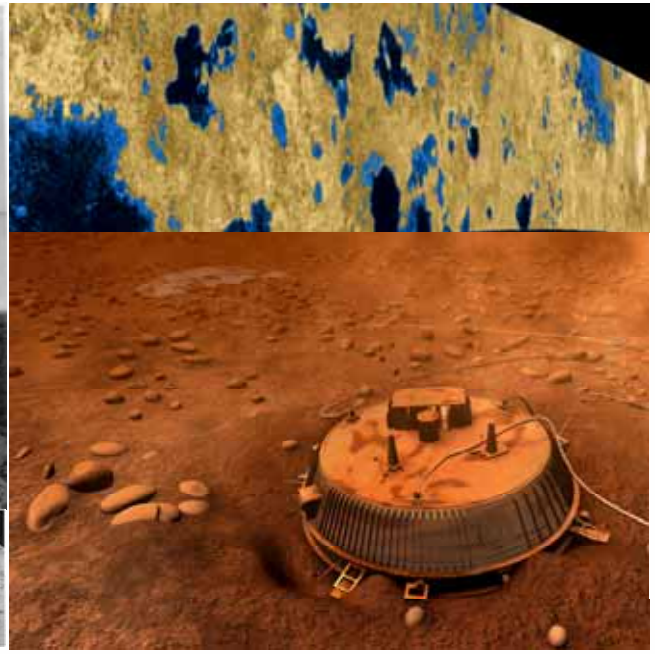


Surveyor III/Apollo 12

Different



Lunokhod-2



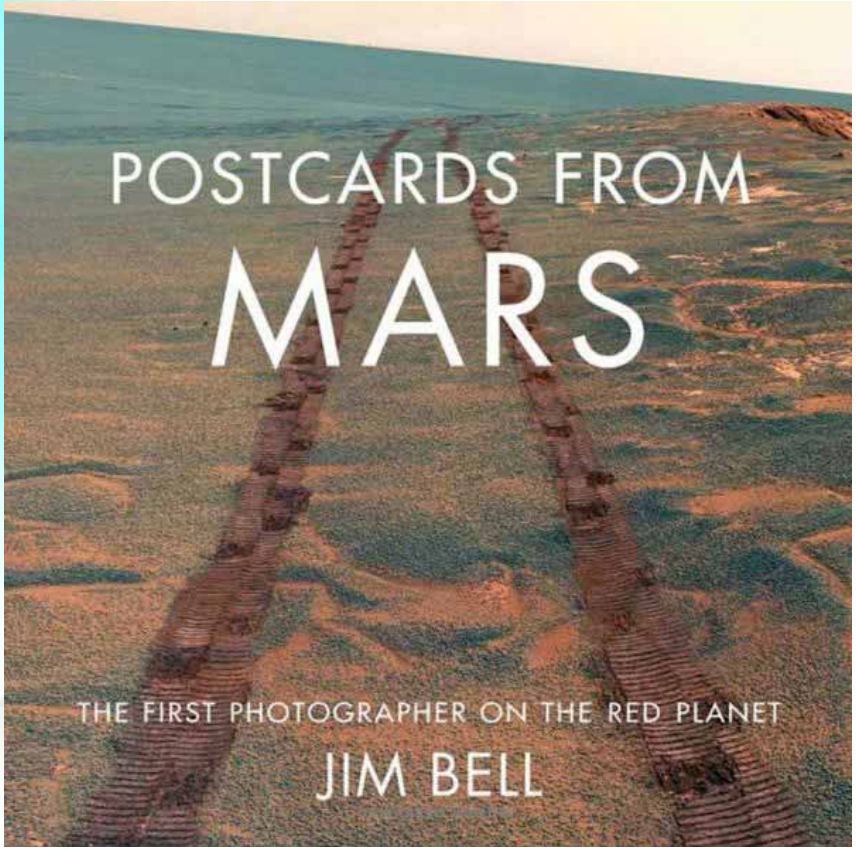
Cassini/Huygens

One Instrument, One Team

"The whole idea behind MER is that these tools work together. Look at the silica discovery. The mobility system, which we use as a soil physical processes tool, trenches up some soil. We notice it with Pancam, we hit with mini-TES; it looks interesting, and we go over and we figure out what it's made of with APXS. Everything works together."

Steve Squyres, *Interview*

Two Boots on the Ground…

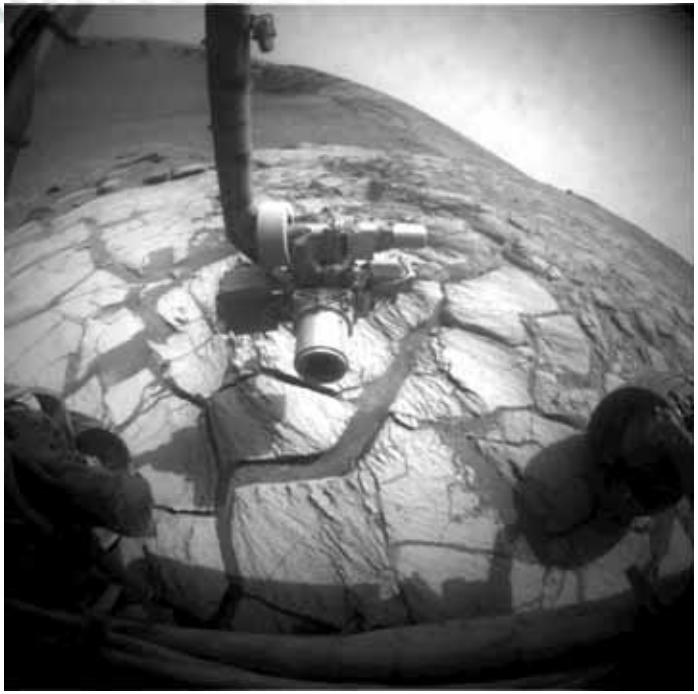


"I put myself out there in the scene, the rover, *with two boots on the ground*, trying to figure out where to go and what to do, how to make that what we're observing with the instruments. By and large, day in day out, it was always the perspective of being on the surface and trying to draw in your own field experience in places that might be similar—how you'd detect a landscape and interrogate it as much as you could."

Jim Rice, MER Scientist, 2006

“We’re on Mars!”

First Person Perspective



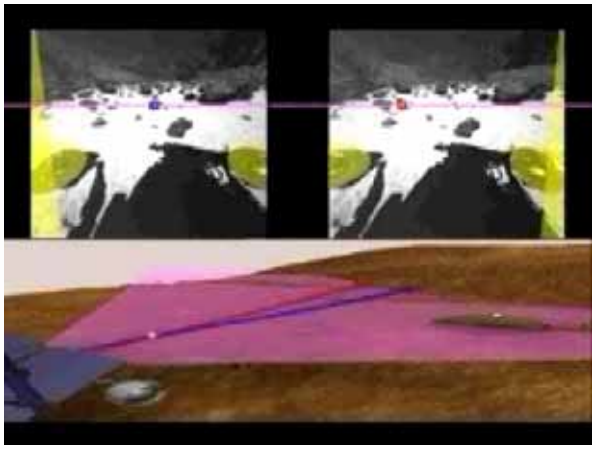
Seeing & Direct Manipulation

“We realized *we had landed in a crater*, probably Eagle Crater, and that’s where we were. And then *we noticed, 800 meters away*—which is more than our 600 meters, but *maybe we can make it*—there’s Endurance Crater. We’re talking about that, “My god, wouldn’t it be great to actually get there!”

Steve Squyres, MER PI, 2007

“We’re on Mars!”

Second Person Perspective



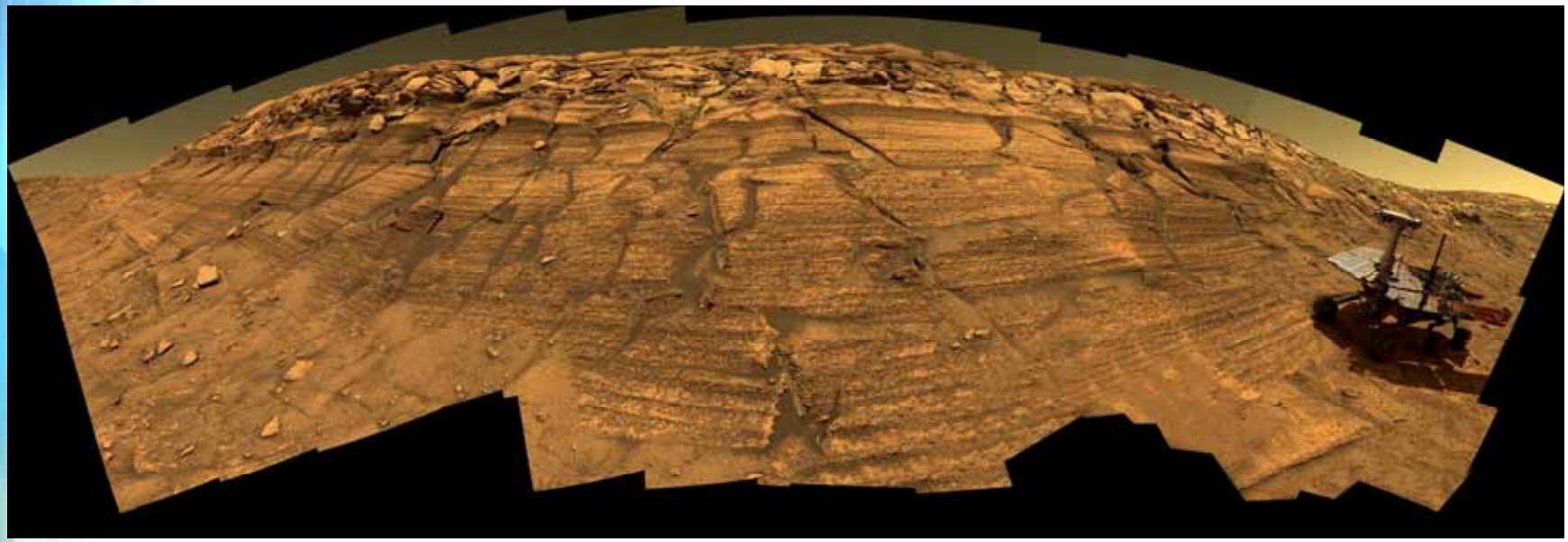
“Partnership” – What You Do and What I Do

“I actually see the rover as an equal partner…. I have my limitations as a robot planner—resources, my time to build a sequence, then time to do the analysis. If I had all the resources in the world, I could …build every little thing that I want the rover to do—intricate sequencing—so that the rover doesn’t have to think for itself. But because of that limitation, I’m forced to work in partnership with the robot.”

Ashitey Trebi-Ollennu, MER Rover Planner, 2007

“We’re on Mars!”

Third Person Perspective



It: The Robotic Geologist…alone in Victoria Crater…

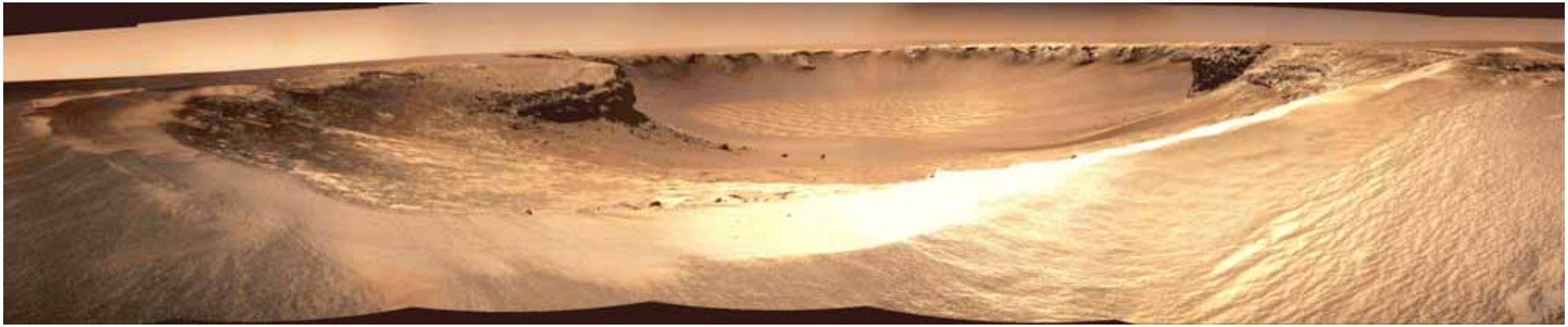
and also

Us: standing before Burns Cliff, observing the robotic laboratory…

Voyages of Discovery

- “A Heroic Journey”
- Move together
- Collaboratively investigate
- Engineers operate vessel
- Survey and study lands known to exist
- “Gathering data for the ages”
- Opportunistic
- Don’t know what we're missing

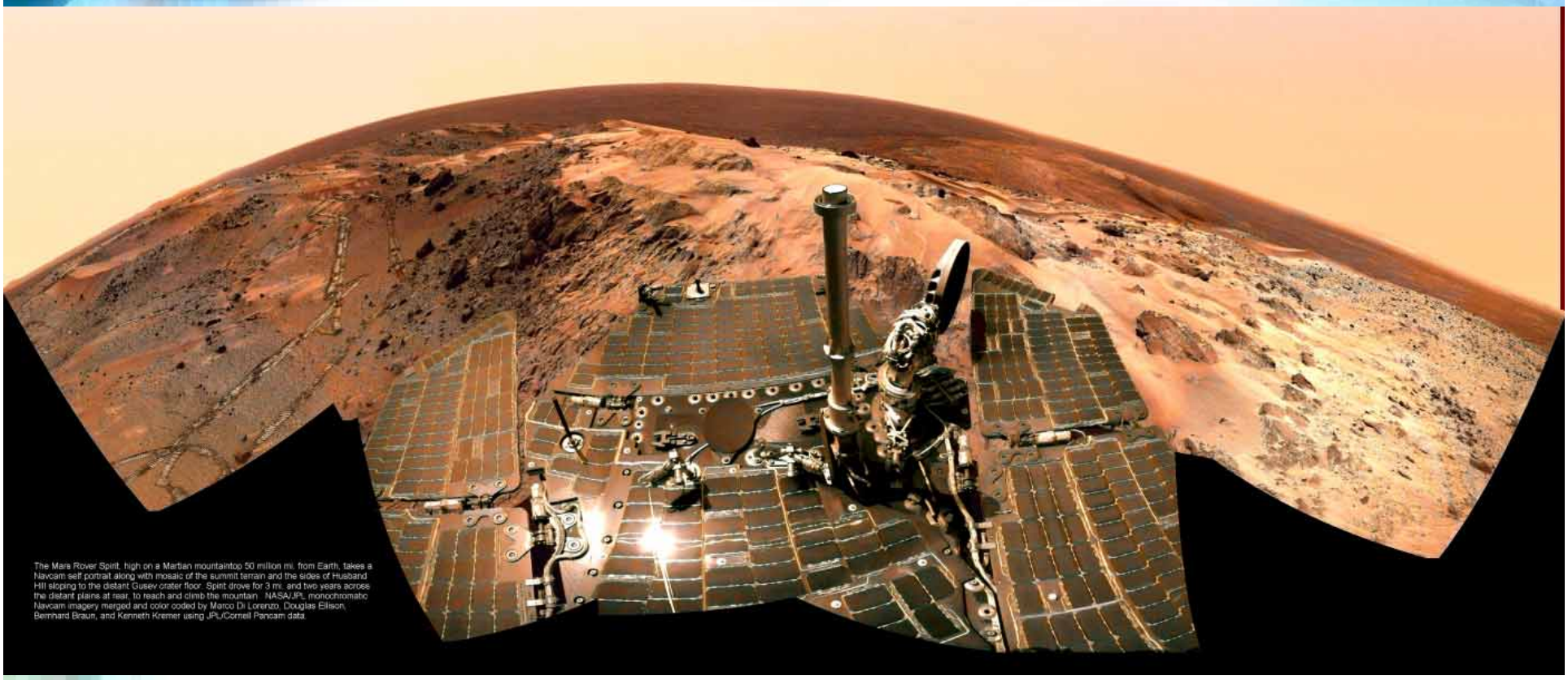
Is part of the allure of Mars its perceived innocence, its pure and unspoiled nature, away from the complexity of Earth?



A Romantic Ideal: "…of a peaceful, prosperous and boundless future through the study, exploration and development of Space for the benefit of all humanity."

ISU Mission Statement

Hodges, *Overview of Tahiti*, 1775



"And insofar as we travel in search of beauty, works of art may in small ways start to influence where we would like to travel *to*."

Alain De Botton, *The Art of Travel*

Our marks on another planet —

The embodiment of human curiosity & probing…
our physical & intellectual reach…