Distributed Crew Interaction with Advanced Life Support Control Systems

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Johnson Space Center

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Future Manned Space OPS Organization

Inside Vehicle/Facility

Water Control

Air Control

Outside Vehicle/Facility

Robot

Automated agents control without human intervention most of the time

- Perform routine control operations
- Manage anticipated failures

Robot

Crew 1

Crew 2

Crew 3

Future Manned Space OPS Organization

Inside Vehicle/Facility

Water Control

Air Control

Outside Vehicle/Facility

Robot

Humans perform tasks other than control most of the time

- Located remote from the control system
- On-call to handle anomalies
- Interleave occasional control task with other tasks

Robot

Crew 1

Crew 2

Crew 3

Future Manned Space OPS Organization

Inside Vehicle/Facility

Water Control

Air Control

Outside Vehicle/Facility

Robot

Human role in control

- Maintain situation awareness to handle unexpected situations & detect long-term performance changes
- Intervene in control to respond to unexpected situations & to perform tasks not easily automated

Robot

Crew 1

Crew 2

Crew 3

Model of Interaction: Loosely Coordinated Groups

- Model interaction among distributed group of humans and automated control agents as *loose coordination*
  - Control responsibilities are allocated to group members based on related but non-overlapping roles
  - Activities of group are coordinated by centralized group plan that manages limited shared resources
  - Unplanned actions conducted by group members are coordinated to minimize interference with the ongoing activities
- Approach: provide *proxy agents* to help users coordinate with control agents and other humans to perform complex control tasks
  - Rich set of models and ontologies: role, activity, location, human presence, saliency, event, notification specs, situation specs
  - Reason over these models using techniques such as planning, inferencing, pattern matching

Future Manned Space OPS Organization

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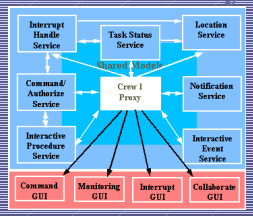
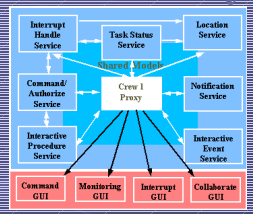
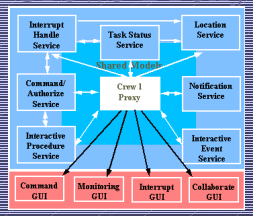
Robot

Robot







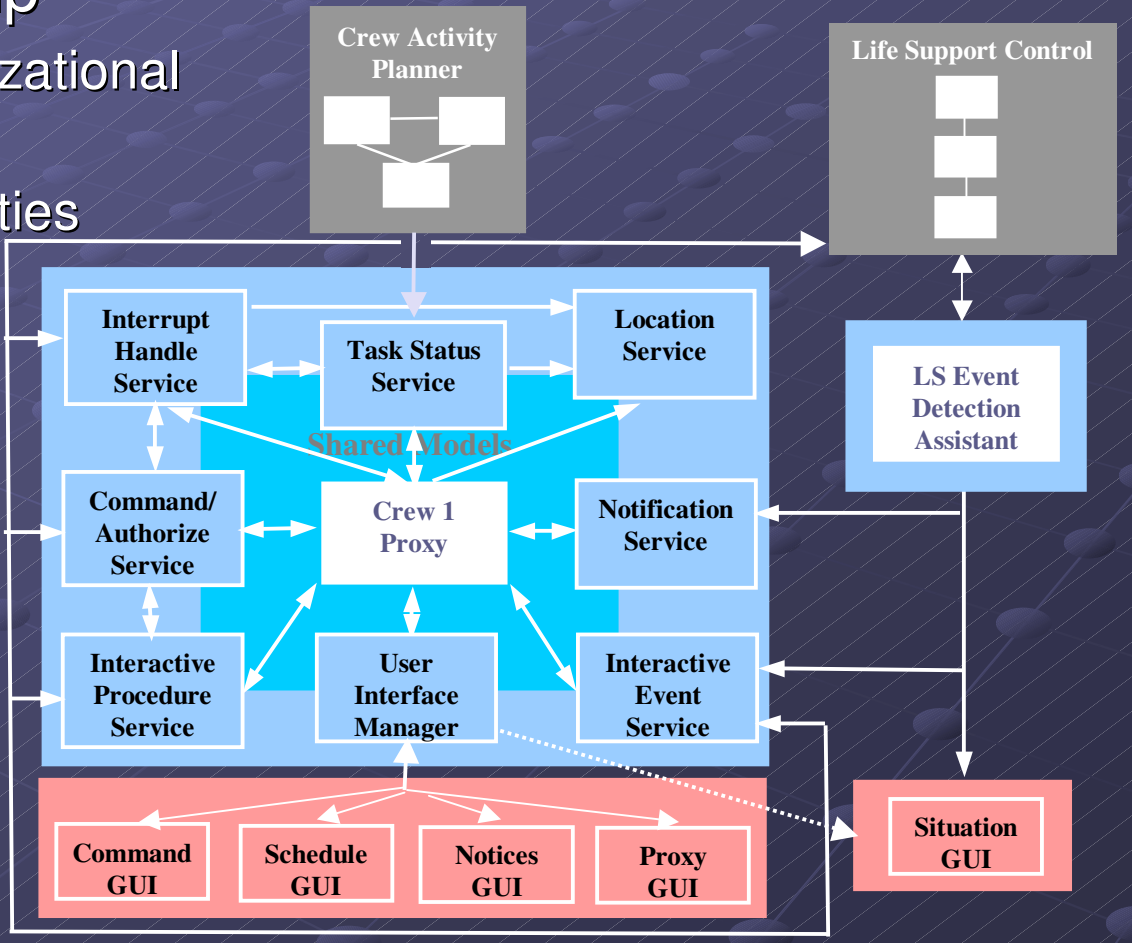
Crew 1

Crew 2

Crew 3

What is Role of Proxy Agent in Group?

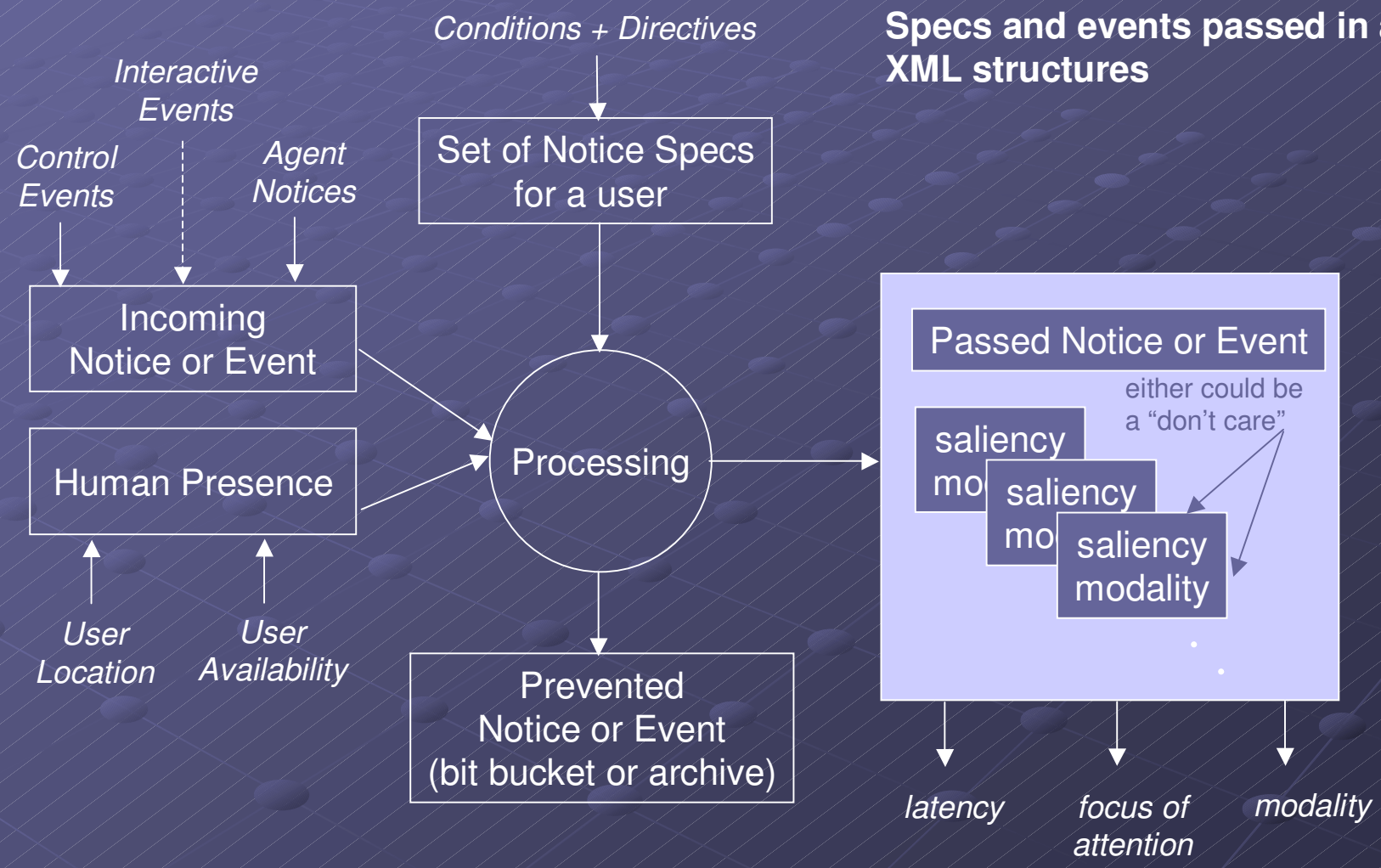
- Facilitate user interaction with control agents and other humans to perform tasks associated with assigned roles in an operational group
  - Communicating in organizational context
  - Coordinating group activities
  - Tracking human location
  - Summarizing complex situations
  - Aiding coordinated, distributed commanding within group (FY03)



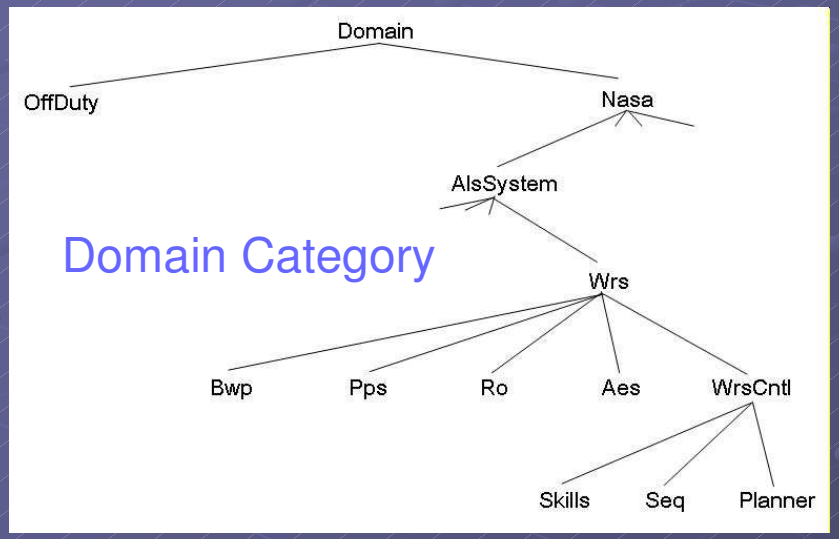
Communicating in Organizational Context

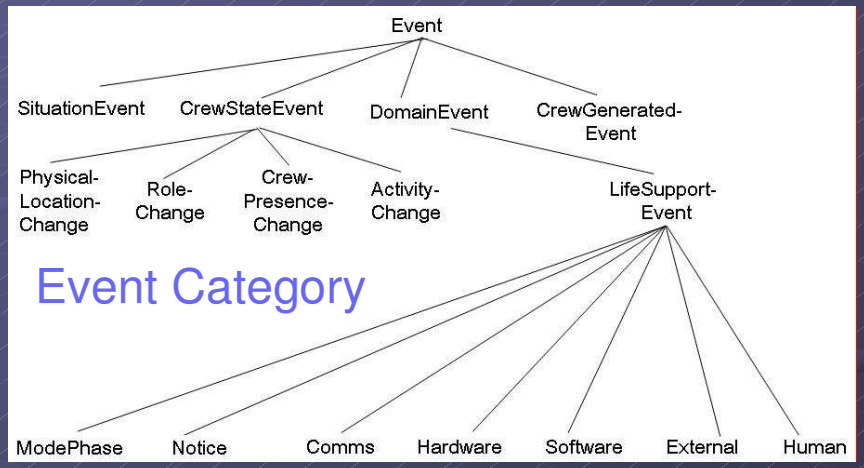
- Proxy notifies user of control events and agent notices based on group role requirements and personal preferences
  - Changes in role alter human information requirements
  - Individual preferences are overlaid on group role requirements without compromising them
  - Notification Service: matches incoming event to notice specs represented using knowledge models (ordinal, exact, ontological, etc. match)
    - User Notification Context determines which specs apply based on user roles and other user state information
    - Notification Conditions determine what events are passed based on event categories, domain categories, notification categories, etc.
    - Notification Directives determine how to inform its user based upon user accessibility and availability (i.e., presence)
  - Location Service: assesses human *presence*

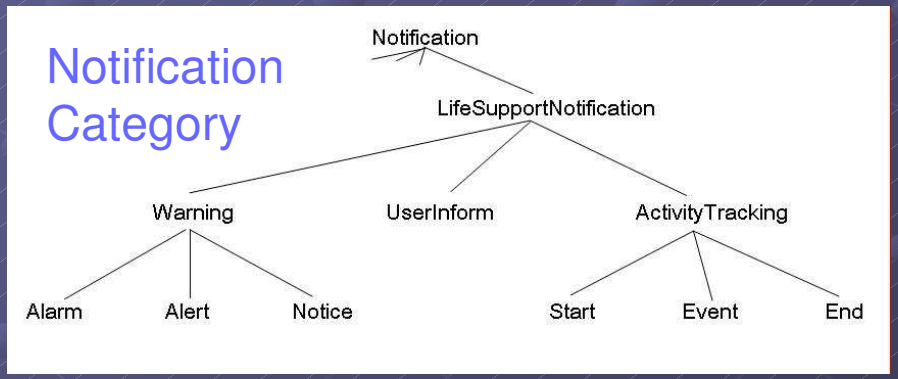
Processing of Notification Specifications

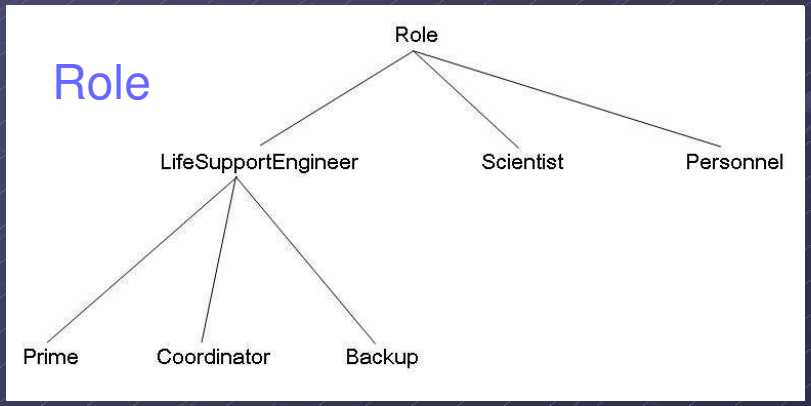


Ontologies for Notification Condition

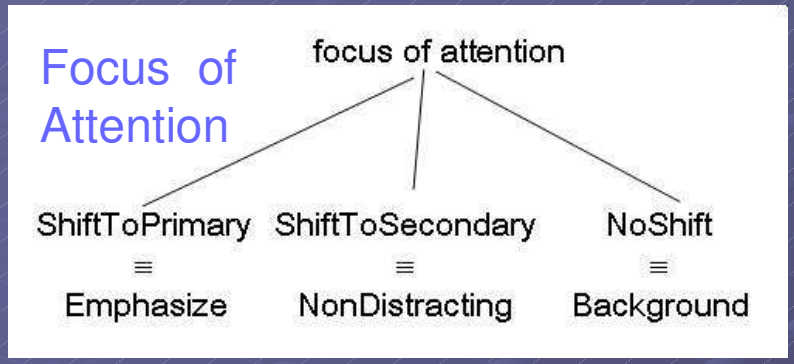


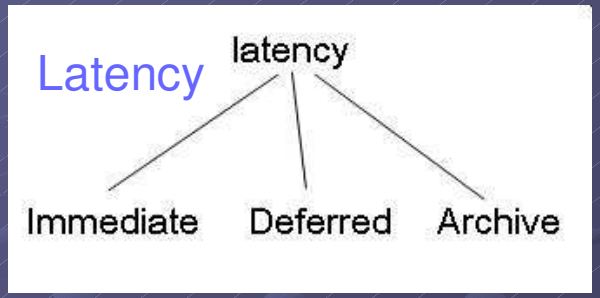


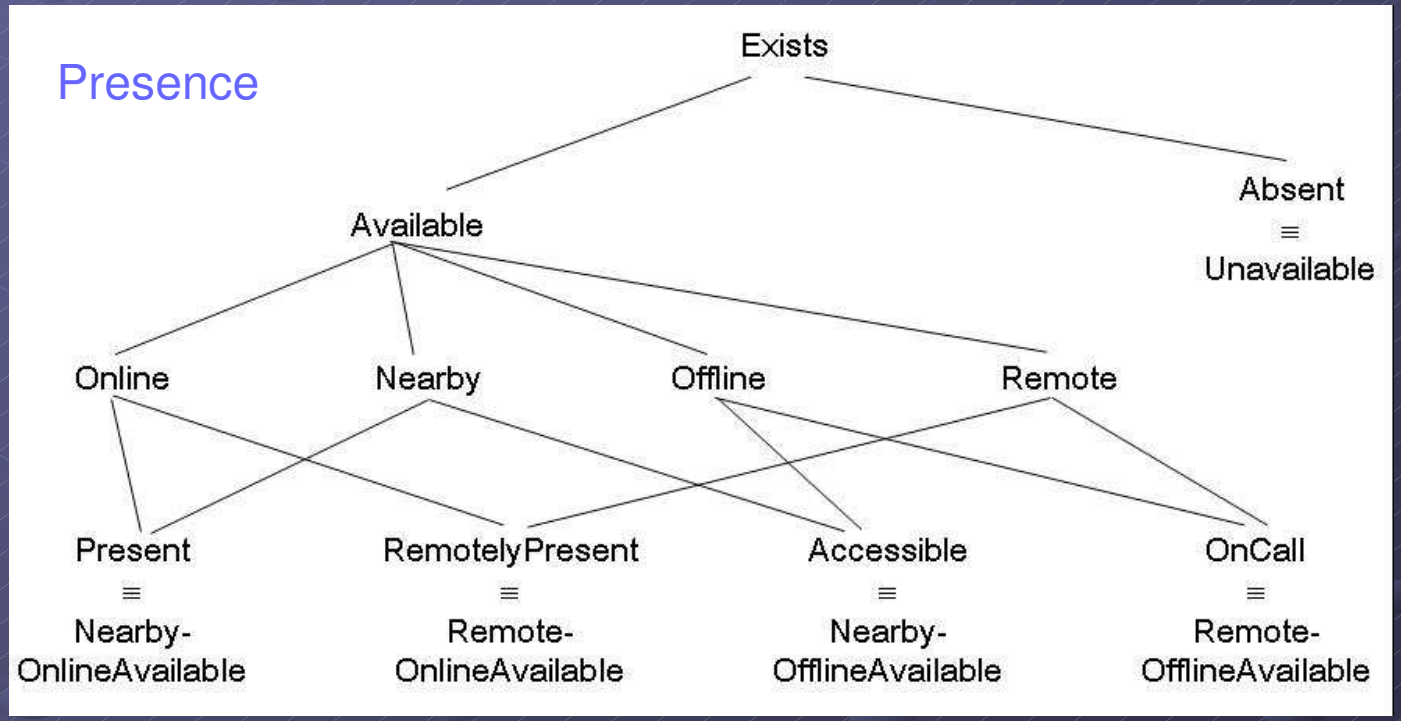




Ontologies for Notification Directive







Examples
for Domain Events

Notice condition ⇒ Notice directive

	Assigned to/by	Event Category	Domain Category	Notification Category	Urg	Latency	Focus of Attention	Crew Presence	Modality
ORG	PRIME/Org (covers LORC/RORC)	Comms	WrsCntl	Warning	L/M/H	immed	primary	online	DISPLAY
								offline	PAGER, D-QUEUE
	BACKUP in WaterLab/Org (covers LORC/RORC)	Comms	WrsCntl	Warning	L/M/H	immed	primary	online	DISPLAY
								offline	PAGER, D-QUEUE
	COORD/Org. (covers LORC/RORC)	Comms	WrsCntl	Warning	L/M/H	immed	secondary	online	DISPLAY
								offline	D-QUEUE

PRIME: WRS control communications warnings are passed with immediate latency and primary focus of attention

If user is online, show notice on proxy display

User preferences can add a modality or increase the latency or focus of attention specified in organizational specs

User preferences cannot remove a modality or decrease latency or focus of attention specified in organizational specs

If user is online, show notice on proxy display

If user is offline, queue for display when logs back in

What's Next for Notification

- FY03 Plans
  - Notification of interactive events
  - Escalation of notification
  - Editing notice specifications
  - Improved user interfaces to notices; includes searching and threading messages

Coordinating Group Activities

- Group plan assigns tasks for group roles & coordinates group actions
  - Activity planner builds centralized group plan, assigns tasks, and marks tasks complete
  - Proxy tracks completion of its user's activities and provides assessment to planner
  - Activity Plan: HTN planner
    - Avoids conflicting commands and over-subscribed humans
    - Coordinates handover between manual & automated tasks
    - Reactive re-plans in contingency situations
  - Task Status Service: inference of completion status
    - Tracks activities using *direct evidence* through computer-mediated tasks and *indirect evidence* based on location
    - Requests user for activity acknowledgement, if needed

Relating Planning Information to Human Model of Activities

Activity Planner

Automated Planner

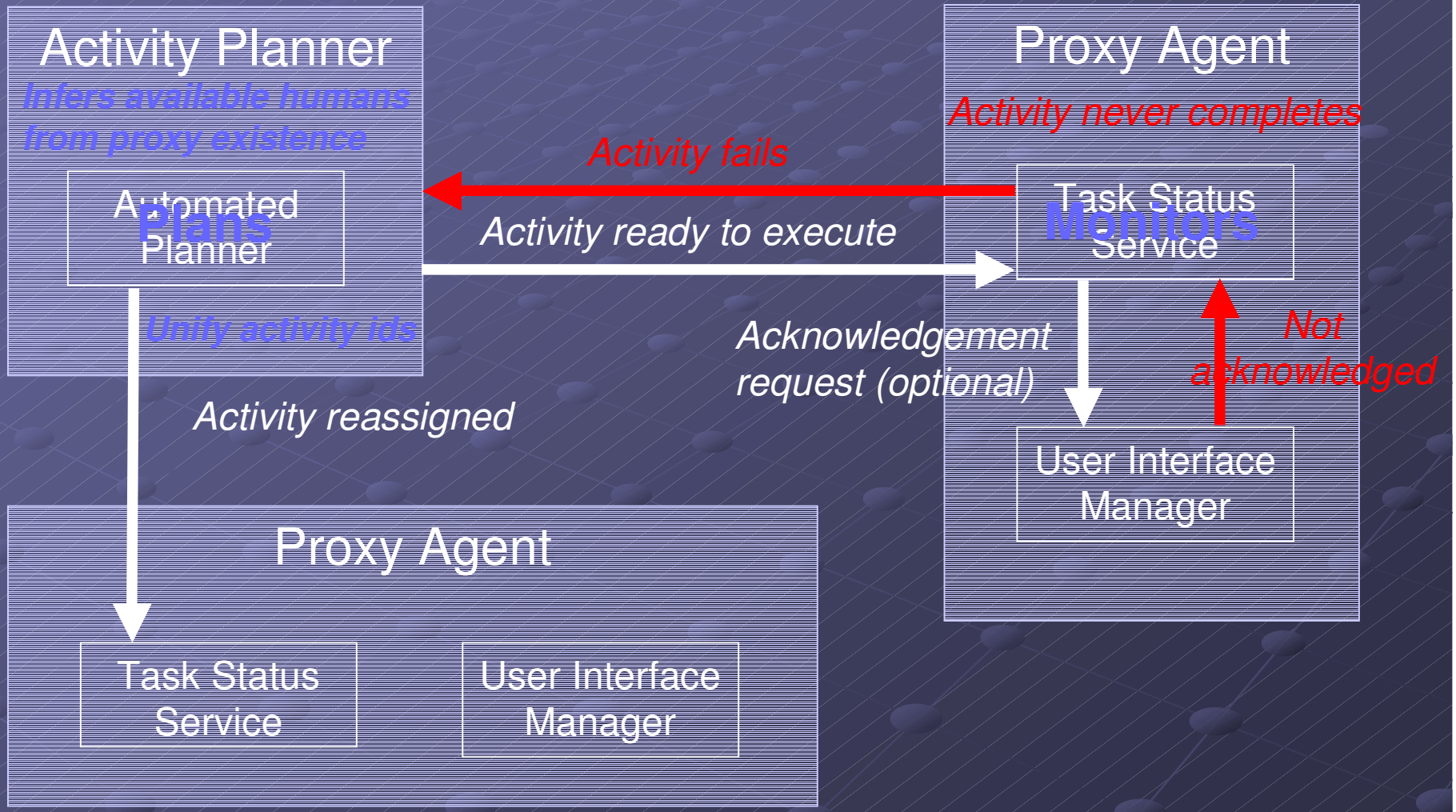
- Maps between human perspective and planner perspective on status
- Reacts to domain contingencies by assigning new tasks; updates completion based on TSS status
- Infers available humans from proxy existence
- Unifies activity ids after re-planning
- Models domain-specific activity information: category, importance

Task Status Service

Human

- Assesses completion status of its user's activities and provides as observations to planner
- Combines direct and indirect evidence to track human activity
- Assume complete and confirm later
- Requests user to acknowledge some activity status changes
- Assigns importance/saliency to acknowledgement request

Relating Planning Information to Human Model of Activities



What's Next for Group Plans?

- FY03 Plans
  - Add capability to change roles dynamically
  - Support human interaction in building and modifying plans
  - Add interface for the user to monitor activities of group members

Tracking Human Location

- Proxy tracks location of its user
  - Location Service: matches incoming readings to knowledge models for location and presence
    - Maps location readings to location ontology
    - Translates location and online/offline information to human presence ontology
    - Location readings
      - Machine locations where users log into and out of proxy
      - Future: GPS readings
    - Generalizes assessment of location and presence over time

Tracking Human Location

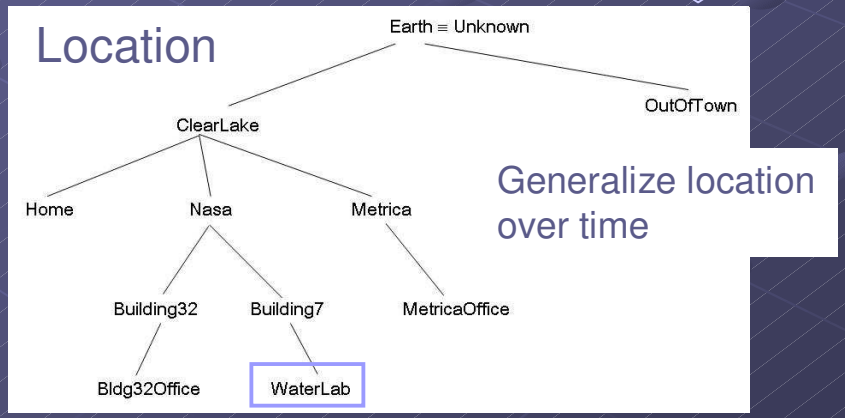
Proxy Access Manager

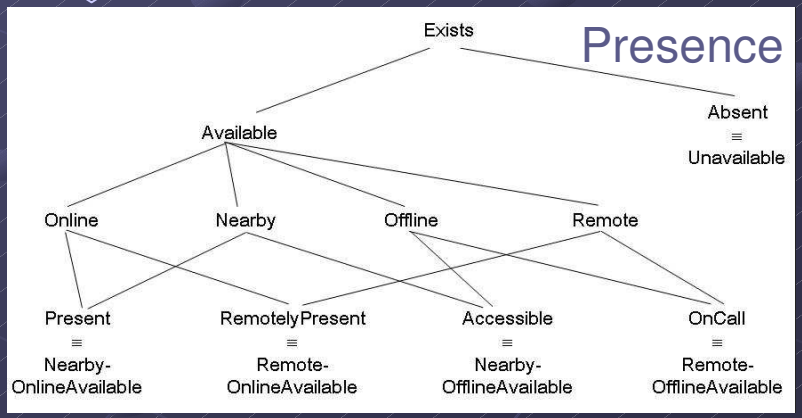
Login & logout

GPS readings

GPS Sensor

Location Service





What's Next for Location Tracking?

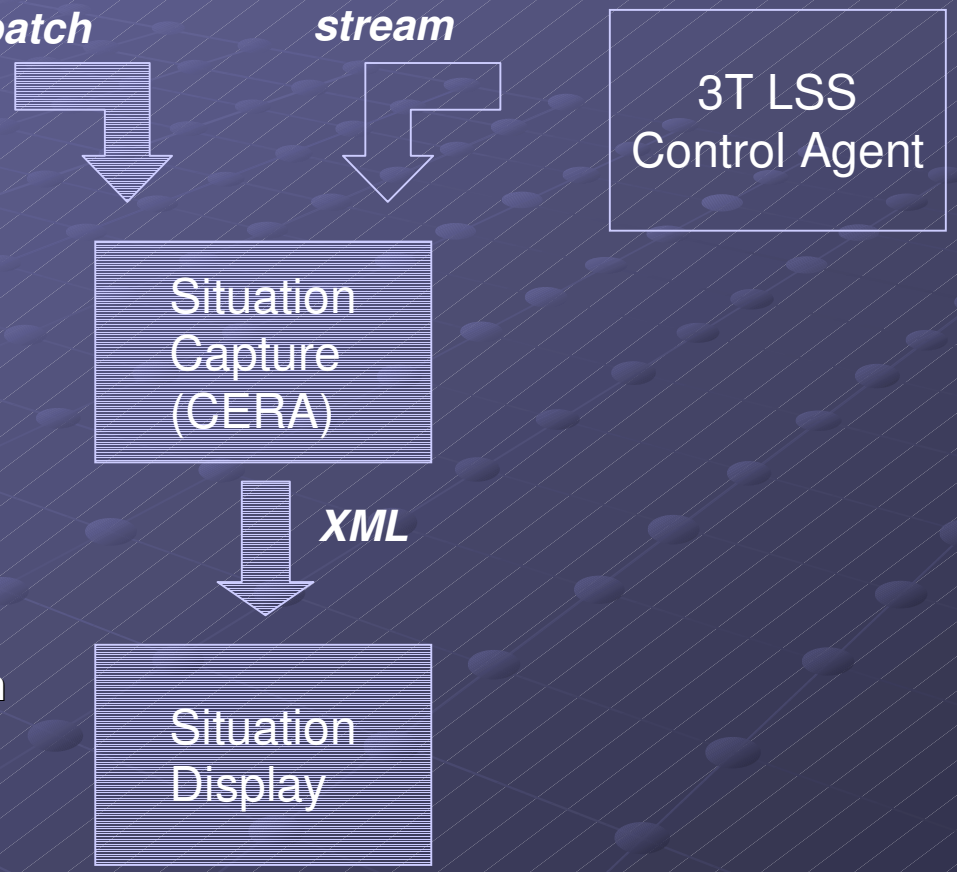
- FY03 Plans
  - Use GPS sensor for tracking outside buildings
  - Add GPS sensor and CORBA comunications to hand-held
  - Add user interface for monitoring locations of group members

Summarizing Complex Situations

- Proxy as gateway to domain situation summaries
  - Situation Capture
    - Uses NASA Phase II SBIR software for Complex Event Recognition (Firby/Inet)
    - Specifies how to capture events in the domain (complex event specification language)
    - Matches incoming data to event specifications to detect and capture event instances
  - Situation View
    - Displays situation objects from Situation Capture software
    - Computes expected values for contents of object
    - Provides capability for users to annotate situation view

Summarizing Complex Situations

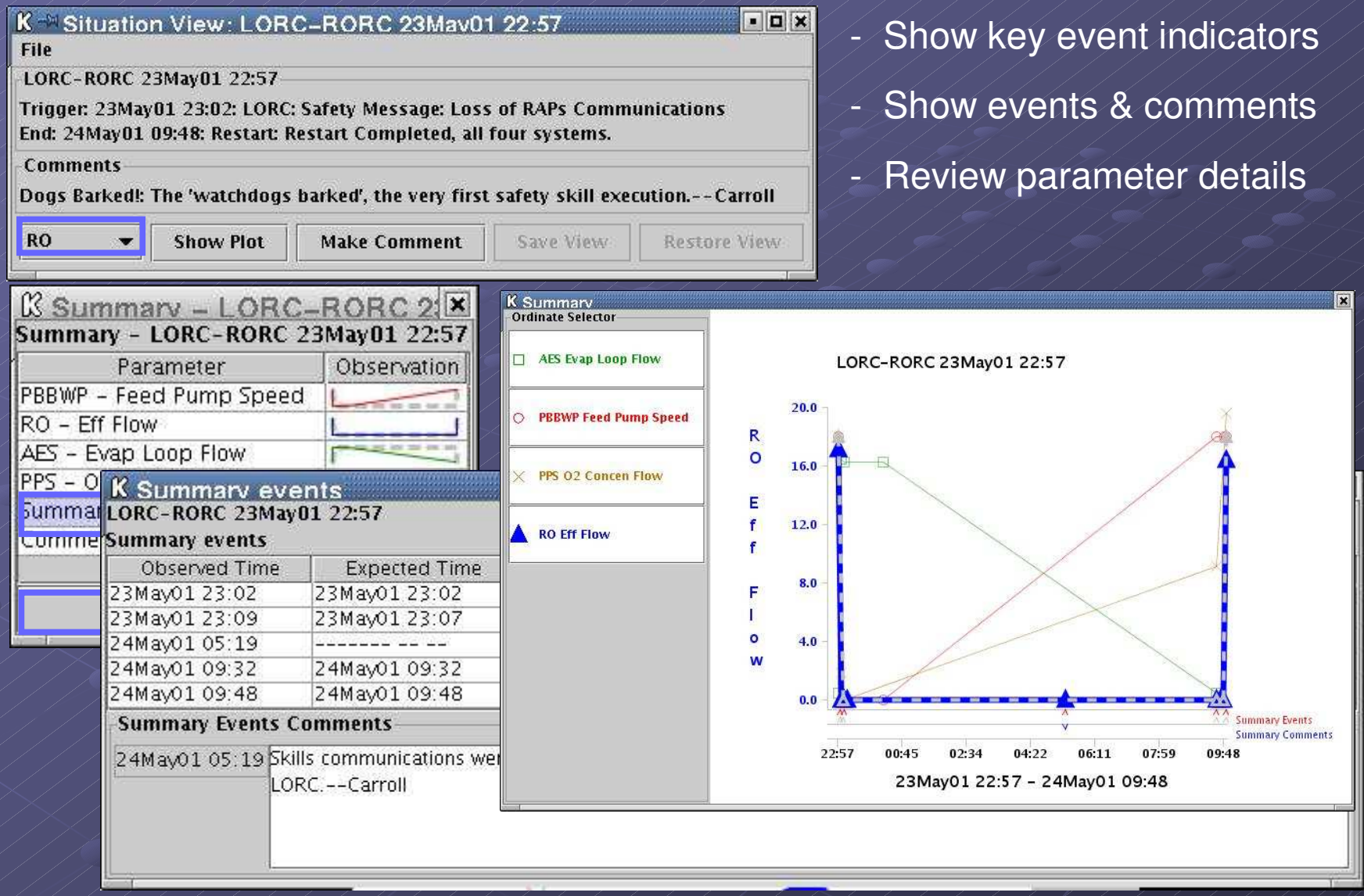
Data recorded in Advanced Water Lab



Model of situation

- **Triggering event**
- **Terminating event**
- **Interim event sequences**
- **Relevant data values with time and expected value**
- **User annotations**

Summarizing Complex Situations



- Show key event indicators
- Show events & comments
- Review parameter details

What's Next for Summarizing Situations?

- FY03 Plans
  - Situation Capture
    - Add CORBA communication for in-line detection and capture of situations
    - Encode additional life support events
  - Situation Display
    - Save display configurations that illustrate a point
    - Provide more flexible plotting capability
    - Begin developing language for describing situation views

Interfacing to the Proxy

- Proxy Agent interface as the public agent interface
  - Defines what is visible to other proxies or control agents
  - Provide public methods for agent communication
- Proxy Access Manager for logging into the Proxy
  - Authenticates user password
  - Tracks user login and logout events
- Proxy User Interface Manager that maintains user interface state separate from displays
  - Brings up multiple proxy guis in different locations that accurately reflect proxy state
  - Updates UI state even when no displays are activated
  - Supports user configuration of proxy displays for different tasks or locations

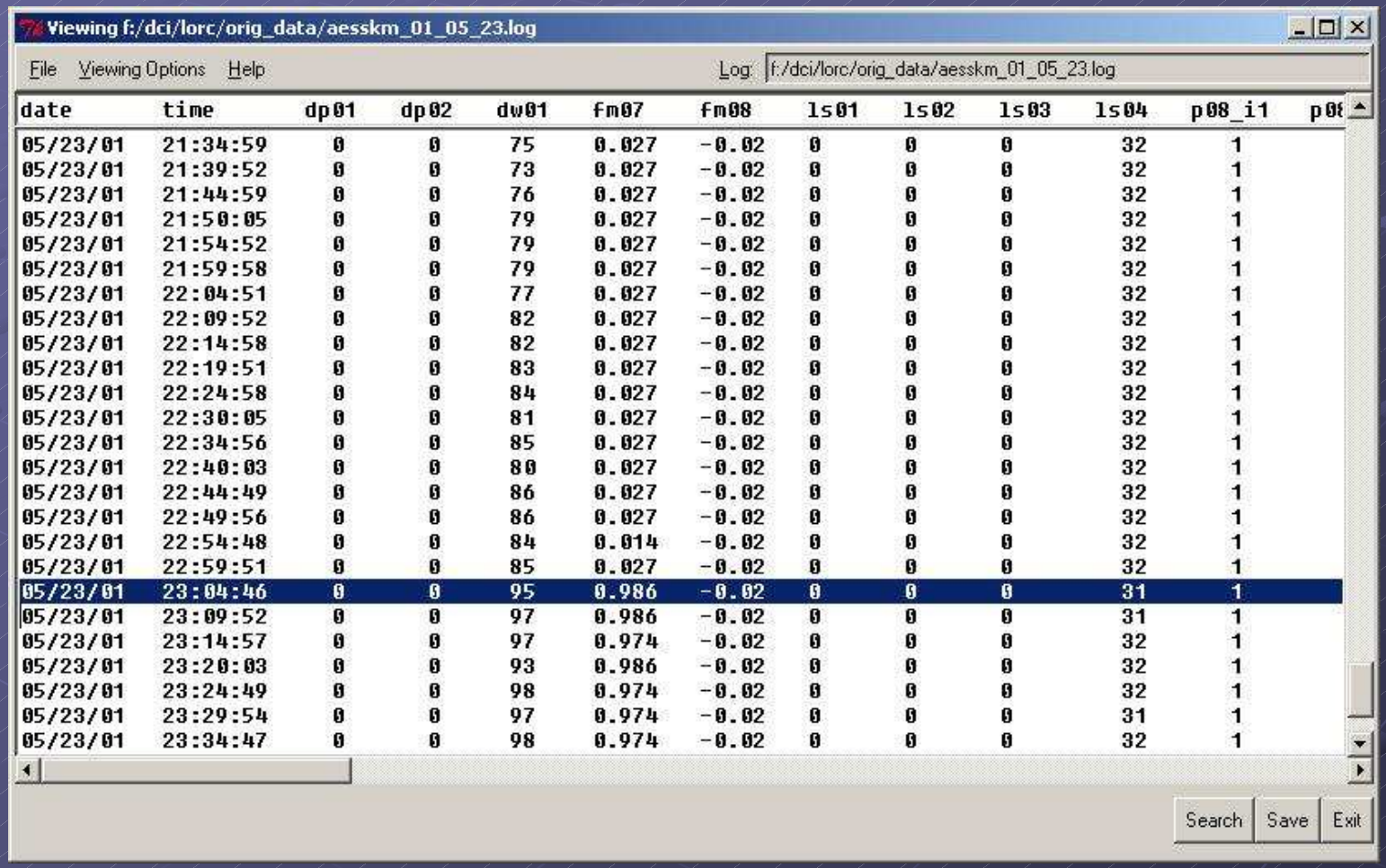
FY02 Evaluation of Notices

- Prototyped web-based interface to notices database
  - Events from the automated control agent
  - Notices from life support engineers
- Deployed notification capability near the end of the Advanced Water Lab test in Spring 2002
- Interviewed life support and control engineers to get feedback on notification capability
- Results
  - Remote access to centralized database of notices was very popular with engineers
  - Data structures for events and annotations used in current proxy
  - Data models in database were revised based on experience with large tables (5000 messages in 16 hours)
  - Requirements were added for searching notices database
  - User interface design changes were identified based on use

FY02 Evaluation of Situation Summaries

- Defined use case from WRS control
  - Loss of Raps Communication (LORC)
  - Recovery of Raps Communication (RORC)
- Captured situations using data recorded during Advanced Water Lab tests
- Viewed captured situations using old and new approach
- Next: Evaluation by control engineers for Advanced Water lab tests

Situation View from Water Test



date	time	dp01	dp02	dw01	fm07	fm08	ls01	ls02	ls03	ls04	p08_i1	p0
05/23/01	21:34:59	0	0	75	0.027	-0.02	0	0	0	32	1	
05/23/01	21:39:52	0	0	73	0.027	-0.02	0	0	0	32	1	
05/23/01	21:44:59	0	0	76	0.027	-0.02	0	0	0	32	1	
05/23/01	21:50:05	0	0	79	0.027	-0.02	0	0	0	32	1	
05/23/01	21:54:52	0	0	79	0.027	-0.02	0	0	0	32	1	
05/23/01	21:59:58	0	0	79	0.027	-0.02	0	0	0	32	1	
05/23/01	22:04:51	0	0	77	0.027	-0.02	0	0	0	32	1	
05/23/01	22:09:52	0	0	82	0.027	-0.02	0	0	0	32	1	
05/23/01	22:14:58	0	0	82	0.027	-0.02	0	0	0	32	1	
05/23/01	22:19:51	0	0	83	0.027	-0.02	0	0	0	32	1	
05/23/01	22:24:58	0	0	84	0.027	-0.02	0	0	0	32	1	
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05/23/01	22:34:56	0	0	85	0.027	-0.02	0	0	0	32	1	
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05/23/01	22:49:56	0	0	86	0.027	-0.02	0	0	0	32	1	
05/23/01	22:54:48	0	0	84	0.014	-0.02	0	0	0	32	1	
05/23/01	22:59:51	0	0	85	0.027	-0.02	0	0	0	32	1	
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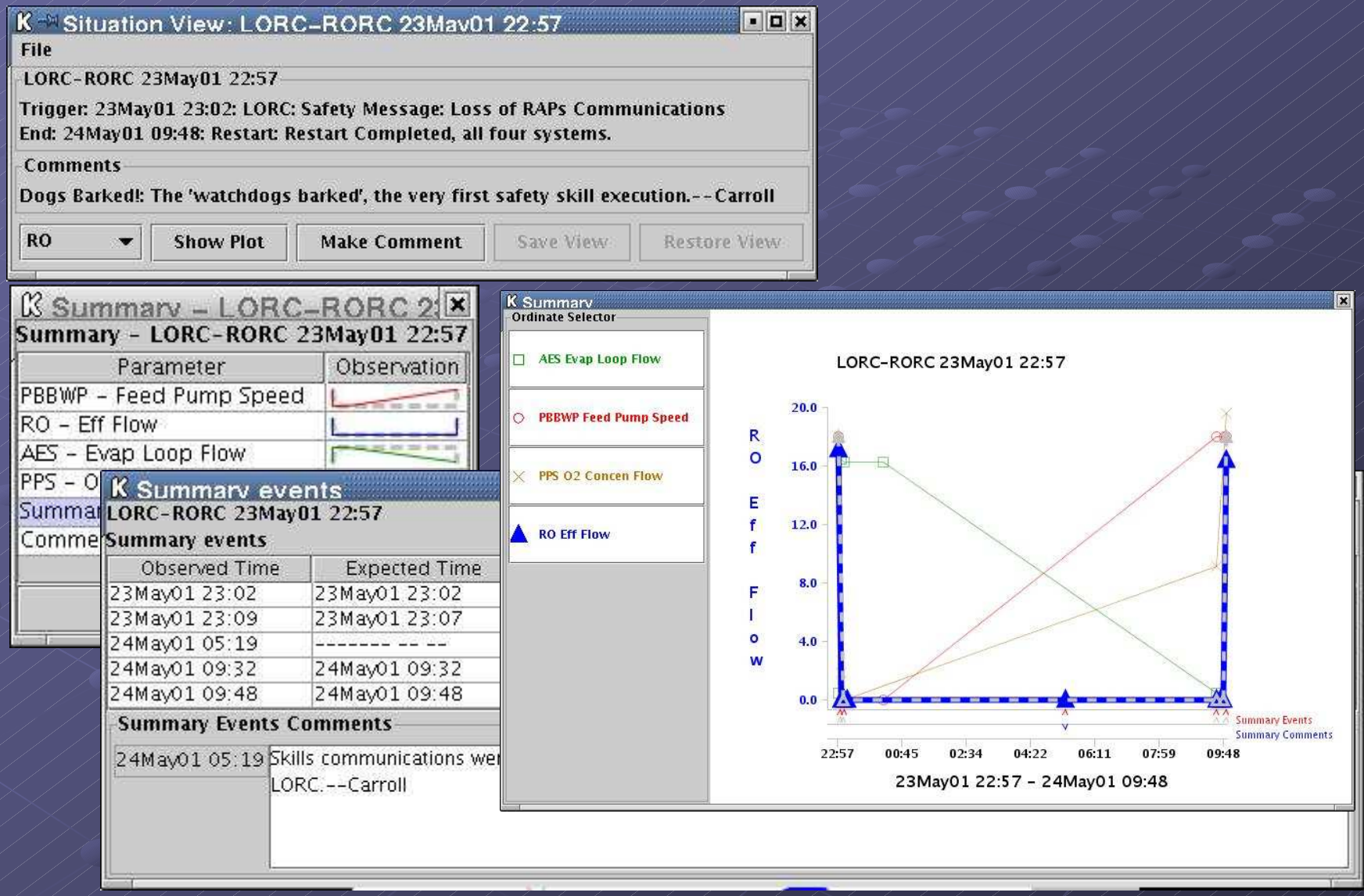
05/23/01	23:24:49	0	0	98	0.974	-0.02	0	0	0	32	1	
05/23/01	23:29:54	0	0	97	0.974	-0.02	0	0	0	31	1	
05/23/01	23:34:47	0	0	98	0.974	-0.02	0	0	0	32	1	

New Design for Situation View



Metrics: Situation Summaries

- Evaluate situation summary views
  - Define use cases
  - Compare the design used in the test to the new design using metrics like the following

Concept	Metrics
1. Ability to understand situation	a. Elapsed time to understand the situation b. Work required to understand the situation (number of information queries, display changes) c. Accuracy of situation understanding (how many erroneous conclusions, how many important events are missed) d. Subjective evaluation of ability to understand situation
2. Ability to determine a response	a. Elapsed time from understanding a situation to responding to it b. Amount of work required to determine a response (number of information queries, display changes) c. Accuracy of control response (how many erroneous or unnecessary actions, how many important actions are not taken) d. Subjective evaluation of ability to determine a response

FY03 Evaluation

- Candidates for evaluation
  - Life support engineers
  - Space Launch Initiative (SLI) subject matter experts
  - Shuttle and Space Station Crew
- Evaluation mechanisms
  - Animated mockups that provide broader context of operations
    - Human perspective
    - Agent perspective
  - Software demonstration or walk-through

Metrics: Remote Distributed Operations

Concept	Metrics
1. Effectiveness of notification strategies	a. How much longer does it take to perform a task interrupted by notification than to perform it without the interruption? b. What additional work is introduced by the notification (additional information queries, display changes)? c. Subjective response: Was intrusiveness of the interruption matched to task? Do the models of latency and focus of attention sufficiently distinguish levels of intrusiveness? To ensure information timeliness?
2. Ability to understand what happened while offline	a. How long does it take to understand and respond to a situation that arose while the user was offline? How does this compare to response times when continuously online? b. Compare error types and rates in these two situations. Errors of commission? Errors of omission? c. Subjective response: Was it clear what happened while you were out and what (if anything) you needed to do about it?
3. Effectiveness of group plan in coordinating group activities	a. Could user respond to important schedule changes in a timely manner? Could the user distinguish important changes from unimportant ones? b. Subjective response: Was the schedule view helpful or distracting? What worked? What didn't? What other capability would you like?

Summary of FY03 Plans

- Add service for remote crew commanding
  - Interaction with automated control agents
  - Execution of manual procedures
- Evaluate operational models of agent interaction
- Improve existing services
  - Notification: escalation of notification, interactive events
  - Task Status: human interaction in plan building, role management
  - Location: using GPS readings from hand-held
  - User Interface
    - Improved interfaces to notices and schedules
    - Support group interaction (status, queries, chat)
    - Proxy interface on handhelds with wireless communications
- Improve proxy assistants
  - Extend Activity Planner for human interaction in building plans
  - Add interactive events and situations to Event Detection

Lesson: Software for Human Perspective

Control Automation

Water Control

Air Control

Interaction Software Layer

- Encodes organizational policies & protocols arising from the operations concept
- Relates information as represented in automation to human mental models of operations
  - Understanding of control situations
  - Coordination of activities in group
- Generates new information solely to support human roles and tasks in the organization
- Models and reasons over indirect evidence to track manual actions
- Aids coordination of human actions with actions of automated agents
- Assists balancing group workload; includes task & role re-assignment

Humans

Carroll

Dave

Pete

Publications

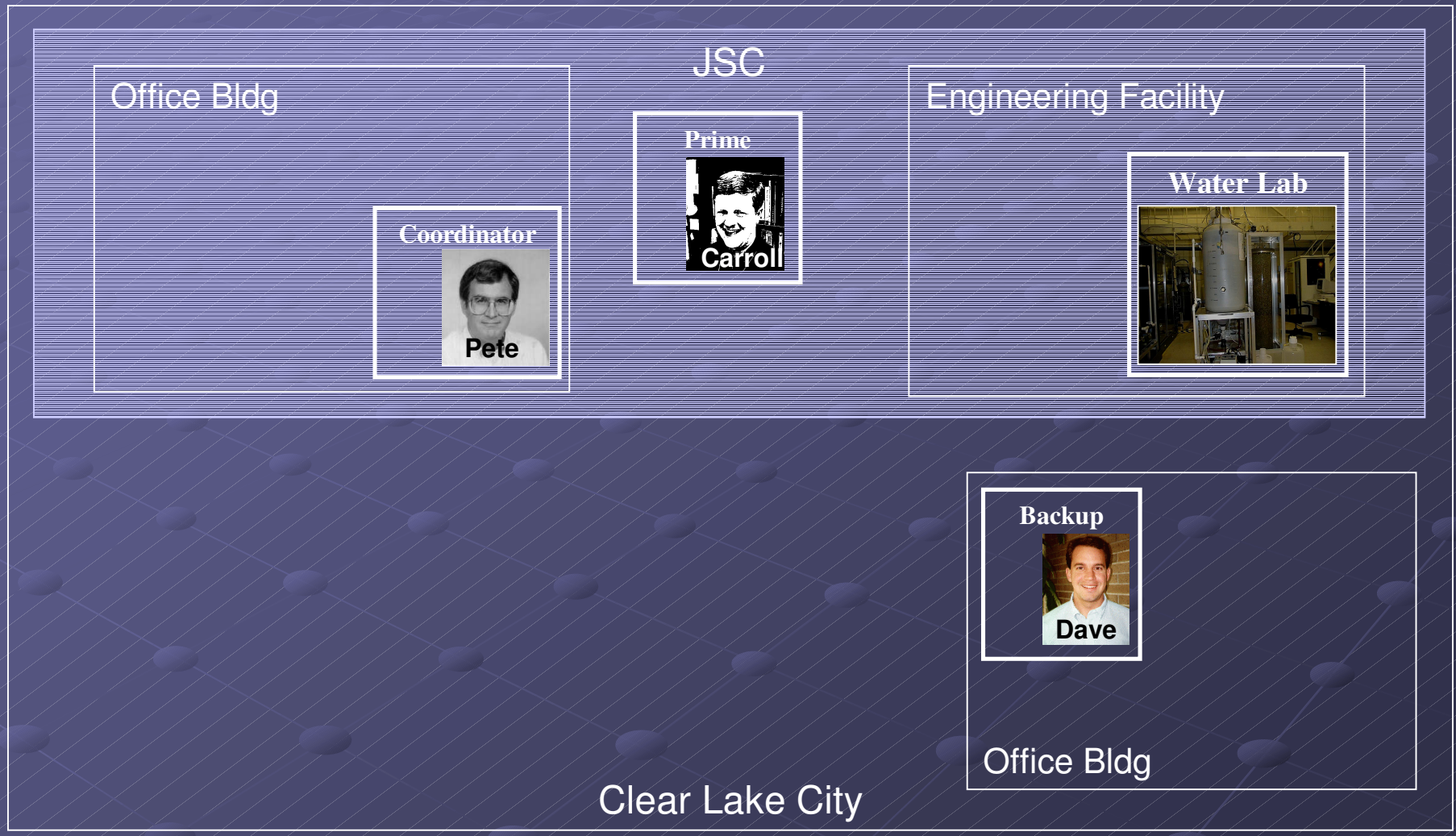
http://postdoc.arc.nasa.gov/postdoc/t/folder/main.ehtml?url_id=82878

- Notification
  - Schreckenghost, D., C. Martin, and C. Thronesbery. Specifying Organizational Policies and Individual Preferences for Human-Software Interaction. AAAI Fall Symposium. *Workshop on Etiquette for Human-Computer Work*. Nov 2002
- Lessons in human-centered computing
  - Schreckenghost, D., C. Thronesbery, P. Bonasso, D. Kortenkamp, and C. Martin. "Applying Human-Centered Computing to Intelligent Control of Life Support for Space Missions". *IEEE Intelligent Systems*, special issue on Human-Centered Computing at NASA. Sept/Oct 2002.
- Loosely coordinated groups
  - Schreckenghost, D., C. Martin, P. Bonasso, D. Kortenkamp, T. Milam, & C. Thronesbery. Supporting group interaction among humans and autonomous agents. *AAAI-02 Workshop on Autonomy, Delegation, and Control: From Inter-agent to Groups".* Jul 2002.
  - Schreckenghost, D., C. Martin, P. Bonasso, D. Kortenkamp, T. Milam, & C. Thronesbery. Supporting group interaction among humans and autonomous agents. *Connection Science.* Publication pending.
- Application to robotics domain
  - Kortenkamp, D., D. Schreckenghost, and C. Martin. User interaction with multi-robot systems. In Multi-robot Systems: From Swarms to Intelligent Automata. A.C. Schultz and L.E. Parker (editors). Kluwer Academic Publishers. 2002 p 213-220.

Demonstration

- Scenario is a ground-based analog that illustrates remote control operations
  - Based on experience in Advanced Water Lab
  - Similarities to crew circumstances
    - Users have direct responsibility to fix problems not handled by automation
    - Most users are not experts in domain
    - User can hold multiple roles and roles change over time
  - Human roles in Water Lab; prime and backup rotate weekly
    - Prime: handle problems in Water Lab
    - Backup: handle problems when Prime does not
    - Coordinator: coordinate group and update control code if needed
- Situation: Loss of Raps Communication (LORC) indicating the control agent comms has failed

Demonstration



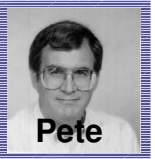
Demonstration

JSC

Office Bldg

Notices

Coordinator



Pete

Situation

Prime

Carroll

Schedule

Engineering Facility

Water Lab

Loss of Communication (LORC) problem in the Water Lab

Backup

Dave

Office Bldg

Clear Lake City

Demonstration

JSC

Office Bldg

Notices

Track group

Coordinator

Pete

Prime

Carroll

Schedule

Engineering Facility

Water Lab

Prime fails to respond to EORC

Backup

Dave

Office Bldg

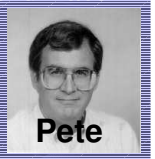
Clear Lake City

Demonstration

JSC

Office Bldg

Coordinator



Pete

Prime

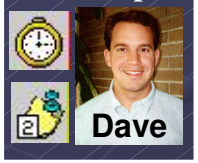
Carroll

Engineering Facility

Water Lab

Handling the LORC is re-assigned to Backup

Backup



Dave

Schedule

Notices

Office Bldg

Clear Lake City

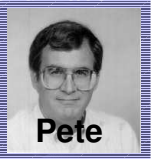
Demonstration

JSC

Office Bldg

Track group

Coordinator



Prime

Situation

Engineering Facility

Water Lab

Backup travels to Water Lab

Backup

Office Bldg

Clear Lake City

Demonstration

JSC

Office Bldg

While you were out ...

Coordinator

Pete

Prime

Carroll

Notices

Situation

Engineering Facility

Backup

Dave

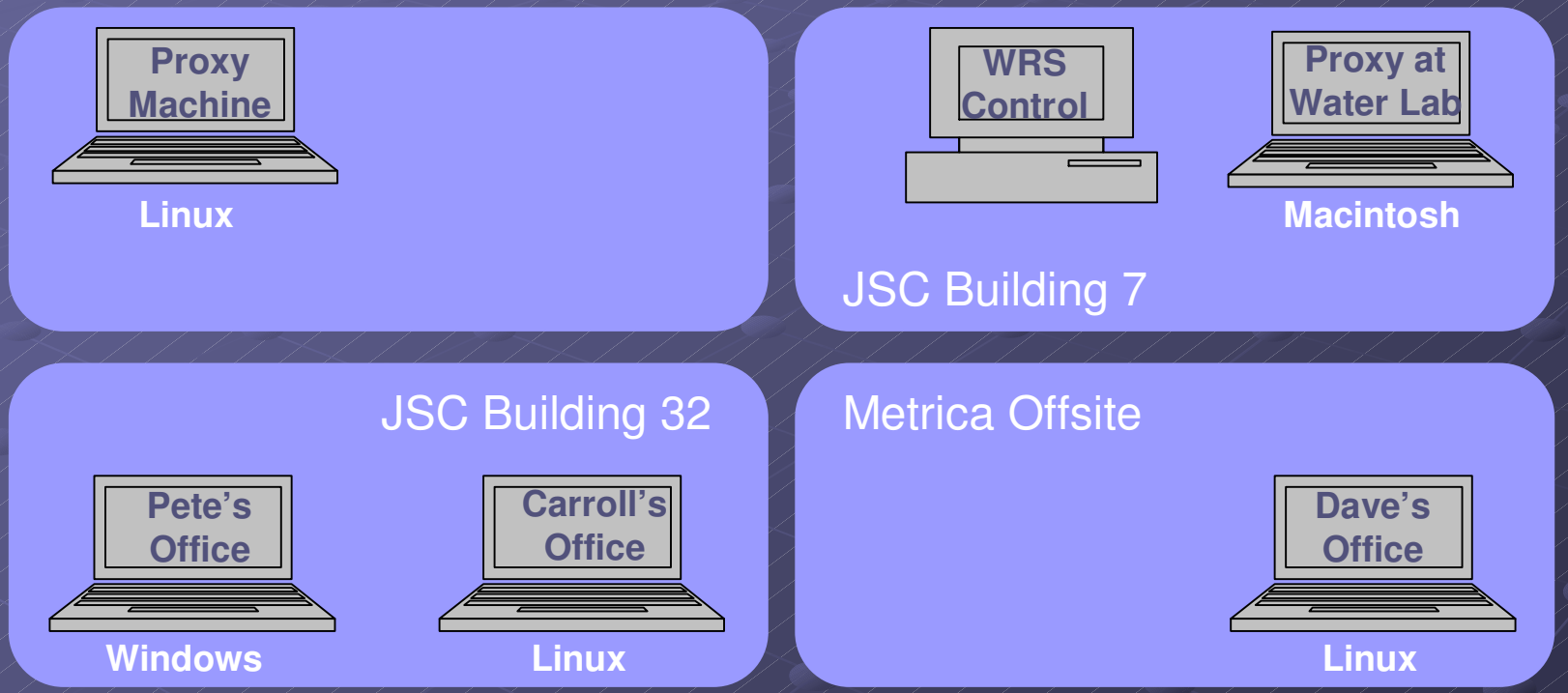
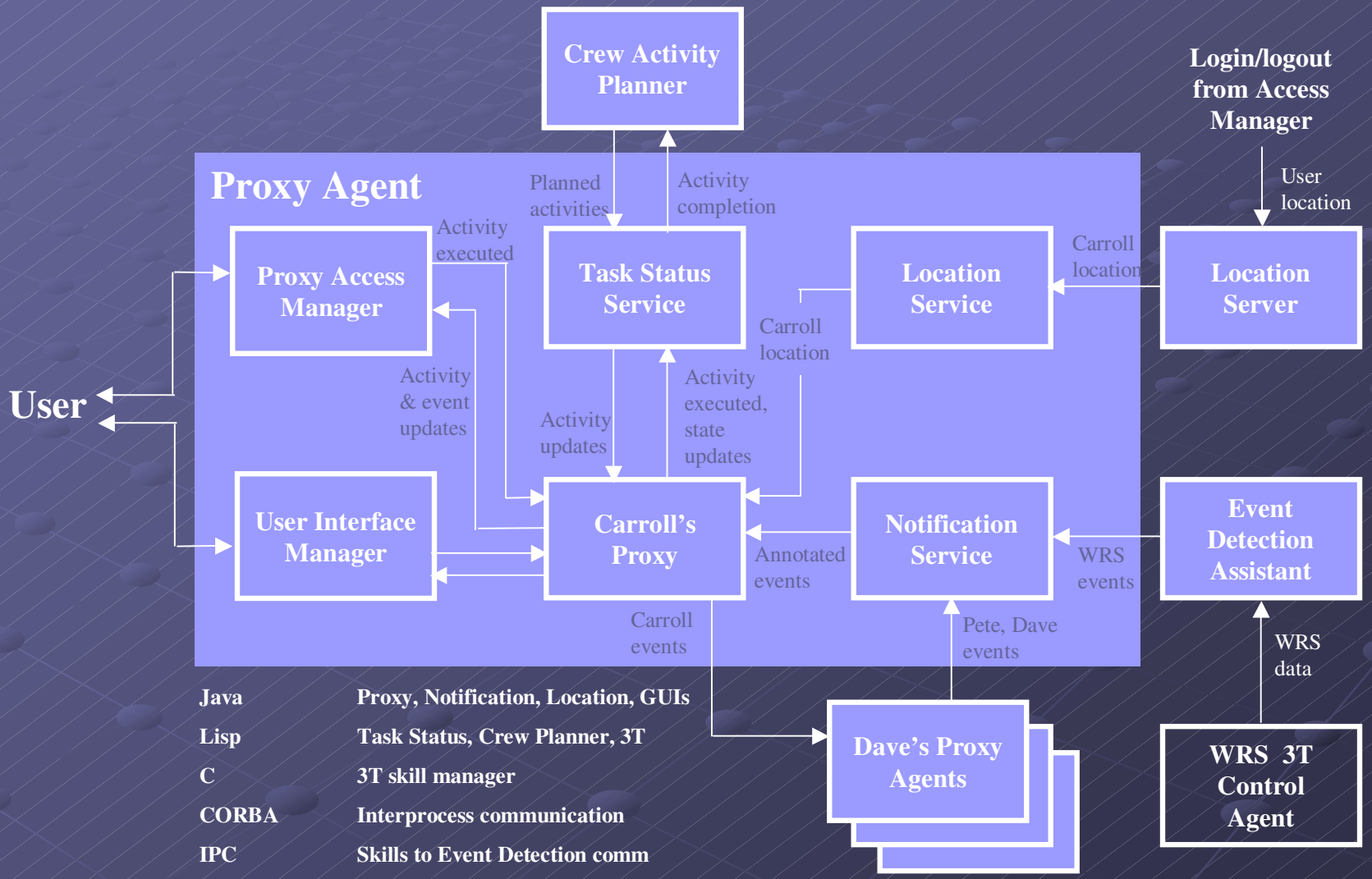
Water Lab

Problem fixed, restoration of communication (ROBC)

Office Bldg

Clear Lake City

Demonstration Layout



DCI Architecture for Demonstration