A Novel Information Management Architecture for Maintaining Long-Duration Space Crews

Principal Investigator:
George Cybenko, Dartmouth College, gvc@dartmouth.edu

Co-Investigators:
Jay Buckey, Jr., Dartmouth Medical School, jay.buckey.jr@dartmouth.edu
Susan McGrath, Dartmouth College, susan.p.mcgrath@dartmouth.edu

Challenges of Long-Duration Space Flight

Physiological

- Bone loss
- Radiation exposure
- Psychosocial adaptation
- Medical care

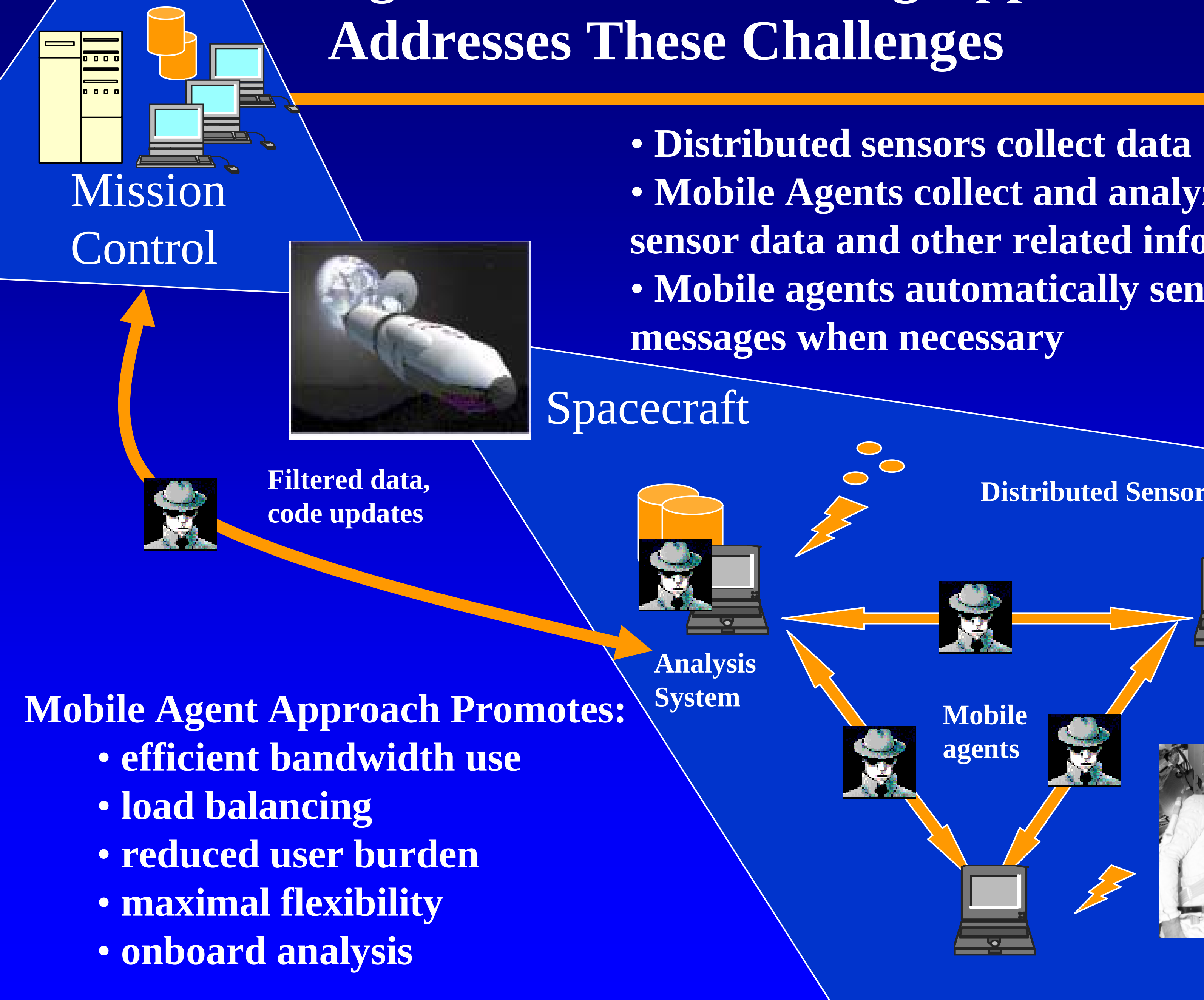
Technical

- Adaptability
- Limits on crew time
- Onboard analysis and feedback
- Autonomy

Physical replenishment is difficult, but software replenishment is easy– and should be exploited

Agent Based Monitoring Approach Addresses These Challenges

- Distributed sensors collect data
- Mobile Agents collect and analyze distributed sensor data and other related information
- Mobile agents automatically send alerts and messages when necessary



Mobile Agent Approach Promotes:

- efficient bandwidth use
- load balancing
- reduced user burden
- maximal flexibility
- onboard analysis

Air Force Office of Scientific Research Multi-University Research Initiative Project: Transportable Agents for Wireless Networks

The ActComm Project

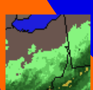
Dartmouth (Prime), ALPHATECH, Harvard, Lockheed Martin, RPI, University of Illinois

http://actcomm.dartmouth.edu

Volatile Network and Information Resources

Maps

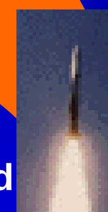
Commands



Weather

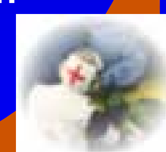
AGENTS

Active Information: standing queries, data fusion, automatic organization



Field Reports

Information Requests



AGENTS

Mobile Users

Active Planning: Network routing and agent itineraries must be planned dynamically using stochastic control.

Active Hybrid Networks: Wireless and volatile networks must reconfigure and relocate servers/proxies for robustness and efficiency

Active Software: Tcl, Java, Python and Scheme mobile agents deliver data and monitor databases

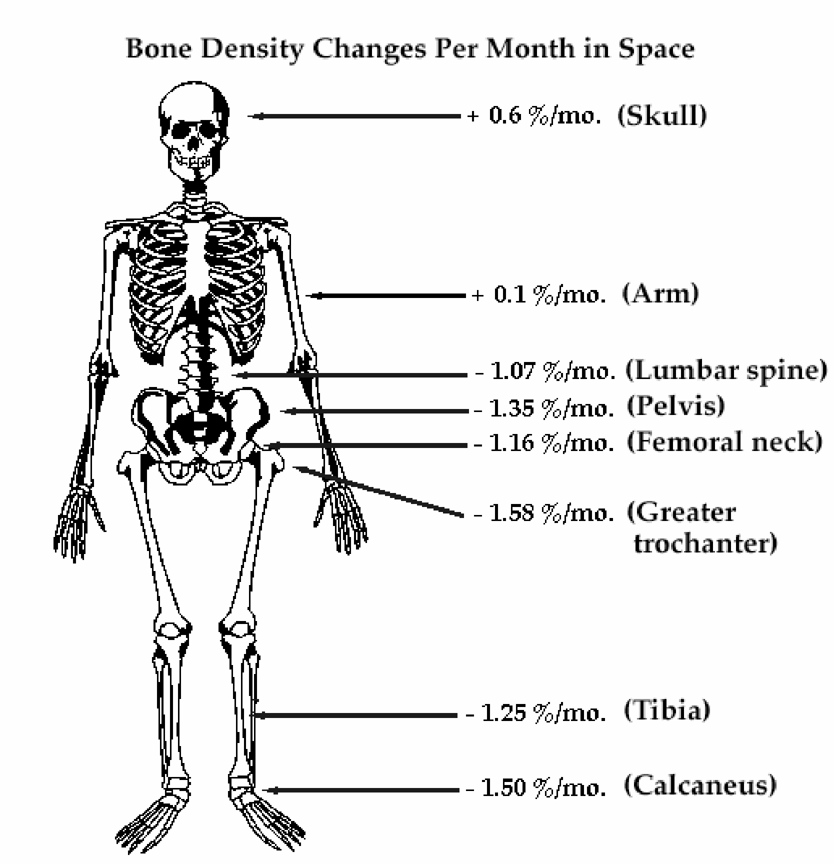
AgentTCL Dartmouth College

CMC The Center for Mobile Computing Dartmouth

Phase I Research Goals

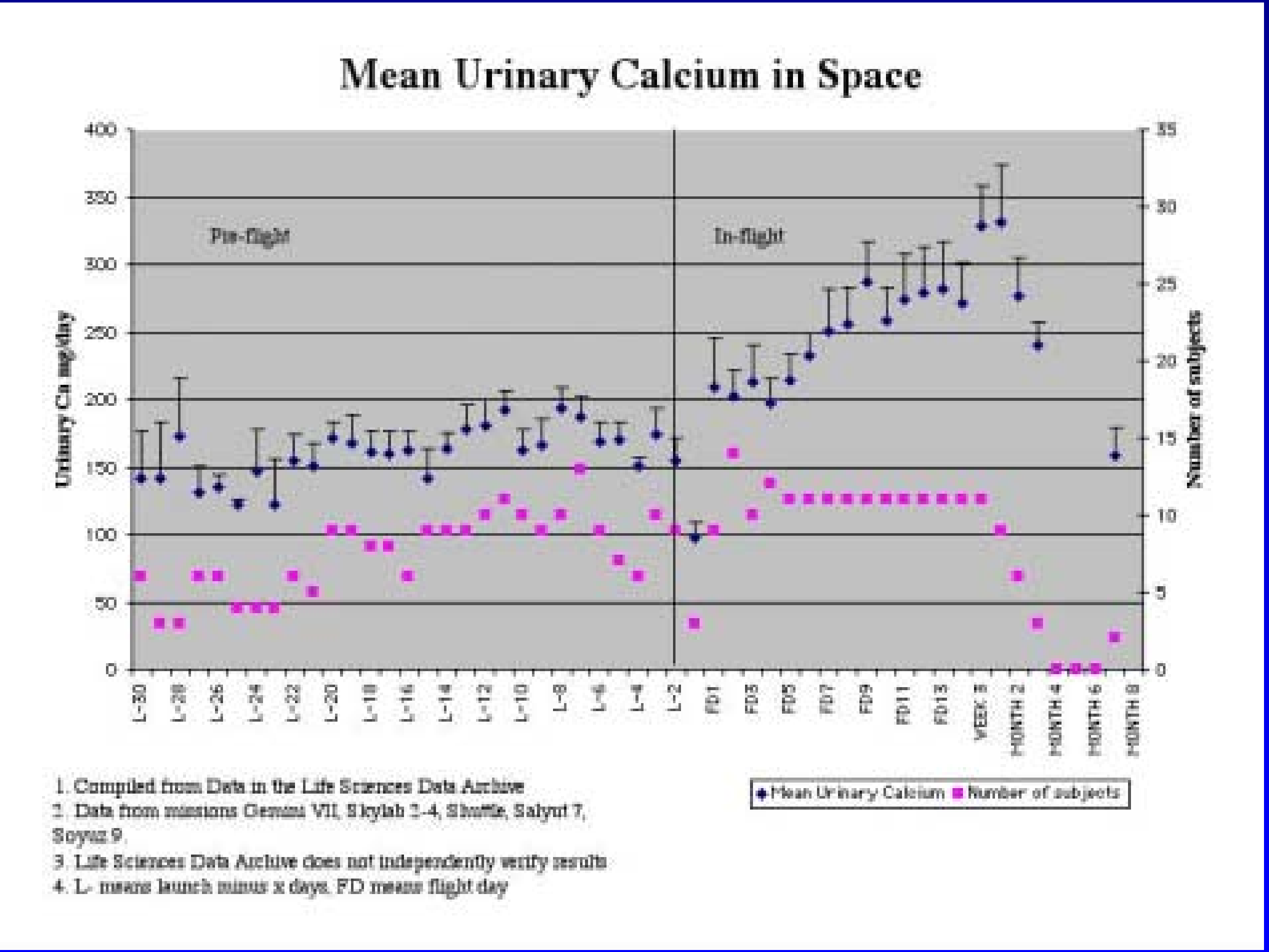
- Develop distributed information retrieval and analysis architecture based on mobile agents
- Apply the architecture to the bone loss monitoring application
  - Analysis model – parameters and their relationships to bone loss
  - Parameter data collection- sensors
  - Identify tradeoffs
- Make recommendations for future work

Test Case: Bone loss



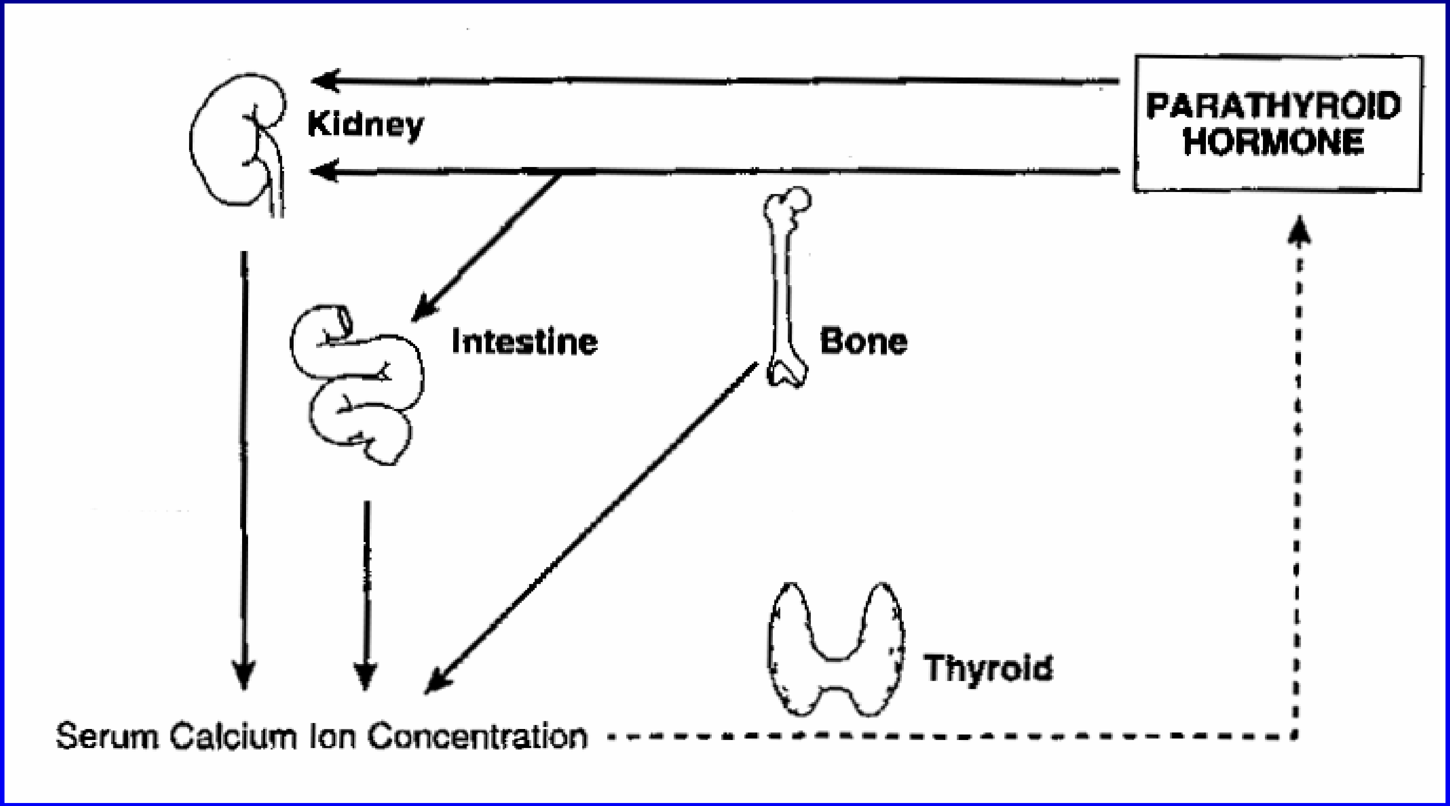
Load bearing areas lose significant amounts of bone

Test Case: Bone loss



Calcium in the urine is comes from load-bearing bone

Test Case: Bone loss



The Calcium regulation system determines urinary Calcium levels

Urinary Calcium Loss Function

$$U_{Ca} = f(X_{static}, X_{impulse}, X_{overall}, X_{Ca}, X_{Na}, X_{protein}, X_{D}, X_{acid\text{-}base}, X_{drug}, X_{noise})$$

where

X_{static} = static loading
$X_{impulse}$ = impulse activity
$X_{overall}$ = overall activity
X_{Ca} = dietary calcium
X_{Na} = dietary sodium
$X_{protein}$ = dietary protein
X_{D} = dietary vitamin D
$X_{acid\text{-}base}$ = acid-base balance
X_{drug} = drug effect
X_{noise} = noise

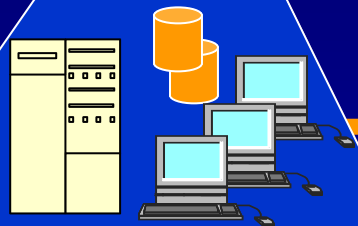
Challenges: How best to quantify the parameters?
How can they be measured?
What are the relationships?

Activity: Impulse

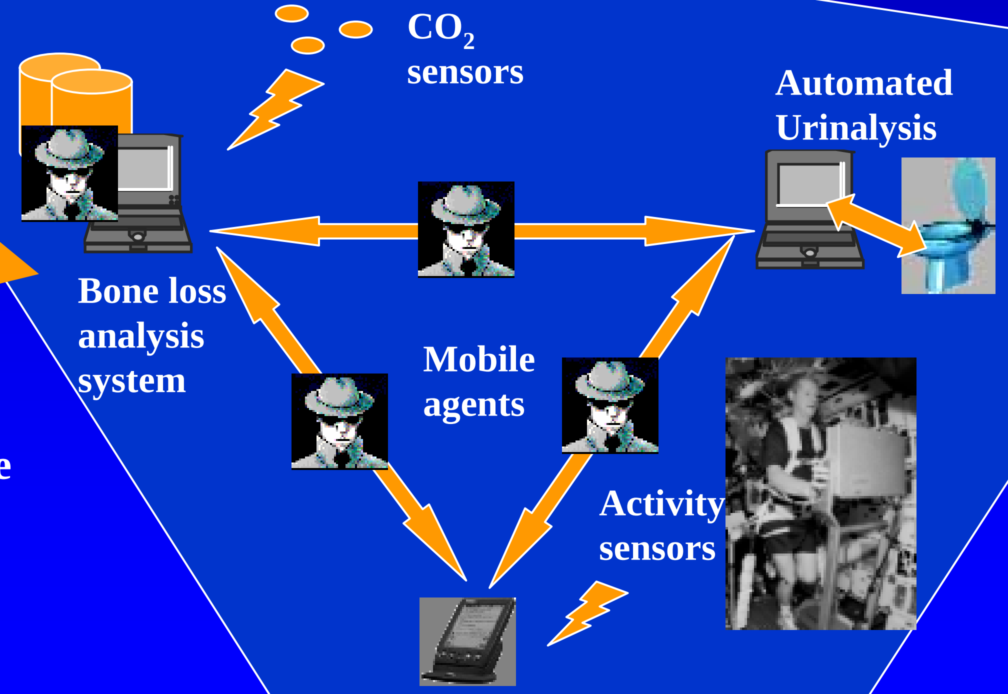
Activity	Parameters	Technology	Specific Device	UCa Rel.	Ref.
Static / Other	1. Acceleration	Accelerometers	G meter	INVERSE	(Rref:36-40)
			Micromachined Thermal Accelerometer		
			Actigraphs		(REF 37)
	2. Hydrostatic pressure	Pressure sensor	Various pressure sensors	INVERSE	
Dynamic	1.Muscular Contraction	Soundmyogram	Acoustic myograph	INVERSE	(Ref 48-49)
		(SMG)	Phonomyograh	INVERSE	(Ref 50-51)
		Electromyography	Surface EMG	INVERSE	(REF 52-53)
		(EMG)	Myotrac Surface EMG		
				INVERSE	(REF 41-43)
	2. Motion			INVERSE	(REF 36)
					(REF 54)
			Wearable sensor jacket		(REF 37)
			Smart Fabric/Washable computing		(REF 38)
Impulse	1.Reaction Forces	Pressure Sensors	LEMS Suit	INVERSE	(REF 54)
			Dynamic load sensors system		(REF 55)
			Instrumented insole		(Ref:57-58)
			Various pH meters		
			BECKMAN PSI 21 PH METER		
Urinary Citrate	2.Urinary Citrate				
Environment					
CO2 levels	1.CO2 Levels	Spectroscopy	Tunable Diode Laser Absorption Spectroscopy		
			Infrared Detector		
			Mass spectrometer		
UV ligtht levels	2.UVLight Levels	Photometer			
Drugs					
	1. Bisphosphonate levels				

Parameters	Technology	Specific Device	UCa Re
1.Reaction Forces	Pressure Sensors	LEMS Suit	INVER
		Dynamic load sensors system	
		Instrumented insole	
		Pedar system	
		F-scan system	
		Partotec-systems device	
		Ground reaction force monitor	
		Smart treadmill	

Bone Loss Monitoring Application



- Autonomous mobile agents collect data related to bone loss, e.g. Urinary Ca, activity, and CO_2 levels.
- Analysis and learning agent integrate, analyzes data & alerts crewmembers when a problem exists
- System can adapt to variability in human response



- Agents transmit bone loss estimates to Mission Control
- In response, algorithms and code can be updated throughout the mission
- Continuous monitoring emphasizes prevention and autonomy

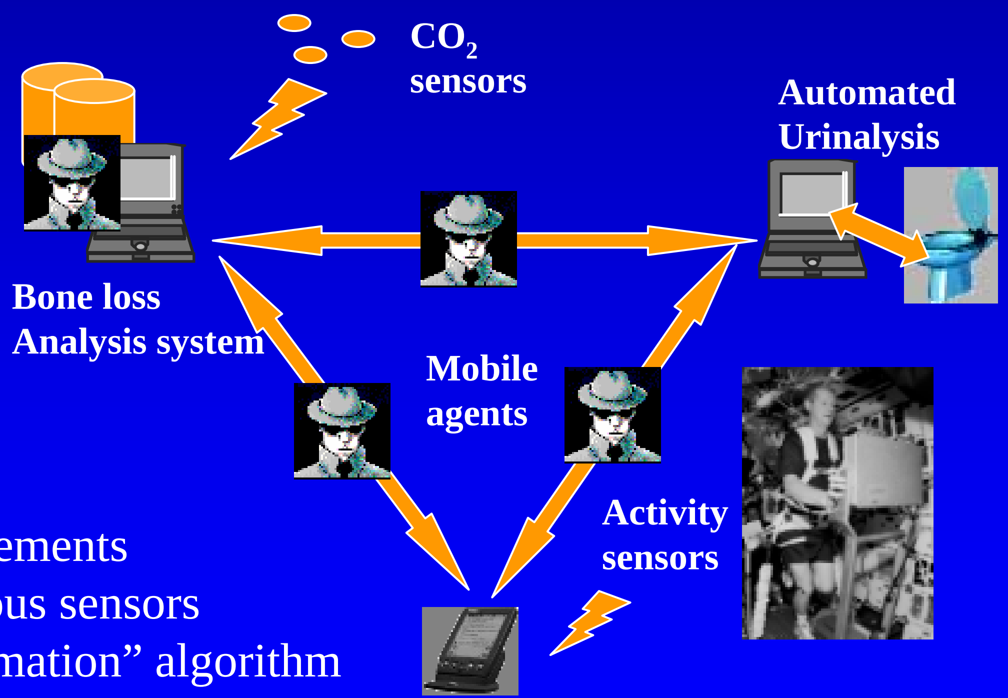
Bone Loss Monitoring Agents

<u>CO_2, Activity,Urinalysis Sensor Systems Agents</u>

- •Collects data at predetermined or event initiated intervals
- •Performs raw data data analysis
- •Moves data to storage and analysis hosts
- •Performs occasional self test, reports to Coordinator

<u>Coordinator Agent</u>

- •Receives input from Mission Control
- •Controls installation of updates/changes on distributed hosts
- •Sends data to Mission Control
- •Analyzes sensor and data performance
- •Acts to remedy problems with subsystems

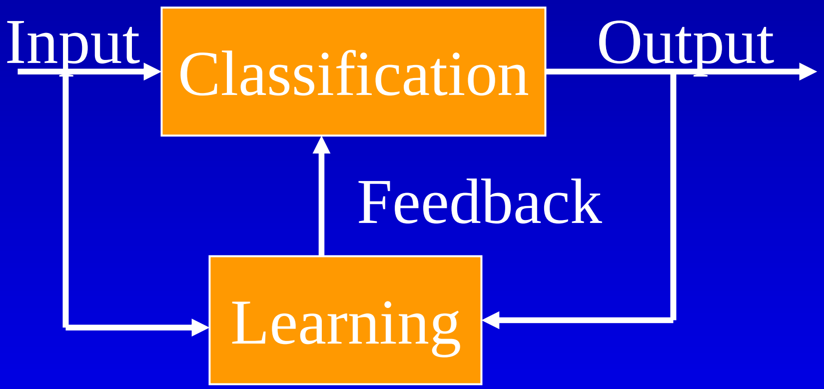


<u>Analysis Agent</u>

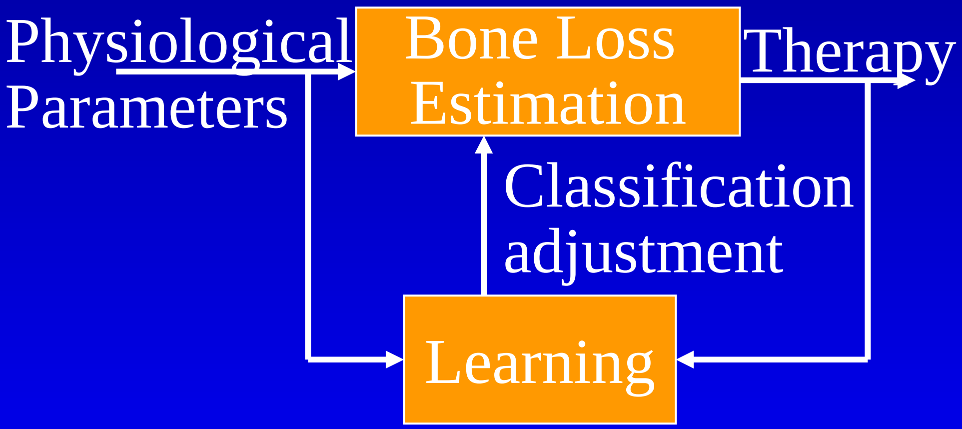
- •Utilizes baseline measurements
- •Receives data from various sensors
- •Executes “bone loss estimation” algorithm
- •Determines appropriate therapy
- •Notifies users of action required (if any)
- •Sends historic and performance data to Coordinator

Mobile Agent System Requirements

Control System Model



Bone Loss Therapy Model



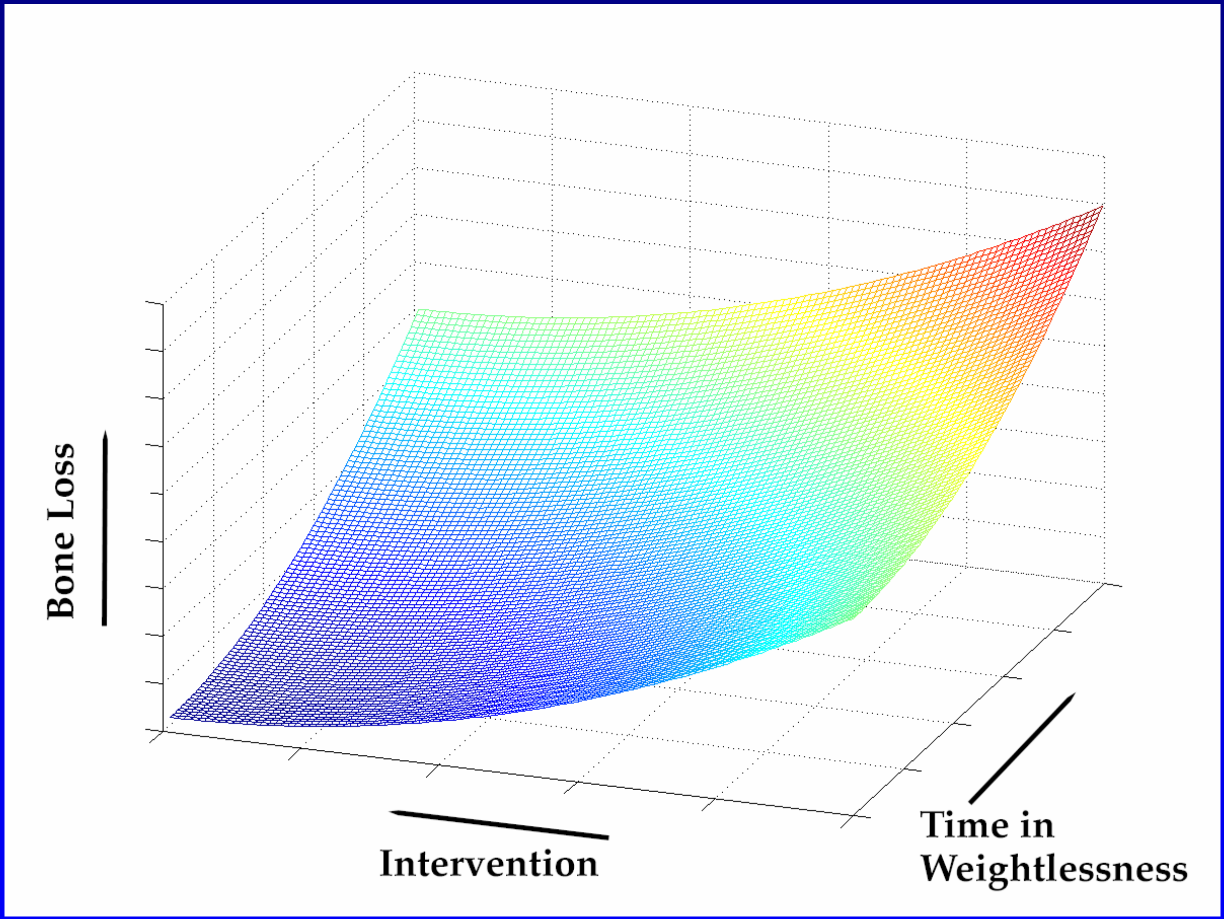
<u>System Functionality</u>

- Baseline information processing
- Sensor data processing
- Individual assessment, recommended therapy
- Alerts, messages
- Learning, adapting

<u>Design Considerations</u>

- Knowledge representation
- Classification
- Learning

Bone Loss Control Surface



The relationship between duration of space flight, bone loss intervention and bone loss must be learned

Conclusions

- Initial assessments are that drug effect, impulse loading and acid-base balance may be the most important factors to follow
- Need to define fully urinary calcium relationships for key variables in order to program agents.
- Need to apply agents in simulated scenarios to test approach– focus on learning the control surface

Summary and Next Steps

Technology	Accomplishments	Next Steps	Long term
Bone loss model	•Defined key parameters and general relationships to bone loss	• Perform experiments & analysis to define specific relationships of parameters to bone loss	Extend to other challenge areas
Sensors and Networking	• Surveyed existing sensors capable of providing needed parameter data • Identified wireless approach to integrate sensor data & agents	• Select sensors for simulation of architecture • Define bandwidth and data processing and storage requirements	Evaluate miniaturization (MEMS) and ubiquitous wireless integration
Agent Architecture	•Identified functionality required for various agents • Defined specific approach for analysis agents	•Implement simulation of agent architecture including analysis and sensors • Consider future software implementations of agent based systems (e.g., XML)	Leverage new standards, COTS