Platform-Based Design of Augmented Cognition Systems

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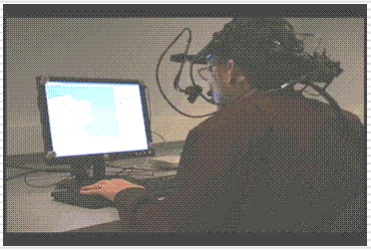
Design & implementation of Augmented Cognition systems:
Modular design can make it possible ◇ Platform-based design makes it feasible

Augmented Cognition

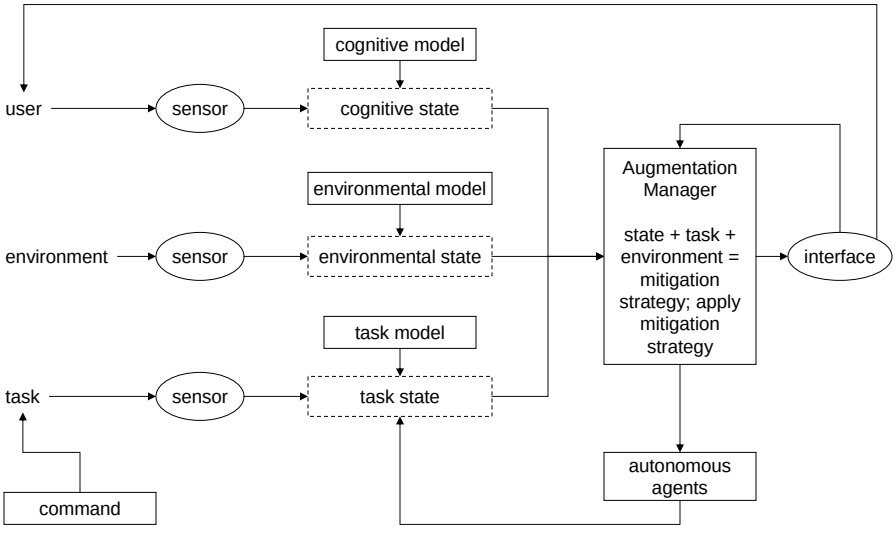
- Augmented Cognition systems use real-time cognitive state data to adapt systems to a user rather than forcing the user to adapt to a system
- Exploit recent technological advancements
  - Neuroscience: sensor design, signal interpretation
  - Signal processing: speed and accuracy
- "21st Century Human Computer Interaction"



Augmented Cognition Enablers

Discipline	System Aspect
Neuroscience	Sensors: development & placement
Math: Signal Processing Artifact Detection	Gauges: Development Ensuring meaningful information
Psychology: Human Factors Neuroergonomics	Operator Environment: Interface design Interface design
Engineering: Mechanical Electrical Systems Cognitive Systems	System Design: Physical Components Component Communication Information Flow "Bringing the Human in the Loop"

System Architecture

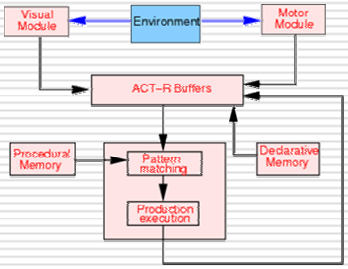


System Architecture - Inputs

- User
  - Any person interacting with an augmented cognition system
  - In a driving environment: the driver
  - In a learning environment: the student
- Environment
  - The environment in which the system is being implemented
  - In a driving environment: the car and its current surroundings
  - In a learning environment: the classroom and any equipment being used
- Task
  - The task that the user is completing; using the augmented cognition system to improve performance
  - In a driving environment: driving (or navigating to an objective)
  - In a learning environment: concept mastery

System Architecture - Models

- Cognitive Model
  - User Model
    - Computational model for how people perform tasks and solve problems, based on psychological principles
    - Enable the prediction of the time it takes for people to perform tasks, the kinds of errors they make, the decisions they make, etc…
- Context Models
  - Environmental Model
    - Incorporates known information about the task environment enable a context-aware environment
  - Task Model
    - Incorporates known information about the task/objective to understand and predict the task that a user is completing
    - Necessary for accurate timing of mitigation strategy execution

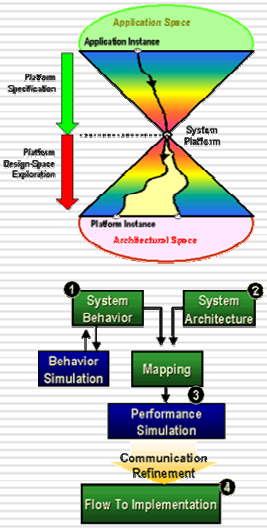


	Location	Conditions	Infrastructure (Computing Environment)	Information on User	Social	User Activity	Time	Device Characteristics
[Benaresti et al. '01]	Physical Environment			Cultural Context				
[Schmidt et al. '99]	Physical Environment			Human Factor			X	
[Lieberman and Selker'00]	User Environment	Physical Environment	X	User Environment			X	
[Hull et al. '97]		Physical Environment		X				X
[Chalmers and Sloman'99]	X		X		X	X		X
[Lucas'01]	Physical Environment			Information context				X
[Schilit et al'94]	Physical Environment		X	User environment				
[Dey and Abowd'99]	X			Identity		X	X	Identity
[Chen & Kotz'00]	Active/Passive							

Comparison of Context Classification Systems

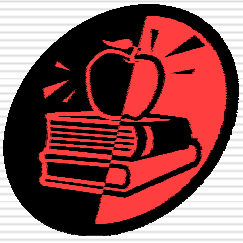
Platform-Based Design

- Platform-based design goes beyond modular design to incorporate information about the application environment into the design process.
- Platform-based design combines top-down and bottom-up design approaches
  - Top Down
    - Platform-mandated constraints
    - Connections and communications between components
    - Consideration of system-level goals
  - Bottom Up
    - Component-mandated constraints
- Benefits of platform-based design include
  - Reuse of designed components
  - Reduced design cycle time
  - Component "swapping" during design process



Platforms of Interest

- Cockpit
  - **Driving**
  - Airplane
- Control Station
  - Unmanned Vehicle Interface
  - Air Traffic Control
  - Command Post of the Future
- Learning Environment
  - Virtual Reality
  - **Classroom**



Component Catalog

- Sensors
  - Cognitive
    - Direct Brain Measures
      - EEG
      - fNIR
    - Psychophysiological Measures
      - HR, EKG
      - Pulse Ox
      - Posture
      - GSR
      - Temperature
      - EOG
      - Pupilometry
      - Gaze Tracking
  - Environmental
    - Platform Measures
      - Location
      - Internal Conditions
      - Fuel
      - *Weapons*
    - External Measures
      - Weather
      - *Presence of Chemical or Biological Agents*
    - Situational Awareness
      - *Hostility*
      - Obstacles
  - Task
    - Status
- Interfaces
  - Visual
    - Heads up display
    - Traditional display
    - Alert
    - Warning
    - Picture
    - Text
  - Auditory
    - Voice
    - Warning
    - Spatially locatable
  - Tactile
    - Warning
    - Directional cue

Component Catalog - Driving

- Sensors
  - Cognitive
    - Direct Brain Measures
      - EEG
      - fNIR
    - Psychophysiological Measures
      - HR, EKG
      - Pulse Ox
      - Posture
      - GSR
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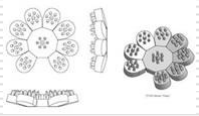
Driving

System Architecture – Driving Components

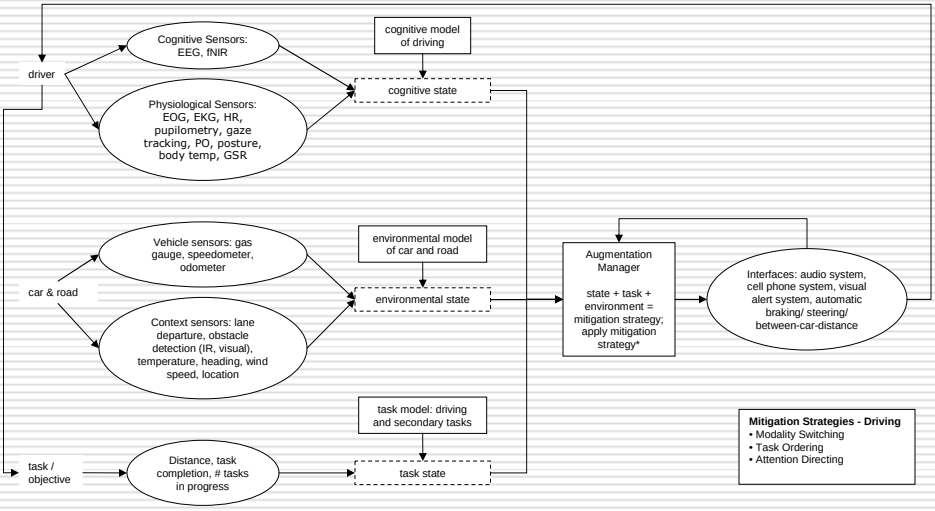










System Architecture - Driving



Driving: Constraint-Based Requirements

- System must be compatible with automobile standard functions
- System shall not inhibit driver's vision of the road and/or surroundings
- No system equipment/procedure shall require driver to migrate attention behind self
- No system equipment/procedure shall require the driver to move beyond driver's seat
- No system equipment/procedure will require the driver to have both hands off of the steering wheel

Driving: System Interfaces & Communications

Module	Platform instance	Input	Output
Level 1			
User	Driver	Interface	Physiological conditions: Pulse, temperature, gaze location, heart rate, moisture content, posture, pupil dilation, electrical activity, and blood oxygenation.
User Sensors	Cognitive & Physical Sensors	user	human mV value, % of oxygenated blood cells, bpm, torso and lower body pressure against seat, skin mV, size of pupil, and eye coordinate.
Cognitive Model		n/a	options of cognitive elements and significance
Cognitive State		user sensors & Cognitive model	Cognitive bottlenecks
Environment	Road conditions	n/a	Geographic & Geologic conditions: Vehicle position, perceiptation collected, depression in roadway, altitude, temperature, and obstacles on surface.
Environment Sensors	Environmental Sensors	environment	Wehicle location, thermal degrees,moisture content in air (%), luminence measurement, time of day, fuel level, road texture, amount of precipation, and obstacle present or not.
Environmental Model	Doppler	n/a	options of environmental elements and significance
Environmental State		environmental sensors & environmental model	Potential environmental hazards
Task	Driving Destination	n/a	Driving mission and objectives.
Task Sensors	Task Sensors	task	tasks completion level
Task Model		n/a	options of task elements and significance
Task State		task sensors & task model	% complete
Augmentation Manager		User state, environmental state, task state, and interfaces.	Mitigation Strategy
Autonomous Agents		Augmentation Manager	
Interfaces		Augmentation Manager	Light/LED, simulated voice command or statement, sound, and
Command		n/a	Feedback & Advise pertaining to mission
Level 2			
User Sensor 1	EEG Sensor	user's electrical activity	human mV
User Sensor 2	Fnir Sensor	user's blood oxygenation	% of oxygenated blood cells
User Sensor 3	THz		
User Sensor 4	Heart Rate Sensor	user's heart rate	bpm
User Sensor 5	Pulse Oximetry	user's pulse rate	
User Sensor 6	Posture Sensor	user's posture	torso and lower body pressure against seat
User Sensor 7	Galvanic Skin Response	user's moisture content	skin mV level
User Sensor 8	Thermometer	user's body temperature	thermal degrees
User Sensor 9	EOG	user's muscluar activity surrounding the eye	eye muscle mV measurement
User Sensor 10	Pulpimetry	user's pupil dilation	size of pupil
User Sensor 11	Gaze Tracking	location of pupil of eye	eye coordinate
Environment Sensor 1	Global Position System	vehicle position & altitude	Vehicle Location
Environment Sensor 2	Thermometer	vehicle temperature	thermal degrees
Environment Sensor 3	Humidity	vehicle moisture content	moisture content of air (%)
Environment Sensor 4	Lighting	vehicle lighting level	luminence measure measurement
Environment Sensor 5	Clock	time	Time of Day
Environment Sensor 6	Fuel gauge	amount of fuel	fuel level
Environment Sensor 7	Condition of Road	percipatation collected and depressions	Road texture
Environment Sensor 8	Weather- percipitation	percipitation	amount of percipitation
Environment Sensor 9	Obstacles	Obstruction in road	obstacle present or not
Task Sensor 1	Task completion	tasks performed	tasks completion level
Interface 1	Visual Alert		Light/ LED
Interface 2	Visual Warning		Light/ LED
Interface 3	Auditory Voice		simulated voice command or statement
Interface 4	Auditory Warning		Audio sound
Interface 5	Auditory Spatially locatable		

Component Catalog - Learning

- Sensors
  - Cognitive
    - Direct Brain Measures
      - EEG
      - fNIR
    - Psychophysiological Measures
      - HR, EKG
      - Pulse Ox
      - Posture
      - GSR
      - Temperature
      - EOG
      - Pupilometry
      - Gaze Tracking
  - Environmental
    - Platform Measures
      - Location
      - Internal Conditions
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  - Auditory
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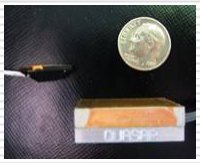
    - Warning
    - Spatially locatable
  - Tactile
    - Warning
    - Directional cue

Classroom Learning

System Architecture – Learning Components

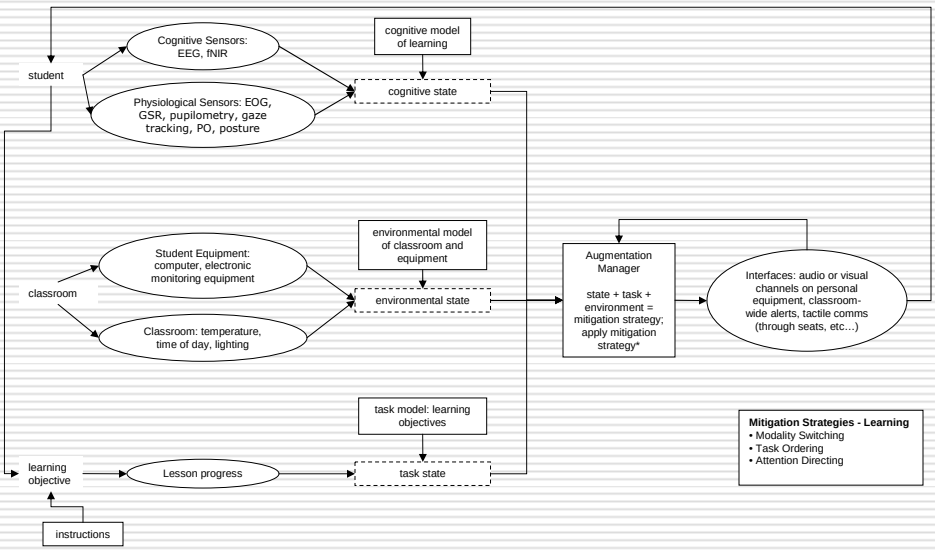






- Future Learning Application Environments
  - Team Training
  - Virtual Reality Training

System Architecture - Learning



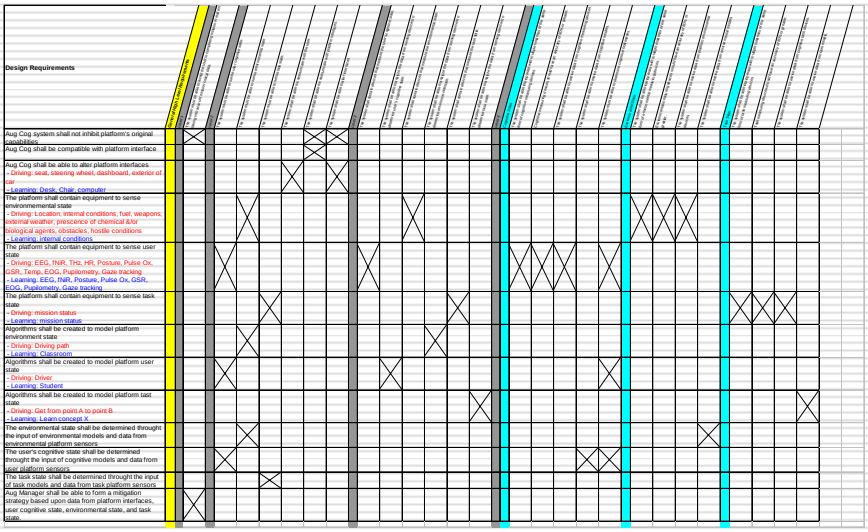
Learning: Constraint-Based Requirements

- System shall be compatible with other instructional instruments in classroom
- System shall be adjustable to fit a variety of young users
- System shall be contained to student desk and chair area
- System shall not inhibit students from hearing and seeing teacher and classmates
- System should allow easy application and removal from student

Learning: System Interfaces & Communications

Module	Platform Instance	Inputs	Outputs
User	Student	Instructions	Brain and muscular electrical activity, brain and blood oxygenation, sitting posture, skin moisture, pupil size, gaze
Environment	Classroom	n/a	Location, temperature, light level, humidity, time of day
Task	Learn objective	n/a	Task completion progress
Command	Teacher instruction	n/a	Instruction
Cognitive Model	Learning	n/a	Predicted cognitive state
Environmental Model	Classroom	n/a	Predicted environmental state
Task Model	Learn objective	n/a	Predicted task state
Cognitive Sensor	EEG	Brain electrical activity	Electrical state in mV
Cognitive Sensor	fNIR	Brain blood oxygenation	Ratio of oxygenated to nonoxygenated hemoglobin
Cognitive Sensor	Posture	Pressure	Newtons of pressure at specific places on seat
Cognitive Sensor	GSR	Skin moisture content	mV of electricity conducted in skin
Cognitive Sensor	EOG	Muscular electrical activity	Electrical state in mV
Cognitive Sensor	Pupilometry	Pupil size	Pupil diameter in mm
Cognitive Sensor	Gaze tracking	Gaze location	XY coordinates on display where gaze is focused at any given point in time
Environmental Sensor	iC - Themometer	Temperature	Thermal degrees
Environmental Sensor	iC - Lighting	Light level	Luminance measure
Environmental Sensor	iC - Humidity	Air moisture content	% moisture content of air
Environmental Sensor	iC - Clock	Time of day	Hour & minute of day
Task Sensor	Status	Task completion status	Aspects of task completed, % of task completed
Cognitive State	n/a	Cognitive sensors, cognitive model	Cognitive state
Environmental State	n/a	Environmental sensors, environmental model	Environmental state
Task State	n/a	Task sensor, task model	Task state
Augmentation Manager	n/a	Cognitive, Environmental, and Task sensors, Interface	Mitigation Strategy
Interface	Traditional display	Aug Manager	Display of information to user
Interface	Visual alert	Aug Manager	Flashing or highlighted information
Interface	Visual warning	Aug Manager	Flashing or highlighted information
Interface	Pictures and graphics	Aug Manager	Information presented in graphical format
Interface	Text	Aug Manager	Information presented in textual format
Interface	Voice	Aug Manager	Information presented vocally
Interface	Auditory warning	Aug Manager	Information presented in an attention-getting auditory format
Interface	Spatially locatable sound	Aug Manager	Information presented auditorily, in such a way that the source of the information can be localized spatially
Interface	Tactile warning	Aug Manager	Information presented in an attention-getting tactile format
Agent	n/a	n/a	n/a

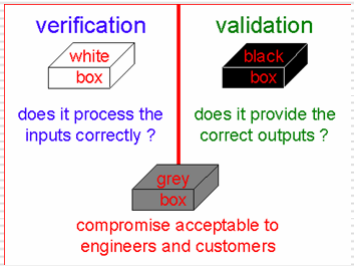
Multi-Level Requirements

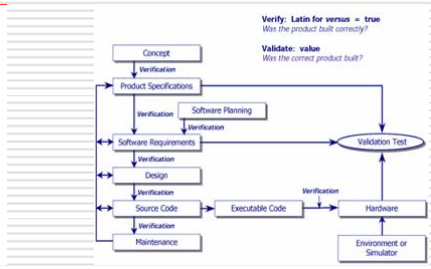


Validation & Verification:
Representative Requirements Trace

Requirements	User	Cog Sensor	Cog State	Environment	Environmental Sensors	Environmental State	Task	Task Indicators	Task State	Aug Manager	Interfaces	
Level 1												
The system must adapt to user cognitive state in real time.												
Level 2												
The system must be able to sense user cognitive state.	X											
The system must be able to sense environmental state				X								
The system must be able to sense task state.							X					
The system shall be able to communicate with the user.										X		
The system shall be able to communicate with platform interfaces.											X	
The system shall be able to alter interfaces.										X	X	
Level 3												
The system shall contain devices that measure the user's cognitive state.		X										
The system shall be able to analyze the data from sensing devices to determine user's cognitive state.			X									
The system shall contain devices that measure theenvironmental state.					X							
The system shall be able to analyze the data from sensing devices to determine environmental state.						X						
The system shall contain devices that measure the task state.								X				
The system shall be able to analyze the data from sensing devices to determine task state.									X			

Validation & Verification: Communications





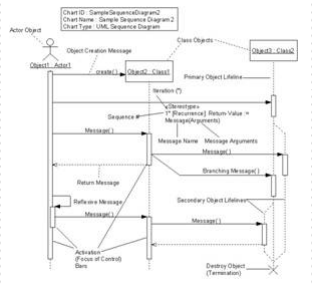
- Utilizing the trace of communications throughout the system enables V&V
- Communications trace takes into account both platform-driven and component-driven aspects of V&V

Spatial Logic

- Driving
  - Confined to automobile instruments
    - Seats
    - Dashboard
    - Exterior of driving
    - Steering Wheel
  - Assembled to maintain user comfort
  - Constraint Variables
    - # of passengers
    - Function of auto
    - Type of vehicle
    - Size of instruments
- Learning
  - Confined to student workstation
    - Desk
    - Chair
    - Computer
  - Assembled to maintain student comfort
  - Constraint Variables
    - Size of group
    - Size of classroom
    - Age of students
    - Size of workstation

Temporal Logic

- Augmented Cognition systems are primarily temporally controlled loops
- Information must flow from input → sensor → state determination → aug manager → interface → input
- Information flow is continually looping
- There are three sub-loops running in parallel (user, environment, task)
- Other considerations
  - Sensing & modeling delays (processing time, required signal averaging)
  - Mitigation strategy "off" signals (task driven, "on" signals are sensor driven)
  - User reactivity time
  - Instrument sensitivity time
  - Timing of outside factors



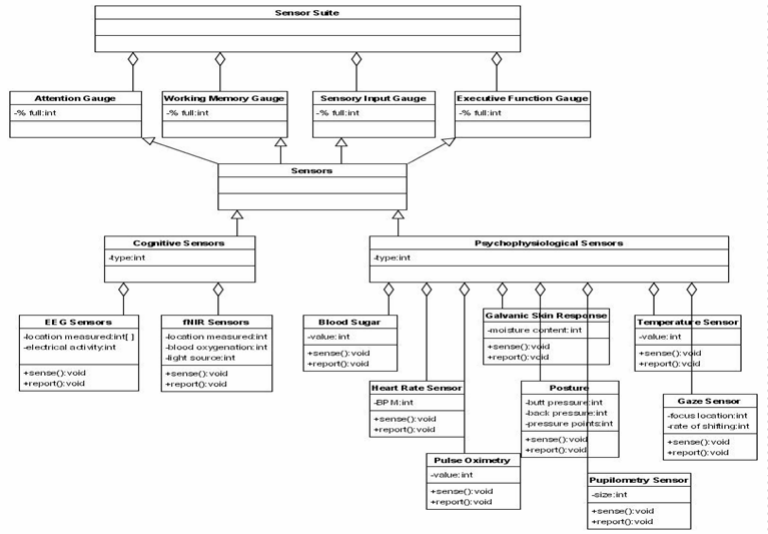
Conclusions

- Platform-based design improves the design process of augmented cognition systems
- Future platforms will be made possible by exploiting this methodology

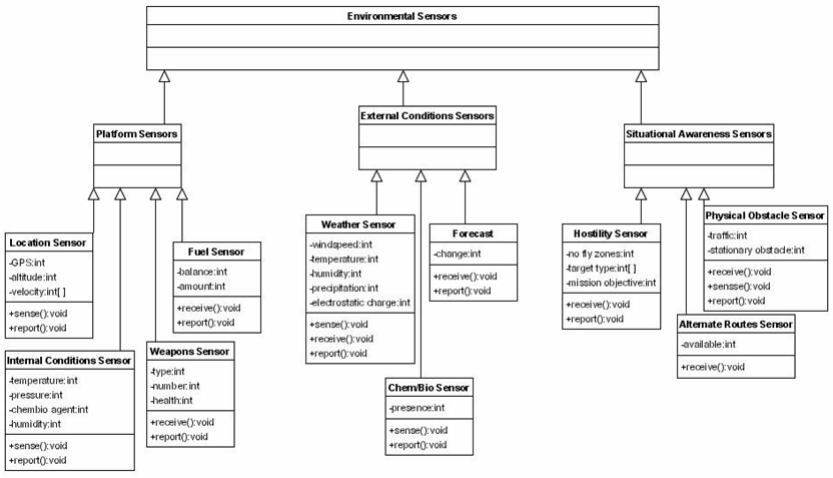



Questions?

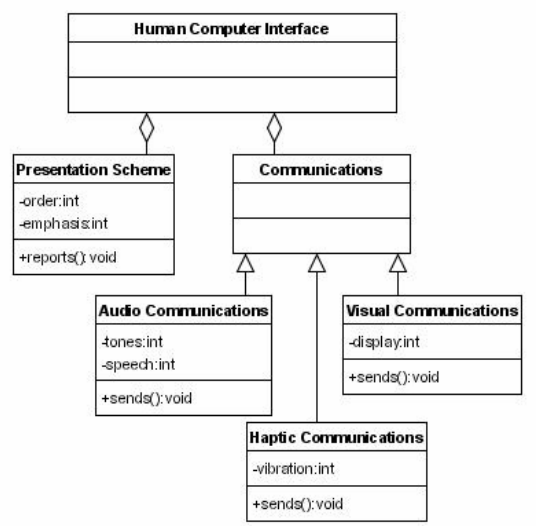
Sensors – Cognitive



Sensors - Environmental



Interfaces


Human Computer Interface
Presentation Scheme
-order:int
-emphasis:int
+reports(): void
Communications
Audio Communications
-tones:int
-speech:int
+sends(): void
Visual Communications
-display:int
+sends(): void
Haptic Communications
-vibration:int
+sends(): void