Platform-Based Design of Augmented Cognition Systems

Latosha Marshall & Colby Raley
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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

<table>
<thead>
<tr>
<th>Discipline</th>
<th>System Aspect</th>
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<tbody>
<tr>
<td>Neuroscience</td>
<td>Sensors: development &amp; placement</td>
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<tr>
<td>Math:</td>
<td>Gauges:</td>
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<tr>
<td>Signal Processing</td>
<td>Development</td>
</tr>
<tr>
<td>Artifact Detection</td>
<td>Ensuring meaningful information</td>
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<td>Psychology:</td>
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<td>Human Factors</td>
<td>Interface design</td>
</tr>
<tr>
<td>Neuroergonomics</td>
<td>Interface design</td>
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<td>Engineering:</td>
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<tr>
<td>Mechanical</td>
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<td>Electrical Systems</td>
<td>Component Communication</td>
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<tr>
<td>Cognitive Systems</td>
<td>Information Flow</td>
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<tr>
<td></td>
<td>“Bringing the Human in the Loop”</td>
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</tbody>
</table>

## System Architecture

![Diagram showing the system architecture with components such as user, sensor, environmental state, task model, and Augmentation Manager.]

- User
- Sensor
- Environmental state
- Task model
- Augmentation Manager
- Interface
- Autonomous agents
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 to 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
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
      - Temperature
      - EOG
      - Pupilometry
      - Gaze Tracking
  - Environmental
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      - Obstacles
  - Task
    - Status

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    - Voice
    - Warning
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    - Directional cue

Driving
System Architecture – Driving Components

- Cognitive Sensors: EEG, fNIR
- Physiological Sensors: EOG, EKG, HR, pupillometry, gaze tracking, PPG, posture, body temp, GSR
- Context Sensors: lane departure, obstacle detection (IR, visual), temperature, heading, wind speed, location

System Architecture - Driving

- Cognitive model of driving
- Environmental model of car and road
- Mitigation Manager
  - state + task + environment = apply mitigation strategy

Augmentation Manager

Mitigation Strategies - Driving
- Modality Switching
- Task Ordering
- Attention Directing

Interfacing: audio system, cell phone system, visual alert system, automatic braking/steering, between-car distance

- Task model: driving and ancillary tasks
- Distance, task completion, # tasks in progress

11/23/2004
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

<table>
<thead>
<tr>
<th>Module</th>
<th>Platform Instance</th>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Sensor 1</td>
<td>EEG Sensor</td>
<td>user’s electrical activity</td>
<td>human mV</td>
</tr>
<tr>
<td>User Sensor 2</td>
<td>Fnir Sensor</td>
<td>user’s blood oxygenation</td>
<td>% of oxygenated blood cells</td>
</tr>
<tr>
<td>User Sensor 3</td>
<td>THz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Sensor 4</td>
<td>Heart Rate Sensor</td>
<td>user’s heart rate</td>
<td>bpm</td>
</tr>
<tr>
<td>User Sensor 5</td>
<td>Pulse Oximetry</td>
<td>user’s pulse rate</td>
<td></td>
</tr>
<tr>
<td>User Sensor 6</td>
<td>Posture Sensor</td>
<td>user’s posture</td>
<td>torso and lower body pressure against seat</td>
</tr>
<tr>
<td>User Sensor 7</td>
<td>Galvanic Skin Response</td>
<td>user’s moisture content</td>
<td>skin mV level</td>
</tr>
<tr>
<td>User Sensor 8</td>
<td>EOG</td>
<td>user’s muscular activity surrounding the eye</td>
<td>eye muscle mV measurement</td>
</tr>
<tr>
<td>User Sensor 9</td>
<td>Pupilimetry</td>
<td>user’s pupil dilation</td>
<td>size of pupil</td>
</tr>
<tr>
<td>User Sensor 10</td>
<td>Gaze Tracking</td>
<td>location of pupil of eye</td>
<td>eye coordinate</td>
</tr>
<tr>
<td>Environment Sensor 1</td>
<td>Global Position System</td>
<td>vehicle position &amp; altitude</td>
<td></td>
</tr>
<tr>
<td>Environment Sensor 2</td>
<td>Thermometer</td>
<td>vehicle temperature</td>
<td>thermal degrees</td>
</tr>
<tr>
<td>Environment Sensor 3</td>
<td>Humidity</td>
<td>vehicle moisture content</td>
<td>moisture content of air (%)</td>
</tr>
<tr>
<td>Environment Sensor 4</td>
<td>Lighting</td>
<td>vehicle lighting level</td>
<td>luminence measurement</td>
</tr>
<tr>
<td>Environment Sensor 5</td>
<td>Clock</td>
<td>time</td>
<td>Time of Day</td>
</tr>
<tr>
<td>Environment Sensor 6</td>
<td>Fuel gauge</td>
<td>amount of fuel</td>
<td>fuel level</td>
</tr>
<tr>
<td>Environment Sensor 7</td>
<td>Condition of Road</td>
<td>percipitation collected and depressions</td>
<td>road texture</td>
</tr>
<tr>
<td>Environment Sensor 8</td>
<td>Weather</td>
<td>percipitation</td>
<td></td>
</tr>
<tr>
<td>Environment Sensor 9</td>
<td>Obstacles</td>
<td>obstacle present or not</td>
<td></td>
</tr>
<tr>
<td>Task Sensor 1</td>
<td>Task completion</td>
<td>tasks performed</td>
<td>tasks completion level</td>
</tr>
<tr>
<td>Interface 1</td>
<td>Visual Alert</td>
<td>Light/LED</td>
<td></td>
</tr>
<tr>
<td>Interface 2</td>
<td>Visual Warning</td>
<td>Light/LED</td>
<td></td>
</tr>
<tr>
<td>Interface 3</td>
<td>Auditory Voice</td>
<td>simulated voice command or statement</td>
<td></td>
</tr>
<tr>
<td>Interface 4</td>
<td>Auditory Warning</td>
<td>Audio sound</td>
<td></td>
</tr>
<tr>
<td>Interface 5</td>
<td>Auditory Spatially locatable</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Component Catalog - Learning

- Sensors
  - Cognitive
    - Direct Brain Measures
    - EEG
    - fNIR
  - Psychophysiological Measures
    - HR, EKG
    - Pulse Ox
    - Temperature
    - GSR
    - Pupilometry
    - Gaze Tracking
  - Environmental
    - Platform Measures
      - Location
    - Internal Conditions
    - Fuel
    - Weapons
  - External Measures
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    - Presence of Chemical or Biological Agents
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    - Obstacles
  - Task
/- Status

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  - Visual
    - Heads up display
    - Traditional display
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    - Picture
    - Text
  - Auditory
    - Voice
    - Warning
    - Spatially locatable
  - Tactile
    - Warning
    - Directional cue

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

<table>
<thead>
<tr>
<th>Feature</th>
<th>Position Instance</th>
<th>Inputs</th>
<th>Outputs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Model</td>
<td>Environment</td>
<td>Level 1</td>
<td>The system must be able to assist the user in completing the mission in real time.</td>
<td>The system shall be able to communicate with platform interfaces. The system shall be able to alter interfaces. The system shall contain devices that measure the user's cognitive state. The system shall contain devices that measure the environmental state. The system shall be able to analyze the data from environmental measuring devices to determine user's cognitive state. The system shall contain devices that measure the task state. The system shall be able to receive data from cognitive task devices. The system shall be able interoperate with multiple instances of the same environment model. The system shall be able interoperate with multiple instances of the same task model. The system shall contain devices that measure user's skin moisture, pupil size, gaze location.</td>
</tr>
<tr>
<td>Task Model</td>
<td>Environment</td>
<td>Level 2</td>
<td>The system shall be able to sense environmental state.</td>
<td></td>
</tr>
<tr>
<td>Task Model</td>
<td>Environment</td>
<td>Level 3</td>
<td>The system shall be able to determine user's cognitive state.</td>
<td></td>
</tr>
<tr>
<td>Task Model</td>
<td>Environment</td>
<td>Level 4</td>
<td>The system shall be able to determine environmental state.</td>
<td></td>
</tr>
</tbody>
</table>

Multi-Level Requirements

[Diagram showing multi-level requirements with checkboxes]
Validation & Verification: Representative Requirements Trace

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system must adapt to user cognitive state in real time.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system must be able to sense user cognitive state.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system must be able to sense environmental state.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system must be able to sense task state.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system shall be able to communicate with the user.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system shall be able to communicate with platform interfaces.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system shall be able to communicate with platform interfaces.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system shall contain devices that measure the user’s cognitive state.</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>The system shall contain devices that measure environmental state.</td>
<td>✔️</td>
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<td>✔️</td>
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</tbody>
</table>

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?
Interfaces

- Human Computer Interface
- Presentation Scheme
  - <under int
  - emphasis:int
  - report():void
- Audio Communications
  - toneslist
  - speechlist
  - send(): void
- Visual Communications
  - display(int
  - send(): void
- Haptic Communications
  - vibration(int
  - sending(): void