An Unobtrusive System to Measure, Assess, and Predict Cognitive Workload in Real-World Environments

Keynote, BIOSTEC 2017

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23 February 2017

Porto, Portugal

Agenda

- Company background
  - Company overview
  - Human sensing projects overview
- Cognitive workload sensing
  - Why do we care?
  - Who cares?
- Methods
  - Custom sensing devices
  - Data handling
  - Information display
- Conclusions

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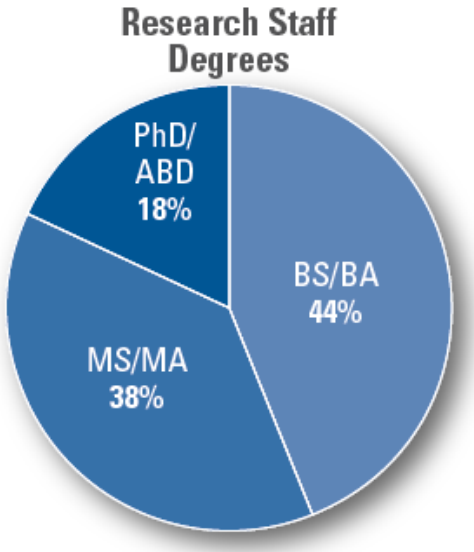
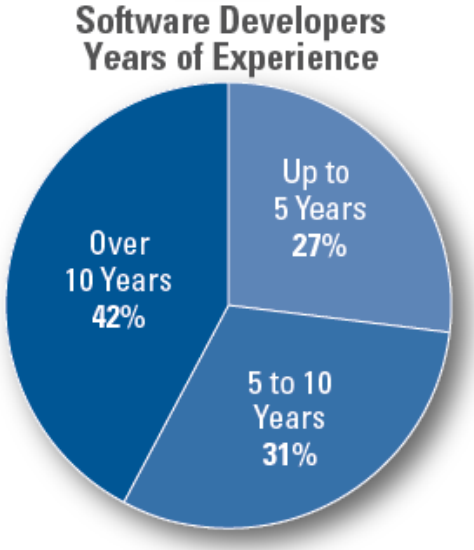
Corporate Background

- Employee-Owned Small Business, Cambridge, MA, USA started in 1983
  - 150+ employees and associates
  - GSA Schedule for IT Services

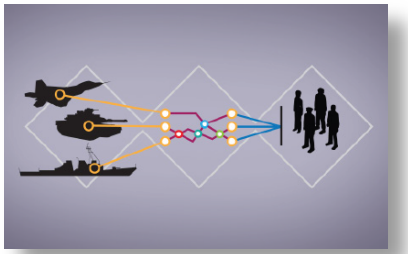
- Bridging the gap between thought leaders in academia and systems developers/ integrators
  - Long-term collaborative partner with world-class universities
  - Strong participation in professional societies/ panels
  - Close relationships with several lead system integrators



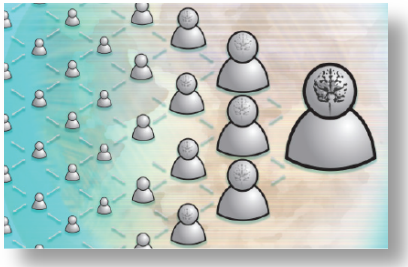


Core Company Competencies

Sensor Processing & Networking
- Automatic target recognition (ATR) and tracking
- Automated analysis of security and surveillance imagery
- Network and software trustworthiness optimization
- Vision-based autonomous navigation
- Image and video enhancement



Decision Management
- Data mining, data/information fusion
  - Event detection and prediction
  - Situation analysis and threat assessment
  - Sensor/resource management
  - Course-of-action analysis
- Cyber security



Socio-Cognitive Systems
- **Sensor-based assessment of human physical and cognitive states**
- **Human behavior modeling for individuals, organizations, and societies**
- **Model-driven and model-backed assessment of complex situations**
- Tactical intelligence management and collection

Human Effectiveness
- Intuitive interfaces and operator support tools for complex systems
- Work analysis, design prototyping, and human-in-the-loop evaluation
- Skill modeling, intelligent tutoring, game- and simulation-based training
- Information visualization

Collaborators

Charles River bridges the gap between **universities'** basic research and **lead system integrators'** needs for mature technology

Universities

Arizona State University
Brandeis University
Brown University
Carnegie Mellon University
Cornell University
Claremont Graduate University
Duke University
George Mason University
Harvard University
Harvard Medical School
Massachusetts Inst. of Technology
Penn State University
Syracuse University
Tufts University
University at Buffalo (SUNY)
University of California at Berkeley
University of Illinois
University of Kentucky
University of Maryland
University of Massachusetts
University of Massachusetts Medical School
University of Pennsylvania
University of Southern California
Vanderbilt Medical School
Wright State University

Other Businesses

Anacapa Sciences, Inc.
Analytic Graphics, Inc. (AGI)
Apelon, Inc.
Aptima, Inc.
Architecture Technology Corp (ATC)
Assured Information Security, Inc.
Aviation Specialties, Inc.
Biosignals PluX
Blue Force LLC
Blyth Consulting Group
Boston VA Research Institute
Boundariez Consulting
Clark & Parsia
Coolhead Consulting
Creation Logic
CUBRC
Data Fusion & Neural Networks
Defense Health Program
Global Training, LLC
Group1 Solutions
InGuardians
Karabaich Strategic Info Services
Massachusetts Eye and Ear Infirmary
Massachusetts General Hospital
McLean Hospital
PAR Government Systems
PatchPlus Consulting
Planet 9 Studios
Referentia Systems Incorporated
Roth Cognitive Engineering
Sensimetrics Corporation
Signet Research & Consulting
Singular Computing LLC
SofCheck
Spaulding Research Hospital
Tech Projects, LLC
Technology Solution Experts
TopCoder
Zanol Consulting, Inc.

Large System Integrators

Applied Research Associates
Aurora Flight Sciences
BAE Systems
Boeing
Booz Allen Hamilton
Charles Stark Draper Laboratory
Chenega Federal Systems
DSS Lab
General Dynamics
Lockheed Martin
L-3 Communications
Metron Scientific Solutions
MIT Lincoln Labs
MITRE
Northrop Grumman Corp
Oculus Innovative Sciences
Pacific Northwest National Laboratory
QinetiQ North America (Foster-Miller)
Raytheon
Science Applications International Corp. (SAIC)
Teledyne-Brown Engineering
Textron Defense Systems

Powerful Productivity Tools

Product	Description
Sherlock™	**Open, extensible software and hardware platform for rapid prototyping of solutions to collect, analyze, visualize, and reason about human physiological, neurological, and behavioral state**
VisionKit®	A library of computer vision software components for developing object recognition, surveillance, video enhancement, and visual navigation systems
BNet®	Bayesian Belief Network development tool and accompanying software development kit
Connect™	Social and Organization Network Analysis tool for domain-independent network analysis
AgentWorks™	Intelligent agent toolkit providing agent-based computational components and integrated system development, validation, and visualization environments
Metronome™	A plug-in based architecture and associated visual software components enabling developers of rich-client applications to create powerful, easy-to-use interfaces for high-availability and mission critical systems
DRIVE™	Toolkit to support rapid generation, reconfiguration, evaluation, and refinement of Information visualization content and format
Figaro™	A language and reasoning framework for probabilistic modeling and inference that provides the basis for many computational intelligence services such as data and information fusion, machine learning, forecasting, state estimation, and sensitivity analysis

Human State Assessment Portfolio

Completed
Current

Area	Project	Customer	Title	Project Theme
Cognitive Workload Assessment	**ADAPTER II**	USAF/AFRL	Handheld Intelligent Tutors Personalized for Individual Training	Cyber teams / cognitive load, stress, fatigue, team dynamics, taskload allocation
	MEDIC II	CDMRP	Aiding Training by Monitoring, Extracting, & Decoding Indicators of Cognitive Load	Medical teams / cognitive load
	CAPT PICARD II	NASA	Precision Information Environment for Coordinated Emergency Support	T&E subjects / Mission analog environments
	ASYMPTOTE	USAF/AFRL	Adaptable System for Measuring Performance of Teams of Operators in Targeted Environments	Real-time assessment of Airmen human readiness level (HRL)
	SEAHAWK	US Navy	A System to Evaluate and Assess Holistic Aircrew Workload	Real-time assessment of novice test subject and prediction of state change after development of expertise
Condition Detection	**SOMBA**	DARPA	Stand-Off Biometric Assay	Stand-off detection of HR
	ADVISOR II	AARL/MRMC	Assessment and Diagnosis of Vestibular Indicators of Soldiers Operational Readiness	Screening for vestibular damage or Mild Traumatic Brain Injury
	READ-IT	ARI	Rapid Ethnographic Assessment and Data Integration Toolkit	Aid capture of social network data
	SERENE	ONR	Framework for Sensing and Representing Negative Effects of Motion	Sense sopite syndrome

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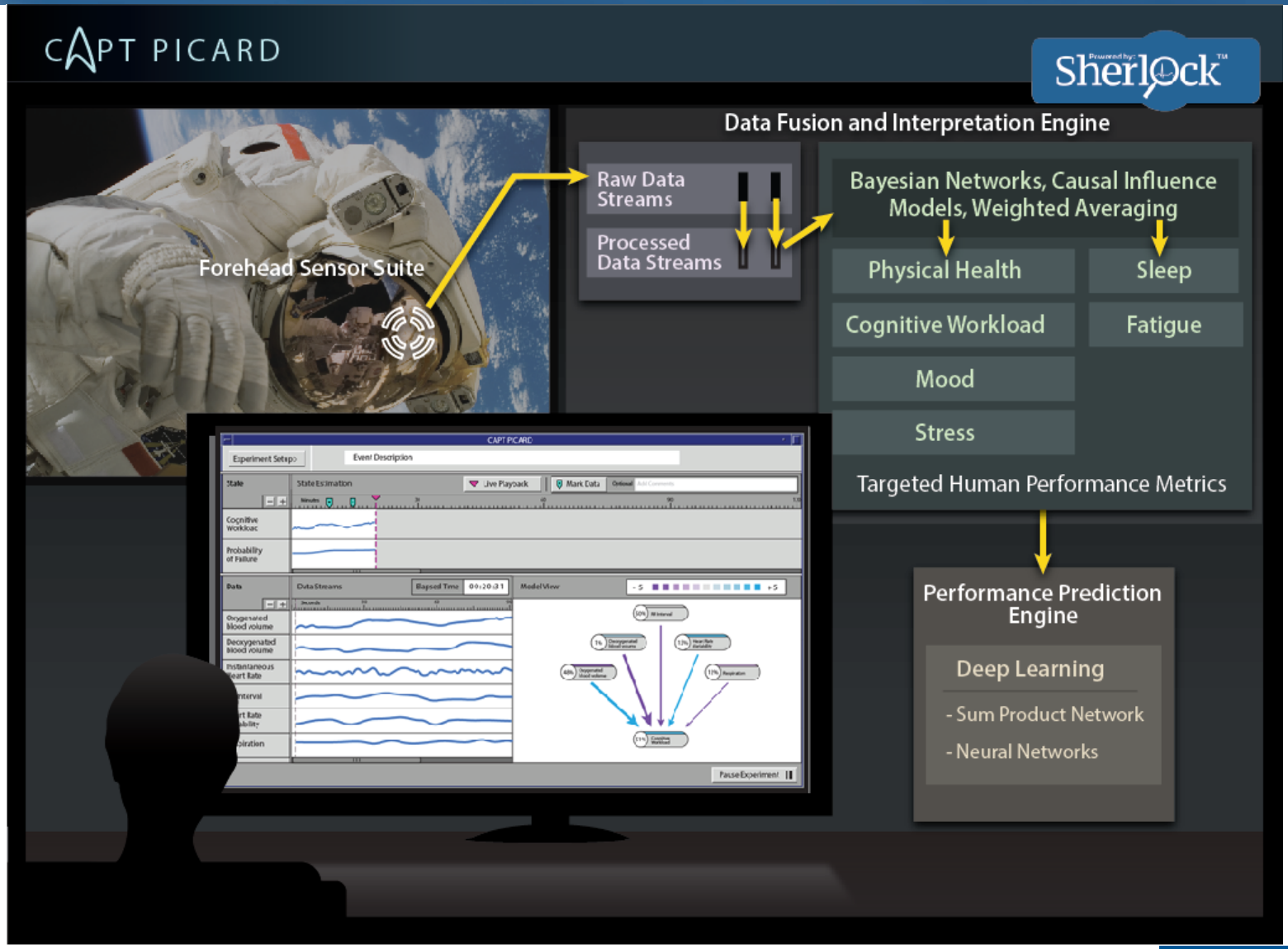
The Need

1. Many work environments fraught with highly variable demands on cognitive workload
   - Fluctuation between cognitive overload and boredom
   - Detrimental to performance

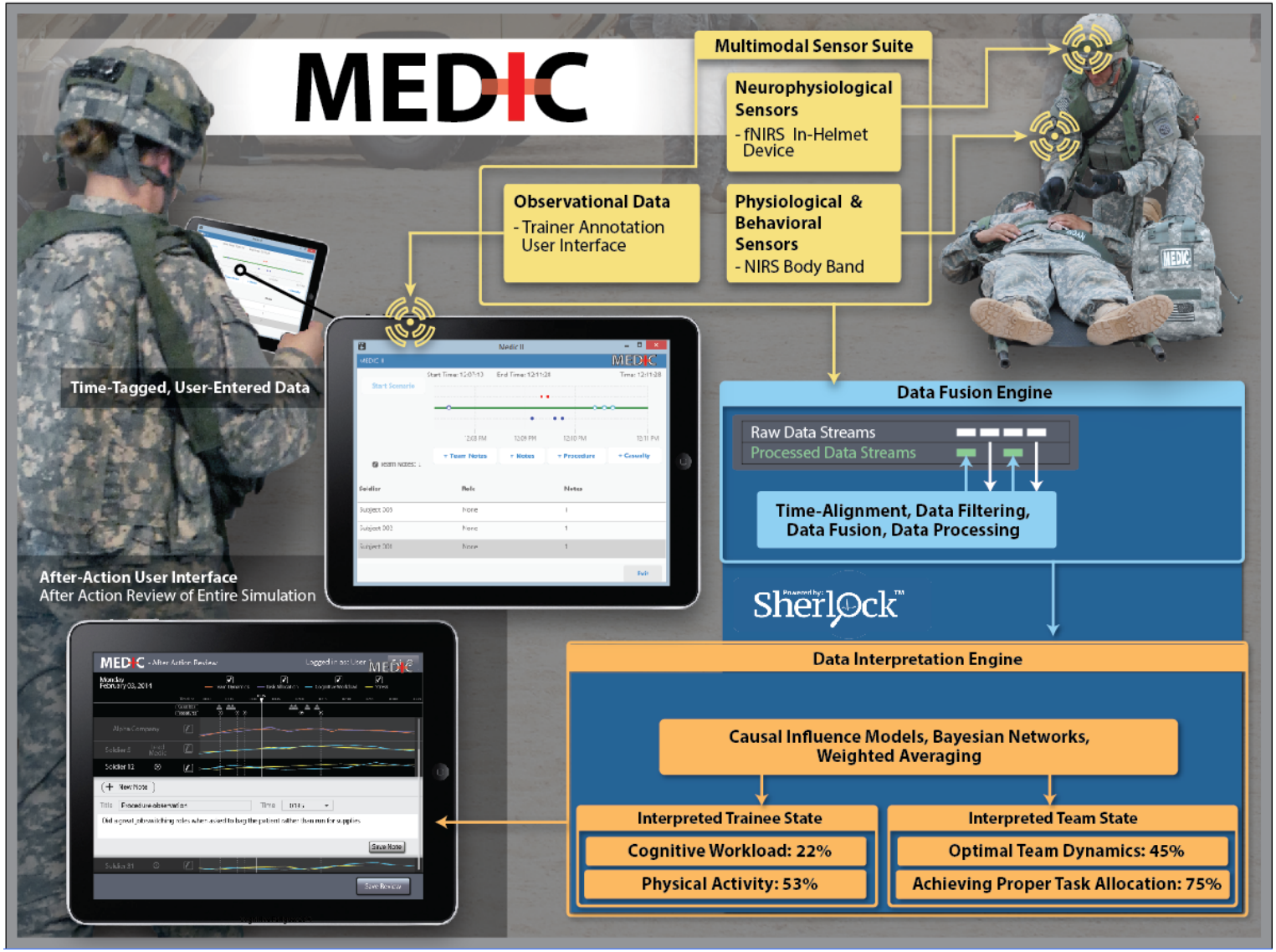
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)



The Need

2. Fast-paced, sometimes dangerous professions require personnel to be trained to perform duties automatically
   - If skill still requires great effort, additional training is necessary
   - Focus training to enhance learning

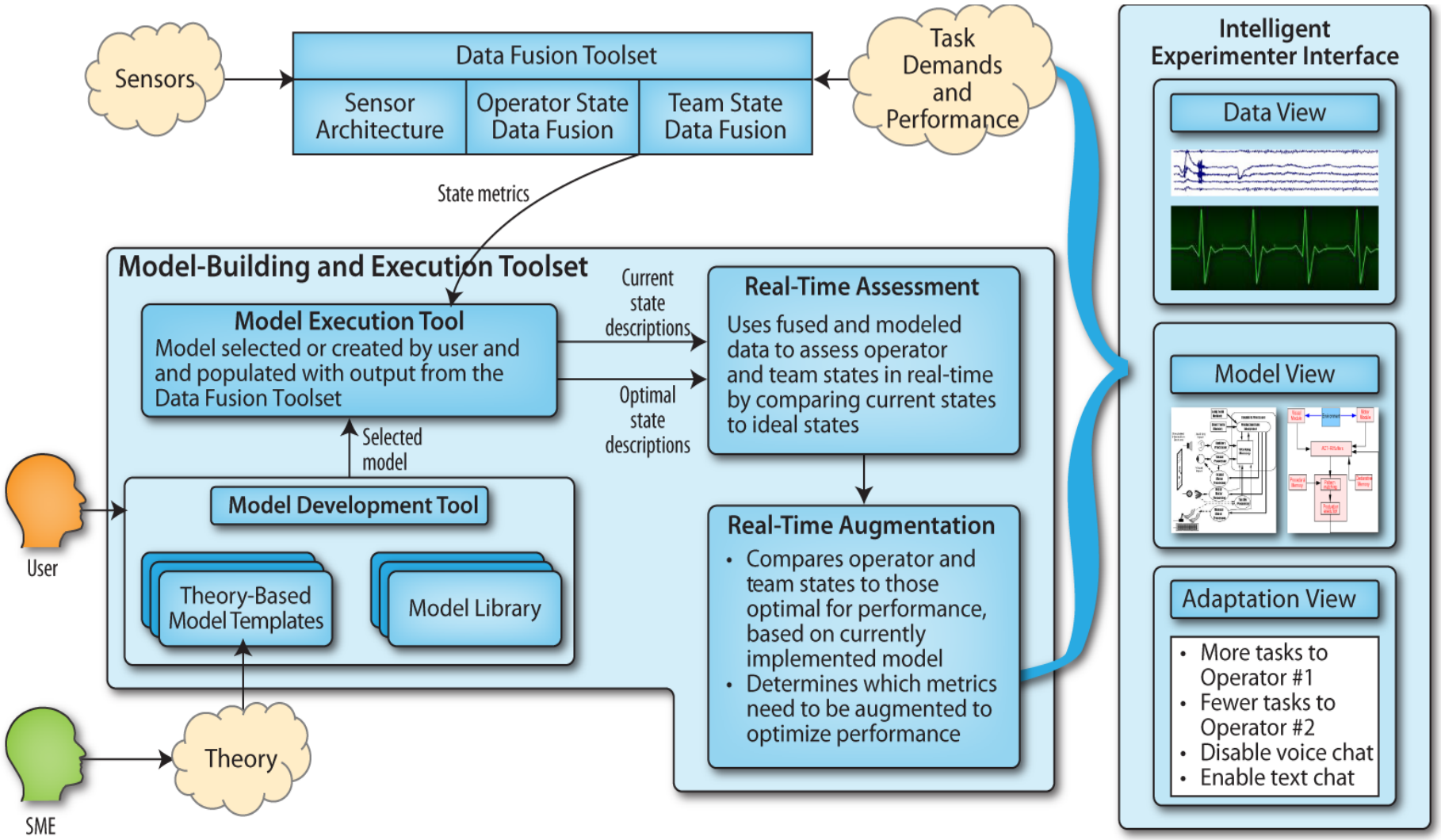
A System for Augmenting Training by Monitoring, Extracting, and Decoding Indicators of Cognitive Load (MEDIC)



The Need

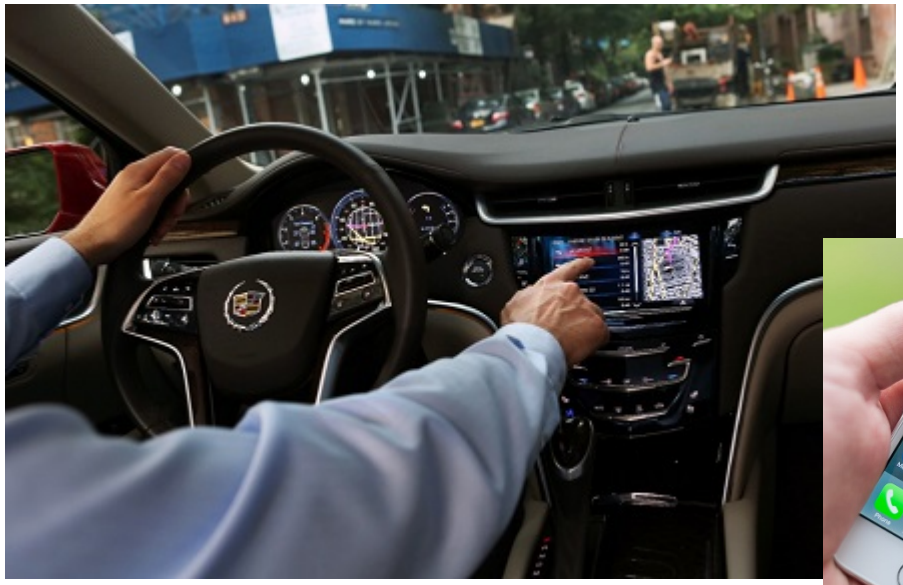
3. Teams of individuals must focus on their own tasks, while maintaining awareness of teammates' tasks
   - Optimize team performance

Adaptive Toolkit for the Assessment and Augmentation of Performance by Teams in Real Time (ADAPTER)



The Need

4. As new tools and systems are developed, their effect on cognitive workload must be assessed
   - Interaction should be intuitive; if additional workload is unacceptable, design must be adapted throughout developmental phases
   - Testing and evaluation in laboratory experiments



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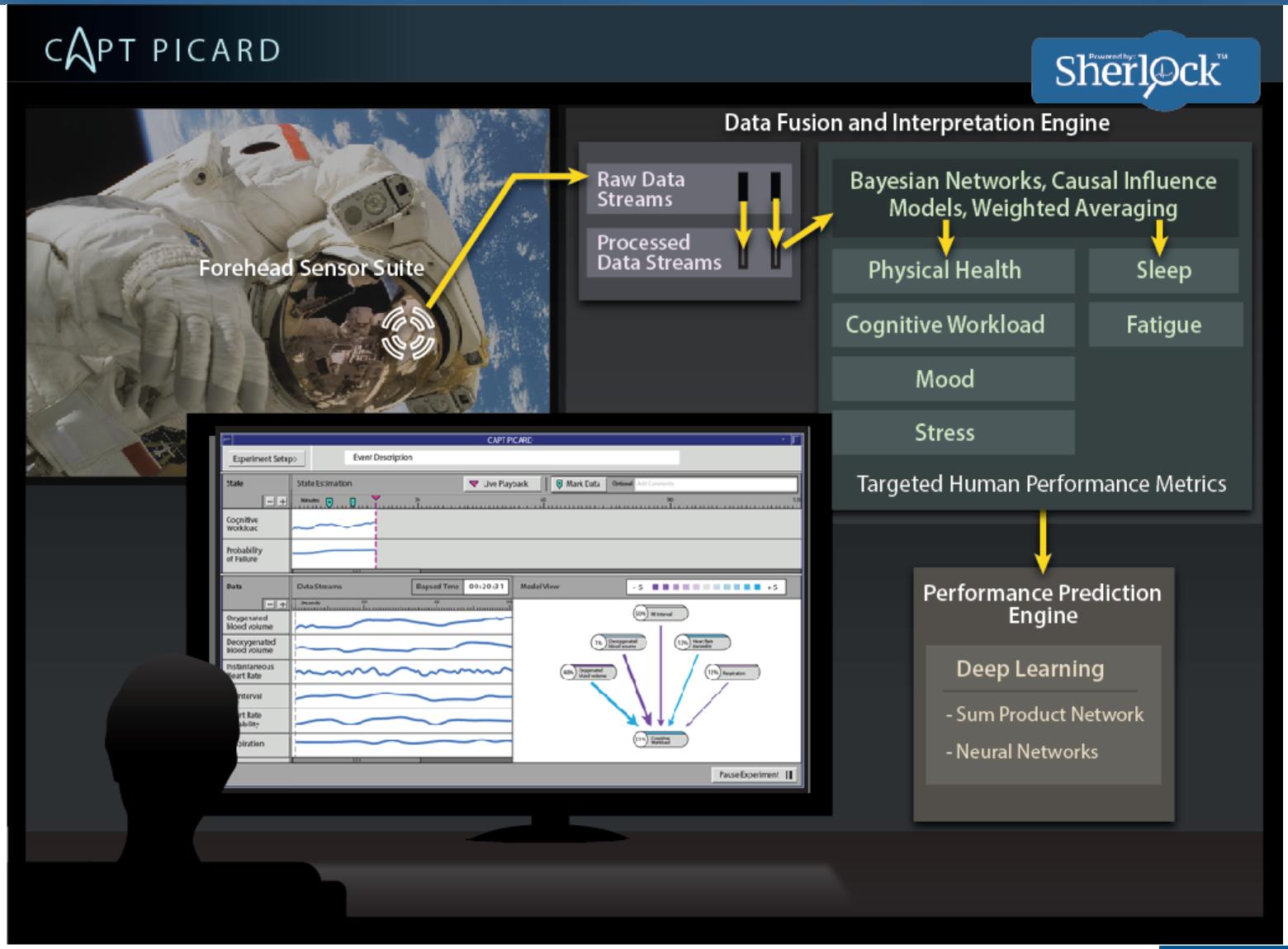

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  - **Data**
  - **Information display**
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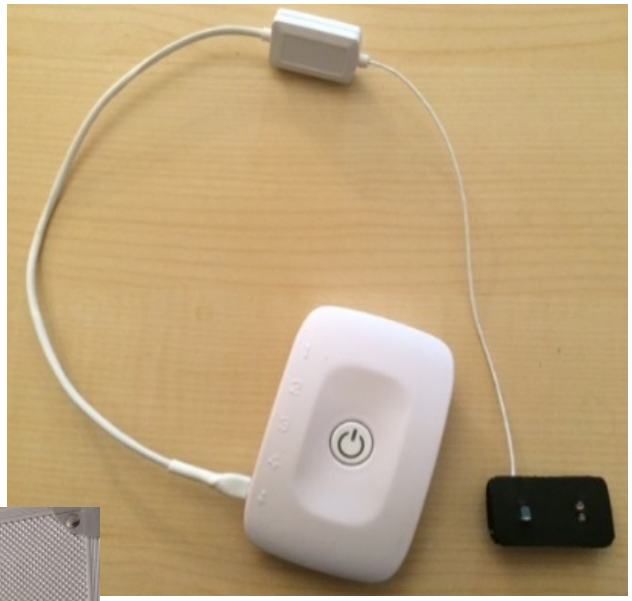
Sherlock™

Open, extensible software and hardware platform for rapid prototyping of solutions to collect, analyze, visualize, and reason about human physiological, neurological, and behavioral state

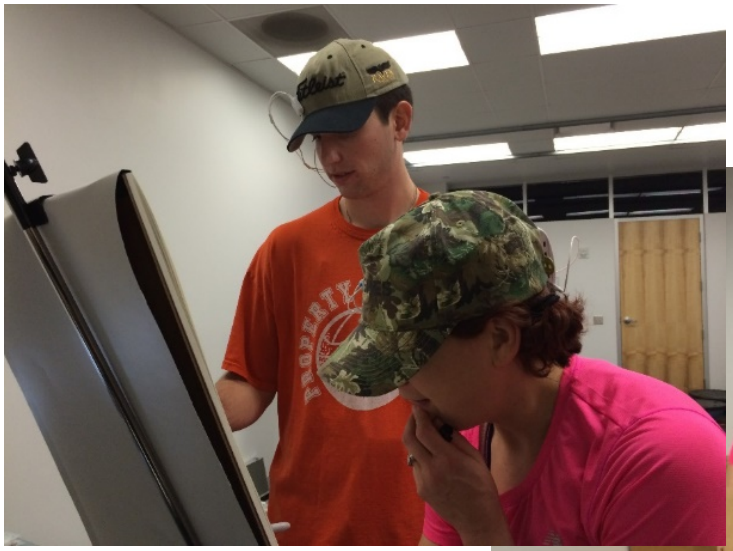
- COTS and custom sensors (patent pending)
- Data processing and analysis
- Classification of human states (e.g., cognitive load)
  - Statistical and probabilistic modeling techniques
- Prediction of performance
  - Machine-learning algorithms, hierarchical modeling

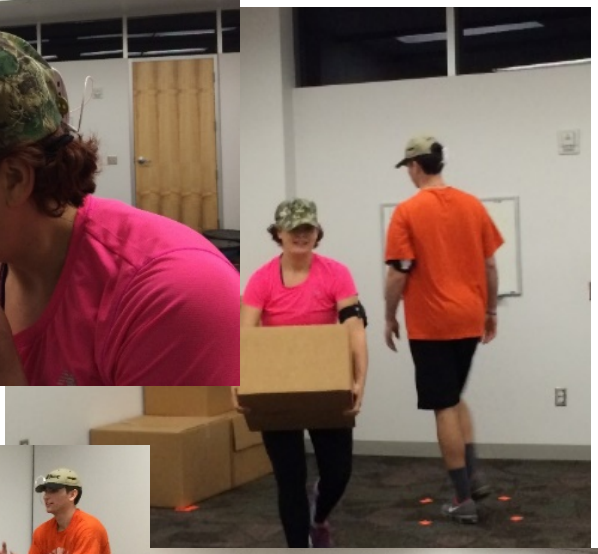
Custom Portable fNIRS Sensor



Mr. Filipe Silva, Biosignals PluX

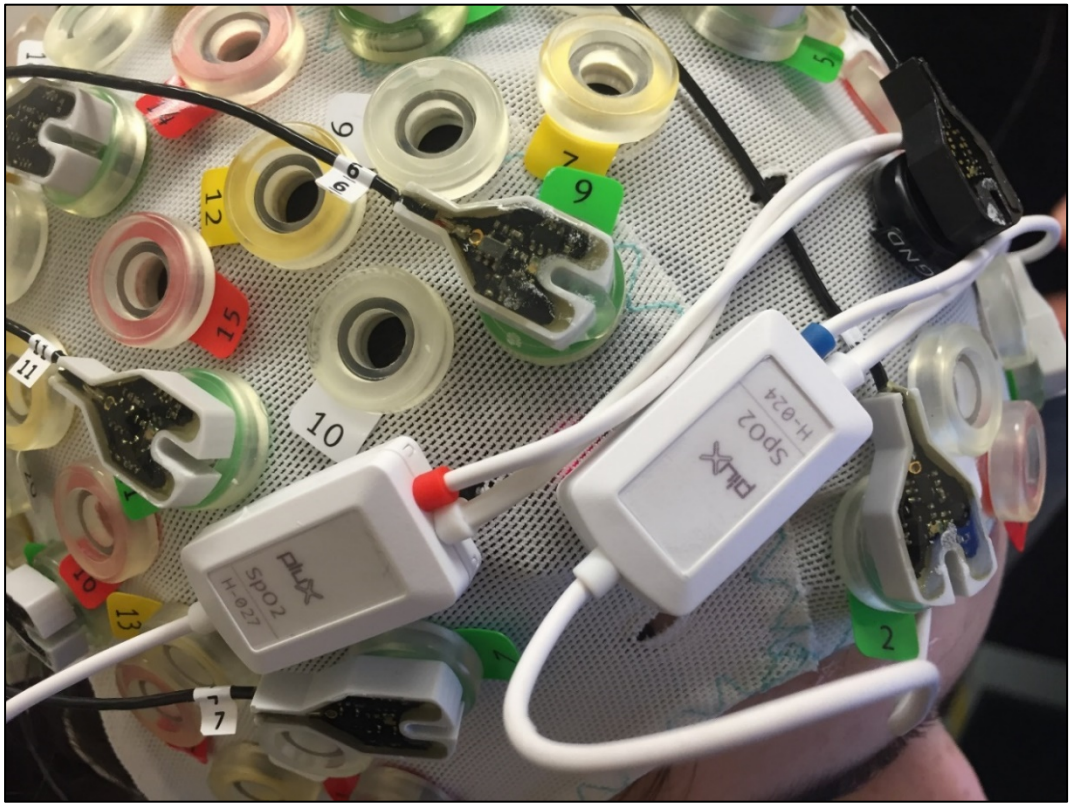
fNIRS In Various Environments





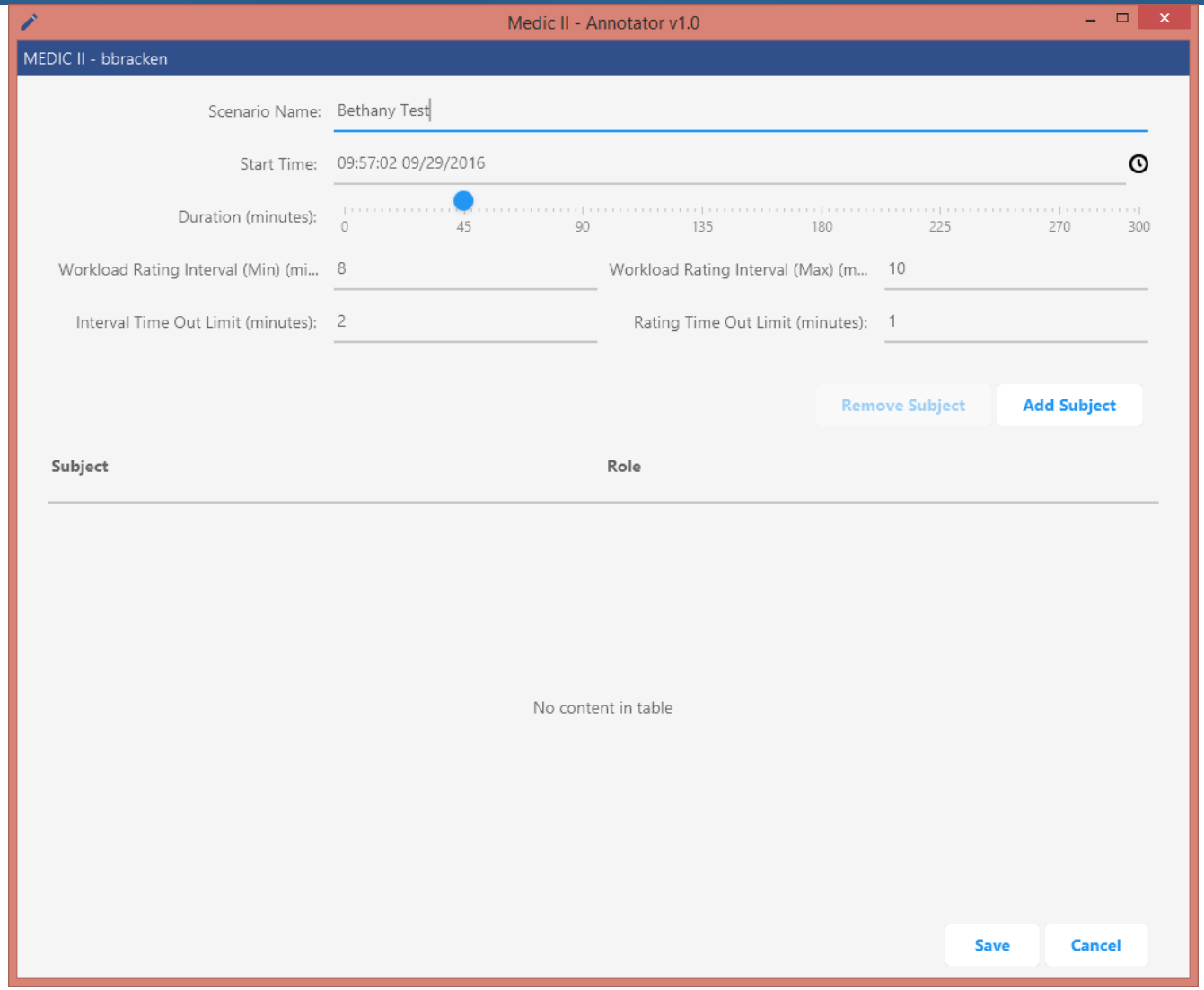
Sensor Validation

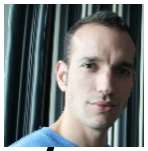
- Simultaneous EEG/fNIRS data collection
- Compare attention/workload measures of both sensors



Dr. Elena Festa, Brown University

Synchronized Annotation Tool

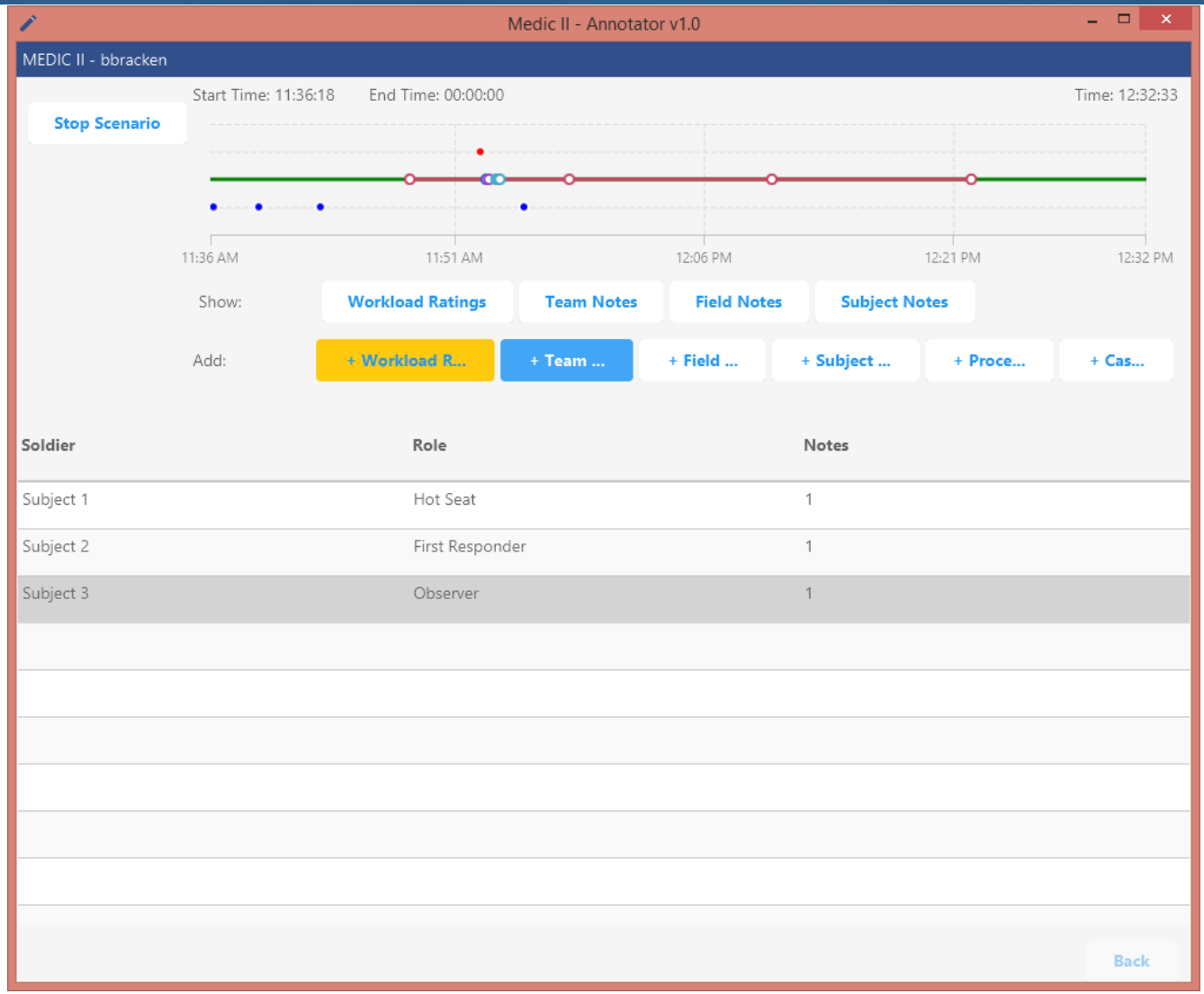




Mr. Alex Negri

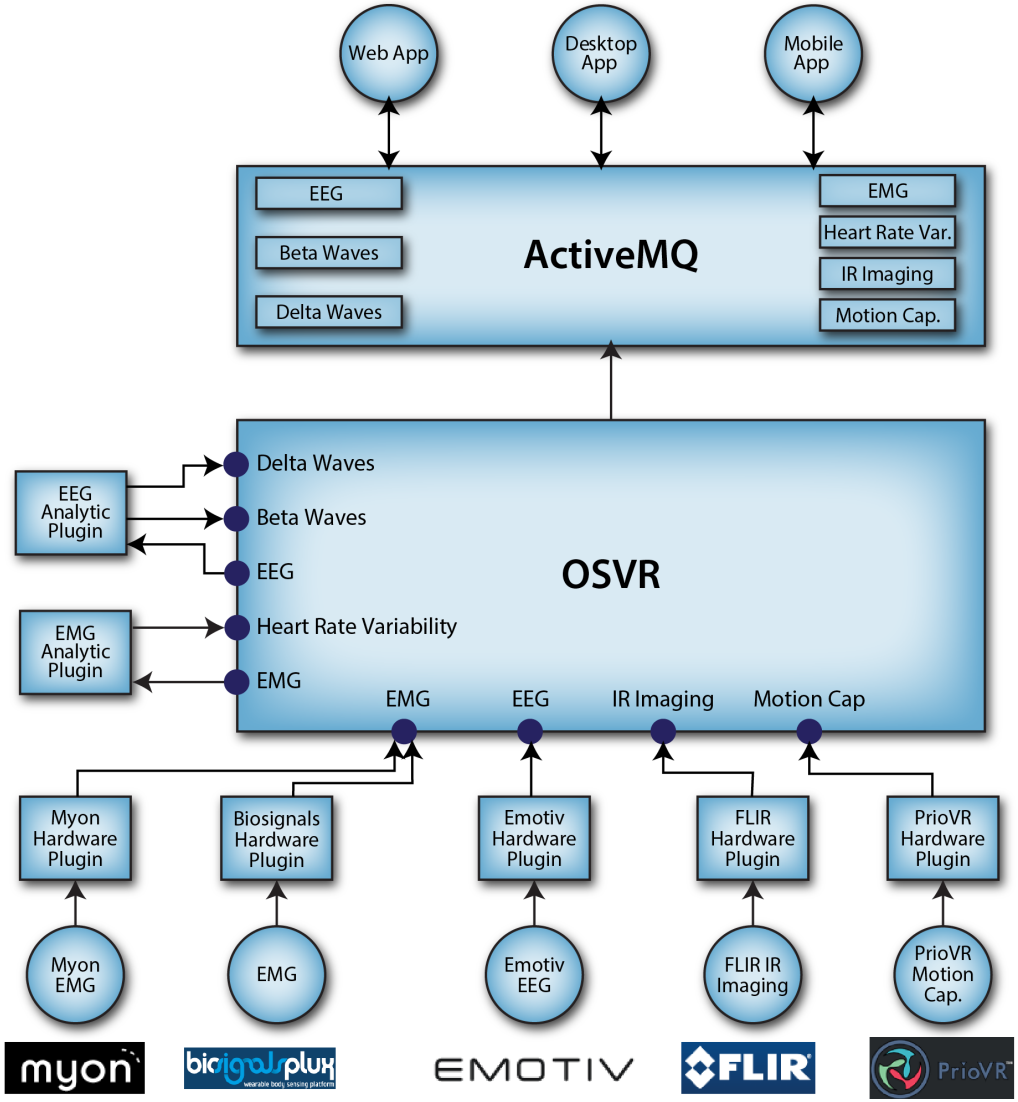
charles river analytics

Synchronized Annotation Tool



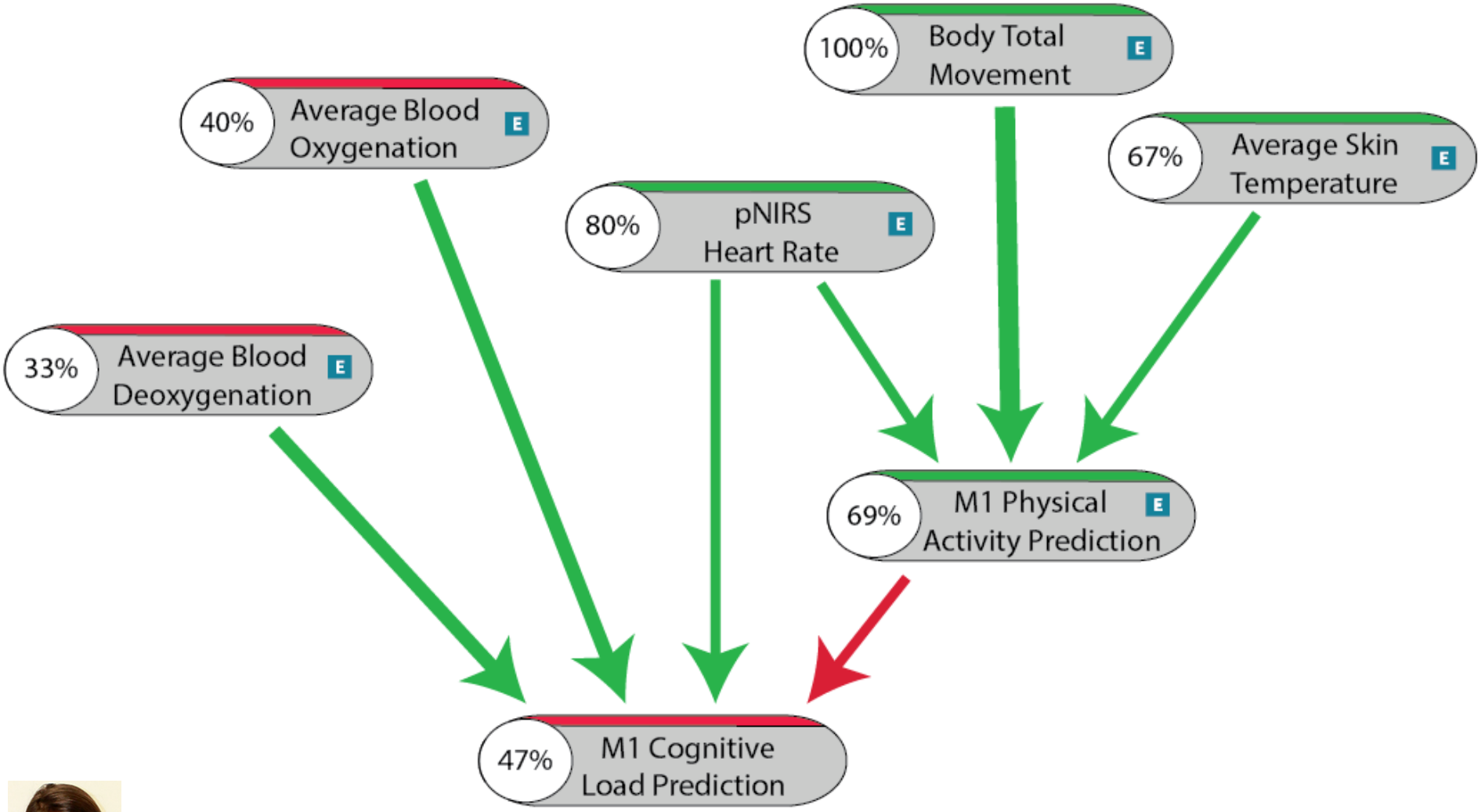
Mr. David Koelle

Data Fusion



Mr. Scott Irvin

Estimating Cognitive Workload



Ms. Noa Palmon

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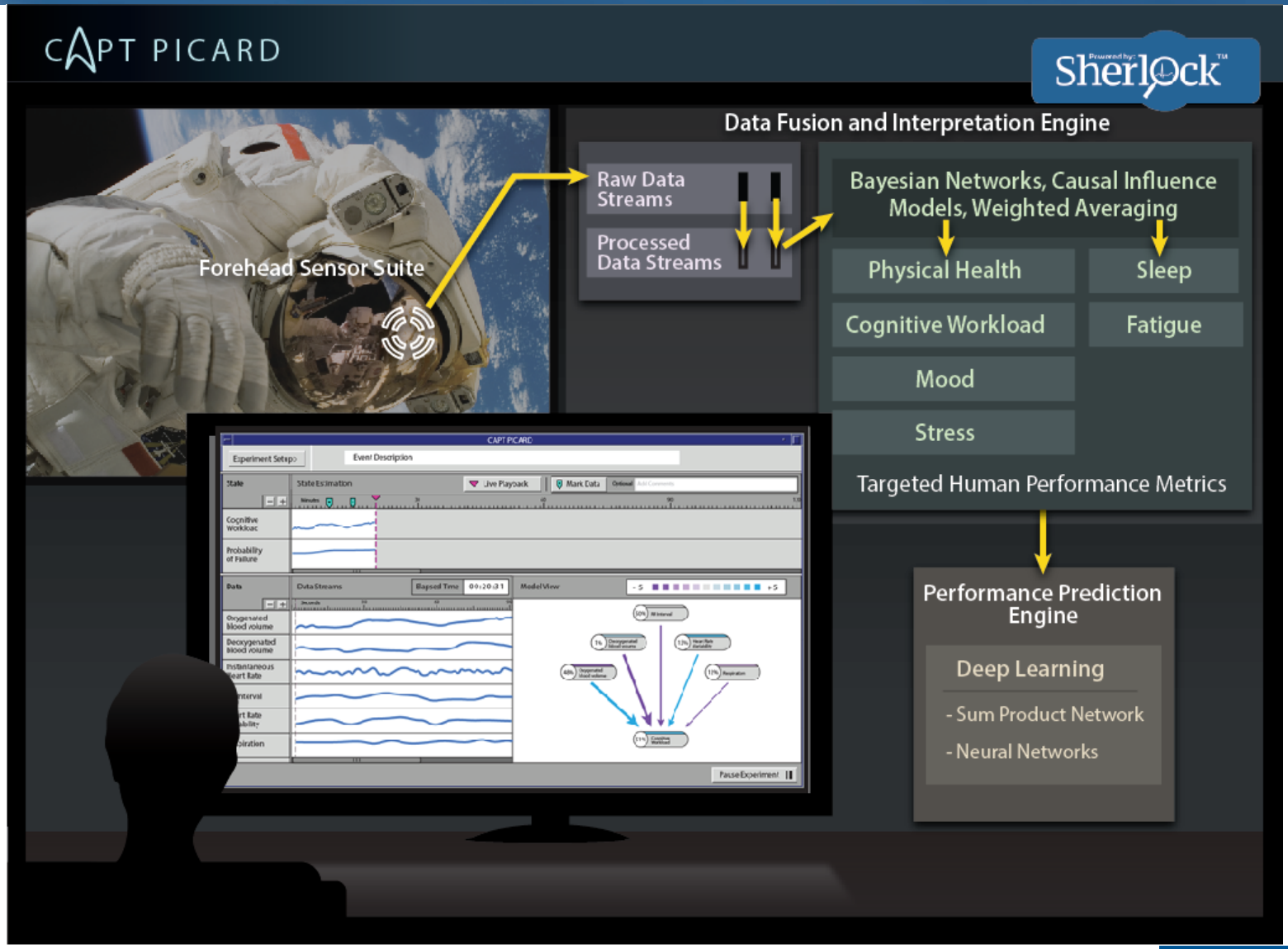
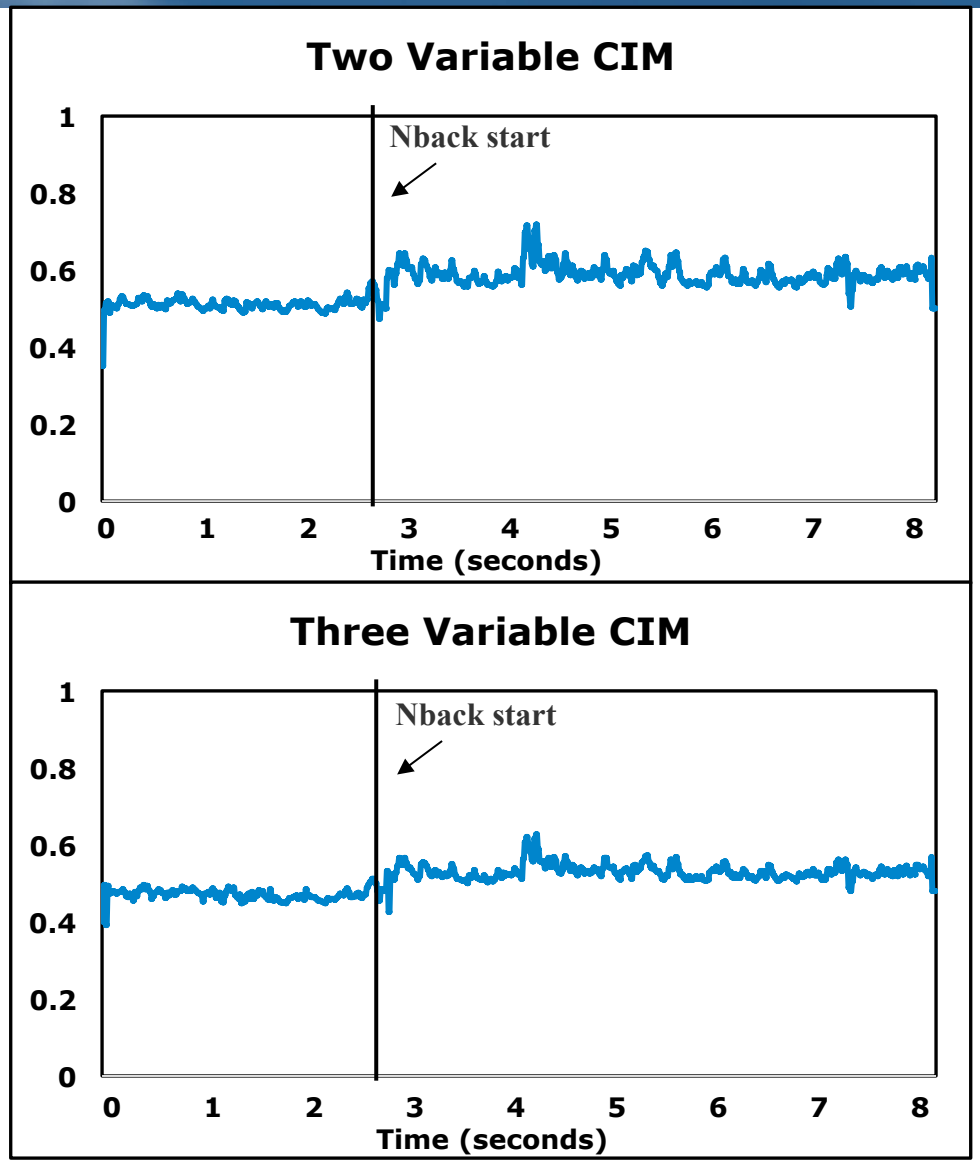
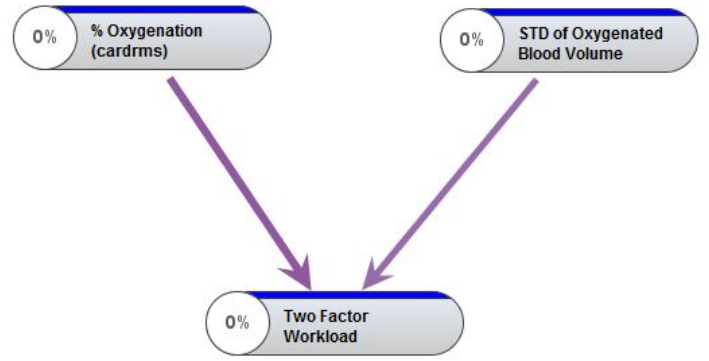
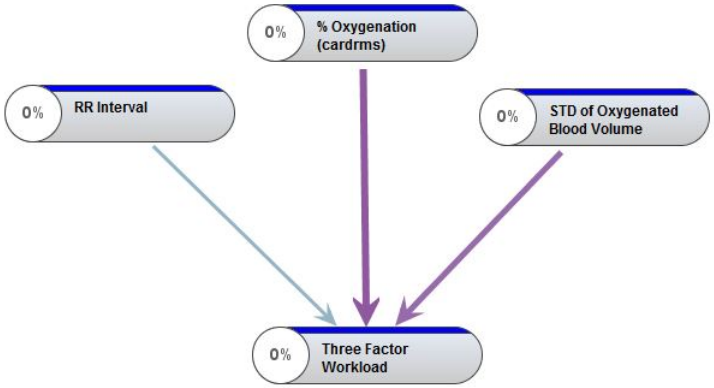


Pilot Study: Estimating Cognitive Workload







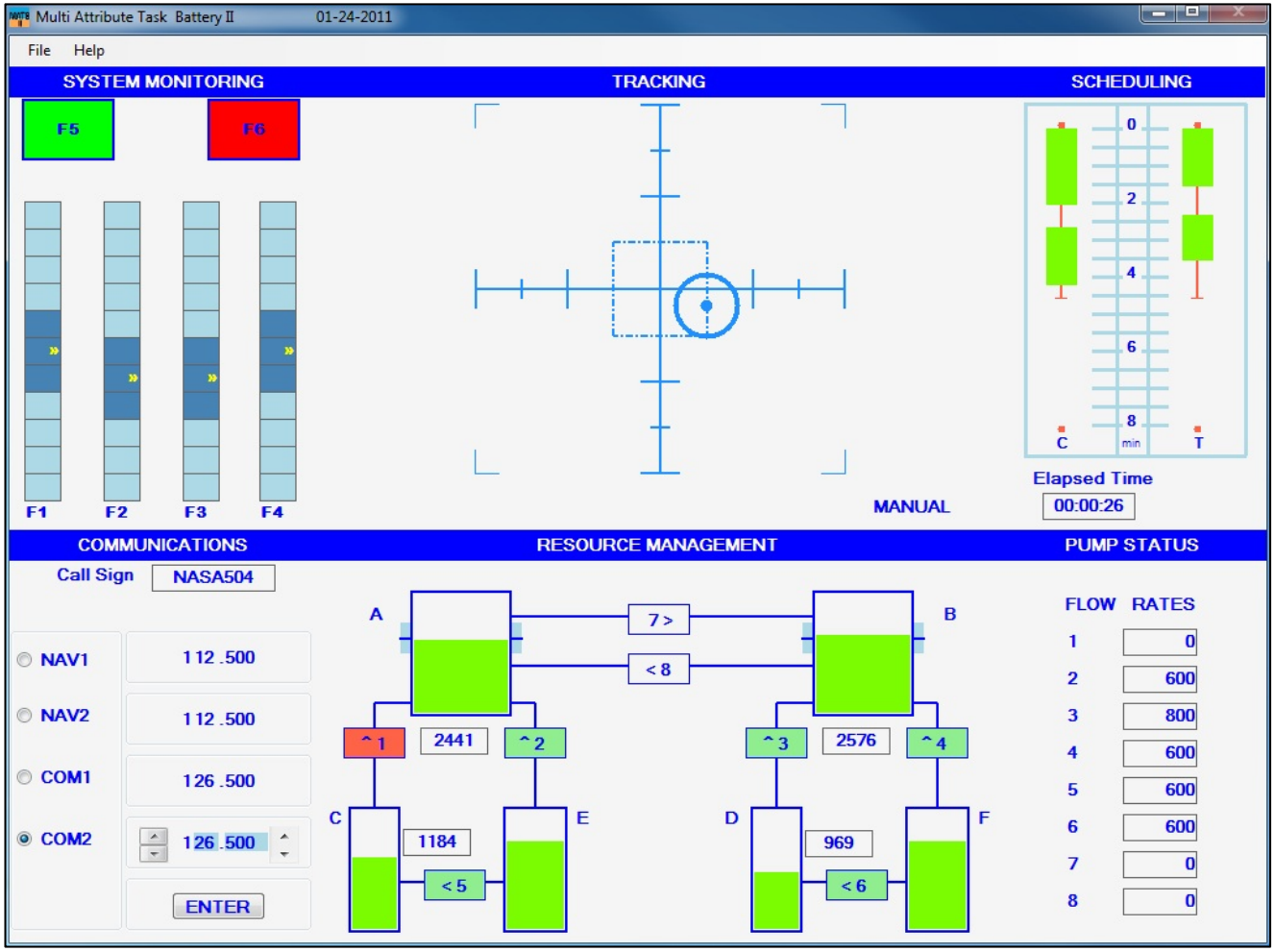
Assessing Cognitive Overload and Boredom

- Baseline Rest
- Cognitive Task Battery
  - N-back (3 levels)
  - Digit Symbol Substitution
  - Psychomotor Vigilance
  - NASA Multi-Attribute Task Battery (3 levels)
- Boredom Induction
  - Peg Turning Task
- Repeat Cognitive Task Battery
- Post Rest

Dr. Elena Festa, Brown University

Assessing Cognitive Overload and Boredom

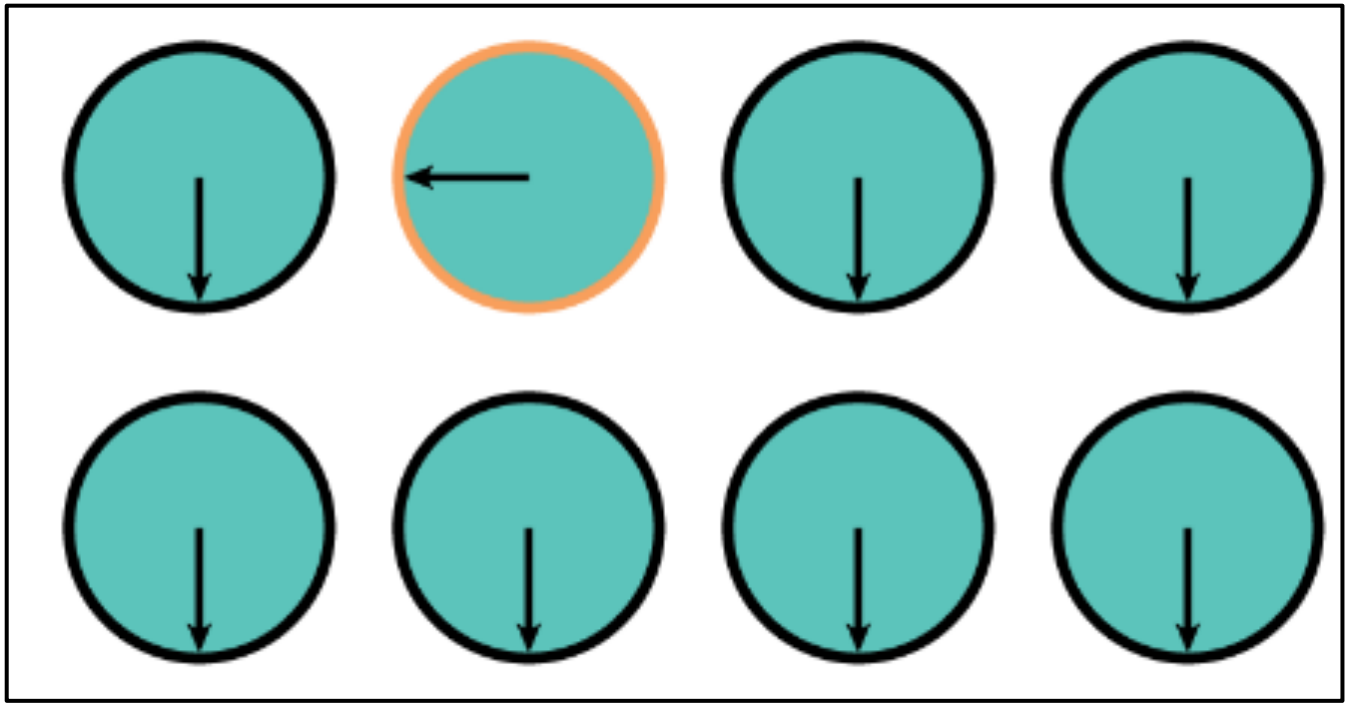
- NASA's multi-attribute task battery (MATB)



Dr. Elena Festa, Brown University

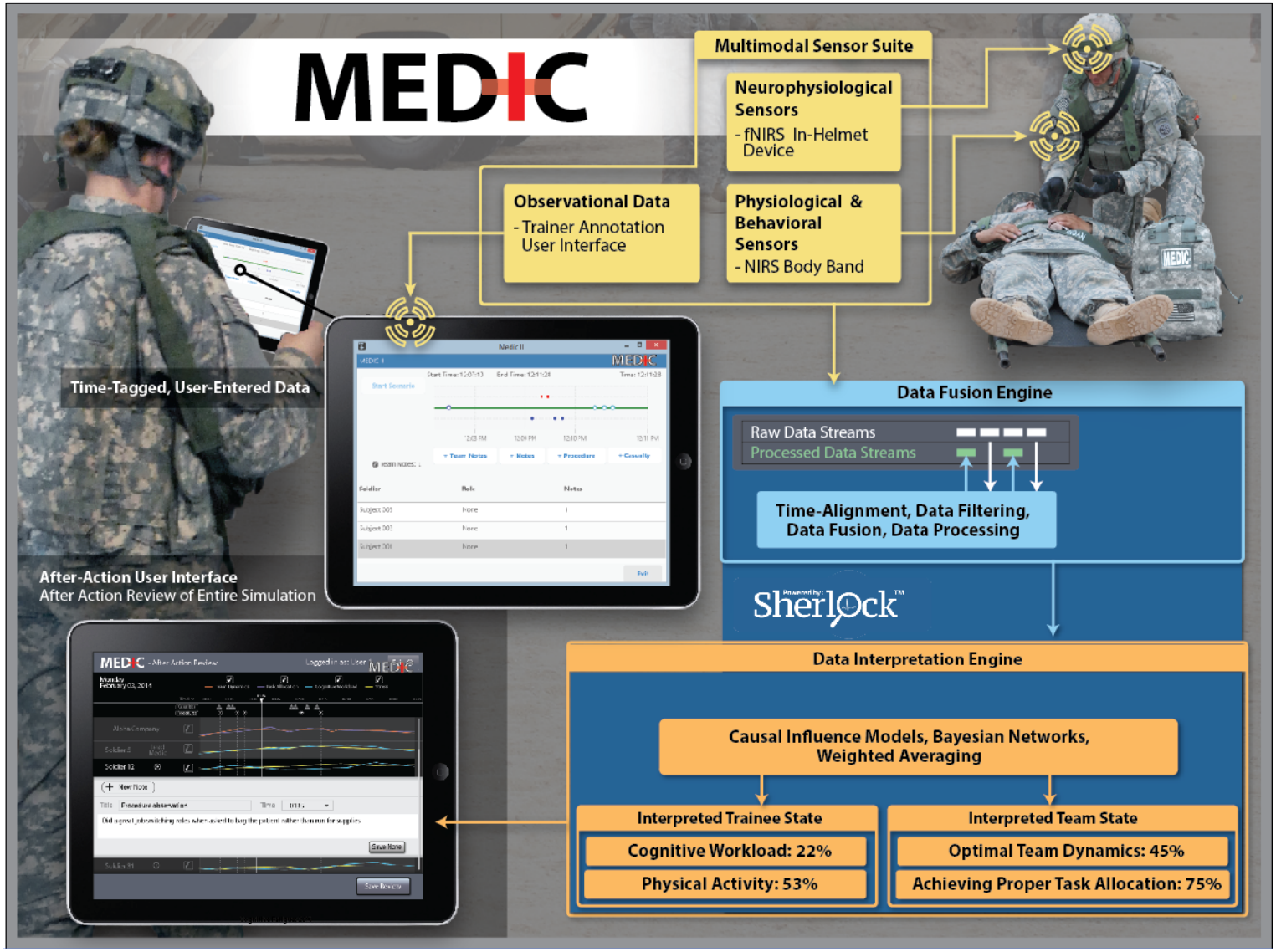
Assessing Cognitive Overload and Boredom

- Boredom induction (Mackey et al., 2014)
  - Peg turning



Dr. Elena Festa, Brown University

A System for Augmenting Training by Monitoring, Extracting, and Decoding Indicators of Cognitive Load (MEDIC)



Assessing Cognitive Overload During Physical Activity

- Baseline
- Word list learning
- Balance ball
- 20 Questions
- Puzzle
- Hot Potato
- Logic problems
- Moving Boxes
- Word list recall
- Team jump rope

- 19 teams completed (excluding pilot data and drop-outs) for a total of 57 participants

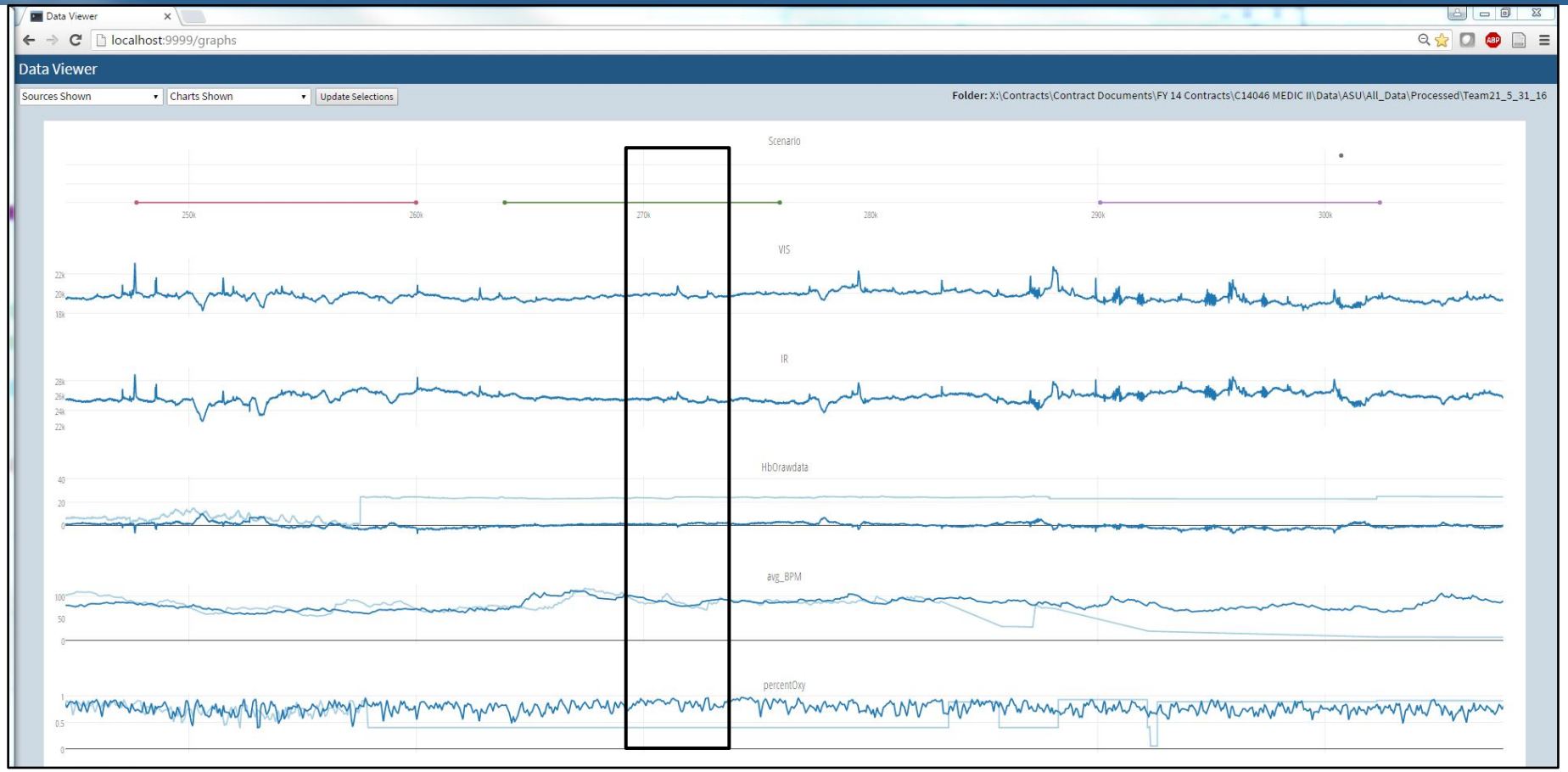
Dr. Polemnia Amazeen, Arizona State University

Data Processing During Motion

Participant 1 Helmet Device
Participant 2 Helmet Device
Participant 3 Helmet Device

Dr. Seth Elkin-Frankston

Data Processing During Motion



Participant 1 Helmet Device
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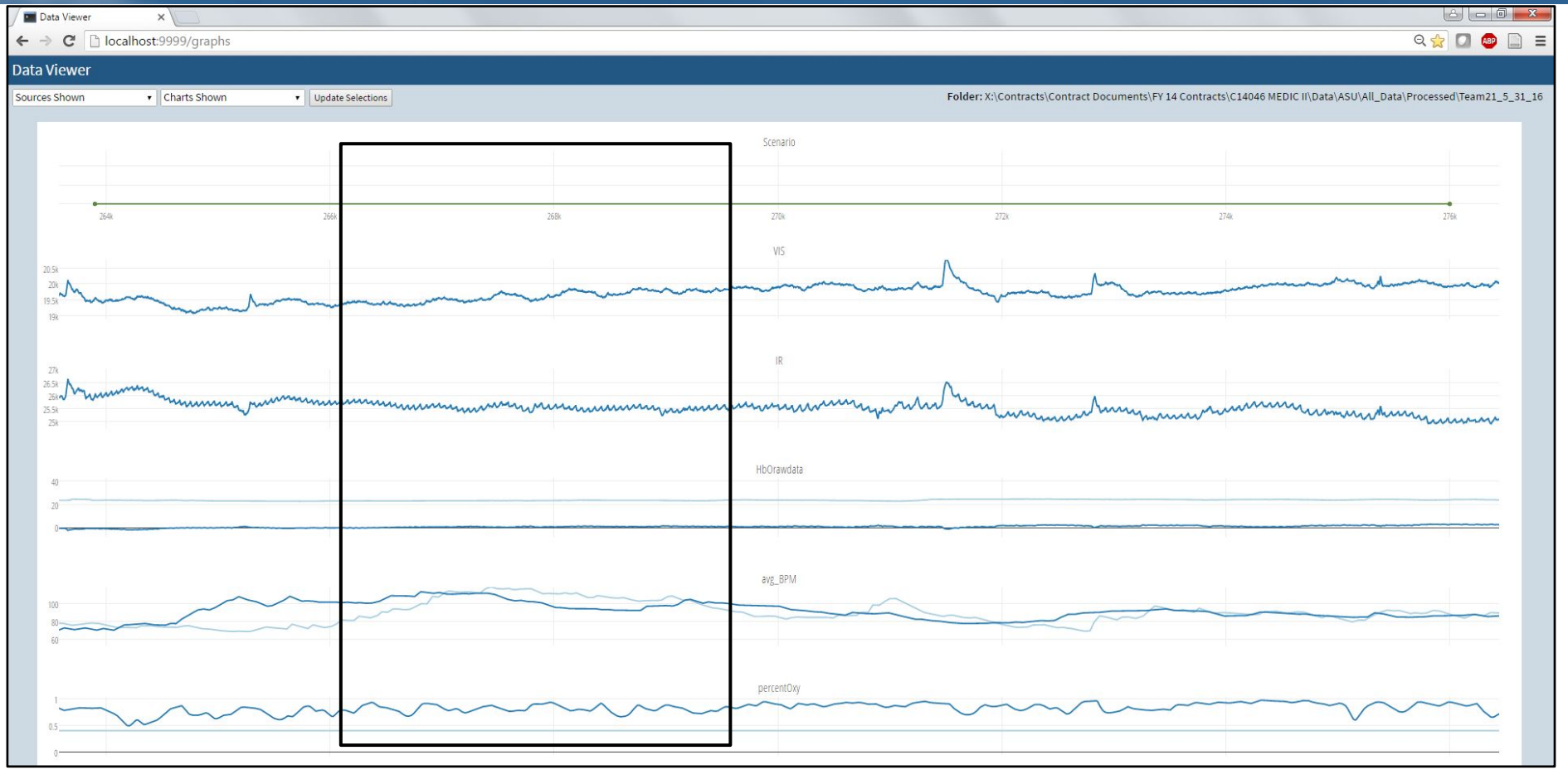
Participant 3 Helmet Device

Dr. Seth Elkin-Frankston

Data Processing During Motion



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Dr. Seth Elkin-Frankston

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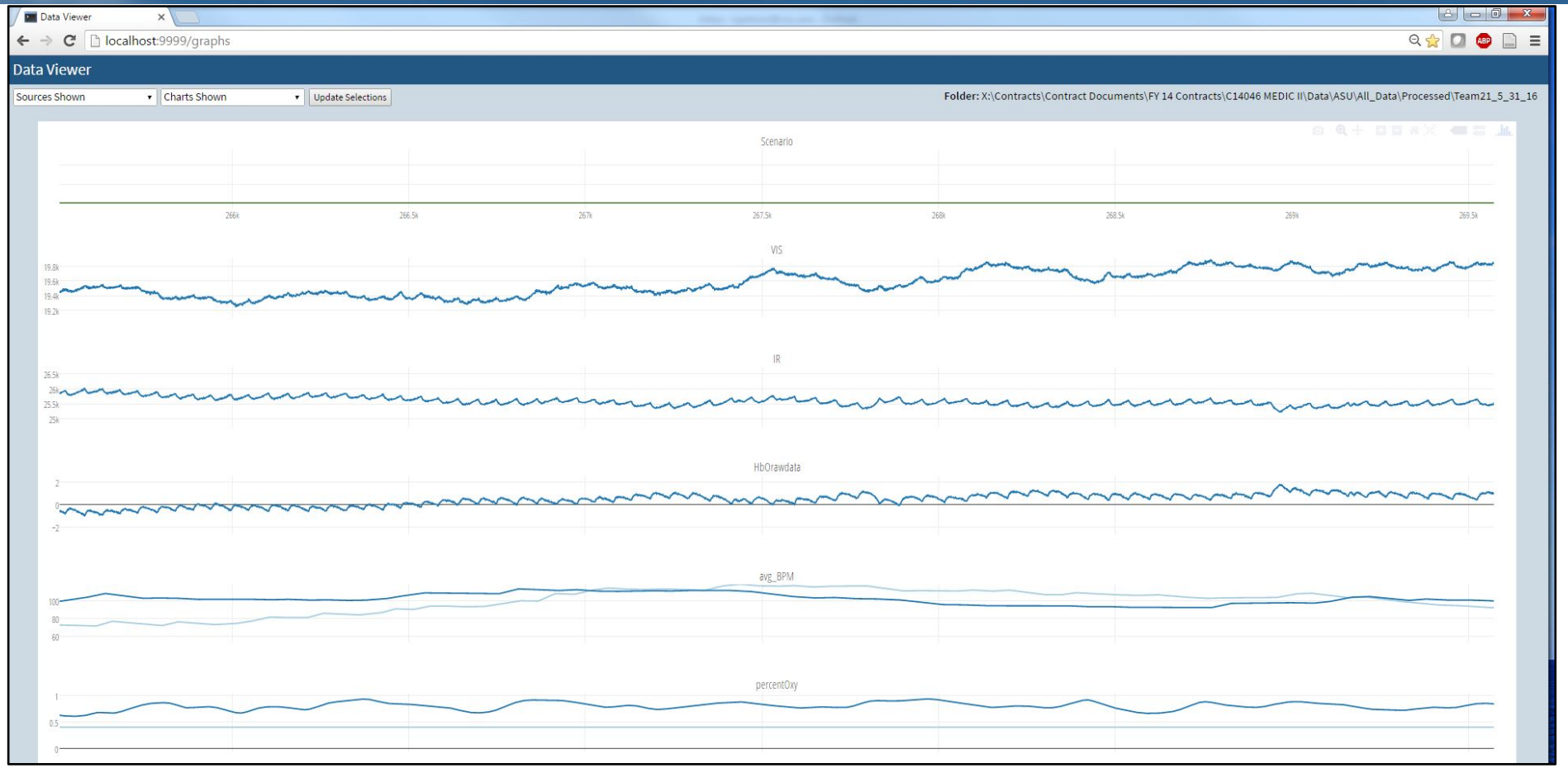


Participant 1 Helmet Device
Participant 2 Helmet Device
Participant 3 Helmet Device

Dr. Seth Elkin-Frankston

Estimating Cognitive Workload During Physical Activity

- Will insert medic modeled data here if we get it done

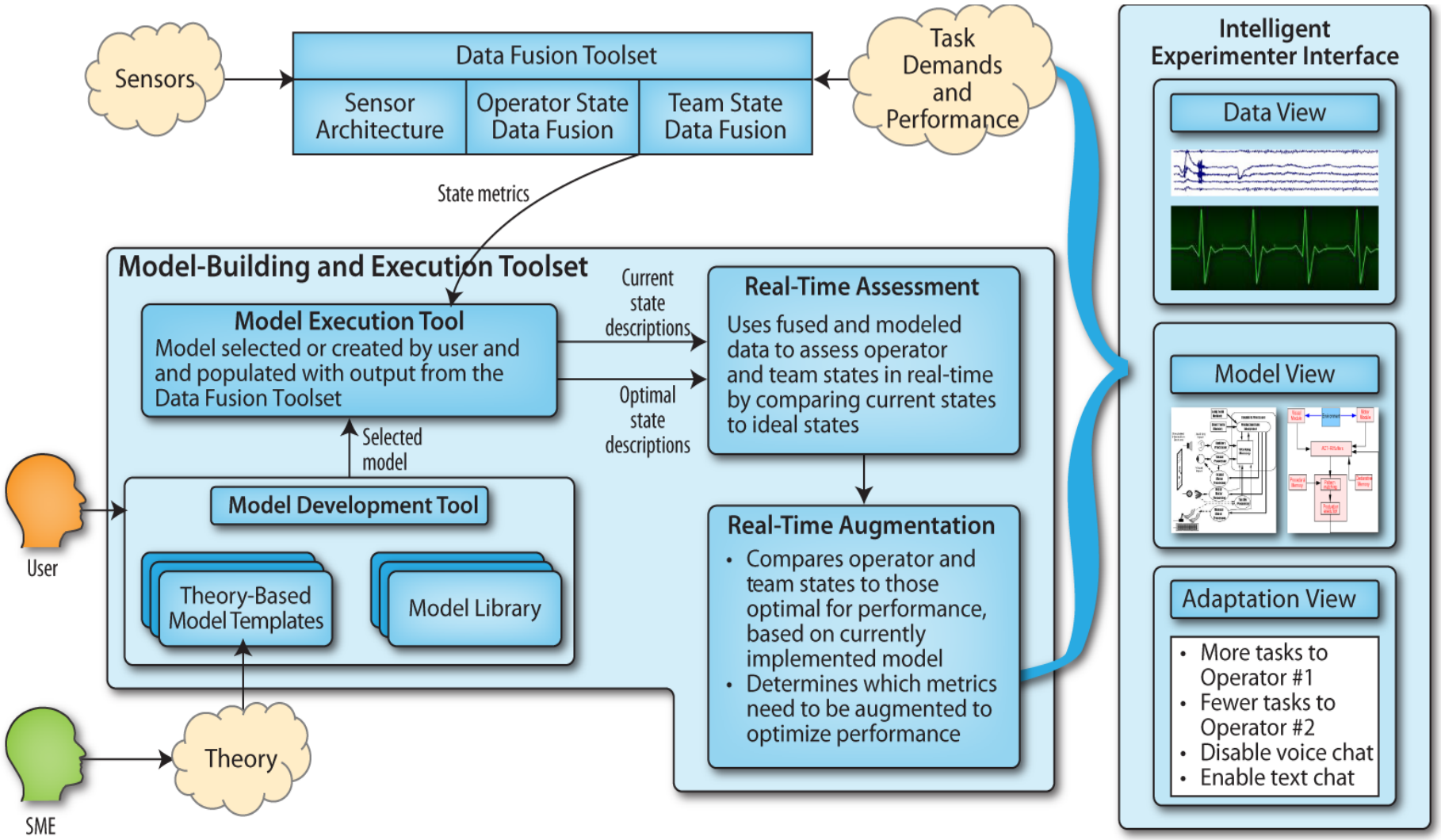
Estimating Cognitive Workload During Physical Activity

- Teams of medical students and faculty members
- High-fidelity medical simulations
- Will update with appropriate data collection statistics (include the data we collected if we can use it, if not estimate when collection will start)

Dr. Matt Weinger, Vanderbilt Medical School

Dr. Arna Banerjee, Vanderbilt Medical School

Adaptive Toolkit for the Assessment and Augmentation of Performance by Teams in Real Time (ADAPTER)



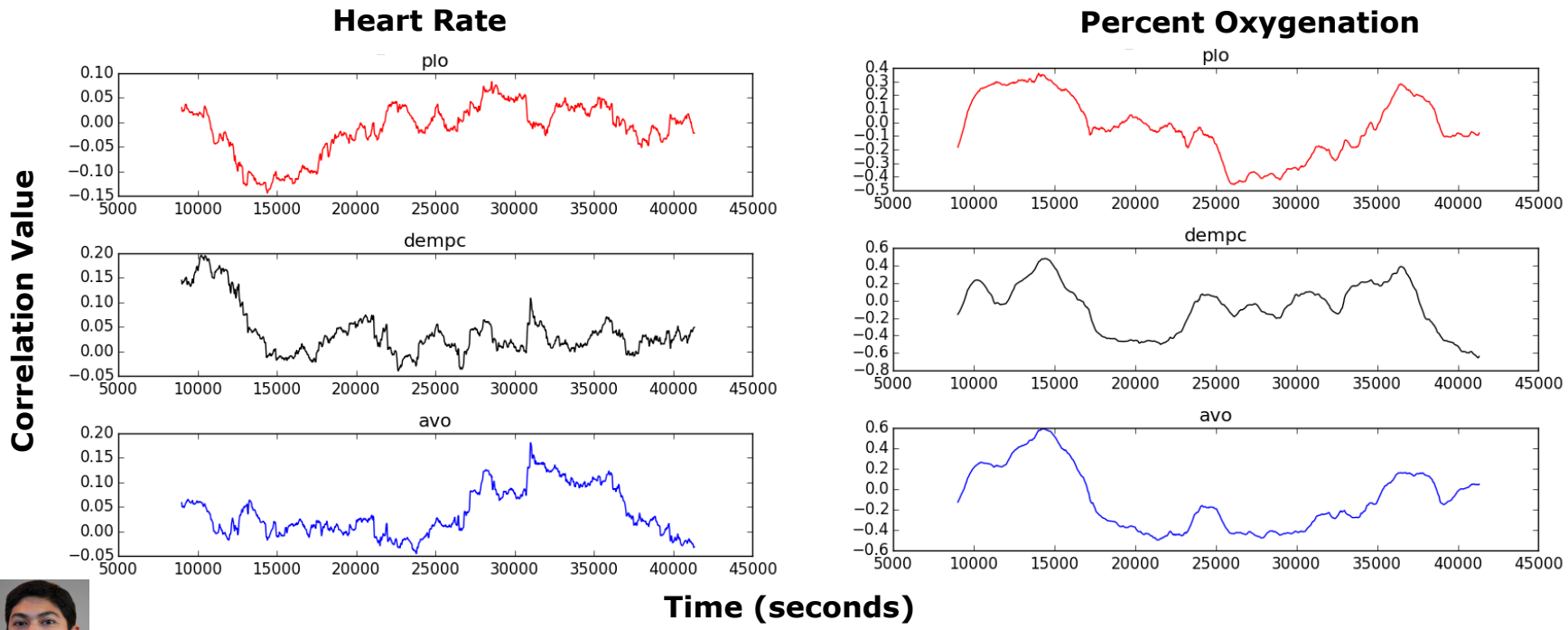
Team-Specific Cognitive Workload Metrics

- Teams of three unmanned aerial vehicle (UAV) task:
  - Air Vehicle Operator (avo) flies the UAV
  - Payload Operator (plo) takes photos of targets
  - Data exploitation, mission planning, and communications operator (dempc) uses a map to plan the UAV route and coordinates with the other teammates

Dr. Nancy Cooke, Arizona State University

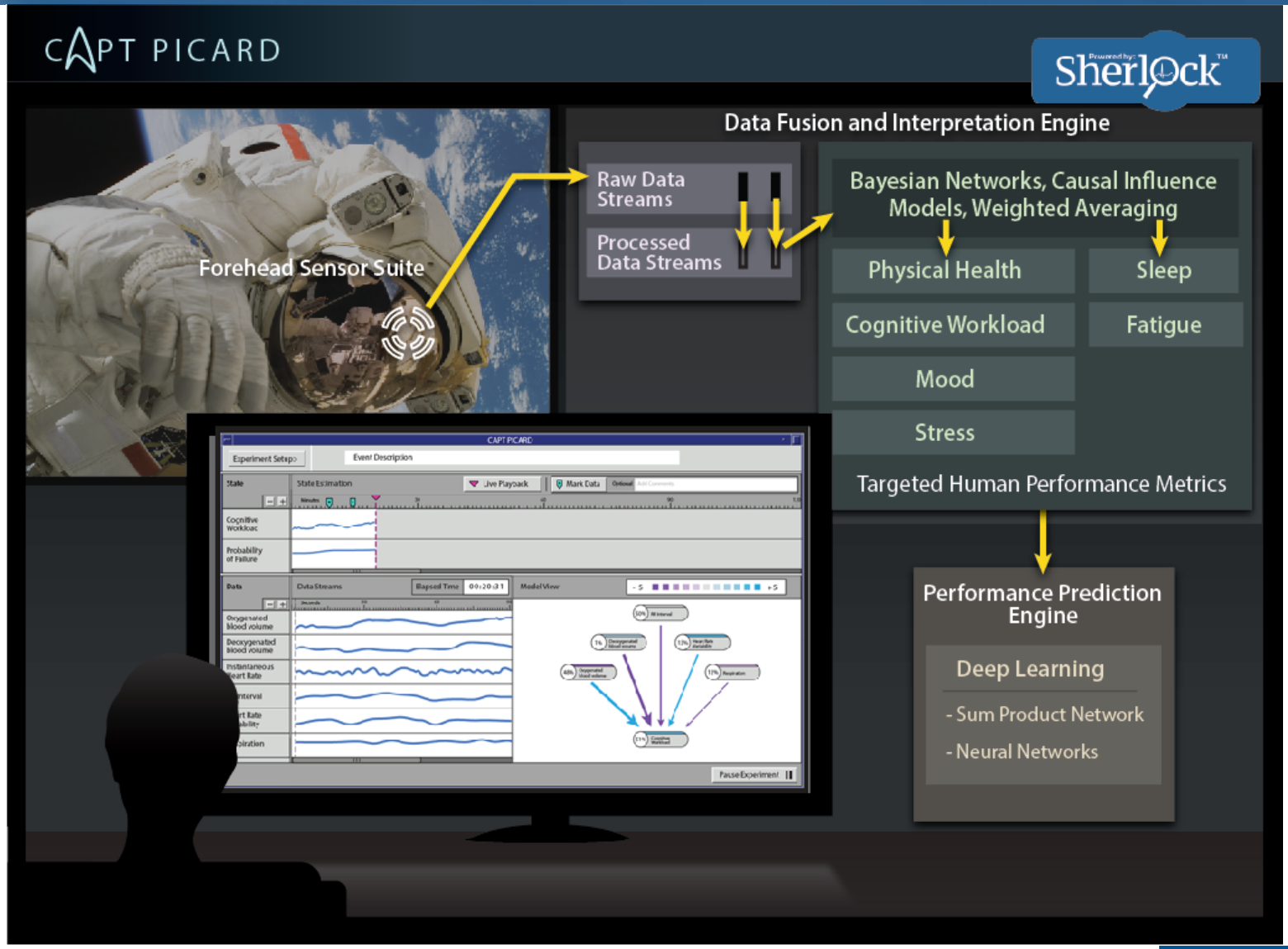
Team-Specific Cognitive Workload Metrics

- Measures of importance are task dependent
- Inter-subject correlation for blood oxygenation significant predictor of team performance (R^2 = .08, $p < .05$)
  - But ONLY for the team leader



Dr. Jorge Barraza, Claremont Graduate University

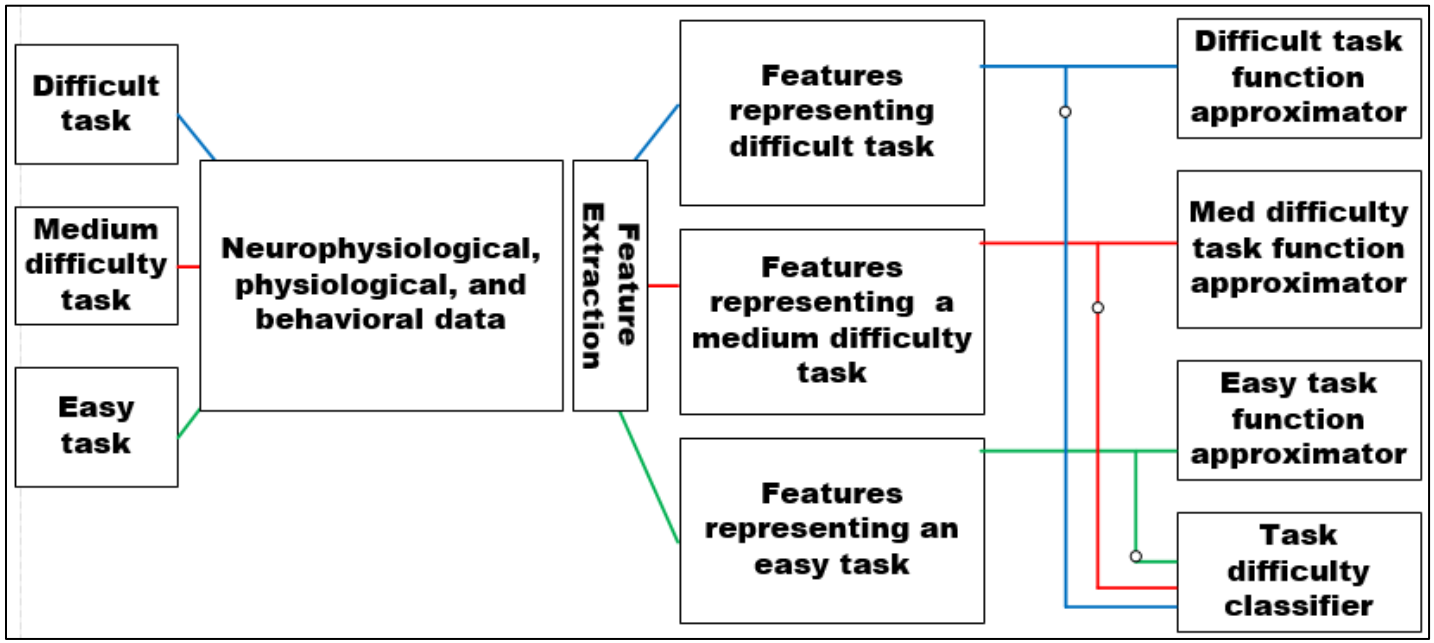
Cognitive Assessment and Prediction to Promote Individualized Capability Augmentation and Reduce Decrement (CAPT PICARD)



Predicting Cognitive Workload and Performance

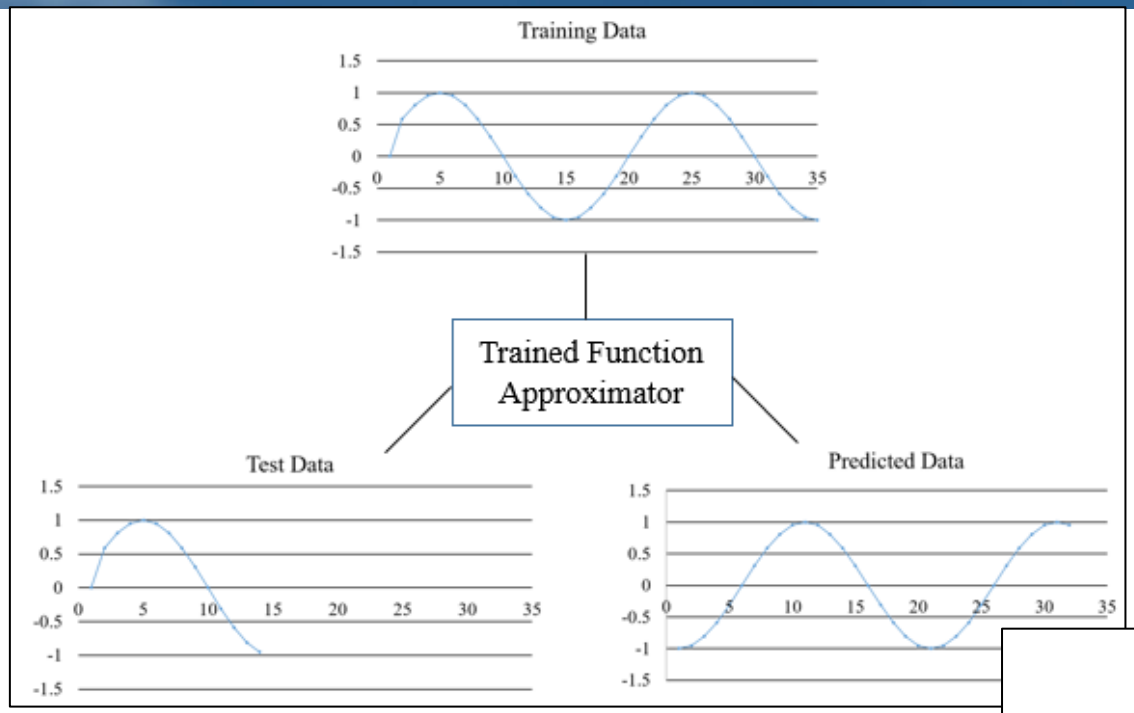
- Design and train classifiers to predict shape of cognitive workload curve (and thus predict when performance will decay) several time steps (seconds or minutes) in advance
  1. Design classifiers to distinguish between groups (bored vs. baseline) and between tasks (e.g., easy, medium, hard)
  2. Curve estimation based on initial portion of curve to predict upcoming decrements

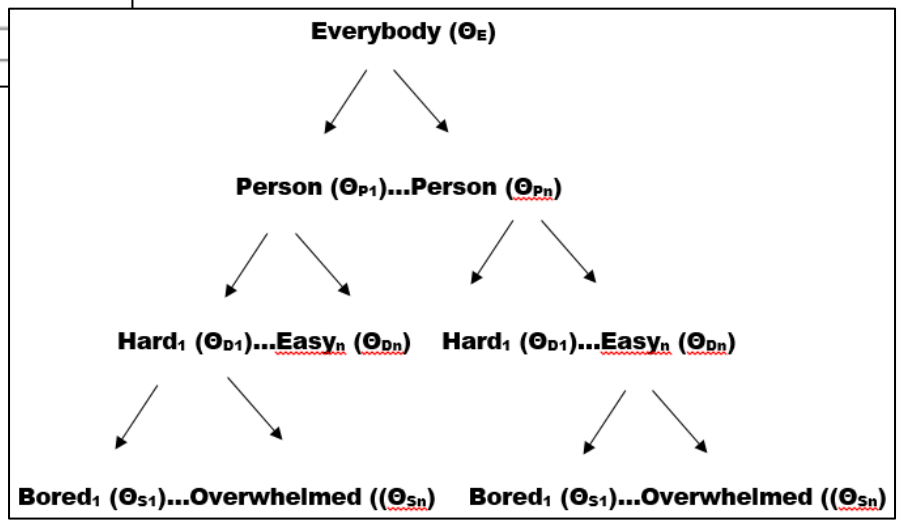
Classifier Design



Mr. Scott Irvin

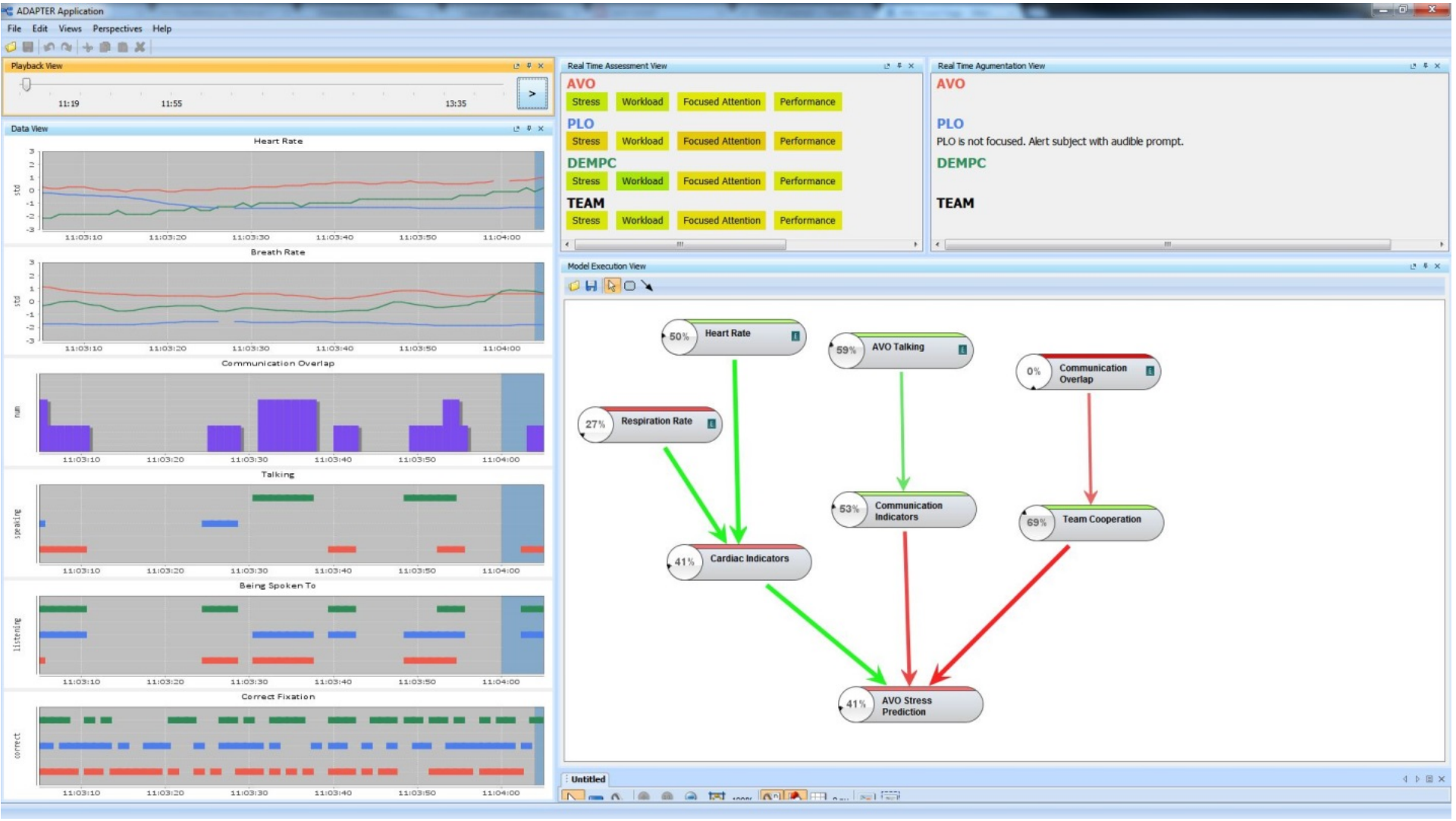
Curve Estimation



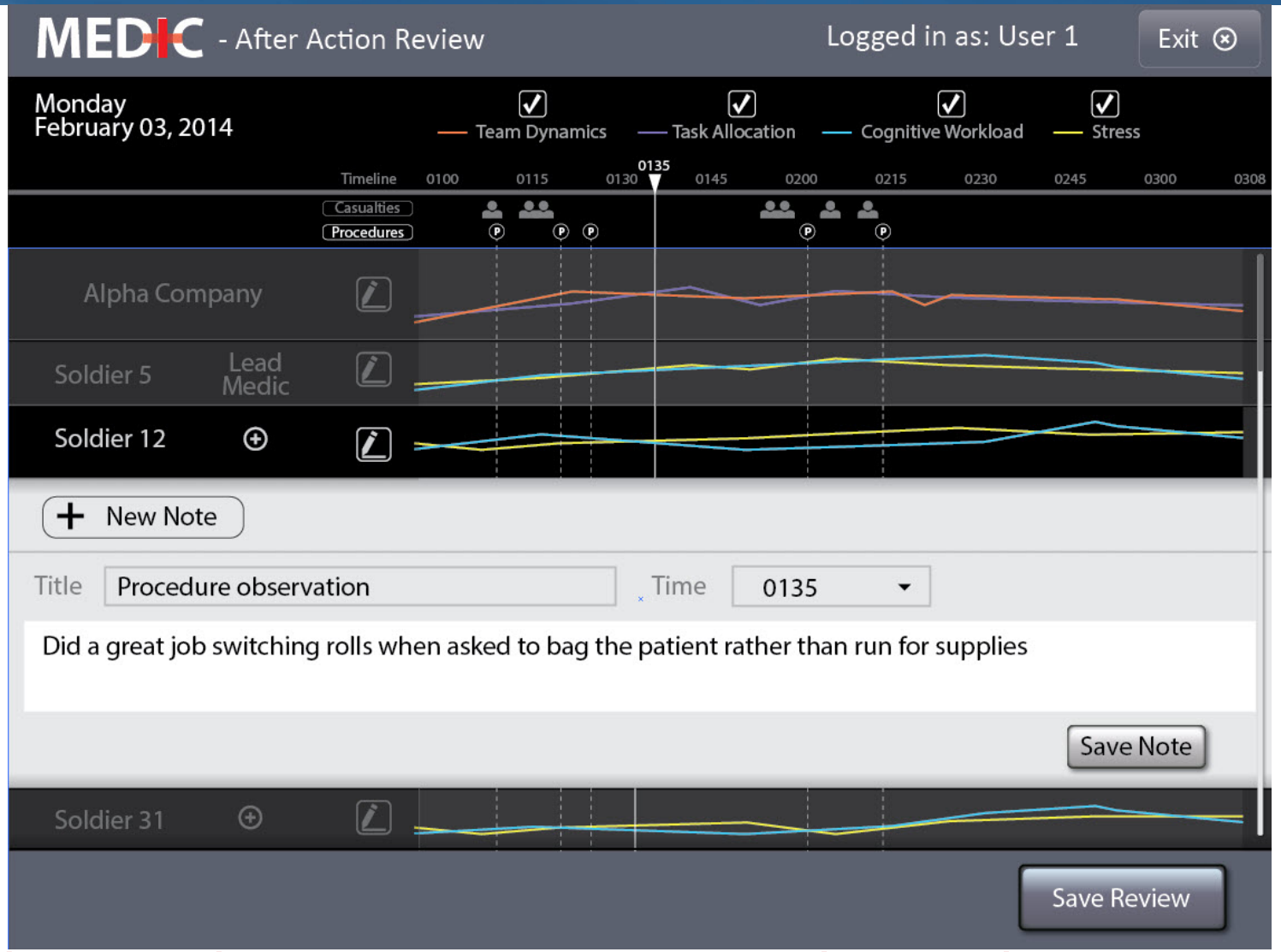


Mr. Scott Irvin

Information Display

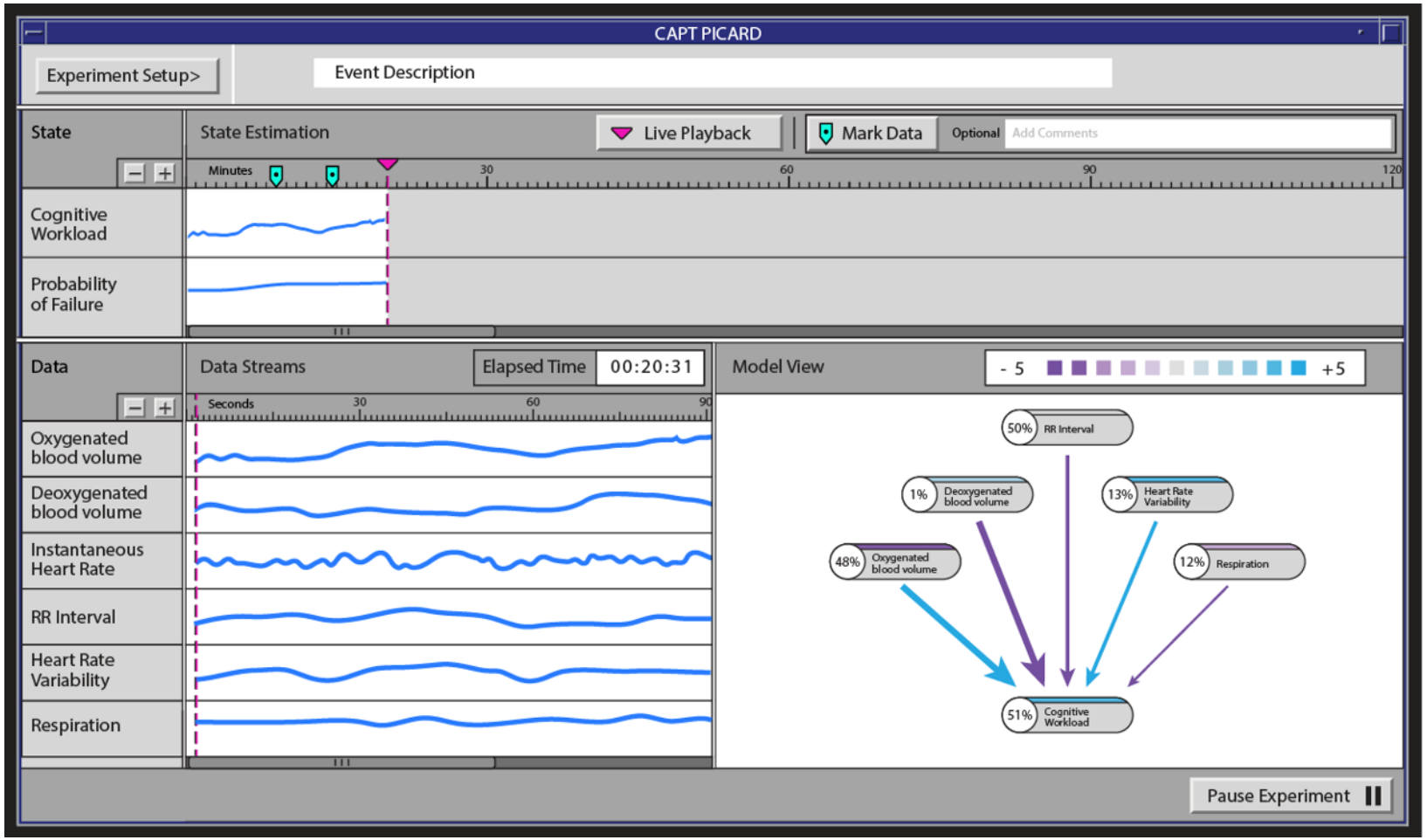


Information Display



Will change this to real UI screen shots when DK sends

Information Display



Agenda

- Company background
  - Company overview
  - Human sensing projects overview
- Cognitive workload sensing
  - Why do we care?
  - Who cares?
- Methods
  - Custom sensing devices
  - Data handling
  - Information display
- **Conclusions**

Generalization of Results

- We believe this approach is widely applicable across domains
- Currently researching commercial applications:
  - Marketing
  - Finance
  - Education
  - Gaming
  - Psychiatric monitoring (e.g., children with ADHD)
- Always looking for collaboration opportunities!

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    - Sensor R&D

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In the conduct of research where humans are the subjects, the investigators adhered to the policies regarding the protection of human subjects as prescribed by Code of Federal Regulations (CFR) Title 45, Volume 1, Part 46; Title 32, Chapter 1, Part 219; and Title 21, Chapter 1, Part 50 (Protection of Human Subjects).

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