U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMY RESEARCH LABORATORY

Cognition and Neuroergonomics (CaN) Collaborative Technology Alliance (CTA) Overview

Dr. Jonathan Touryan, Collaborative Alliance Manager (ARL)

Tim Lee, Program Manager (DCS Corp)

Prof. Paul Sajda, Science Lead (Columbia University)

2020

INTRODUCTION

Cognition and Neuroergonomics (CaN)
Collaborative Technology Alliance (CTA)

Program Year 10
2010 – 2020

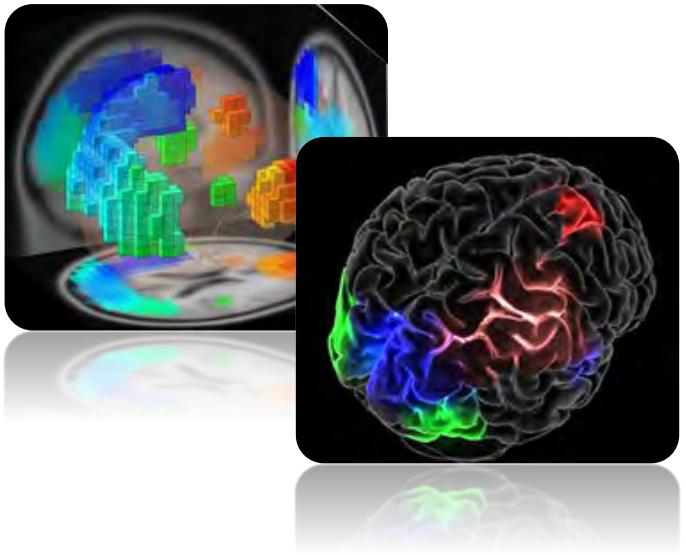
CaN CTA Objective:

The development and demonstration of fundamental translational principles that govern the application of neuroscience-based research and theory to complex operational settings.

Type of Activity = 6.1 Fundamental Research

OUTLINE

- CaN CTA's Role in:
  - Army S&T Efforts
  - The Neuroscience and Neurotechnology Community
- Publication Highlights
- Collaboration History
- Notable Outcome:
  - Large Scale Data Analysis
- Community Influence & Transitions



ESSENTIAL RESEARCH PROGRAMS

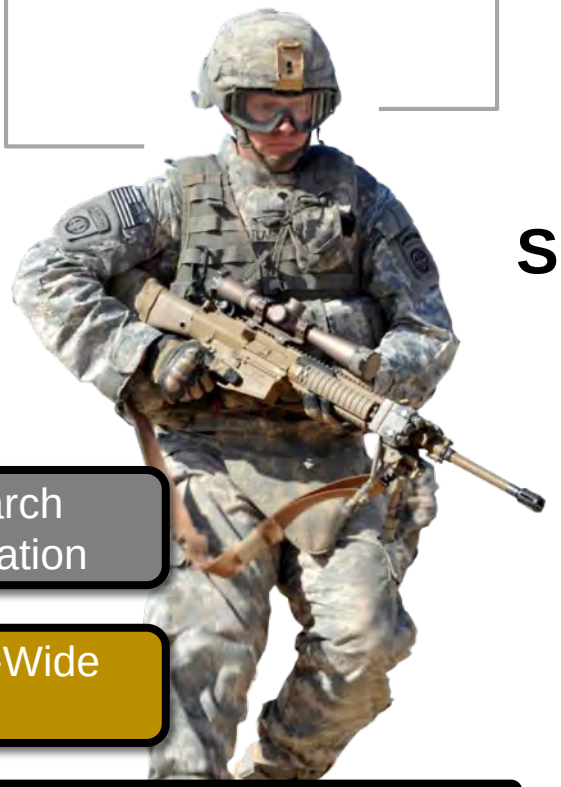
Aligned to the Army's Modernization Priorities for Mid & Far Term

Human Autonomy Teaming
Next Gen Combat Vehicle

AI for Maneuver and Mobility
Next Gen Combat Vehicle

The Army's Corporate Research Laboratory

Human Sciences



Soldier Lethality

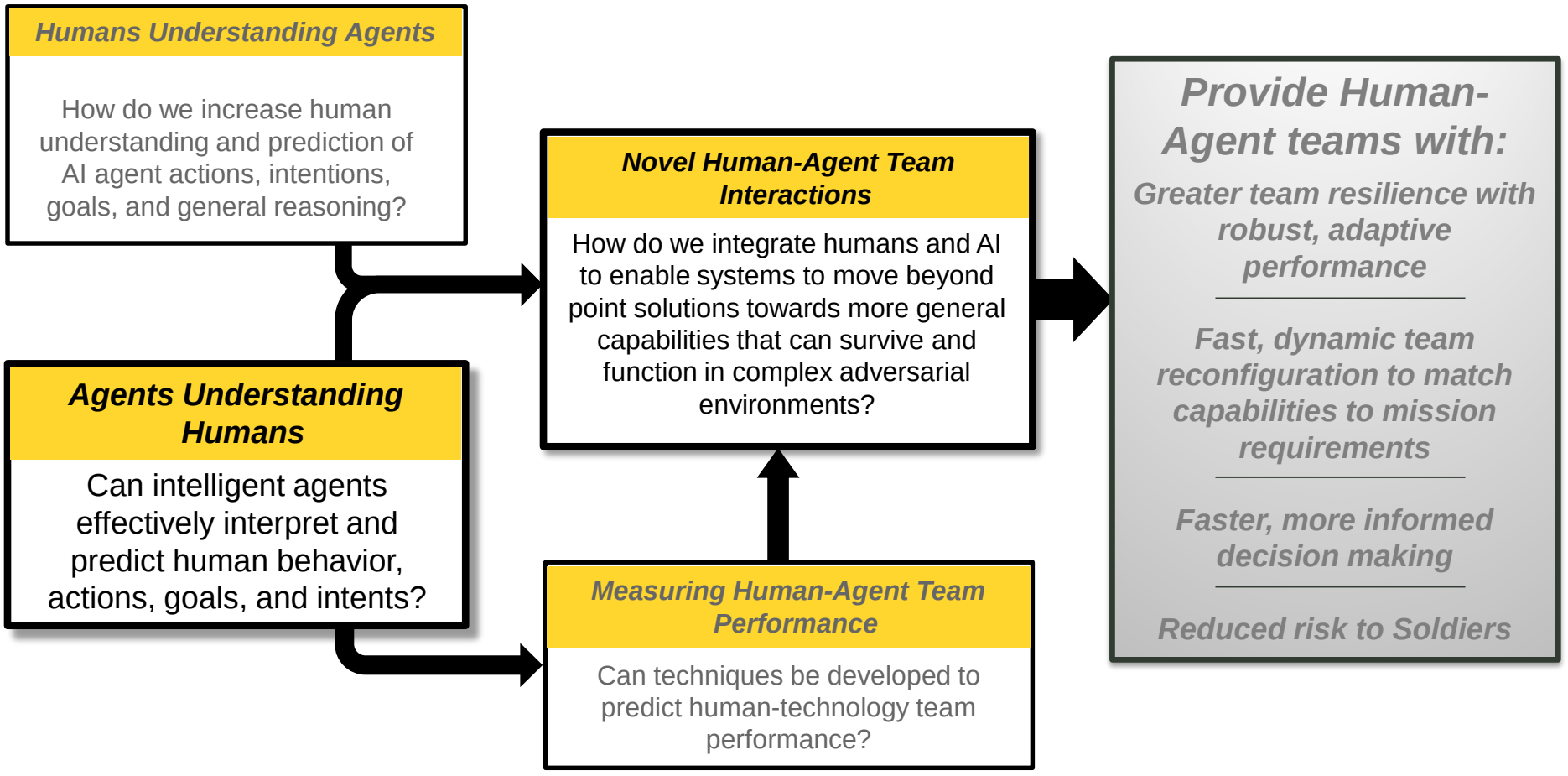
Next Generation Combat Vehicle

Disruptive Foundational Research Supporting U.S. Army Modernization

The Army Interface to the World-Wide Scientific Community

Discovery

HUMAN AUTONOMY TEAMING



OBJECTIVE

Objective*

The development and demonstration of fundamental translational principles governing the application of neuroscience-based research and theory to complex operational settings.

Enable revolutionary advances in Soldier-System performance by integrating modern neuroscience with human factors, psychology and engineering to enhance our understanding of Soldier function and behavior in complex operational settings.

* Initial Program Plan (2010)

Technical Areas*

Advanced Computational Approaches (ACA):

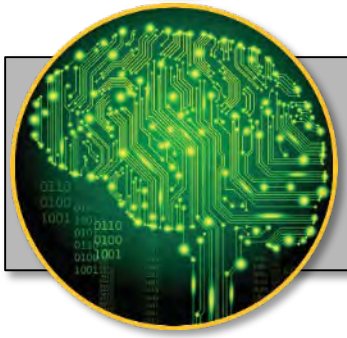
Real World Neuroimaging (RWN):

Brain Computer Interaction (BCI):

* Reorganized in PY4

SCIENTIFIC ORGANIZATION

Advanced Computational Approaches (ACA):
What is the optimal way to decode, track, and fuse neural and non-neural sources of information to infer state?



Real World Neuroimaging (RWN):
How does the brain function in the real-world, outside the constraints of the lab?

Brain Computer Interaction (BCI):
How do we use neural signals to improve human interactions with computers, autonomous agents, their environment, and even other humans?

Key Crosscutting Goal: Continuous and robust estimate of cognitive state in complex tasks and real-world environments

Collaborative Alliance Manager: **Jon Touryan**
Program Manager: **Tim Lee**
Technology Transition COR: **Jon Touryan**
Jonroy Canady

Advanced Computational Approaches

Science Area Leads:

Piotr Franaszczuk **Paul Sajda**

Real World Neuroimaging

Science Area Leads:

Dan Ferris **Dave Hairston**

Brain Computer Interaction

Science Area Leads:

Nick Waytowich **Tzyy-Ping Jung**

STRATEGIC ALIGNMENT

ACA

BCI

RWN

CaN CTA

HAT ERP (NGCV CFT)

Human-Autonomy Teaming
Next Gen Combat Vehicle

INFORMS

INFORMS
Information for Mixed Squads Laboratory

TACK (SL CFT)

Tactical Awareness via Collective Knowledge
Soldier Lethality

STRATEGIC ALIGNMENT

DEVCOM ARMY RESEARCH LABORATORY

HAT ERP

ACA

BCI

CaN CTA

RWN

Army Gaps:

- Understanding between Soldier and autonomous Agents: Teams of distributed Soldiers and agents must have comprehension of each team member's *actions, intentions, goals*, and general reasoning.

Near-Term Roadmap Products

- Algorithmic methods to enable technology *adaptation to individual operators*
- Crew technology to enhance teaming by predicting and adapting to *evolving intent*

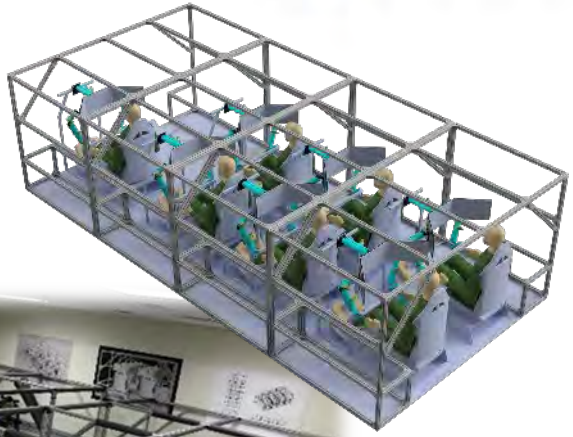
INFORMS

Information for Mixed Squads Laboratory

INFORMS

MUM-T EXPERIMENTAL LAB (MEL)

INFORMS | Information for Mixed Squads Laboratory



Facility to study crew interactions with intelligent agents

- First-of-a-kind platoon-level (dual 7-person) crew station test beds
- Operationally relevant scenario simulations
- Rapid concept development and evaluation of ARL technologies
- Mechanism for addressing constant change

Uses LSL for event logging and multi-modal human sensing synchronization.

Leverages CTA-developed algorithms and approaches for cognitive state estimation and system adaptation.

HRED Bldg. 459

A BRIEF TIMELINE OF THE WORLDWIDE NEUROTECH LANDSCAPE

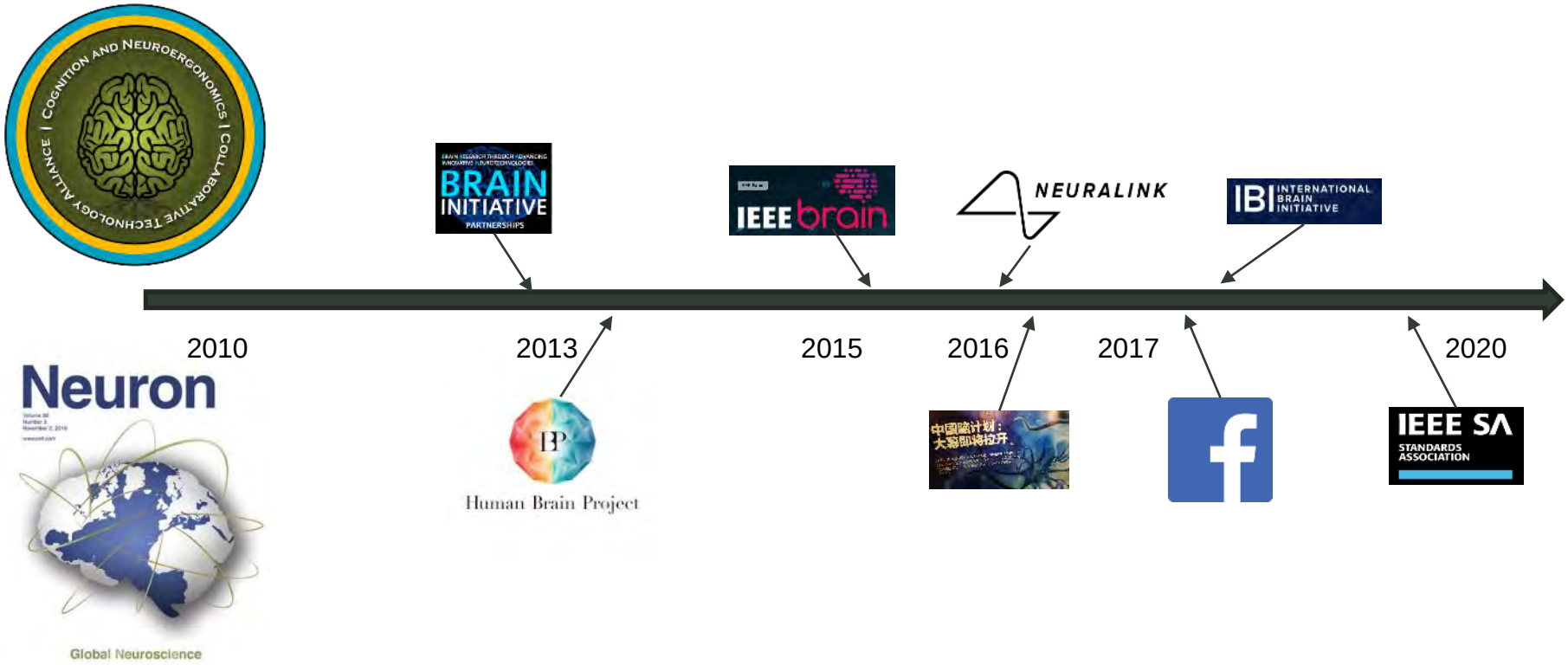
World-wide brain initiatives have been up and running and gaining momentum over the past 10 years

- Integrated efforts involving government, academia, private foundations, and industry
- Near term focus on technology and tool development

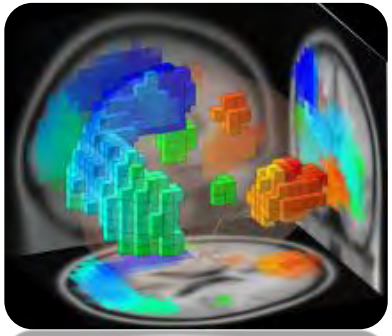
New activities have emerged in professional societies

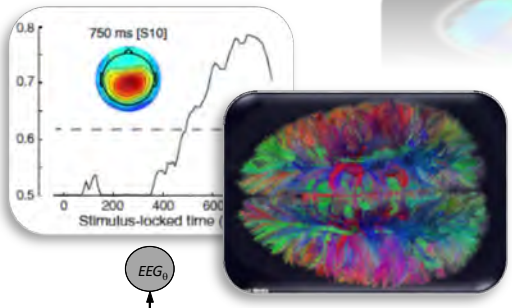
- Focus on standards, ethics, and translation

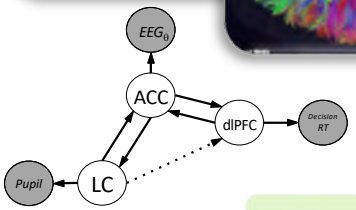
Tech community/Silicon Valley taking notice and starting new ventures

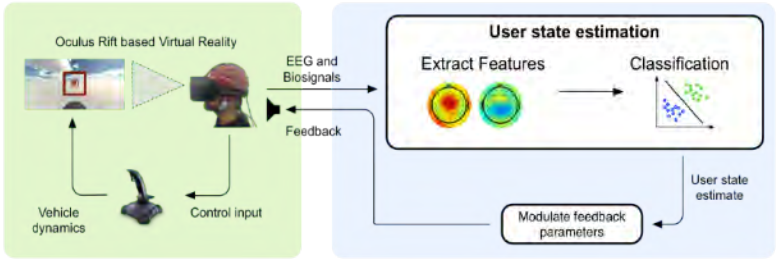


UNIQUE POSITION OF THE CTA





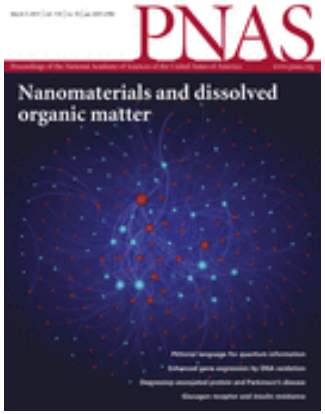




Research Emphasis

- ❑ Human neuroscience
- ❑ Individual differences
- ❑ Brain-state influenced by arousal, fatigue and stress
- ❑ Non-invasive measurements
- ❑ Data fusion and modeling
- ❑ Real-time closed-loop BCI
- ❑ Human-AI interaction
- ❑ Social context

SCIENTIFIC IMPACT



Impact Factor: 9.4
h5-index: 215

Regulation of arousal via online neurofeedback improves human performance in a demanding sensory-motor task

Faller J., Cummings J., Saproo S., Sajda P. (2019) *Proceedings of the National Academy of Sciences (PNAS)*

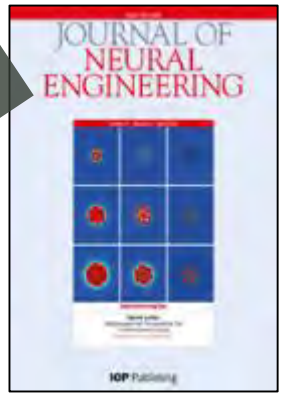
First demonstration of a closed-loop BCI for dynamically shifting arousal to affect online task performance in accordance with the Yerkes and Dodson law.

EEGNet: a compact convolutional neural network for EEG-based brain–computer interfaces*

Lawhern V.J., Solon A.J., **Waytowich N.,** Gordon S., **Hung C.P., Lance B.J.** (2018) *Journal of Neural Engineering*

Compact CNN for neural decoding that generalizes across paradigms better than, and achieves comparably high performance to, the state-of-the-art BCI algorithms.

2019 ARL Award for Seminal Work



Impact Factor: 3.3
h5-index: 51

Bold Names = *ARL* Personnel

* Already has over 450 citations

SCIENTIFIC IMPACT

Human electrocortical dynamics while stepping over obstacles

Nordin A.D., **Hairston W.D.,** Ferris D.P. (2019),
Scientific Reports

During obstacle avoidance supplementary motor area and premotor cortex interrupted the gait cycle, while posterior parietal cortex tracked obstacle location for planning foot placement nearly two steps ahead of reaching the obstacle.

Impact Factor: 5.6
h5-index: 78

Automated EEG mega-analysis II: Cognitive aspects of event related features

Bigdely-Shamlo N., **Touryan J.**, Ojeda A., Kothe C., Mullen T., Robbins K. (2019) *NeuroImage*

Applies Hierarchical Event Descriptors (HED tags) to capture cognitive aspects of events and statistically significant relationships between EEG signals and event types across heterogeneous collections of EEG datasets (17 studies from 6 sites).

Impact Factor: 5.4
h5-index: 117

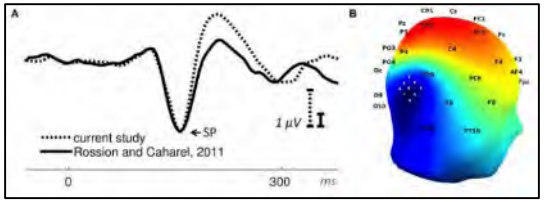
Bold Names = *ARL* Personnel

SCIENTIFIC IMPACT

Impact Factor: 3.6
h5-index: 79

Subjects, Systems, Sessions: to what extent do these factors influence EEG data?

Melnik A., Legkov P., Izdebski I., Kärcher S.M., **Hairston W.D.,** Ferris D.P., König P. (2017) *Frontiers in Human Neuroscience*

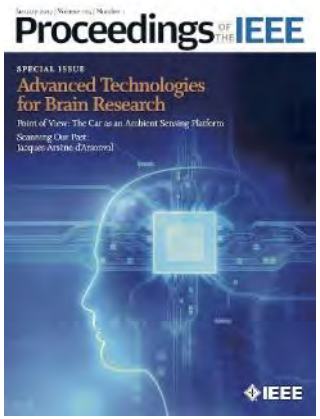


Utilizing a variety of standard laboratory tasks, this study revealed that EEG acquisition hardware system contributes to the overall signal variance as much as inter-subject differences and within-subject fluctuations over time.

Applications of Community Detection Techniques to Brain Graphs: Algorithmic Considerations and Implications for Neural Function

Garcia J.O., Ashourvan A., Muldoon S.F., **Vettel J.M.,** & D. S. Bassett (2018)
Proceedings of the IEEE

A review on how network science tools provide interpretive power and a framework to understand how neural units cluster into densely interconnected groups that are responsible for perception, action, and adaptive behaviors.



Impact Factor: 9.2
h5-index: 83

Bold Names = *ARL* Personnel

SCIENTIFIC IMPACT

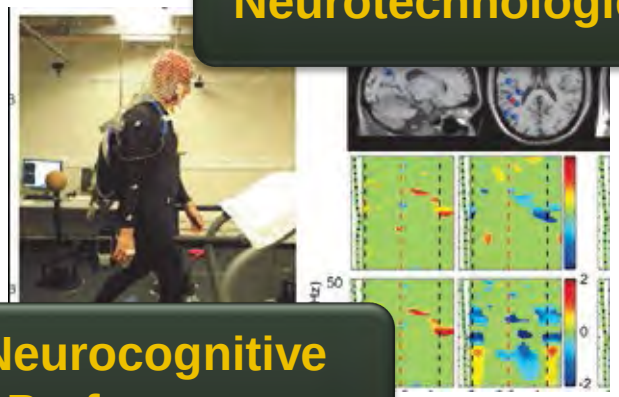
Selected Publications from Ten Years of Research

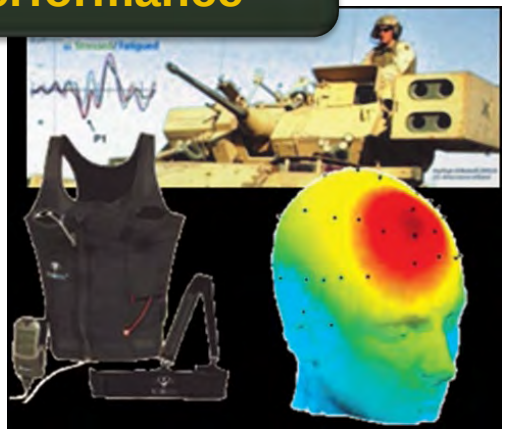
50 selected publications from 10 years of research

Collaboration History

2010 - 2020

PY 1: Initial Program Plan





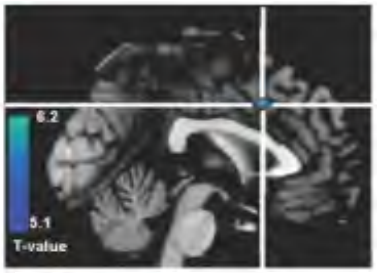
Neurotechnologies

Neurocognitive Performance

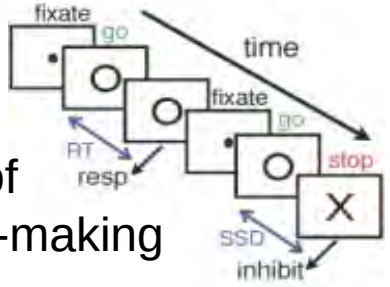
Advanced Computational Approaches

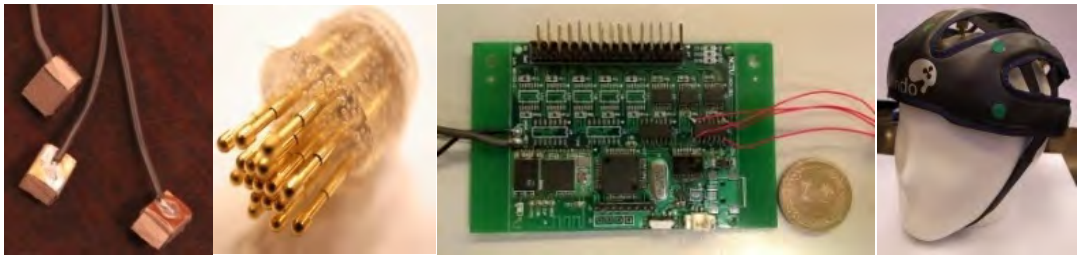
PY 2: Refine and Adjust

Multi-Screen Search

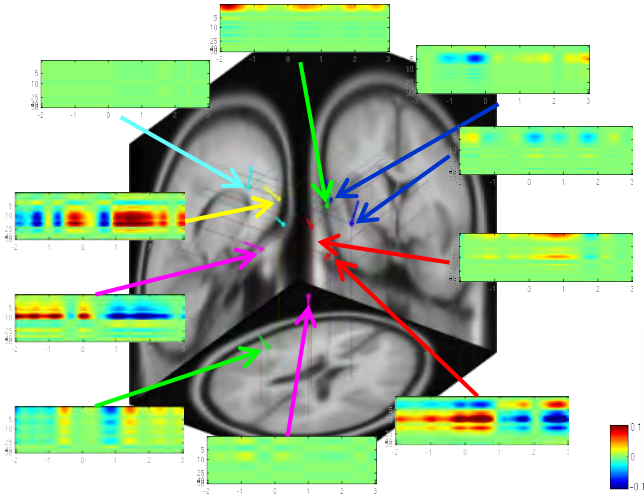


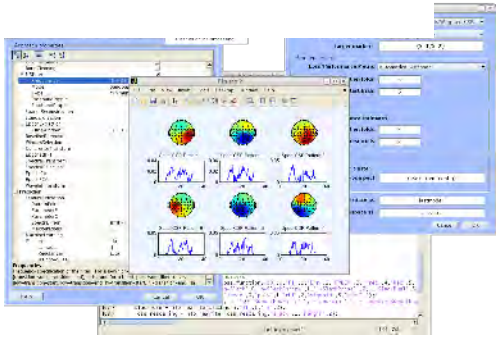
Models of Decision-making



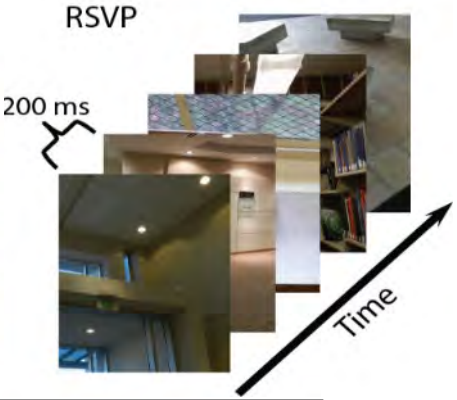


PY 3: Build Tools and Methods





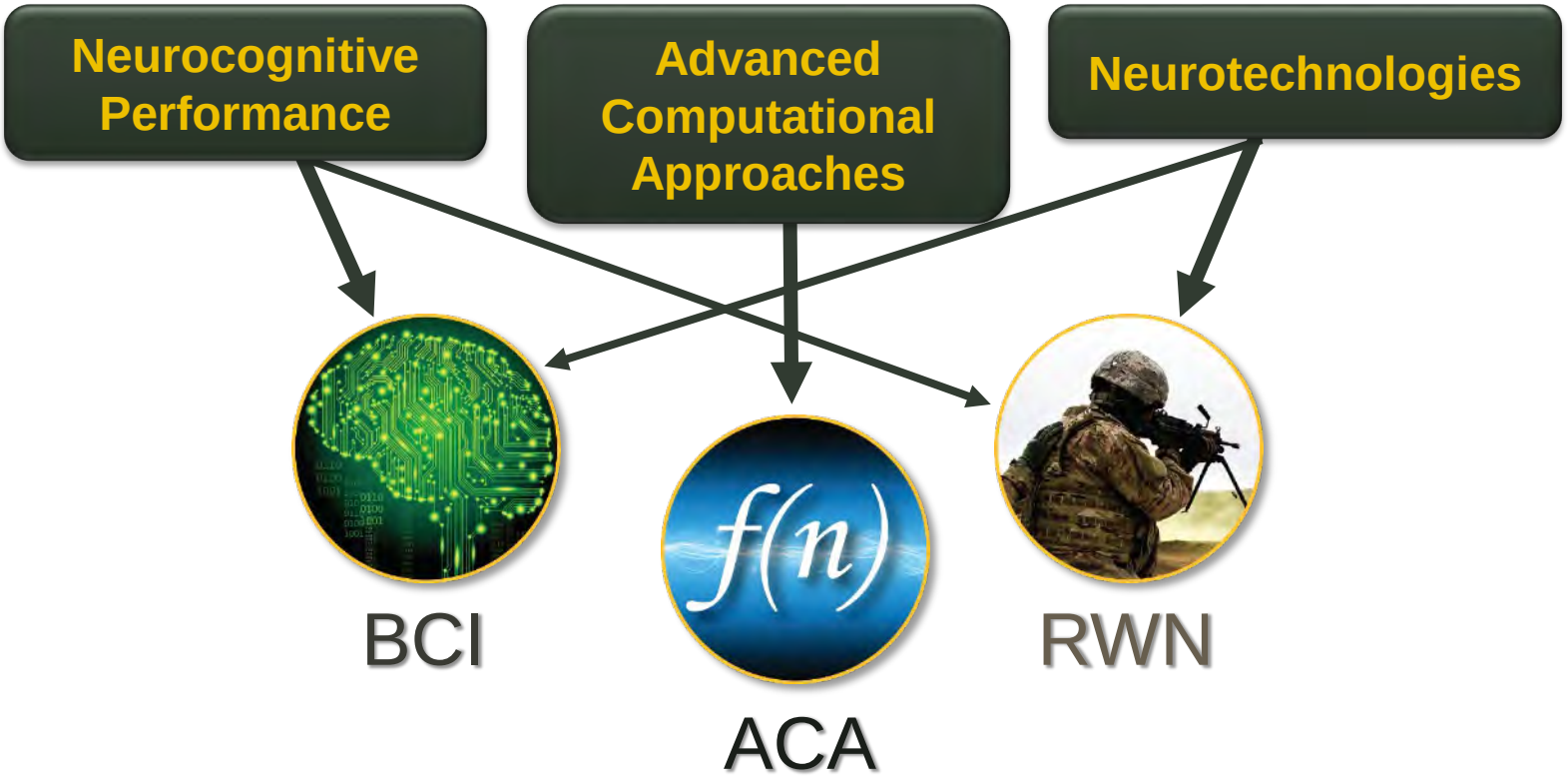
PY 4: Data Collection



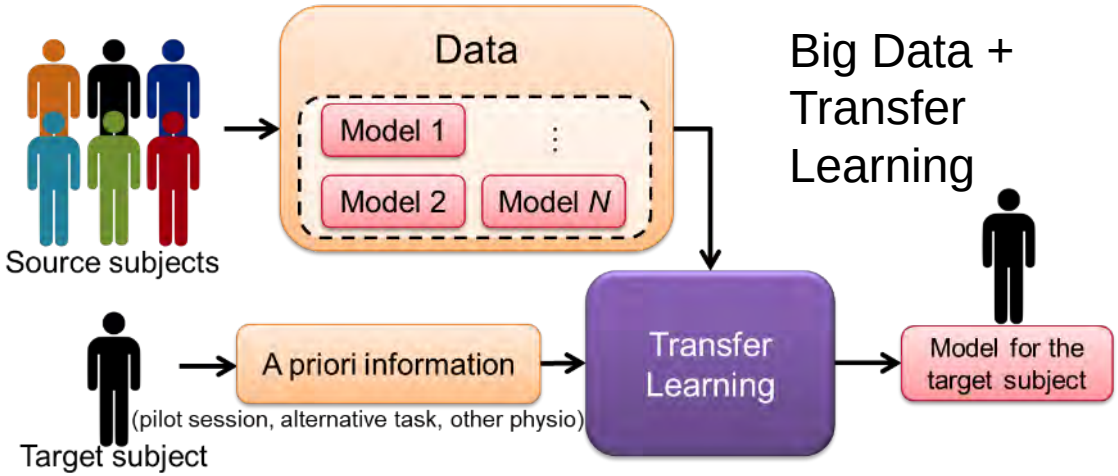
Large scale data collection in less constrained environments

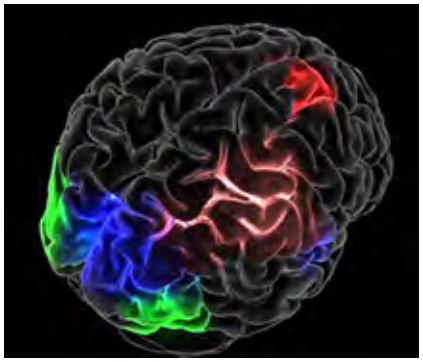
Real-world neuro signal extraction algorithms

PY 5: Program Refocus

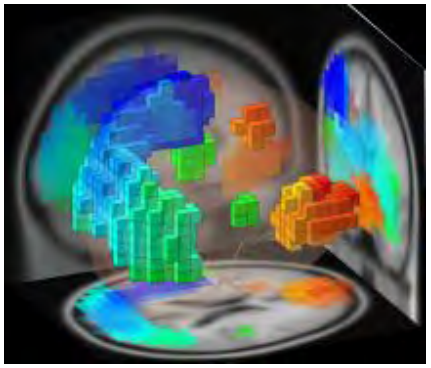


PY 6: Advancing Algorithms

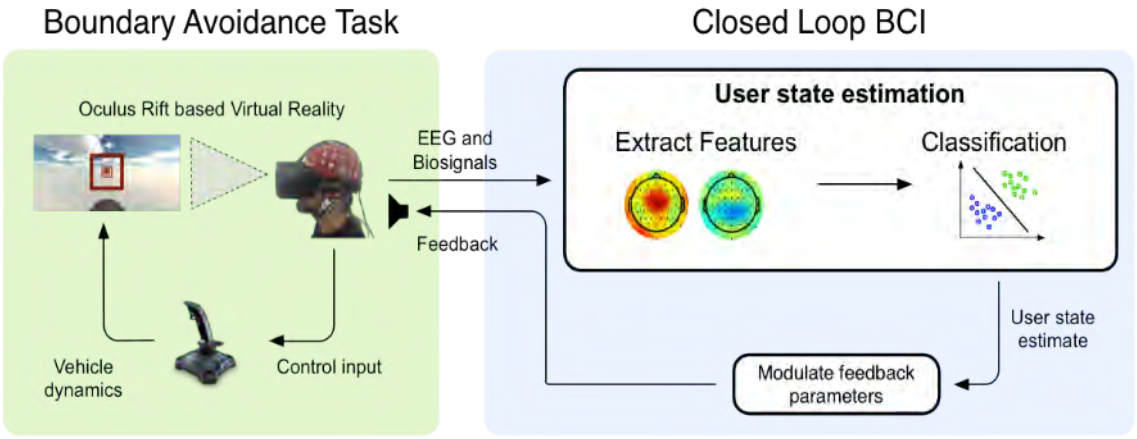


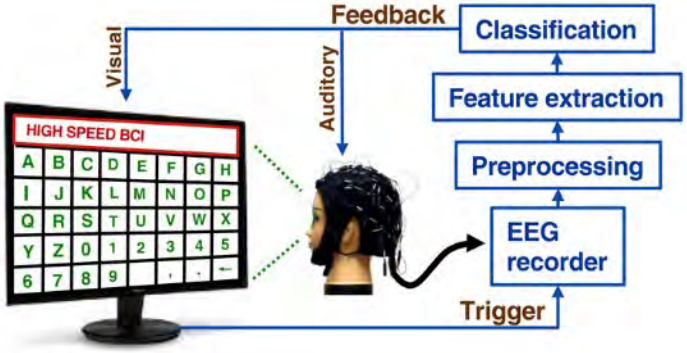


Improved Tools

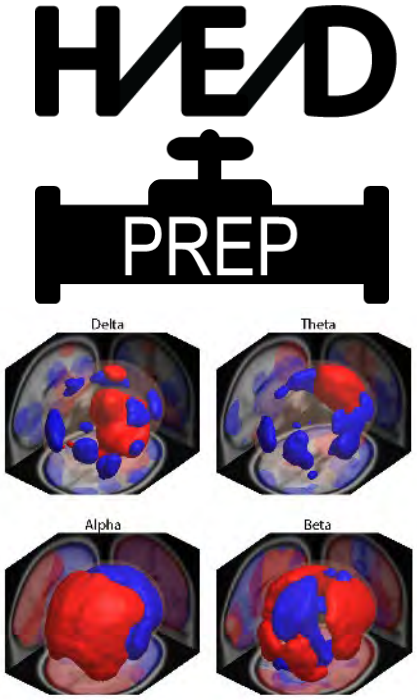


PY 7: Real-time / Closed-loop

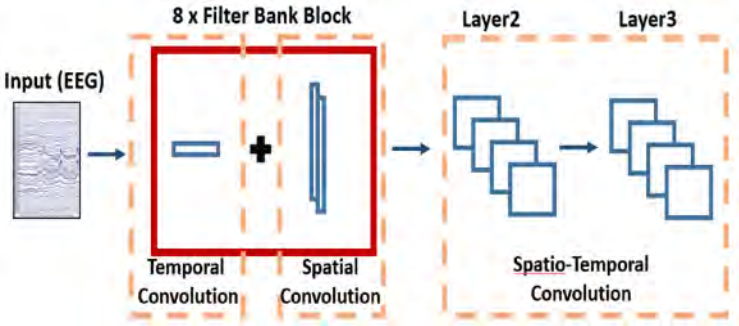


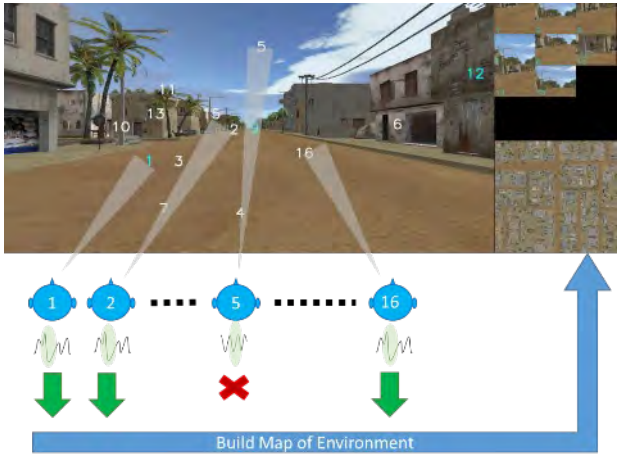


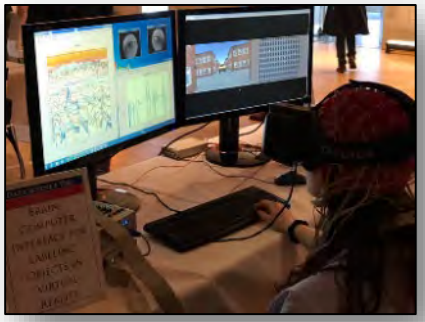
PY 8: Big Data Standards and Approaches



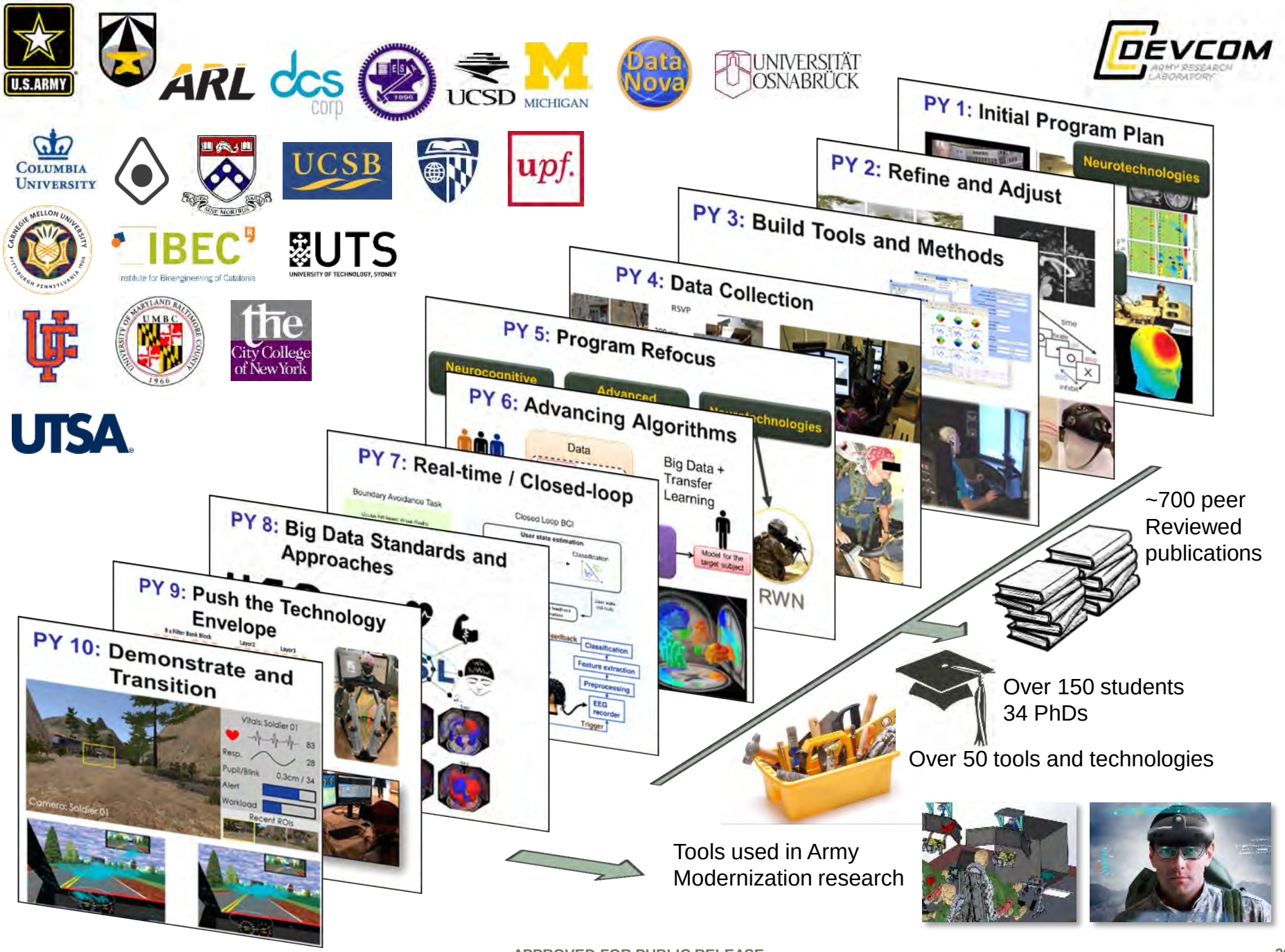
PY 9: Push the Technology Envelope







PY 10: Demonstrate and Transition


PY 1: Initial Program Plan
Neurotechnologies
PY 2: Refine and Adjust
PY 3: Build Tools and Methods
PY 4: Data Collection
RSVP
PY 5: Program Refocus
Neurocognitive
Advanced
PY 6: Advancing Algorithms
Data
Big Data + Transfer Learning
Model for the target subject
RWN
PY 7: Real-time / Closed-loop
Boundary Avoidance Task
Closed Loop BCI
User state estimation
Classification
Feature extraction
Preprocessing
EEG recorder
Trigger
PY 8: Big Data Standards and Approaches
PY 9: Push the Technology Envelope
PY 10: Demonstrate and Transition
Vitals: Soldier 01
Resp.
Pupil/Blink
Alert
Workload
Recent ROIs
Camera: Soldier 01
~700 peer Reviewed publications
Over 150 students
34 PhDs
Over 50 tools and technologies
Tools used in Army Modernization research

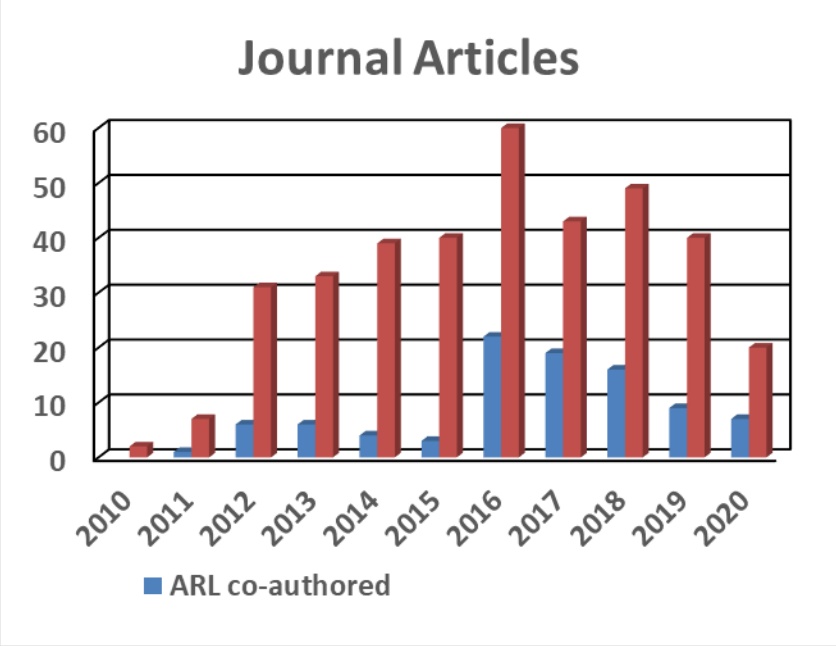
PRODUCTIVITY TO DATE (TOTALS) – AS OF OCTOBER 2020

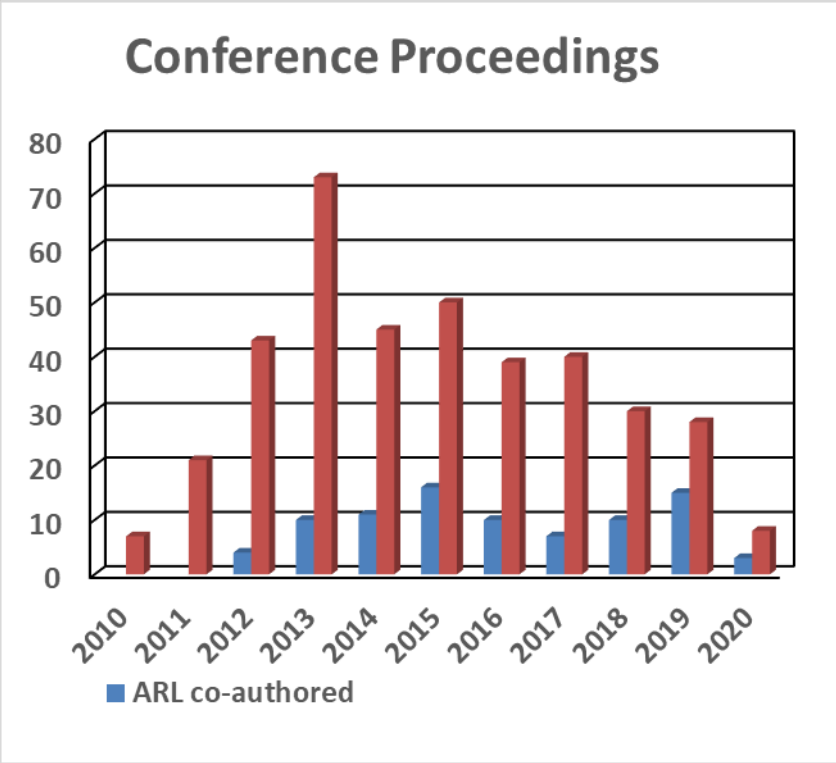
Publications	• 364 refereed journal articles, book chapters • 93 with ARL coauthor
Conferences	• 384 refereed conference submissions • 86 with ARL coauthor
Collaboration Events	• 10 CTA all-hands events, 4 at APG • 10 CTA workshops, 2 at APG
Inventions & Patents	• 4 invention disclosures, 35 patents awarded (includes foreign)
Transitions	• 54 technologies developed / transitioned
Education	• 158 students supported, • 34 PhD completed
Staff Rotation	• >35 MY of rotation into ARL by 51 consortium members

PRODUCTIVITY HISTORY (BY CY)

A core of co-located researchers is critical to multi-disciplinary efforts:

- ✓ 3 on-site personnel at the end of year 1
- ✓ 30 on-site personnel currently





26% ARL coauthored

22% ARL coauthored

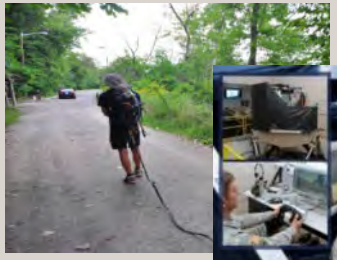
- ARL co-authors: **Bradford, Canady, Franaszczuk, Garcia, Hairston, Kerick, Lawhern, Lance, Lieberman, Marathe, McDowell, Oie, Passaro, Touryan, Whitaker, Wickenden, Vettel, Vindiola, Waytowich**

Large Scale Data Analysis

LARGE SCALE DATA ANALYSIS

CTA and ARL datasets:

- Seated experiments
  - Computer-based simulation
  - Ride-motion simulation
  - Individual and team tasks
  - Primary and side tasks
  - Urban landscapes
- Ambulatory experiments
  - Indoor and outdoor
- Multi-aspect data collection
  - High-density EEG
  - Eye tracking
  - Physiology (*heart rate, respiration, etc.*)
  - Motion capture
  - Audio and video



"Big Data"

- ❑ Repository now includes over 1000 subjects, and data from over 2000 sessions
- ❑ Experiments and datasets differ in **design**, **organization**, **structure**, **modality**, and **size**

(over 3TB of raw data)

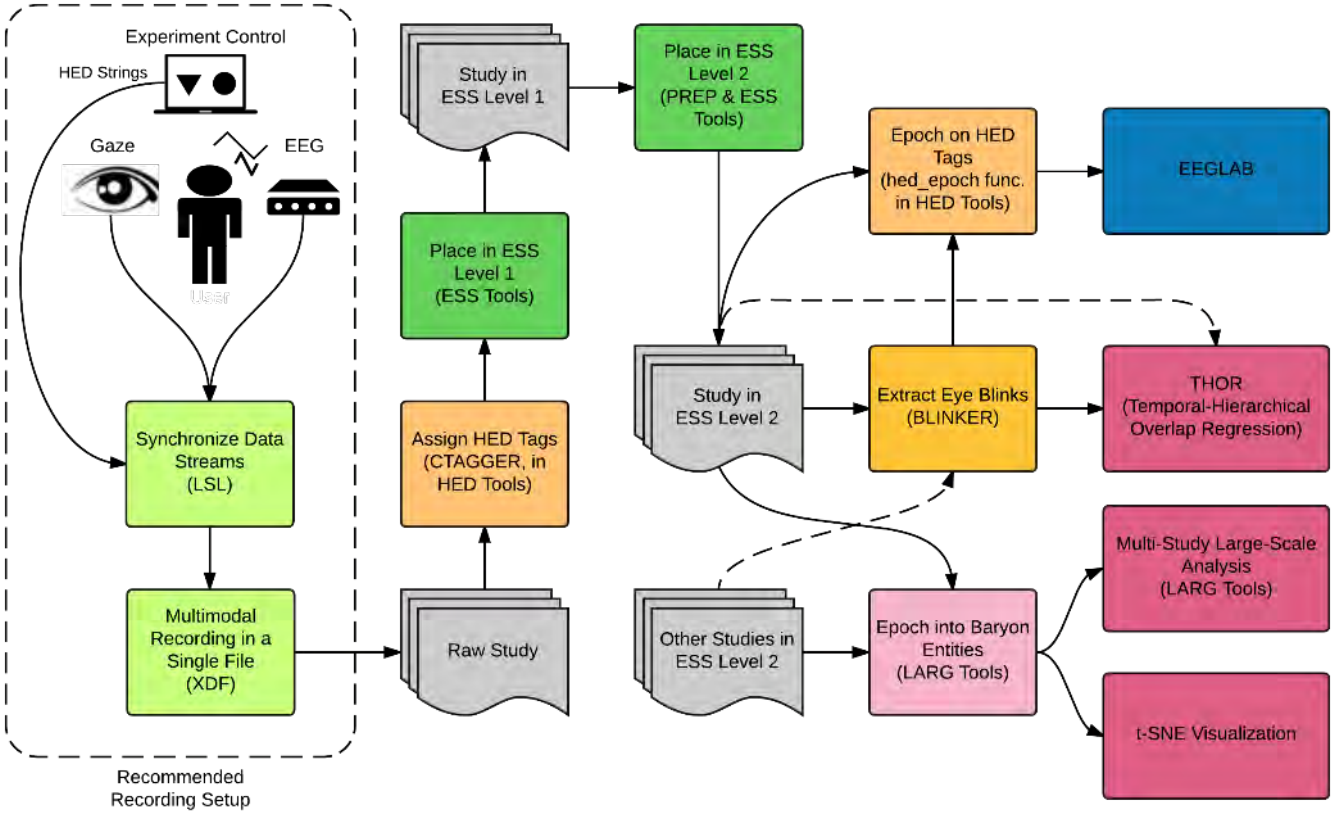
CaN CTA Consortium Data Server (C3DS)

How can a common analysis be applied to such large and heterogeneous data?

- Annotation and Standardization
- Algorithm and Analyses
- Validation and Discovery

LARGE SCALE DATA ANALYSIS

- Annotation and Standardization:
  1. Requires a common language to describe the data
  2. Requires a common schema to index, store and retrieve data
  3. Requires an approach to bring disparate dataset into a standardized representation



HED
Hierarchical Event Descriptor (Bigdely-Shamlo, 2016)

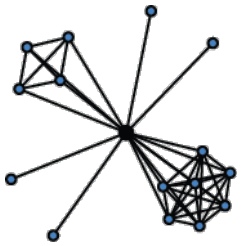
ESS
EEG Experiment Schema (Bigdely-Shamlo, 2016)

PREP
Preprocessing Pipeline (Bigdely-Shamlo, 2015)*

* Has over 180 citations

LARGE SCALE DATA ANALYSIS

- Algorithms and Analyses:
  - The analysis of these complex and heterogeneous datasets requires an understanding and quantification of the manifold sources of single trial (single instance) variability



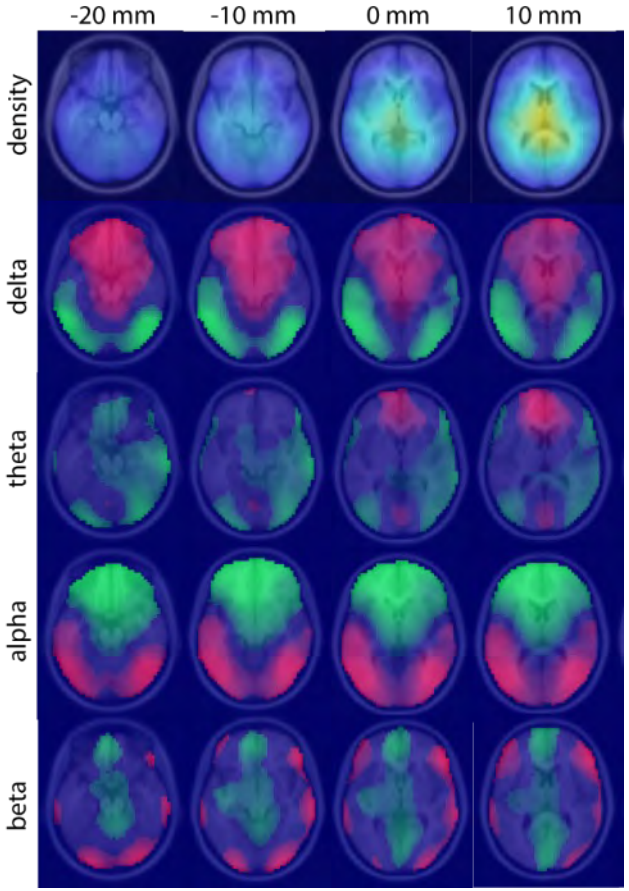
Social network

Stress

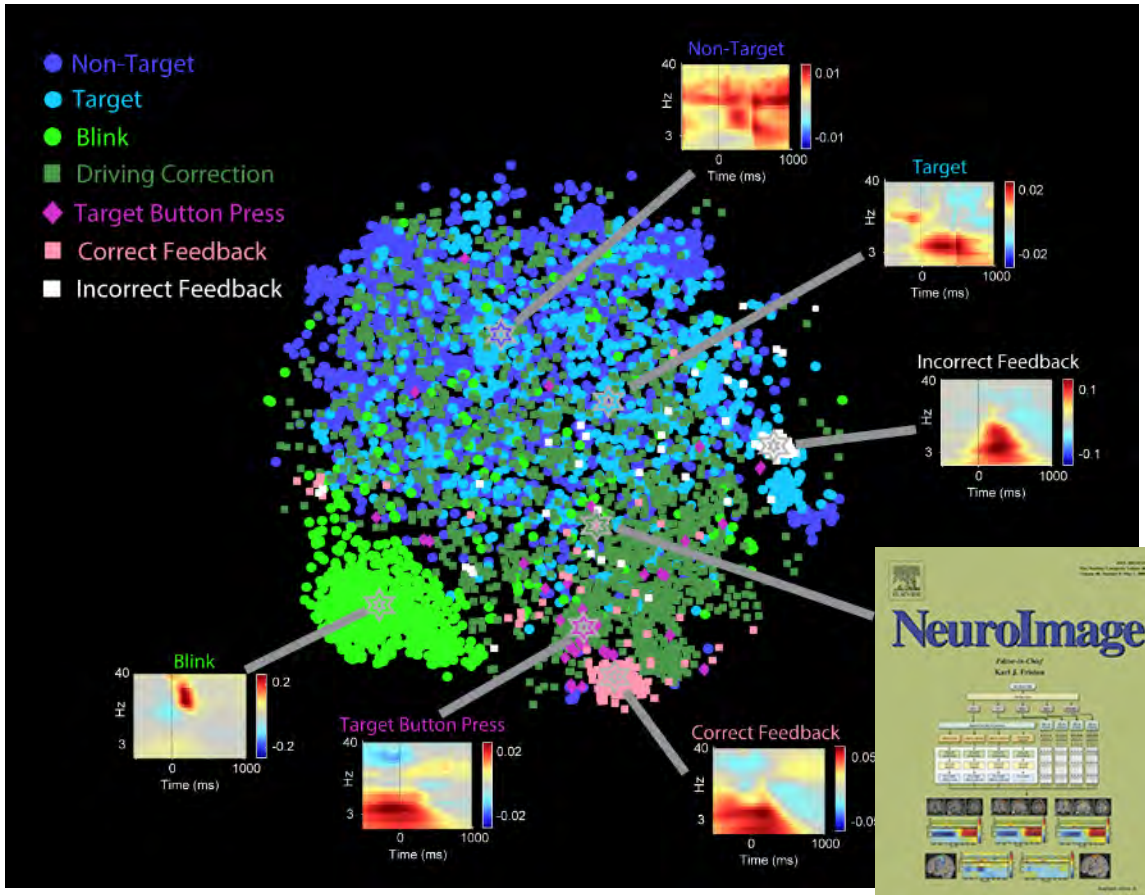
physiology

LARGE SCALE DATA ANALYSIS

- Validation and Discovery:
  - Large scale analyses enables us to represent and quantify brain dynamics that can generalize across contexts (individuals, tasks, and states)



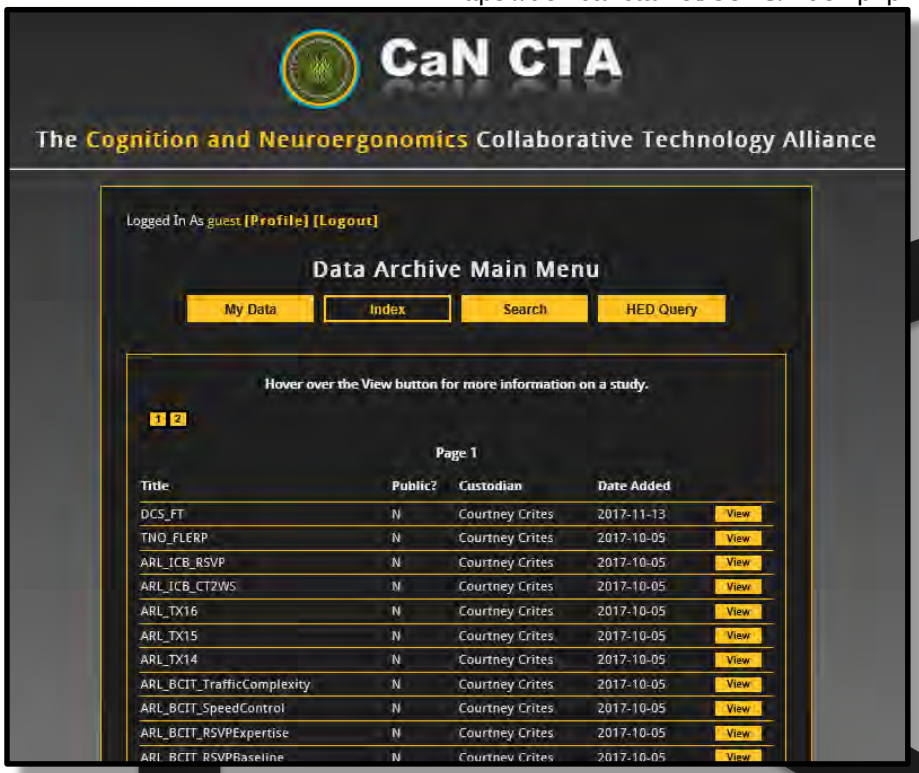
7,234 dipoles (brain sources) from 12 studies



(Bigdely-Shamlo, 2019)

DATA REPOSITORY

https://dev.cancta.net/C3DS/index.php



oculus

VR experience, BCI

OpenNEURO

NSF

NIH

Brain Imaging Data Structure (BIDS)

DARPA

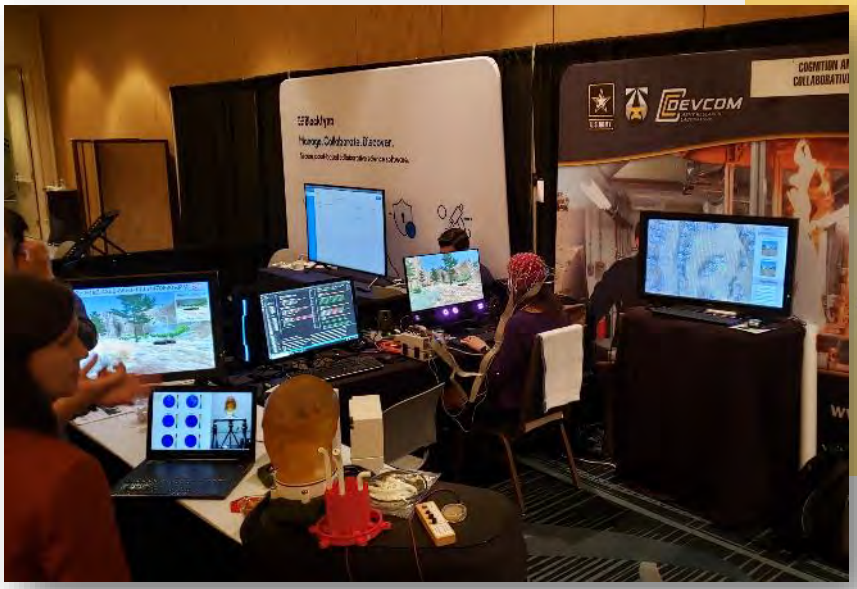
DARPA Agile Teams (A-Teams) program

PM John Paschkewitz

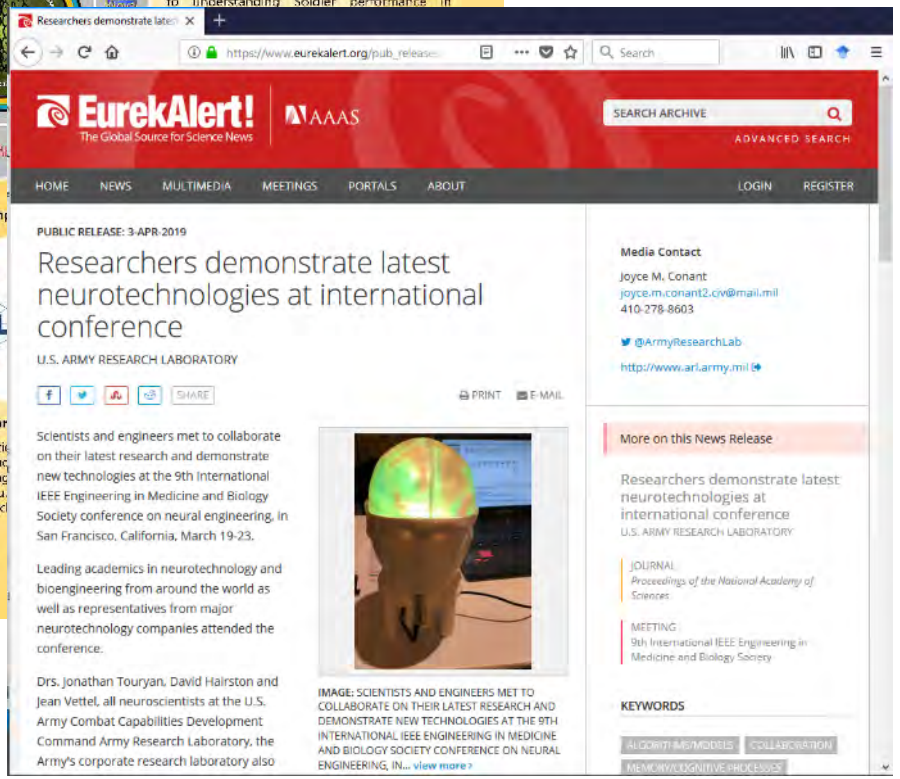
Community Influence & Transition

NEURAL ENGINEERING 2019

- 1-day workshop
- 2-day booth
- 10 demonstrations

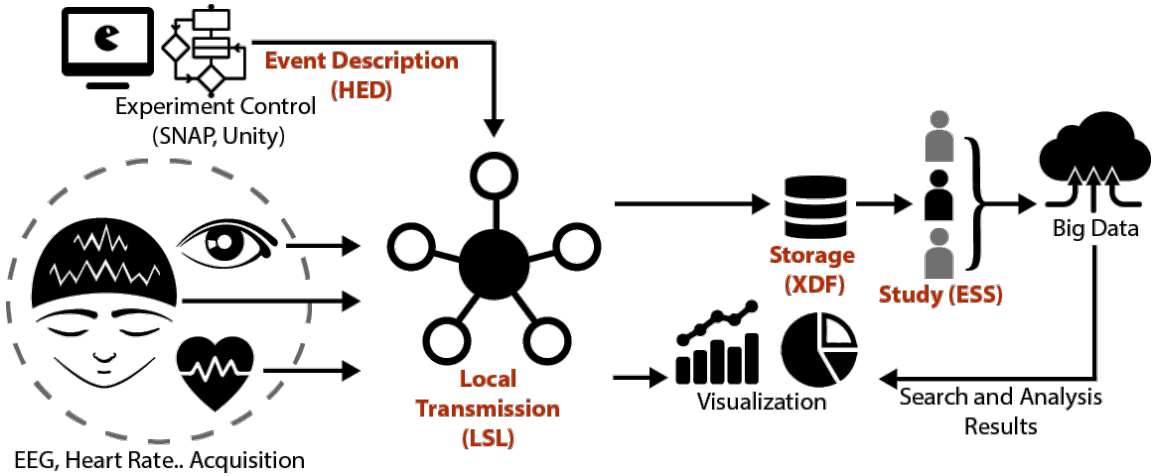


IEEE brain



STANDARDS

The Consumer Electronics Association (CEA), an ANSI-accredited standards developer, has formed a Working Group to standardize consumer EEG event description, metadata encapsulation, data transmission and storage.



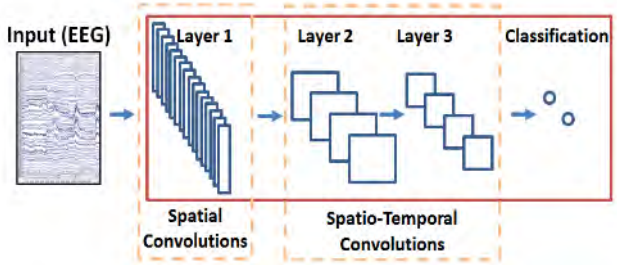
Standard for Consumer EEG File Format ANSI/CTA-2060

Lab Streaming Layer (LSL), a system for the unified collection of measurement time series with millisecond-level synchronization, is being adopted by a growing number of commercial developers and vendors of human sensing technologies.

TECHNOLOGY TRANSITION

Technology: novel machine learning algorithms and real-time architecture that exploit neurophysiological data to understand human situational awareness.

Key Technical Demonstration: **Identifying human interest in dynamic environments**



- **1st Place in international EEG data challenge to detect brain signals related to human interest *(NAILS Task)***
- **Proof-of-Concept demonstration of AI that detects human interest in unstructured environments *(HID)***

NAILS: Neurally-Augmented Image Labeling Strategies **HID: Human Interest Detector**

Enhancing situational awareness through improved insight into Soldier's cognition

Key Publications:

Lawhern, et al (2018). *EEGNet: A Compact Convolutional Network for EEG-based Brain-Computer Interfaces*

Solon, et al (2018). *Deep Learning Approaches for P300 Classification in Image Triage: Applications to the NAILS Task*

Solon, et al (2019). *Decoding P300 Variability using Convolutional Neural Networks*

Potential:

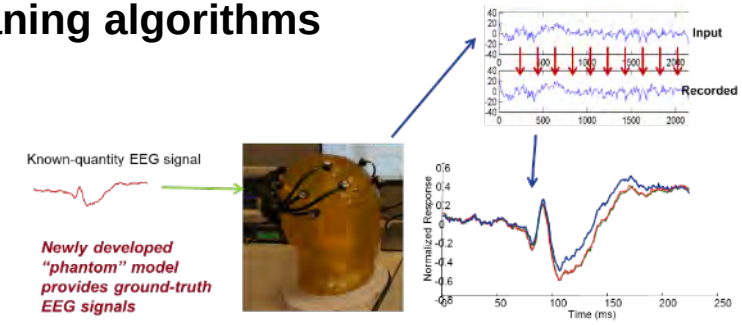
- Algorithms that provide insights and prediction of human actions, intentions, goals, and general reasoning
- Novel technologies that improve human-AI integration by exploiting individual characteristics
- Detecting high level and potential sub-conscious cognitive constructs (e.g., danger) and social intuition w/o burdening Soldier

TECHNOLOGY TRANSITION

Technology: Novel methods & materials for testing and validating new biosensing devices and algorithms

Key Technical Demonstration:

Developed new methods and devices for providing missing "ground truth" necessary for T&E of previously unproven neuro-sensing hardware and cleaning algorithms



- **In use by multiple 3rd-party laboratories worldwide**
- **Negotiating with EEG manufacturers for pairing with systems at point of sale**
- **Enabled many new technological advances in biosensing**

Enabling (missing) validation of EEG equipment efficacy

Example Press:

MedGadget
https://www.army.mil/article/158604/phantom_head_may_one_day_take_guesswork_out_of_eeg_monitoring

IdeaConnection
https://www.ideaconnection.com/new-inventions/phantom-head-could-improve-eeg-technology-10317.html

Potential:

- Provide key verification of sensor and system efficacy early in developmental pathway
- Enable additional applied research for real-world Soldier biosensing
- Enable game-changing research on cognitive fluctuations in real-world scenarios

TRANSITION OF EXPERTISE

Transition to ARL

- Dr. Nina Lauharatanahirun (2018) Univ. Pennsylvania
- Dr. Nicholas Waytowich (2016) Columbia Univ.
- Dr. Gregory Lieberman (2016) Univ. New Mexico
- Dr. Cortney Bradford (2015): Univ. Michigan
- Dr. Antony Passaro (2015): Univ. Texas Health Science Center via DCS
- Dr. Jason Metcalfe (2015): DCS research scientist
- Dr. Javier Garcia (2015): University of California, San Diego
- Mr. Paul Riggs (2015): DCS computer engineer
- Dr. Vernon Lawhern (2014): Univ. Texas, San Antonio

Transition to Academia or other Government Research

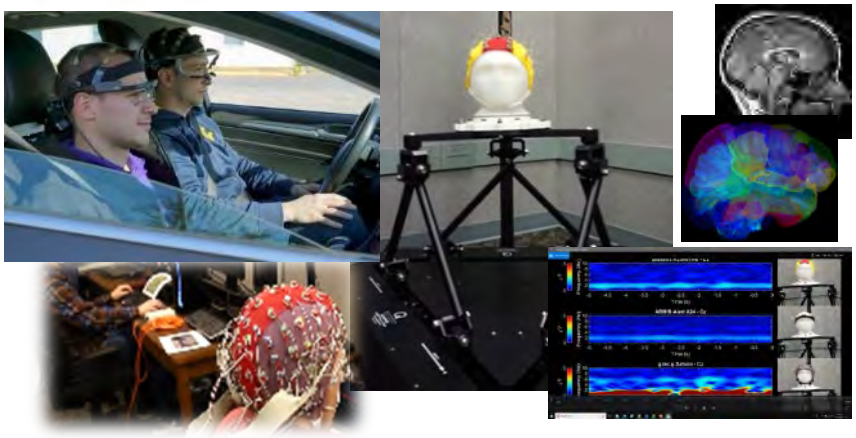
- Sarah Muldoon (2015): Transitioned from Univ. Pennsylvania to faculty position at SUNY Buffalo
- Anderson Oliveira (2015): Transitioned from Univ. Michigan to faculty position at Aalborg Univ.
- Ken Ball (2015): Transition from UTSA to staff researcher at the EPA
- David Jangraw (2014): Transition from Columbia University to postdoctoral researcher at NIH

Transition to Industry

- Tim Mullen, Nima Bigdely-Shamlo, Christian Kothe (2014-2015): Transitioned from UCSD to a startup company specializing in methods for applied neuroscience (Intheon)
- Silke Kärcher (2015): Transitioned from Univ. Osnabrück to a startup company specializing in personal navigation technologies (feelSpace)
- Shao Wei Lu (2014): Transitioned from NCTU to a BCI-focused startup company (Brain Rhythm)

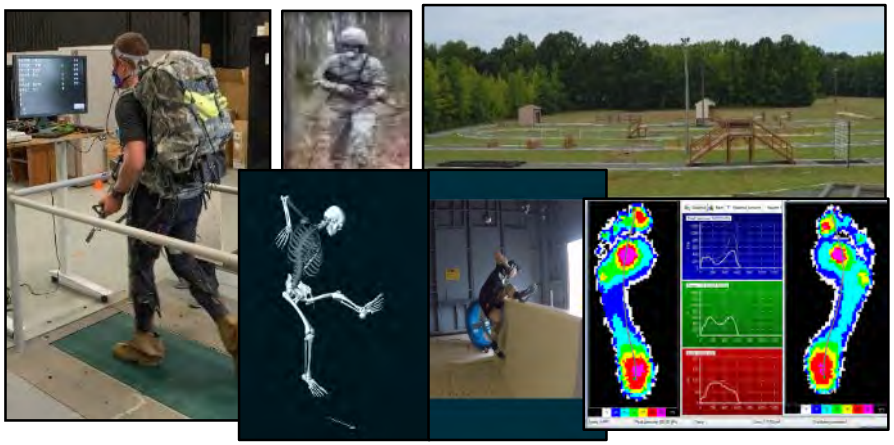
TRANSITION OF CAPABILITIES

Mission Impact through Neurotechnology Design (MIND)



Neural, physiological, and behavioral recording in both a highly controlled lab setting and complex, mobile environments.

Soldier Performance and Equipment Advanced Research (SPEAR)

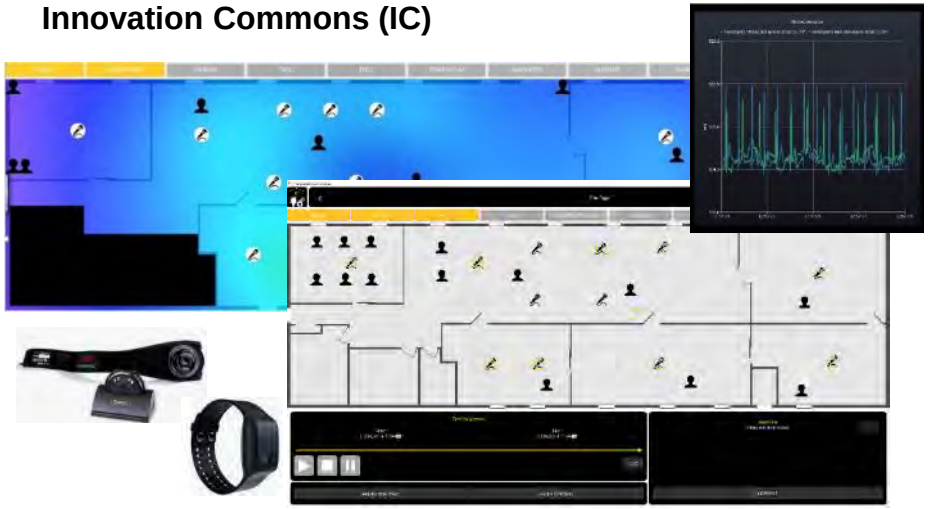


Dismounted Soldier performance in both high-resolution laboratory and operationally relevant settings.

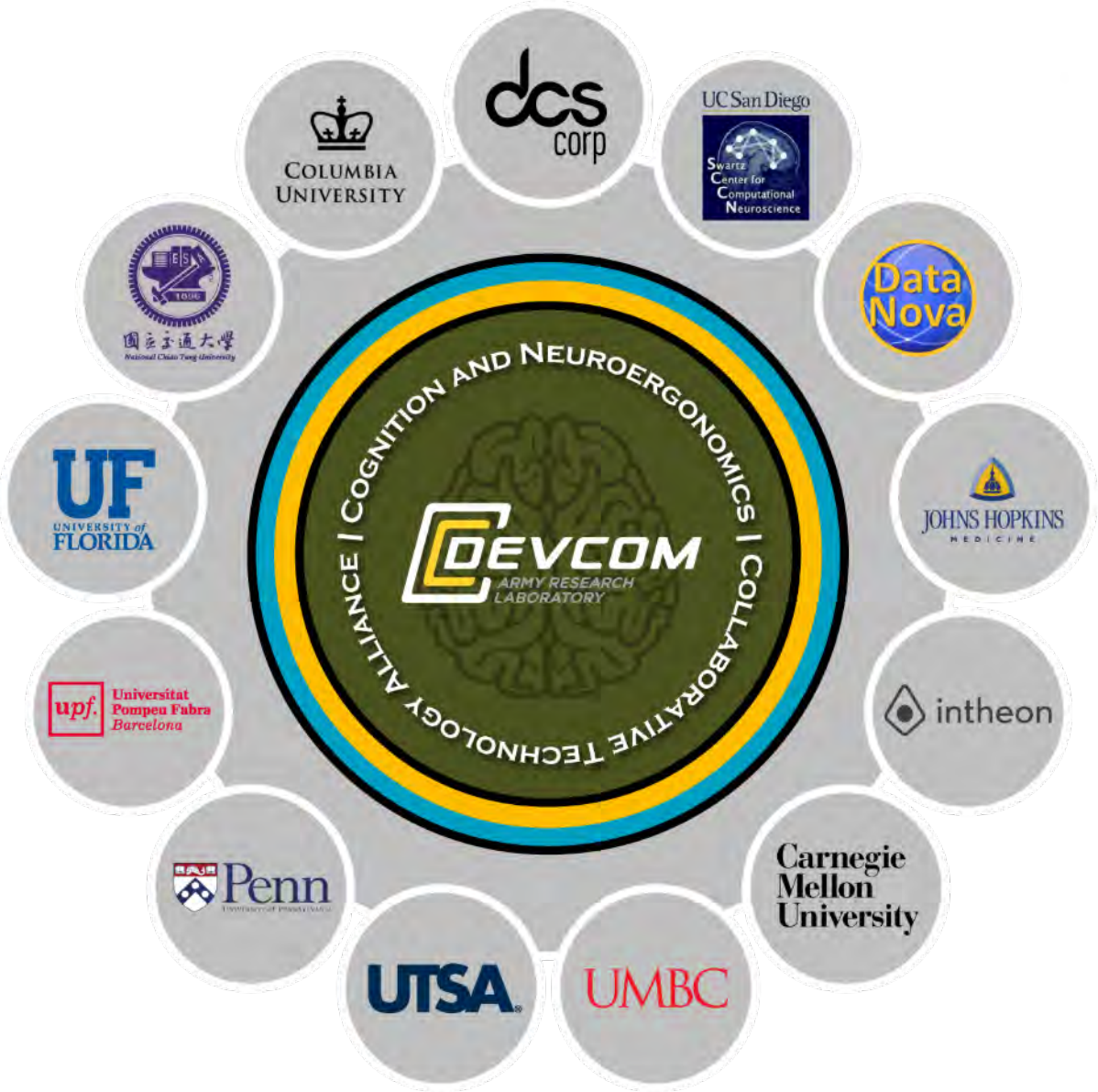
Cognitive Assessment Simulation and Engineering Laboratory (CASEL)

Cognitive/physiological assessment and optimization of human-AI team performance through opportunistic sensing.

Innovation Commons (IC)



Real-world assessment of individual and team states and processes, including human-to-human/AI interactions.



https://www.arl.army.mil/cast/CaNCTA