Cognitive Fatigue and Cognitive Security

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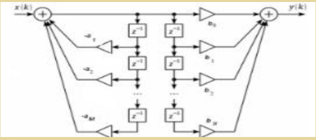
67 Years of Technical Achievement

First Continental Air Defense System

Protected US from Soviet nuclear attack for 20 years

Digital Signal Processing & Error-Correcting Codes

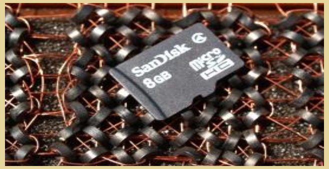


Inventions of recursive digital filters and Reed-Solomon codes

First Fully-Transisterized Real-Time Computer

Spawned commercial mini-computer industry

Coincident Core Memory

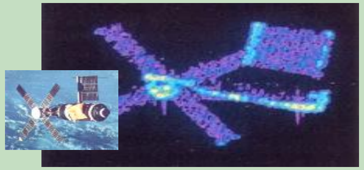


Birth of nonvolatile memory

First Television Picture Transmission via Satellite

Used NASA'S Echo I Satellite

First RADAR-based Satellite Imaging

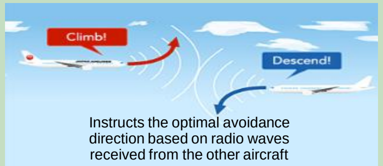


ALCOR radar located at Kwajalein

First Transmission of Packetized Speech

Forerunner of voice over internet protocol (VoIP)

Airborne Collision Avoidance System



Installed on *all* planes with >19 passenger seats

First Prototypes for All Military Comm. Satellites

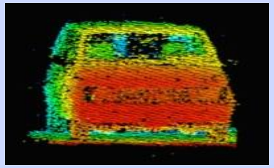
DSCS, MILSTAR, WGS, AEHF, MUOS

- 1950–1960s
- 1970–1980s
- 1990–present

Air Defense of the National Capital Region

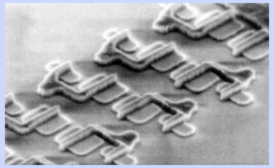
Rapid deployment post 9/11

3-D Laser Imaging



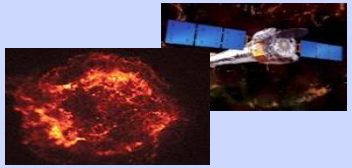
Permits airborne 3D imaging through trees

193nm Optical Lithography



Leap ahead in integrated circuit technology

NASA Chandra X-Ray Observatory



Advanced CCD imaging spectrometer

First Laser Communi-cations from Lunar Orbit

622 Mbps downlink for 30 days with zero bit errors

MIT Lincoln Laboratory

DoD Federally Funded Research and Development Center

Massachusetts Institute of Technology

MIT Lincoln Laboratory

Mission: Technology in Support of National Security

Key Roles:
- System architecture engineering
- Long-term technology development
- System prototyping and demonstration

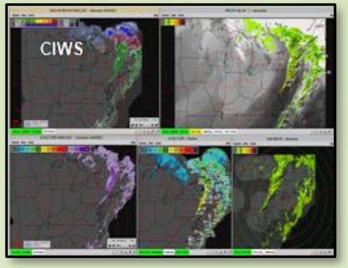
Mission Areas:

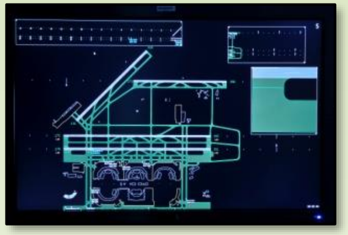
- Air, Missile & Maritime Defense
- Homeland Protection
- Air Traffic Control
- Communication Systems
- Cyber Security
- Advanced Technology
- Space Control
- ISR Systems and Technology
- Tactical Systems
- Engineering

Homeland Protection & Air Traffic Control Division

Developing systems & technologies to improve the safety, security, resilience, and efficiency of U.S. Homeland and its people

Transportation




Air Traffic Surveillance

Weather Sensing/Forecasting

Air Traffic Control Automation

UAS Airspace/Collision Avoidance

DoD Transportation

Homeland Protection


Homeland Air Defense/Security

Counter-WMD

Borders & Maritime Security

Critical Infrastructure Protection

HA/DR

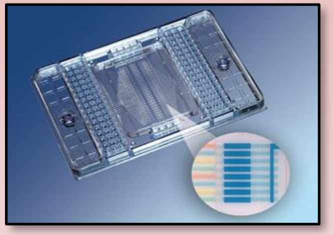
Disaster Relief Tech

Decision Support & Collaboration Tools

Humanitarian Tech

Bioengineering






Biomedical Sensors & Systems

Biomedical Informatics

Engineered & Synthetic Biology

Brain & Cognitive Systems

Human Systems Engineering

Systems Analysis – Architectures – Prototyping – Testing – Decision Support

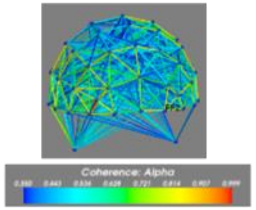
HA/DR-Humanitarian Assistance and Disaster Relief

Bioengineering R&D Across MITLL

By Application Area

Biosecurity

Brain Science

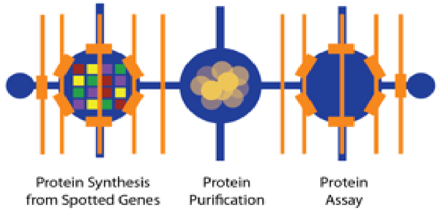


Connectivity Graph

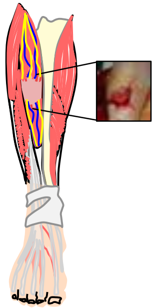
Data Management

Human ID/ Forensics

Molecular Prototyping and Sensing

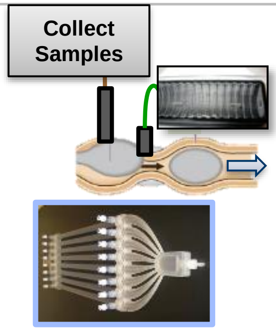


Musculoskeletal Injury



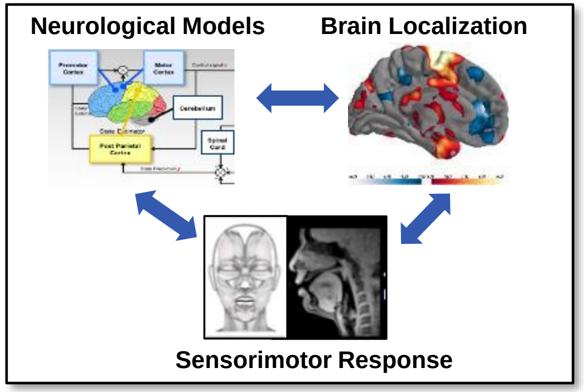
Noise-Induced Hearing Injury

Nutrition & Microbiome



Physiological Status

Extend Neurological & Behavioral Assessments for Psych Health, Cognitive Status, and Neurotrauma



Operational Monitoring

- Cognitive fatigue
- TBI sensing
- Suicide ideation
- Aberrant behavior & threat risk

Diagnostic Aids (in person or remote)

- Depression
- mTBI
- PTSD
- Pain quantification
- Environmental stressors

Intervention Efficacy

- Therapeutic/nutritional
- Brain stimulation
- Pain management

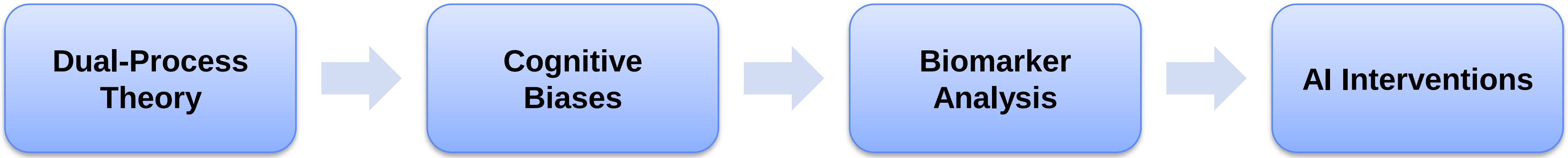
TBI: Traumatic Brain Injury
PTSD: Post Traumatic Stress Disorder

Presentation Roadmap

- **Claim: Cognitive fatigue can lead to a state of cognitive "in-security" in which one is induced into making a non-optimal, irrational decision**

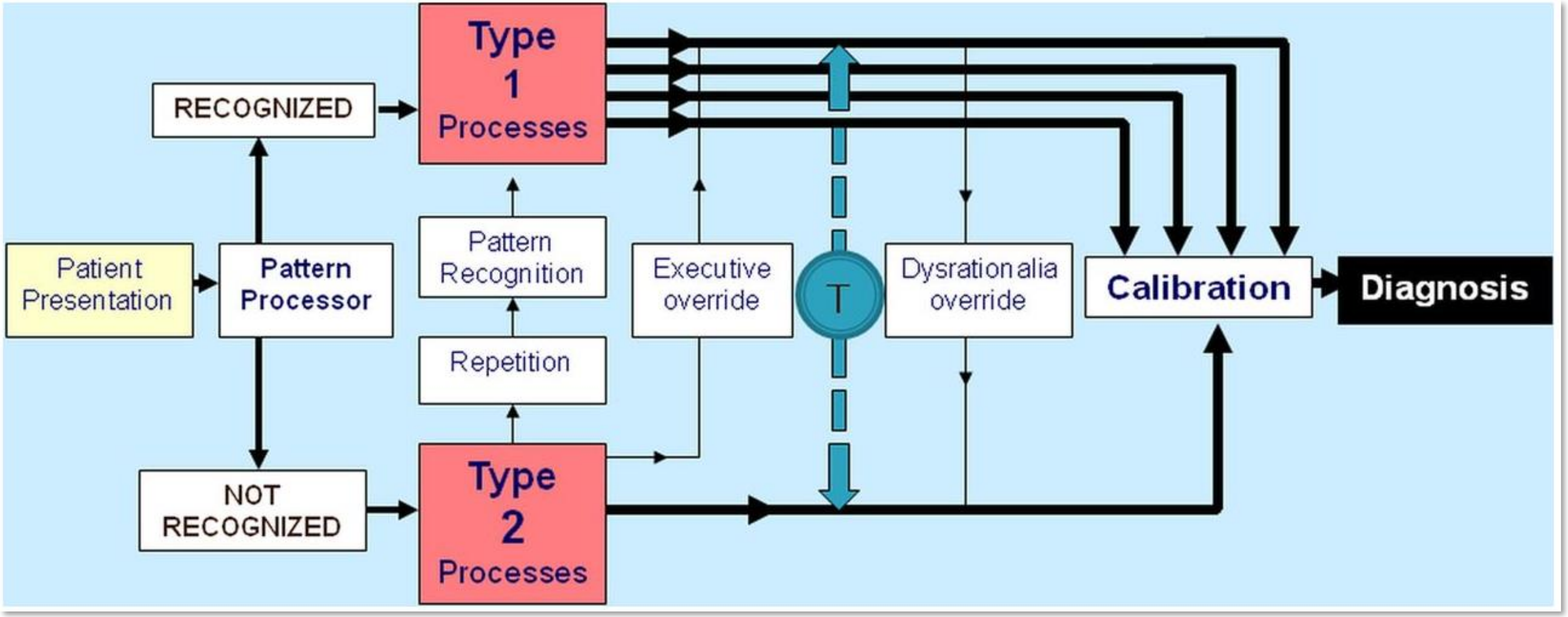
- **Thesis: Cognitive fatigue can be detected and mitigated to restore cognitive security**

- **Application domains:**
  - **Intelligence analysis, Cyber decision-making, Medical diagnosis, Fake News detection**



Dual-Process Model for Decision Making

(Medical Domain)



Dysrationalia - the inability to think and behave rationally despite adequate intelligence.

Croskerry P, . *A universal model of diagnostic reasoning. Acad Med 2009;84:1022–8.*

Dual-Process Model for Decision Making

- Type 1 processing is fast, autonomous, and where we spend most of our time. It usually works well, but as it occurs largely unconsciously and uses heuristics heavily, unexamined decision making in the intuitive mode is more prone to biases.
- Type 2 processing is slower, deliberate, rule-based and takes places under conscious control, which may prevent mistakes.
- The predictable deviations from rationality that eventually lead to errors tend to occur more frequently in the Type 1 processes, in line with findings of dual-process researchers in other domains.24–26
- Repetitive processing using Type 2 processes may allow processing in Type 1. This is the basis of skill acquisition.
- Biases that negatively affect judgments, often unconsciously, can be overridden by an explicit effort at reasoning. Type 2 processes can perform an executive override function—which is key to debiasing.
- Excessive reliance on Type 1 processes can override Type 2, preventing reflection and leading to unexamined decisions—this works against debiasing.
- The decision maker can toggle (T) back and forth between the two systems—shown as broken line in figure 1.
- The brain generally tries to default to Type 1 processing whenever possible

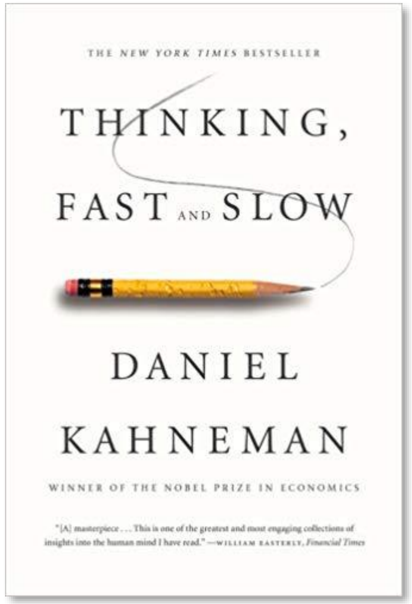
Croskerry P, . *A universal model of diagnostic reasoning. Acad Med 2009;84:1022–8.*

Cognitive Biases*

- “At its core, cognitive science is the study of how our minds process and transform information. And over the past few decades, researchers have found that a number of glitches are hard-wired into the human brain in ways that adversely affect our ability to seek out objective truth” [1]

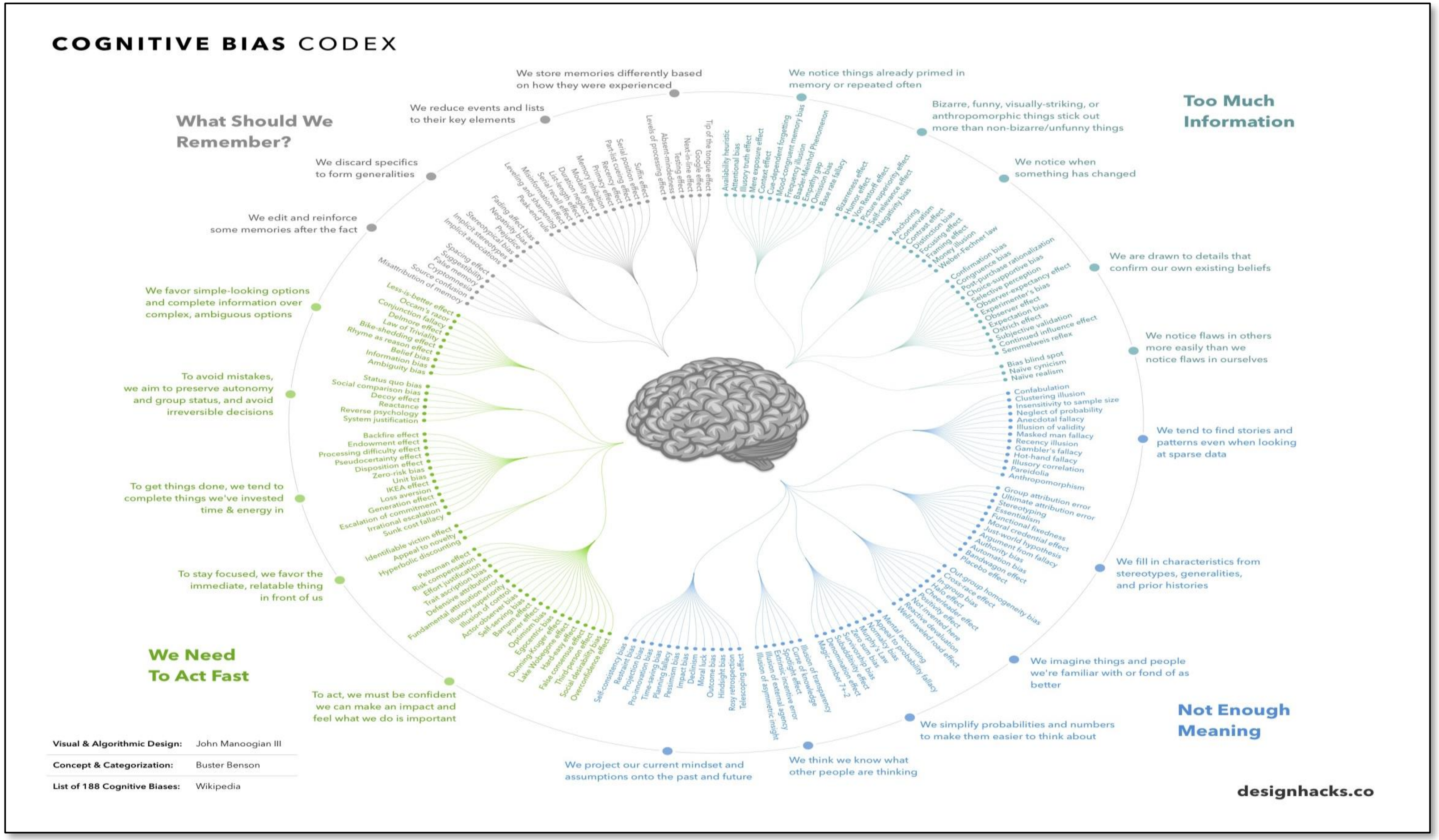
- Cognitive Bias – ‘a predictable deviation from rationality’ [2]

- Cognitive Biases examples [3]
  - Confirmation bias – we see what we want to see
  - Optimism bias – we over estimate our abilities
  - Self-serving bias – good things happen because of us
  - Recency bias – recent past more important than distant past
  - Bias for bias – we are prone to influence by biases
  - ...



* - https://humanhow.com/en/list-of-cognitive-biases-with-examples/

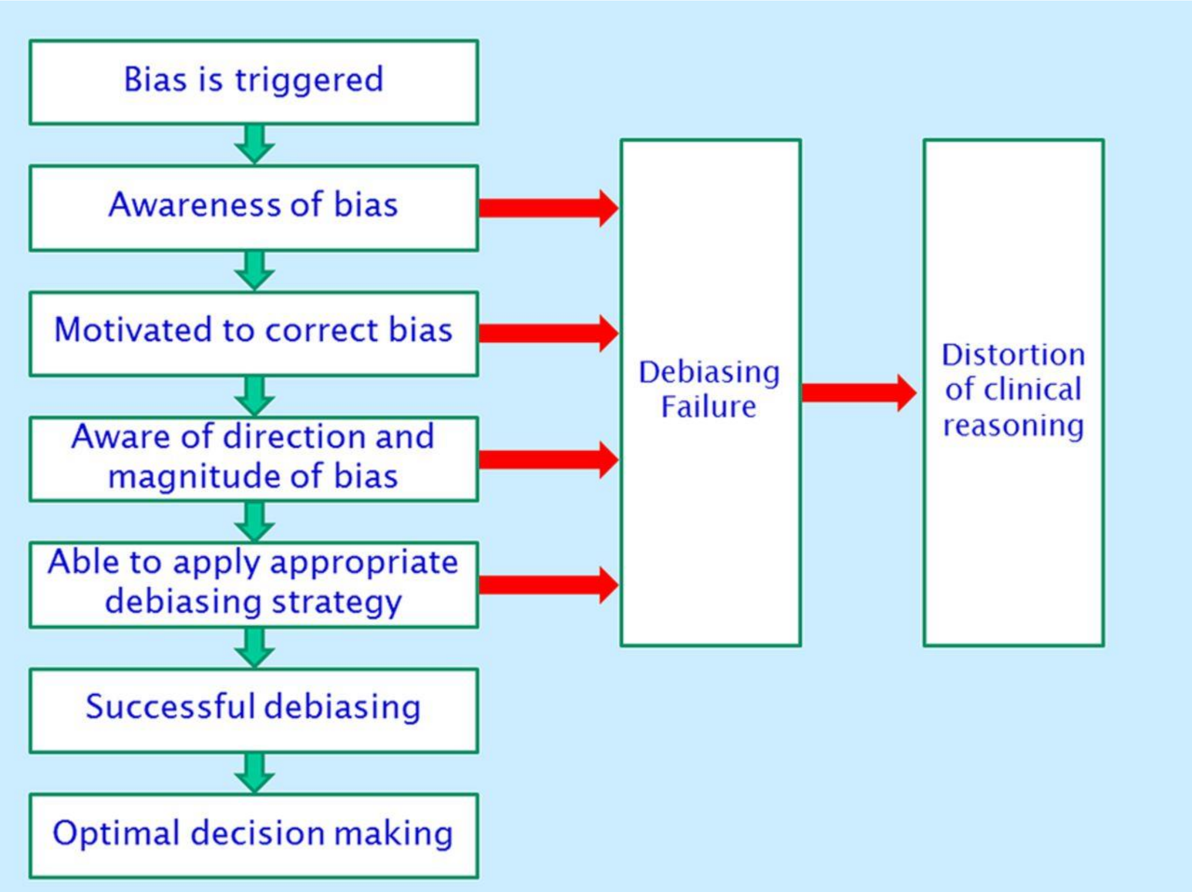
Cognitive Bias Codex*



Some 180 cognitive biases have been defined and are routinely identified by cognitive scientists

* - https://www.teachthought.com/critical-thinking/the-cognitive-bias-codex-a-visual-of-180-cognitive-biases/

Combating Bias in Decision Making



Awareness of bias can lead to correcting it and arriving at an optimal decision

https://qualitysafety.bmj.com/content/qhc/22/Suppl_2/ii58/F3.large.jpg

High-risk situations for biased reasoning*

High-risk situation	Potential biases
1. Was this patient handed off to me from a previous shift?	Diagnosis momentum, framing
2. Was the diagnosis suggested to me by the patient, nurse or another physician?	Premature closure, framing bias
3. Did I just accept the first diagnosis that came to mind?	Anchoring, availability, search satisficing, premature closure
4. Did I consider other organ systems besides the obvious one?	Anchoring, search satisficing, premature closure
5. Is this a patient I don't like, or like too much, for some reason?	Affective bias
6. Have I been interrupted or distracted while evaluating this patient?	All biases
7. Am I feeling fatigued right now?	All biases
8. Did I sleep poorly last night?	All biases
9. Am I cognitively overloaded or overextended right now?	All biases
10. Am I stereotyping this patient?	Representative bias, affective bias, anchoring, fundamental attribution error, psych out error
11. Have I effectively ruled out must-not-miss diagnoses?	Overconfidence, anchoring, confirmation bias

[1] Croskerry P, . *ED Cognition: any decision by anyone at any time. ED administration series. CJEM In press 2012*

Cognitive Fatigue: Some Background*

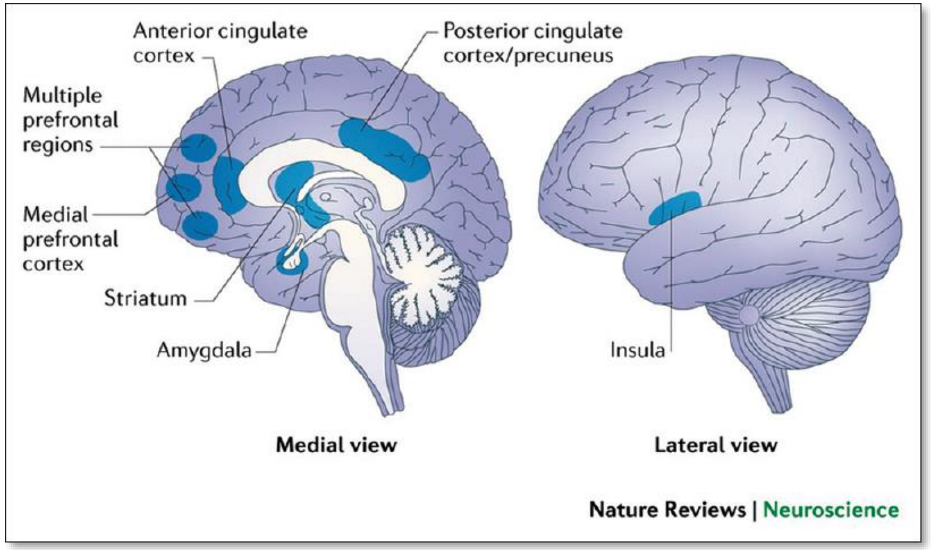
- **Definitions:**
  - Subjective lack of mental energy that is perceived by the individual (or caregiver) to interfere with usual and desired activities[12]
  - Decrease in cognitive resources developing over time on sustained cognitive demands, independently of sleepiness
- **Observed in the context of various attentional and executive cognitive functions with, amongst others, developing**
  - Difficulties to suppress irrelevant information during selective attention
  - Increased perseverations and time needed to plan,
  - Weakened cognitive control and decreased high-level information processing
  - Even declining physical performance
- **A significant contributing factor in**
  - Loss of productivity
  - Poor academic and professional performance
  - Increased risks of accidents and
  - Reduced quality of life in normal and clinical populations

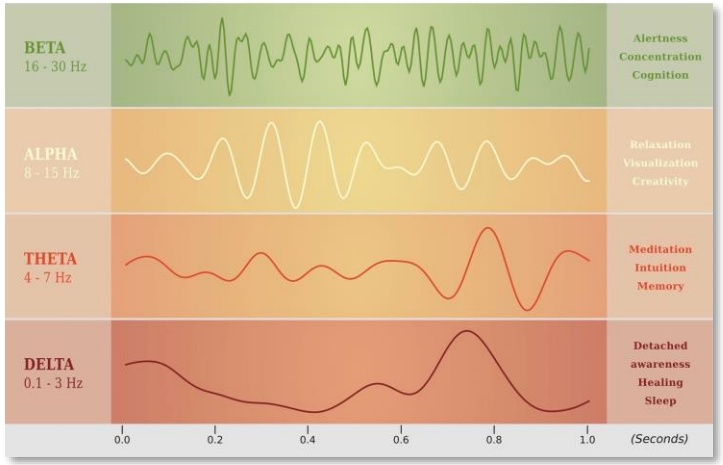
https://blog.usejournal.com/the-dangers-of-cognitive-fatigue-cfbd433dfc92

Environmental and Neural Bases of Cognitive Fatigue

- **Environmental:**
  - **Information overload**
  - **Too many choices**
  - **Lack of sleep**
  - **Excessive task duration**

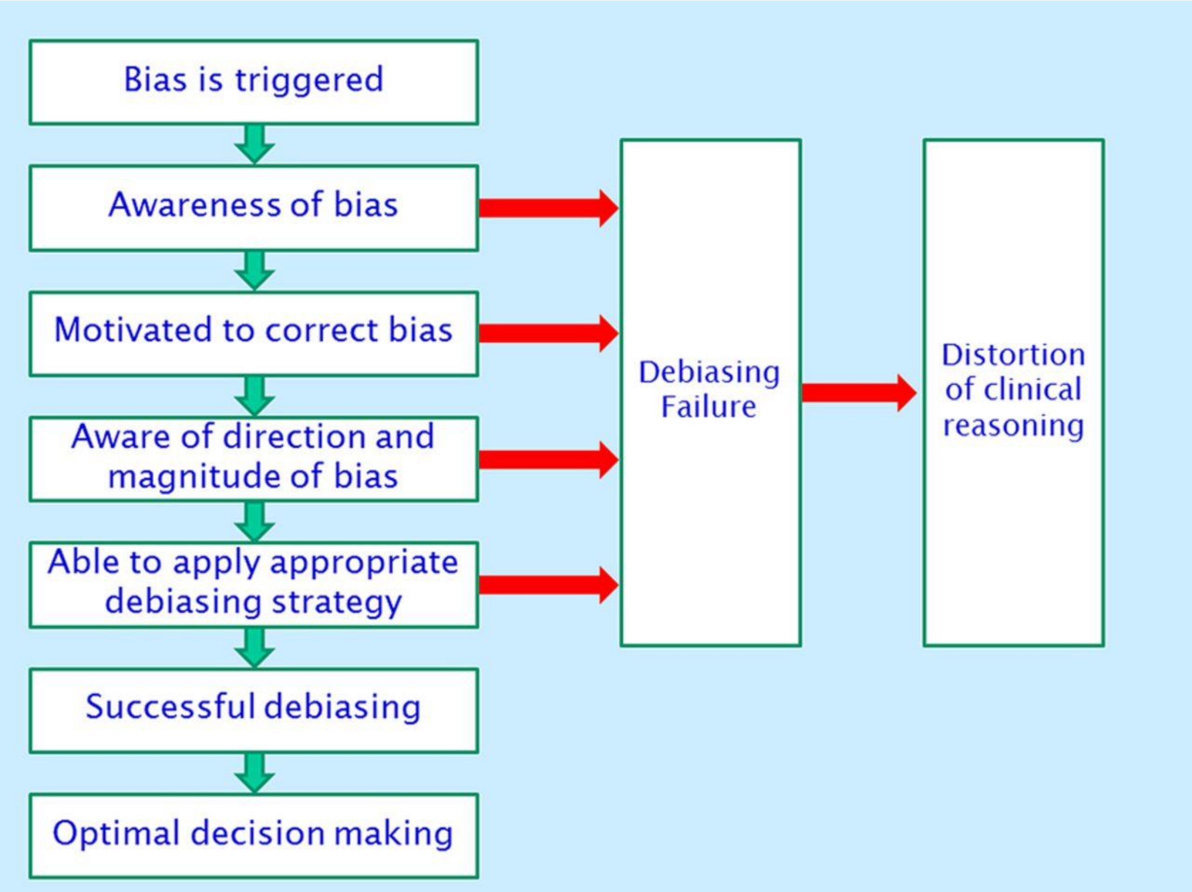
- **Neuroanatomy:**
  - ***Anterior cingulate cortex*, responsible for attention, runs out of dopamine**
  - ***Striatum*, responsible for planning physical activity, slows down**
  - **Brainwaves become altered unsynchronized**





Brain waves and their function

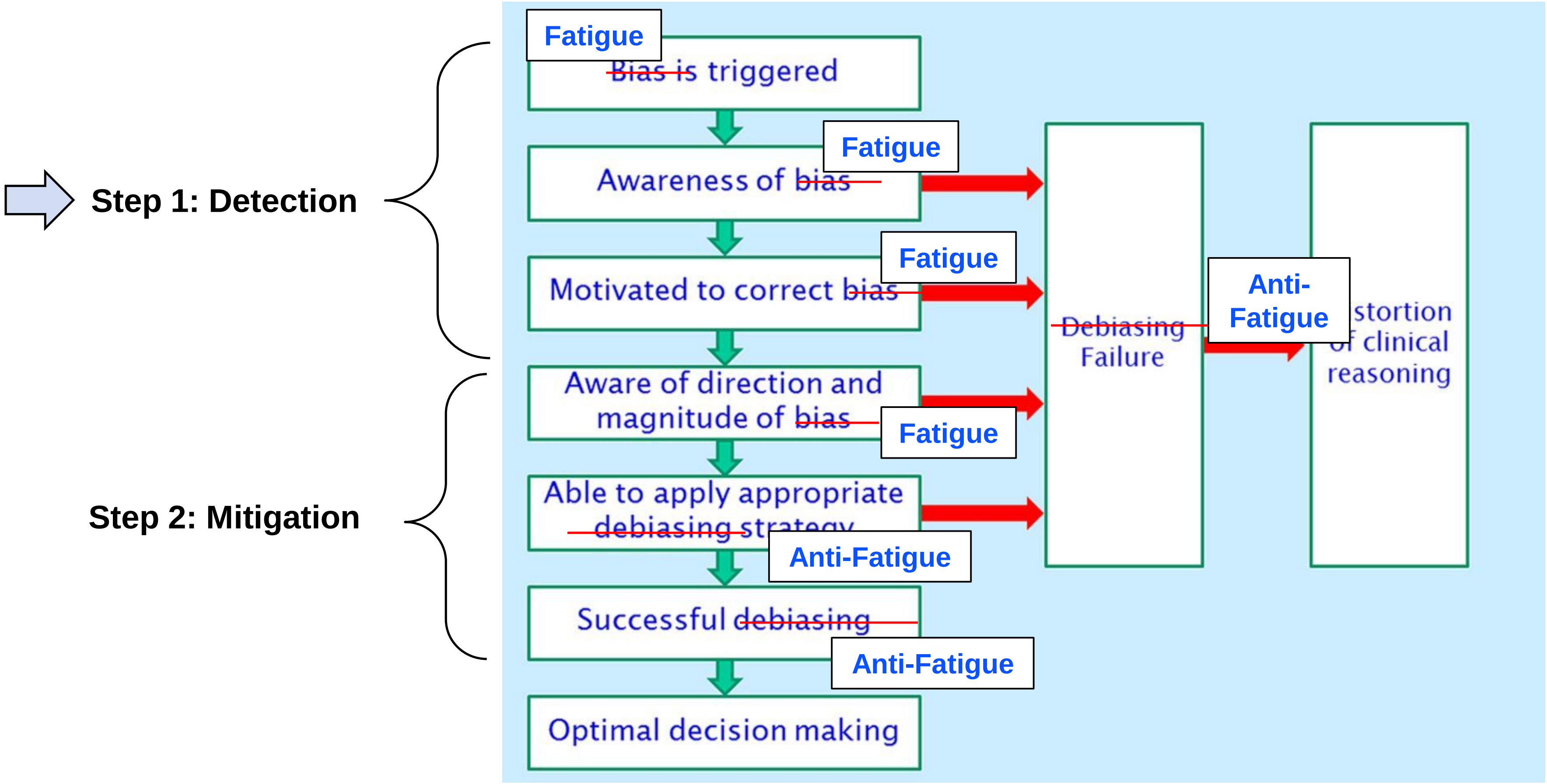
Combating Bias in Decision Making



However, detecting bias and then correcting it may be difficult...

https://qualitysafety.bmj.com/content/qhc/22/Suppl_2/ii58/F3.large.jpg

Combating Cognitive Fatigue in Decision Making



Maybe we can focus on fatigue, instead...

Adapted from: https://qualitysafety.bmj.com/content/qhc/22/Suppl_2/ii58/F3.large.jpg

Methods to Detect Neurological State

Brain Imaging (MRI, MEG, CT)

Electrophysiology (EEG, EMG)

Clinical Assessment

Physical Exam

Molecular Diagnostic

Standard Approach

- Time consuming, invasive, expensive
- Largely qualitative trending
- Primarily clinical populations

Desired Characteristics

- Simple, noninvasive, inexpensive
- Objective, quantitative measures
- Access large populations via mobile devices

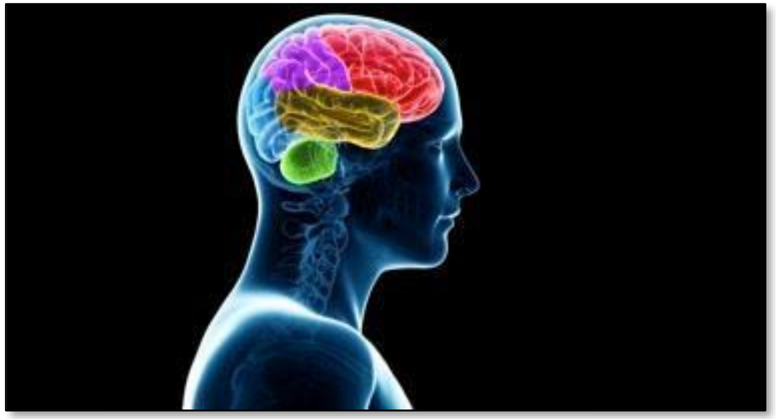
MRI: Magnetic Resonance Imaging
MEG: Magnetoencephalography

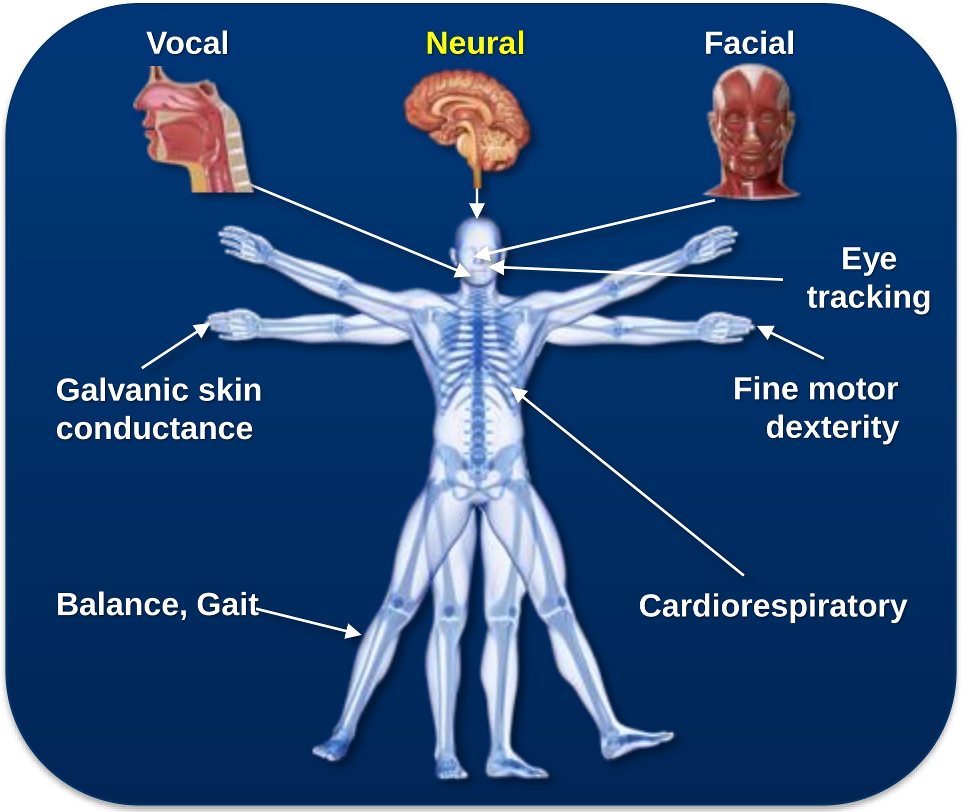
CT: Computer Tomography
EEG: Electroencephalography
EMG: Electromyography

Biomarkers of Human Behavior

Desired properties

1. **Changes in motor control of a behavior due to change in brain function**
2. **Changes in timing and coordination within components of the behavior**



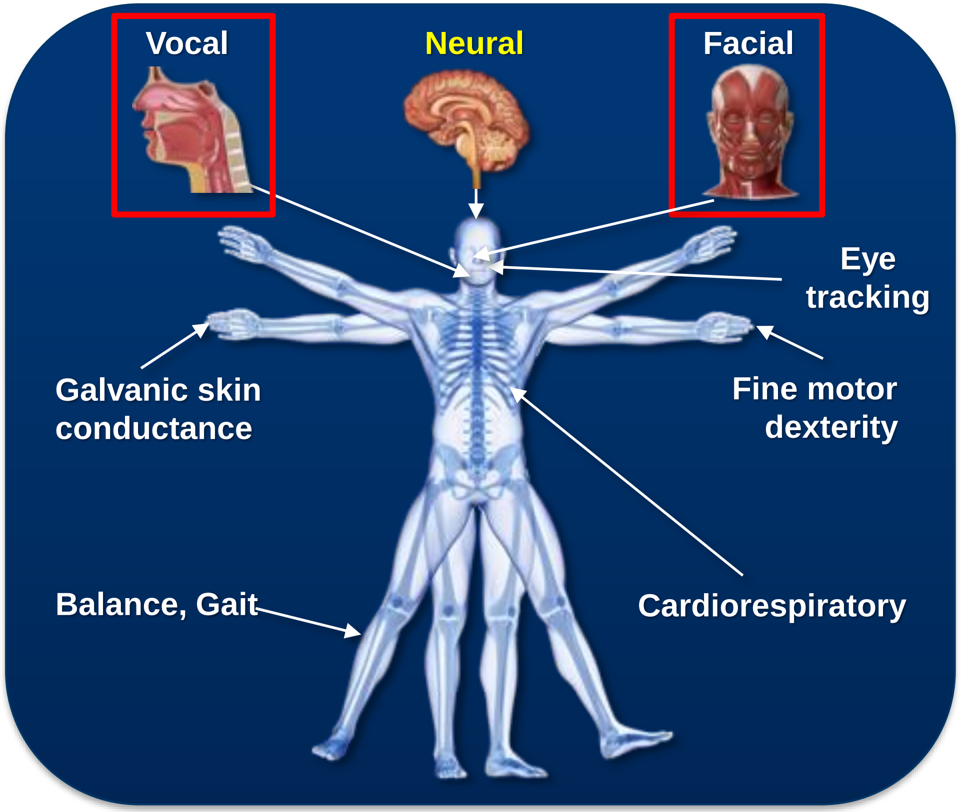


Neural timing and coordination across different parts of the brain essential in motor control

Vocal (and Facial) Biomarkers

One focus is on vocal and facial gestures during speaking

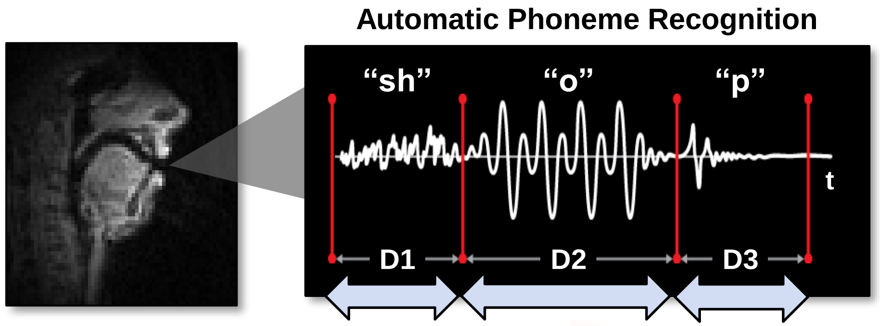
- Easily and noninvasively measured behaviors
- Many standard signal processing techniques can be leveraged for analysis
- Highly complex human behavior that requires coordination across the brain

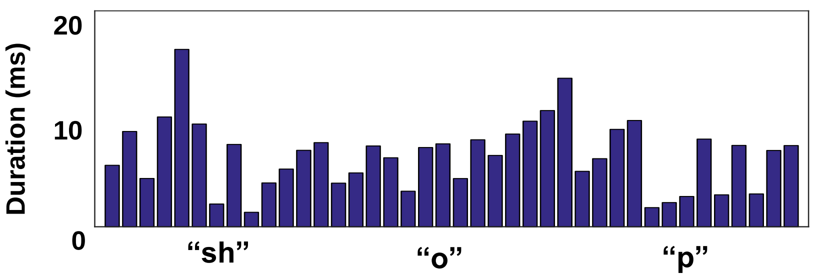


Coordination can be a hidden aspect of human behavior that can be brought into a realm that is tractable and understandable.

Vocal Timing and Coordination

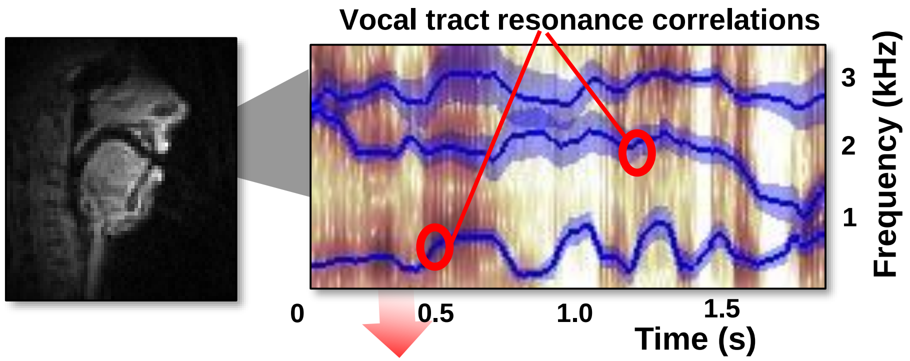
Changing of speaking rate at phoneme level

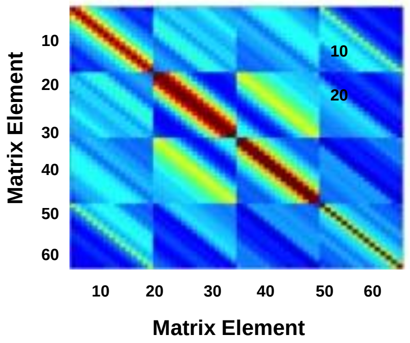




Average phoneme durations to quantify change in average speaking rate of each phoneme for each subject

Loss of motor coordination, i.e., complex synchrony, of speech articulators (tongue, lips, jaw)



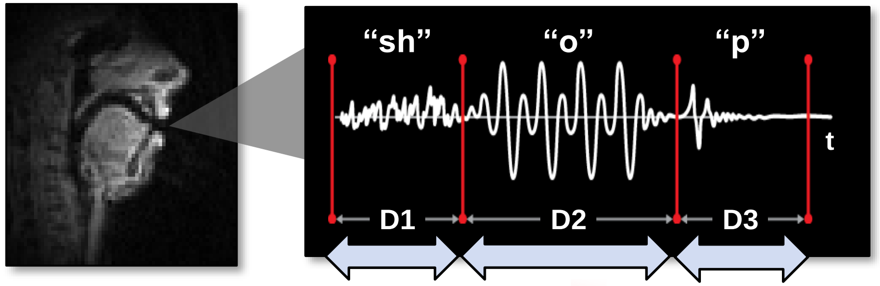


Eigenvalues to quantify coordination

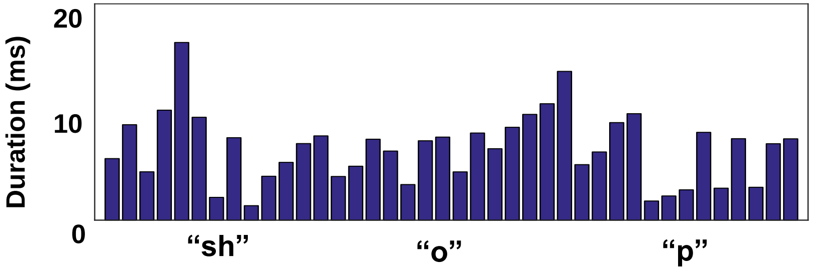
Vocal Timing and Coordination

Changing of speaking rate at phoneme level

Automatic Phoneme Recognition



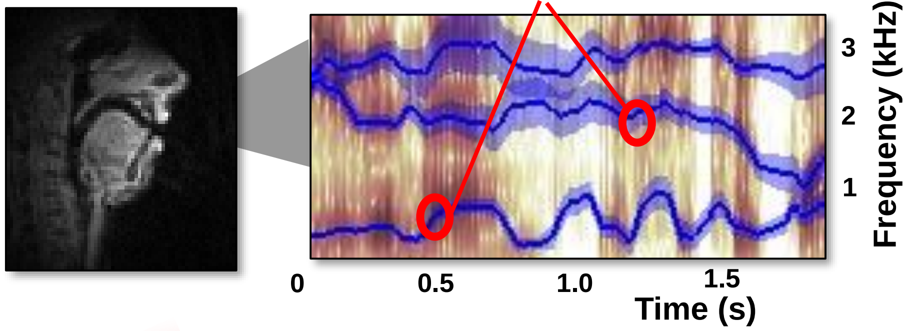
Average phoneme durations for a subject

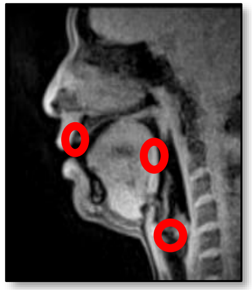


Average phoneme durations to quantify change in average speaking rate of each phoneme for each subject

Loss of motor coordination, i.e., complex synchrony, of speech articulators (longue, lips, jaw)

Vocal tract resonance correlations





Can also investigate coordination across different speech production sub-systems: vocal folds and articulators

Timing and Coordination of Facial Action Units

Facial Action Units

- Represent muscle groups that underlie facial expressions

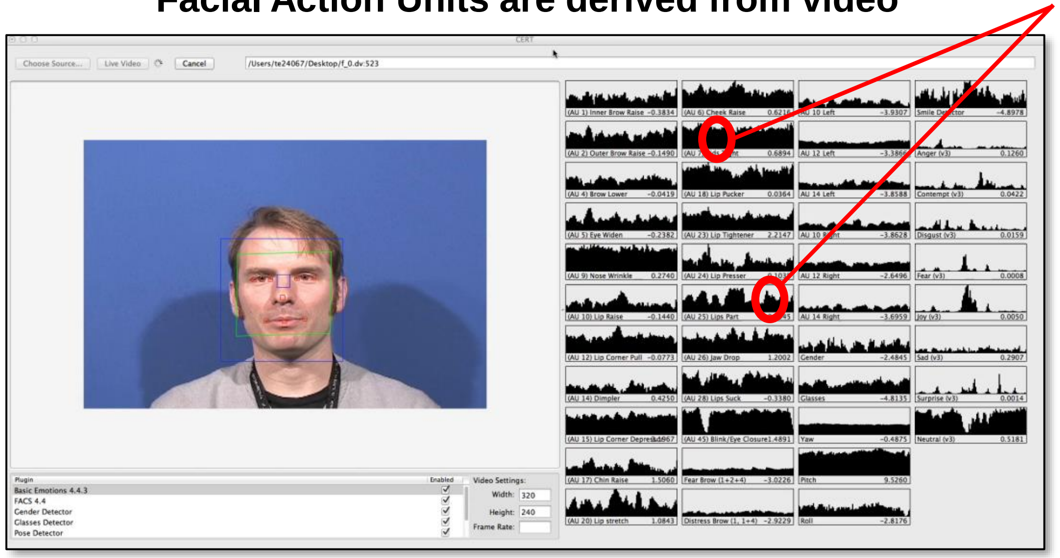
Lip Corner Pull

Lip Tightening

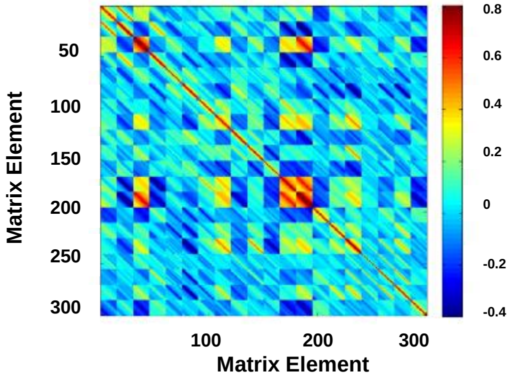
Brow Lowering

Facial Action Units are derived from video

Facial action unit correlations



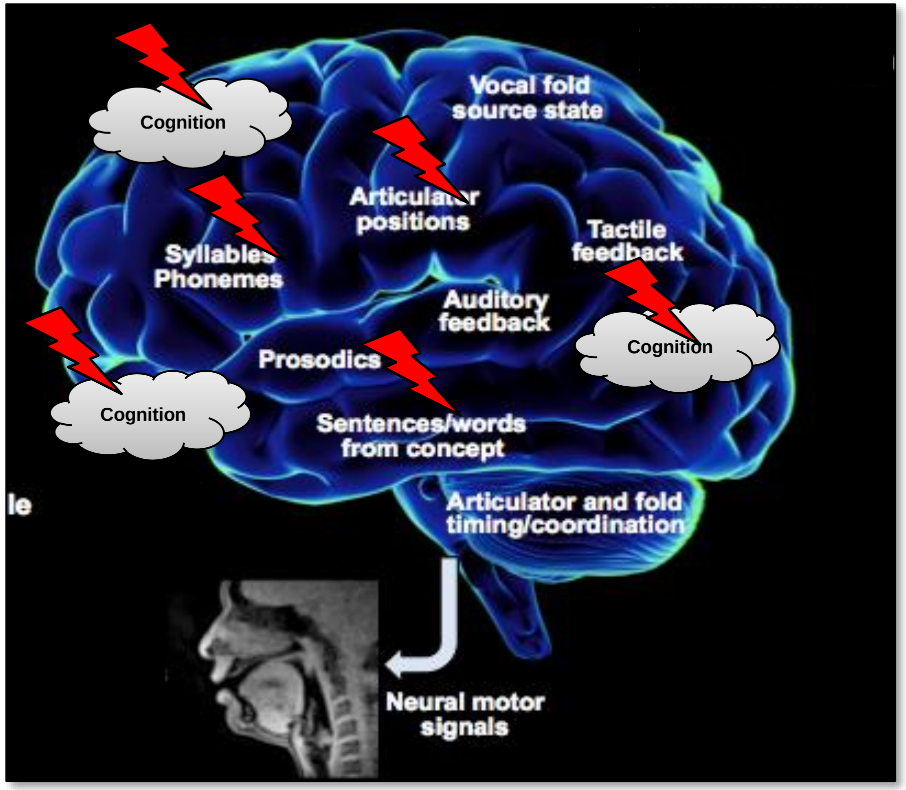
Correlation matrix



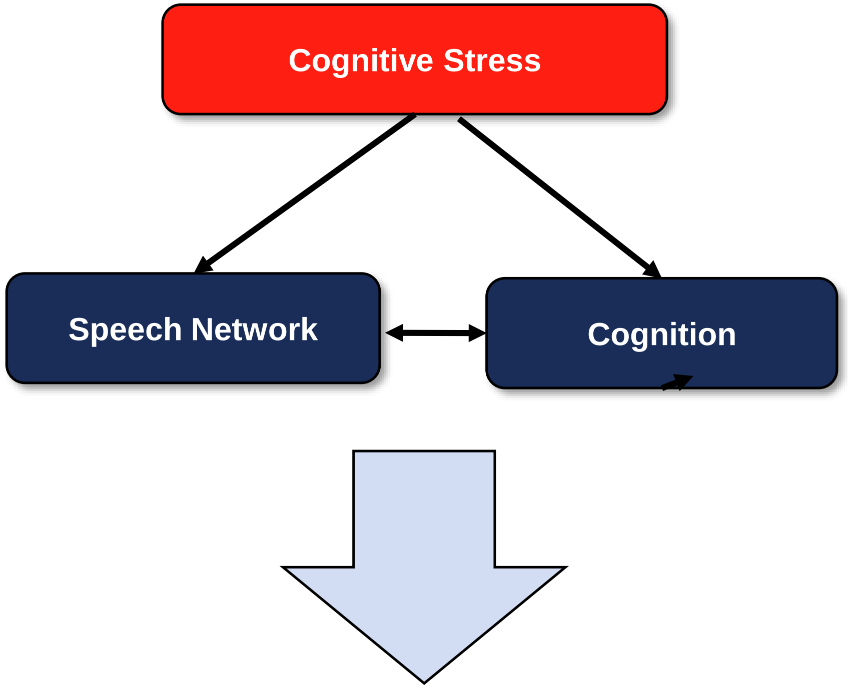
Eigenvalues to quantify coordination

Stress on the Brain from Cognitive Overload

Insult by head impact



Cognitive stress can cause neurocognitive and sensorimotor changes



Hypothesis: Can assess cognitive changes using speech (facial) biomarkers

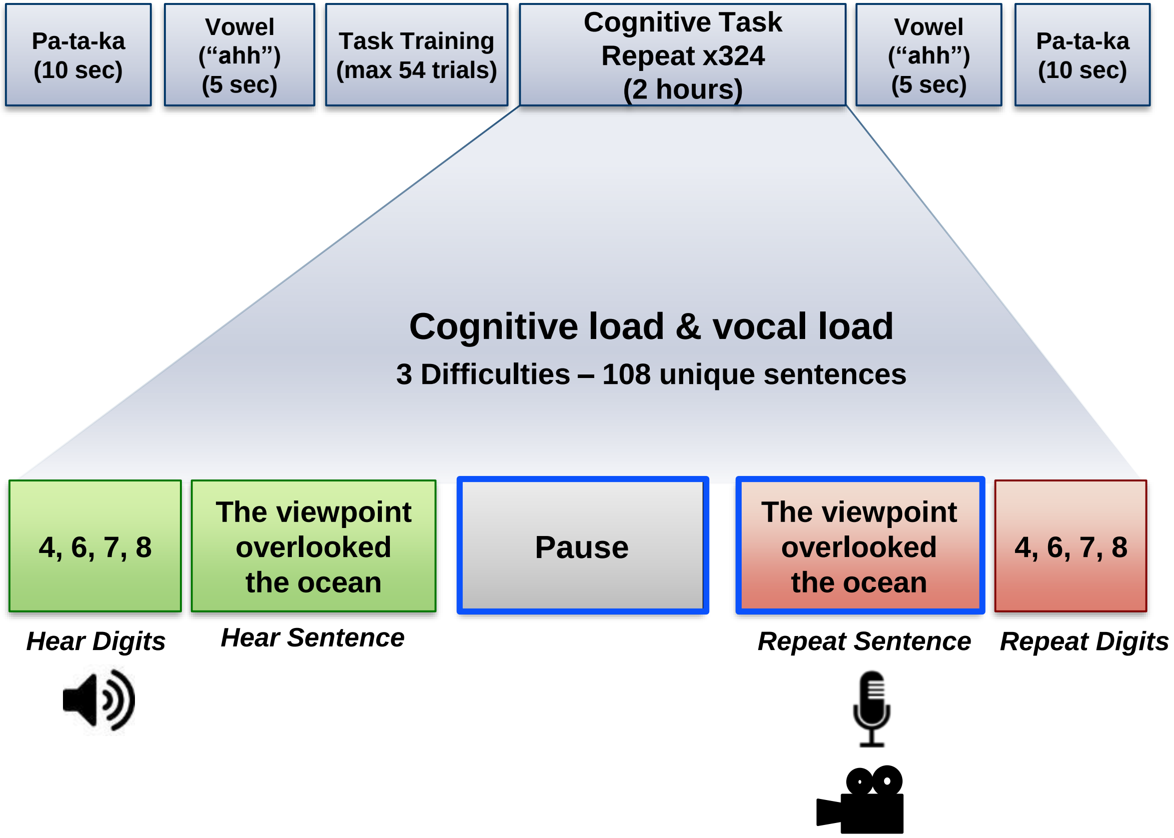
Detecting Cognitive Load & Fatigue

LL Biomedical Speech/Hearing and Neurocognitive Laboratory

Cognitive Load Study

- **Objective: Detect one of two load conditions**
- **Digit & sentence recall task**
- **Multiple sensor modalities**
  - Audio
  - Video
  - EEG (considered a gold standard for cognitive load)

Cognitive Load Protocol



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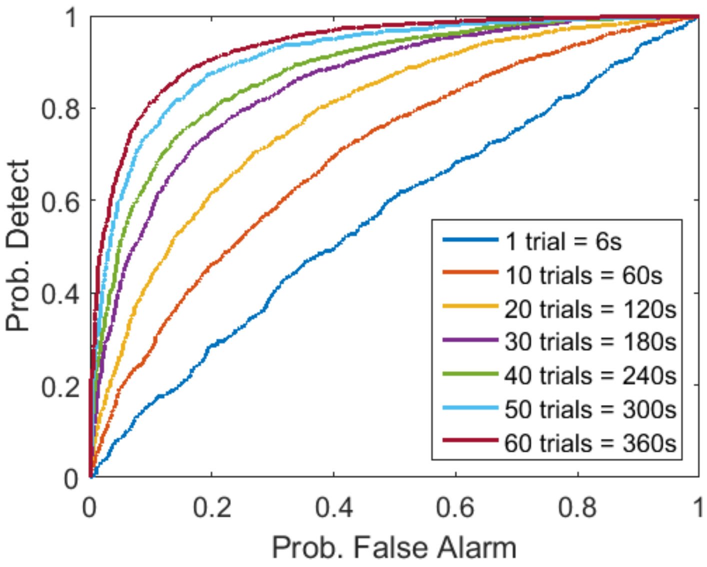
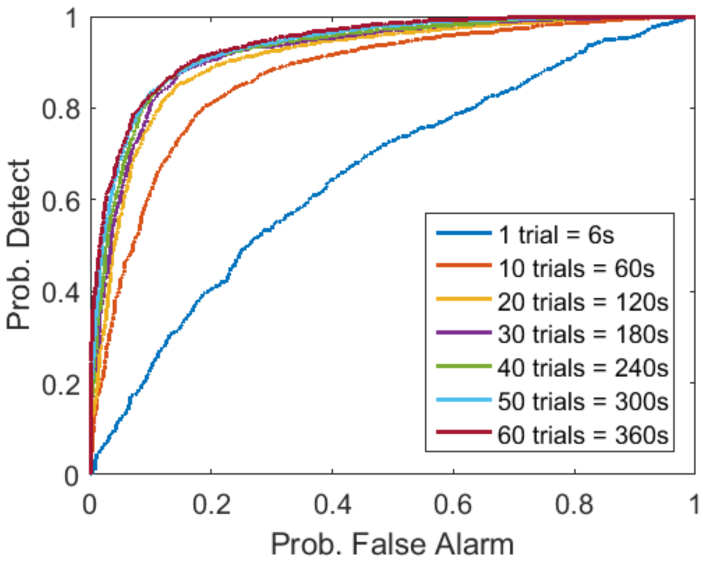
Detecting Cognitive Load & Fatigue

EEG, Audio/Video Fusion

Audio + Video



EEG

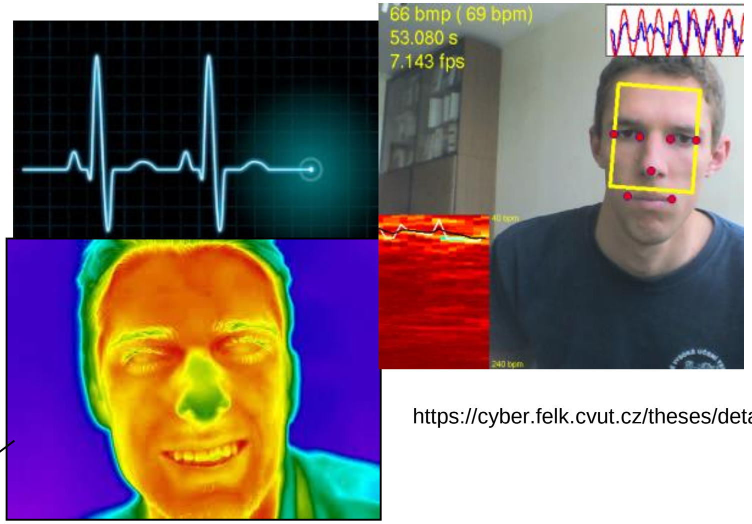


- **Multiple trials of digit & sentence recall task**
- **11 subjects in lab-based collection**
- **Expanded to portable collection platforms**

Noninvasive vocal and facial biomarkers approaching gold-standard EEG performance

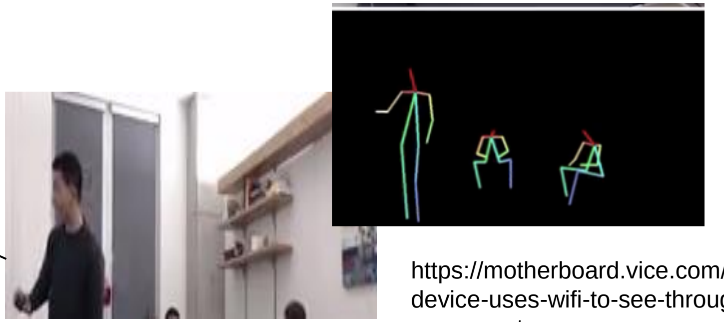
Other Passive and Stand-Off Sensing

- **Other passive wearable or standoff monitoring from video, infrared, WIFI/RF**
  - **Heartrate and respiration**
  - **Skin conductance and temperature**
  - **Fine and gross movements**



https://cyber.felk.cvut.cz/theses/detail.phtml?id=495

- **Examples**
  - **Emotion from video and infrared cameras on smartphones and tablets**
  - **Movement through walls using WIFI and RF**



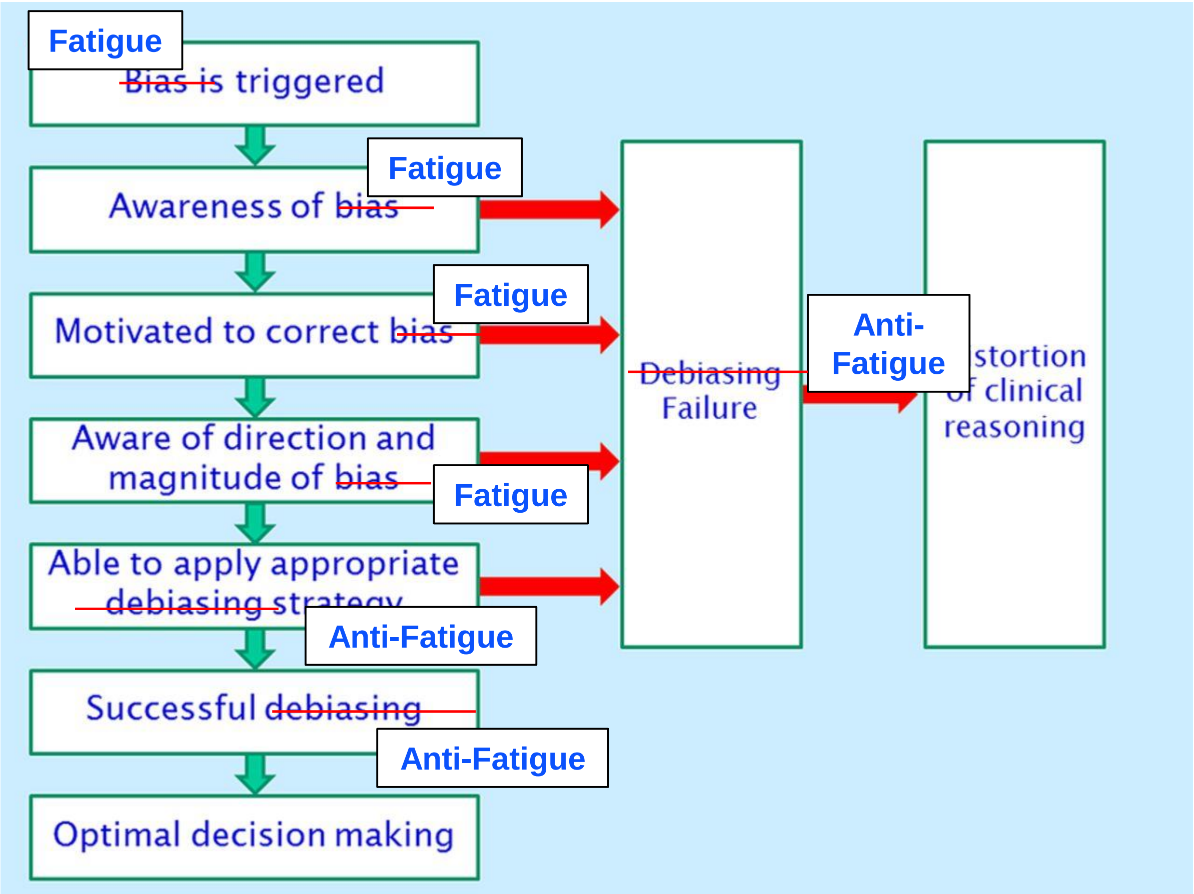
https://motherboard.vice.com/en_us/article/a3aaqp/mit-device-uses-wifi-to-see-through-walls-and-track-your-movements

State-of-the-art mobile technology allow for a large array of non-obtrusive behavioral sensing

Combating Cognitive Fatigue in Decision Making

Step 1: Detection

Step 2: Mitigation



Maybe we can focus on fatigue, instead...

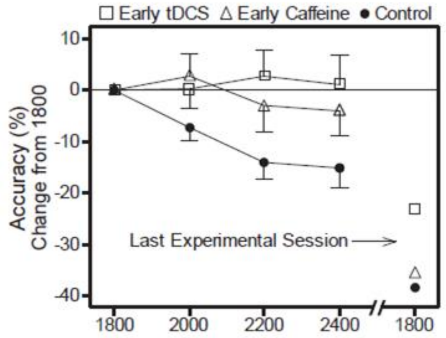
Adapted from : https://qualitysafety.bmj.com/content/qhc/22/Suppl_2/ii58/F3.large.jpg

Interventions

- **Rest**
  - Sleep is a good defense
  - Switching tasks

- **Chemical interventions**
  - Caffeine can do wonders
  - "Go pills" are common and approved in military

- **Transcranial Direct Current Stimulation**
  - Has shown great promise in improving cognitive function
  - Has lasting effect for improvement over fatigue and overload

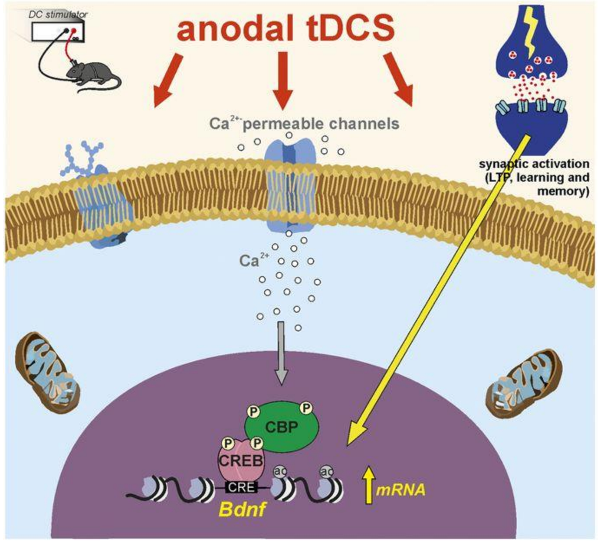


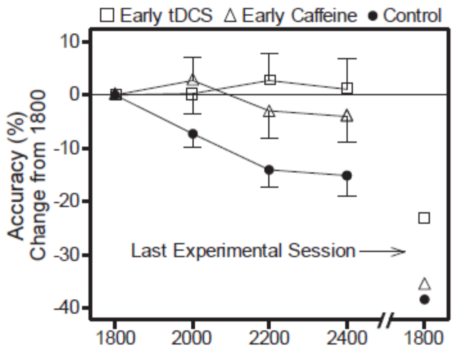
[1] McIntire, et al., "Transcranial direct current stimulation versus caffeine as a fatigue countermeasure." Brain Stimul. 2017 Nov - Dec;10(6):1070-1078. doi: 10.1016/j.brs.2017.08.005. Epub 2017 Aug 18.

tDCS

- **How does it work?**
  - **Provides 2mA stimulation through the skull to dorsal parietal lobes to counteract effects of fatigue.**

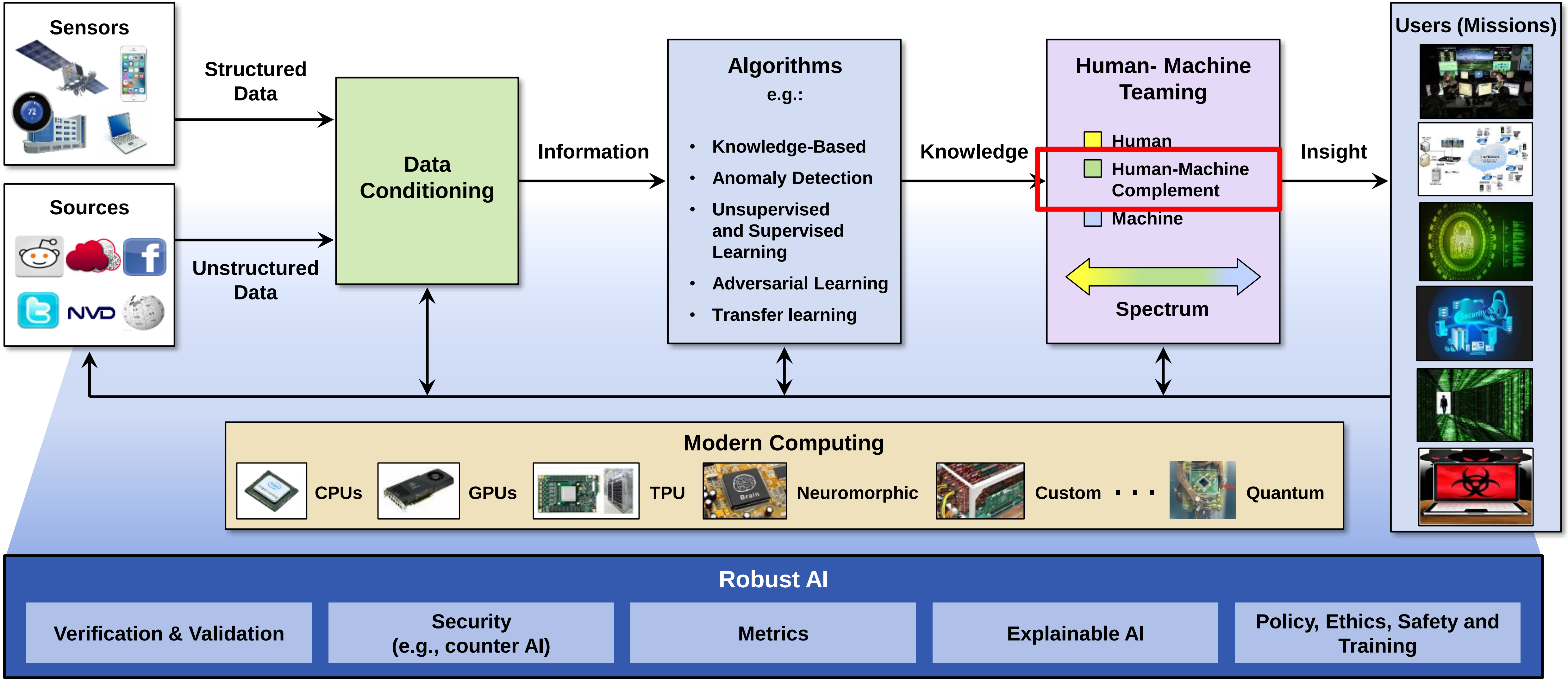
- **Role of AI in interpreting current data and applying stimulation in correct way to improve function**



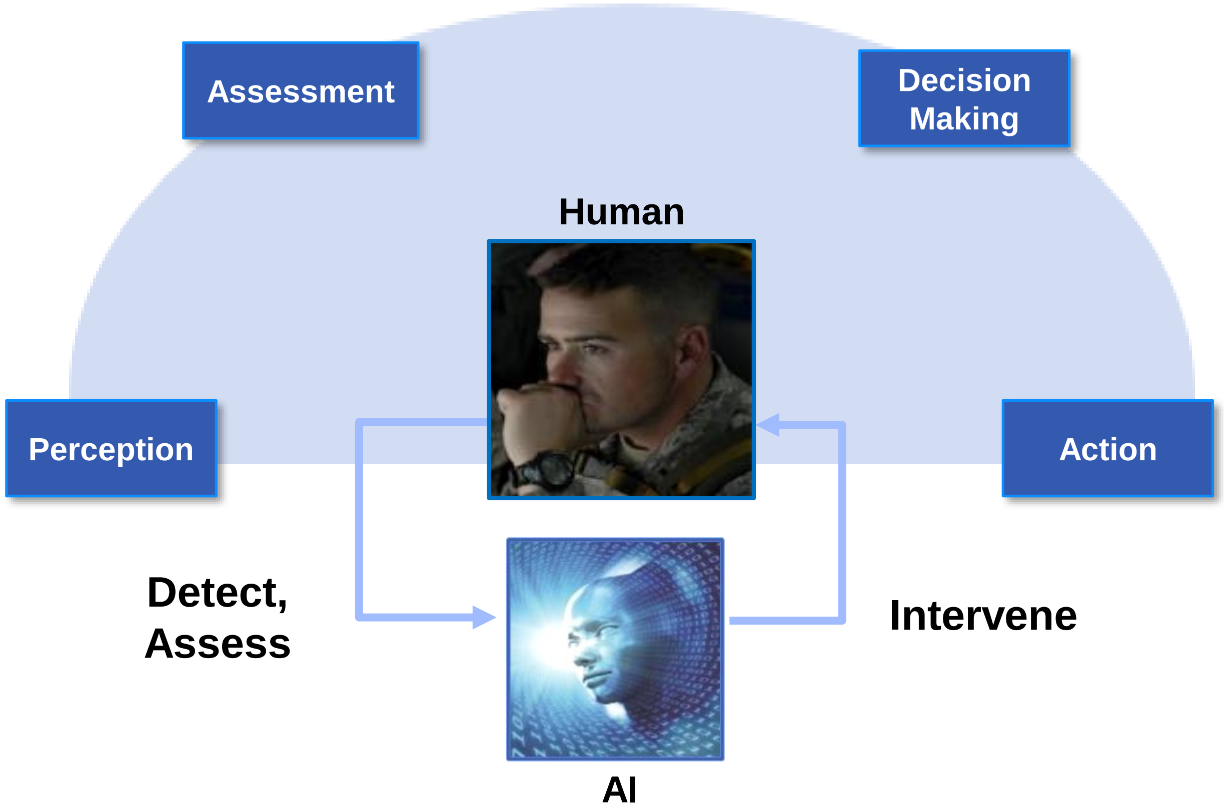


[1] McIntire, et al., “Transcranial direct current stimulation versus caffeine as a fatigue countermeasure.” Brain Stimul. 2017 Nov - Dec;10(6):1070-1078. doi: 10.1016/j.brs.2017.08.005. Epub 2017 Aug 18.

Canonical Architecture for AI



Human-Machine Teaming Model to Combat Cognitive Fatigue, Ensure Cognitive Security



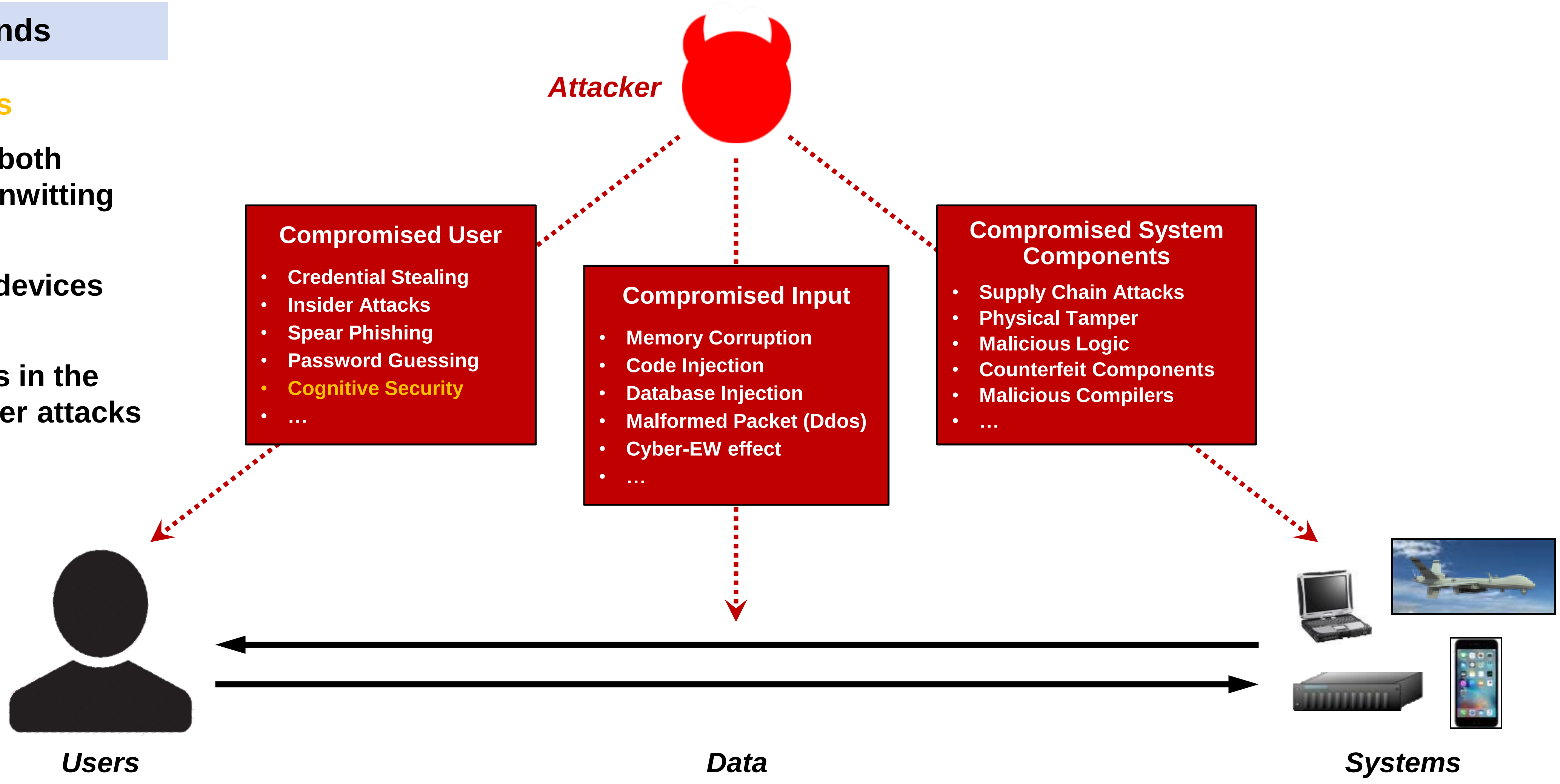
- ✓ Gather relevant cognitive biomarkers
- ✓ Assess aspects of cognitive fatigue
- ✓ Recommend intervention with appropriate measure to maintain optimal performance

Artificial Intelligence can be leveraged to identify fatigue in biomarker data and recommend appropriate intervention

Cyber Security: Critical Threat Surfaces

Global Trends

- Vulnerable users
- Insider threats (both malicious and unwitting insiders)
- Proliferation of devices (e.g., IoT)
- Mission success in the presence of cyber attacks
- Attacker use of automation / AI



Adapted from: Prof. Howie Shrobe, AICS17 Keynote, 2017, San Francisco, CA

Achieving Cognitive Security:

Potential Research Directions

- Systems to detect and avert fatigue quickly
- Non-invasive ways to sense cognitive fatigue
- HCI that incorporates cognitive fatigue feedback
- Human-machine teaming that offloads human when fatigued
- New types of interventions: work-sharing, goat-yoga
  - Depends on cause of fatigue...

- Role of cognitive fatigue in cognitive security (e.g., decision making)
- Other cognitive disorders that effect human performance
  - Depression, ADHD, affect, etc. ...

Summary

- **Cognitive fatigue negatively effects decision capabilities of humans**
  - **Humans will continue to be an integral part of automated systems**

- **Cognitive fatigue could be an advantageous attack surface for a motivated attacker**
  - **Leads to non-optimal, biased decisions in many domains**

- **Cognitive fatigue can be detected unobtrusively and mitigated to restore optimal performance**
  - **Biomarkers manifest fatigue, interventions provide mitigation**

- **MIT Lincoln Laboratory is working to better understand phenomenology and implement solutions**