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Adaptive Cyber-Physical Human Systems

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Outline

- Cyber-Physical-Human Systems
- Adaptive CPH Systems
- Adaptation and Learning in CPS
- Key Considerations
- Exemplar Application
- Expected Results
- Potential Transitions

Project Team

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Cyber-Physical-Human Systems

- Are socio-technical systems
  - exist at multiple scales (CP elements, humans)
  - ability to continuously improve (learning)
  - capable of mutual adaptation (changing context)
- Are complex engineered systems
  - built from computational algorithms, physical components, and human agents
  - performance depends on shared awareness, mutual predictability and trust even in the face of disruptions
  - difficult to assess their long-term impact (hidden interactions, change cascades)

Cyber-Physical-Human Systems: Key Characteristics

- Are purposeful arrangements of sensors, computers, communication devices, and humans
  - jointly perform missions that unfold over time and across space
- Make provision for other systems to connect/disconnect as needed for successful mission accomplishment
- Allow for different roles for humans and cyber-physical elements in CPH architecture
  - based on operational context including state of humans, cyber-physical elements, and environment
- Capable of learning and adaptation
  - mutual adaptation
  - adaptation to changes in environment
- Can be viewed from the perspective of a high performance team
  - require shared awareness, mutual predictability, and trust

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Human Roles in CPH Systems

- Shared task performer
- Monitor (with over-ride privileges)
- Controller
- Performance analyzer
- Behavior influencer

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Adaptive Cyber-Physical-Human Systems

- Learn and adapt dynamically
  - —new contexts
  - —each other
- Machine learning options
  - —supervised learning
  - —unsupervised learning
  - —reinforcement learning
- Multiple sources of learning
  - —sensors
  - —networks
  - —people
- Complicating factors
  - —partial observability
  - —noisy sensors
  - —disrupting events

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Human Modeling in CPH Systems

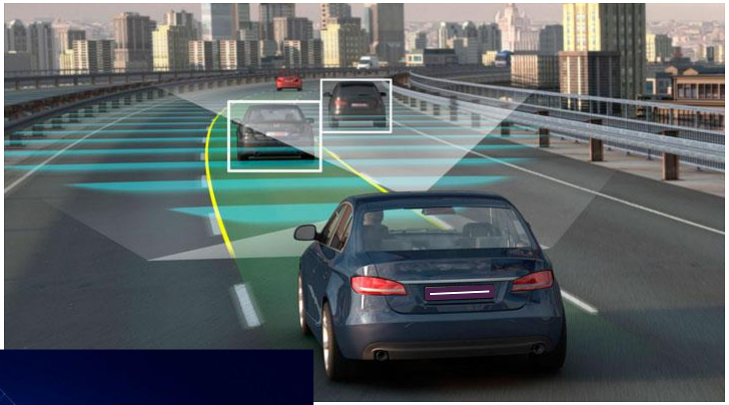
- Humans have:
  - —kinematic constraints
  - —cognitive limitations
  - —dynamic behaviors
- Not all aspects of humans participate in CPH activities
- Question: how should humans be modeled (i.e., represented) for a specific CPH system?
- Question: is there a methodological basis for determining appropriate sparse representation of a human for a particular class of activities?

Learning in CPH Systems

- Human information preference
  - supervised learning
- Human intent inferencing
  - from noisy signals and context
  - supervised and reinforcement learning
- Shared perception
  - context-driven localization vs. object recognition within scenes
- Shared decision making
  - objective structuring and option evaluation vs creative option generation
- Mutual adaptation
  - as a function of context
  - supervised learning
- Bi-directional transfer of control
  - passing the "conn" between captain and OOD
- Manual backup for malfunctioning CPS
  - understanding human limitations and context-awareness

Exemplar CPH Systems

- Self-Driving Vehicles
- Smart Buildings
- Smart Manufacturing
- Medical Devices
- Unmanned Aerial Vehicles



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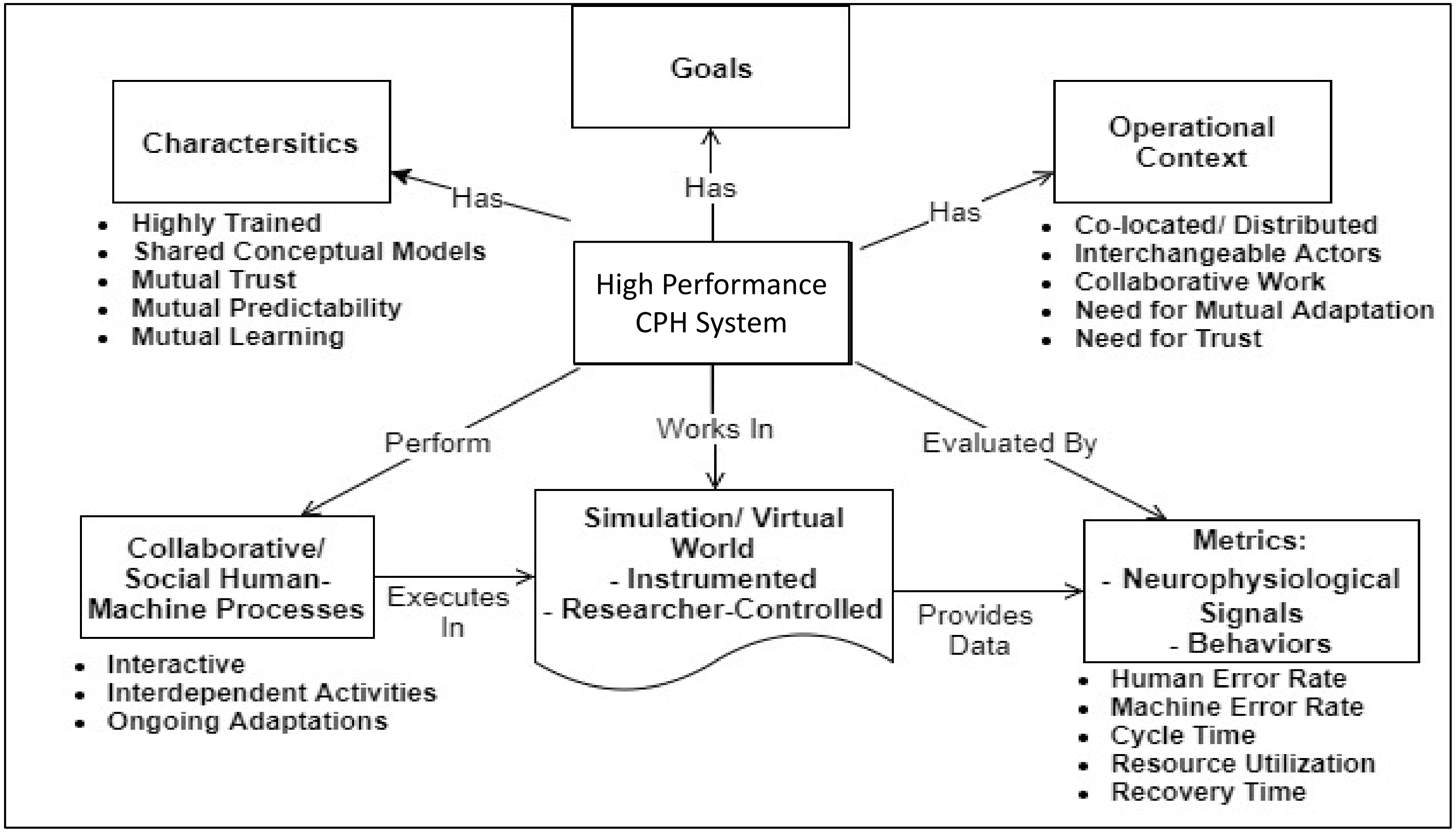
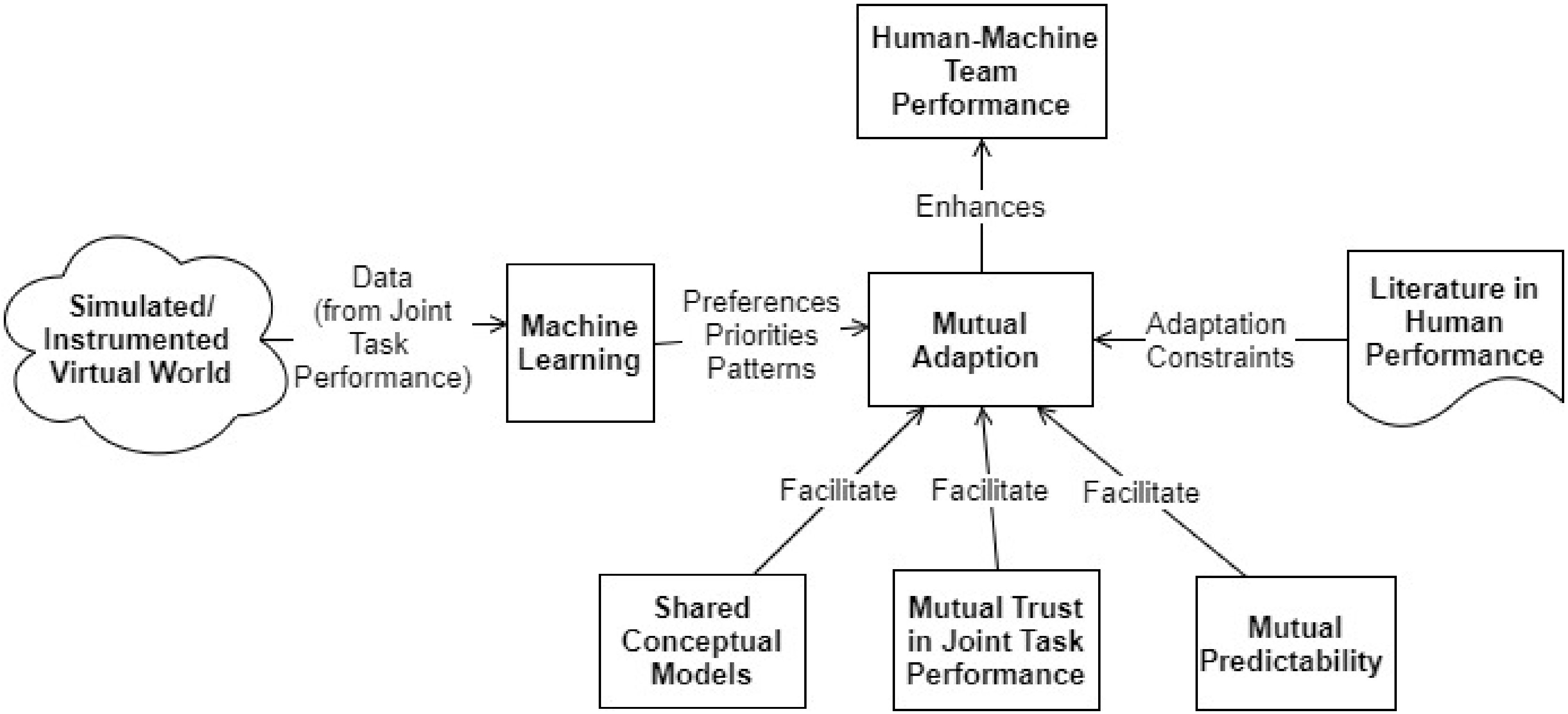
Teaming Construct for CPH Systems

- View CPS and Human within a Team construct
  - —teamwork is key to sustained high performance
- What Makes a High-Performance Team?
  - —capitalize on each other's strengths
  - —circumvent each other's limitations
  - —maintain shared awareness, mutual predictability and trust
  - —jointly adapt to contingencies and respond to disruptions
  - —rapidly re-establish cognitive coupling after disruption
- Successful Mutual Adaptation
  - —shared conceptual model after adaptation
  - —mutual predictability after adaptation
  - —mutual trust after adaptation
- Constraints
  - —CPS and Human have adaptation constraints
  - —CPS cannot adapt faster than human
  - —CPS has technology limitations

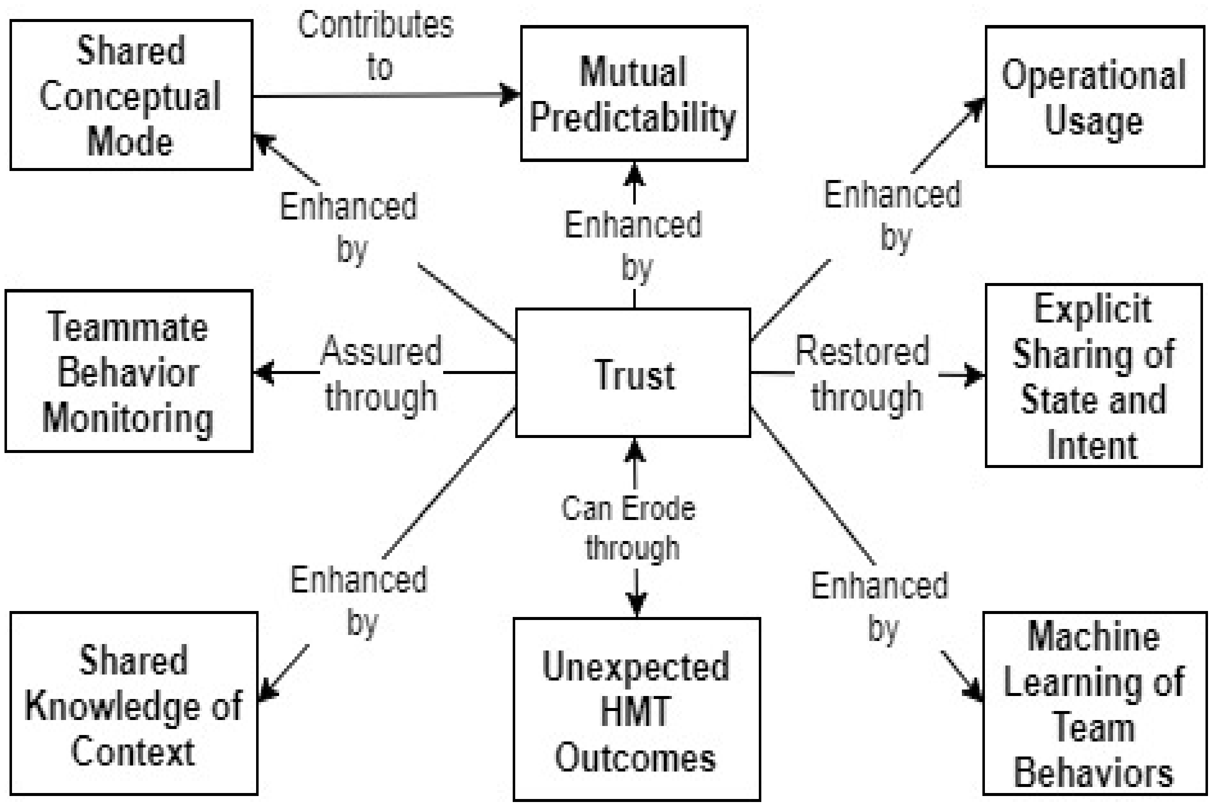
Conceptual Schema for High-Performance CPH System



Mutual Adaptation in High-Performance CPH System



Various Dimensions of Trust



Human Roles

- Observer: Outside Control Loop
- Decision Maker/Approver: Within Control Loop
- Interactive Controller of Sensors/Actuators: Within control loop
- Sensor Monitor: Inside one or more sensor loops
- Status Monitor: Inside one or more actuator loops
- Combinations of the Above

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CPS Role: Monitor and Correlator

- Humans can’t control many physiological reactions
- What can/should CPS monitor to determine whether to trust or question human
  - e.g. can CPS know difference between an elevated heart rate due to stress versus too much caffeine?
- Can correlating with other sensors help distinguish stress from caffeine?
- How should machine behavior/actions change based on such evaluations?
- A few papers discuss using HMM in adaptive control systems
  - to monitor human behavior
  - to change control functions based on predicted state

Shared Decision Making and Dynamic Allocation of Responsibility

- Humans good at:
  - —understanding complex situations (contextualization)
  - —making high-level decisions
- CPS good at:
  - —implementation of high level decisions (local level)
  - —embedded and remote sensing
  - —fast computation and multi-source information aggregation
- Function/task performed by human(s) and CPS can be re-allocated based on context (poor performance, inability to perform, request for help)
- Need a way to assess human-CPS interactions so that right (safe, correct, efficient) allocation of functions is achieved
- Need to understand that boundaries of responsibilities can change (performance, context)
  - —e.g., if human drowsy, CPS takes over
  - —e.g., if CPS headed into trouble or signals handoff, human takes over

Types of Human and CPS Interaction: Examples

- Direct human control of CPS (primarily supervisory control)
  - —1: human intervenes in the control algorithms and adjusts set points
  - —2: CPS accepts & carries out human commands, reports results, awaits next cmd
- CPS monitors human passively; takes appropriate action if needed
  - —can be open loop or closed loop systems
- For example, sleep tracking device to track sleep quality (open loop)
  - —also monitors sound, light, temperature and motion sensors to record environmental conditions during sleep (i.e., context);
  - —this information is presented to the user on a tablet or smart phone to apprise them of possible causes of disruption
  - —here the human is in the loop but does not directly control the system
  - —the system does not take any proactive action to improve sleep quality (i.e., it is an open loop system); if it did, then it would be a closed loop system
- For example, smart thermostat (closed loop human-in-the –loop)
  - —uses sensors to detect occupancy and sleep patterns in home
  - —uses patterns to proactively turn of HVAC system to save energy

Types of Human and CPS Interaction: (continued)

- Human monitors CPS which is in control; human decides to take back control (by taking back the “conn”)
  - key construct: passing the “conn” – a naval metaphor for control between the captain and Officer of the Deck (OOD)
  - Captain can retain the conn, or give it to the OOD
  - Captain can command through the OOD or monitor OOD’s decisions/actions
  - If captain does not like the OOD’s commands to subsystems, captain can revoke “conn” and assume command; then can command through the OOD

Use of Human Behavior Models

- State-of-the-art techniques to model human behavior
  - —very general
  - —very specific
- For example, Smart Thermostat uses Hidden Markov Model to model occupancy and sleep patterns of residents to save energy
  - —it captures human behavior at a very high level
- For example, impulsive injection of insulin uses math models
  - —for diabetes mellitus
  - —very specific model determines need for insulin injection by monitoring glucose level relative to threshold level for administering insulin

Failure Detection: Key Questions

- How does CPH system detect failure?
- What/who is responsible?
- What needs to be fixed to either enable CPH to continue operating, or to place the CPH into a safe mode?
- POMDP concepts can apply here with some modifications
  - POMDP evaluates the probability of being in observable and hidden systems states and determines what actions to take based on maximizing a reward
  - need to go beyond autonomous actions by using human strengths in pattern recognition and non-linear thought
  - need hierarchical construct for dynamic allocation of control either to human or CPS depending on context (i.e., safety concerns, risk, availability)

Modularity and Reconfigurability

- Creation of reusable building blocks that can be adapted to multiple CPH system applications
  - hardware, software, interfaces, sensors, actuators
- Primarily an engineering question
- However, open research questions when CPH systems involve networks, WiFi, etc.

Expected Results

- Models of human-system interactions
- Models of CPH system patterns
- Development of a lab model that illustrates human-system collaboration

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Transitions

- SERC-identified organization(s)
- The Aerospace Corporation
- Periodic demos of progress
- Unique constraints of transition sites
- Constraints-aware technology platform
- Incremental - to sustain interest and solicit feedback
- SAE 599 course on CPH Systems to be offered in Spring 2018

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Where We Are Headed

- Finalize CPH system of interest to DOD
  - fits within project scope
  - transition opportunities exist
  - leverages SERC investments to date
- Prototype CONOPS
  - operational context
  - sources of disruption
  - examples mutual adaptation
- Define Adaptation and Learning Concepts
  - adaptation criteria
  - data sources
  - data collection constraints

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Thank You!