Holistic Design Methodology for Automated Implementation of Human-in-the-Loop Cyber-Physical Systems

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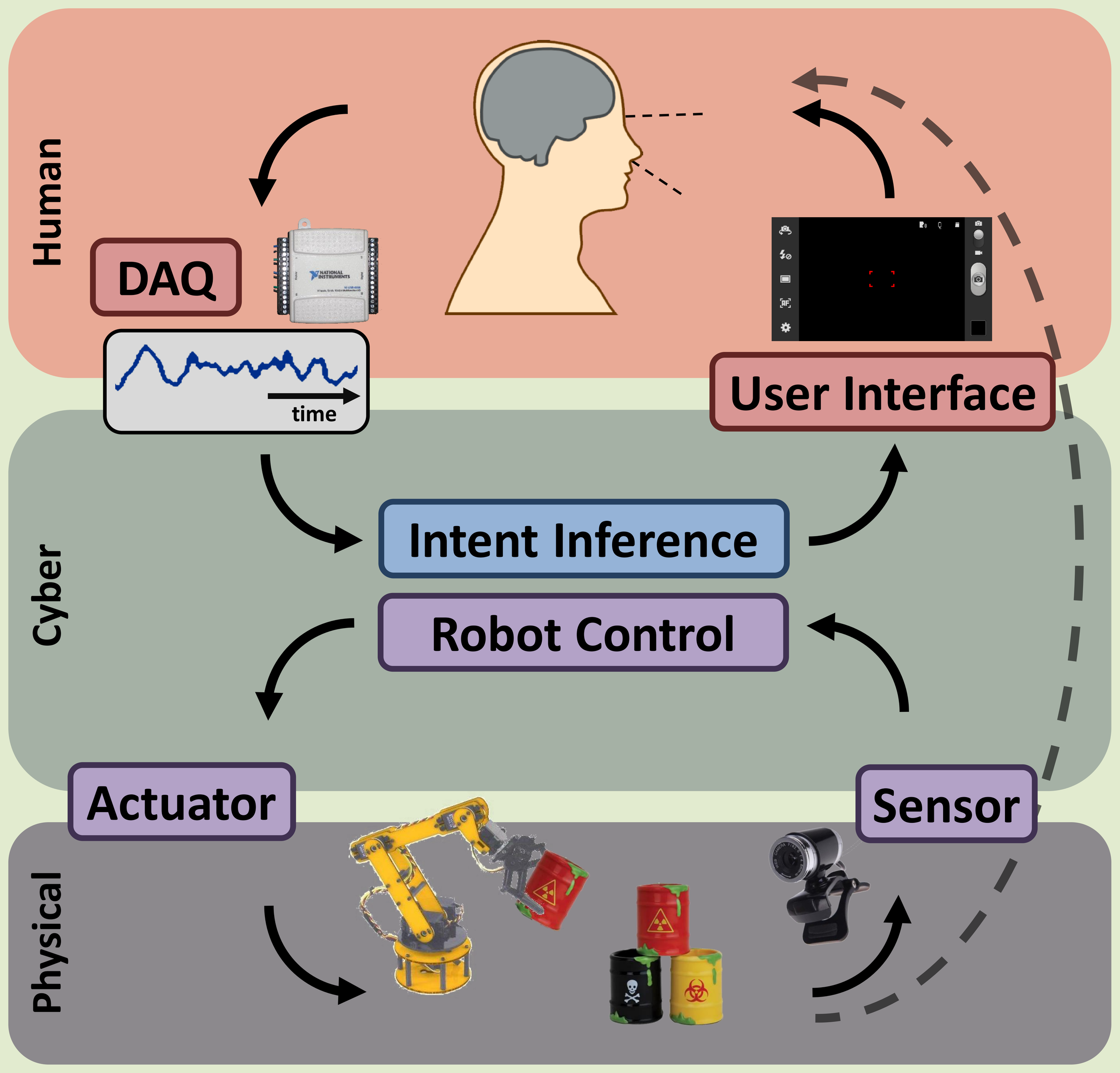


Motivation:

- Approximately **3.7 million people worldwide with motor and/or communication disabilities** arising from afflictions such as ALS, stroke, multiple sclerosis, and traumatic brain injuries.
- Brain computer interfaces (BCIs): restore autonomous actions by **allowing users to communicate and control devices** through the measurement of signals from their brains.
- Designing reliable BCIs: a tremendous multi-disciplinary challenge in BCIs, robotics and embedded design.
- Isolated design between these disciplines: NO cross-discipline optimizations.

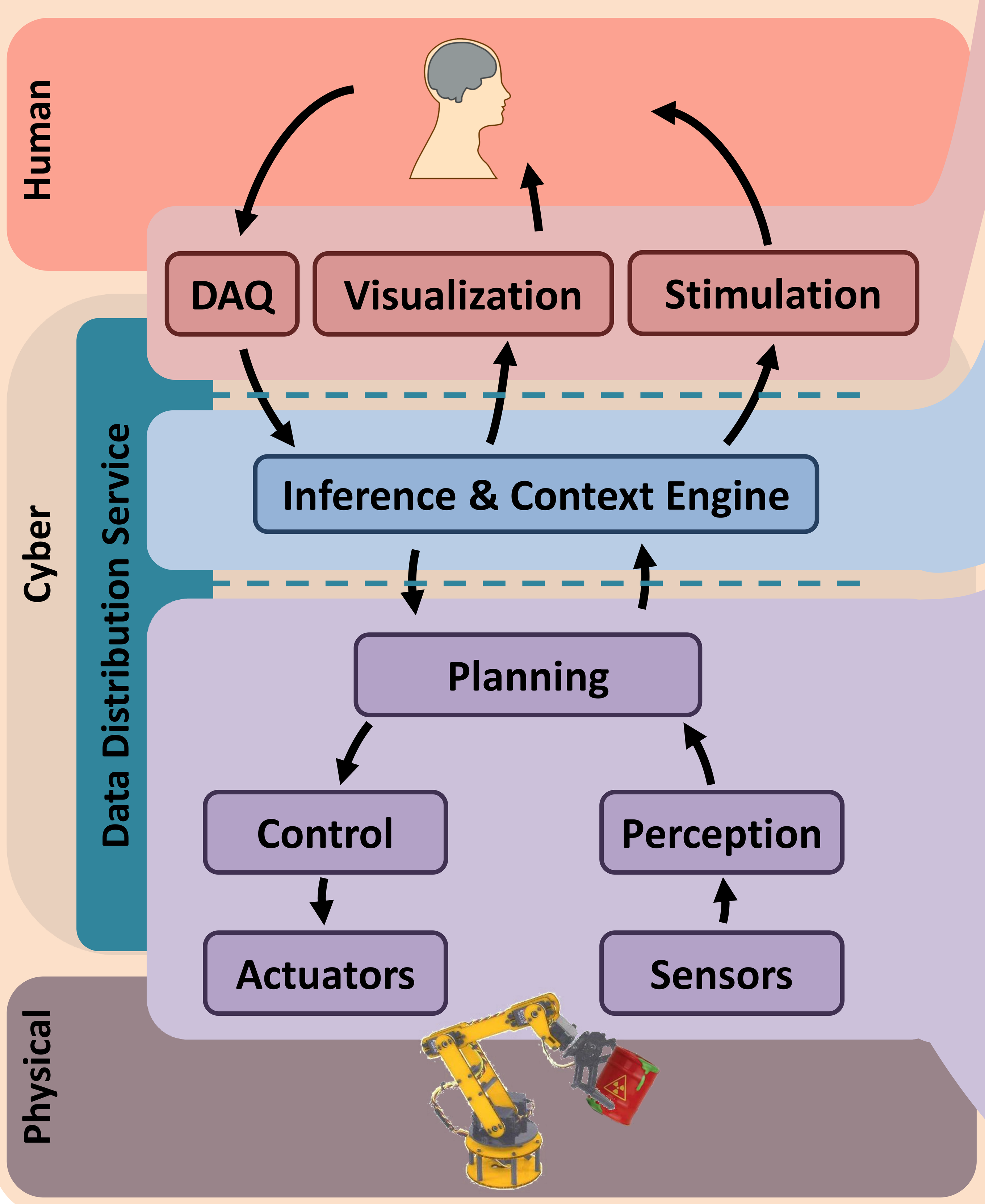
Goal:

- We propose to build a **unifying framework for the design of human-in-the-loop cyber-physical systems** (HiLCPS) that integrates rapid prototyping of body/brain computer interface (BBCI) algorithms with the development of robotic navigation and control.

People with Locked-In-Syndrome would like to:
- Move to places independently
- Communicate with friends
- Interact with the environment

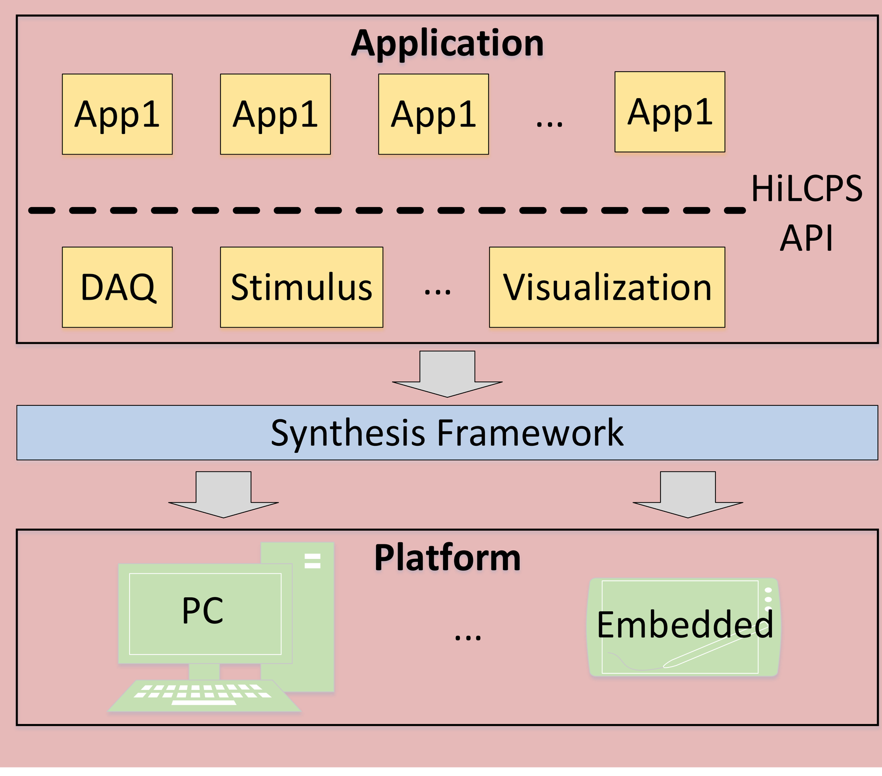
Framework:

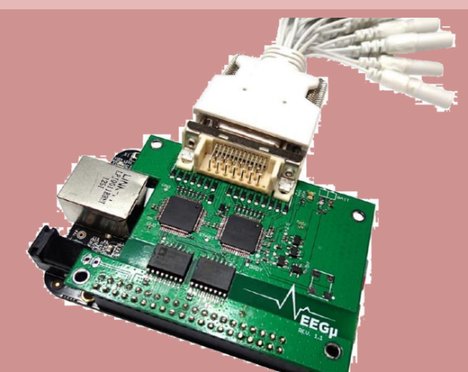
- Offer a **common base** of HiLCPS framework and prototyping platform.
- Accelerate the design of **re-targetable, reliable and efficient applications.**
- Employ **Data Distribution Service (DDS)** to integrate physically distributed components.
- **3-level Control Loop**:
  - Human controls the Inference/Context Engine via DAQ and receives feedback via Visualization & Stimuli.
  - Robot controls actuators and percepts the environment via sensors
  - Human observes environment and react via HLCPS.

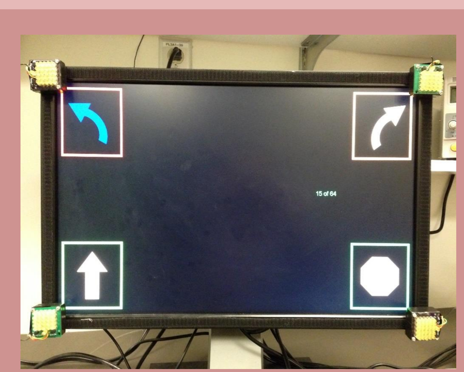


Embedded Design:

- **Synthesis Framework**
  - Automatic path from HiLCPS applications to embedded solution
  - Empower algorithm researcher: rapid prototyping





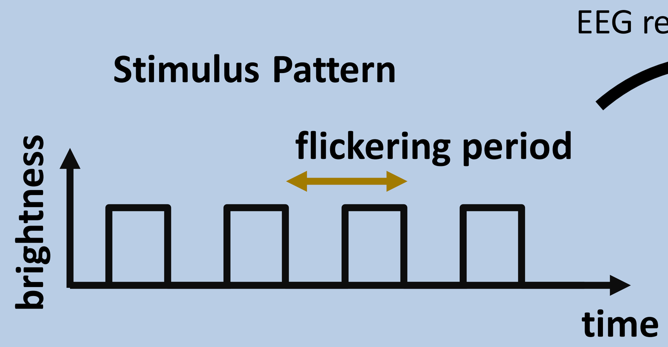


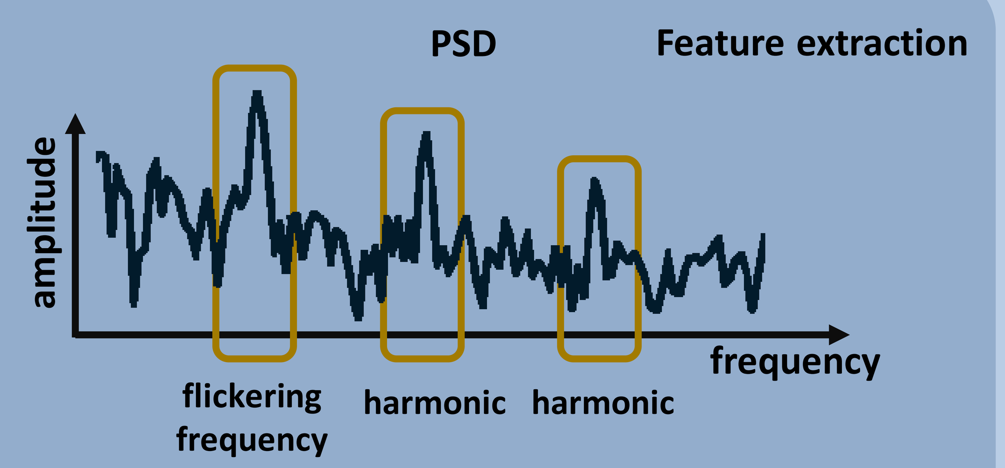
- **EEGu:**
  - Acquisition: 16 channel EEG front-end, 24bit A/D
  - Input referred noise: 1.83uV
  - Real-time Processing: BeagleBone Black with ARM Cortex-A8 1GHz
- **Stimulus:**
  - 8 channel LED checkerboard
- **Visualization:**
  - Any monitor or tablet based on Simple DirectMedia Layer

Data | Stimulus

Intent detection:

- **Steady State Visually Evoked Potentials (SSVEP)** repetitive or random blinking pattern that generates characteristic EEG responses.
- **Learn user specific responses** during training.
- **Probabilistic classification:** optimally fuse context information with physiological evidence to infer desired action





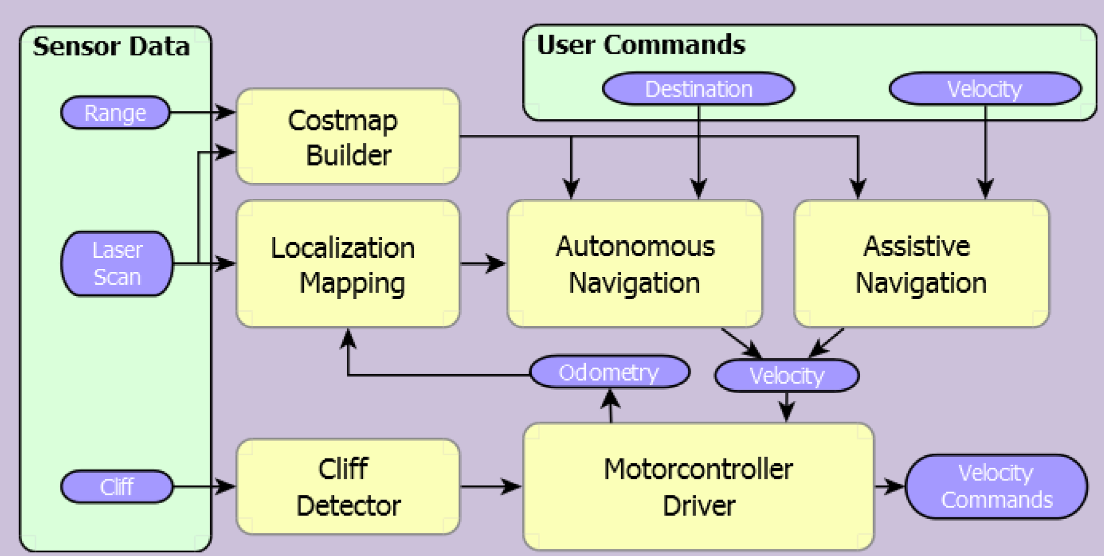
Inference with context information fusion

$$p(c_s = c|\mathbf{X}, \omega) = \frac{\prod_i p(\mathbf{x}_i|c_s = c)p(c_s = c|\omega)}{p(\mathbf{x}|\omega)}$$

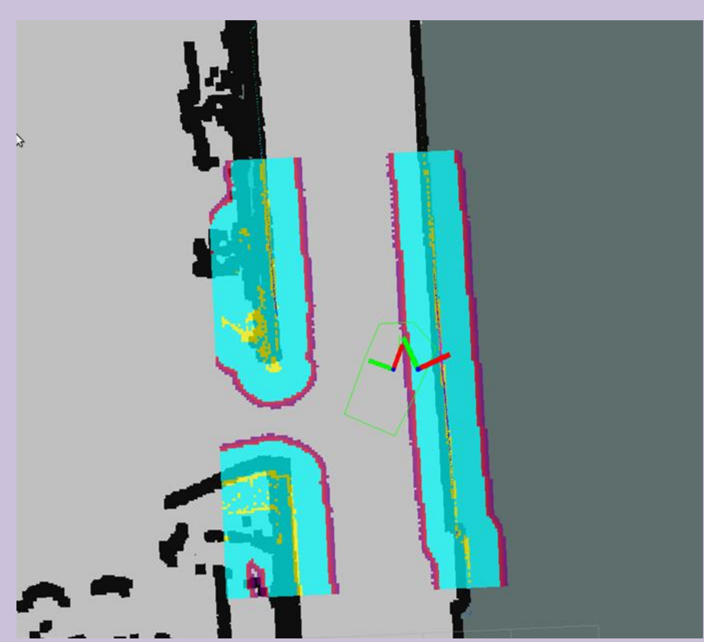
EEG evidence: $\mathbf{X} = [\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N]$ ω context information

Inferred Action | Context Information

Robotics:



- **Motion planning** (assistive drive): obstacle and cliff avoidance



- **Environment awareness**: mapping, localization, obstacle detection and cliff detection