CPS Technology Foundations: *Quō vādis?*

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Some Successes of CPS Technology Research

sufficiently SOLVED

I. Rich, continual, and pervasive sensing and actions



In Our Phones



In Our Places

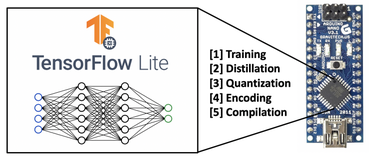
Exploiting data, physics, ML/AI, etc.



Sensors on (and in) Our Bodies

Smart Spaces
Healthy Individuals
Sustainable Systems

II. Embedded & connected intelligence



TinyML









III. Precise location & timing ubiquitously

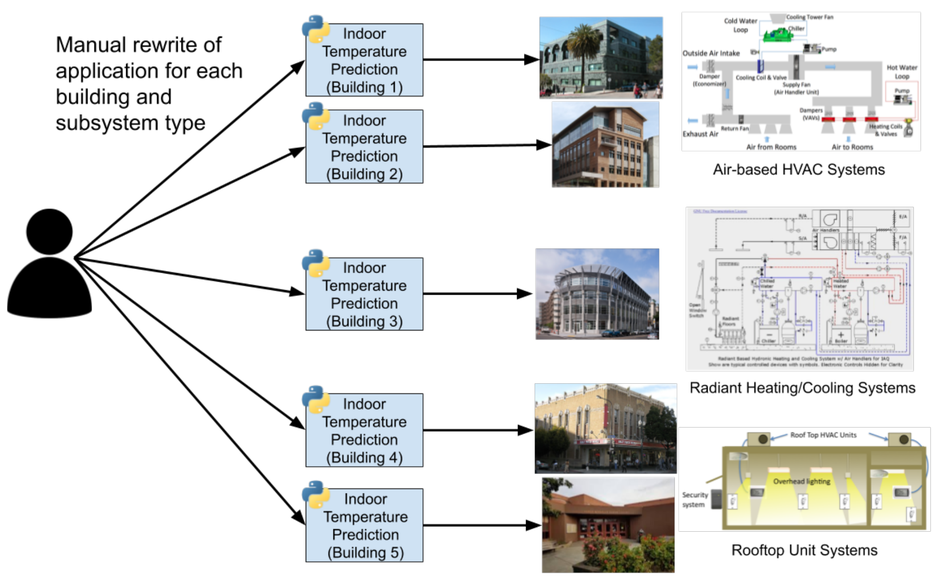




Some Open Challenges for CPS Technology Research

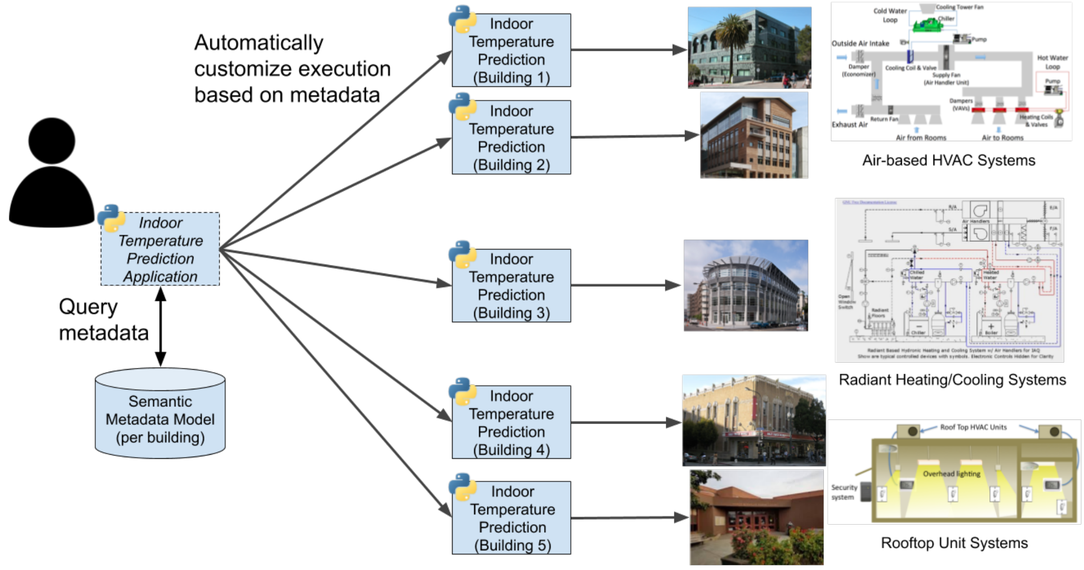
I. How to write “portable” CPS-IoT applications under variations & uncertainty?

Current State of the Art



- Hard to author and deploy apps at scale
  - Extreme heterogeneity: deployment are usually “one-off”
  - Missing/incomplete/ad-hoc metadata
  - Porting app requires manual rewriting/reconfiguration

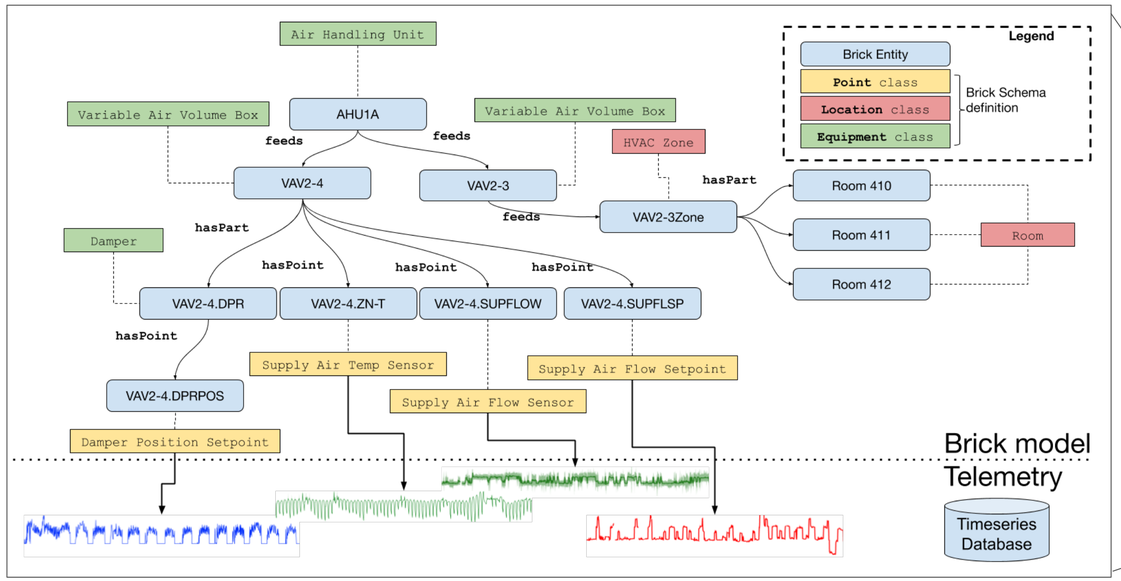
Imagine a future where…

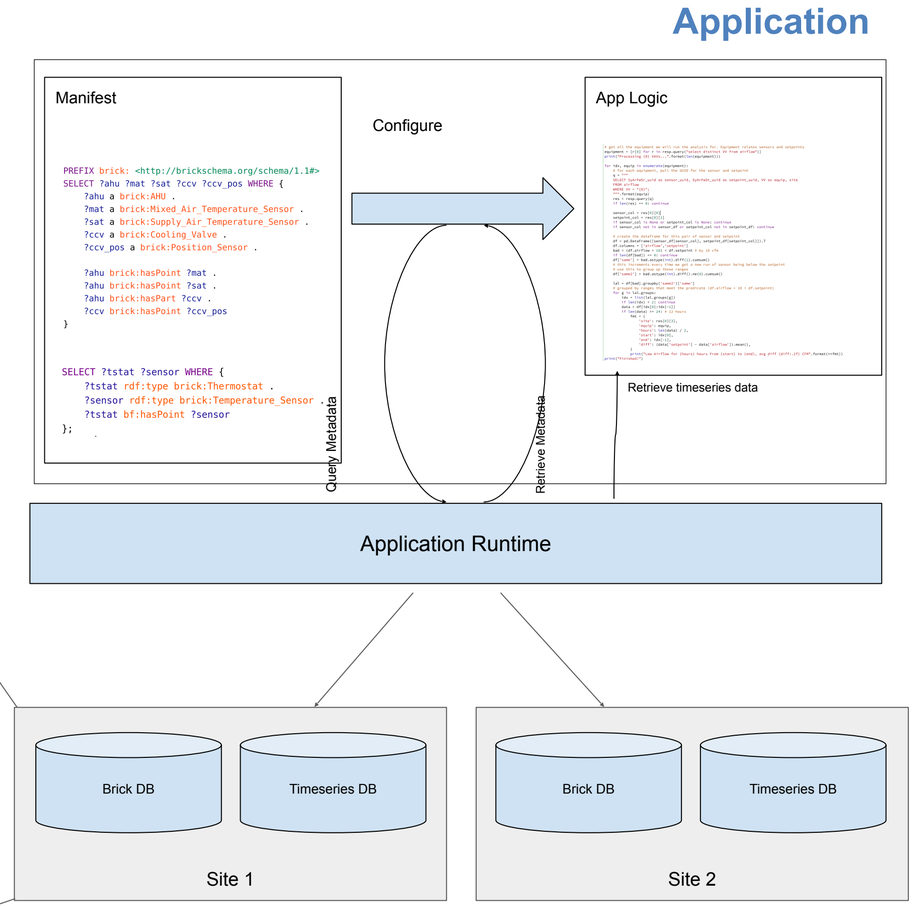


- Applications query graph-based semantic metadata to configure their behavior and adapt to the specific environment they are deployed in

CPS with Metadata-driven Self-Adapting Software Stacks

- Ontology for formal metadata about deployment
- Scalable, low-latency graph databases with support for semantic queries
- Incremental maintenance of semantic metadata as deployment changes

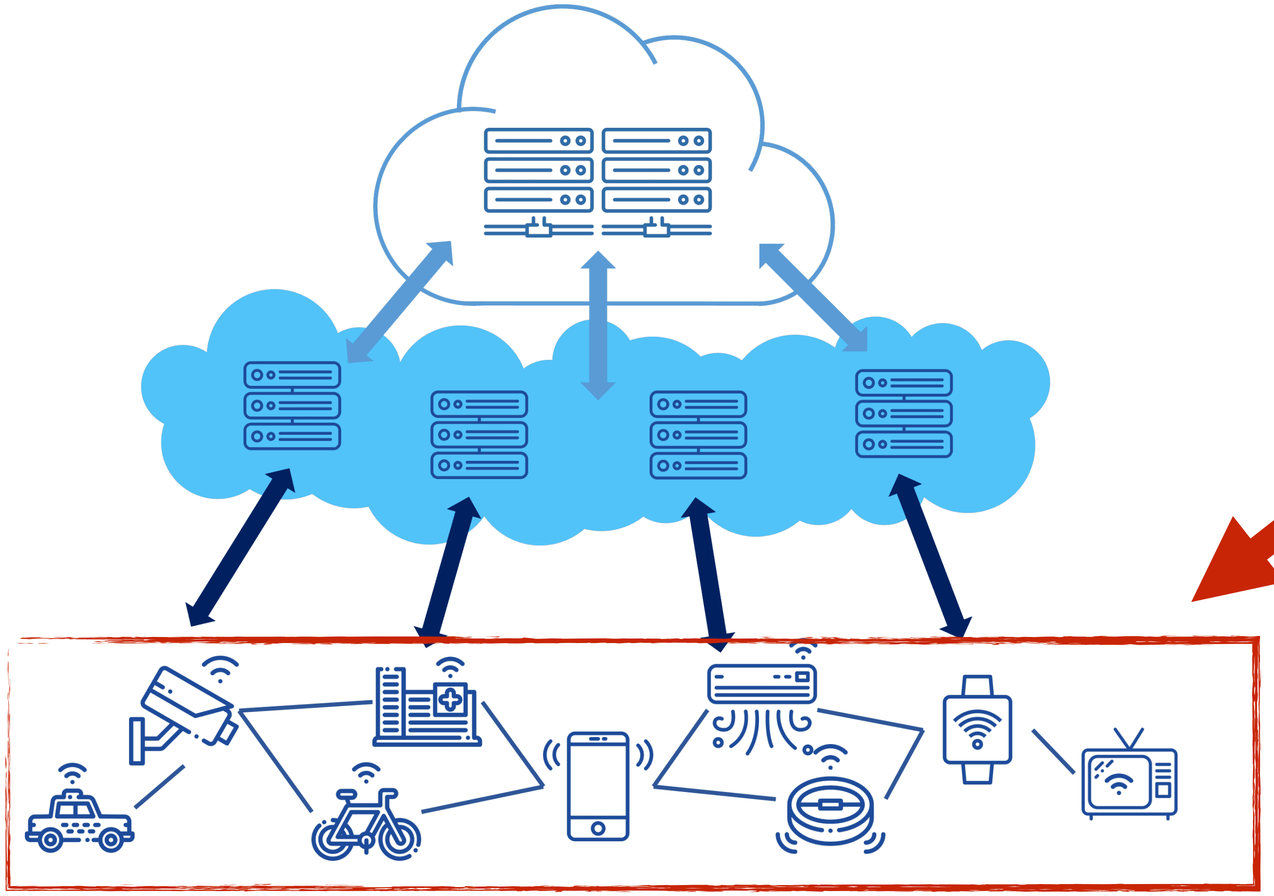




Gabe Fierro (UCB), Jason Koh and Dezhi Hong (UCSD)

Some Open Challenges for CPS Technology Research

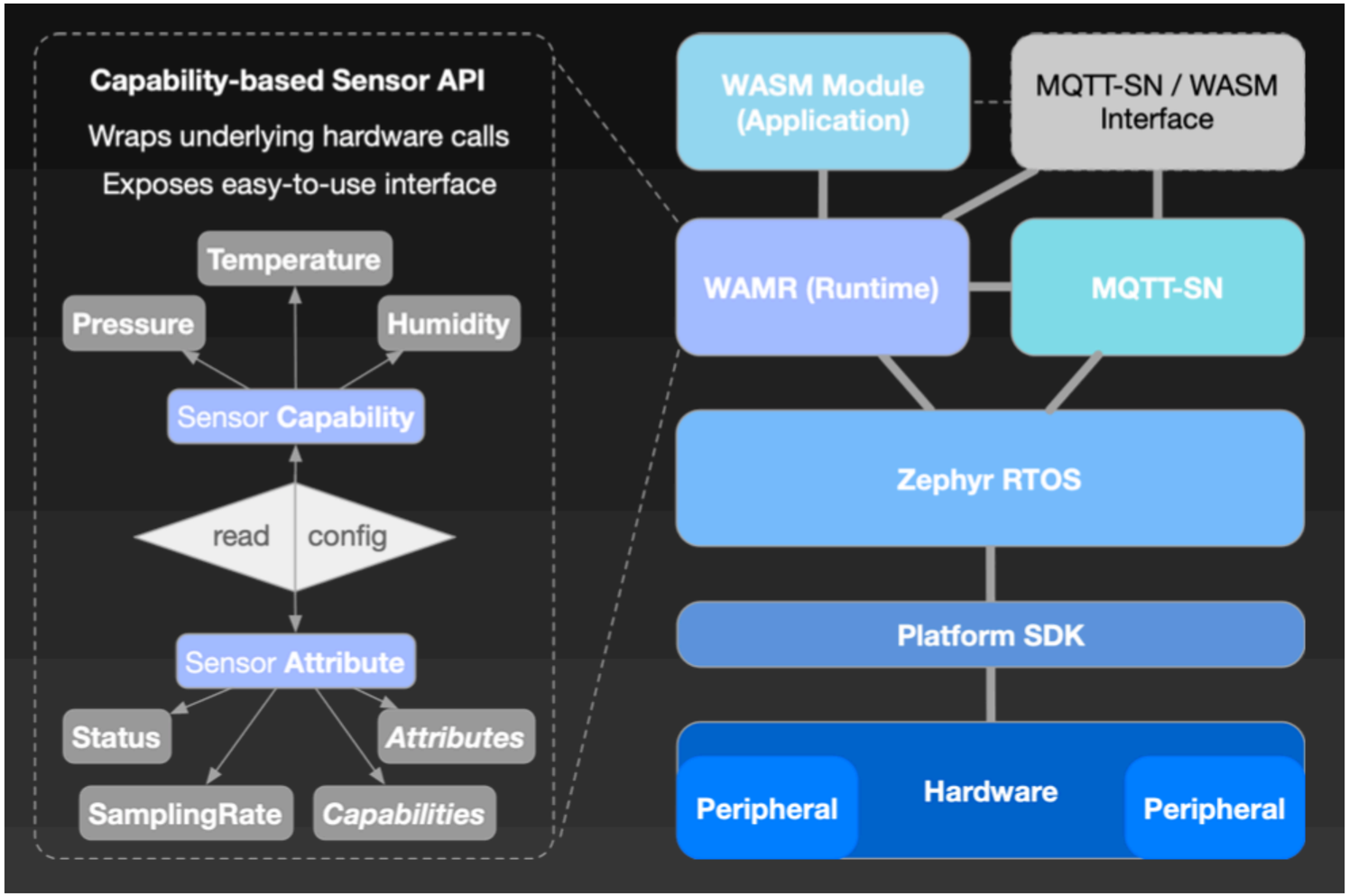
II. Scaling to a Multitenant Internet of Trillion Things: sharing edge resources across multiple CPS “tenant” applications



Currently the CPS edge has mostly single-application devices with often duplicated capabilities

Future: apps on devices that help and learn from each other via edge resource management and knowledge sharing

Efficient, Portable & Secure Multi-tenancy for the CPS/IoT Edge



Embedded WASM

- New portable binary format, originally designed for web browsers
- Near-native performance with sandboxed execution, control-flow integrity, bounded memory, and software fault isolation
- Runtime supported on embedded (e.g. Cortex-M class) processors
- Portable and secure low-footprint WASM interfaces to:
  - edge ML accelerators
  - sensors and actuators

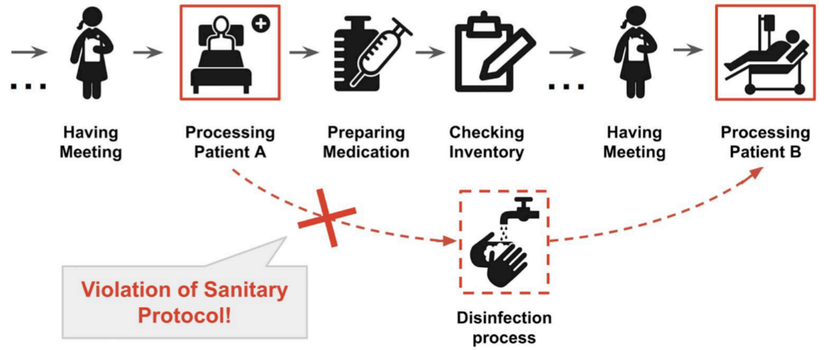
Some Open Challenges for CPS Technology Research

III. Infer and learn “complex” spatiotemporal events in dynamic environments

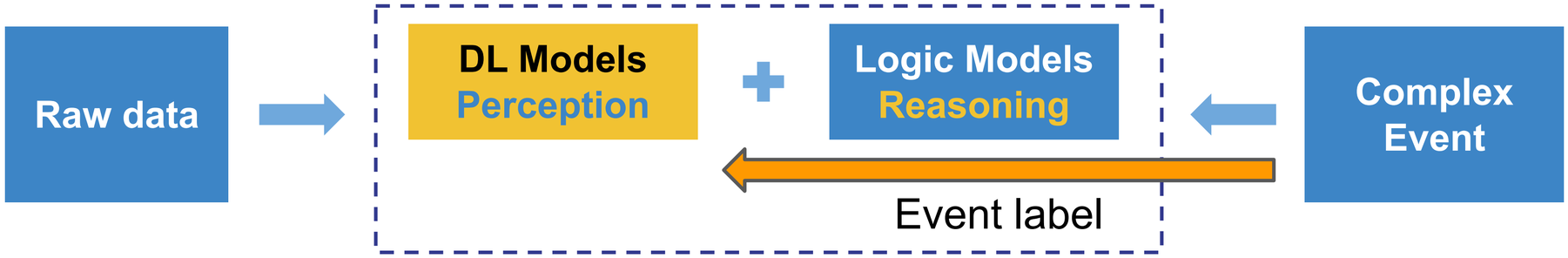
Complex Events: Patterns of atomic sensor events separated by long time intervals or across distributed sensors (“connect the dots”)

Challenges: High-dimensionality sensors require deep learning models, which do not handle CE well (limited data, insufficient memory); Domain shifts



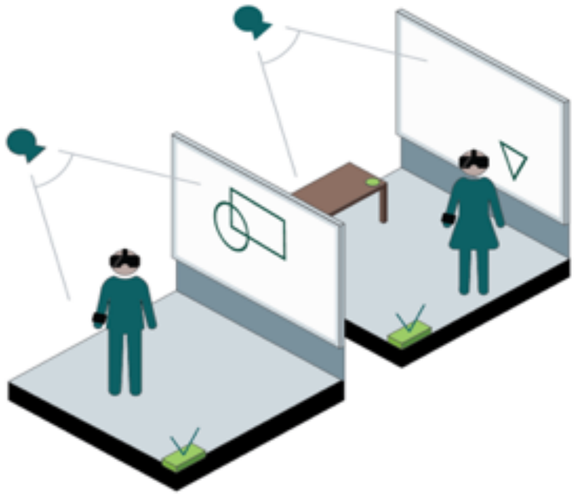


CPS that combine neural (data) and symbolic (first-principles) processing?



Next Generation of CPS Applications: Intelligence and Autonomy in Complex & Dynamic Human Spaces

Mixed Reality Systems



Compute intensive
Data volume & velocity
Multimodal sensing & UI
Spatial content/computing
AI/ML enabled

+

Urban Robotics



Control & coordination
Low latency
Hyper-mobility
Human-in-loop
Safety

+

Enhanced Situational Awareness

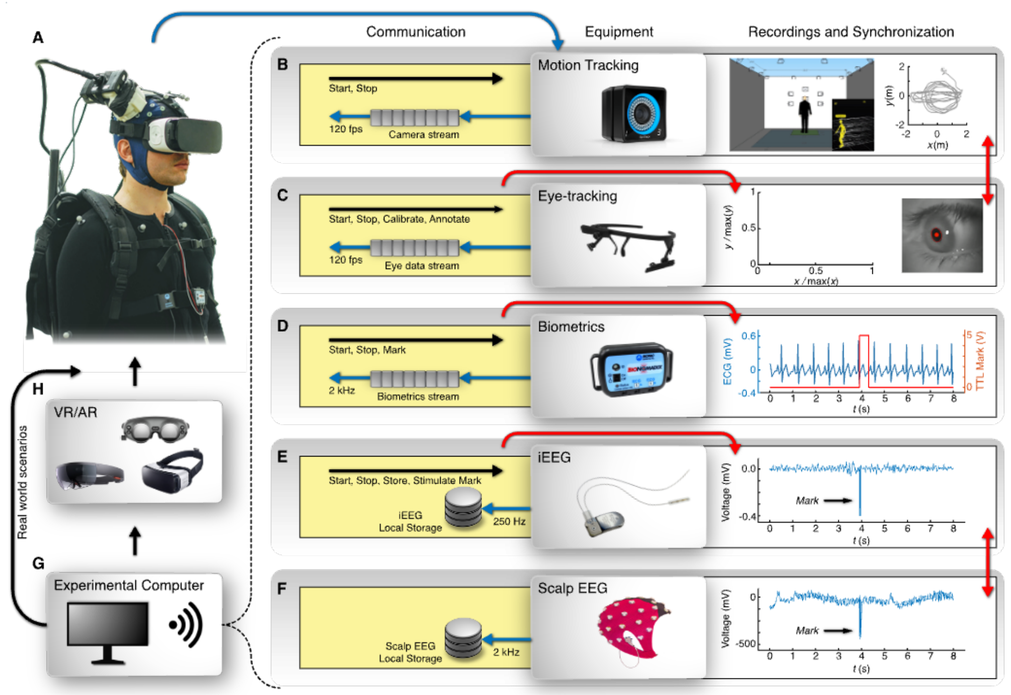


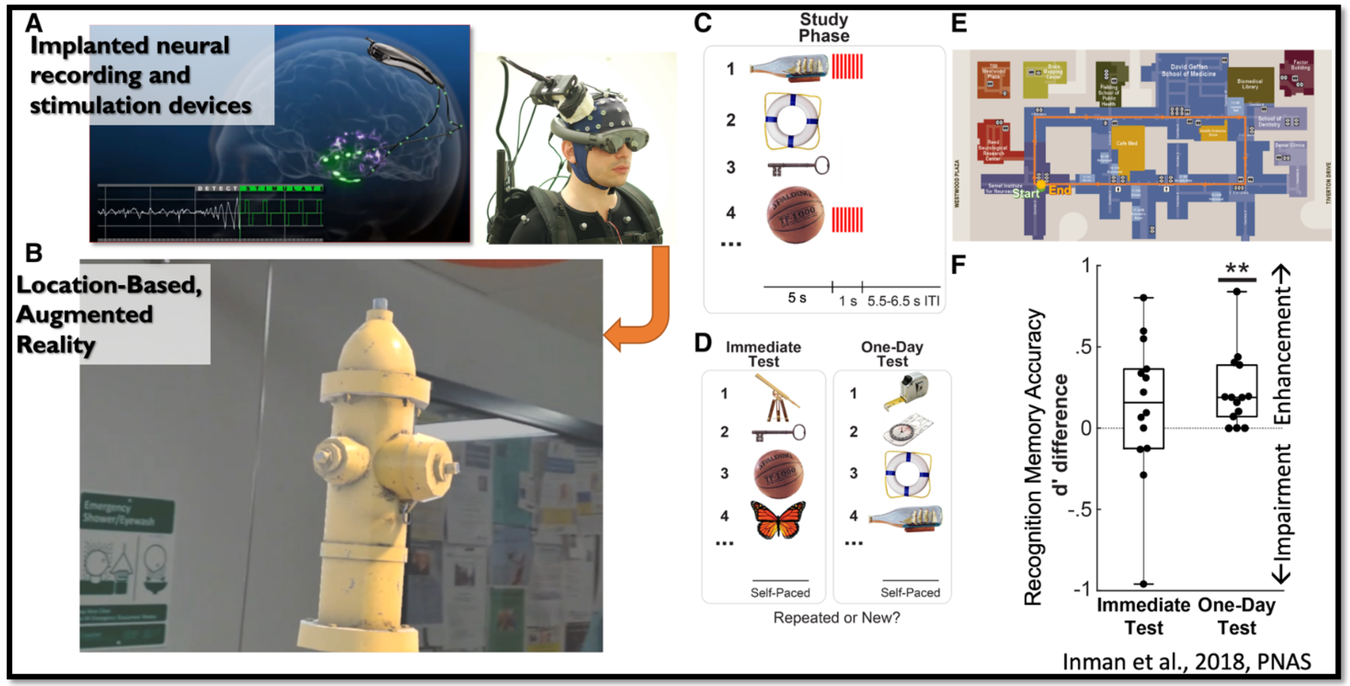
Scale & heterogeneity
Multiple tenants & admins
Complex events
Intermittent connectivity
Security & privacy

Challenge:
Establishing *Semantic Alignment* between Humans and CPS

How do we align or synchronize the embeddings learnt by the deep learning models in a CPS with the experience of the interacting humans?

Can this alignment be used to assist the human or enhance human performance, such as memory retention?





Ack: Cory Inman (U. Utah), Luis Garcia (USC-ISI)
[both formerly UCLA]

Common Mistakes

I. Failing to strike a suitable balance of research idea and application

- Easy to get stuck at one of the two extremes
  - Abstract and disconnected from realistic applications $\Longrightarrow$ *low utility*
  - Lost in the minutiae of a single application $\Longrightarrow$ *low generalizability*

II. Failing to adequately anticipate and plan for integration challenges

- Meaningful CPS application present significant engineering challenges, deployments costs, IRB challenges, etc.

III. Failing to prioritize third-party adoption and reproducibility of research

- Much CPS research unaccompanied by necessary data, code, etc.
- Benchmarks, challenge problems, open testbeds, synthetic environments

Portability
Scalability
Multitenancy
Complex Events
NeuroSymbolic

