VeHICaL: Verified Human Interfaces, Control, and Learning for Semi-Autonomous Systems

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THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

NSF CPS PI Meeting
October 31, 2016

Human Cyber-Physical Systems (h-CPS)

CPS that operate in concert with humans

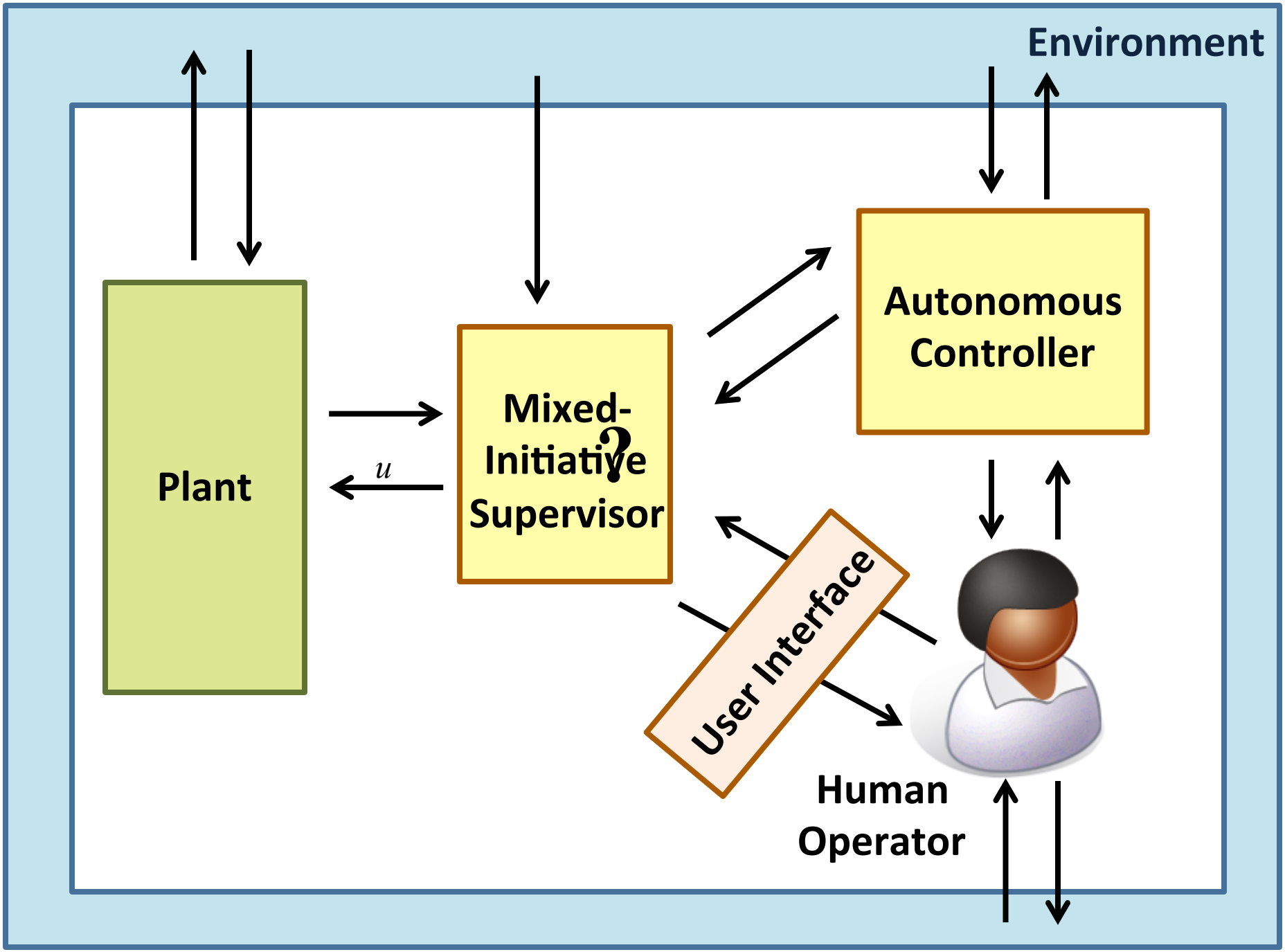
Driver Assistance in Cars

Fly-by-wire Cockpit Interfaces

UAVs with Human Operators

Robotic Surgery & Medicine

Semi-Autonomous Manufacturing


Environment
Plant
u
Mixed-Initiative Supervisor
?
Autonomous Controller
User Interface
Human Operator

Overall Project Objective of VeHICaL

*To develop a **science of verified co-design** of controllers for semi-autonomous cyber-physical systems and interfaces between humans and cyber-physical components*

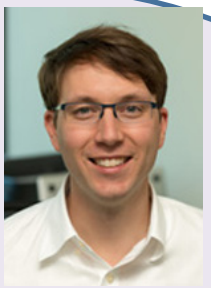
Team

Bajcsy

Robotics & Perception

Griffiths

Psychology & Cognitive Science



Hartmann

Human-Computer Interaction

Sastry

Tomlin

Control Systems

Murray

Seshia

Formal Methods

Sturton

Security & Privacy

Motivating Applications

- **Semi-Autonomous Automobiles**

TECHNOLOGY

The New York Times

The 15-Point Federal Checklist for Self-Driving Cars

By CECILIA KANG SEPT. 20, 2016

A Lesson of Tesla Crashes? Computer Vision Can't Do It All Yet

- **Semi-Autonomous UAVs**

FAA Expects 600,000 Commercial Drones In The Air Within A Year

August 29, 2016 · 3:10 PM ET npr

AARIAN MARSHALL TRANSPORTATION 08.30.16 1:28 PM WIRED

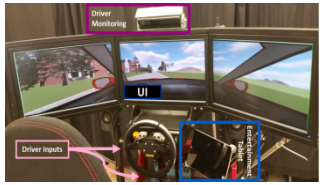
HOW TO ACE THE FAA'S NEW TEST AND BECOME A PRO DRONE PILOT

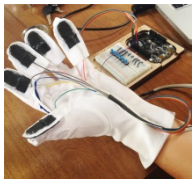
Project Goal: Develop Science of Design of h-CPS with Provable Guarantees on Behavior

Some Major Unsolved Problems to be Tackled:

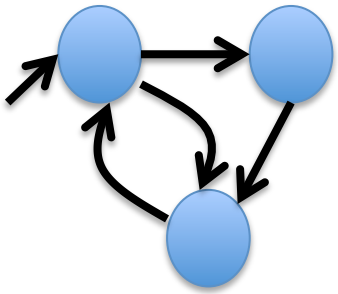
- Effective Sharing of Control between Human and Autonomous Controller
- Modeling Human Cognition, Perception, and Action, and developing Sensing Strategies to infer and evaluate such models
- Uncertainty in h-CPS Dynamics *and* in Modeling: need new techniques blending Verification, Learning, and Control
- Verifiable Human-Computer Interface Design *integrated with* Control System Design
- Privacy-preserving Learning of Models of h-CPS

Sensing & HMI Design



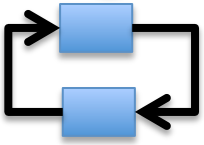


Formal Modeling & Specification



Verification

Control

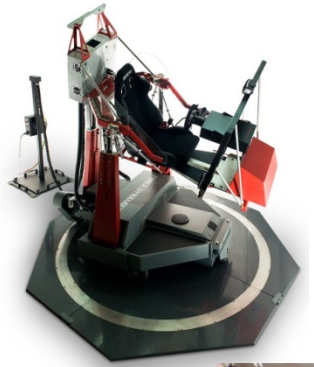


Security & Privacy

VeHiCal

System-level Integration & Validation

Learning Models from Data



Evaluation & User Studies

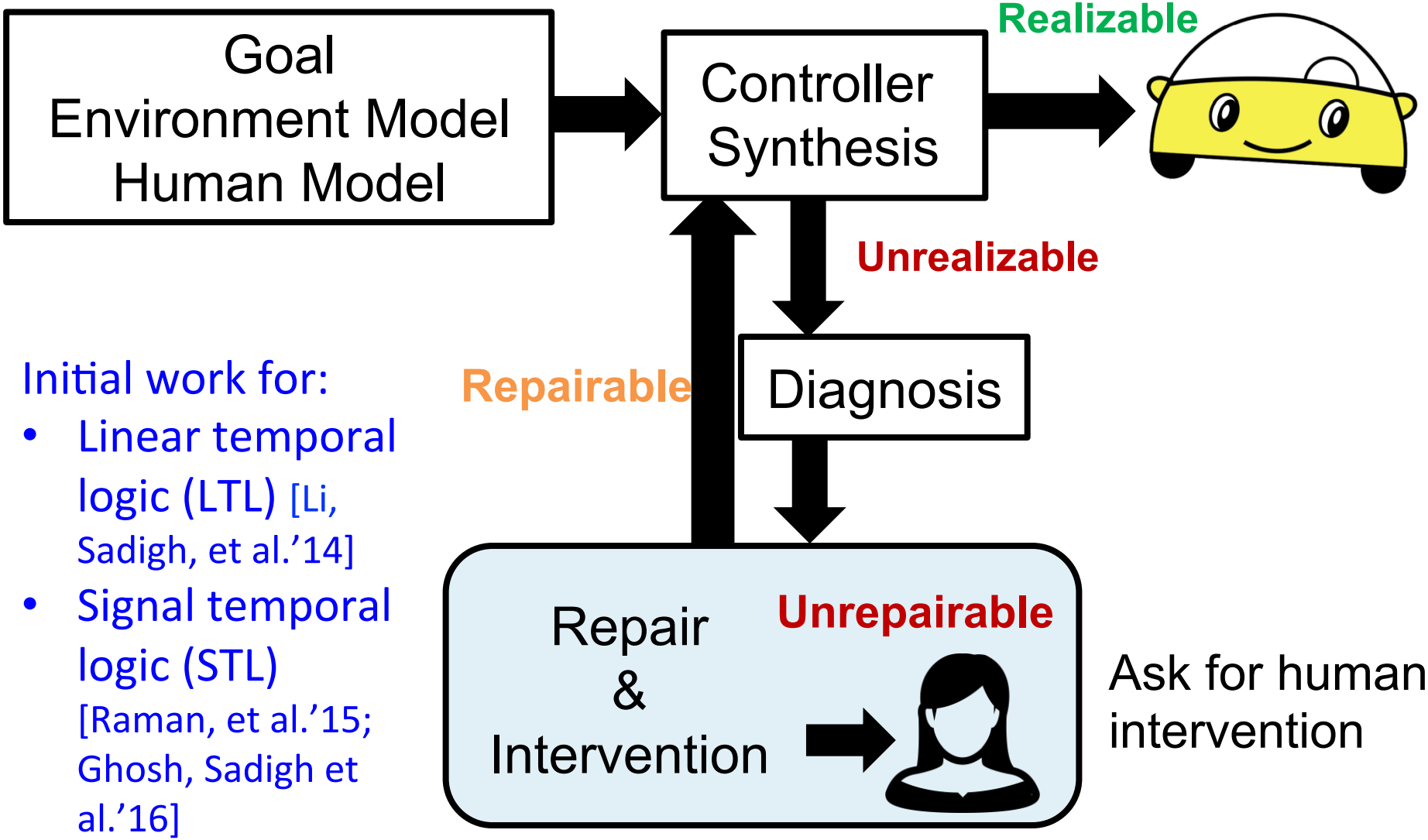
Four Project Thrusts

1. Specification and Modeling
2. Learning, Verification, and Control
3. Human-Machine Interface Design & Verification
4. Testbed and Evaluation

Specification for h-CPS: What does "correctness" mean? [Li, Sadigh, Sastry, Seshia, TACAS'14]

- Safe & Correct Autonomy
  - Autonomous mode should be proved correct
- Effective Monitoring
  - Must monitor all relevant environment variables
- Prescient Switching
  - Sufficient lead time to switch between human & auto
- Minimally Intervening
  - Should *rarely* request human intervention
- Other Properties:
  - Security & Privacy
  - HMI Properties: Absence of Mode Confusion, ...
  - ...

Correct-by-Construction (Semi-Autonomous) Control



Initial work for:

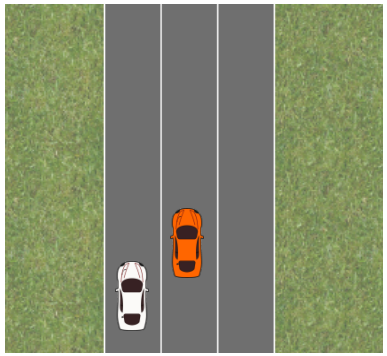
- Linear temporal logic (LTL) [Li, Sadigh, et al.'14]
- Signal temporal logic (STL) [Raman, et al.'15; Ghosh, Sadigh et al.'16]

Human-Aware Control of Vehicles

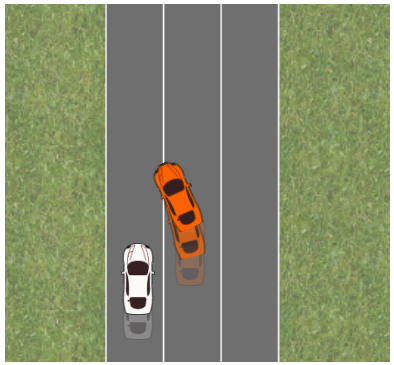
[Sadigh, Sastry, Seshia, Dragan; RSS, IROS '16]

Leverage human *responses* to estimate human internal state.

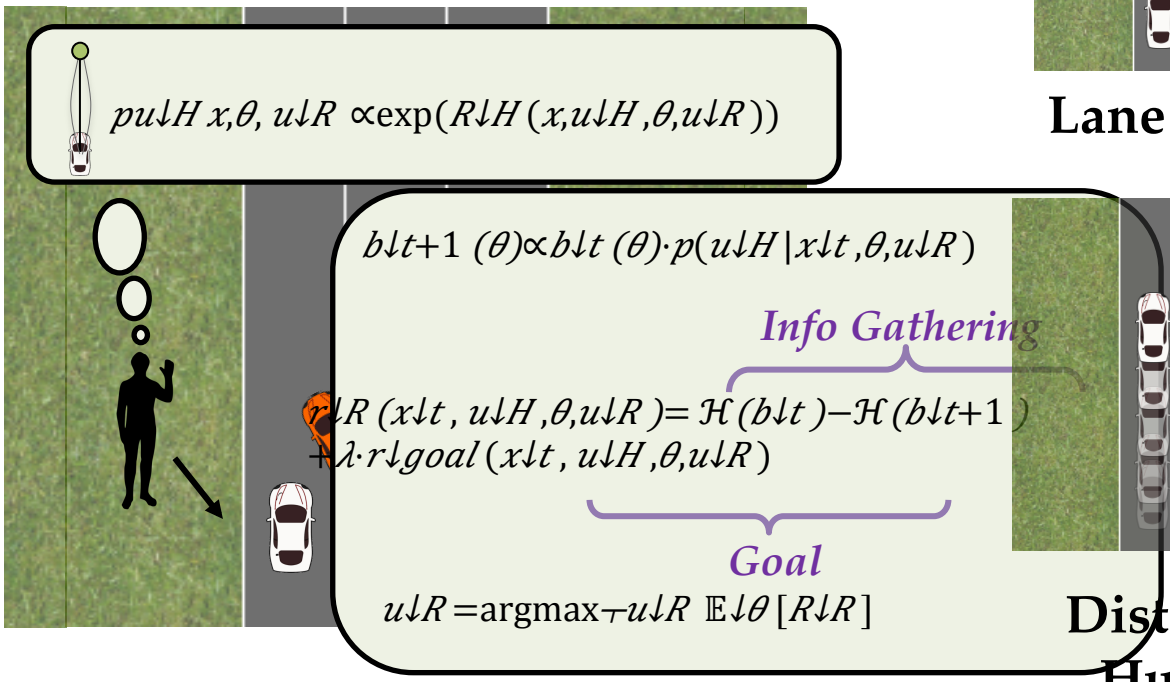
SAMPLE RESULT

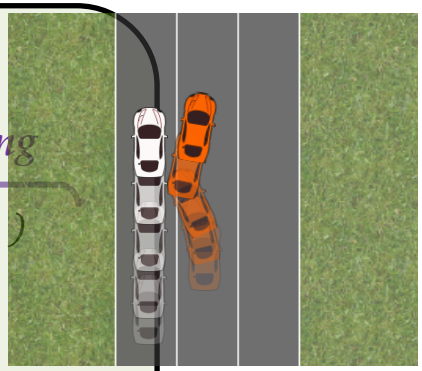


Lane Change

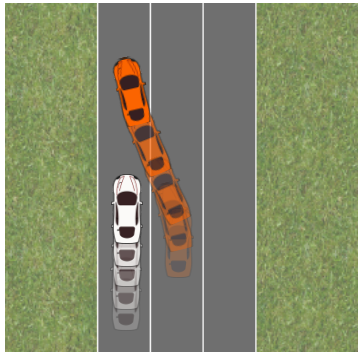


Nudging In





Distracted Human



Attentive Human

Human Modeling: Data-Driven Modeling and the "Bounded Optimal" Model

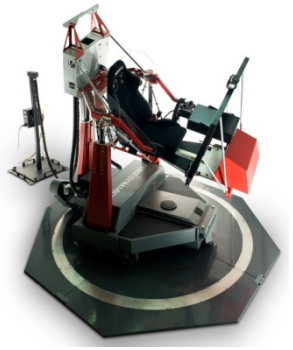
- Uncertainty in human behavior and variation (person to person) are central aspects of h-CPS
  - Probabilistic formalisms, learned from data
  - Consistent with formalisms using in verification and control
- Model human behavior based on "Resource Rationality" [Griffiths, Lieder, & Goodman, 2015]
  - Trade off error with the cost of computation, assuming an abstract computational architecture
  - an instance of "bounded optimality": choosing the best algorithm to solve a problem (Russell, 1995)

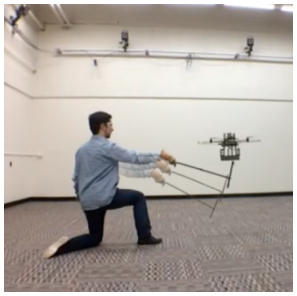
Resource rationality in VeHICal: Directions

- **Prediction:** Modeling the allocation of cognitive resources in dynamic environments
  - e.g., do we make rational choices about when to check our texts when driving?
- **Inference:** Developing models that can be used to infer when/how humans are resource-limited
  - e.g., behavior patterns that result from having less resources for tracking, relevant to prescient switching

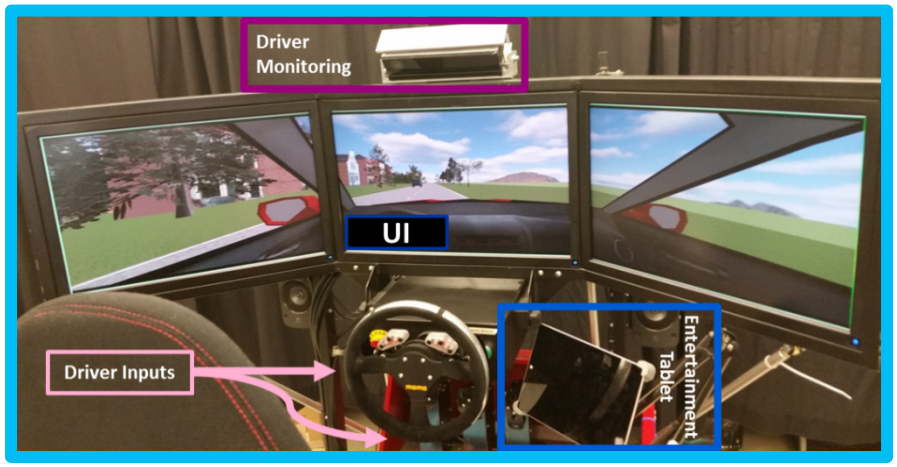
Experimentation on CPS Testbeds

- **Driving Simulator Testbed:** Force Dynamics 401CR (industrial simulator with motion feedback)
- **Automotive:** Partnerships with automotive companies
- **UAVs:** Tomlin lab, partnerships with drone companies
- **Jacobs Hall**: State-of-the-art labs for rapid prototyping of interfaces and hardware



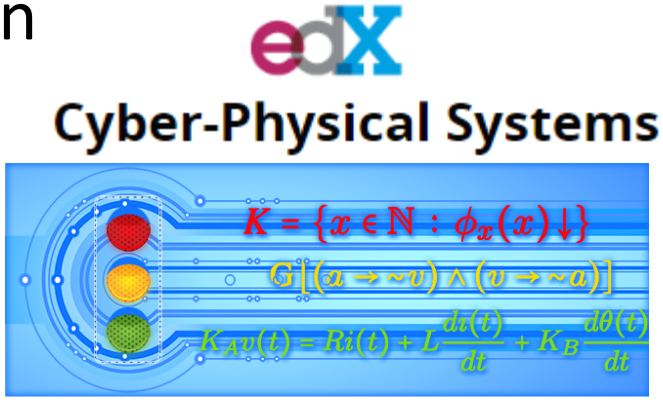


Initial work [Rezvani et al., ITSC'16]: Impact of user interface design on transfer of control



Education and Outreach activities

- Joint development and dissemination of educational materials on h-CPS
  - *Online course on h-CPS* jointly offered by PIs
- Joint mentoring of postdoctoral researchers
- Summer programs for undergraduate and high/middle school students
  - Projects conceived of jointly and offered in a coordinated manner to amplify the overall impact



Seventh Annual
Cyber-Physical Systems Principal Investigators' Meeting
Arlington, VA | October 31 – November 1, 2016

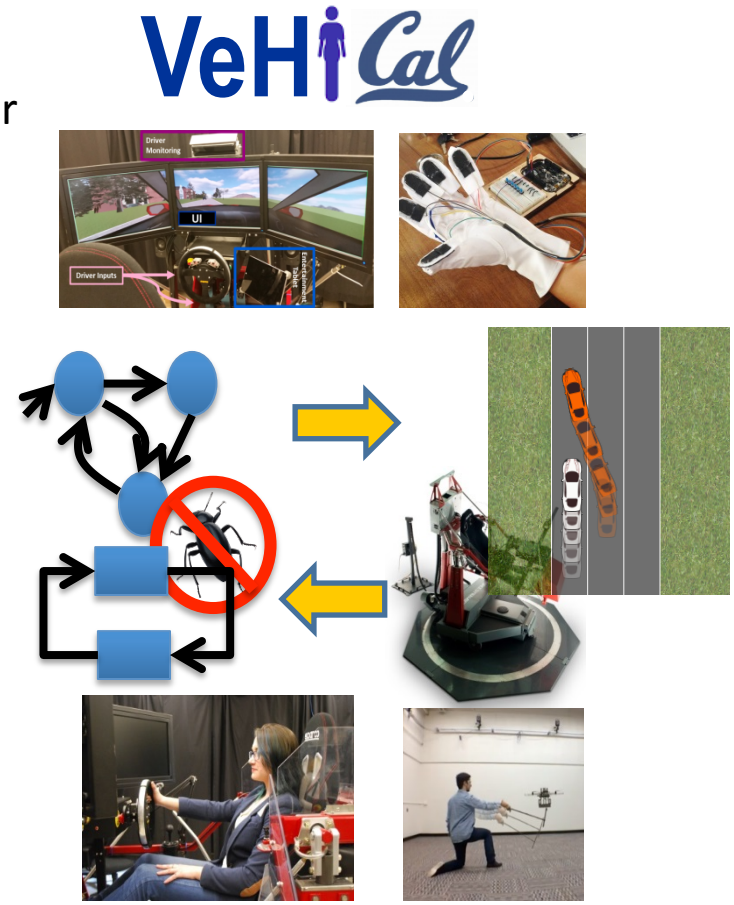
VeHICaL: Verified Human Interfaces, Control, and Learning for Semi-Autonomous Systems

Challenge:

- *Co-design human interfaces and control* for human-cyber-physical systems with *provable guarantees*
- Apply to semi-autonomous vehicles (ground and air)

Solution:

- Integrate Learning, Verification and Control
- Bounded Resource Rational Human Modeling
- Prototype Controllers & Interfaces, Evaluate on Testbed



Scientific Impact:

- Developing a Science of Co-Design of Human Interfaces and Control
- Bridging Model-Based and Data-Driven Design of CPS

Broader Impact:

- Significantly improve safety, security, and performance of systems where humans interact closely with automation
- Involve middle/high-school and undergraduate students in VeHICaL activities

CPS Awards 1545126, 1544714, 1544924

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