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

S. A. Seshia, R. Bajcsy, T. Griffiths, B. Hartmann, S. S. Sastry, C. Tomlin (Berkeley), R. Murray (Caltech), C. Sturton (UNC Chapel Hill)

Annual Meeting
October 4, 2018

http://vehical.org

Human Cyber-Physical Systems (h-CPS)

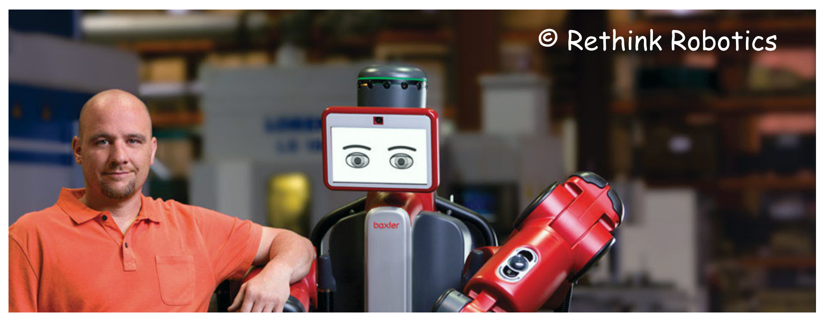
CPS that operate in concert with humans

Driver Assistance in Cars

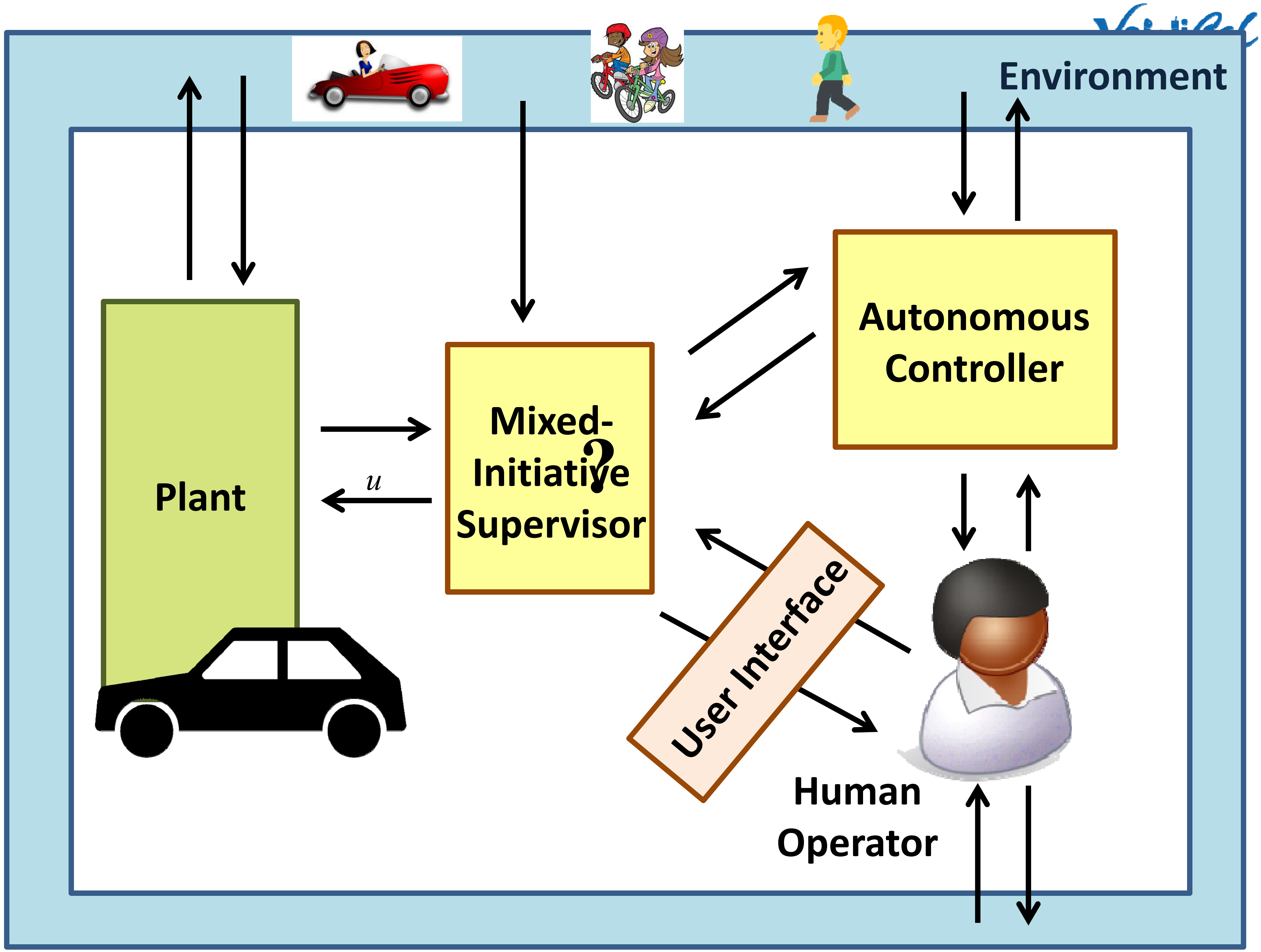
Fly-by-wire Cockpit Interfaces

UAVs with Human Operators

Robotic Surgery & Medicine



Semi-Autonomous Manufacturing


Environment
Plant
Mixed-
Initiative
Supervisor
?
u
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*

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

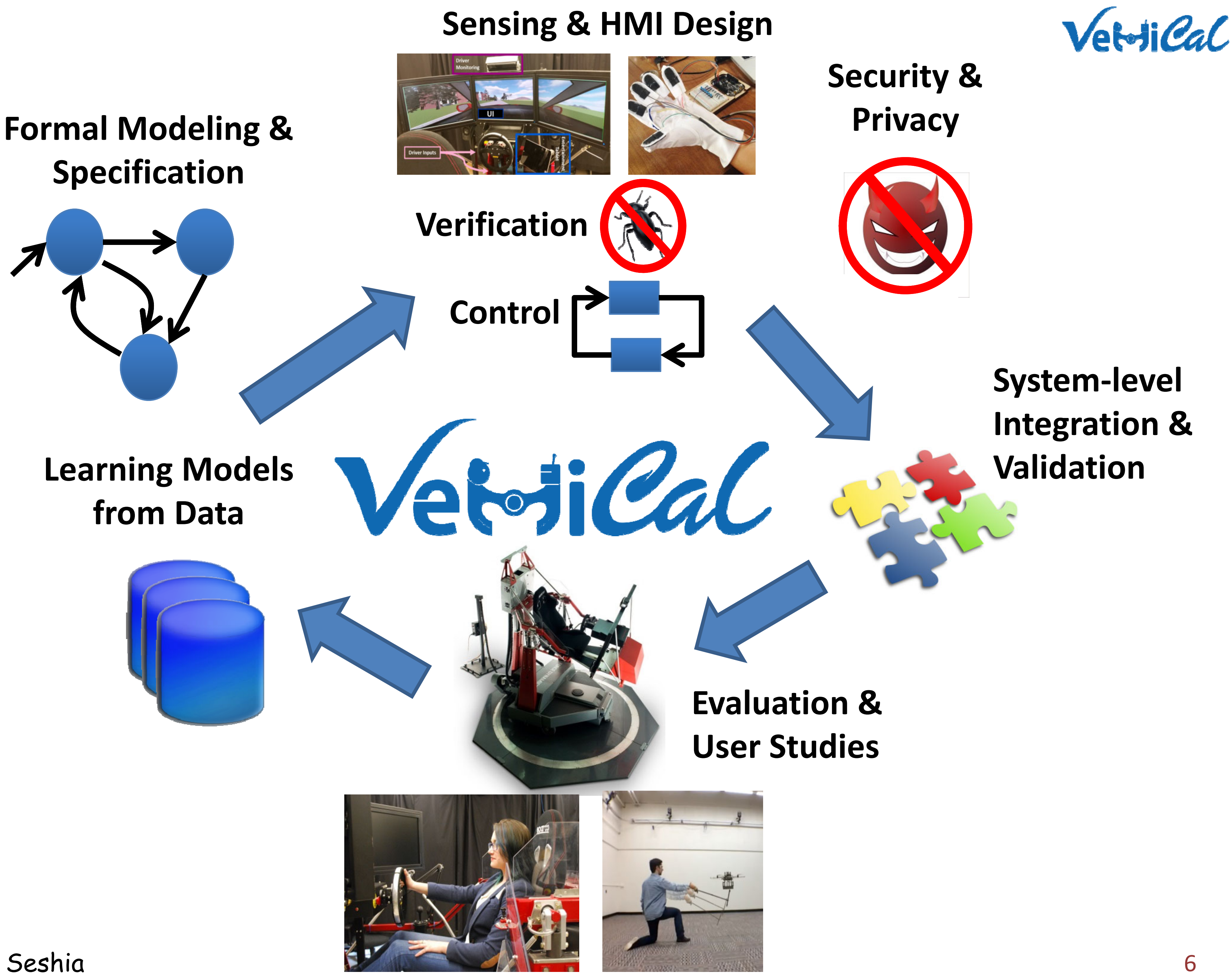
- **Semi-Autonomous UAVs**

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


Sensing & HMI Design
Security & Privacy
Formal Modeling & Specification
Verification
Control
System-level Integration & Validation
Learning Models from Data
VeHiCaL
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

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

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

VeHiCaL

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

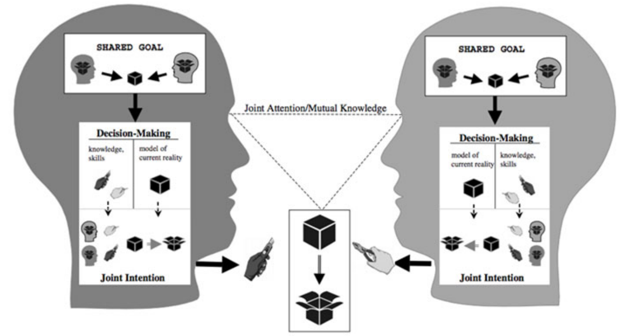
Learning and Teaching in Human-Robot Teams

[PIs: Griffiths, Seshia]

Good Communication is Crucial

Demonstrations,
Natural Language
…

Cost Functions,
Logical Specs.
…



How can we hand off control reliably and intuitively?

Boolean (logic) specifications:

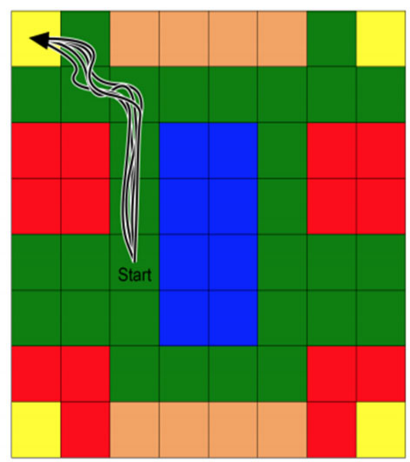
- Composable
- Non-Markovian tasks
- Leverage formal methods

Learning Boolean Specifications from Demonstrations

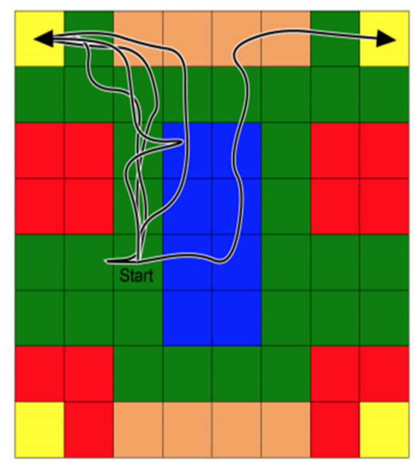
Target Specification:

Go to a yellow tile without going on a red tile. If a blue tile is steped on, step on a brown tile before stepping on a yellow tile

Doing Task



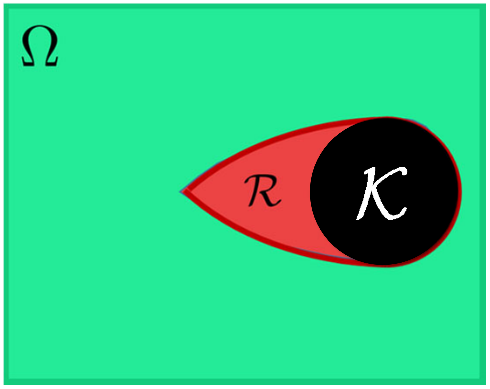
Communicating Task

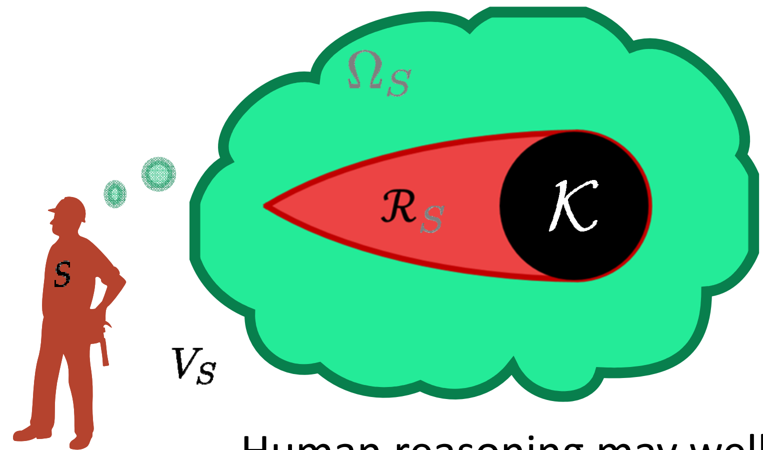


[Vazquez-Chanlatte, Ho, et al., NIPS'18; CPHS'18]

Modeling Supervisor Safe Sets for Human-Robot Teams

[PIs: Sastry, Tomlin, Griffiths]

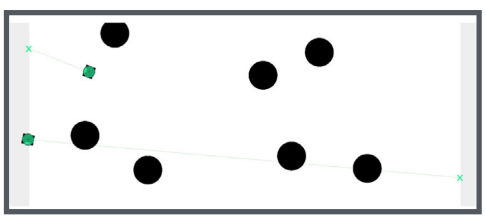


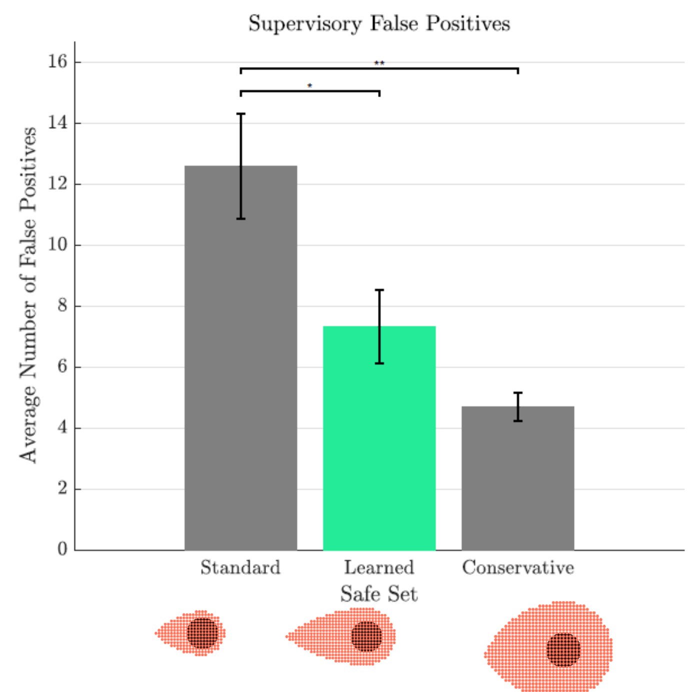


Human reasoning may well be explicable by safe sets: perhaps conservative ones.

User Study: robots avoiding obstacles

- Phase 1: Familiarization
- Phase 2: Intervention Data Collection
- Phase 3: Human Robot Teaming Tasks

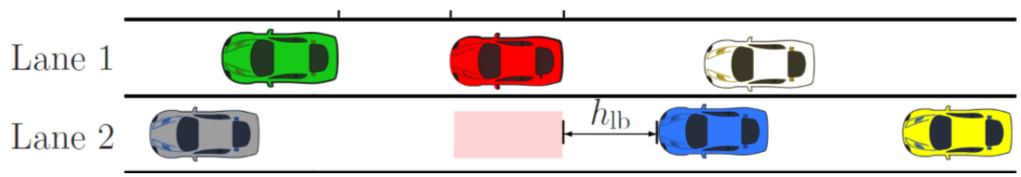




[D. McPherson, D. Scobee, J. Menke, A. Yang and S. Sastry, IROS 2018]

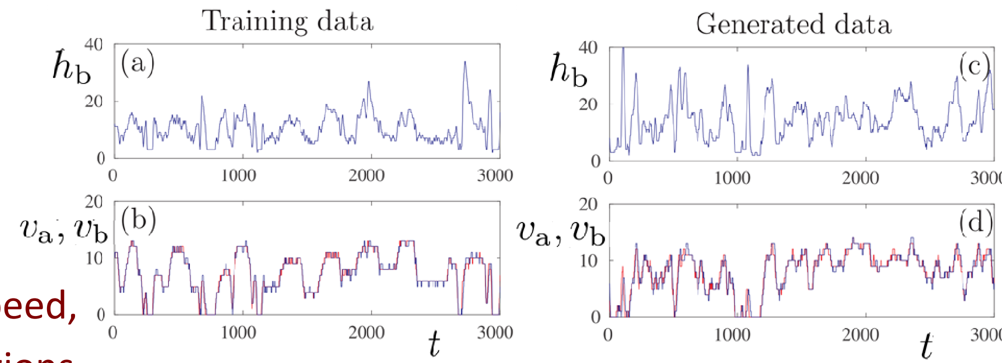
Control Improvisation for Vehicle Modeling & Control

[PIs: Murray]

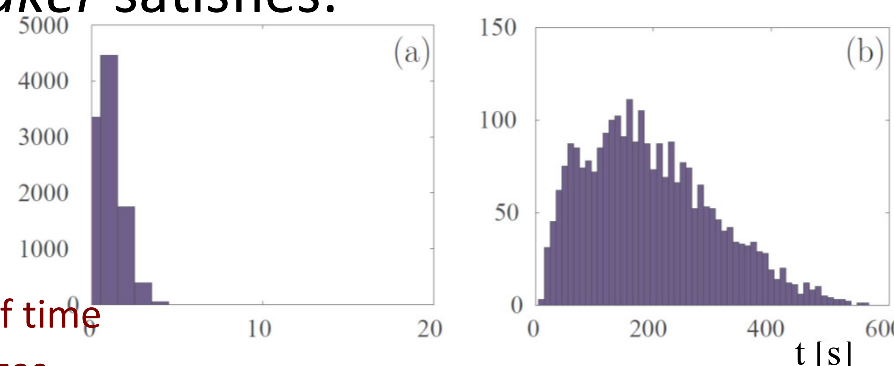


[Ge et al., CDC 2018]

- Synthesize Markov models for *human-driven cars* satisfying:
  - Hard constraints
    - No collisions between humans
    - Cars drive forward
  - Soft constraints
    - Concentration of relative distance, speed, and acceleration based on traffic conditions
  - Randomness (a motion sequence is repeated with low probability)



- Verify that *lane-change decision-maker* satisfies:
  - Hard constraints
    - No collisions due to lane change
    - Next lane is faster
  - Soft constraints
    - a) Number of lane changes during a period of time
    - b) Time between two consecutive lane changes
  - Randomness (repeat the same decision sequence with low probability)



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

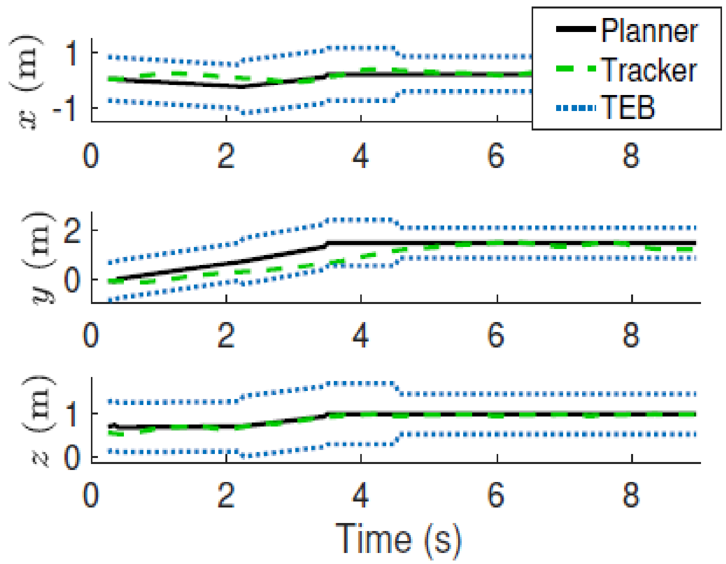
VeHiCal

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

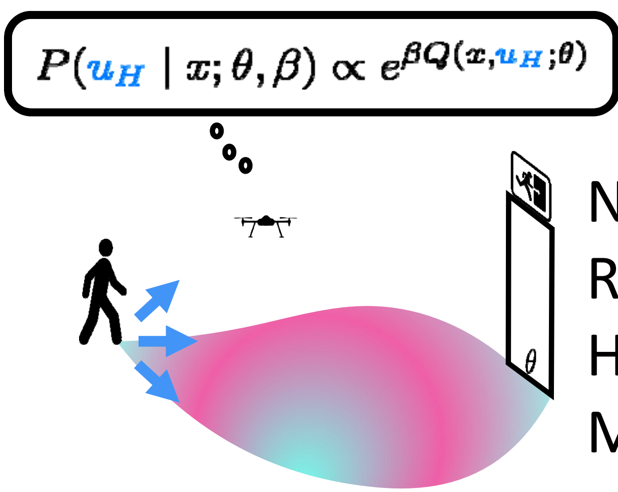
Probabilistically Safe Motion Planning around People

[PI: Tomlin]

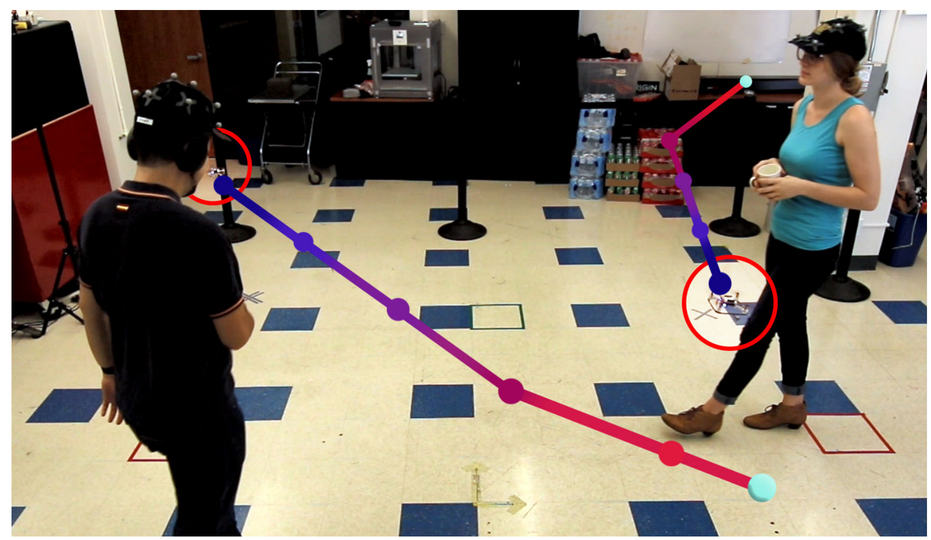


Fast and Safe Tracking (FaSTrack)

A Scalable Framework for Real-time, Multi-Robot, Multi-Human Collision Avoidance



Noisily Rational Human Model



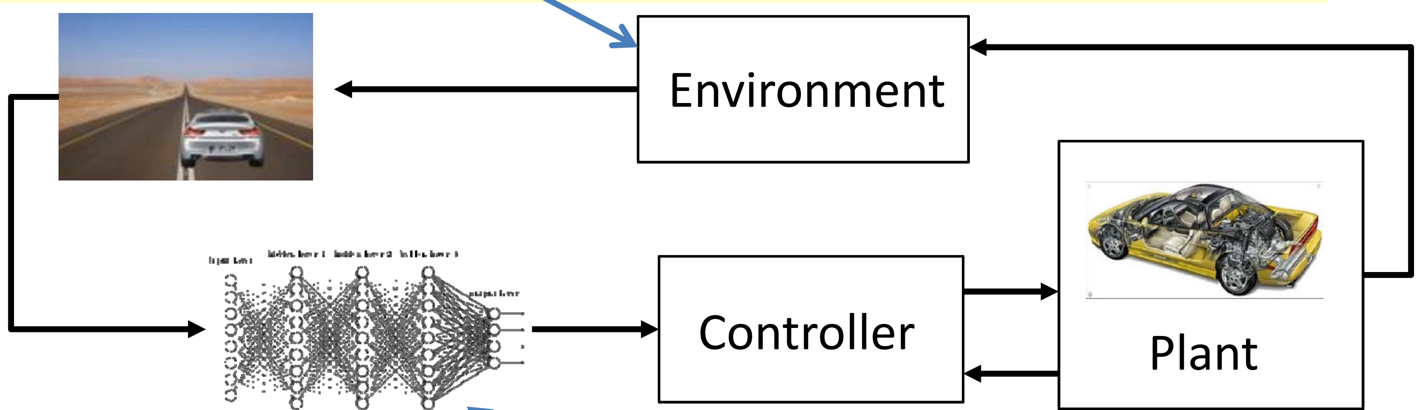
[Andrea Bajcsy, Sylvia Herbert, David Fridovich-Keil, Jaime Fisac, 2018]

Modeling, Design & Verification of Learning-Based h-CPS

[PIs: Murray, Seshia]

First Scalable, Compositional approach to Temporal Logic Falsification of Learning-Based CPS [Dreossi et al., NFM'17, RMLW'17, CAV'18]

SCENIC: Probabilistic Language for Environment Modeling [Fremont et al., '18]



Deep Learning-Based Perception

Abstractions for Neural Network Analysis [Dathathri et al., '18]

Counterexample-guided data augmentation [Dreossi et al., IJCAI'18]

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

VeHiCal

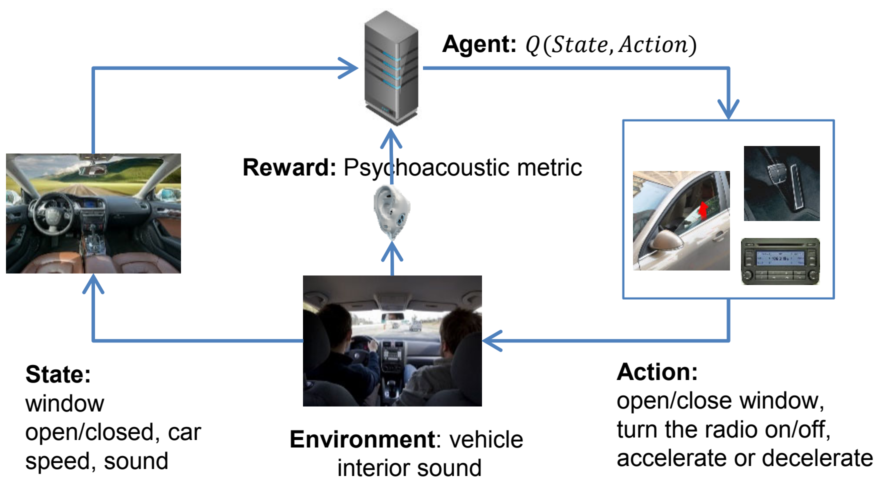
Some Major Unsolved Problems to be Tackled:

- 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

Vibro-Acoustical Approach to Driver Interfaces

[PI: Ruzena Bajcsy]

The passengers, the driver and the vehicle should be treated as components of a vibro-acoustic system.



Psychoacoustic Indices

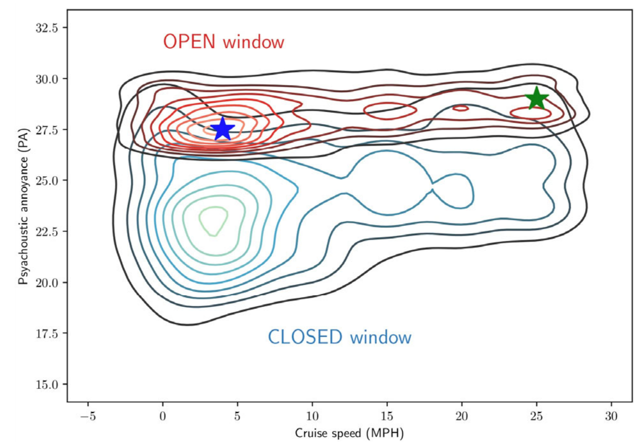
Humans and the psychoacoustic properties:

- **Fluctuation (F) and Roughness (R)**: modulated signal has a higher roughness and fluctuation and is considerably more unpleasant;
- **Sharpness (S)**: depends on the spectral composition.
- **Loudness (L)**: takes into account the distributions of critical bands in the human hearing.

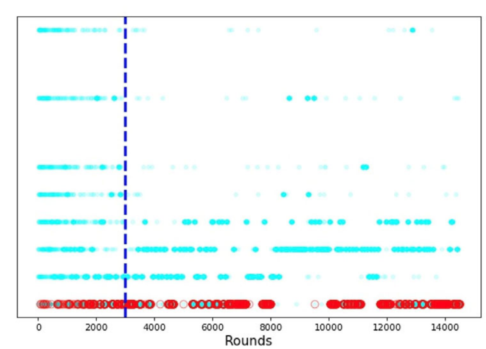
[Nascimento et al., IROS'18]

Experiments and Results

Psychoacoustic annoyance measured in different configurations of the window status and cruise speed. Red curve depicts when the window is open and the blue curve when window is closed.



Rounds where there was noise, and the window's state was open (red circles).



Education and Outreach

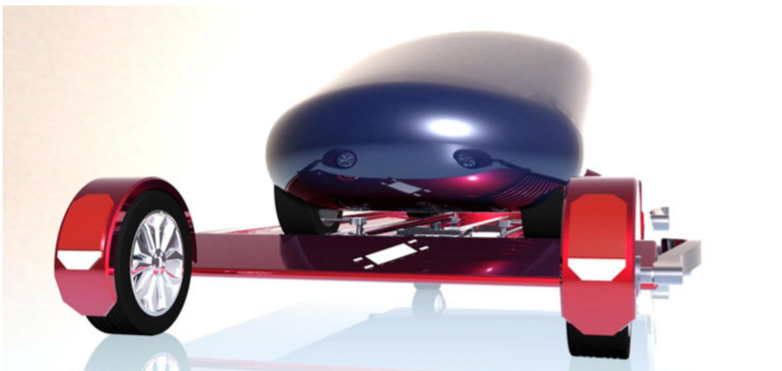
- New courses at the Jacobs Institute of Design Innovation (Hartmann)
- Girls in Engineering summer outreach program (Tomlin, Hager-Barnard)
- NHTSA Engagement on defining a testing methodology for autonomous vehicles (report just published this week)
- Participation in NSF Workshop on Semi-Autonomous Trucks (Seshia)
- International Collaborations: Slovakia, India, Brazil (Bajcsy)
- …

Education Activities

VeHiCal

[PI: Hartmann]

DES INV 190:
Reimagining Mobility



Jacobs Institute for Design Innovation

CS 294-137:
AR/VR and Immersive Computing

AR/VR Lab in Blum Hall

In Conclusion:
Key Envisioned Contributions to CPS Science

- Developing a Science of Co-Design of Human Interfaces and Control
  - Turning design of h-CPS from an art to a science by systematic design and verification of human interfaces
- Making Uncertainty a first-class citizen in Verification and Control
  - New algorithms and models to deal with uncertainty in CPS dynamics *and* the design process
- Bridging the Schism between Model-Based Design and Data-Driven Methods
  - A new design methodology for CPS that blends data-driven analytics with formal modeling and proof engines