Collaborative Research: CPS: Frontier:

Computation-Aware Algorithmic Design for CPSs

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Industry and Academic Collaborators

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Summer Robotics

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SCIENCE INTERNSHIP PROGRAM

MESA
Math · Engineering · Science Achievement

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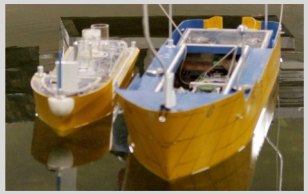
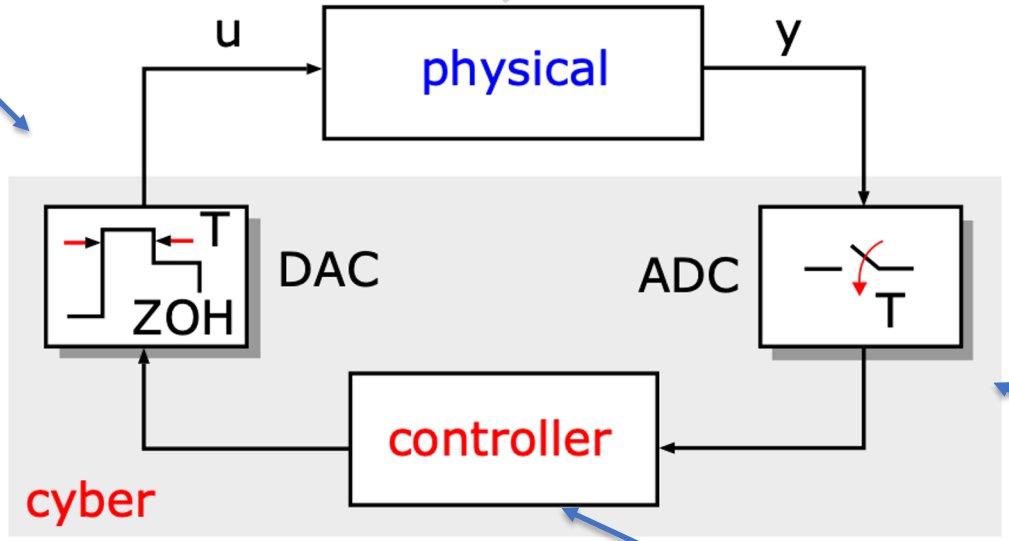
Algorithms for CPSs Have to be Aware of Computing Limitations



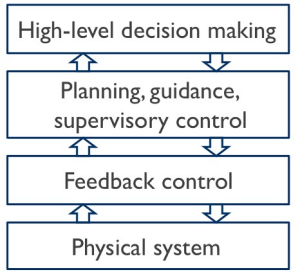




intelligent transportation applications

update



Our project focuses on the full control stack



sample

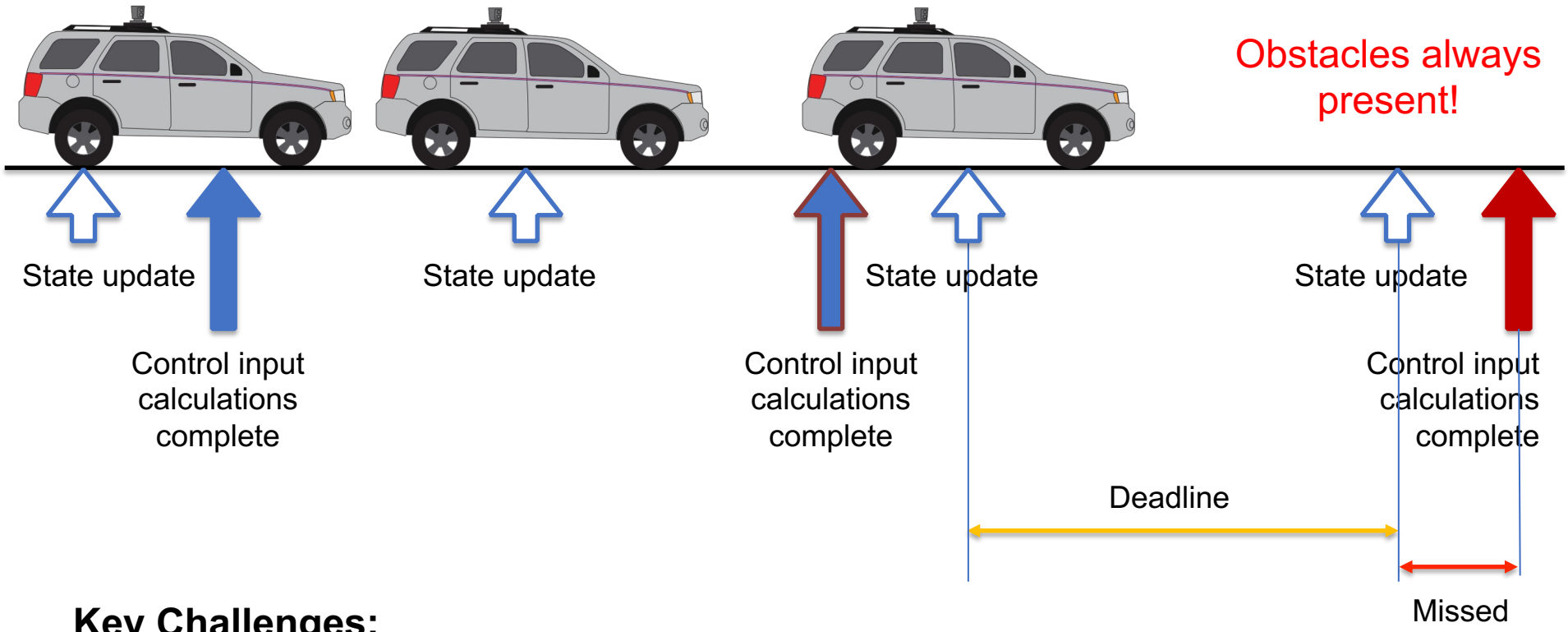
feedback controllers

computation time?

disjoint

hardware architecture

Algorithms for CPSs Have to be Aware of Computing Limitations

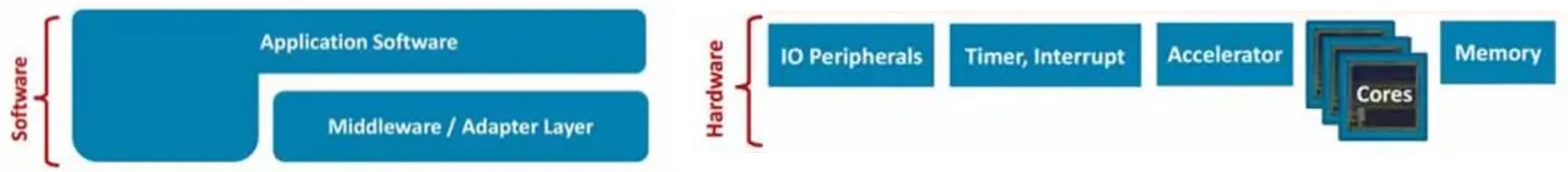


Key Challenges:

- Models that integrate hardware and software features are seldom available
- The algorithms required for intelligent transportation exceed the computational capabilities of traditional single-core processors
- On-the-fly changes in the control stack require advanced algorithm design techniques not yet available

Generate tools for high-performance holistic codesign of the hardware, software, and control algorithms in which control algorithms and computing platforms adapt to each other.

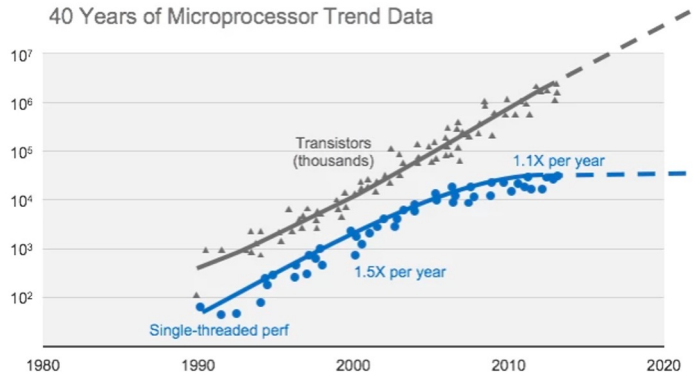
joint design!



This project will overcome the stated challenges by delivering a suite of models, hardware, and software that are **tailored** to feedback control.

Why codesign?

- CPSs are at an inflection point
- Hardware performance no longer scales
- CPSs are complex (Automotive systems >100 ECUs)
- Holistic cross-layer optimization required



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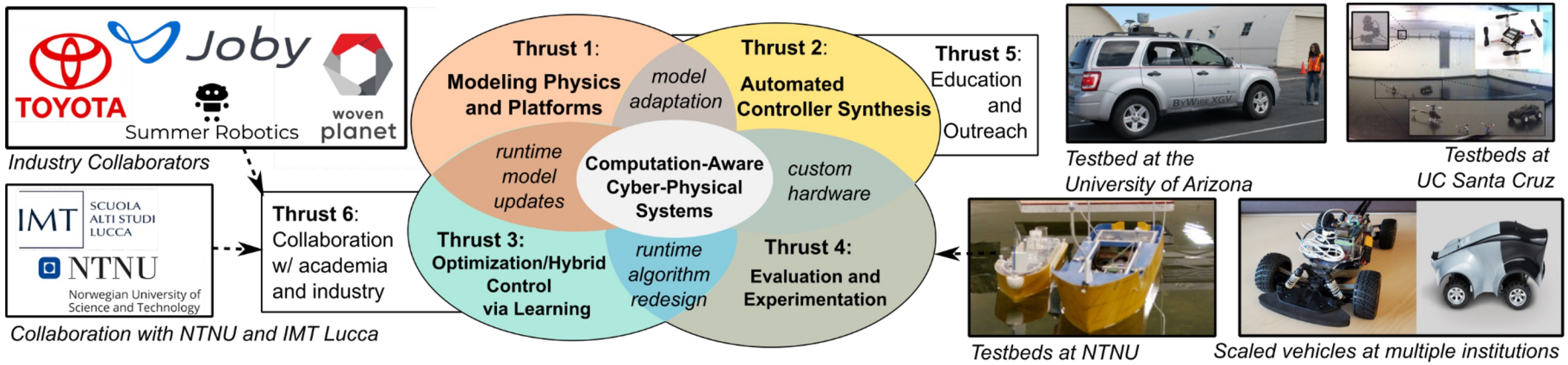
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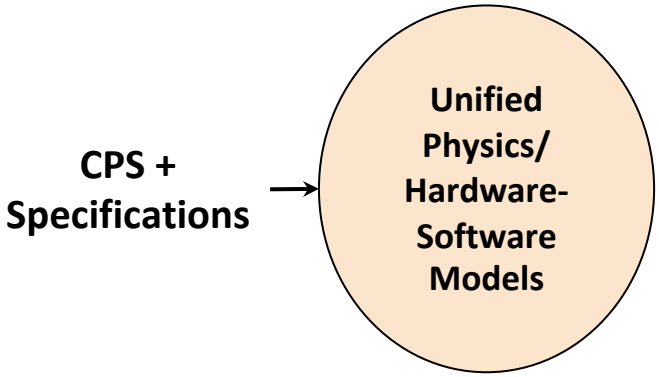
IMT SCUOLA ALTI STUDI LUCCA
NTNU
Norwegian University of Science and Technology
Collaboration with NTNU and IMT Lucca
Thrust 6: Collaboration w/ academia and industry
Thrust 1: Modeling Physics and Platforms
Thrust 2: Automated Controller Synthesis
Thrust 3: Optimization/Hybrid Control via Learning
Thrust 4: Evaluation and Experimentation
Thrust 5: Education and Outreach
model adaptation
runtime model updates
runtime algorithm redesign
custom hardware
Computation-Aware Cyber-Physical Systems
Testbed at the University of Arizona
Testbeds at UC Santa Cruz
Testbeds at NTNU
Scaled vehicles at multiple institutions

Computation-Aware Algorithmic Design for CPSs

CPS +
Specifications

Computation-Aware Algorithmic Design for CPSs



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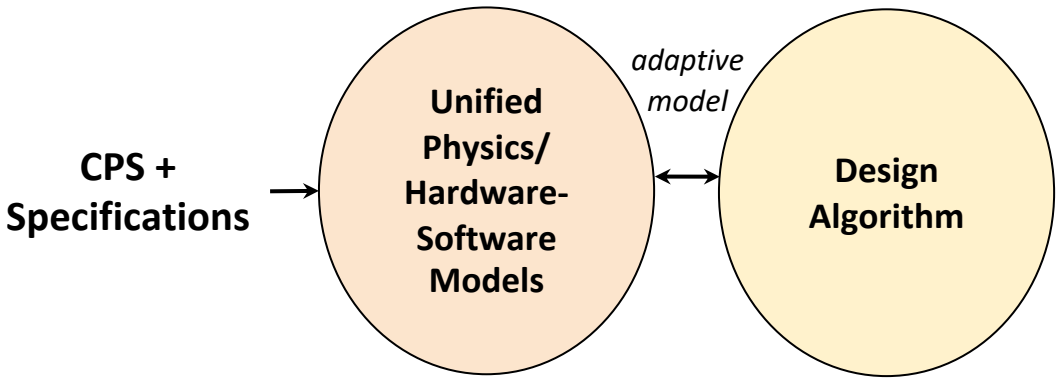

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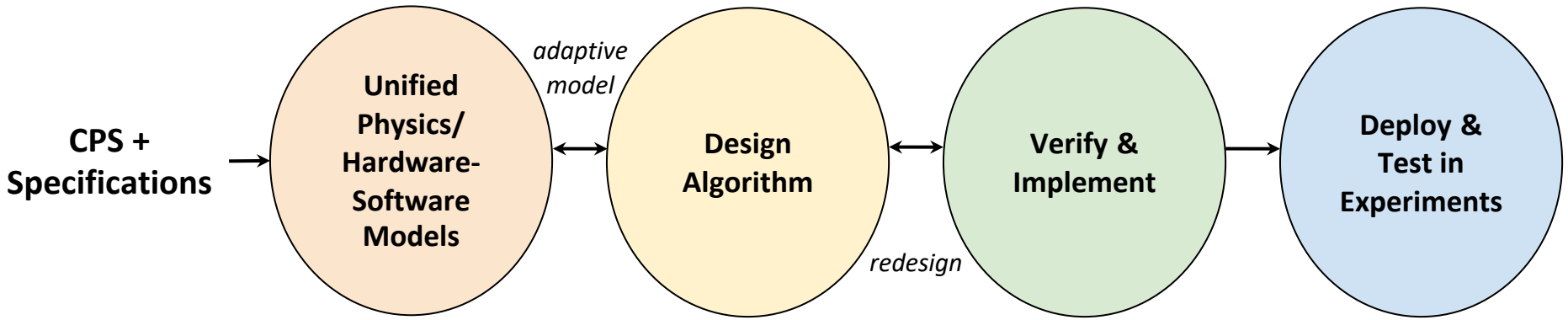

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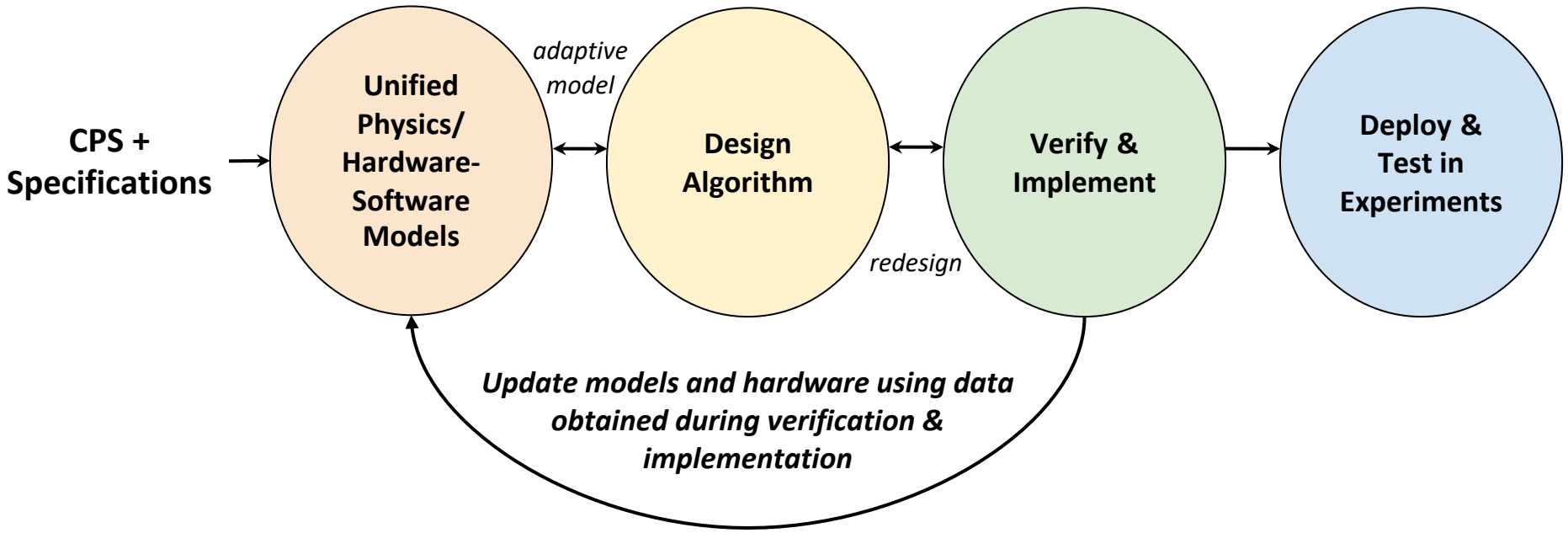

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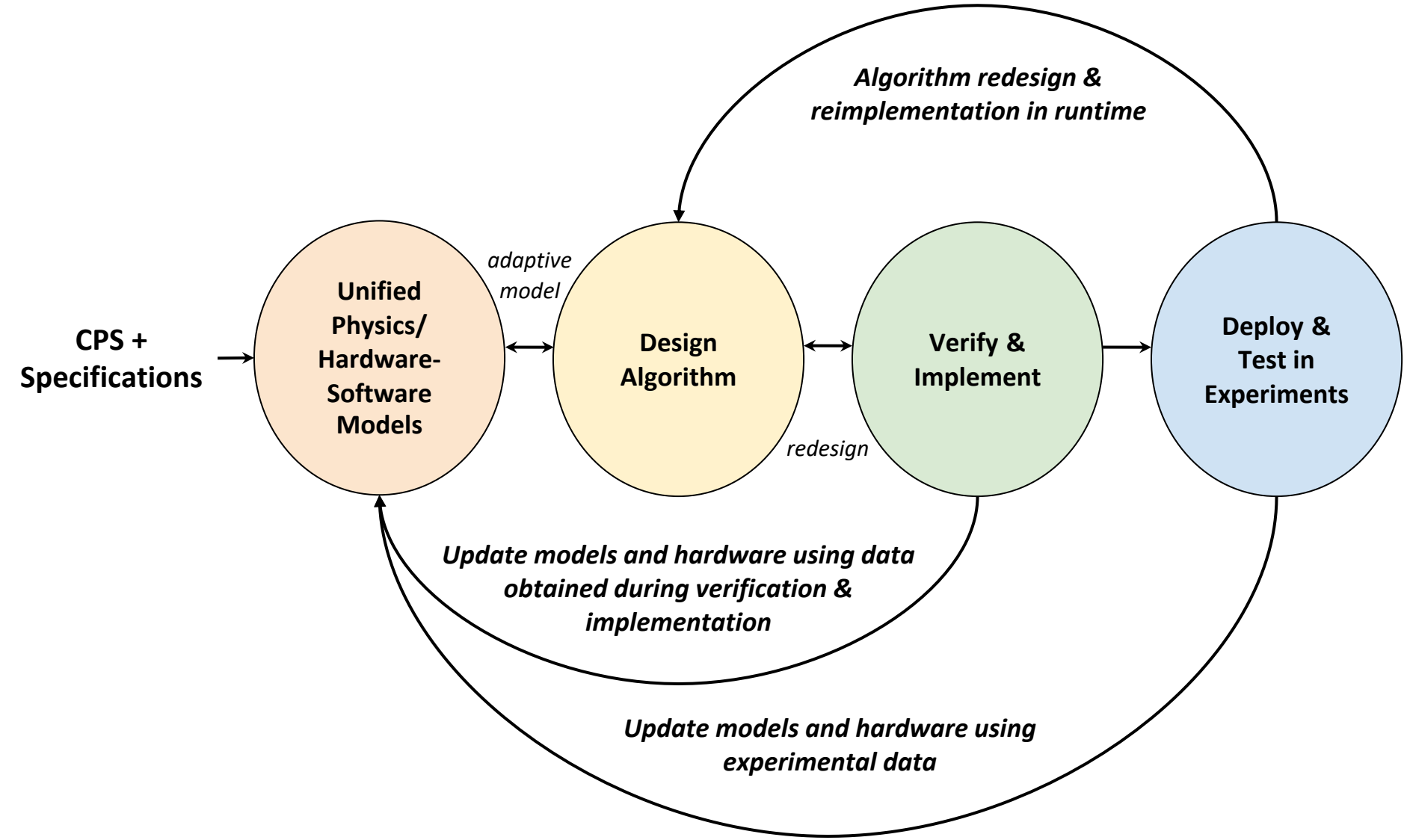

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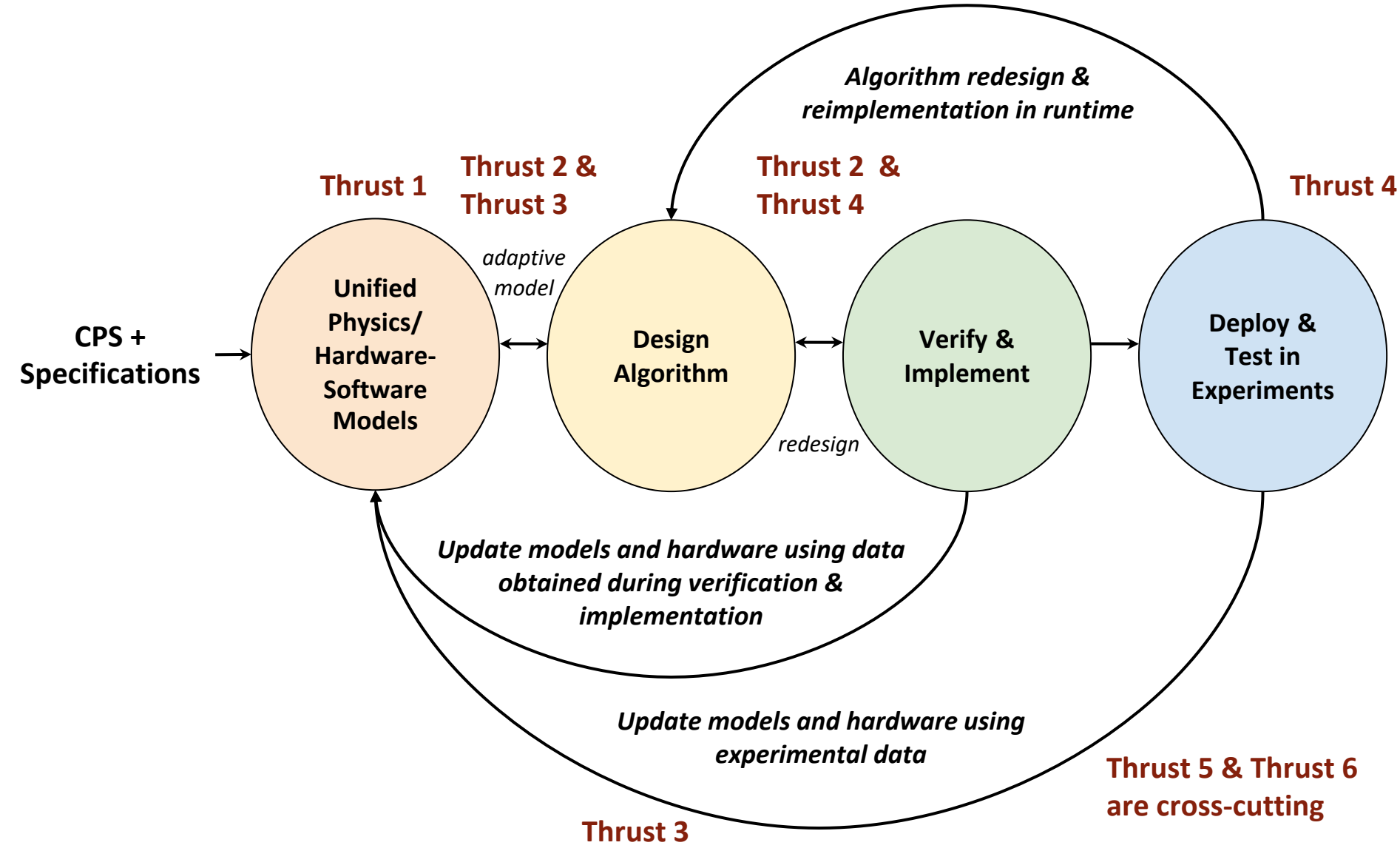
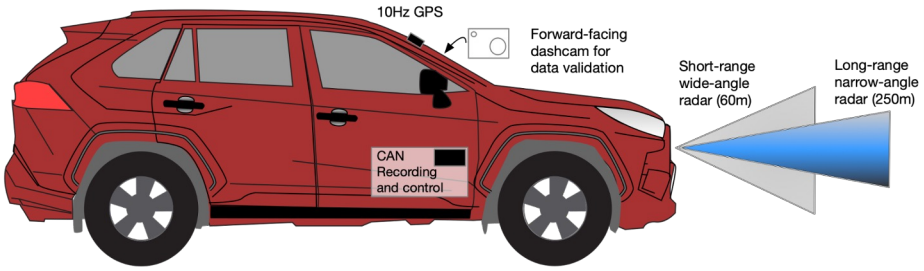
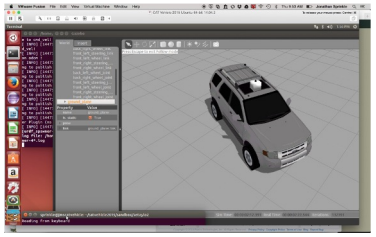


Multi-platform Computational and CPS Validation

Data and platforms from multiple domains, providing paths for transferability, translatability, and generalizability.

Naturalistic driving data, and control, with commodity vehicles

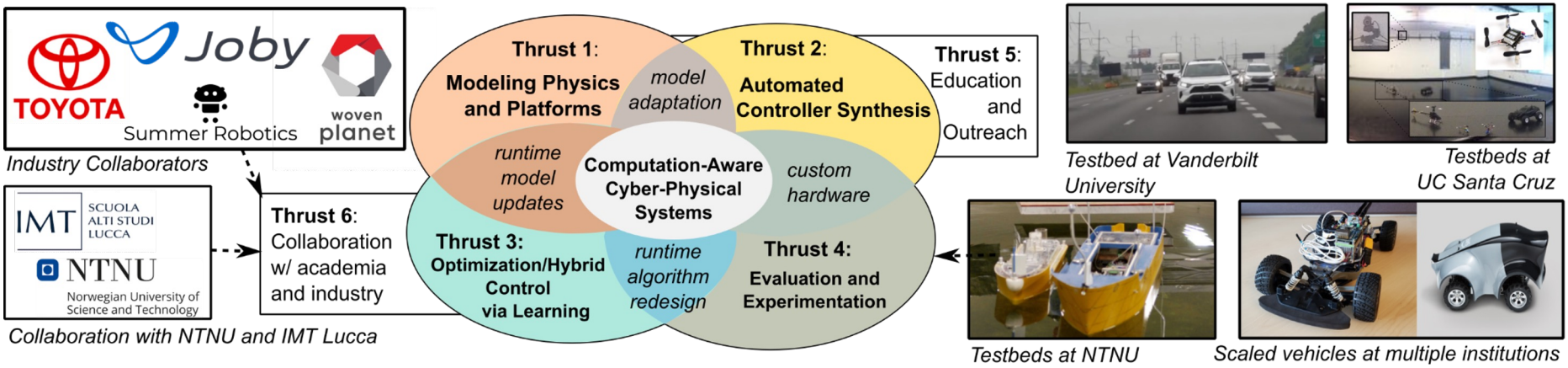




Smaller, shared platforms w/ different dynamics, different computational capabilities

Significantly different dynamics, varying safety constraints, with uncertainty from myriad of sources

Intellectual Merit, Broader Impacts & Expected Accomplishments/Transformation



Intellectual Merit

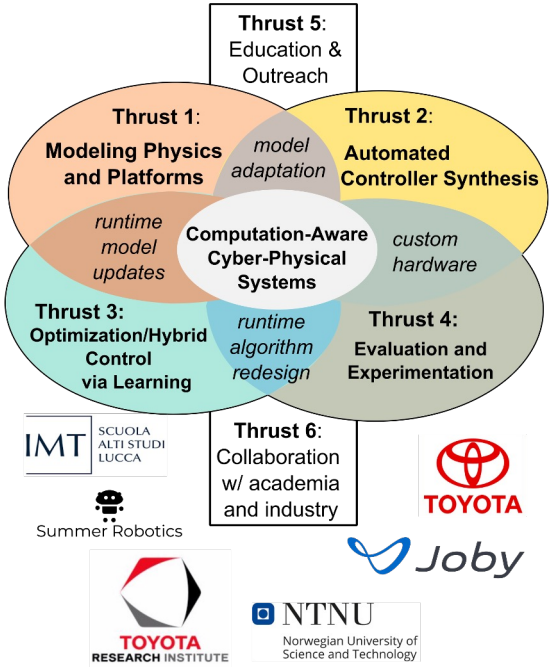
This project will generate

- New CPSs hardware and control software that adapt to the specifications and the environment they are deployed on.
- New tools to codesign hardware and control software reducing development cost and time.

within a framework to mathematically model and codesign feedback control algorithms and platforms.

Concretely, the results from the effort will provide

1. Novel algorithm architectures that learn and adapt in runtime to the specifications and resources.
2. Novel hardware architectures that are tailored to the execution of feedback control algorithms.
3. New scheduling techniques for executing multiple controllers on shared hardware resources.
4. Tools and design techniques that automatically synthesize and implement controllers in runtime.



Broader Impacts

The proposed research will have broader impact by

- Improving the safety and energy-efficiency of autonomous systems

  a multi-billion dollar market

- Enabling a new generation of transportation systems that improve the efficiency and reliability for users

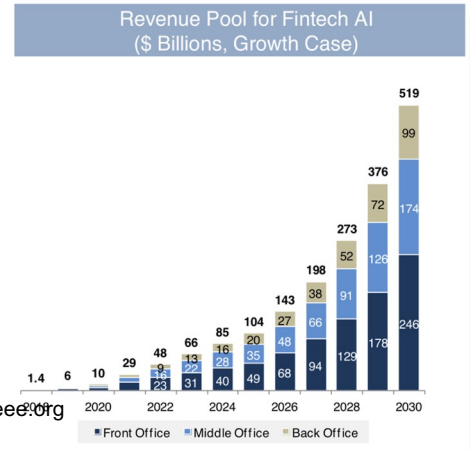
  reduction of global carbon footprint

- Providing open source models, algorithms, software, and platform designs that are suitable for deployment in industrial systems

  industry adoption through collabs

- Train the workforce of the future in CPS via educational and outreach activities with involvement of students, shared postdocs, in industry and academia

  workforce development



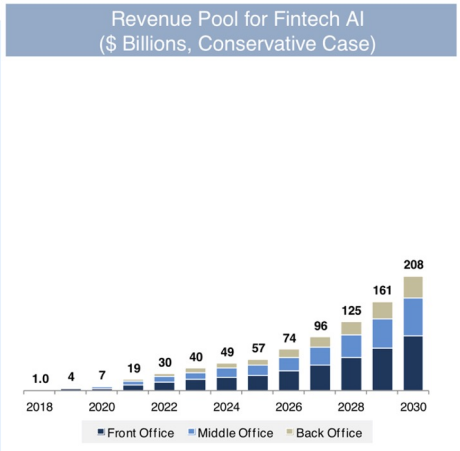


Image: cmte.ieee.org

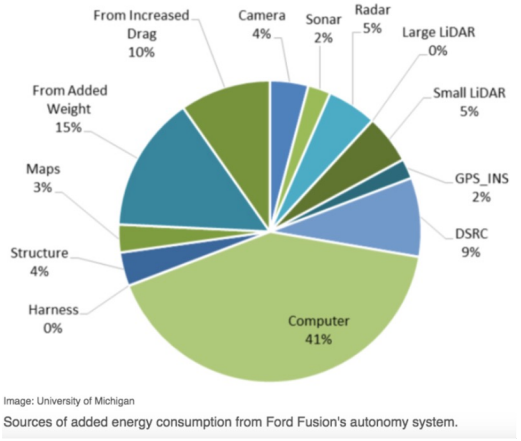


Image: University of Michigan

Sources of added energy consumption from Ford Fusion's autonomy system.

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Broad dissemination of results:

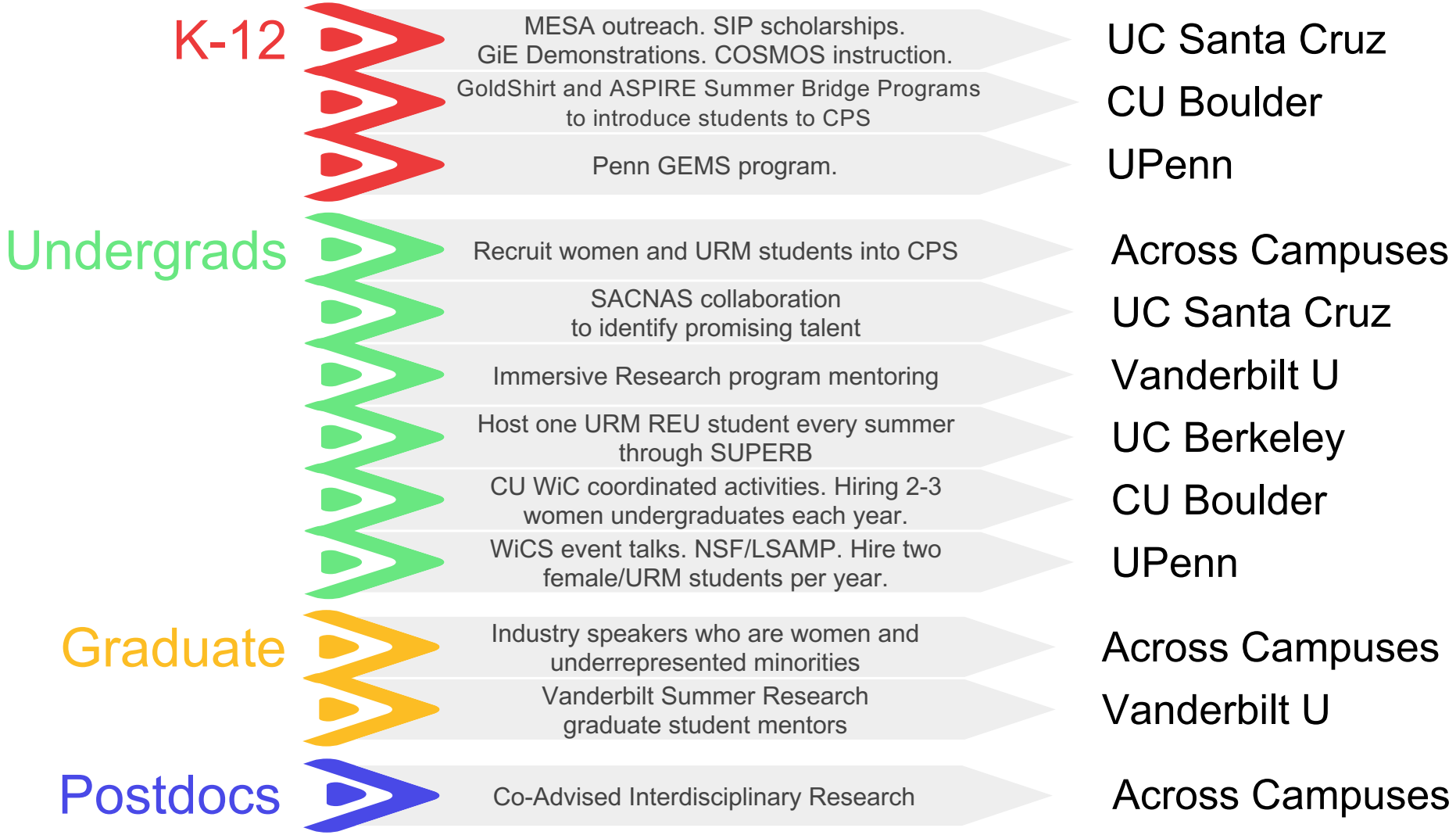
- Academia: via conferences, workshops, publications, models, data sets
- Industry: via regular planned meetings
- Workforce: to students at all levels via Thrust 5
- Community: via UC Berkeley, CU Boulder, Vanderbilt U, UPenn, UC Santa Cruz, and news outlets, their College of Engineering newsletters, the CPS-VO website, and the Cyber-Physical Systems Research Center

A project website and the team members' websites will report progress quarterly.

Image:

Broadening Participation in Computing

GOAL: expand the pool of women and URM talent in CPS



Fast Forward Accomplishments and Transformation

This project will have several societal impacts by enabling fast, cost-efficient, and reliable design of autonomous systems. We will improve the systematic design of CPS for intelligent transportation applications in the following ways:

- **New knowledge:** deeper understanding of how to co-design controllers with computational limits as models, rather than constraints
- **Reliability improvement**: Going beyond worst case hardware-software performance, to guarantee responsive timely controller actions
- **Cost reduction:** Building accurate models eliminates hardware overprovisioning, simplifies software designs, enables broader reuse
- **Capabilities**: Addressing hardware performance bottlenecks enables new capabilities, such as improving the response time of autonomous systems

Measures of success (compared to state-of-the-art systems):

- Greater than 4x improvement on schedulability of feedback control processes;
- Greater than 3x reduction on control software development time;
- At least 2x reduction of feedback control latency;
- At most 20% performance variation with order of magnitude hardware/energy savings.

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Thank you for your attention

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Sankar Basu **David Corman**

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