How can CPS education provide what the industry needs?

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What do “CPS people” in automotive industry do?

- Research and Advanced Development
  - Design control software for new hardware
  - Model hardware, environment for software
  - Exhaustively test and worry about correctness

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What do “CPS people” in automotive industry do?

- Advanced Production Development
  - Map software to a particular platform
  - Integrate their software with legacy software
  - Exhaustively test and worry about correctness

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What do “CPS people” in automotive industry do?

- Production
  - Calibration and Tuning
  - Occasionally fix logic issues
  - Exhaustively test and worry about correctness

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Research & Advanced Development Needs

- Control Design Theory
  - Linear systems theory: Basic linear algebra, PID control, Frequency domain analysis, Gain/Phase margin, Bode plots, etc.
  - Nonlinear systems: Lyapunov theory, Feedback linearization, etc.
  - Control algorithms: MPC, Sliding-mode, State-Observation and Estimation
  - Implementing control algorithms
- Control Design Tools
  - Matlab®
  - Simulink® and its toolboxes
  - LabView™, and related tools
  - Optimization tools and packages

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Research & Advanced Development Needs

- Modeling Theory
  - Causal versus acausal modeling
  - ODEs vs DAEs
  - Model order reduction (Rigorous transformations vs. approximations)
  - System identification
  - Making models fast
- Modeling Tools
  - Modelica language: Dymola, OpenModelica
  - Maplesoft tools
  - Simscape from The MathWorks

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Research & Advanced Development Needs

- Verification/Validation/Testing Theory
  - Software testing: Test-case generation, code coverage.
  - Real-time computing
  - Formal Requirements in Logic
  - Hybrid & Continuous dynamical systems theory: Reachability analysis, Stability theory, Invariants
- Verification/Validation/Testing Tools
  - Not many standard tools
  - Current state-of-the-art:
    - Open-loop : Simulink Design Verifier, Reactis, EmbeddedTester, LabView™ and related tools, dSpace, Model checkers, ….
    - Closed-loop: (Testing) S-TaLiRo, Breach; (Verification) SpaceEx, Flow*, Model checkers

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Advanced Dev + Production Dev Needs

- Real-time Software Theory
  - Models of Computation: Asynchronous Message-passing vs. Synchronous Dataflow vs. Discrete-Event Systems
  - Schedulability, Worst-case Execution Time Analysis
  - Software/Hardware architectures
  - Real-time Deadline-driven Concurrency Analysis

- Skills: Knowledge of standards such as AUTOSAR, MISRA-C, DO-178B, ISO 26262

What will an ideal CPS engineer look like?

- Three Masters degrees, Two PhDs, plus 10years experience?

- Let's look at what we can add:
  - How could we CPS up a CS major?
  - How could we CPS up an EE/ME (controls) major?

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Switch from CS to CPS is generally harder

- Control software development is *different*:
  - You don't write code, you "draw" specs, generate code (e.g. Simulink, Ptolemy, TargetLink etc.)
  - Memory management is simplistic: shared memory organized in global variables
  - No object-oriented-ness, no functional languages
  - Very few pointers, dynamic typing, etc.

- Formal Methodists often cringe at qualitative requirements

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Switch from CS to CPS is generally harder

- CS curricula generally:
  - Avoid ODEs, real numbers
  - Rarely include real analysis, Laplace transforms, etc.
  - Give students strong skill-set to be successful at traditional "software engineer" positions at Google, Facebook, Microsoft, Amazon, making apps, etc.
- Big challenge: How to generate excitement about the CPS challenges in mainstream CS?

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Controls to CPS easier, but need upgrades

- Controls curricula generally do not stress:
  - Formal methods, Automata theory (e.g. hybrid automata)
  - Distributed Systems
  - Logical requirements
    - Compare: $\Diamond\Box_{(t_{settle},\infty)}|x| < 0.01$
    - Step response looks good
  - Formal Verification vs. Testing

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Controls to CPS easier, but need upgrades

- Multi-core platforms are coming!
  - Need training in concurrency theory, synchronization, memory models, schedulability, etc.
  - Hardware and software architectures
- V2V communication, active safety, driver assistance systems are already here
- Big data is coming
  - Machine learning, Data mining techniques will become prevalent
- Abstraction/Refinement, logical foundations for sound reasoning, Compositional reasoning

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What the industry should also need

(but is currently not)

- Very little focus on correct-by-construction design
  - Enormous strides in program synthesis, SMT, SAT can be leveraged
- Design by abstractions and refinements
  - Hardware (mechanical components) and Software evolve independently and simultaneously
  - Makes verification, testing, calibration arduous and difficult: the shifting target problem
- Formal Requirements
  - Even “as-is” requirements are not common
  - How do I design “improve gas-mileage?”

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CPS academia and industrial CPS: Symbiosis?

- Industry → Academia
  - Challenge problems: verification, design
  - Representative models
  - Internships!

E.g. Berkeley's MOOC course: Partnership of UCB with NI, excellent example of cross-pollination

- Academia → Industry
  - Tools, tools, tools!
  - Scalability, simplicity over features
  - Solutions to challenge problems

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Thank You!