CDS 110/ChE 105: Lecture 1.1
Introduction to Feedback and Control

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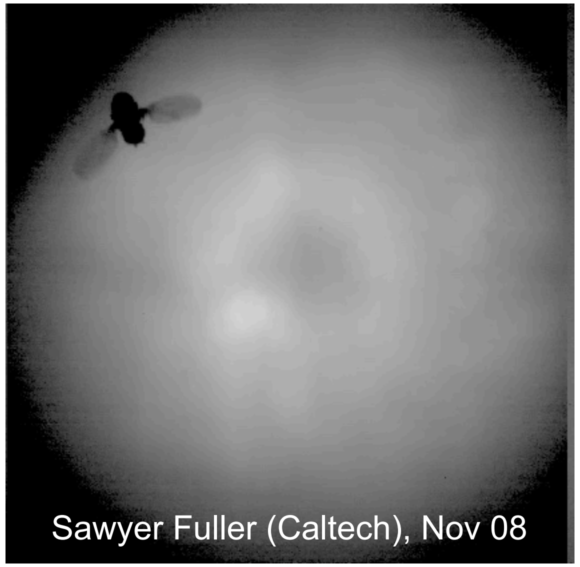
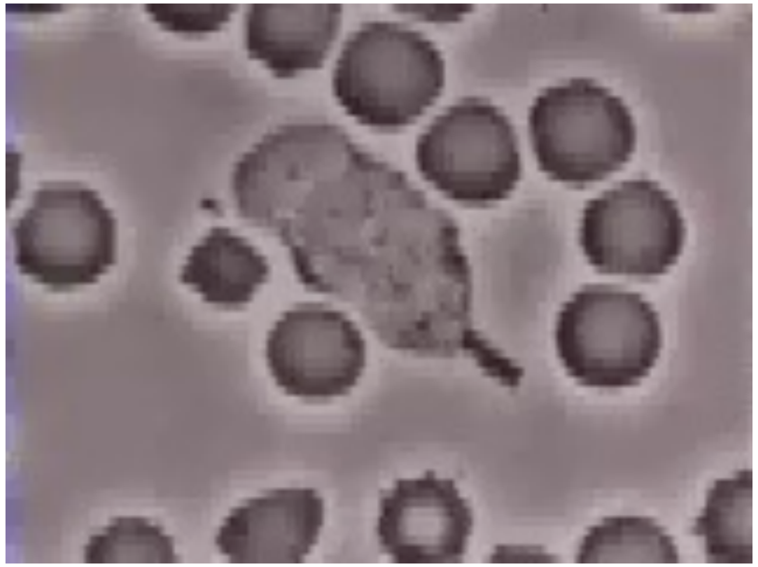
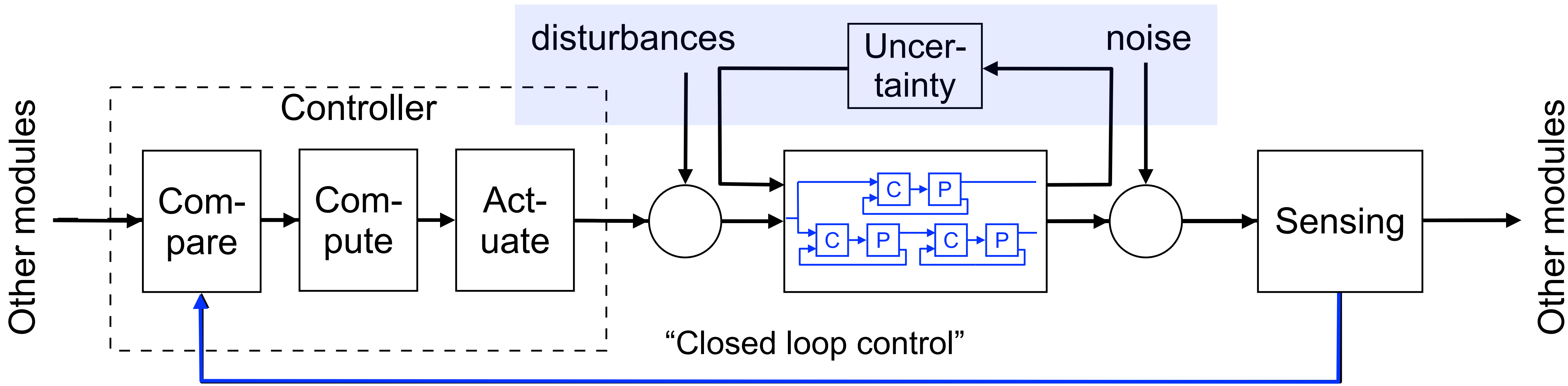
1 April 2024

Goals for today
- Introduce concepts to be covered in the course (w/ context)
- Course structure & administration





Control System "Standard Model"



Feedback

Key elements

- Process: input/output system w/ dynamics
- Actuation: mechanism for manipulating process
- Sensing: mechanism for detecting process state
- Compute: compare actual / desired; determine action
- Environment: description of the uncertainty present in the system (bounded set of inputs/behaviors)

Advantages of feedback

- Design of dynamics
- Robustness to uncertainty
- Modularity and interoperability

Disadvantages of feedback

- Increased complexity
- Potential for instability
- Amplification of noise

Important Trends in Control in the Last 15* Years

(Online) Optimization-based control

- Increased use of online optimization (MPC/RHC)
- Use knowledge of (current) constraints & environment to allow performance and adaptability

Layering, architectures, networked control systems

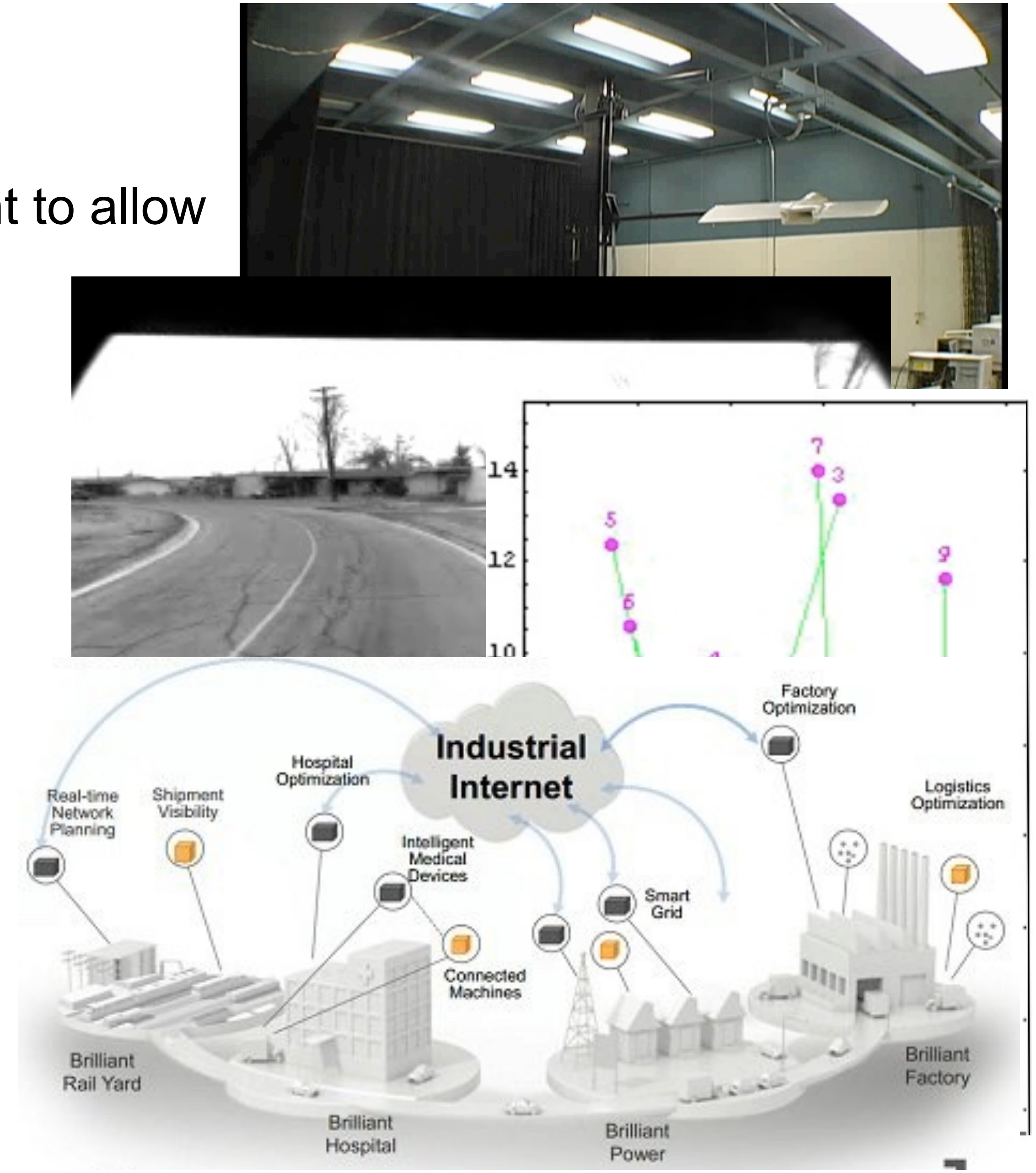
- Command & control at multiple levels of abstraction
- Modularity in product families via layers

Formal methods for analysis, design and synthesis

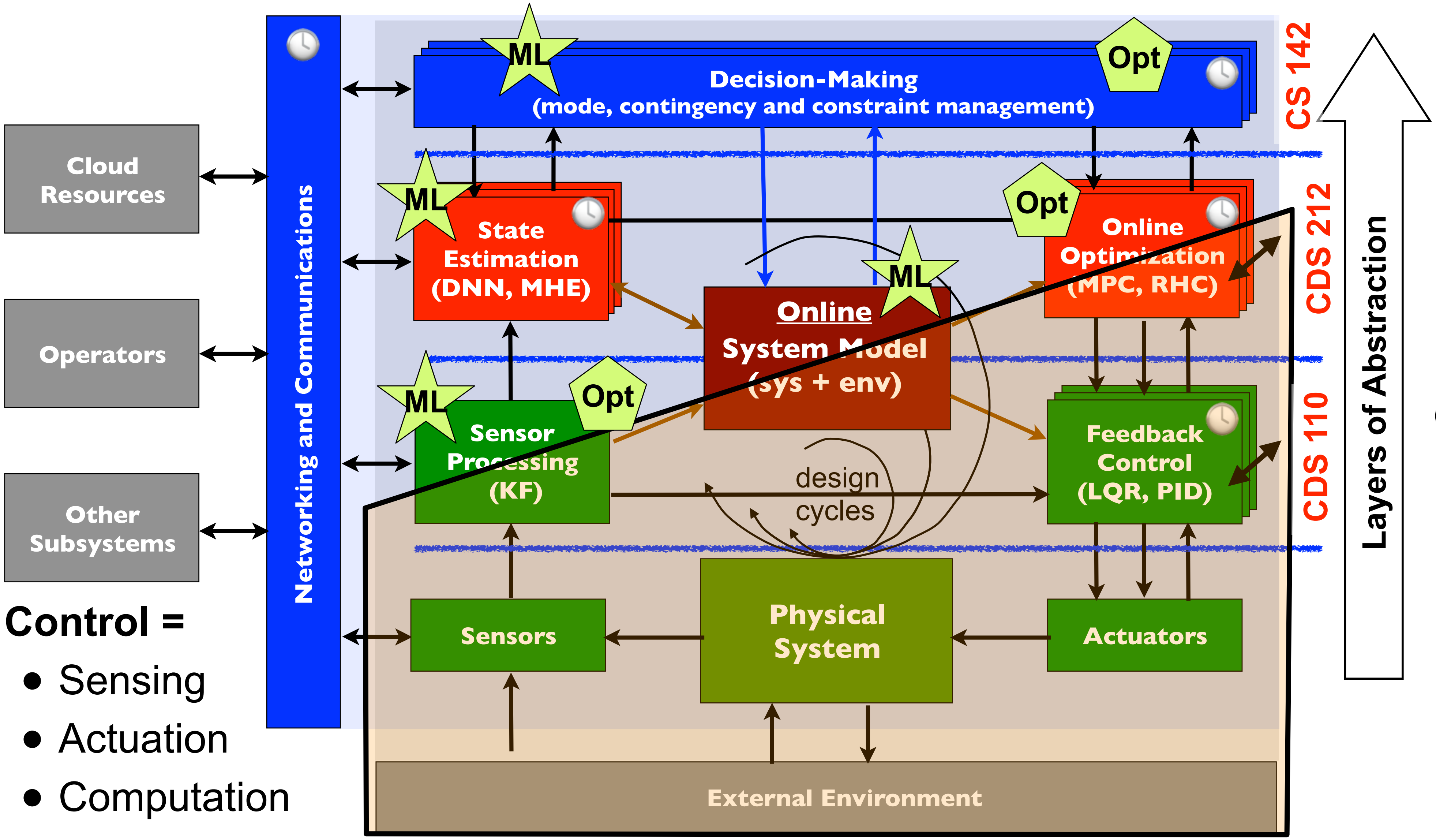
- Build on work in hybrid and discrete event systems
- Formal methods from computer science, adapted for "cyberphysical" (computing + control) systems

Components → Systems → Enterprise

- Increased scale: supply chains, smart grid, IoT
- Use of modeling, analysis and synthesis techniques at all levels. Integration of "software" with "controls"



Design of Modern (Networked) Control Systems



Control =

- Sensing
- Actuation
- Computation

Examples

- Aerospace systems
- Self-driving cars
- Factory automation/ process control
- Smart buildings, grid, transportation

Challenges

- How do we define the layers/interfaces (vertical contracts)
- How do we scale to *many* devices (horizontal contracts)
- Stability, robustness, security, privacy

Control = dynamics, uncertainty, feedforward, feedback

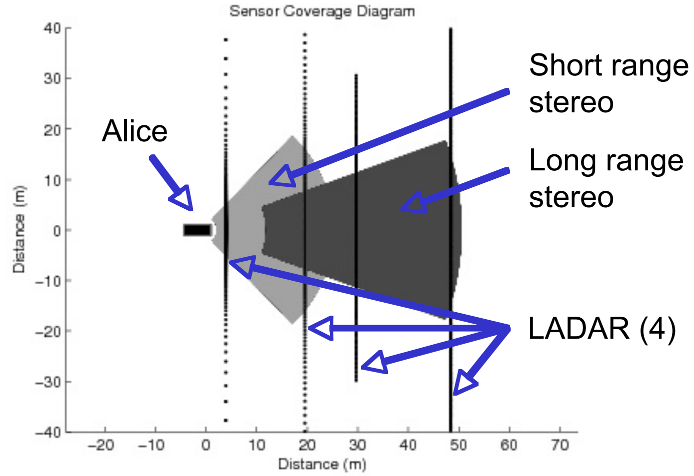
Example: Autonomous Vehicles (Alice)

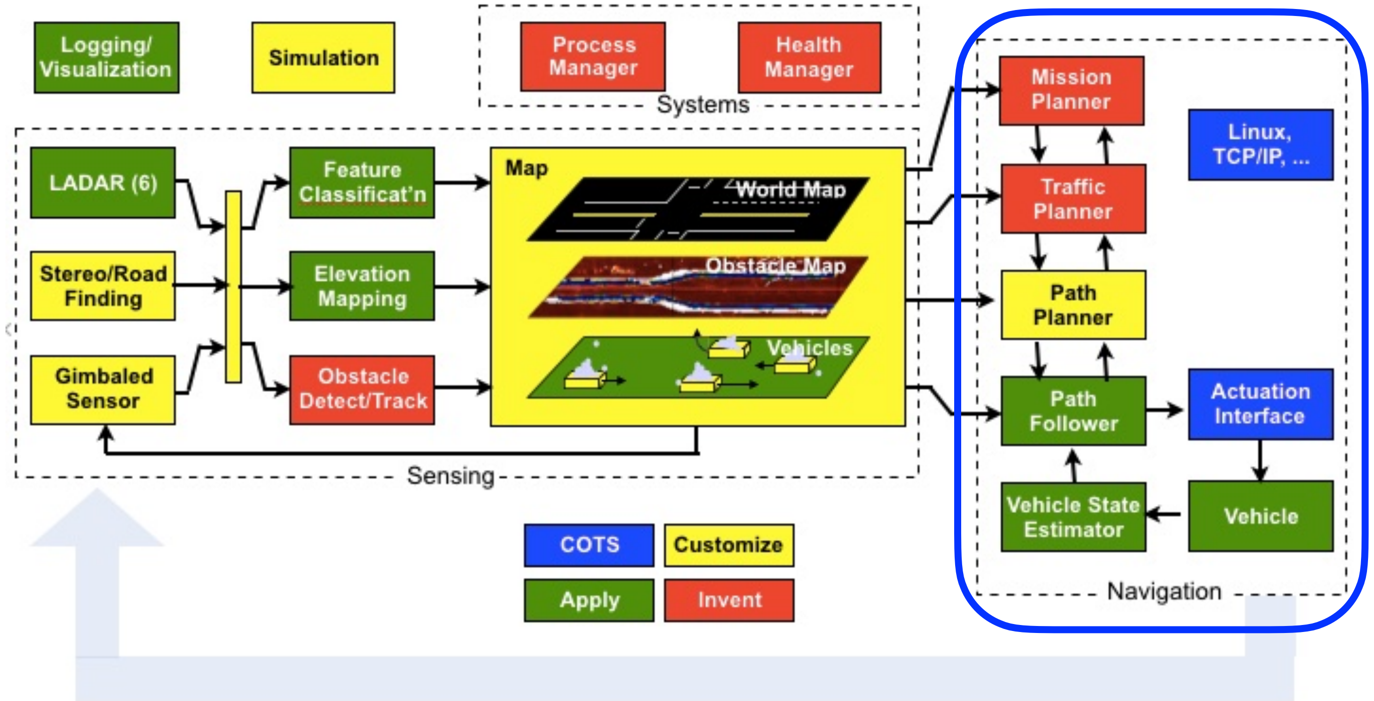
Vehicle
- 2005 Ford E-350 Van
- Drive-by-wire steering, brakes, accel

Sensing
- 5 cameras: 2 stereo pairs, roadfinding
- 5 LIDARs: long, med*2, short, bumper
- 2 GPS units + 1 IMU (LN 200)

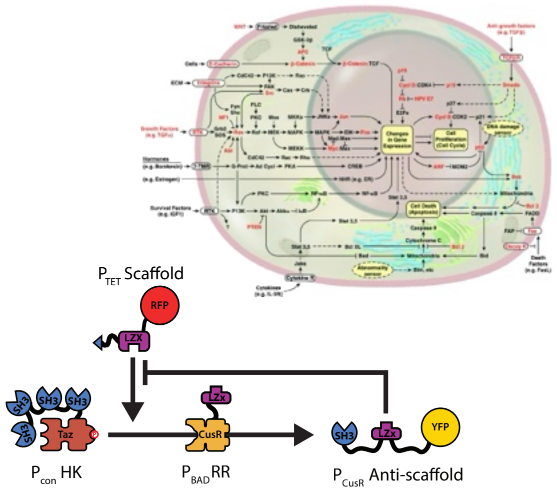
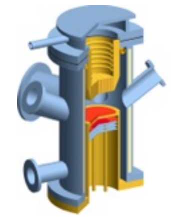
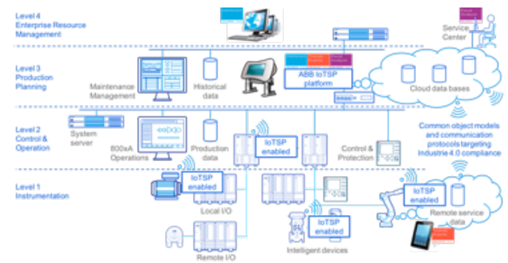
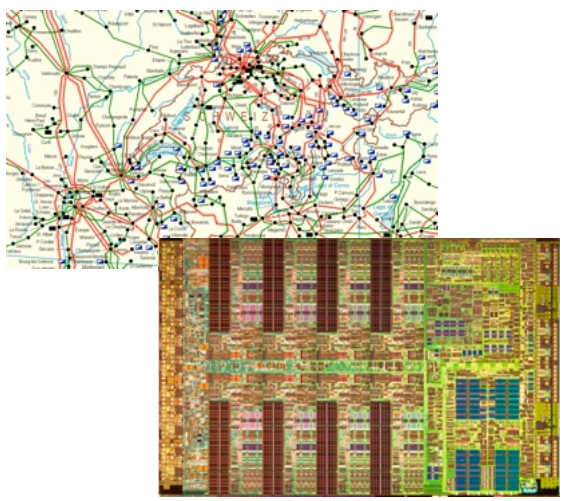
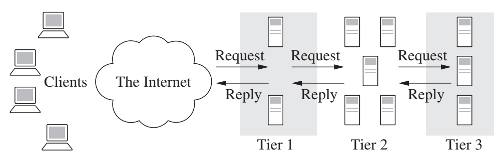
Computing (2005)
- 6 Dell PowerEdge Servers (P4, 3GHz)
- 1 IBM Quad Core AMD64 (fast!)
- 1 Gb/s switched ethernet

Software
- 15 programs with ~100 exec threads
- 100,000+ lines of executable code





Feedback Control System Examples

Aerospace Engineering	Bioengineering	Chemical Engineering
		  
Electrical Engineering	**Computer Science**	**Mechanical Engineering**
	 	

Questions to answer

- Controlled variable:
- Performance goal:
- Source of uncertainty:
- Inputs:
- Outputs:
- States:

Course Structure

Part I: Modeling and Analysis (W1-W3)

- State space modeling, stability, phase portraits
- Input/output response (mainly linear systems)

Part II: State Space Control Design (W4-W6)

- State feedback
- Trajectory generation

Part III: Frequency Domain Analysis (W7-W9)

- Frequency response
- Robustness and fundamental tradeoffs

Course architecture

- Monday: big picture, conceptual view
- Wednesday: analytical techniques
- Friday: computation techniques

Lectures + reading + homework => expertise

Introduction and review

- Course overview and logistics
- Introduction to feedback and control
- Introduction to python-control

Modeling, Stability

- State space models
- Continuous and discrete time
- Phase portraits and stability

Linear Systems

- Input/output response of LTI systems
- Matrix exponential, convolution equation
- Linearization around an equilibrium point

State Feedback

- Reachability
- State feedback and eigenvalue placement
- Linear quadratic regulators (LQR)

State estimation

- Observers, observability
- Control using estimated state
- Kalman filtering (intro)

Trajectory generation and tracking

- Two degree of freedom design
- Gain scheduling
- Model predictive control

Frequency domain analysis

- Bode and Nyquist plots
- Stability margins

Robustness and fundamental tradeoffs

- Sensitivity functions
- Bode integral formula

PID control

- Frequency domain design concepts
- Windup and anti-windup