Module 01
Course Syllabus, Prerequisites, Applications, Course Overview

Ahmad F. Taha

EE 5243: Introduction to Cyber-Physical Systems

Email: ahmad.taha@utsa.edu

Webpage: http://engineering.utsa.edu/~taha/index.html

August 19, 2015

Course Instructor: Background & Interests

Background

- Born and raised in Beirut, Lebanon
- Finished my Ph.D. in ECE from Purdue University in August 2015
- Undergraduate education: American University of Beirut — Class of 2011, B.E., ECE
- Assistant Professor, ECE Department @ UTSA
- At UTSA since . . . August 10, 2015

My Ultimate Objective

Understand how complex systems operate and utilize this knowledge to create tools & control algorithms that would be leveraged to solve system-level challenges

Essentially, this should improve the quality of our lives...Hopefully!

Module 01 Outline

1. You will tell me about yourselves: careers, objectives, education
2. Course syllabus and expectations *(very high ones, believe me!)*
3. Course outline
4. Homework #1
5. The fun stuff starts — we will introduce CPSs and chat about them

Part I — Your Turn to Introduce Yourselves! ☺

Part II — Course Syllabus, Outline, and HW # 1

Course webpage & Communication

Course Pages:

- UTSA Blackboard: http://utsa.blackboard.com
- My Webpage: http://engineering.utsa.edu/~taha
- *Email is the best form of communication!*

Office Hours:

- Mondays, 14:00 – 15:00
- Wednesdays, 16:00 – 17:30
- Or by appointment

Course Description

- Modeling, analysis and design of cyber-physical systems (CPS)
- Who should/can take the course?
- Ask yourself if you are genuinely interested in CPSs in general...
- ...And control and optimization of CPSs, in specific

Course Description — Cont'd

- Fundamentals of CPSs are covered with emphasis on the control and the optimization aspects
- Covered topics: networked control systems, cyber-attacks, linear systems theory and design, state-estimators
- ...fault-tolerant controllers and observers, and convex, multi-objective, bi-level & multi-time scale optimization
- Applications is smart-grids are discussed

Main References

- No textbook is required for the class
- Lecture notes will be provided as handouts or presentation slides
- You may need to consult the following, mostly, free texts:
  - C. T. Chen, *Linear System Theory and Design*, Oxford University Press, 1995.
  - F. Y. Wang and D. Liu, *Networked Control Systems, Theory and Applications,* Springer-Verlag London, 2008.
  - E. Lee and S. Seshia, *Introduction to Embedded Systems, A Cyber-Physical Systems Approach*, Second Edition, LeeSeshia.org, 2015. Book available online: http://leeseshia.org/releases/LeeSeshia_DigitalV2_0.pdf.
  - S. Boyd, L. El Ghaoui, E. Feron and V. Balakrishnan, *Linear Matrix Inequalities in System and Control Theory*, SIAM, 1994. Book webpage: http://web.stanford.edu/~boyd/lmibook/.
  - S. Boyd and L. Vandenberghe, *Convex Optimization*, Cambridge University Press, 2004. YouTube videos for the class: https://www.youtube.com/watch?v=McLq1hEq3UY and book webpage: http://web.stanford.edu/~boyd/cvxbook/.
- Research papers

Course Objectives & Expected Outcomes

- This course is designed for graduate students who are interested in learning about CPSs
- Course includes a wide range of topics related to CPSs
- At the end of the semester, students are expected to have a good understanding of the basic principles governing CPSs' operation...
- ...And a reasonable depth related to a specific CPS topic that relates to their projects

Prerequisites

An undergraduate-level understanding of:

- Multi-variable calculus
- Control theory and feedback systems
- Linear algebra
- Basic optimization principles
- Basics related to the aforementioned topics will be covered in the first two weeks of classes

Grading Policy

- Homework assignments and quizzes (20%)
- One Exam (30%)
- Project (40%) — divided as follows: initial proposal (20%), progress report (20%), final presentation (20%), final report (40%)
- Attendance and instructor evaluation (10%)

Course Grade Cutoffs

- A−, A, A+: 85–100
- B−, B, B+: 70–84
- C−, C, C+: 55–69
- D−, D, D+: 40–54
- F: $\leq$ 39

Important Dates

Project Proposal .... Friday, September 18, 2015, 23:59:59

Progress Report .... Sunday, November 1, 2015, 23:59:59

Exam .... Wednesday, November 11, 2015, In Class

Final Report .... Tuesday, December 8, 2015, 23:59:59

Mark them down please!

Programming Tools

- MATLAB and Simulink will be required for homework assignments and course projects
- Students can obtain the discounted student version of MATLAB and Simulink
- It's encouraged to use LaTeX for homework assignments and course projects (honestly, there's no good reason not to!)

Class Policies

- Course projects
- Regular attendance
- Emailing me
- Showing up early
- Aim of the project (and reward)
- Late submission policy
- Changes to the syllabus

Tentative Class Schedule

Part I — CPS Review & Background .... ≈ 5–6 classes
- Course introduction & syllabus, prerequisites, major applications, course overview

Part II — Linear & Nonlinear Networked Systems Theory .... ≈ 4–5 classes
- Recent relevant theories on linear and nonlinear systems

Part III — State Observation & Estimation of CPSs .... ≈ 4–5 classes
- Dynamic state estimation of dynamic CPSs

Part IV — CPSs & Convex Optimization .... ≈ 3–4 classes
- Basic principles on convex optimization for generic systems

Part V — Progress Reports Presentations .... ≈ 1–2 classes
- Students will give short presentations on their progress reports

Part VI — Optimal Control of CPSs .... ≈ 1–2 classes
- Linear quadratic regulator, optimal state-feedback control, principle of optimality

Part VII — Exam .... 1 class
- In class exam

Part VIII — Networked Control Systems .... ≈ 1–2 classes
- Recent results on networked control systems, fault detection, cyber-attacks

Part IX — Applications .... ≈ 1–2 classes
- Smart-grids, transportation networks, robotics

Part X — Project Presentations .... ≈ 2–3 classes
- Students will present their projects

Homework #1

- It's not really a homework
- Good news: you'll receive credit for it anyway
- Bad news: it will be graded
- Deadline: Sunday, August 23rd, 23:59:59

Part III — Cyber-Physical Systems: History and Introduction

Cyber-Physical Systems — The *Ubiquity is Real!*

- CPSs: integrating computing, data analysis, communication, & control with physical processes
- Infrastructures are reliant on CPS-techs & communication networks
  - *The Physics and The Cyber: Intertwined responsibilities*

- CPSs are *inherently uncertain*; *vulnerable* to hackers & natural adversities

Trust Issues

Can we trust computers to manage, control, and optimize physics?

CPS History [Jeschke, 2013]

1898: Nikola Tesla's Radio-Controlled Boat — *Teleautomaton*

CPS History [Jeschke, 2013]

1898: Nikola Tesla's Radio-Controlled Boat — *Teleautomaton*

↓

1948: Norbert Wiener's Cybernetics

CPS History [Jeschke, 2013]

1898: Nikola Tesla's Radio-Controlled Boat — *Teleautomaton*

↓

1948: Norbert Wiener's Cybernetics

↓

1961: Charles Draper — Apollo Guidance Computer

CPS History [Jeschke, 2013]

1898: Nikola Tesla's Radio-Controlled Boat — *Teleautomaton*

↓

1948: Norbert Wiener's Cybernetics

↓

1961: Charles Draper — Apollo Guidance Computer

↓

1999: Kevin Ashton's Internet of Things

CPS History [Jeschke, 2013]

1898: Nikola Tesla's Radio-Controlled Boat — *Teleautomaton*

↓

1948: Norbert Wiener's Cybernetics

↓

1961: Charles Draper — Apollo Guidance Computer

↓

1999: Kevin Ashton's Internet of Things

↓

2006: Helen Gill's CPS Definition

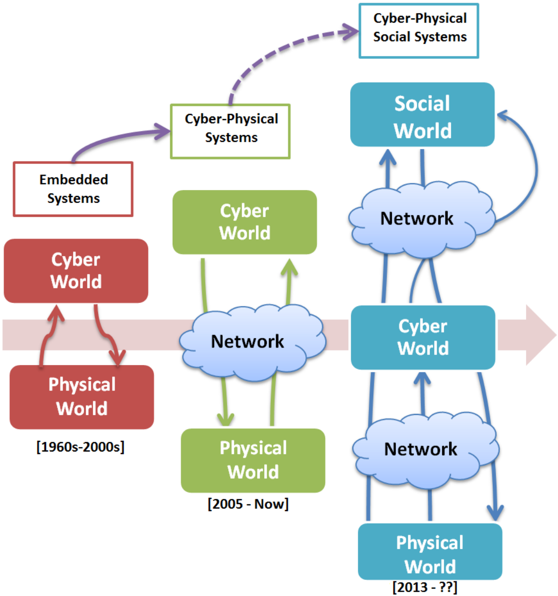
Helen Gill's CPS Definition

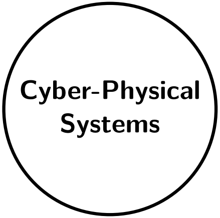
"A cyber-physical system (CPS) is an integration of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.

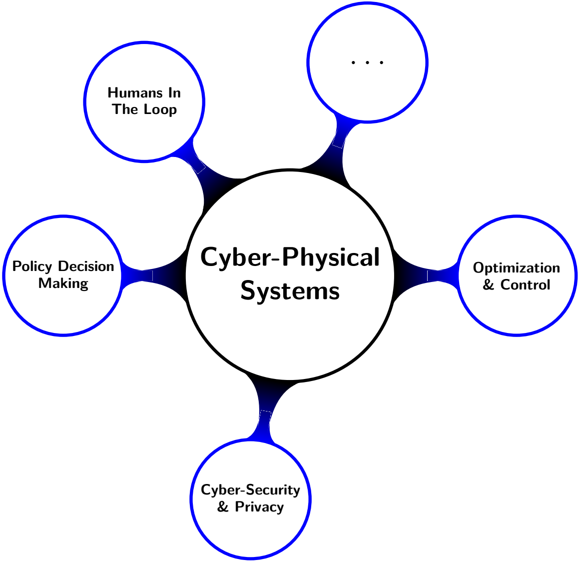
As an intellectual challenge, CPS is about the intersection, not the union, of the physical and the cyber. It is not sufficient to separately understand the physical components and the computational components.

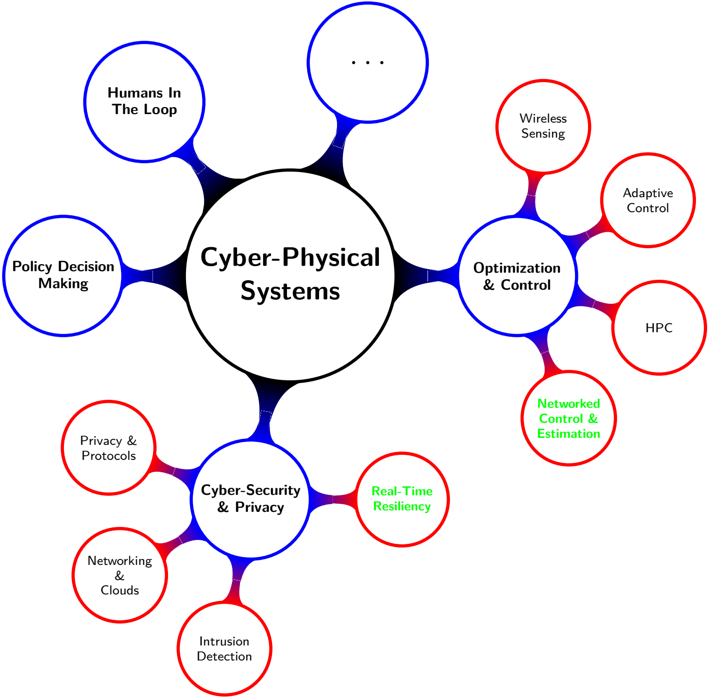
We must instead understand their interaction. The design of such systems, therefore, requires understanding the joint dynamics of computers, software, networks, and physical processes. It is this study of joint dynamics that sets this discipline apart." — Helen Gill, NSF, 2006

CPS & CPSS Evolution

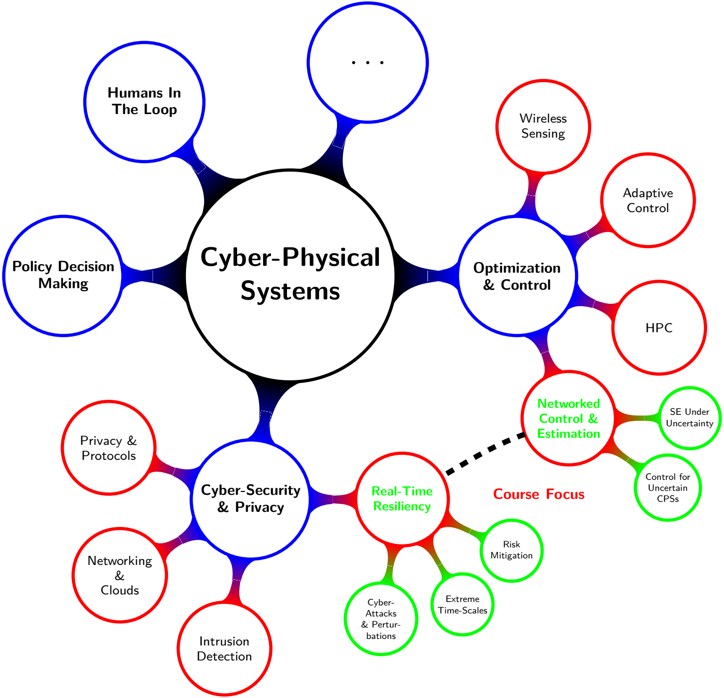



Cyber-Physical
Systems

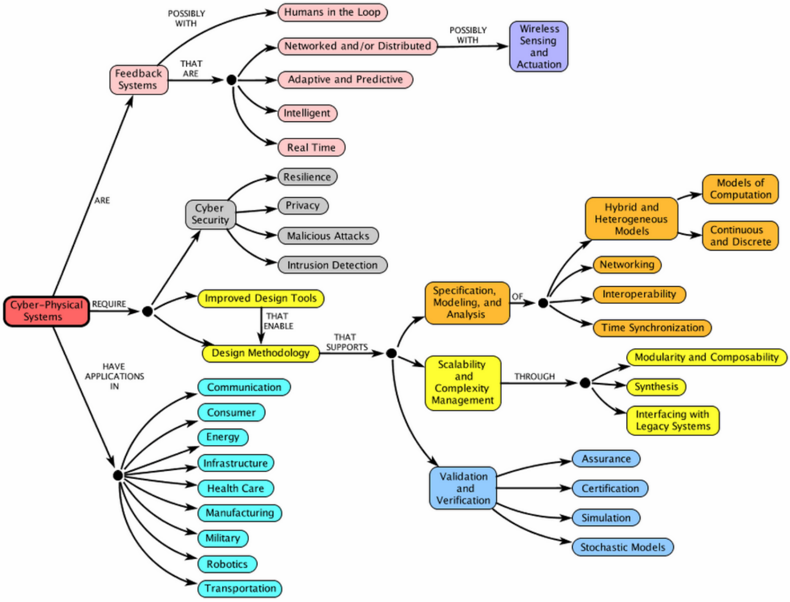

Humans In The Loop
. . .
Policy Decision Making
Cyber-Physical Systems
Optimization & Control
Cyber-Security & Privacy



Cyber-Physical Systems
Humans In The Loop
. . .
Policy Decision Making
Optimization & Control
Wireless Sensing
Adaptive Control
HPC
Networked Control & Estimation
Cyber-Security & Privacy
Privacy & Protocols
Real-Time Resiliency
Networking & Clouds
Intrusion Detection

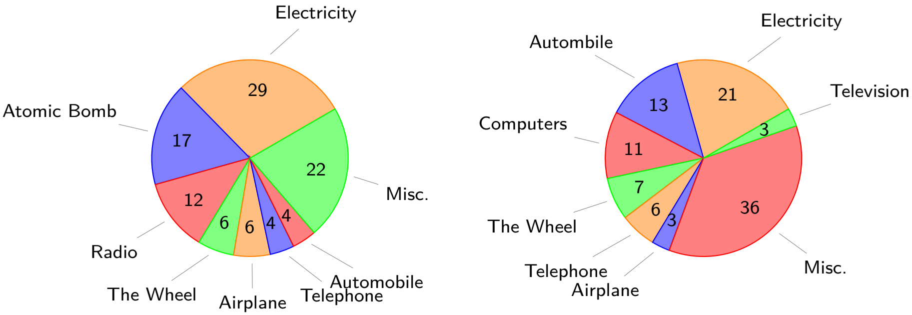

Cyber-Physical Systems
Humans In The Loop
. . .
Policy Decision Making
Optimization & Control
Wireless Sensing
Adaptive Control
HPC
Networked Control & Estimation
SE Under Uncertainty
Control for Uncertain CPSs
Cyber-Security & Privacy
Privacy & Protocols
Networking & Clouds
Intrusion Detection
Real-Time Resiliency
Risk Mitigation
Extreme Time-Scales
Cyber-Attacks & Perturbations
Course Focus

Another Concept Map [Lee et al., 2014]



Polls of Greatest Inventions

- Polls of greatest inventions ever made — in 1947 & 2005 [Gallup, 2005]
- Most are CPSs: varying in complexity and size



- With increasing role of **networks**, security has been identified as one of the main issues [Sridhar et al., 2012]

CPS Vision & Mission

- **Vision**: *building* ***secure & resilient critical infrastructure***
- ***Mission***: *leading efforts to secure infrastructure by* ***managing risk & enhancing resilience*** *through open collaborations* — a DHS mission [DHS, 2015]

Research **Focus**

Developing secure computational methods for uncertain CPSs with applications to dominant CPS applications

References I

DHS (2015). http://www.dhs.gov/office-infrastructure-protection.

Gallup (2005). http://www.gallup.com/poll/17881/electricity-retains-power-greatest-invention.aspx.

Jeschke, S. (2013). Cyber-physical systems — history, present and future.
URL http://www.ima-zlw-ifu.rwth-aachen.de/fileadmin/user_upload/INSTITUTSCLUSTER/Publikation_Medien/Vortraege/download//CPS_27Feb2013.pdf

Lee, E. A., Asare, P., Broman, D., Torngren, M., & Sunder, S. S. (2014). http://cyberphysicalsystems.org/.

Sridhar, S., Hahn, A., & Govindarasu, M. (2012). Cyber-physical system security for the electric power grid. *Proceedings of the IEEE*, *100*(1), 210–224.

Questions And Suggestions?

Thank You!

Please visit

engineering.utsa.edu/~taha

IFF you want to know more ☺