CS557: Cyber-Physical Systems

Networking and Algorithms

Prof. Xiang Yang Li

Fall 2013
Computing, Networking

Opportunities and Challenges from Computing, Networking

1946
Computer
Auto computing

1965
Super Computer
High performance

1980
PC
User centered

1995
Internet
New networking service, cyberword

2010
CPS
Pervasive & sensor computing

Computing model involution.

Network service
COMPUTING
First Digital Computer: ENIAC 1943-1946

Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.
“Smallest”: Monster Spider 2011

The prototypical sensor device developed by researchers at the University of Michigan is intended to monitor eye pressure for glaucoma patients. It connects wirelessly to other computers and is charged with a solar cell, needing just 1.5 hours of sunlight or 10 hours of indoor light to reach full power.
Google Glass (expected 2014)
Google Glass
Computers are faster and cheaper

1980 1990 2005

$400,000/MIPS (Cray-I)

$500/MIPS (i860)

$1/MIPS

How to connect them?
Client-Server Model

- Clients send request to servers
- Servers finish work and send back response to clients
- **Small** number of servers serve for **large** number of clients
- Example: web service
Peer-to-Peer Model

• P2P
  ‣ Link the resources of all peers
  ‣ Resources: storage, CPU cycles, content, etc.
  ‣ All peers are servers and equal – highly scalable
  ‣ All peers are autonomous (different owners)
  ‣ Peers are both clients and servers

• Examples: Napster, Gnutella, KaZaA, Bit-Torrent, E-Donkey…
Why P2P popular...

- 150 years ago…all performance was live!
- If you wanted music, the best way is you do it yourself… and almost everyone did.

- This all changed in 1877
  - When Thomas Edison invented Phonograph, able to reproduce the recorded sound
I can only say that I am astonished and somewhat terrified at the results of this evening's experiment -- astonished at the wonderful power you have developed, and terrified at the thought that so much hideous and bad music may be put on record forever.

But all the same I think it is the most wonderful thing that I have ever experienced, and I congratulate you with all my heart on this wonderful discovery.

London, October 5, 1888
MicroDot Audio

• So Small, You Need A Magnifying Glass To Even Notice It!
  
  • Voice Activation
  • Time And Date Stamping
  • 18.6 Hours Recording Time
  • Programmable Time Start
  • Fast USB File Transfer

So Small It Has To Be Manufactured Under A Microscope!

Tiny Nano Size Dimensions: mm 12x35x17 inches 0.47 X 1.37 X 0.6693 thick
Pervasive Computing

Mark Weiser 1988

• From Mark Weiser’s paper
  ▶ …making many computers available throughout the physical environment, but making them effectively invisible to the user.
  ▶ The most profound technologies are those that disappear.
  ▶ 4A Service: Anytime, Anywhere, Any device, Any data!!
Where Computing is Done

1. Streaming information to/from physical world
2. Number Crunching Data Storage
3. Productivity interactive

Year
Many Active Projects

- **MIT Oxygen Project**
- **Microsoft EasyLiving**
- **Stanford Interactive Workspaces Project**
- **IBM Blue Space**
- **IBM Dream Space**

...
COMMUNICATION
From Internet

- Internet is everywhere
- But still mainly connecting computers/human users
To Internet of Things
To Cyber-Physical Systems
CPS
Instrument and Connect the World!

Bridge Monitoring
Building
Environment
Controls
Earthquake Monitoring
Elder Care
Factories
Fire Response
First Responders
Forest Management
Soil Monitoring
Supply Chain
Wind Response
…and more more
Control !!

Figure 8 Feedback Control System Block Diagram
Networked Control Systems
IoT and CPS

Are Twins?
CPS

IoT and CPS

Internet or Cyber world

Internet of Things

C=C1 ∨ C2 ∨ ... ∨ Cn
P=P1 ∨ P2 ∨ ... ∨ Pn

CPS

C1

C2

Cn

P1

P2

Pn
All such buzzwords refers to the same balloon. When it is blown to large size, it is called Smart Planet; when to middle size, it is called CPS; When to small size, it is called pervasive or embedded system.
Concept of IoT/CPS

Ordinary objects are instrumented;
Autonomic terminals are interconnected;

Based on the traditional information carriers including Internet, telecommunication network and so on, Internet of Things (IOT) is a network which can interconnect ordinary physical objects with identified addresses.

Pervasive services are intelligent.
## CPS Conferences

<table>
<thead>
<tr>
<th>Names</th>
<th>Type</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSF Workshop on Cyber-Physical Systems</td>
<td>Workshop</td>
<td>2006</td>
</tr>
<tr>
<td>International Workshop on Cyber Physical Systems</td>
<td>ICDCS Workshop</td>
<td>2008, 2009</td>
</tr>
<tr>
<td>CPS Track</td>
<td>ICDCS</td>
<td>2008</td>
</tr>
<tr>
<td>CPS Summit</td>
<td>Summit</td>
<td>2008</td>
</tr>
<tr>
<td>Cyber-Physical Systems Challenges and Applications</td>
<td>DCOSS Workshop</td>
<td>2008</td>
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<tr>
<td>CPS Week</td>
<td>RTAS, IPSN, HSCC--CPSWeek</td>
<td>2008---2011</td>
</tr>
<tr>
<td>The International Workshop on Cyber Physical and Social Computing</td>
<td>ATC Workshop</td>
<td>2009</td>
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Computing Fundamentals: New Foci of NSF

• Cyber-Physical Systems
  ‣ Growing reliance on CPS for everything we do—from daily life, to commerce, to transportation, to healthcare, …, to national security
  ‣ Challenges: Ensuring reliability in the face of complexity, uncertainty, dynamism

• Data-Intensive Computing
  ‣ Interests: Analyzing massive data sets, engineering ultra-large-scale reliable data clusters, enabling new scientific and societal applications, training the workforce

• Software for Complex Systems
  ‣ Growing reliance on software as the critical component of all systems
  ‣ Interests: Developing foundations of software design and engineering that scale to real-world systems

First and third are PCAST/NITRD Priorities #1 and #2.
Computing Fundamentals: New Foci/Scope of Existing Programs

• Cybersecurity
  ‣ Theoretical foundations, privacy, usability

• Network Science and Engineering
  ‣ Understanding complexity of networks, across multiple dimensions from underlying technology to societal uses

• People+Computers
  ‣ Understanding “What is computable?” when humans and machines work together to solve problems neither can solve alone.
CS557: Cyber-Physical Systems
Networking and Algorithms

Course Managerial Information
Course Information

Instructor: XiangYang Li
  - Office: 229 C SB
  - Email: xli@cs.iit.edu
  - Office hour: Monday, Wednesday 2:00 to 3:00PM

Lecture time and room
  - Monday 6:25 to 9:05PM, August 19th to November 30th, 2013
  - Room 106 SB

Recommended books, journals and conference proceedings
  - International Conference on Cyber-Physical Systems (ICCPS)
  - NSF workshops
  - IEEE transactions
Course Info

• Webpage
  - http://www.cs.iit.edu/~xli/cs557/lectures.htm
  - http://www.cs.iit.edu/~xli/cs557/papers.htm

• see IIT calendars for holidays:
  - Labor Day break, September 2\textsuperscript{nd}, Monday
  - Fall breaks, October 7\textsuperscript{th}, Monday
  - Thanksgiving Break, Begins Nov 27\textsuperscript{th}, Wednesday
Materials to be Covered

• Basics of Cyber physical systems
• Basics of Wireless sensor networks and RFID
• Basics of real-time computing
• System theoretic approach to engineering design
• Dynamical Systems
• The Importance, Design and Implementation of a Middleware for Networked Control Systems
Course Objectives

• To understand:
  1. Basic characteristics, concepts, principles and techniques in CPS
  2. Basic characteristics, concepts, principles and techniques in Wireless Sensor Networks
  3. Basic requirements of real-time systems and applications and how these requirements are realized
  4. What’s new for CPS?
  5. Stimulate research interest in the emerging area
     1. Medical devices, and mobile health
     2. Industrial applications
     3. Green energy, and green environment
Course Structure

The course is an integration of two components

- **1\(^{st}\) component**
  - Lectures (slides and research papers will be provided)
  - Invited speakers from industry, national labs, other engineering department

- **2\(^{nd}\) component**
  - Seminar: students read, present, and discuss up-to-date research results
  - Course projects
  - Project presentations

Communication convention

- Please use prefix: CS557 in your email subject for expedited response
Course Load and Grading Policy

• Course load
  ‣ One term paper (30%)
  ‣ One term project (50%) (team project is encouraged, but the team size should NOT have more than 3 members)
  ‣ Class Attendance and Paper presentation (20%)
    • Each student is expected to read and present at least ONE research paper and be able to lead the discussion about the paper
  ‣ No exams 😊

• Grading policy
  ‣ No plagiarism will be tolerated
Term Project

• All students are required to do group term project
  ‣ 3 students a group at maximum

• You are encouraged to propose your own team projects, and discuss with me the feasibility of your projects

• Modeling/Simulation/Verification/Synthesis/Implementation of some CPS systems

• Something related to your own research.
  ‣ You implement the protocols you designed and then evaluate the performances of your protocols in real systems or testbeds.

• Real CPS systems, such as
  ‣ WSN, monitoring, security protocols for CPS, real-time control, video-WSN
Possible Projects

1. Passive smartphone authentication/identification
2. Multihop Sensor Networks to control lighting (smart home)
3. Multihop sensor networks to control mobile car, AC of car?
4. Smart mobile health system using portable sensors and smartphones
5. HVAC systems
6. City navigation systems using Smartphone
7. Smart building structure health monitoring
8. Video monitoring systems, integrating sensors and cameras
9. Coexistence of different wireless communication technologies
10. Privacy issues in CPS (protecting user privacy in smart grid)
11. CPS for electric vehicles (charging predication and scheduling)
12. Data cleaning and aggregation for crowdsourcing systems
13. Incentive mechanisms for crowdsourcing systems
Project deliverables

- 2 page project proposal by the end of the 4th week (September 9th).
- 15-20min presentation at the middle of the semester to introduce your project (September 23).
- 15-20min presentation at the late weeks of the semester to demo the progress of your project (October 28).
- 15-20min presentation at the end of the semester to demo the final results of your project (November 25th).
- 8-15 pages paper in IEEE conference format (thus counted as term paper for team project).
  - The paper is due on November 29th.
Project Grading

A successful project paper should be of the order of a conference paper. In particular, the following four aspects of a paper were considered in project grading:

1. Project has a clear **goal**
2. Goal has a clear **value** if achieved
3. There are **novel** ideas involved in achieving the goal
4. These ideas **work**
The presentation dates are:

1. Project Kickoff Presentation: {September 23},
2. Technical Paper Presentation: {October 14, 21, November 4, 11, 18}, and
3. Project Mid-stage Presentation: {Oct 28},
4. Final Project presentation {November 25th}

The Technical paper presentation:

- EACH student has to do one technical paper presentation. The paper is selected from the list of papers provided by me (or approved by me)
- The selection of the paper from the list is first-come-first-service. No TWO students are allowed to select the SAME paper. Send me your selection of the paper no later than September 16th, 2013.
Technical Paper presentation

• Besides the PPT presentation, you need to read several papers related to the one you read and present
  ▸ Check the most recent conferences and journals for related papers
  ▸ Check news reports also

• You also need to submit a written summary about the papers you read (within 1 week of your presentation)
  ▸ The summary is about 5 pages in IEEE format.
  ▸ See the following link on how to write a good summary paper
Remote Students

• You are still encouraged to do team projects
  ‣ But not required for remote students
  ‣ You can do individual programming project

• Your presentation will be played on the empty slots that are not reserved by other students or groups.

• If you do individual term project
  ‣ You still need to write a term paper that successfully addressed some research questions.
  ‣ Your project still need to work!
  ‣ You can do some scaled-down project that should be finished in time!
For Programming Projects

• **Presentation Kickoff**
  - What is your proposed project?
  - Define clearly the goal of your project and what we should expect from your project.
  - The background and literature review of existing projects related to your proposed project.
  - The possible challenges in implementing your projects.
  - The possible design and implementation approaches.

• **Presentation Mid-Stage**
  - Explain your design. Discuss design alternatives, Computer science and cyber-physical system aspects of your project, such as algorithms, choice of programming languages, software architecture, development tools, testing, etc;
  - The current status of your project;
  - The possible challenges faced by your group in implementing the project;
  - Management aspects such as your project plan, critical paths, means of team communication (e-mail, chat room, meetings, version control system).
For Group Projects (2)

• **Presentation Final:**
  - Explain your design. Discuss design alternatives, Computer science and cyber-physical system aspects of your project, such as algorithms, data to show the performance of your systems, system architecture.
  - The challenges faced by your group in implementing the project and how you address these challenges;
  - Results achieved in your project, and comparisons with state of the art
  - Lessons learned from the project, and future plan for the project.
  - Management aspects such as your project plan, critical paths, means of team communication (e-mail, chat room, meetings, version control system).
  - Any business potential for your project?
What Projects?

Application oriented project
• Target end-users

Research oriented project
• Target research challenges
Guidelines for Projects:  
1) Application-led research

What makes good application-led research?

Picking research problems

Computer Science issues in Cyber-Physical Systems
Defining Application-Led Research

- Application-Led Research
  - Driven by domain problem
  - Evaluated by quantifying benefits brought to domain

- Technology-Led Research
  - Not necessarily motivated by potential domain benefits
  - Interesting or challenging from a technical perspective

- Research Goals Should (do you agree?)
  - Identify users’ problems and application requirements
  - Provide infrastructure developers with application requirements
  - Validate technology and provides insights into its use
Selecting Your Projects

- Will this change the way people think?
  - If nothing changes after your research, what’s the point?

- Must make an impact on computer science
  - Just impacting biology or civil engineering is not enough
  - Starting from scratch can make this more difficult or easier

- If system building, what will you learn from it?
  - There must be an important question in there!
    - You need identify IMPORTANT research question in your project before or during your project

- Identify and attack “severe and persistent problems”

- Avoid trivial “proof-of-concept” research projects
  - Team up with domain experts when selecting problems
  - Make sure there’s a concept and it’s worth proving
Implementing Your Projects

• To start from scratch or not?
  ‣ Benefits?
  ‣ Drawbacks?

• Is building reusable infrastructure worth it?
  ‣ Research community values novelty over good engineering
  ‣ Research community doesn’t value pure implementation as research
    • Although implementation is tedious and time consuming

• Reframe the question: What are your options? (Aside)
  ‣ Your efforts can be directed structurally or strategically
    • Structural: change the community so that it values infrastructure
    • Strategic: pick the right topic, and your work will be broadly used (and well referenced)
Evaluating Your Projects

• **Small, lab-scale evaluations**
  - Useful: in the *early* stages of design
  - Insufficient: impossible to understand the impact of
    - Environment on technology
    - Technology on environment
    - Often hard to teach these apart – hence “systems” research

• **Projects are evaluated only against themselves**
  - Self-evaluation is insufficient
  - Requires applications, infrastructure, and data to be shared
    - Is this a good idea?
    - Is it done in other fields?
Recommendations

• **Choose your projects carefully**
  ‣ Address severe persistent problems; avoid trivial ones
  ‣ People care
    • Research community, and industry

• **Share technical infrastructure**
  ‣ Design reusable SW/HW; publicly release code

• **Evaluate your projects in realistic environments**
  ‣ Only way to investigate interactions between tech/env/users
  ‣ “The real world is it’s own best model” – Rodney Brooks

• **Perform comparative evaluations**
  ‣ Release data sets from field trials; allows other to analyze
Guideline for Projects:  
2) Science-led Research Project

• Good science responds to real problems

• Good science is in the details

• Good science makes a difference
Good science/theory responds to real problems

What is the scientific issue in your research project?

- Don’t pick fantasy problems
- Don’t pick trivial “proof-of-concept” problems
- Too many real pressing real-world problems!
- Pick “severe and pressing” problems
Good science/theory is in the details

• Takes the form of a working model
  ‣ The artifact is about understanding, not building
  ‣ Must build when analysis is too complex
  ‣ Brooks’ quote: “The real world is its own best model”

• Includes detailed analysis or implemented models
  ‣ Allows others to benefit from work at an abstract level
  ‣ Enables comparisons between difference approaches
Good science/theory makes a difference

• Measures of contribution:
  ▸ How it solves a real problem
  ▸ How it shapes the work of others

• Solves a real problem
  ▸ The problem sets the crucial context for the work
  ▸ A million ideas to pursue, but which ones are worth doing?

• Shapes the work of others
  ▸ Highest goal: change other people’s thinking
  ▸ Paradigm changes are the most impactful [Kuhn]
  ▸ Lay the foundation of some field, or
  ▸ Summarize the fundamental results in the field
Examples of projects

Application-led project
- Passive-authentication of users with smartphone
- Time synchronization implementation

Science-led project
- Verifiable computing in cloud computing
- Time synchronization protocols
Clock Synchronization—System/Application

- **FLIGHT: Clock Calibration Using Fluorescent Lighting**, (Slides), Zhenjiang Li, Wenwei Chen, Cheng Li, and Mo Li (Nanyang Technological University, Singapore); Xiang-Yang Li (Illinois Institute of Technology, USA); and Yunhao Liu (Tsinghua University, China)
Clock Synchronization – Science/Theory

- **Tight Bounds for Clock Synchronization**
  Christoph Lenzen, Thomas Locher and Roger Wattenhofer.
  Documents: paper [pdf](#)

- **Clock Synchronization: Open Problems in Theory and Practice**
  Christoph Lenzen, Thomas Locher, Philipp Sommer and Roger Wattenhofer.
  Documents: paper [pdf](#)
Semester Schedule

• **Important due dates:**
  - Group Information: Sept 6th.
  - Paper selections/presentation are due by Sept 16
  - Send me the PPT or PDF file of your presentation one week in advance
    - October 14, 21, November 4, 11, 18
  - **Project Proposal due: September 9 at 11:59**
  - First draft of Term paper due: Nov. 7 at 11:59pm
  - Final project due: November 29th at 11:59pm
  - Term paper update due: November 29th at 11:59pm

• **Course arrangements:**
  - As of today, total 37 students registered
  - Students are expected to lead a paper discussion on lecture starting from Oct. 14th.
  - Expect about 3-5 invited speakers from outside the department
  - Final project presentations on **Nov 25th, 26th**
POSSIBLE PROJECTS
CPS for Wastewater Processing
Power Optimization using DO
Medical Usage/ Body Area Networks
BAN– Body Area Networks
Sensor Node Design for Medical Usage
What We Expect

- Shimmer System
- MCU
- Zigbee
- Bluetooth
- Micro SD
- USB
Object tracking using sensor networks or RFID
What we want to do?
Wind Farm monitoring system using sensor networks
Wind Farm
Failure
How they are currently inspected

- Inspecting the drive train with **Vibration measurements**:
  During vibration measurements, information about the condition of **teeths** and **bearings**, **misalignment** of drive train and rotor unbalance will be collected. Vibration sensors are placed on the rotor and the drive train and by monitoring the frequency and amplitude of the vibrations early warning of damage and misalignment can be reached.
How they are inspected

- Inspection of rotor blades

The turbine blades are, due to the constant wind contact, highly stressed parts and have to be inspected regularly by experts. However, the current inspection techniques are only very rough and limited to visual inspections and manual tapping tests, which require a highly experienced expert and are not able to detect internal damages at an early stage.

Modern wind turbine blades mainly are built from fiber reinforced plastics combined with either glass fiber reinforced plastics (GFRP) or carbon fiber reinforced plastics (CFRP). GFRP is cheaper than CFRP, thus preferred.
Health Monitoring of Blades

Damages in wind turbine blades:

- Fatigue: The leading edge has to stand the wind forces and the gelcoat is eroded and water and UV-radiation is able to infiltrate and weaken the GFRP.

- Manufacturing errors: Manufacturing errors are difficult to be detected by monitoring system since they are in the blade from the outset.
Coordinated automatic car driving

Leading car driven by driver; other cars use radars, communications and swarm intelligence to follow
Smart camera and networks

Weijia Jia, City U HK & Shenzhen
House Safety Alarm

- Surveillance alarm can dial up a 3G phone when any abnormal scenario is detected;
- making the video record and keep checking via 3G cell phone.
Smart Grid
Sensors, Computing, Communication
Mobile Crowdsensing

iPhone 4: Camera, audio, GPS, accelerometer, Gyroscope, Compass, Proximity, ambient light

Intel’s sensor for air quality

Bluetooth to mobile phone

ECG enabled mobile phone

iPhone 4

User contributed change shortens a route
Users improve map quality

Resolving circled areas: Intersections? Bridges? Blocked?
Vehicle Networks

- communication protocols for delivering timely information to drivers in a cost-effective manner;
The vision = simple vehicular cloud
Security Protocols for Various Sensor Networks
Topics

- Data Encryption
- Signature and Data Authentication
- Hash Algorithms, AES, DSA and so on
- Key Management
- Local file encryption
- Access Control
Dynamic Programming Protocols for Large Scale Sensor Networks
Topics

• **When we need to update code for sensor nodes**
  - Do it wirelessly
  - Need to optimize the code
  - Need to optimize the energy cost, memory cost
  - Need to ensure the stable system transition

• Existing protocols:
  - Deluge, de facto
Localization Protocols for Large Scale Sensor Networks
Topics

• **Find the locations of nodes**
  
  ▶ Using small number of anchor nodes
  
  ▶ Good accuracy
    • Indoor, outdoor
    • Large scale, small scale?
    • Centralized, distributed
    • Static network, mobile network?