Real-time and Cyber Physical Systems

http://courses.engr.illinois.edu/cs424/

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Dept. of Computer Science

University of Illinois at Urbana Champaign

Logistics

- **Instructor**
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  4126 Siebel Center
- zaher@illinois.edu

A Little About Me

- Ph.D. in QoS Adaptation in Real-Time Systems, Department of Computer Science, University of Michigan, 1999.
- 1999-2005: Assistant Professor, Department of Computer Science, University of Virginia.
- 2005-now: Professor, Department of Computer Science, University of Illinois at Urbana Champaign
- Research Interests: Embedded Systems, Real-time Computing, Cyber-physical Systems, Social Sensing

Where and When

- **Lecture Times**

  Tuesdays and Thursdays, 2:00-3:15pm,
  1109 Siebel Center

Grading

- Participation: 10%
  - Assigned for individuals' attendance, quizzes, and discussion
- Homework: 15%
  - Assigned for 4 homeworks
- Programming Assignments: 25%
  - Assigned for 4 team programming assignments
- Midterm #1: 15%
  - Assigned for an open-book in-class midterm
- Midterm #2: 15%
  - Assigned for a second open-book in-class midterm
- Final: 20%
  - Assigned for an open-book final.

4th Credit Project

- Graduate students are expected to take this course for 4 credits
  - 4th credit unit: Group project with the purpose of delivering an interesting and novel real-time service

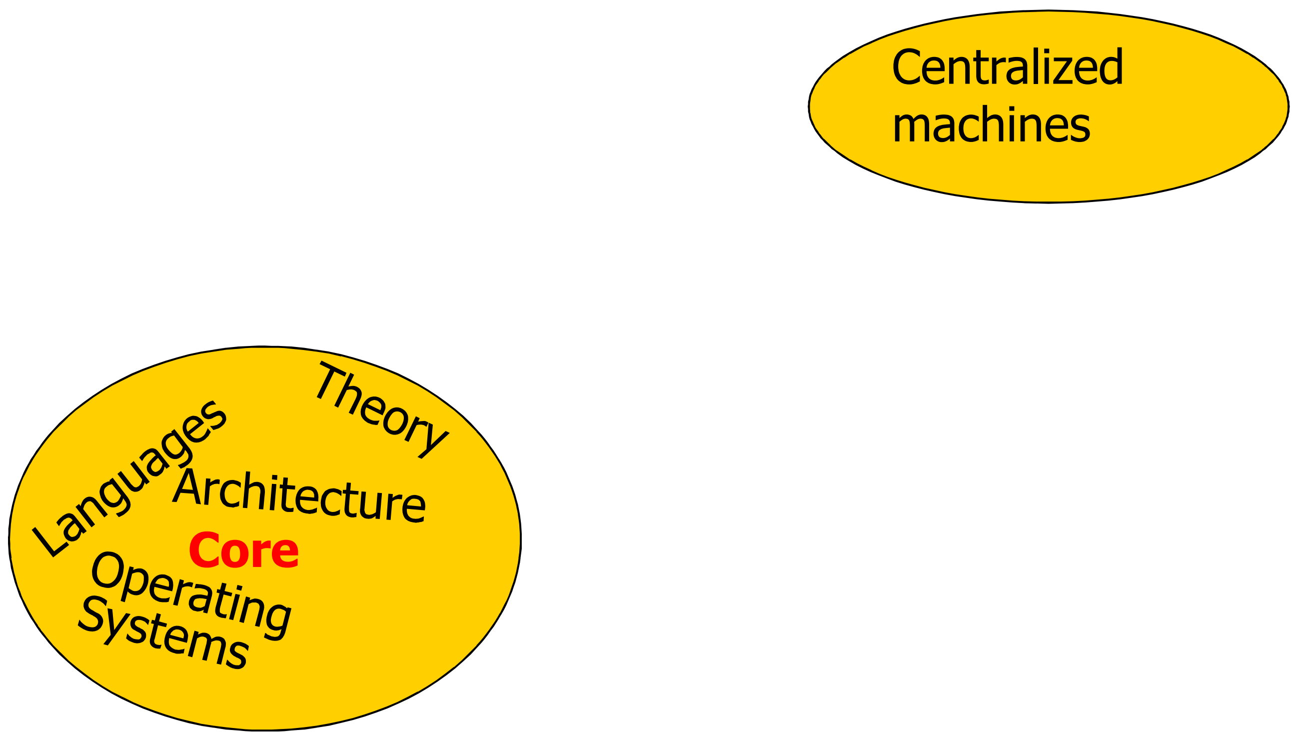
Schedule

- See Website:

http://courses.engr.illinois.edu/cs424/

Where is Computer Science Research Going?

The beginning:



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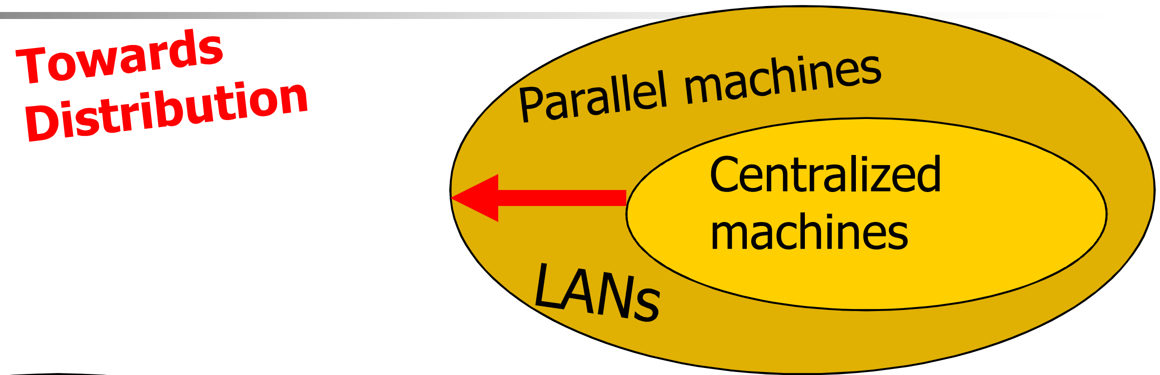

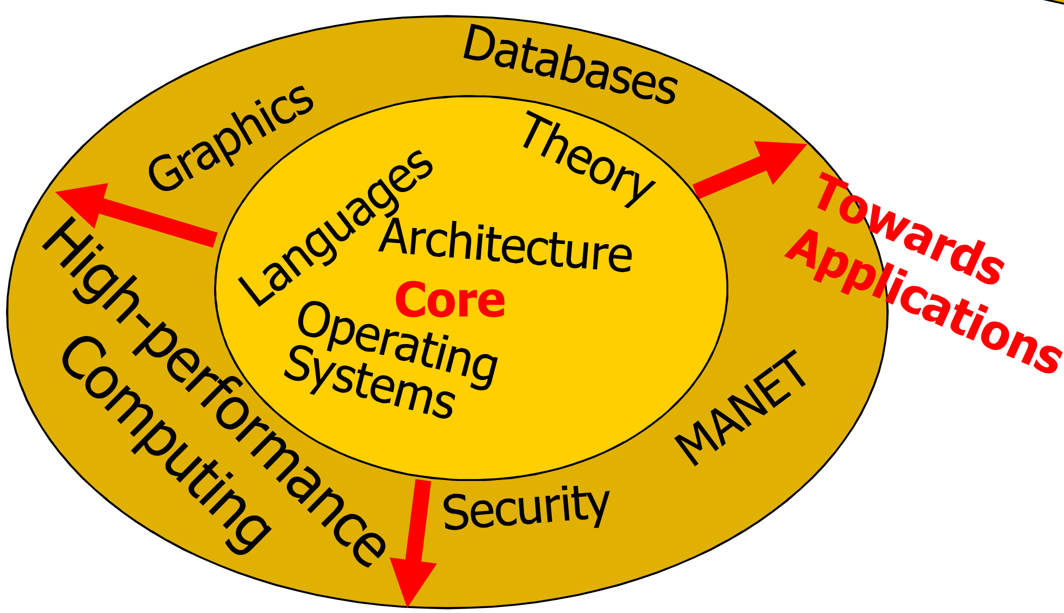

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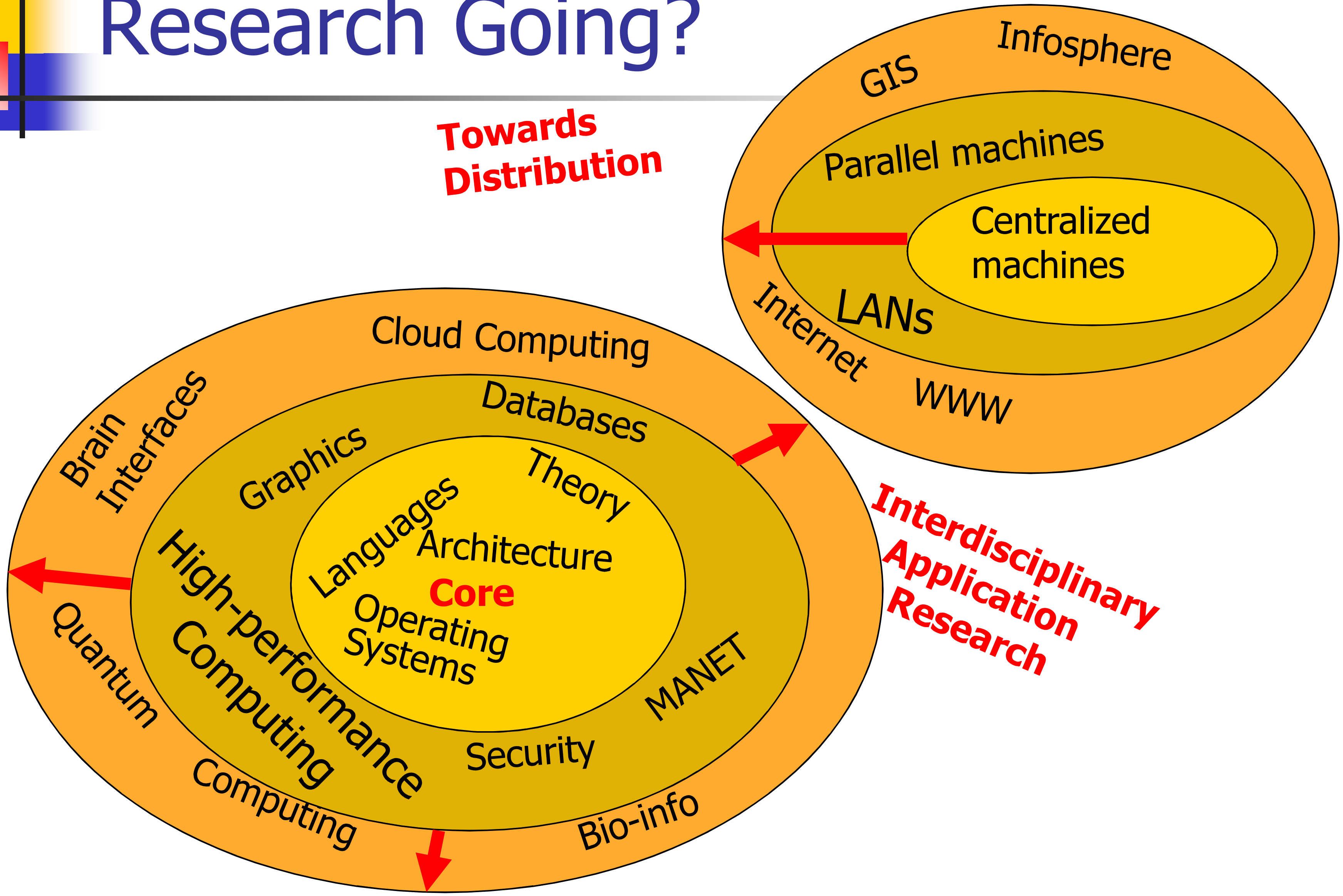

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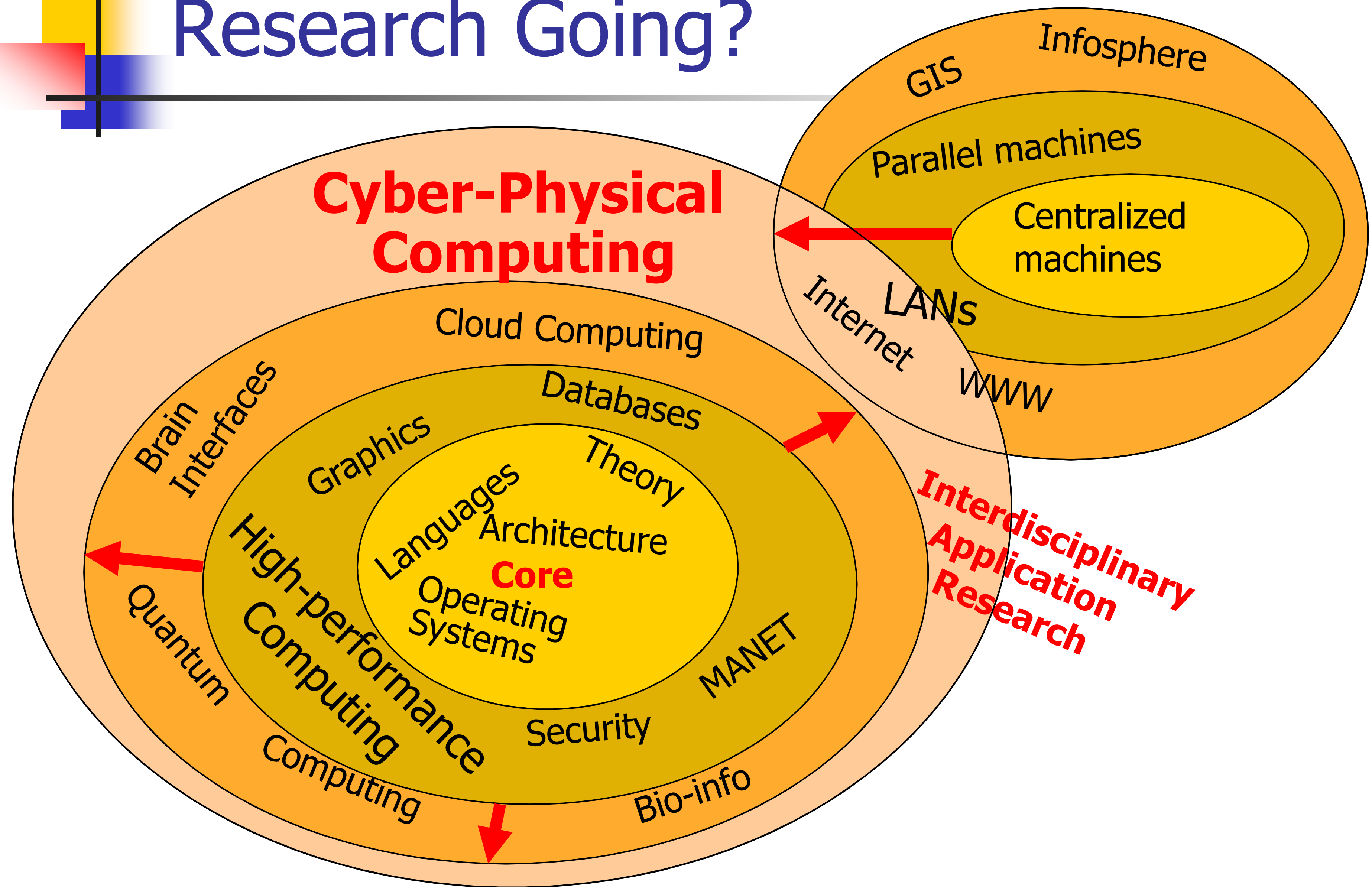

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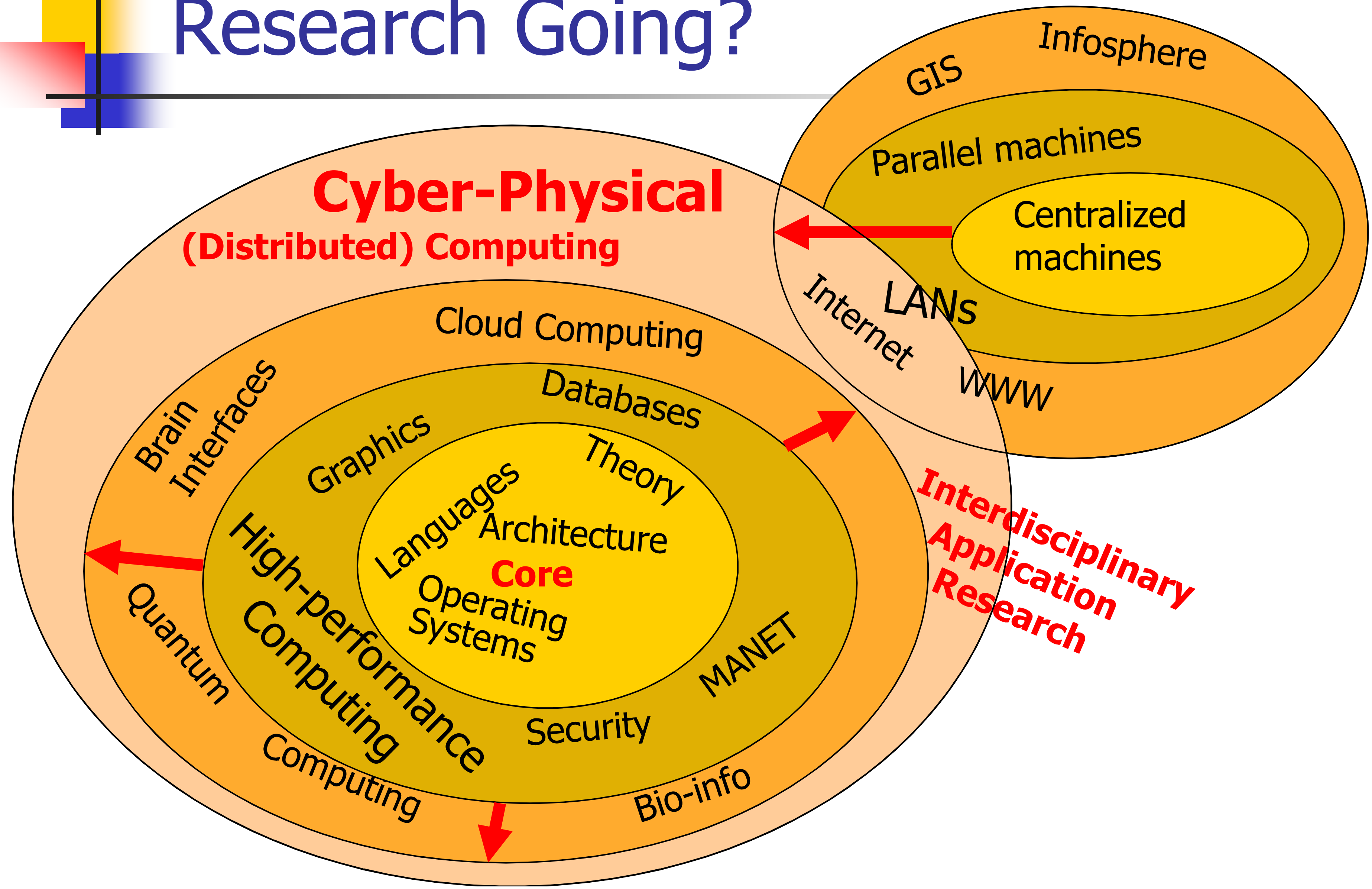
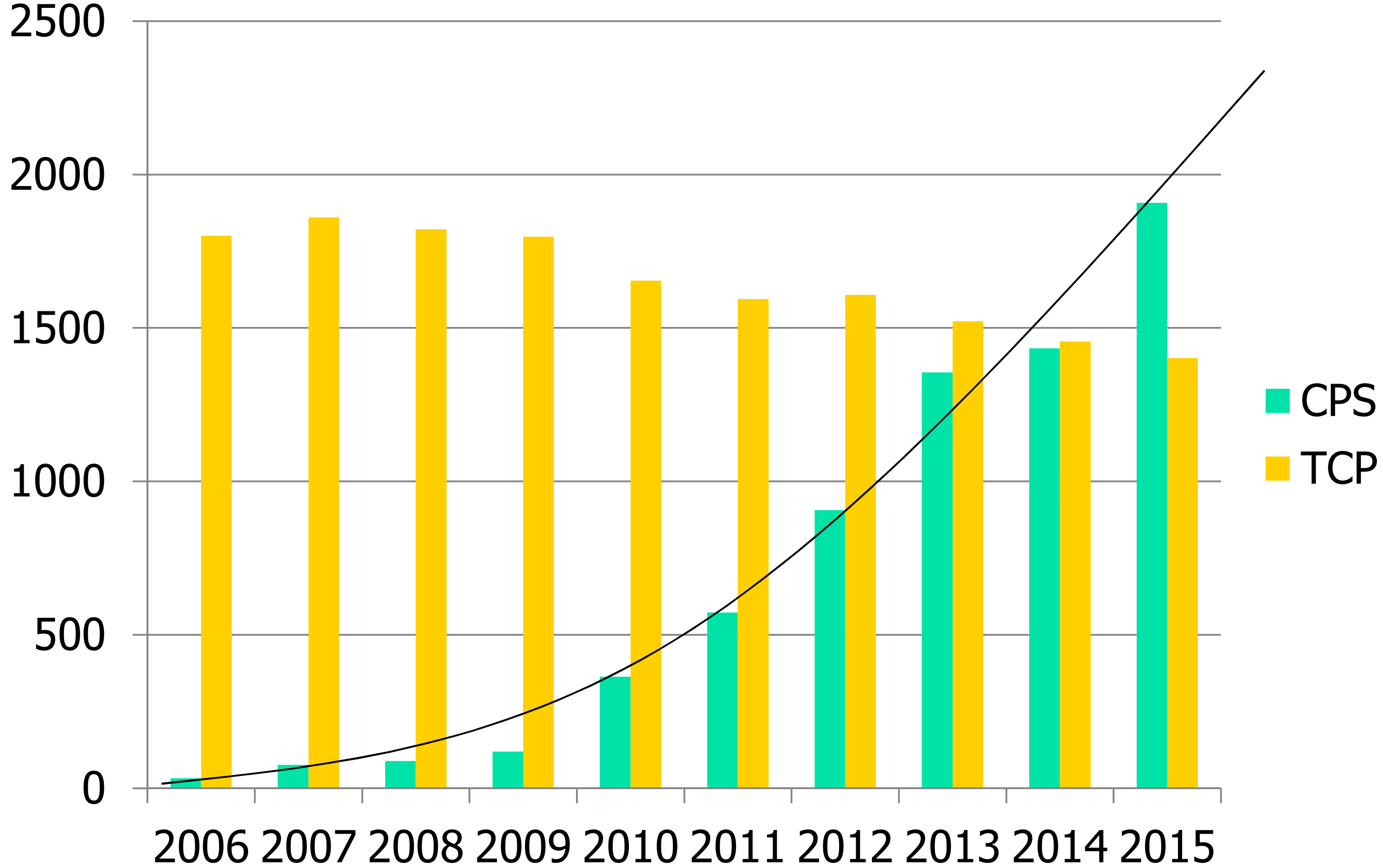
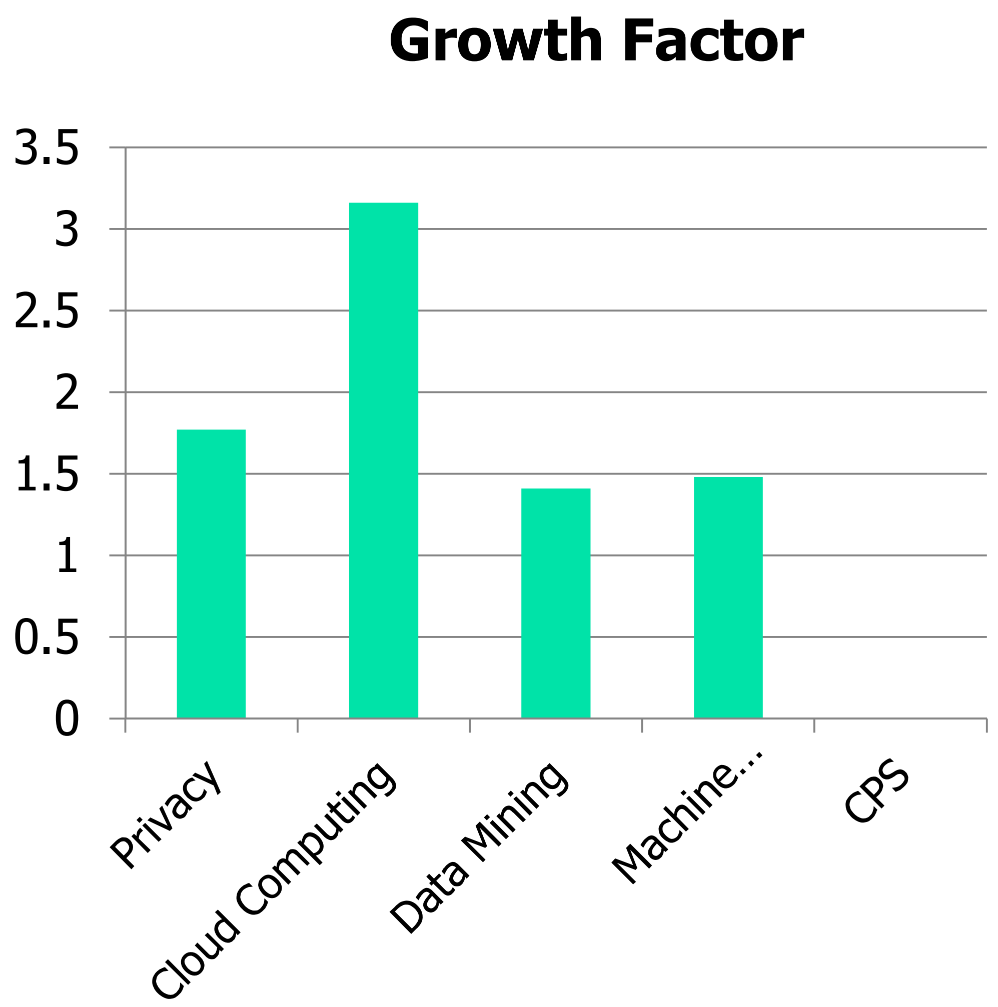


Keyword Trends (On Compendex)



Keyword Trends (Continued): 2015/2010 Multiplicative Factor



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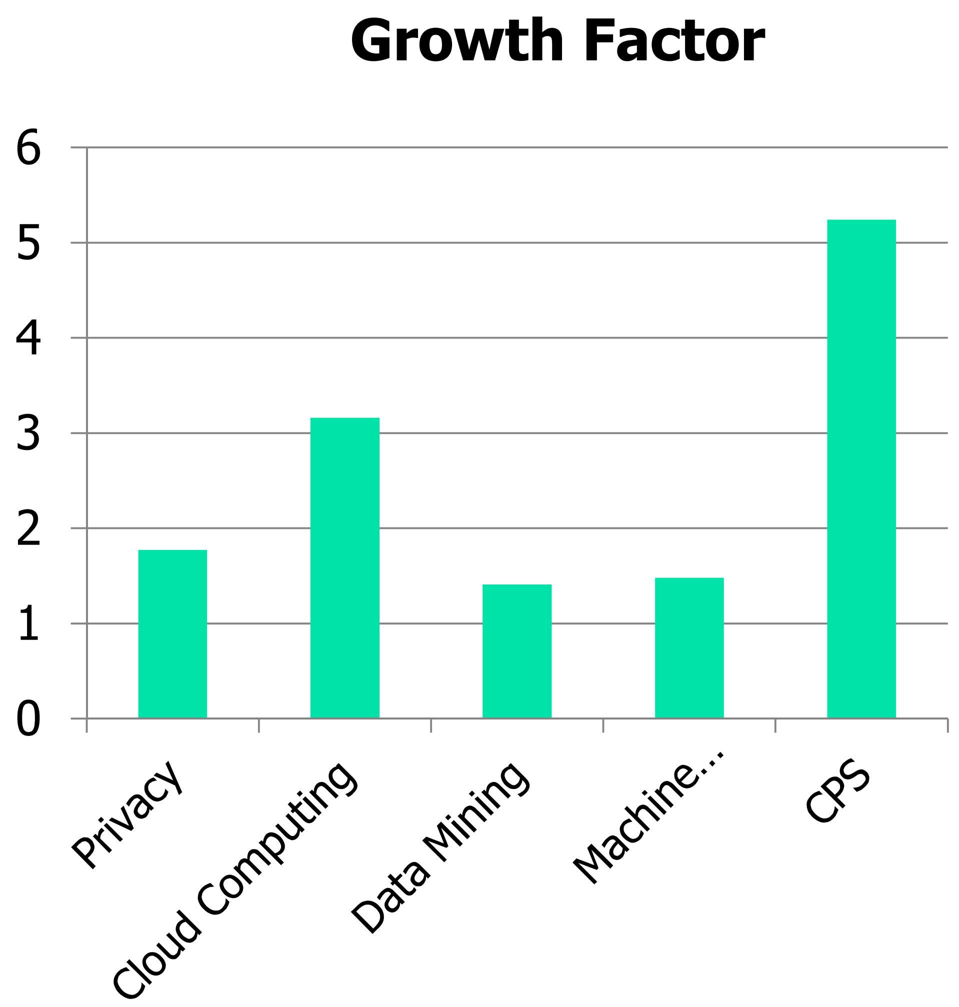
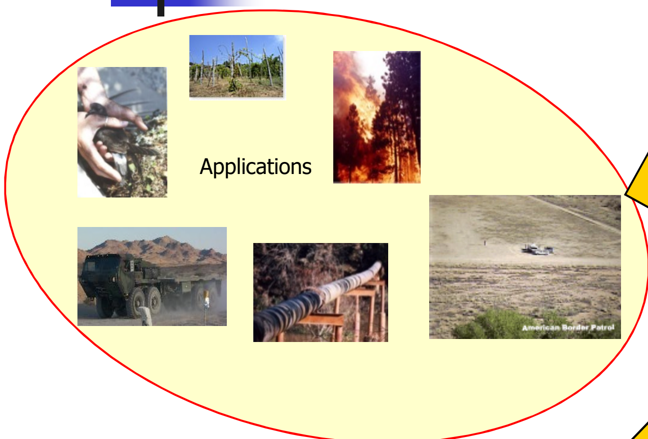


Force #1: Device proliferation

Cyber Physical Networks



"Classical"
- Unattended multihop ad hoc wireless

Medical

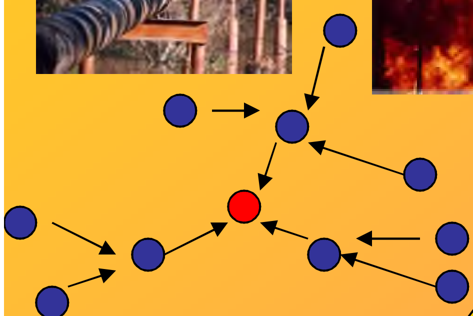
Ubiquitous Computing

Industrial
- Single-hop: monitor cargo, machinery factory floor, …
- Send to base.

Force #2: Integration at Scale
(Isolation has cost!)

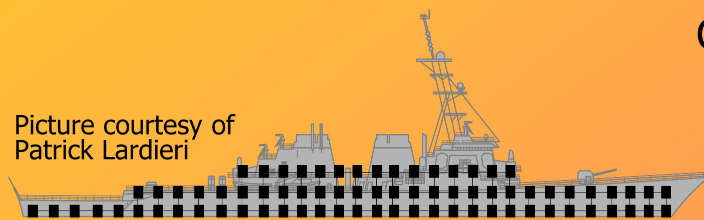
- Low end: ubiquitous embedded devices
  - Large-scale networked embedded systems
  - Seamless integration with a physical environment

- High end: complex systems with global integration
  - Examples: Global Information Grid, Total Ship Computing Environment



World Wide Sensor Web
(Feng Zhao)

Picture courtesy of
Patrick Lardieri



Total Ship Computing Environment
(TSCE)

Global Information Grid

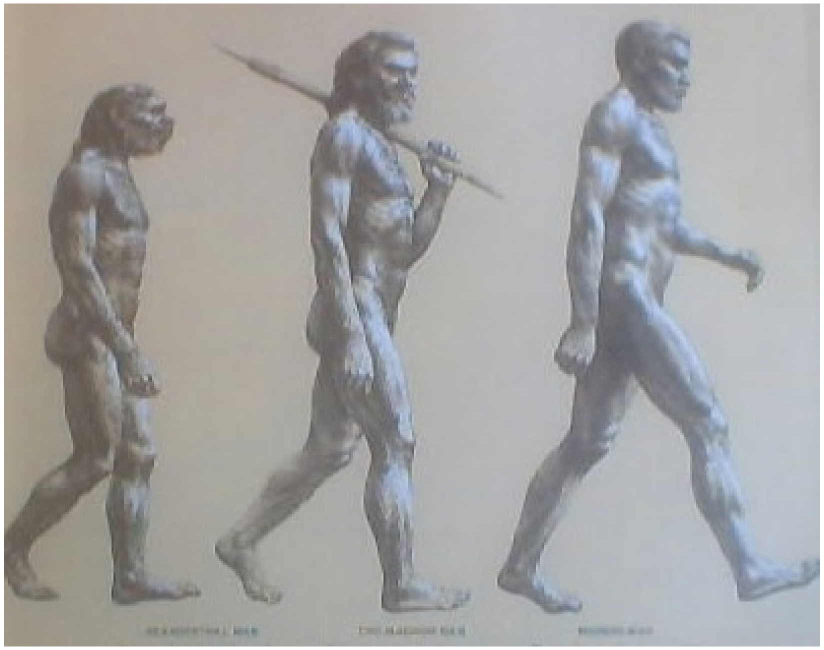
Future Combat System
(Rob Gold)

Integration and Scaling Challenges

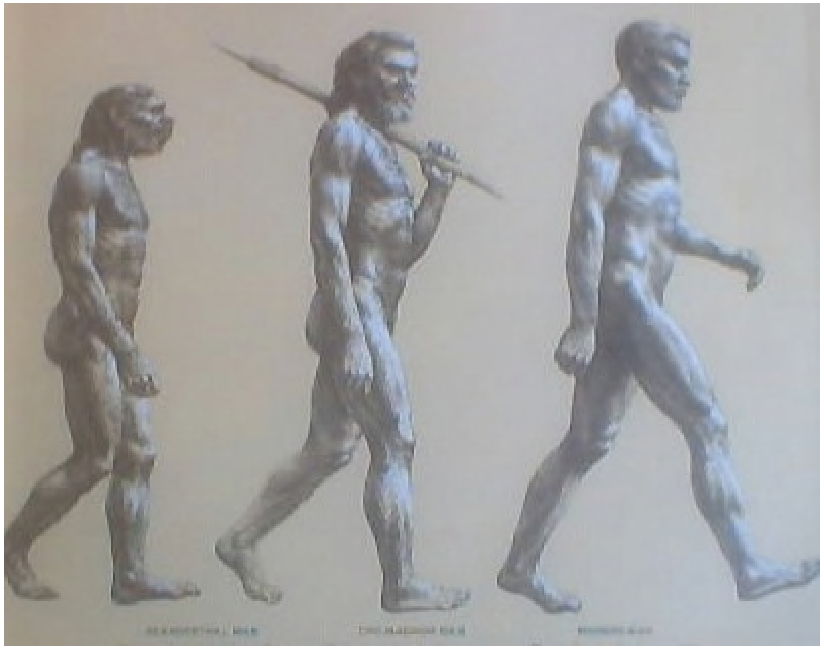
Low End

High End

Force #3: Biological Evolution



Force #3: Biological Evolution

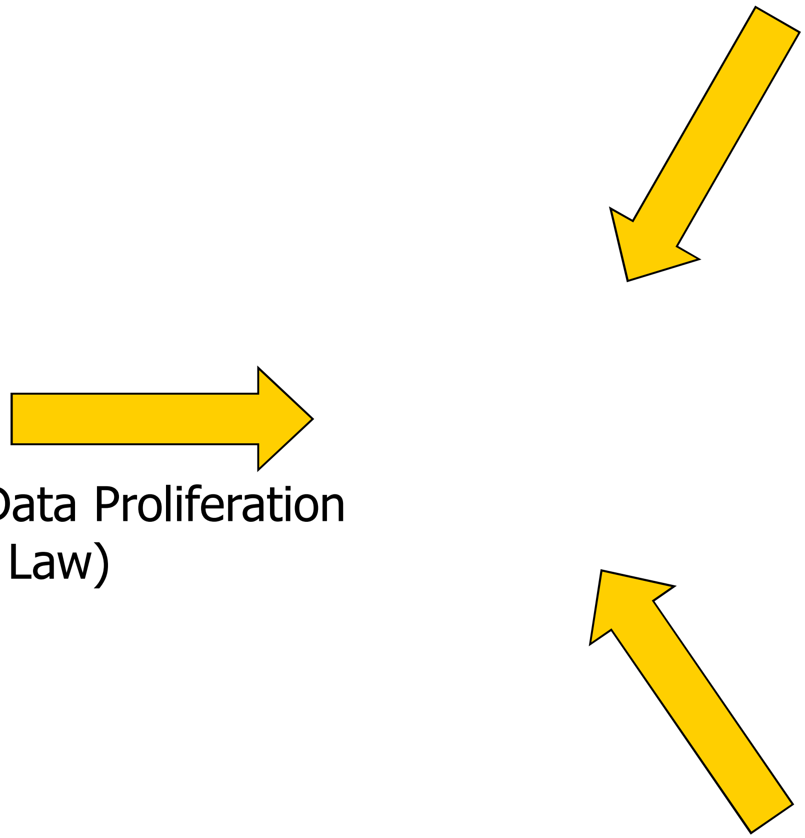


- **It's too slow!**
  - The exponential proliferation of data sources (afforded by Moore's Law) is ***not*** matched by a corresponding increase in human ability to consume information!

→ Increasing focus on information distillation and automation to support decision making

Confluence of Trends
The Overarching Challenge

Trend2: Integration at Scale
(Isolation has cost)



Trend1: Device/Data Proliferation
(by Moore's Law)

Trend3: Relative Autonomy
(Humans are not getting faster)

Confluence of Trends

The Overarching Challenge

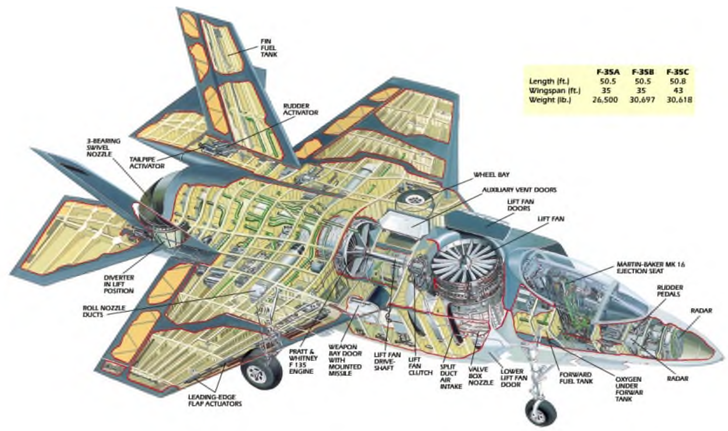
Trend2: Integration at Scale
(Isolation has cost)

Core Challenges:
Distributed CPS +
Information Distillation

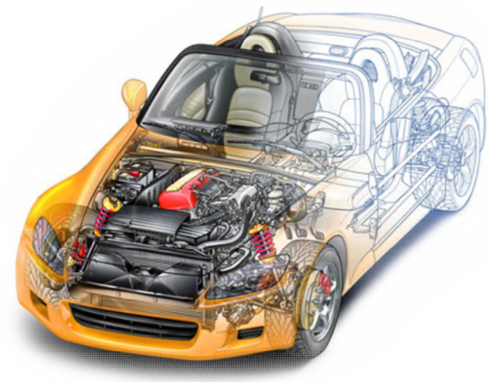
Trend1: Device/Data Proliferation
(by Moore's Law)

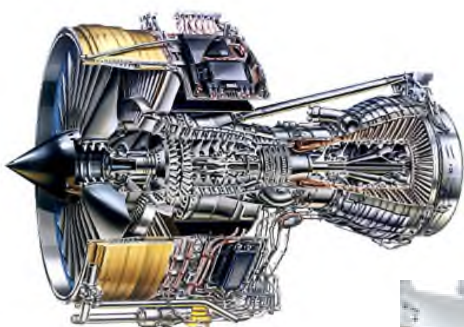
Trend3: Relative Autonomy
(Humans are not getting faster)

Traditional Embedded Computing (Cyber+Physical)



Embedded Computing Systems

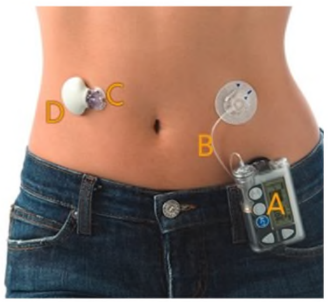




Emerging Directions

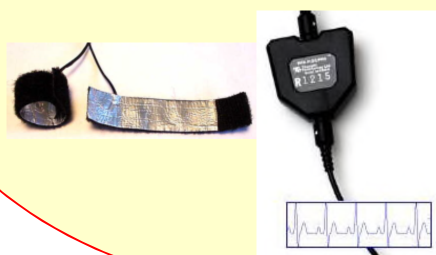
Distribution,
Humans in the Loop,
"Big" Data from the Physical World

CPS Applications – Medical



Medical
Insulin pumps, pacemakers, glucose monitors, …

Bio-feedback Sensors



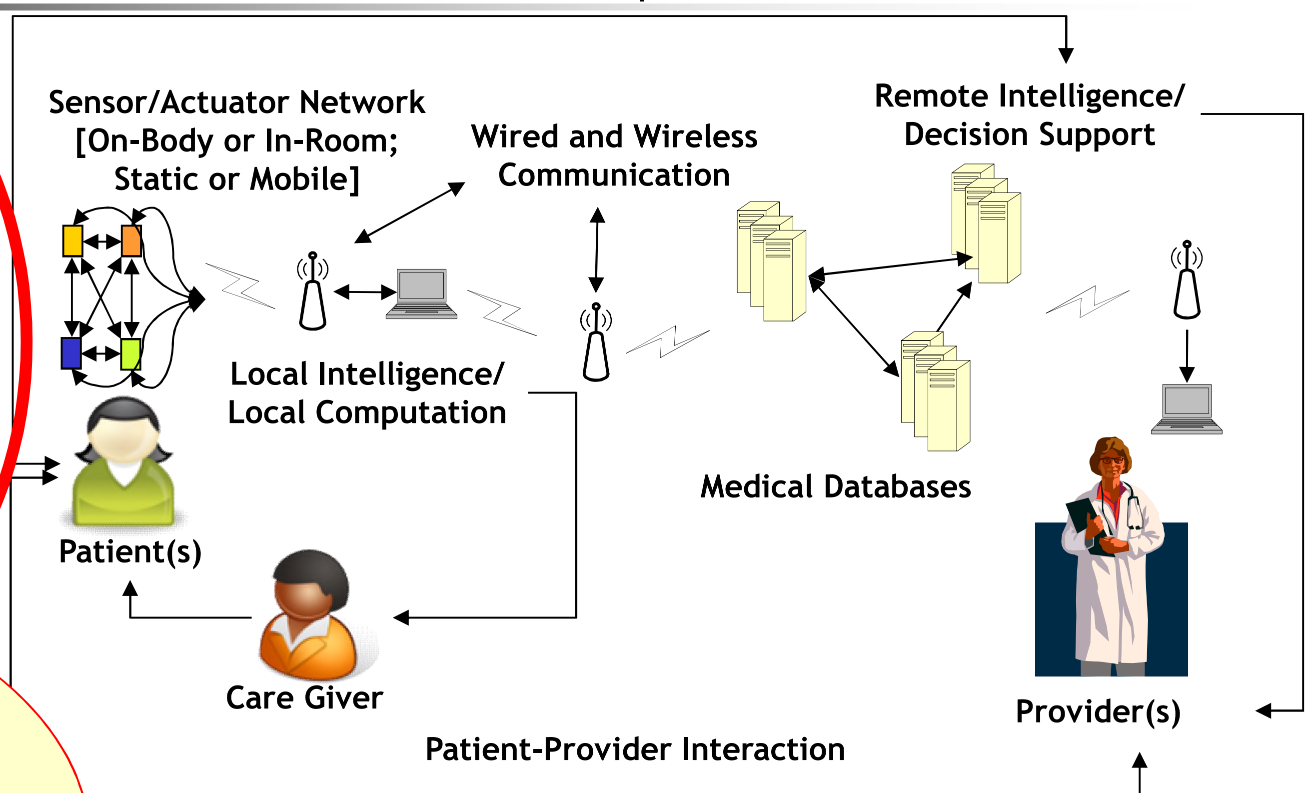
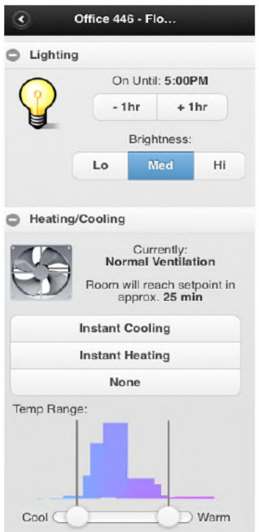
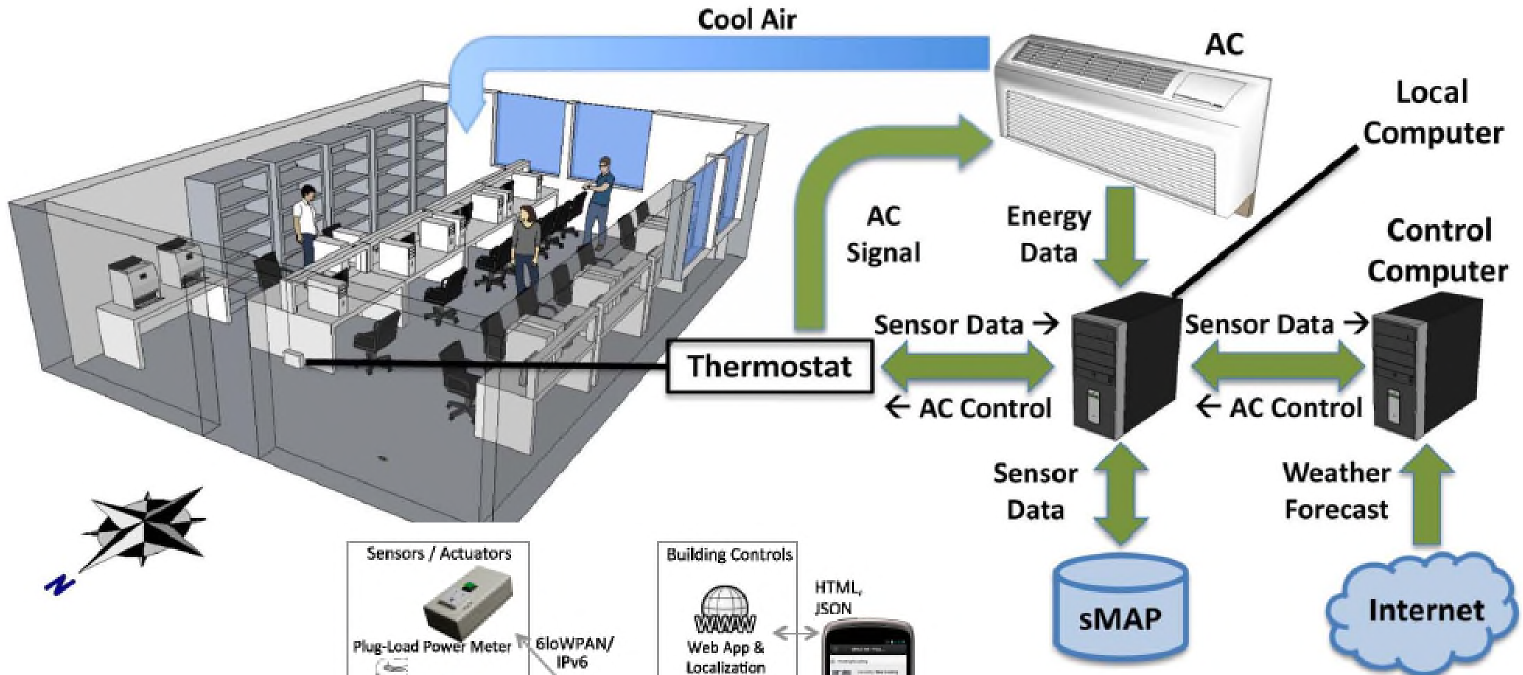


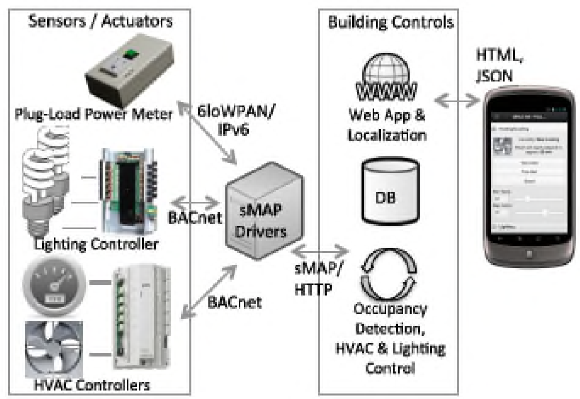
Figure courtesy of Mark Spong and Bill Sanders

Medical

CPS Applications – Energy





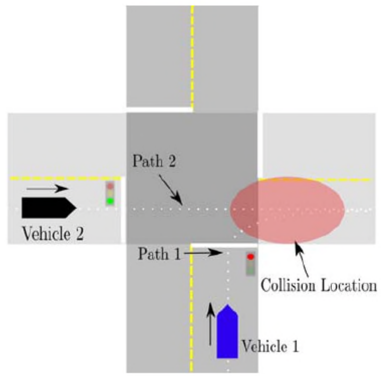


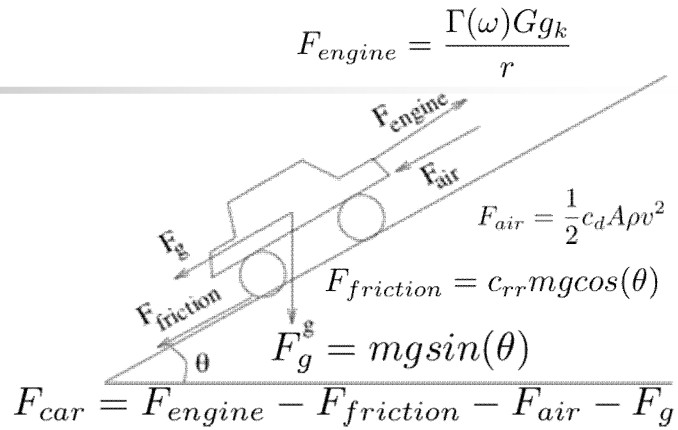
Figures courtesy of Berkeley BRITE Lab

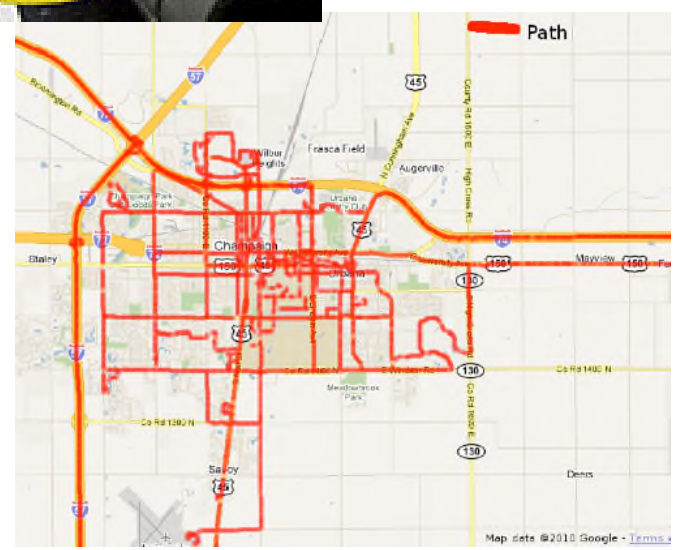
Zero-energy Building: Science House at the Science Museum of Minnesota

Residential Energy

CPS Applications – Transportation



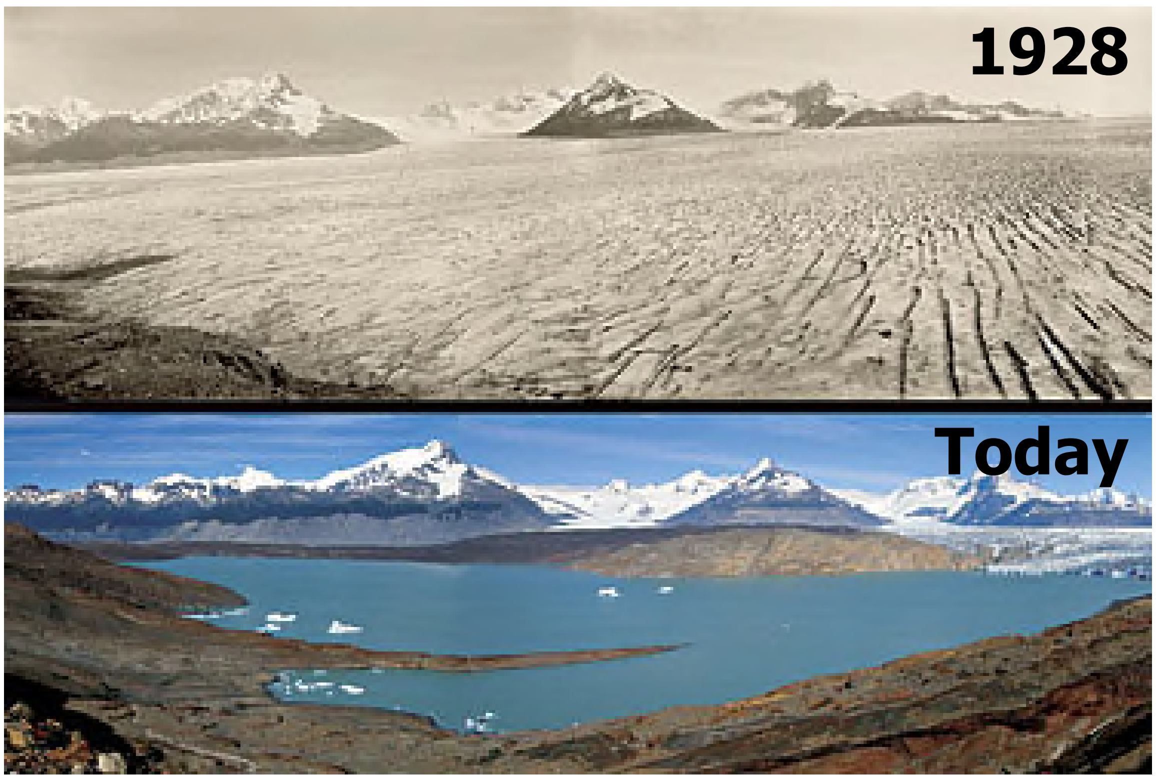


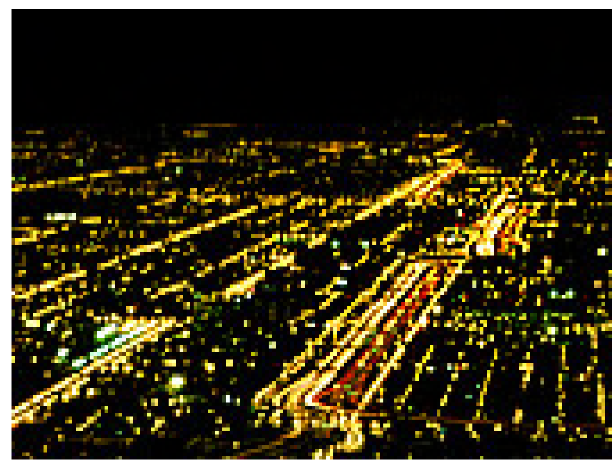


Transportation

CPS Applications – Sustainability

Upsala Glacier (Time Magazine, Special Issue on Global Warming, March 26, 2006)





Sustainability

What Do CPS Systems Have in Common?

The need for reliability/correctness: If system fails, bad consequences will occur (restarting a crashed computer is annoying, but restarting a crashed computer in a medical robot performing a surgery can be life-threatening)

- Software correctness
- Data correctness
- Timing correctness

The Safety/Performance Trade-off in CPS

Performance: Exploring the edge of feasibility

Robustness: Guaranteeing delivery in the face of adverse conditions

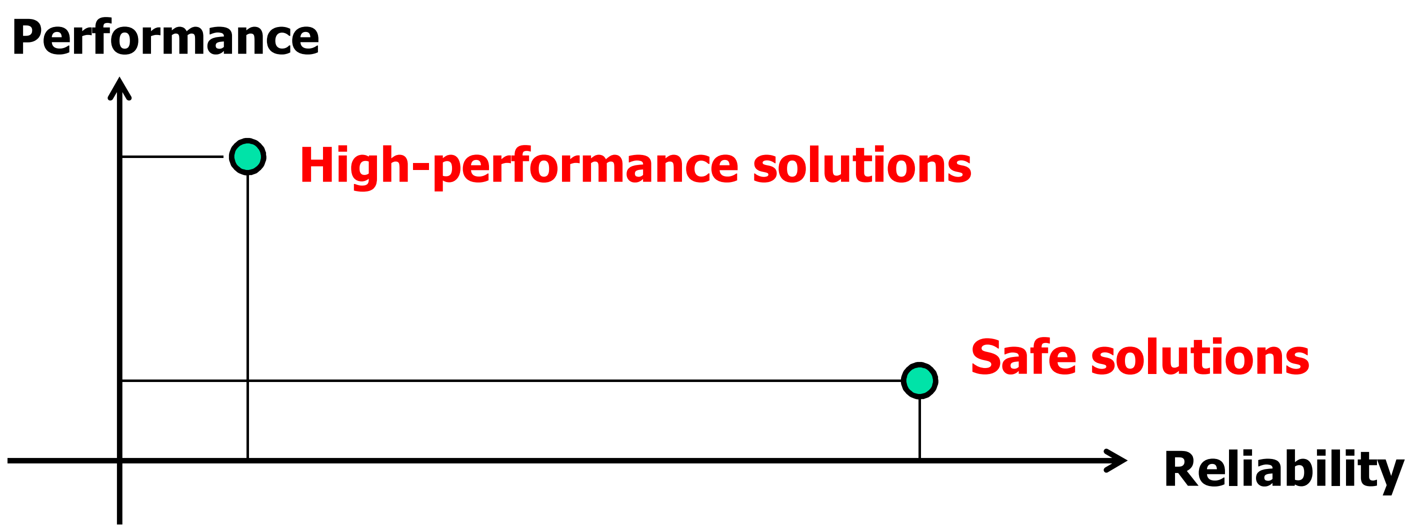
The Safety/Performance Trade-off in CPS

Performance: Exploring the edge of feasibility *(often in the presence of high complexity)*

Robustness: Guaranteeing delivery in the face of adverse conditions *(implying simplicity to ensure predictability)*

The Safety/Performance Trade-off in CPS

- *Safe* solutions and *high-performance* solutions are in different regions of the design space



Important CPS Problem
“Safety + Performance” Architectures

- Architectures and design paradigms for combining safety and high performance will play an important role in CPS

Lab

- Build software for a human-controlled robot that ensures safe operation!

Important CPS Problem
Real-time Scheduling

- Resource scheduling policies that ensure meeting time constraints of applications

Important CPS Problem
Energy

- Embedded devices are often battery powered or energy limited. Saving energy becomes important.

Important CPS Problem
Data Reliability

- How to determine the level of noise in the data that the system operates on? This is of increasing importance in new applications that rely on crowd-sourcing

Emergence of Social Sensing

Information Services for a Smarter World

People

Sensors

Analytics

Data

Future Applications

Social Sensing (Crowd-sensing) Humans + Cyber + Physical

http://www.golem.de/news/crowd-management-smartphone-soll-massenpanik-verhindern-1209-94331.html

http://vimeo.com/album/2020385

Ensuring safety of pilgrims during Hajj
http://www.crowdsensing.net/crowdsensing/

http://asmarterplanet.com/studentsfor/blog/category/transportation-systems

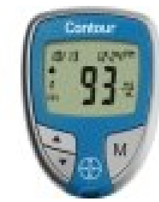
Social Sensing:
A Confluence of Three Trends

Mass Dissemination Media

Sensors

Cell-phones

Cars on Internet



Glucose monitor

GPS

Sportsware

Smart Meter

Pulse oximeter

Game Consoles on Internet

Connectivity

Towards Information Distillation Services

- Much like Google organizes (relatively static) world content, we need an engine for organizing real-time/streaming data feeds and:

Reconstructing the "State of the World", Physical and Social!

A firehose of text, images, video, sound, and time-series data

Information distillation

Clean structured representation, high quality of information

Application Example: Disaster Response

Japan’s Tsunami and Nuclear Event (2011)

Other Applications
Zero Energy Buildings

- How can computing help?

Environmental Technology Center at Sonoma State University

Science House at the Science Museum of Minnesota

Aldo Leopold Legacy Center

Oberlin College Lewis Center

Hawaii Gateway Energy Center

Other Applications: Smart Grid

- Connecting millions of intermittent sources?