# Real-time and Cyber Physical Systems

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

Tarek Abdelzaher

*Dept. of Computer Science*

*University of Illinois at Urbana Champaign*

# Logistics

- **Instructor**
  Tarek Abdelzaher, 4126 Siebel Center,
  Tel: 265-6793
  Office Hours: Fridays, 11am-noon, 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. The 4th credit unit can be received for either of the activities below:
  - Survey on a real-time topic of choice
  - Novel capability involving robotic vision, navigation, or human-machine interface

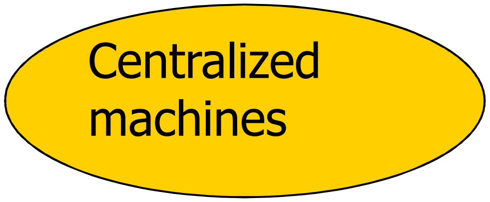
# Schedule

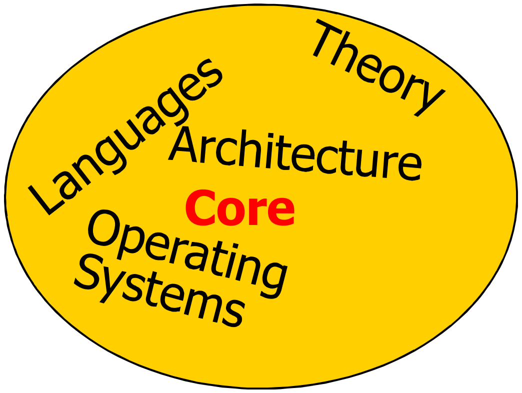
- See Website:

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

# Where is Computer Science Research Going?

The beginning:



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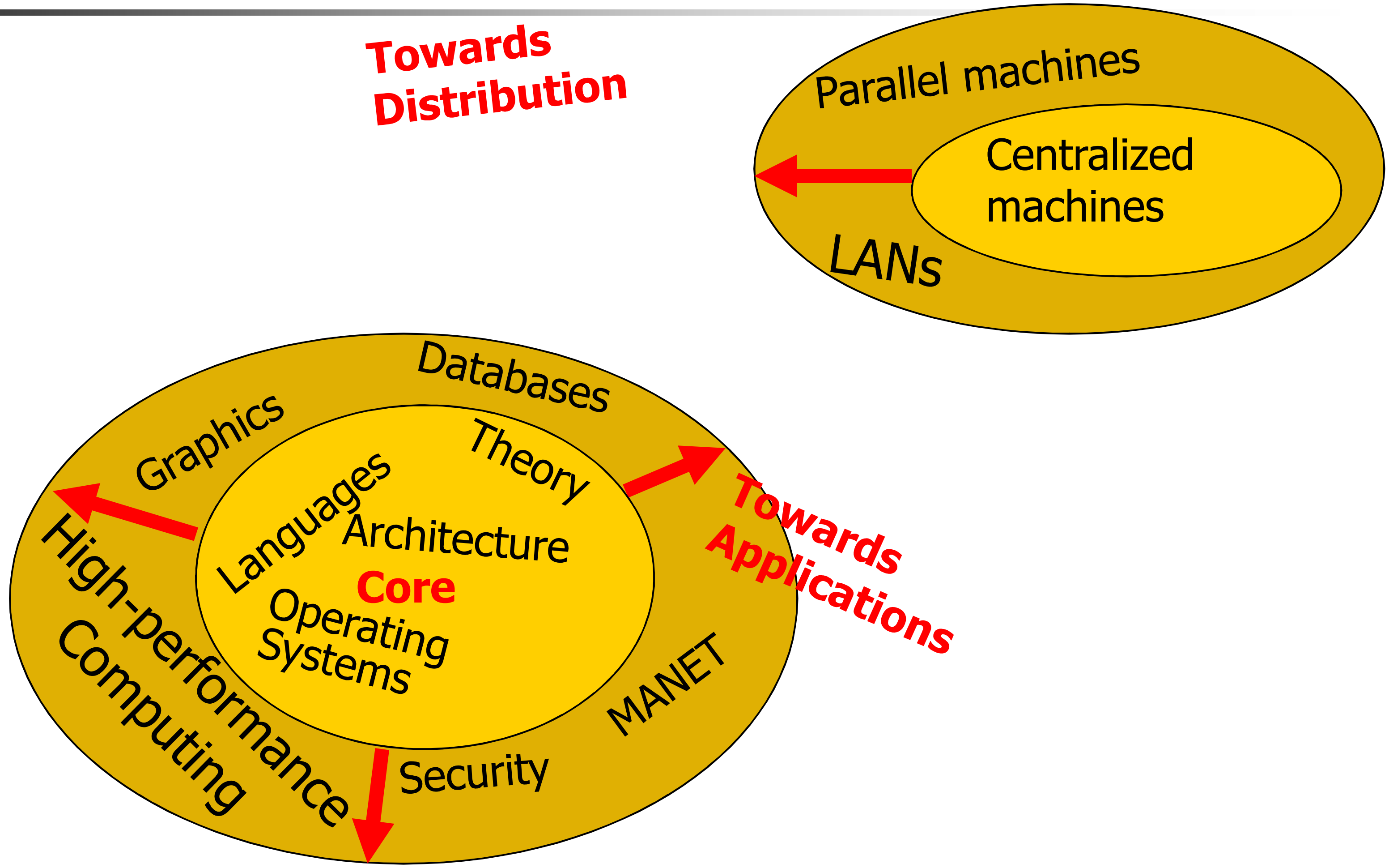

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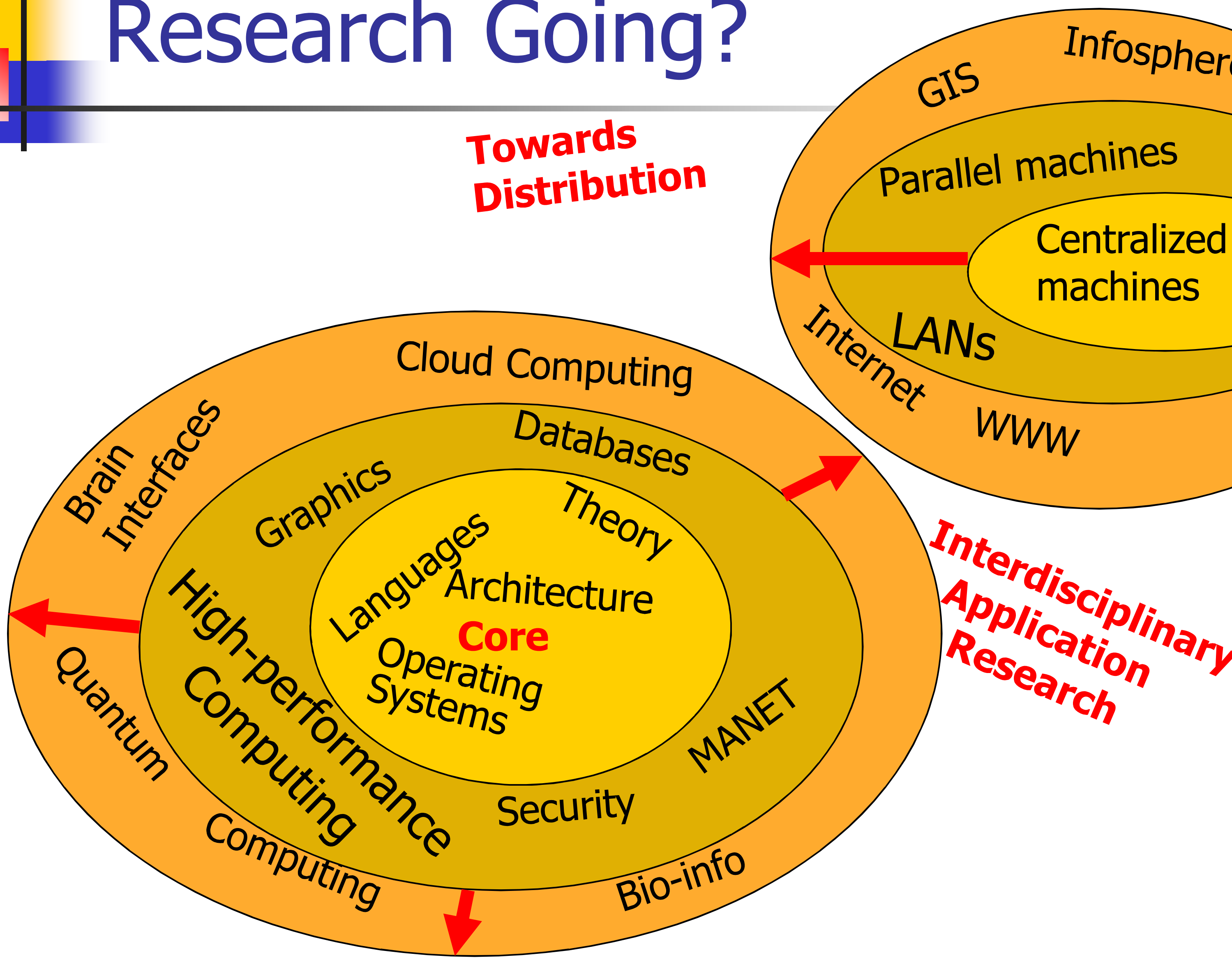

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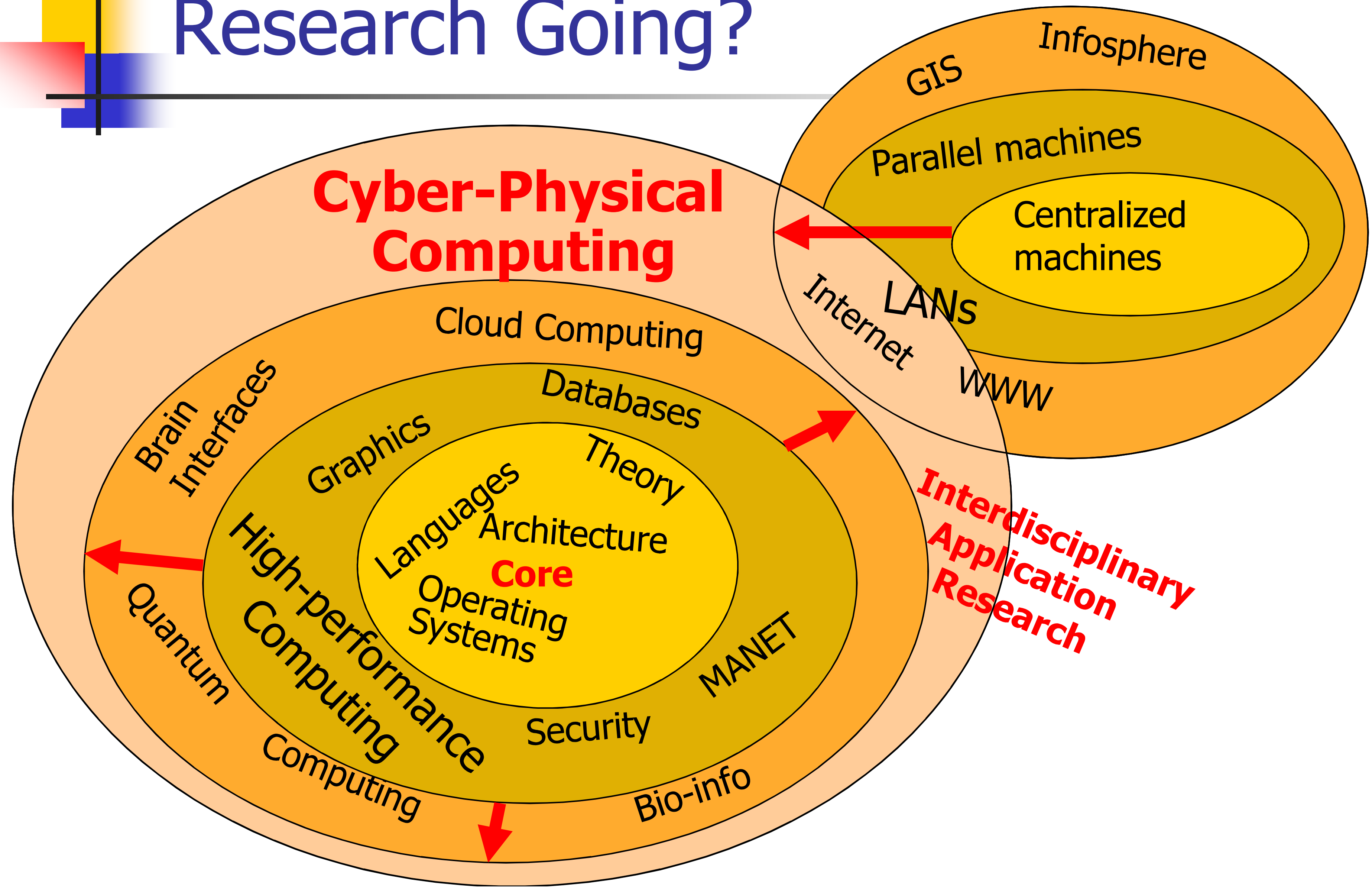

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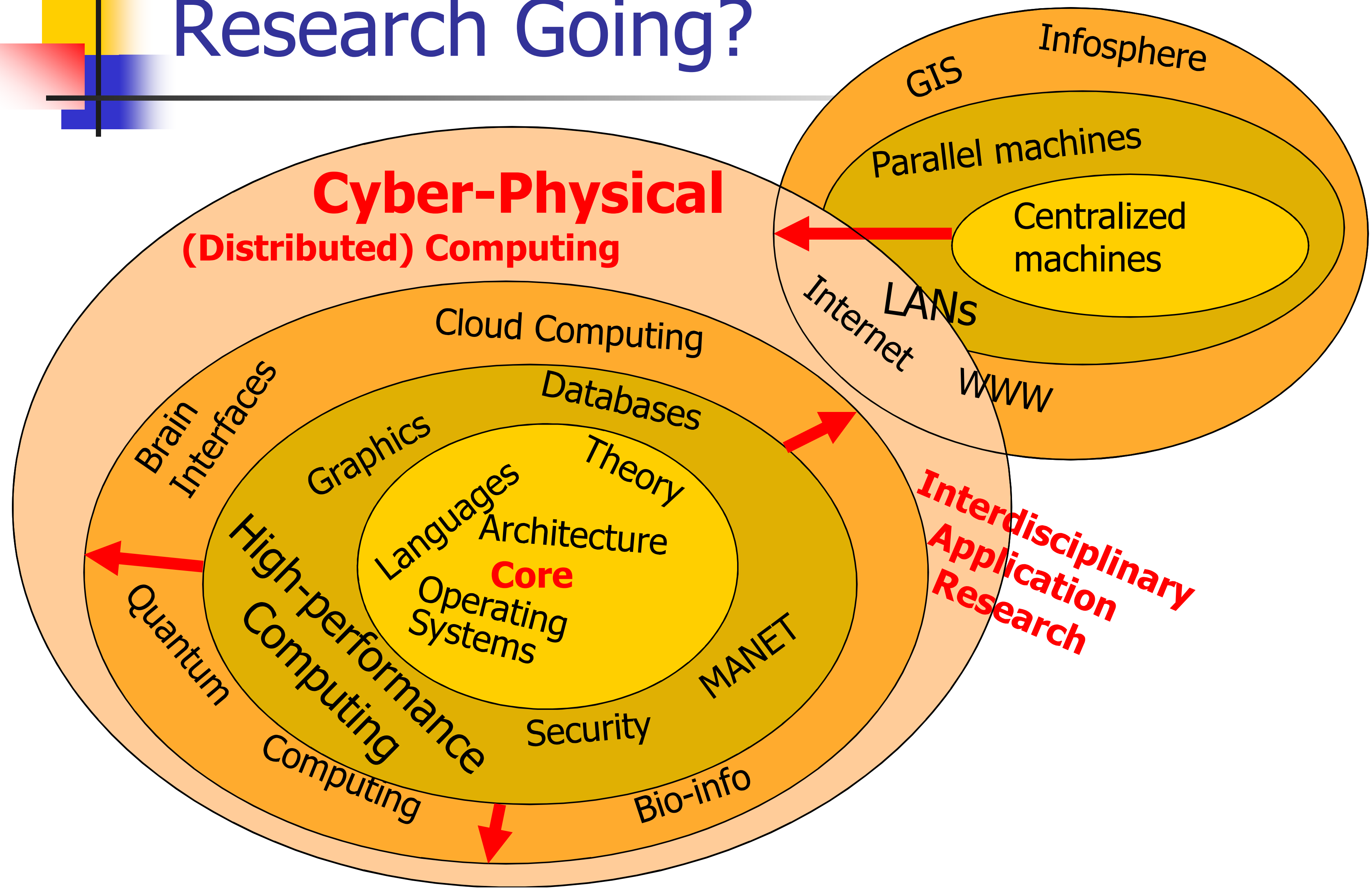
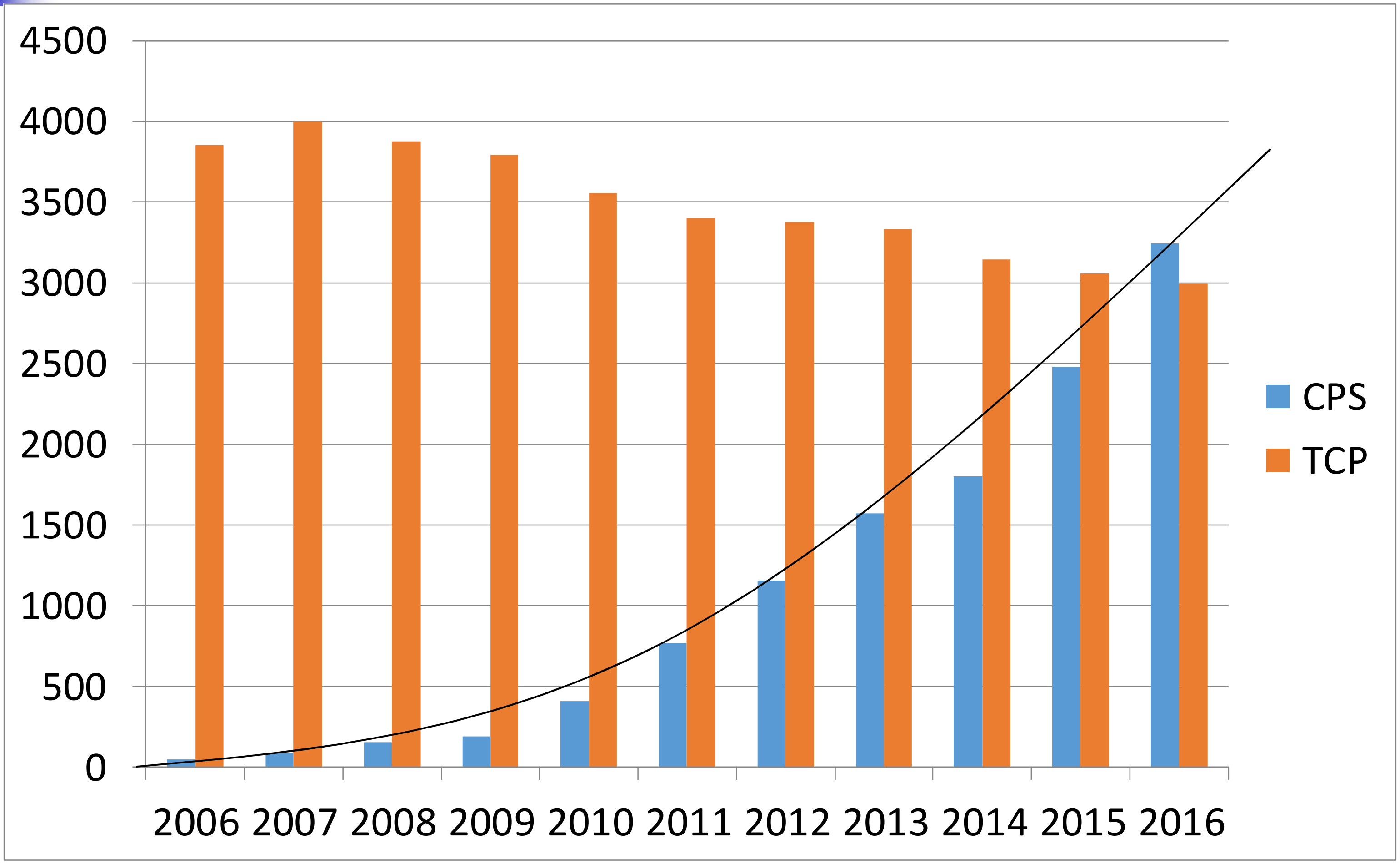
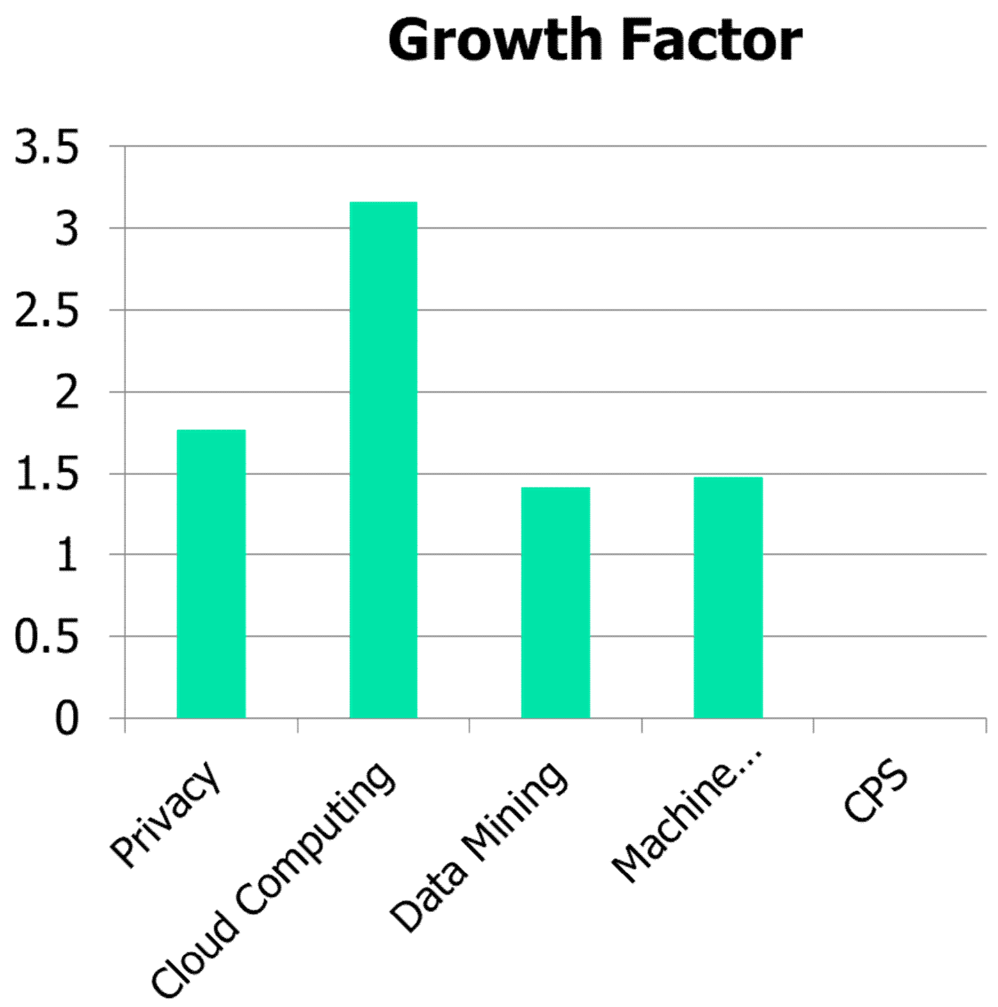


# Keyword Trends (On Compendex)



# Keyword Trends (Continued): 2015/2010 Multiplicative Factor



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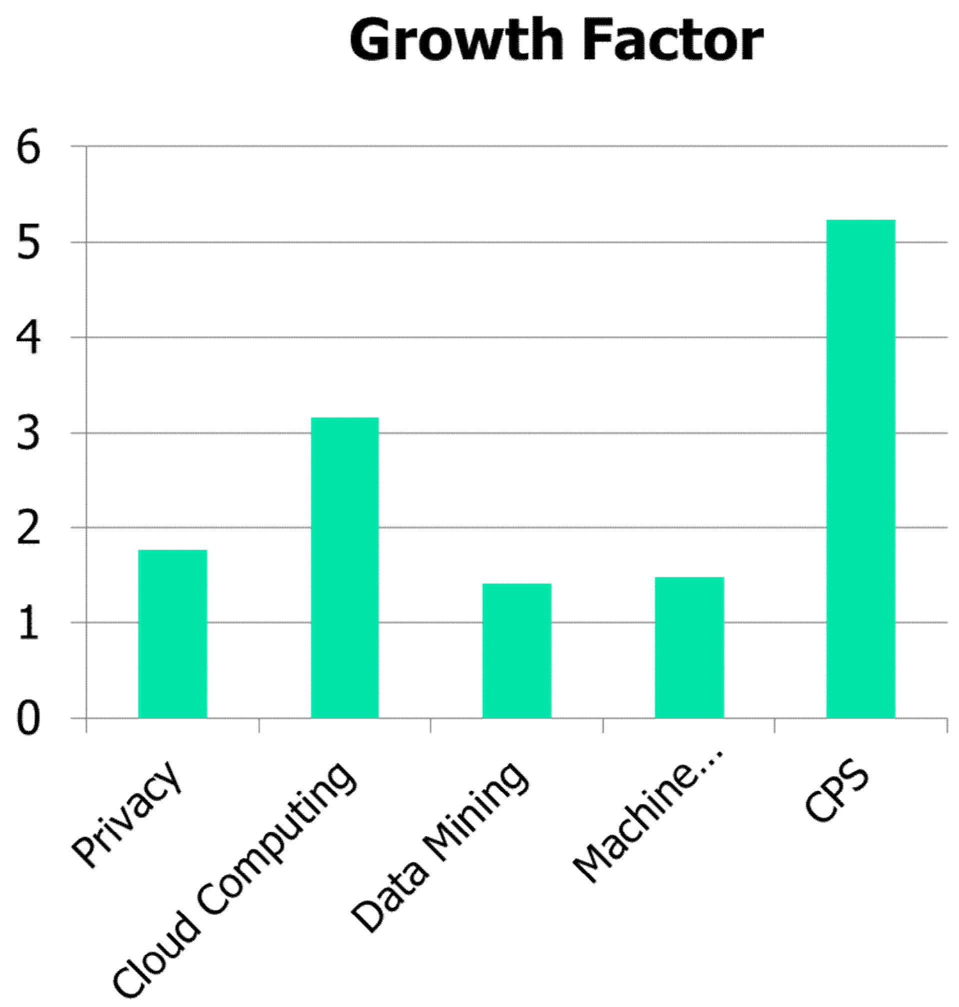
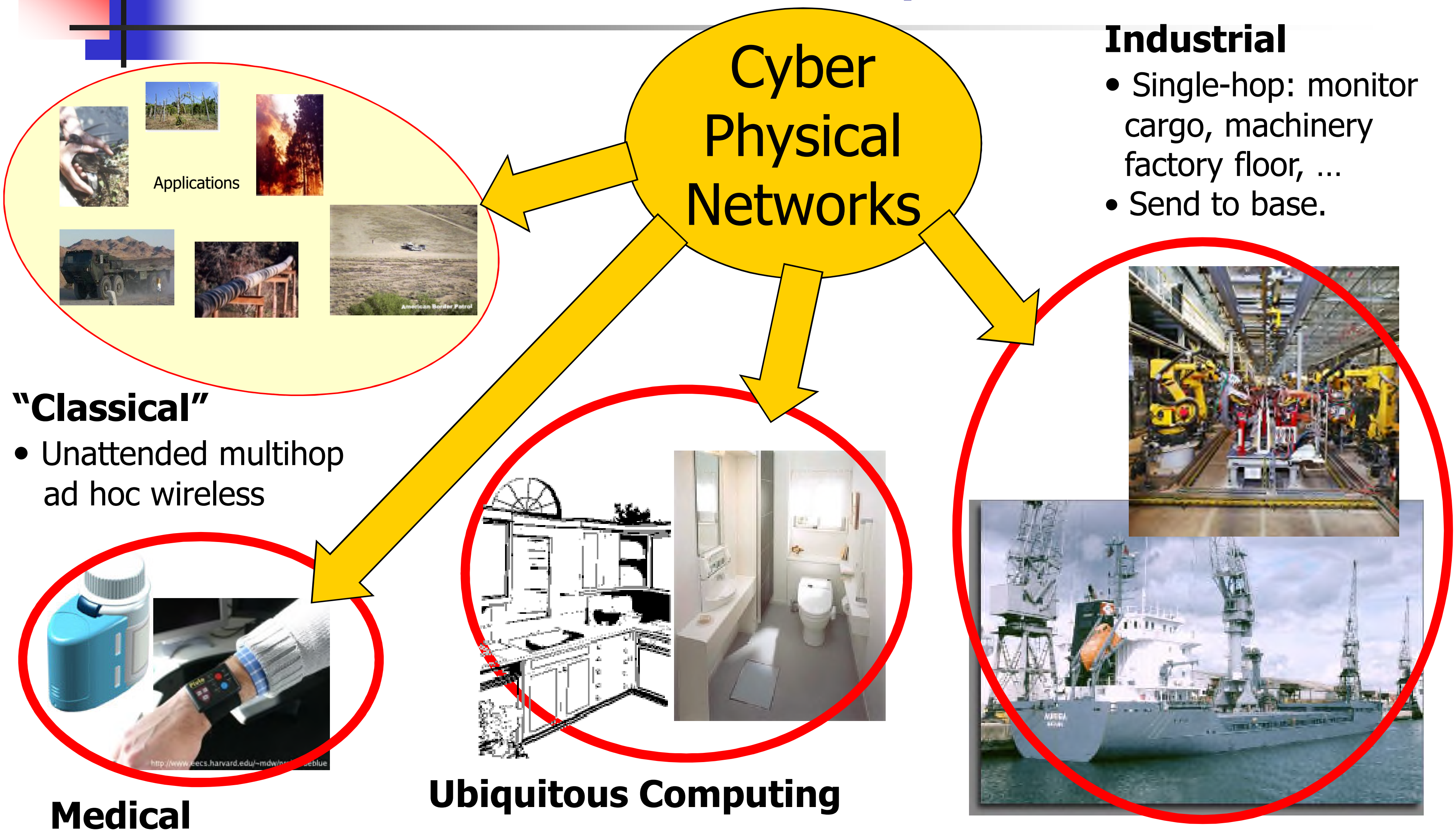
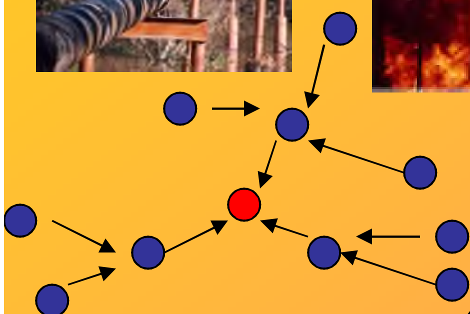


# **Force #1:** Device proliferation



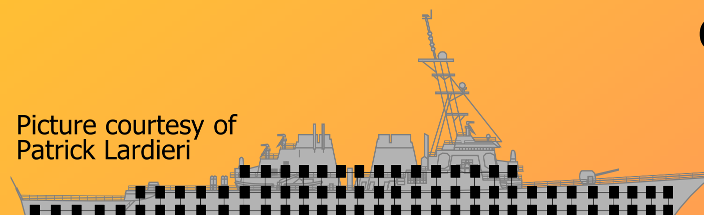
# **Force #2:** Integration at Scale
## (Isolation has cost!)

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



World Wide Sensor Web
(Feng Zhao)

Picture courtesy of
Patrick Lardieri



Total Ship Computing Environment
(TSCE)

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

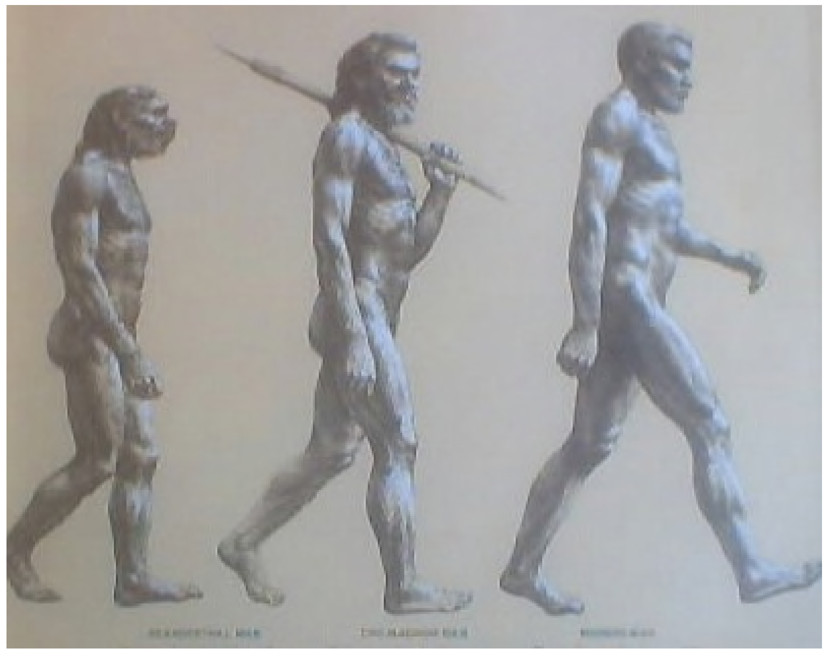
Global Information Grid


Future Combat System
(Rob Gold)

Integration and Scaling Challenges

Low End ⟷ High End

# **Force #3:** Biological Evolution



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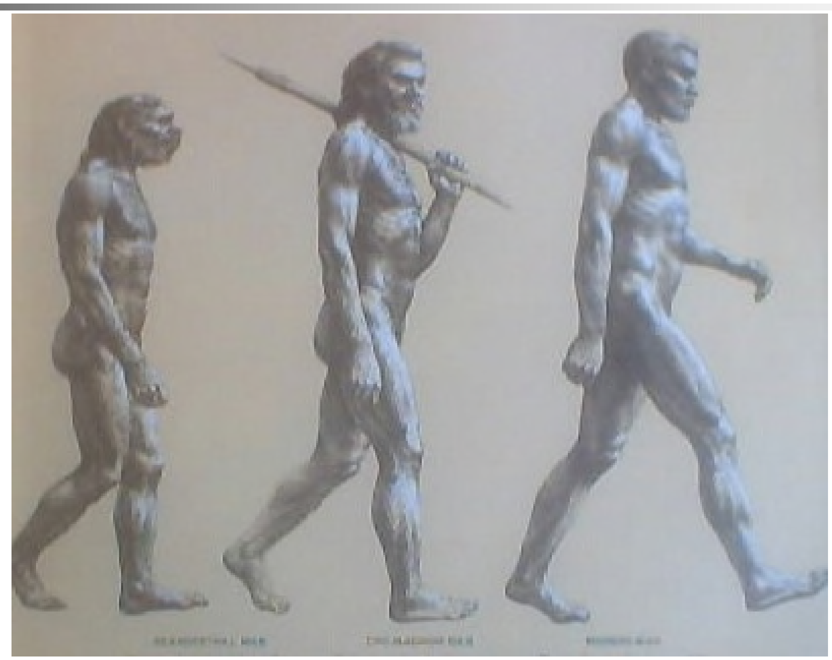
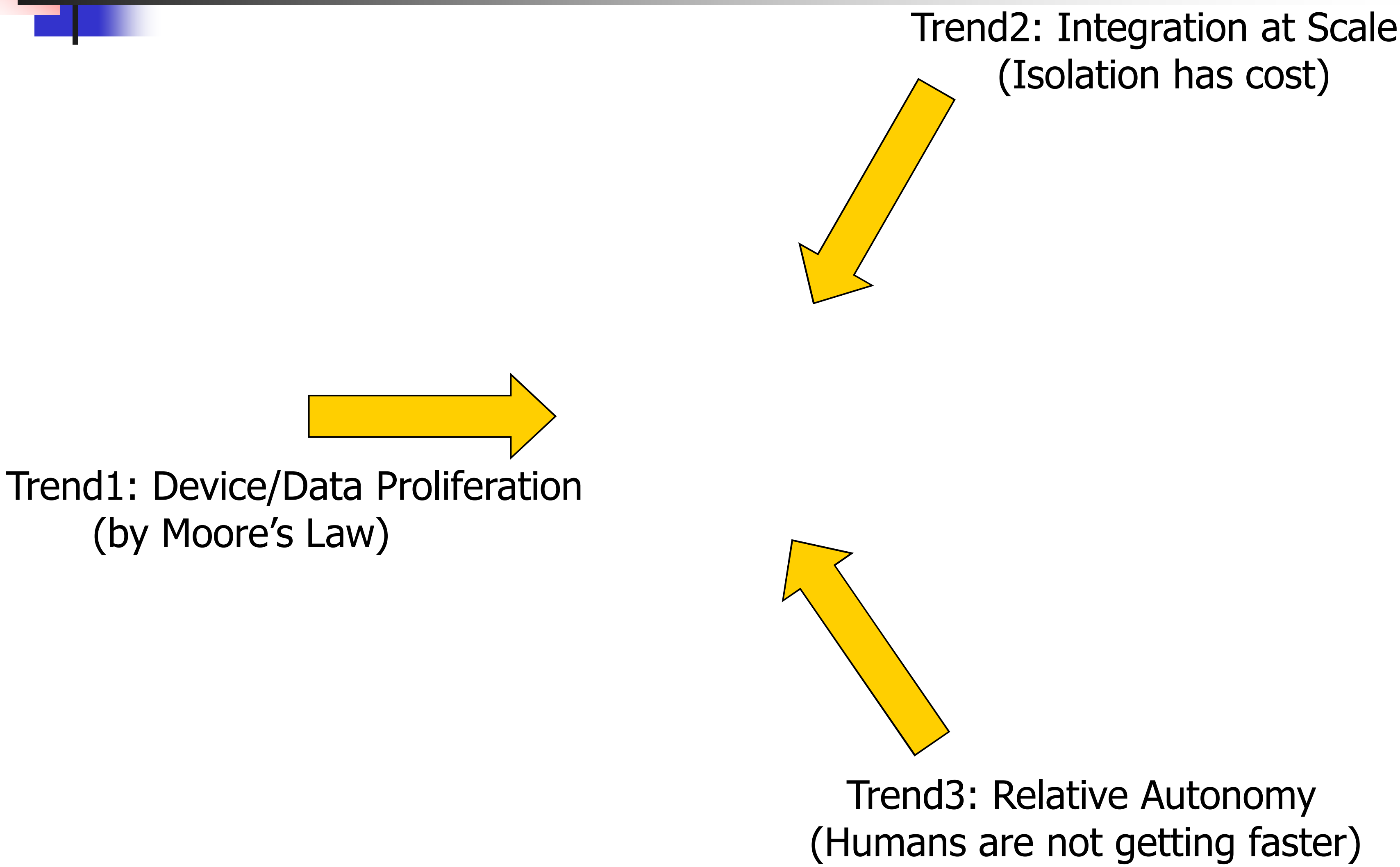


- **It's too slow!**
  - The exponential proliferation of data sources (afforded by Moore's Law) is ***not*** matched by a corresponding increase in human ability to consume information!

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

# Confluence of Trends

## The Overarching Challenge



# Confluence of Trends
## The Overarching Challenge

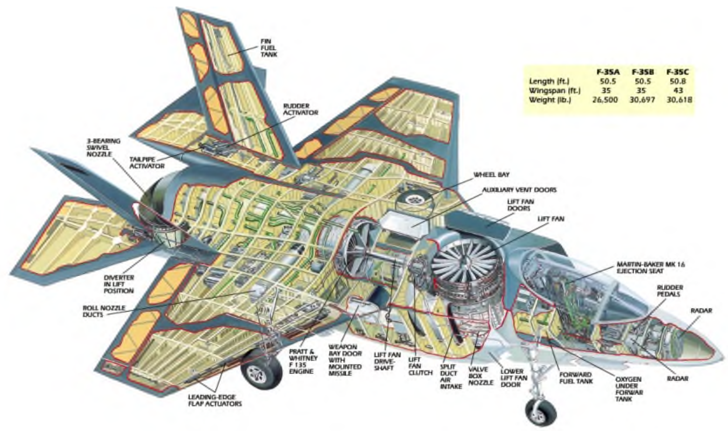
Trend2: Integration at Scale
(Isolation has cost)

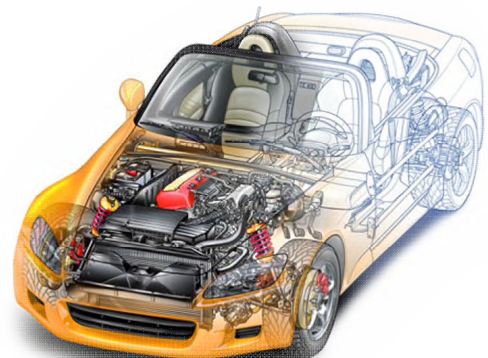
Core Challenges:
Distributed CPS +
Information Distillation

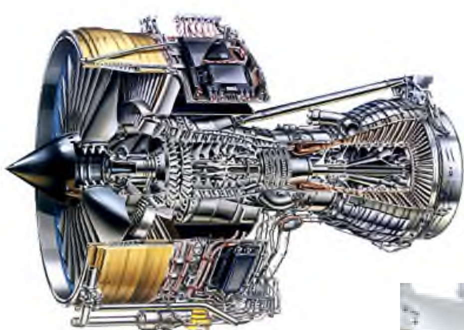
Trend1: Device/Data Proliferation
(by Moore's Law)

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**

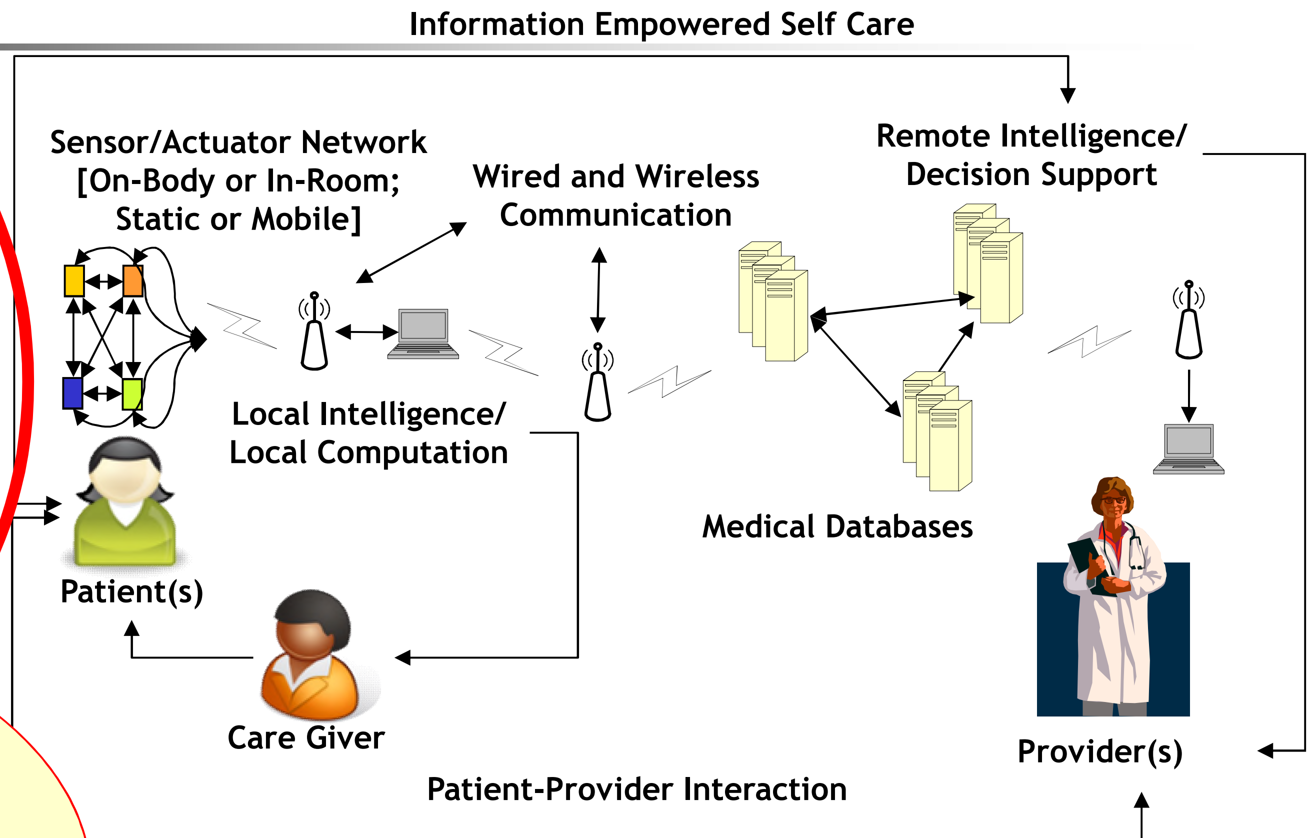
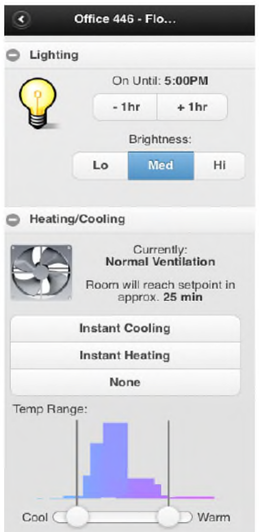
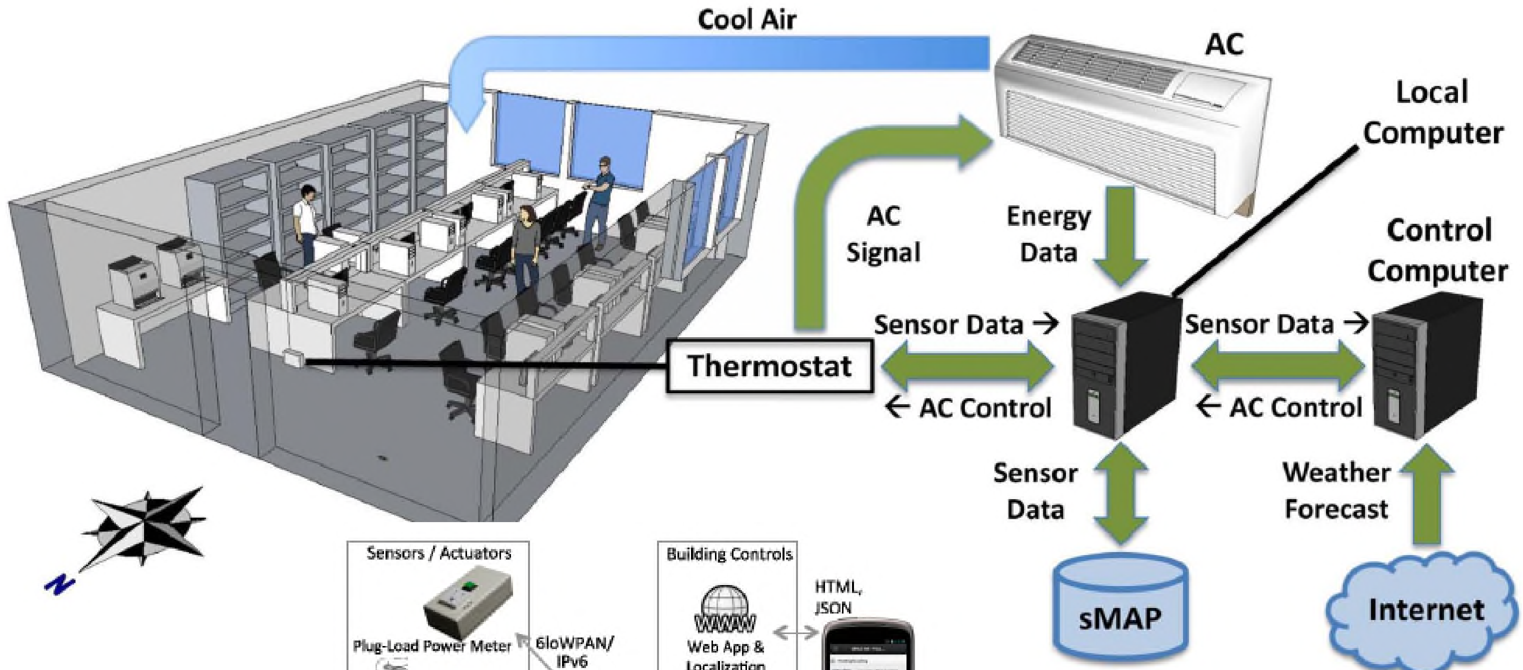


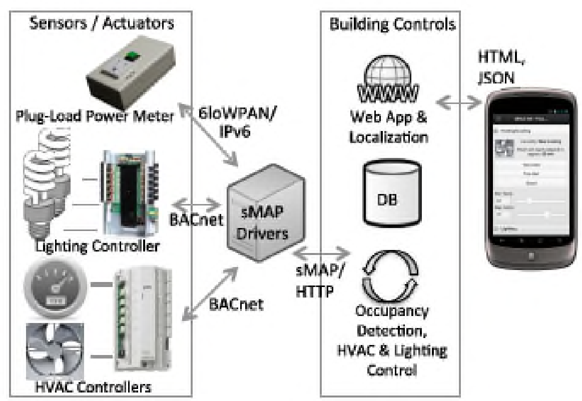

Figure courtesy of Mark Spong and Bill Sanders

Medical

# CPS Applications – Energy



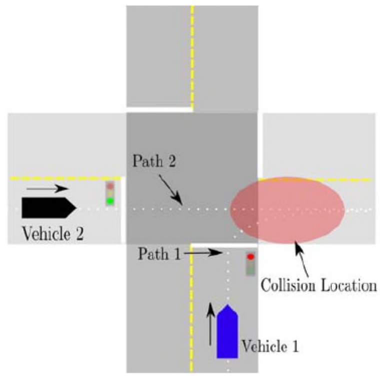



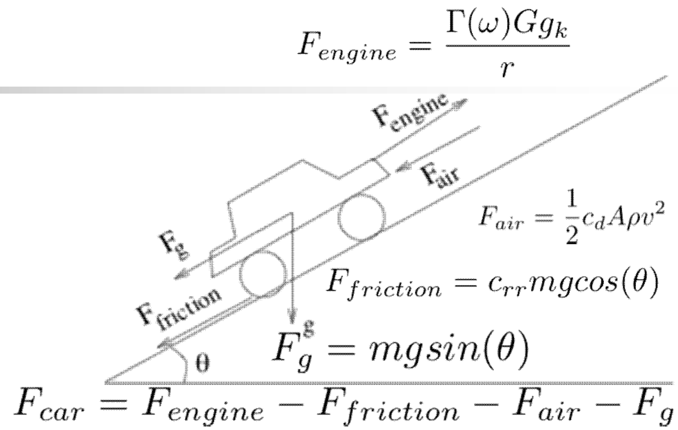

Figures courtesy of Berkeley BRITE Lab

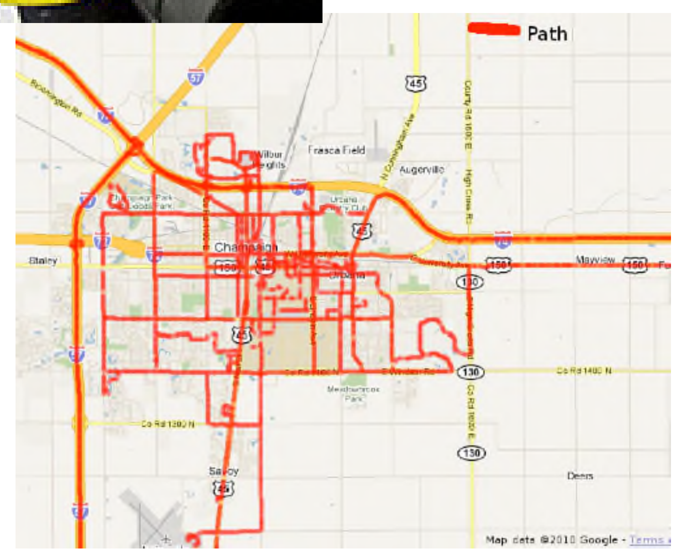
Zero-energy Building: Science House at the Science Museum of Minnesota

Residential Energy

# CPS Applications – Transportation



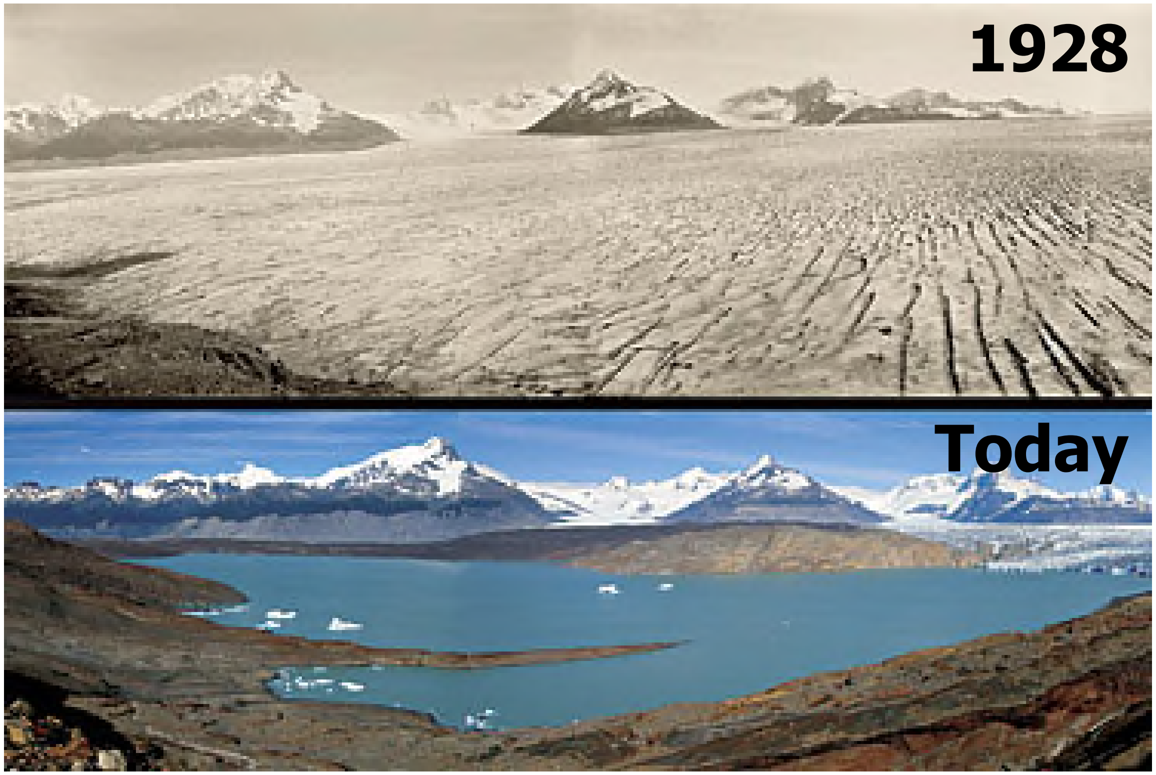



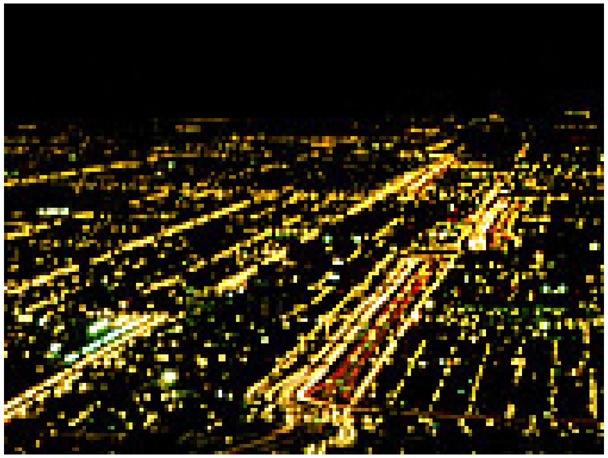




Transportation

# 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

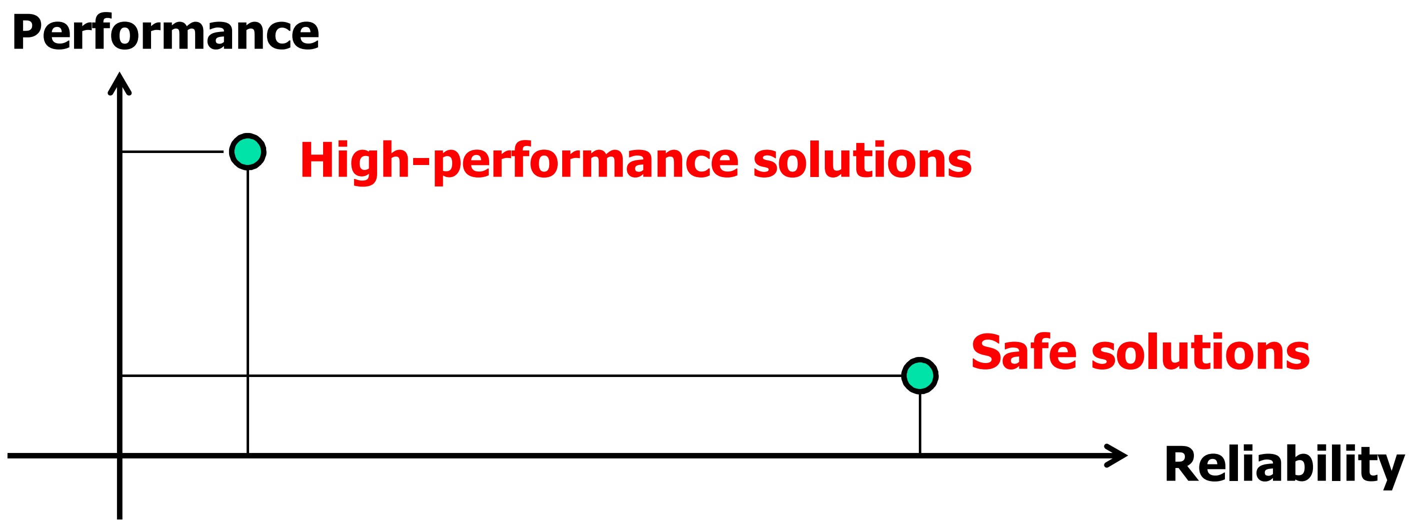
# The Safety/Performance Trade-off in CPS


**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

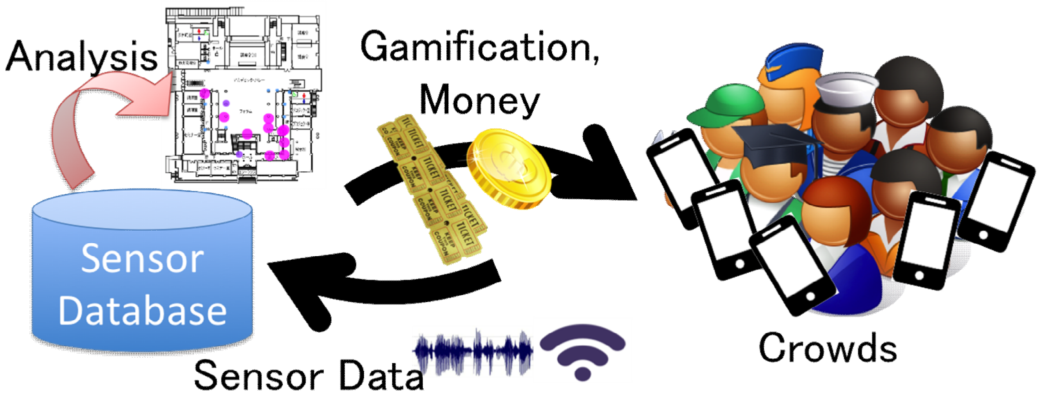
Data


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



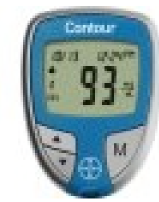

http://asmarterplanet.com/studentsfor/blog/category/transportation-systems

# Social Sensing: A Confluence of Three Trends

**Mass Dissemination Media**

**Sensors**

Cell-phones



Glucose monitor

Cars on Internet

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?