Real-time and Cyber Physical Systems

From Control Systems to the Internet of Things

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

Tarek Abdelzaher

Dept. of Computer Science

University of Illinois at Urbana Champaign

Logistics

- **Instructor**
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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, CPS, or IoT topic of choice
  - Novel capability involving CPS/IoT devices, robotic vision, machine intelligence (for CPS/IoT devices), or human-machine interfaces

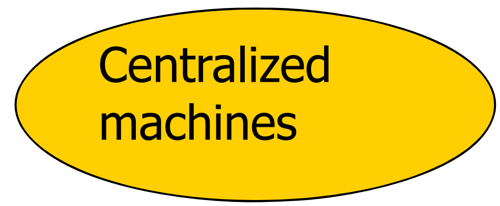
Schedule

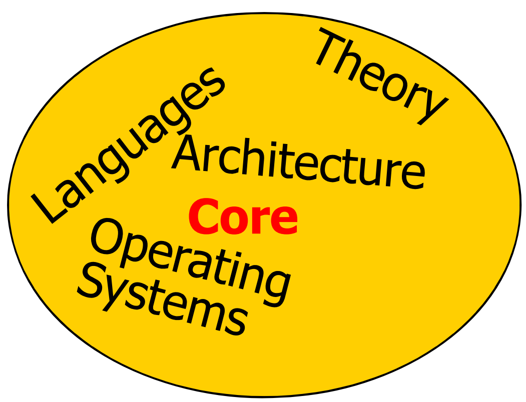
- See Website:

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

Where is Computer Science Research Going?

The beginning:





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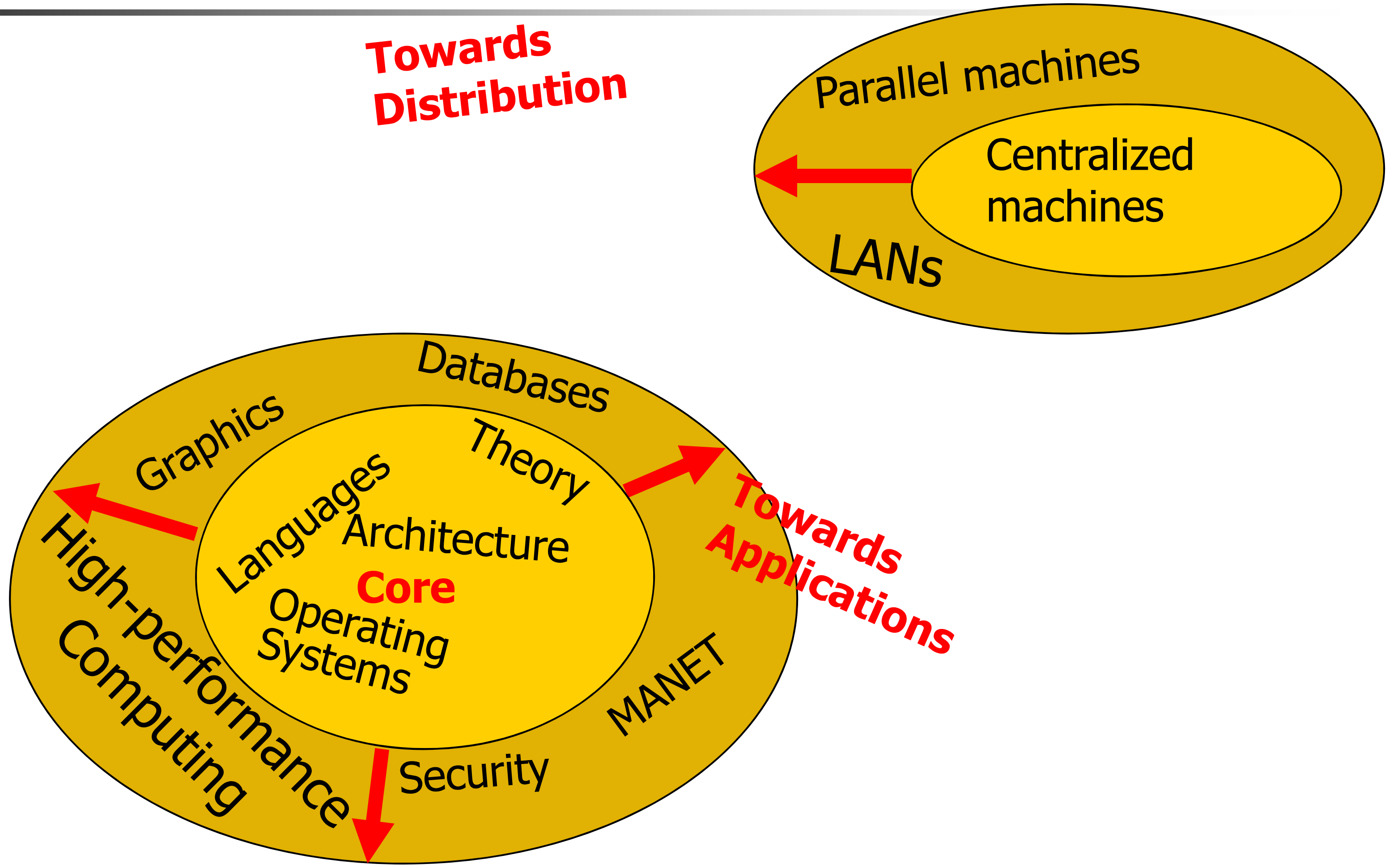

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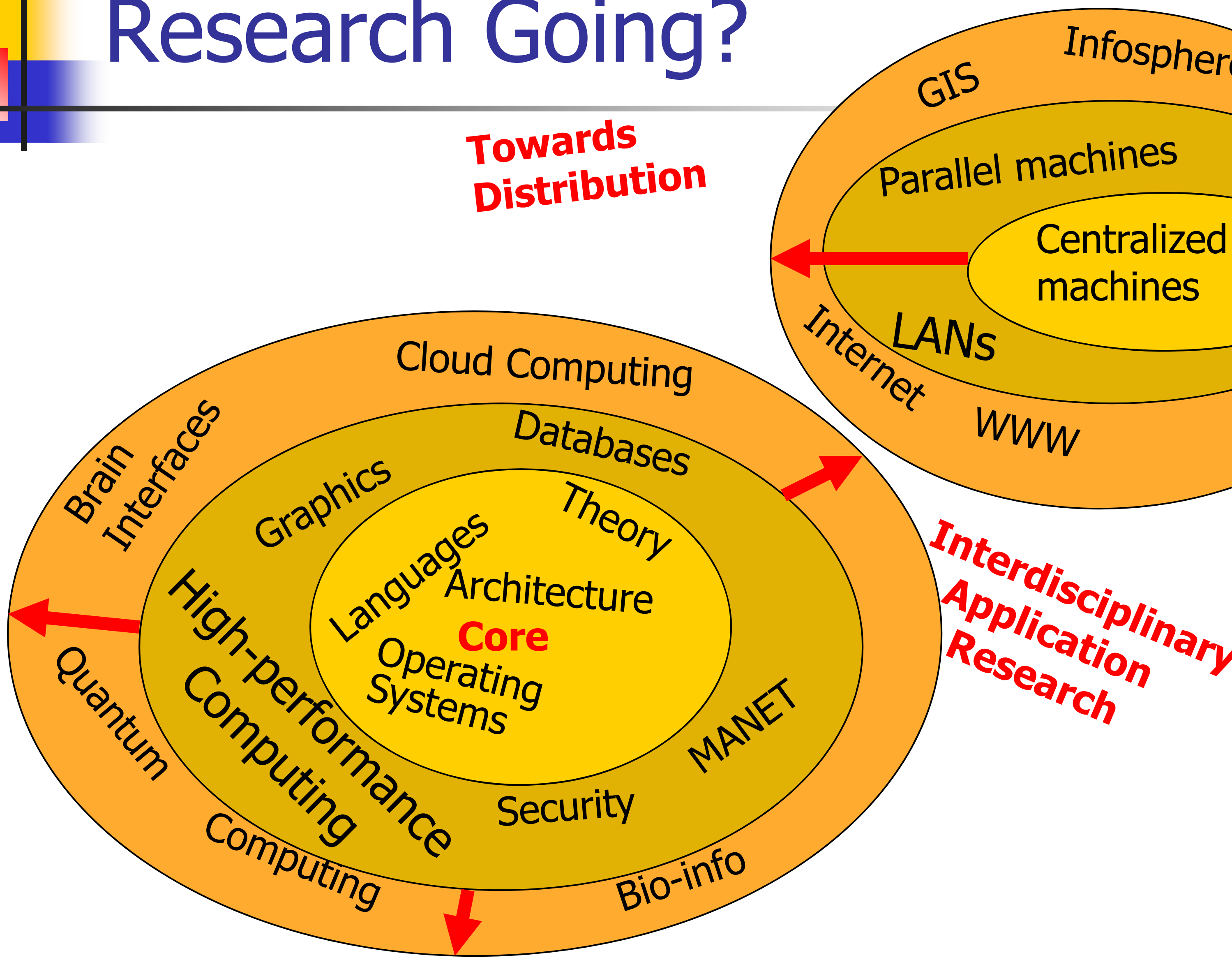

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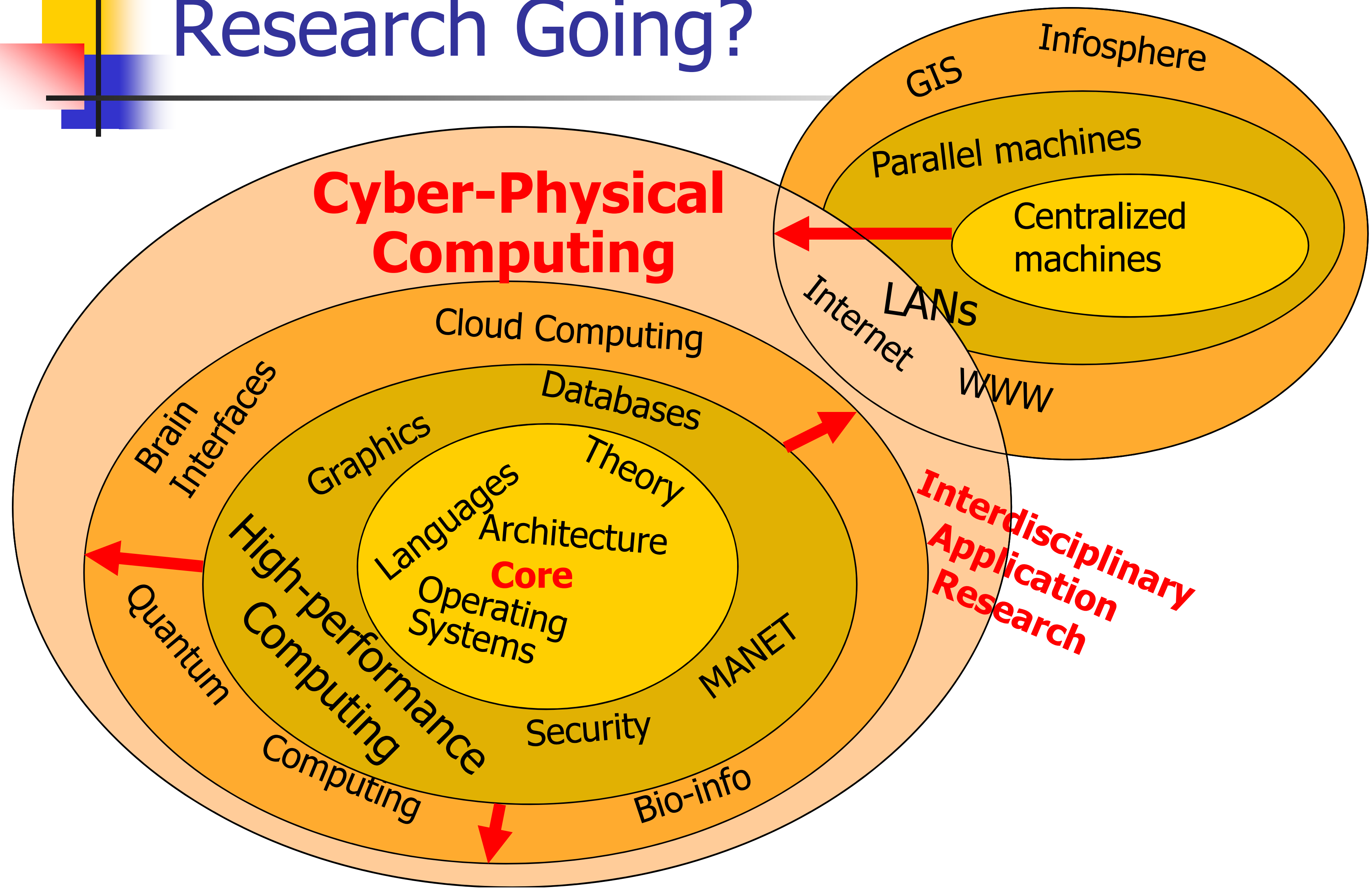

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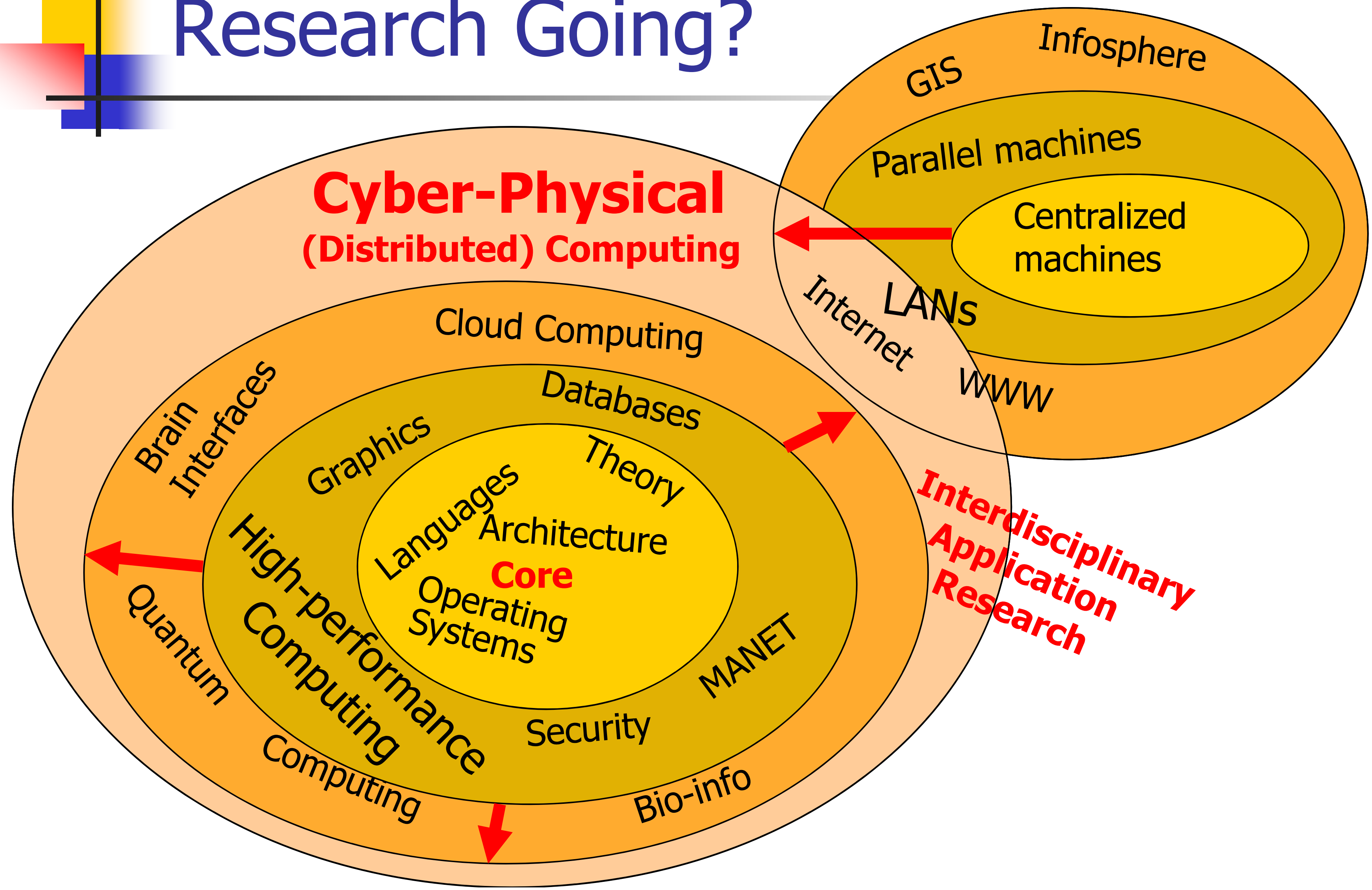

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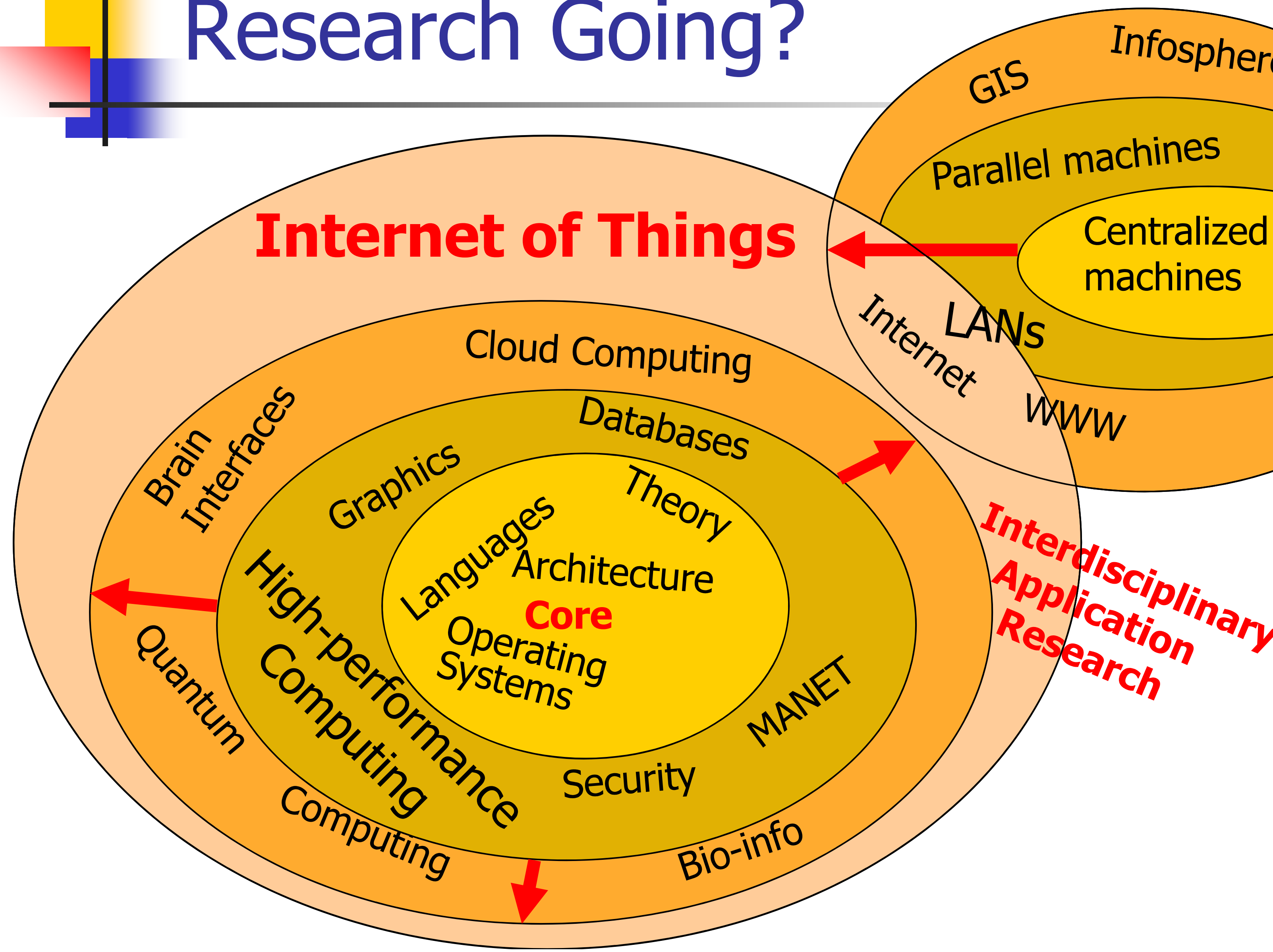
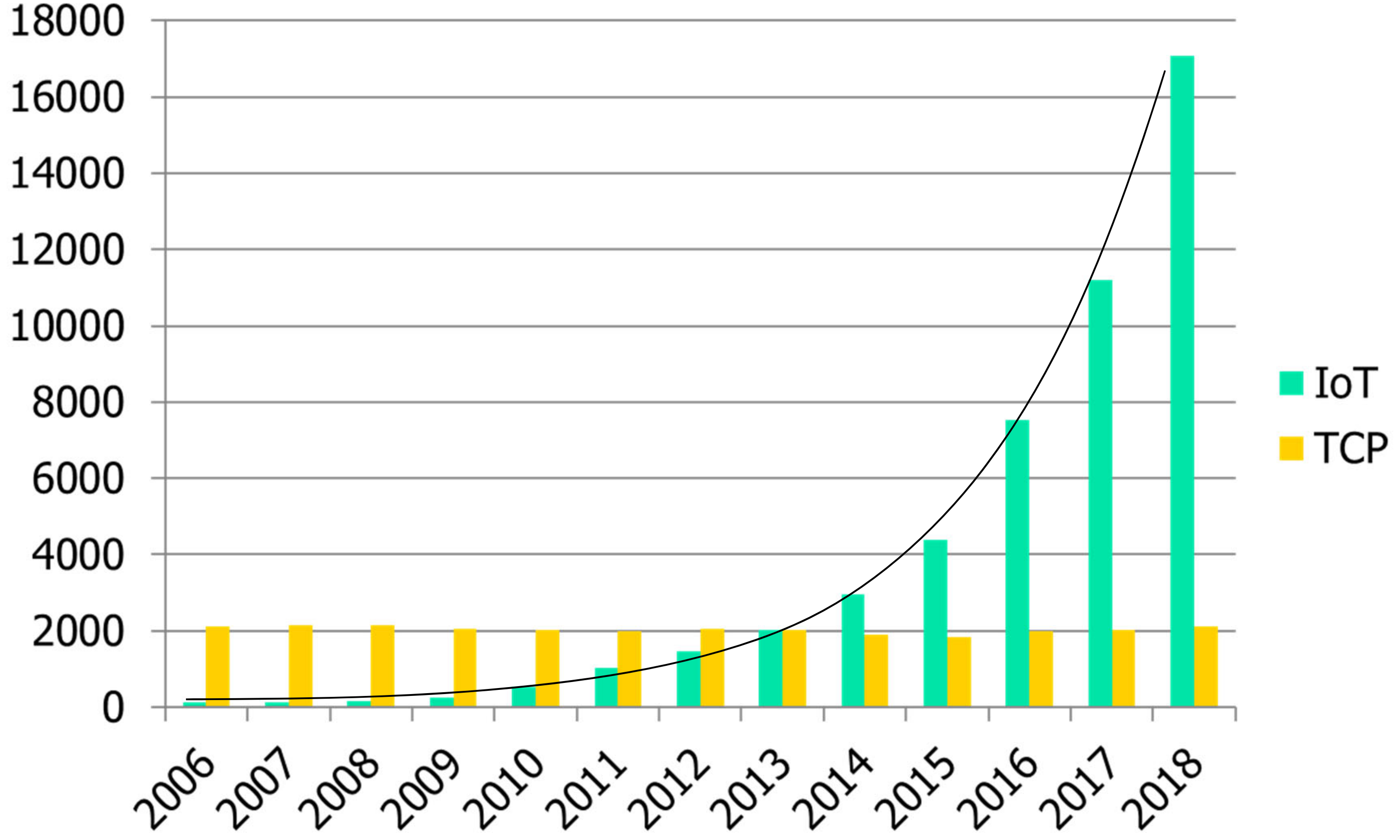
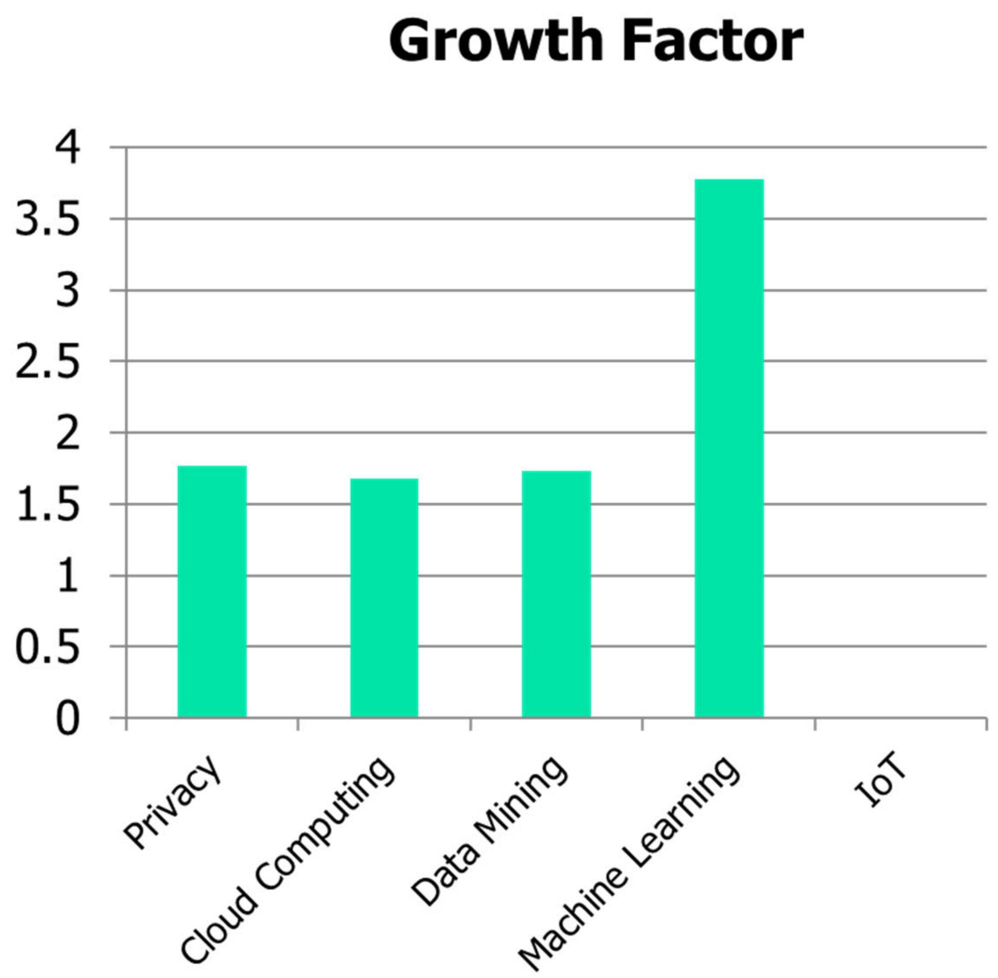


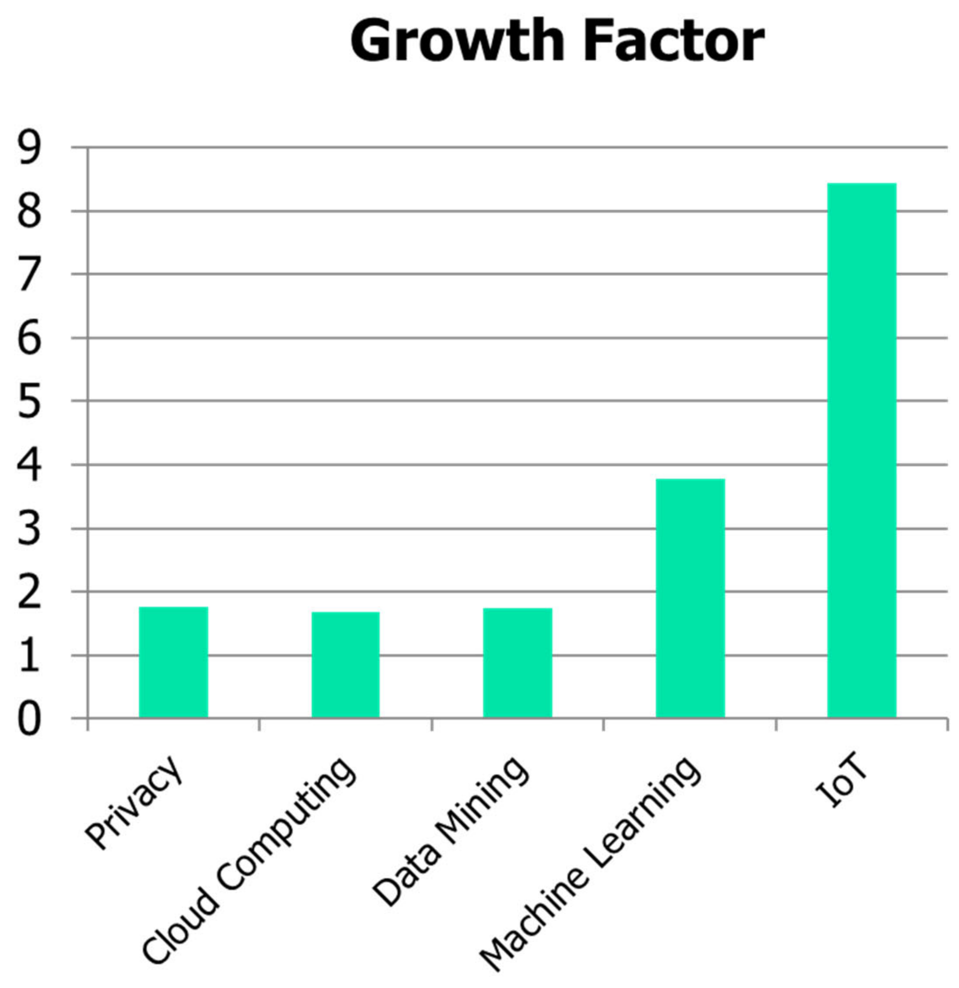
Keyword Trends (On Scopus)



Keyword Trends (Continued): 2018/2013 Multiplicative Factor

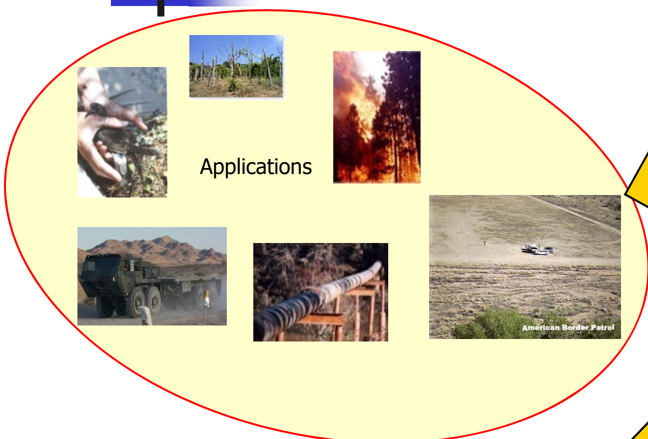


Keyword Trends (Continued): 2018/2013 Multiplicative Factor



Force #1: Device proliferation

IoT Applications



"Classical"

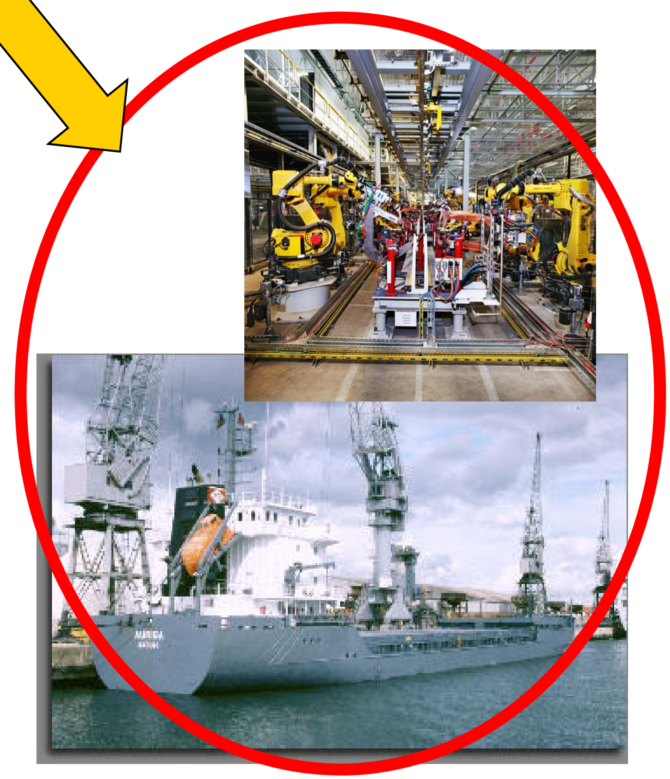
- Unattended multihop ad hoc wireless

Industrial

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

Medical

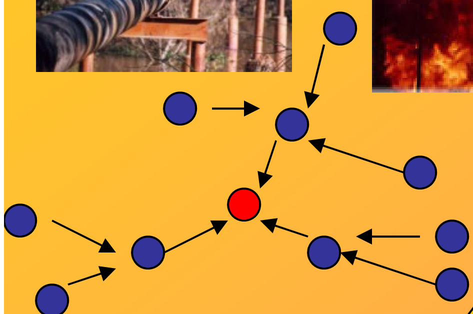
Ubiquitous Computing



Force #2: Integration at Scale

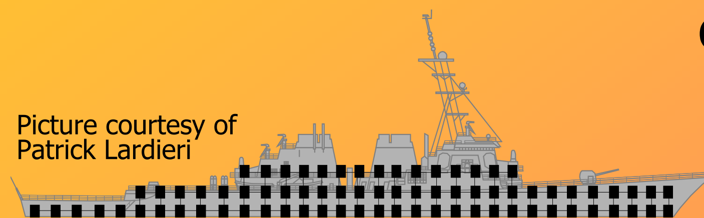
(Isolation has cost!)

- 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)

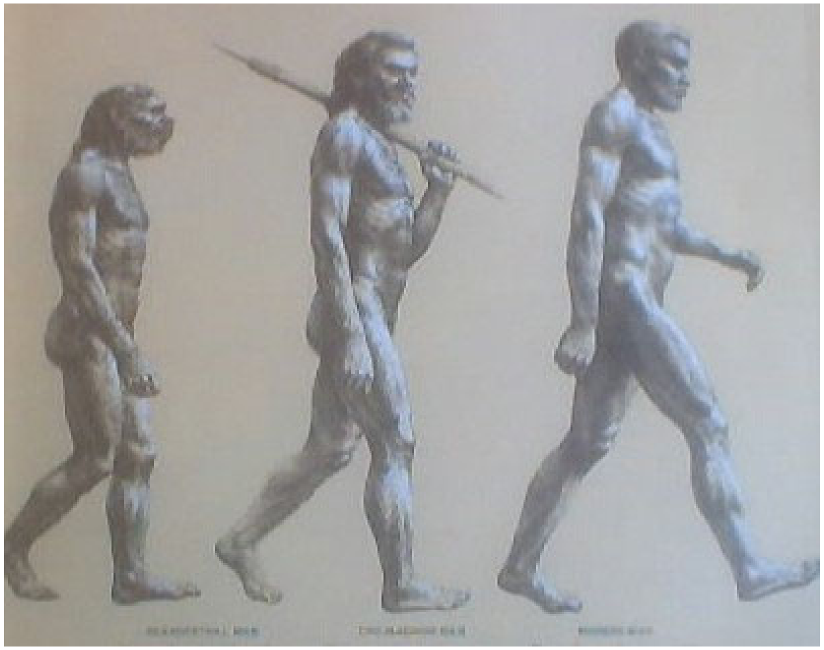
Global Information Grid

Future Combat System
(Rob Gold)

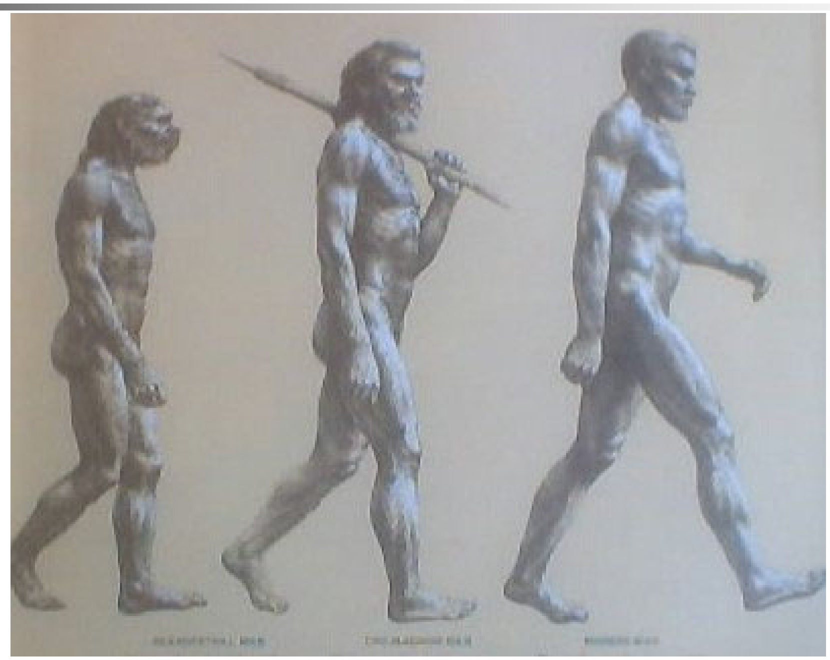
Integration and Scaling Challenges

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 (machine intelligence) 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

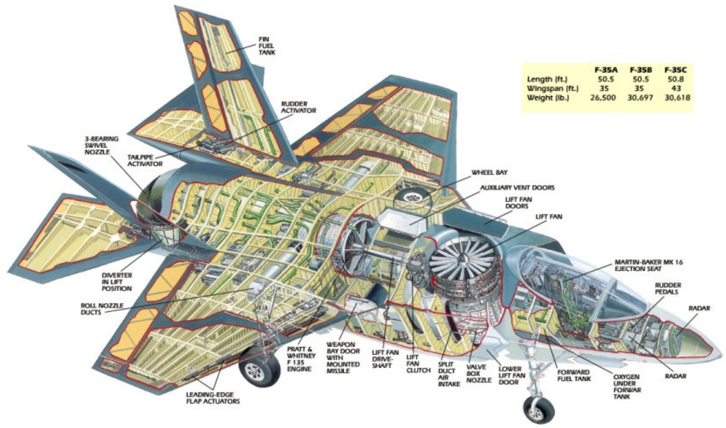
Trend2: Integration at Scale
(Isolation has cost)

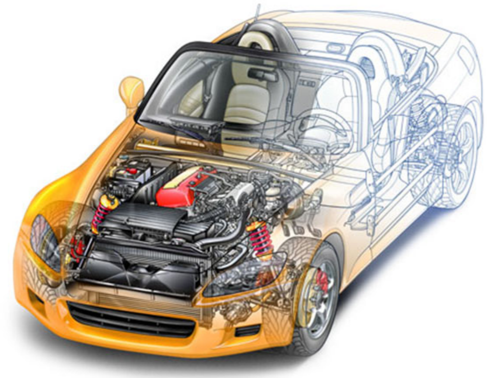
Core Challenge:
Intelligent, Real-time Systems
of Connected Things (IoTs)

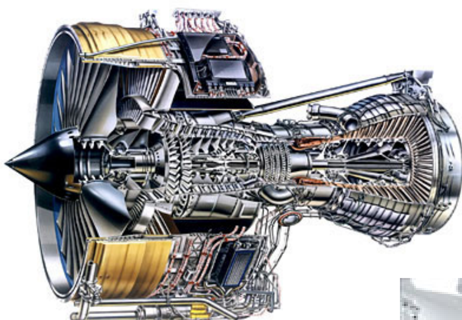
Trend1: Device/Data Proliferation
(by Moore's Law)

Trend3: Relative Autonomy
(Humans are not getting faster)

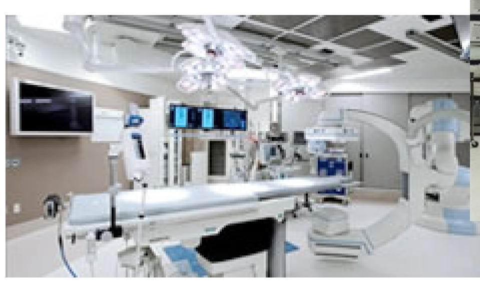
Traditional Embedded Computing (Cyber+Physical)



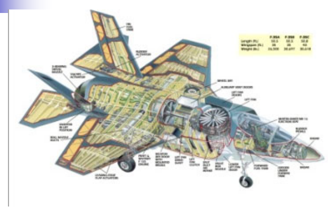


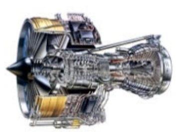


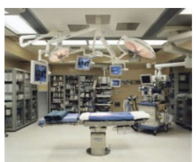
Embedded Computing Systems



Emerging Directions

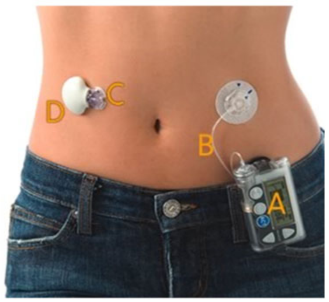






Distribution,
Humans in the Loop,
“Big” Data from the Physical World

CPS/IoT Applications – Medical



Medical
Insulin pumps, pacemakers, glucose monitors, …

Bio-feedback Sensors

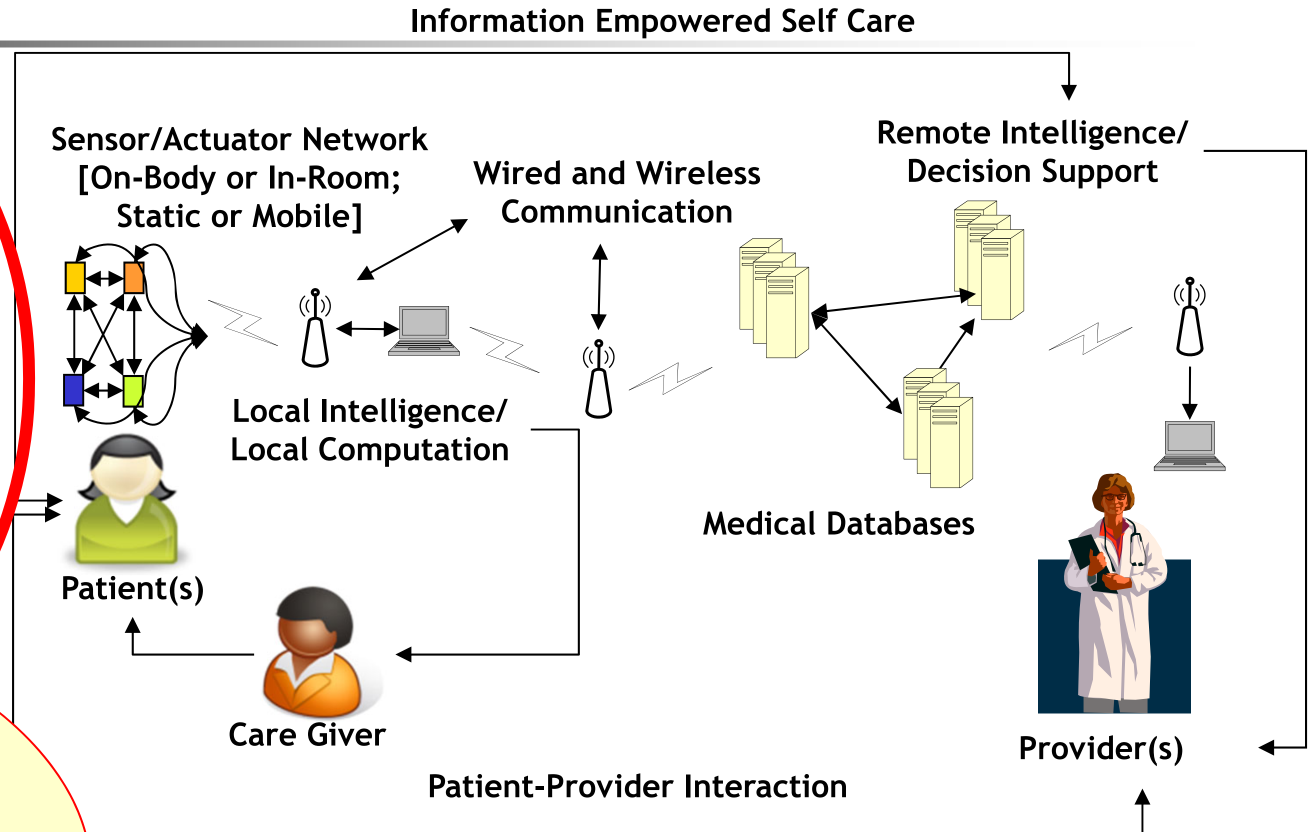
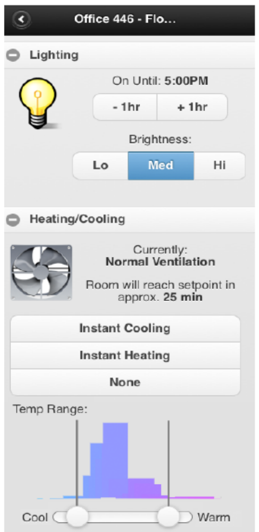


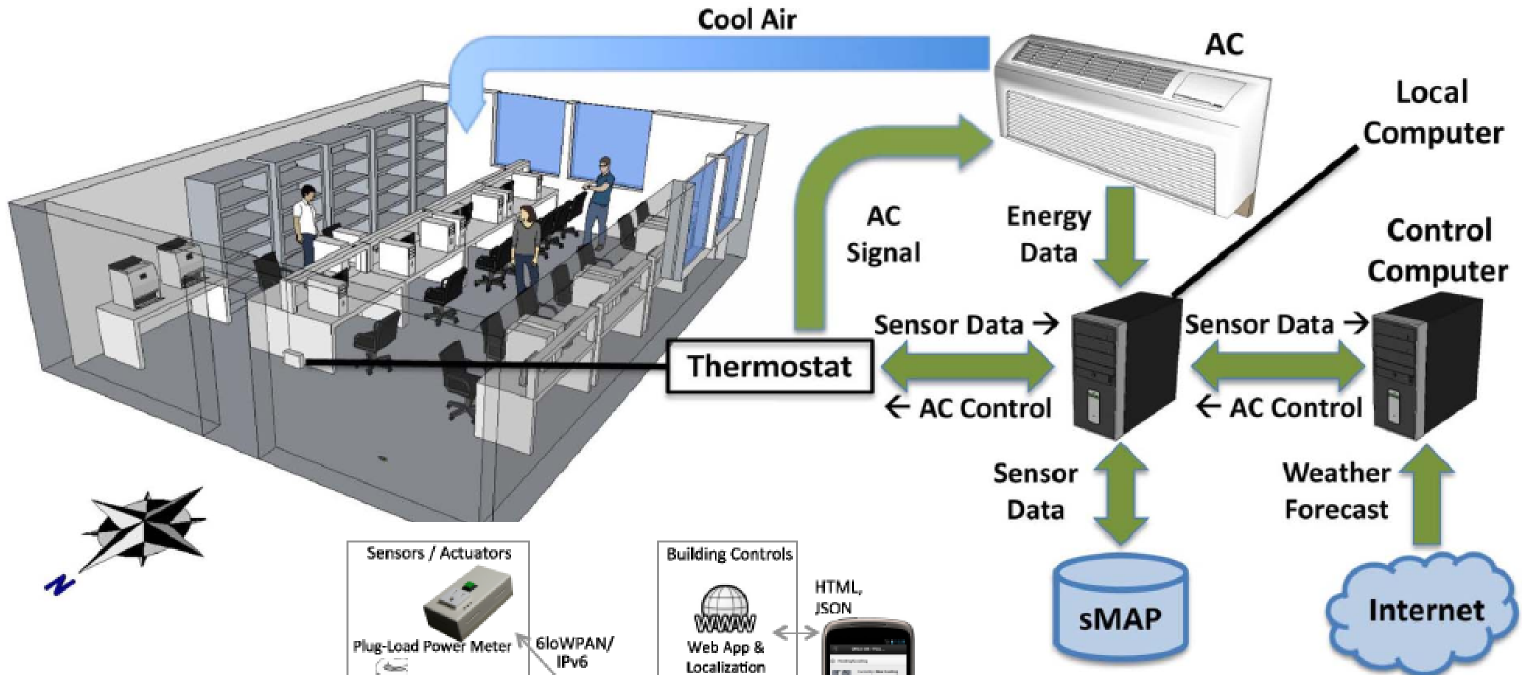
Figure courtesy of Mark Spong and Bill Sanders

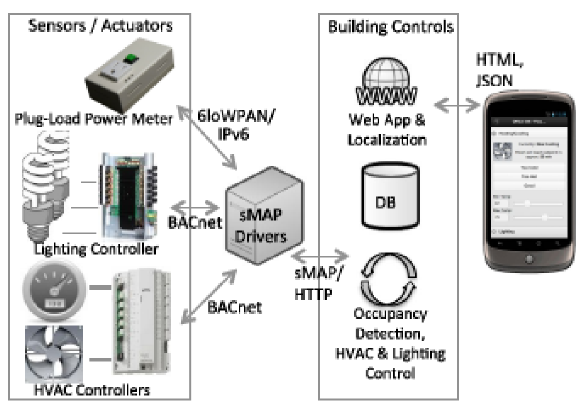
Medical

CPS/IoT Applications – Energy



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

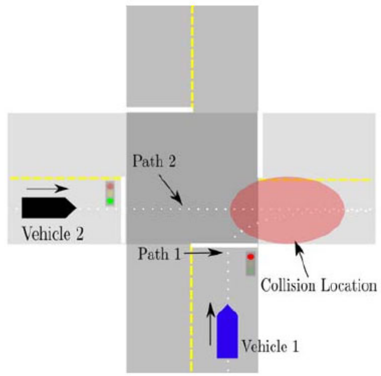


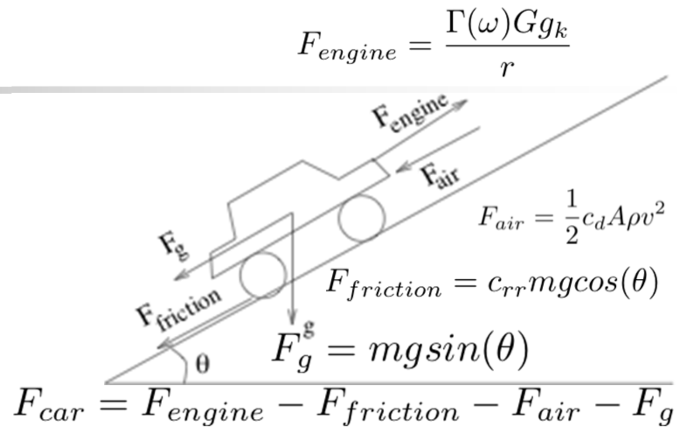


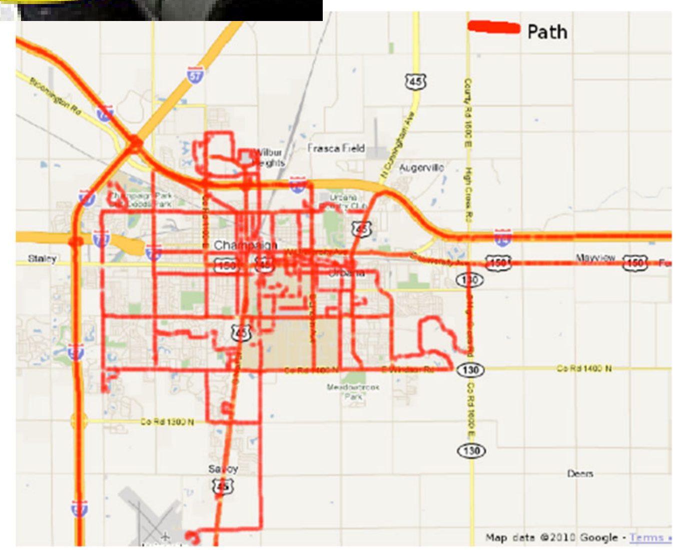
Figures courtesy of Berkeley BRITE Lab

Residential Energy

CPS/IoT Applications – Transportation



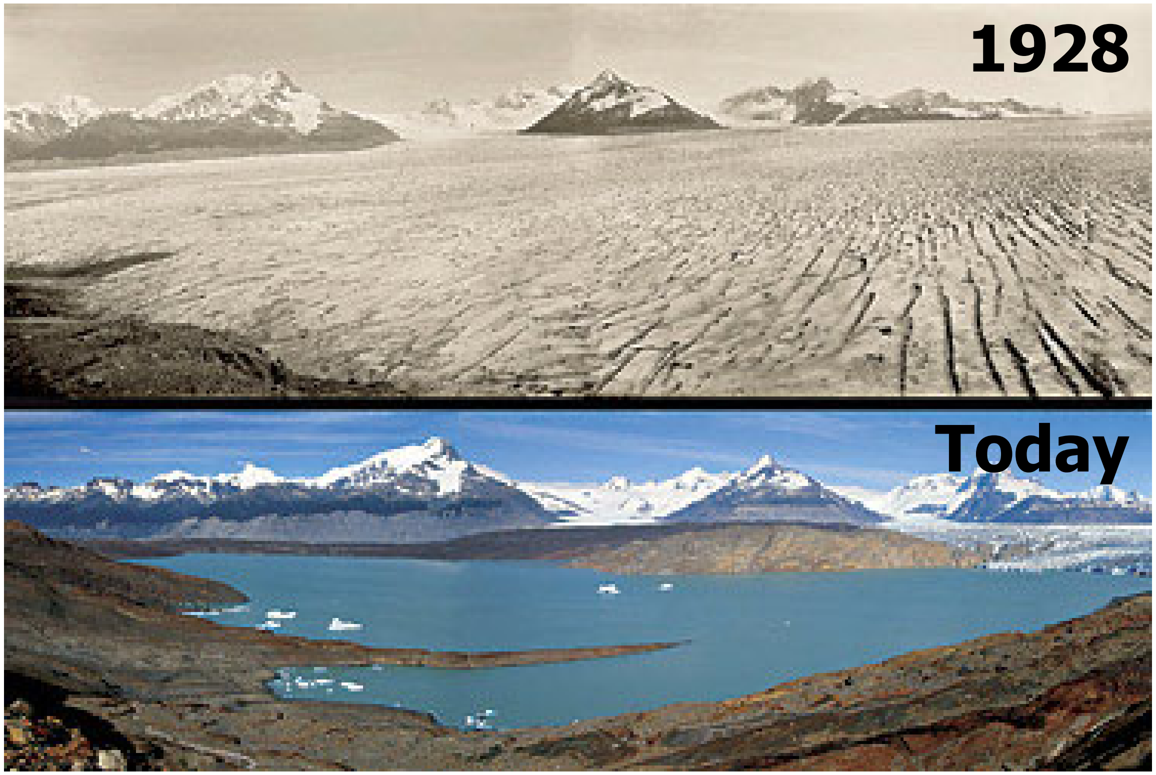


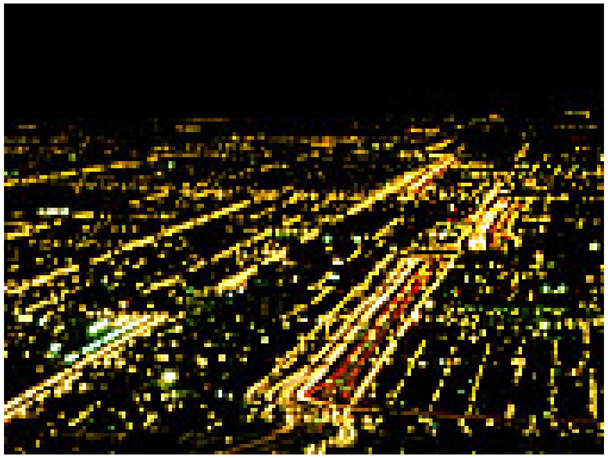


Transportation

CPS/IoT Applications – Sustainability

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





Sustainability

What Do CPS/IoT 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/IoT Systems

Performance: Exploring the edge of feasibility

Robustness: Guaranteeing delivery in the face of adverse conditions

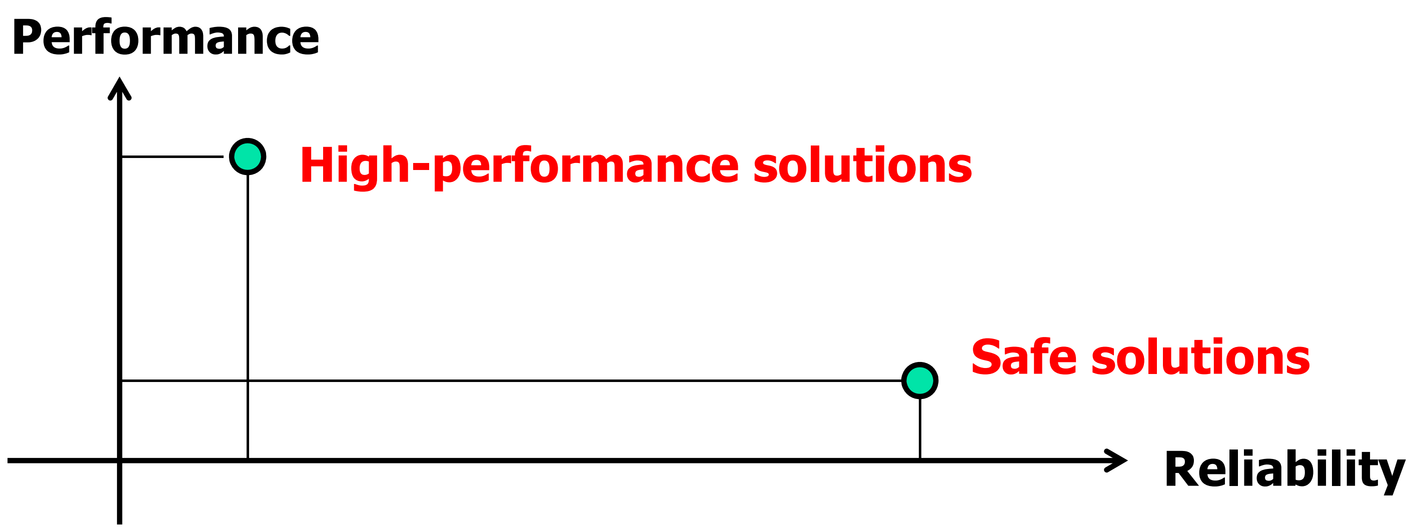
The Safety/Performance Trade-off in CPS/IoT Systems

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/IoT Systems

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



Important CPS/IoT Problem
"Safety + Performance" Architectures

- Architectures and design paradigms for combining safety and high performance

Lab

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