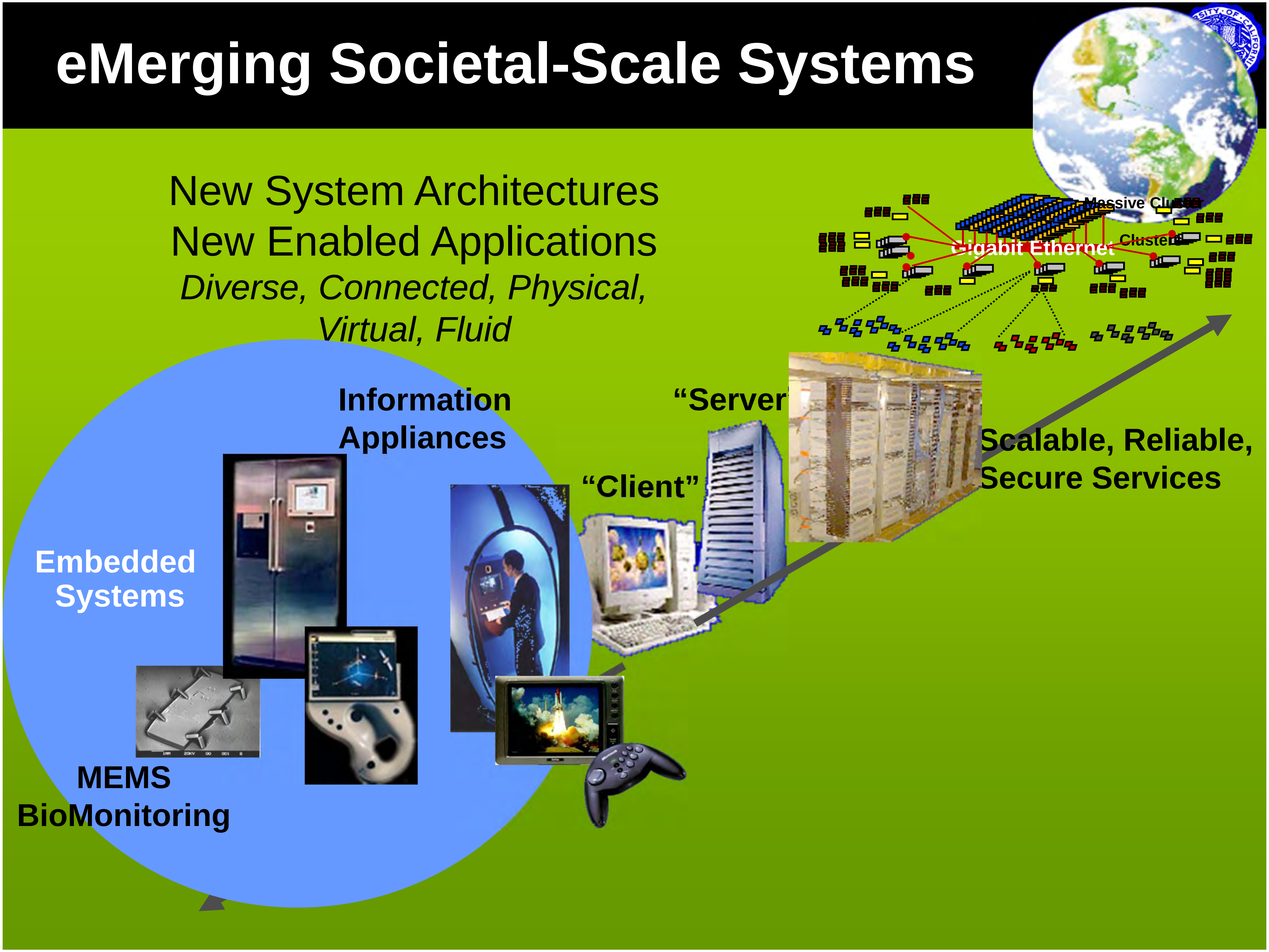
EE249
Embedded System Design: Models, Validation and Synthesis

Alberto Sangiovanni Vincentelli

"I believe we are now entering the Renaissance phase of the Information Age, where creativity and ideas are the new currency, and invention is a primary virtue, where technology truly has the power to transform lives, not just businesses, where technology can help us solve fundamental problems."

Carly Fiorina, CEO, Hewlett Packard Corporation



eMerging Societal-Scale Systems
New System Architectures
New Enabled Applications
Diverse, Connected, Physical,
Virtual, Fluid
Massive Cluster
Gigabit Ethernet
Clusters
"Server"
"Client"
Information
Appliances
Scalable, Reliable,
Secure Services
Embedded
Systems
MEMS
BioMonitoring

Embedded Systems

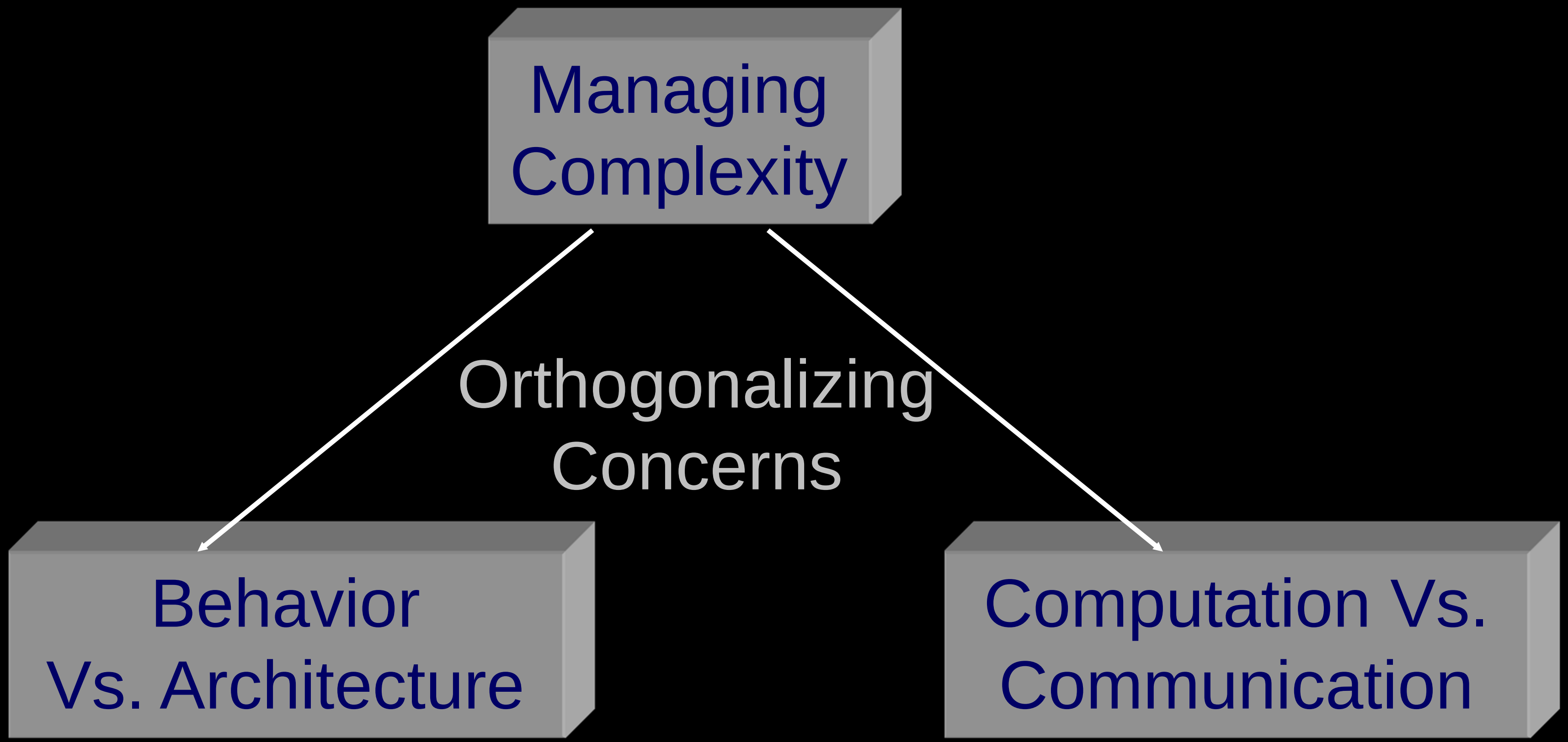
- Computational
  - but not first-and-foremost a computer
- Integral with physical processes
  - sensors, actuators
- Reactive
  - at the speed of the environment
- Heterogeneous
  - hardware/software, mixed architectures
- Networked
  - shared, adaptive

Source: Edward A. Lee

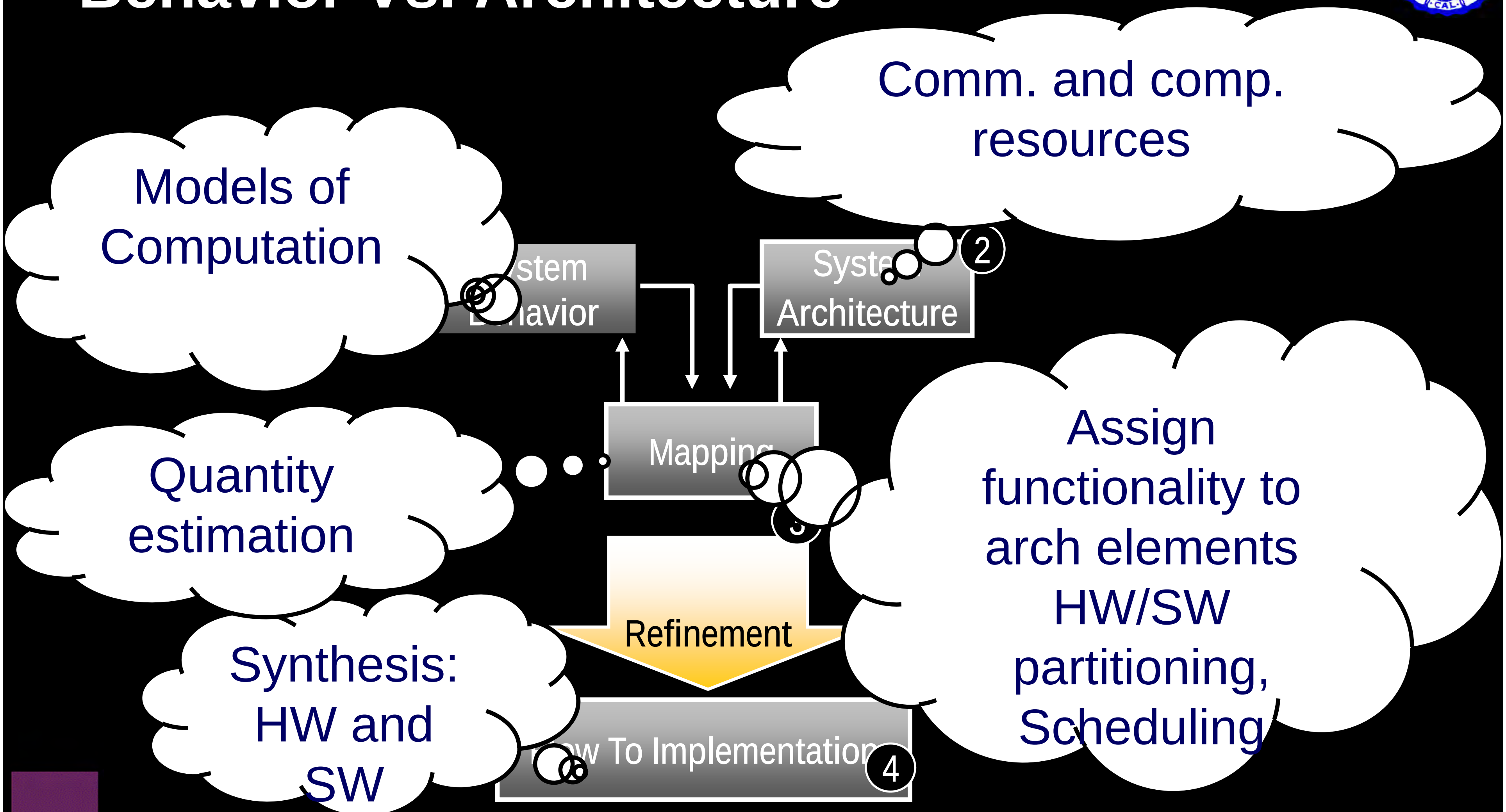
Observations

- We are on the middle of a revolution in the way electronics products are designed
- System design is the key (also for IC design!)
  - Start with the highest possible level of abstraction (e.g. control algorithms)
  - Establish properties at the right level
  - Use formal models
  - Leverage multiple “scientific” disciplines

Course overview



Behavior Vs. Architecture



- Polis (1990-1996)
- VCC (1996-2003)
- Metropolis (2003-present)

Behavior Vs. Communication

- Clear separation between functionality and interaction model
- Maximize reuse in different environments, change only interaction model

Administration

- Office hours: *Alberto : Tu-Th 12:30pm-2pm or (better) by appointment (2-4882)*
- Teaching Assistant:
  - **Liangpeng (Leo) Guo, glp**@eecs.berkeley.edu

Grading

- Grading will be assigned on:
  - Homework (~30%)
  - Project (~50%)
  - Reading assignments (~10%)
  - Labs (10%)
- Bi-weekly homework.
  - HW #n is due the same day HW #n+1 is handed out

Schedule

Schedule is tight
Don’t fall behind!!!

- Labs (Th. 4-6):
  - Presentation of tools followed by hands-on tutorial and assignments
- Discussion Session (Tu. 5-6)
  - Each student (possibly in groups of 2 people) will have to make one or more oral presentations during the class
- Last two weeks of class dedicated only to projects (usually due the 1st or 2nd week of Dec.)
- Auditors are OK but please register as P-NP (resources are assigned according to students…)

Links

- Class website

http://chess.eecs.berkeley.edu/design/index.html

Outline of the course

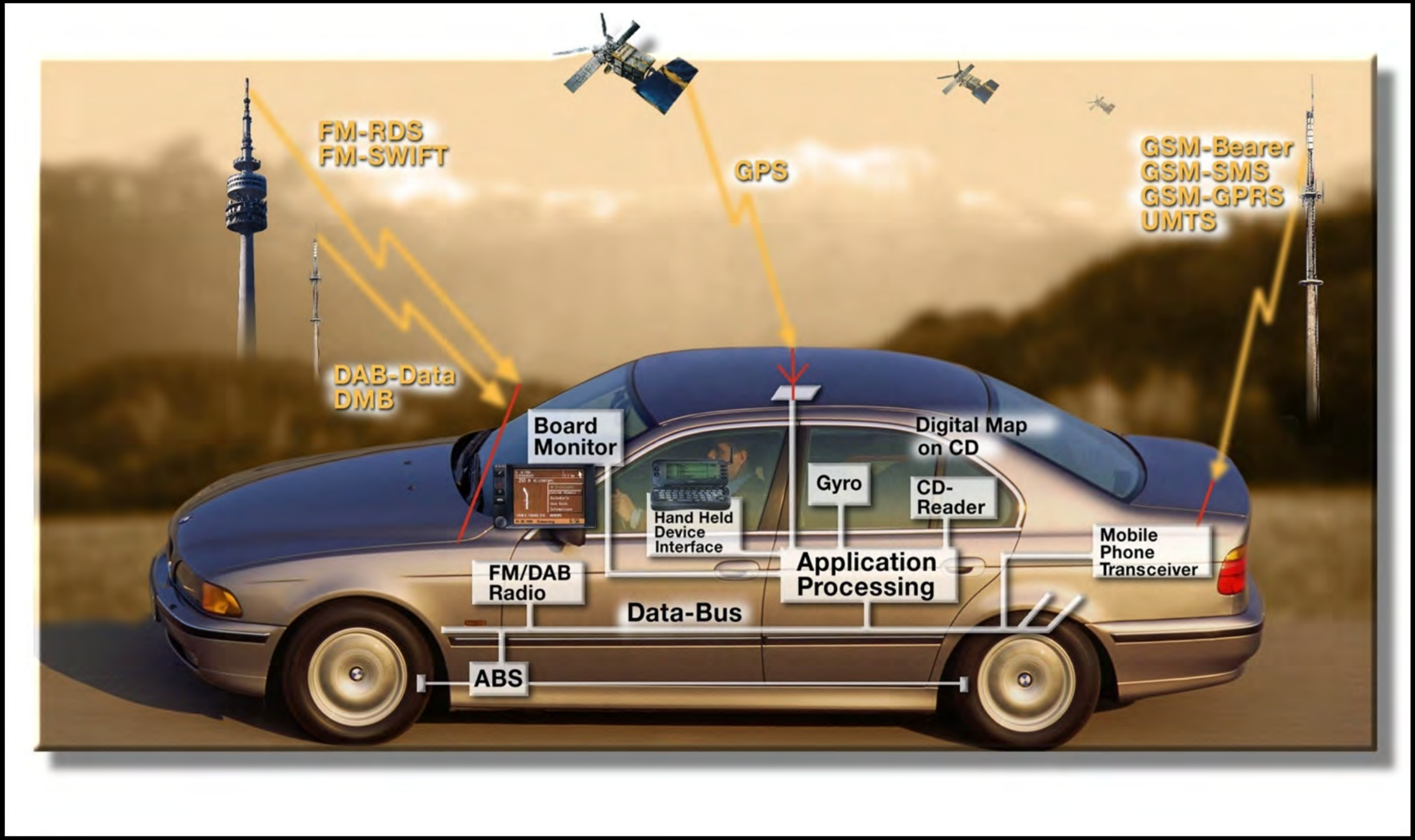
Part 1: Introduction	Design complexity, Example of embedded systems, traditional design flow, Platform-Based Design
Part2: Design Capture	Formalisms for design capture. DOORS
Part 3: Functional modeling, analysis and simulation	Introduction to models of computation. Finite State Machines and Co-Design Finite State Machines, Kahn Process Networks, Data Flow, Petri Nets, Hybrid Systems. Unified frameworks: the Tagged Signal Model, Agent Algebra
Part 3: Architecture and performance abstraction	Definition of architecture, examples. Distributed architecture, coordination, communication. Real time operating systems, scheduling of computation and communication.
Part 4: Mapping	Definition of mapping and synthesis. Software synthesis, quasi static scheduling. Behavioral synthesis. Communication Synthesis and communication-based design
Part 5: Verification	Validation vs Simulation. Verification of hybrid system. Interface automata and assume guarantee reasoning.
Part 6: Applications	Distributed Systems Avinics and Automotive: CAN,Flexray, Auotosar Architecture, GM car architecture, Power generation subsystems in Airplanes, scheduling and timing analysis Building automation: BanNet, LonWorks, ZigBee with applications to energy efficiency and security

Outline for the Introduction

- Examples of Embedded Systems
- Their Impact on Society
- Design Challenges
- Embedded Software and Control

Electronics and the Car

- More than 30% of the cost of a car is now in Electronics
- 90% of all innovations will be based on electronic systems



Automotive Industry
Three Levels of Players

Automakers

- 2005 Revenue: $1.1T
- CAGR 2.8% (2004-2010)

Tier 1 Suppliers

90%+ of revenue from automotive

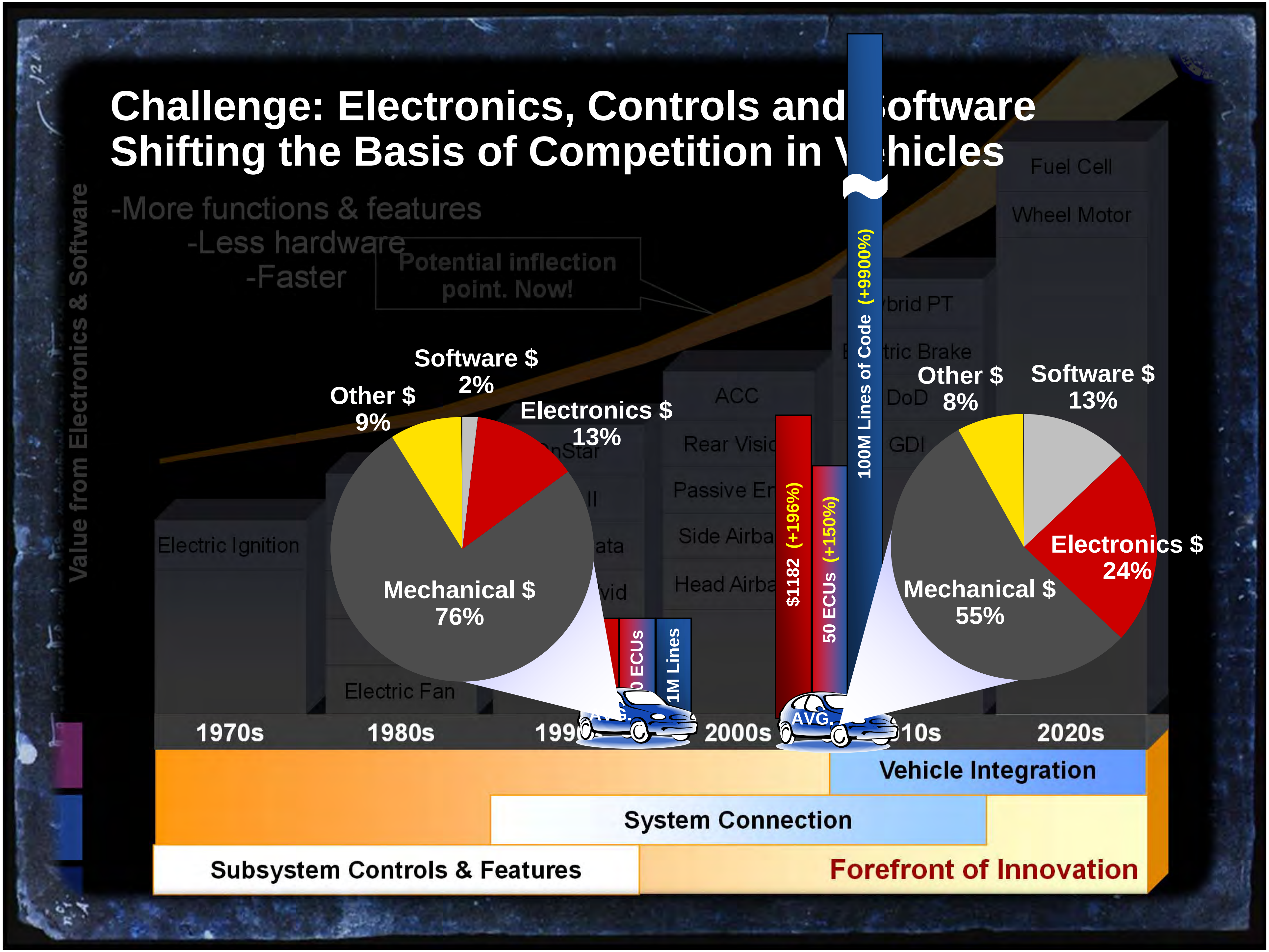
- 2004 Revenue ~$200B
- CAGR 5.4% (2004-2010)

IC Vendors

~15% of revenue from automotive

- 2005 revenue $17.4B
- CAGR 10% (2004-2010)

Source: Public financials, Gartner 2005

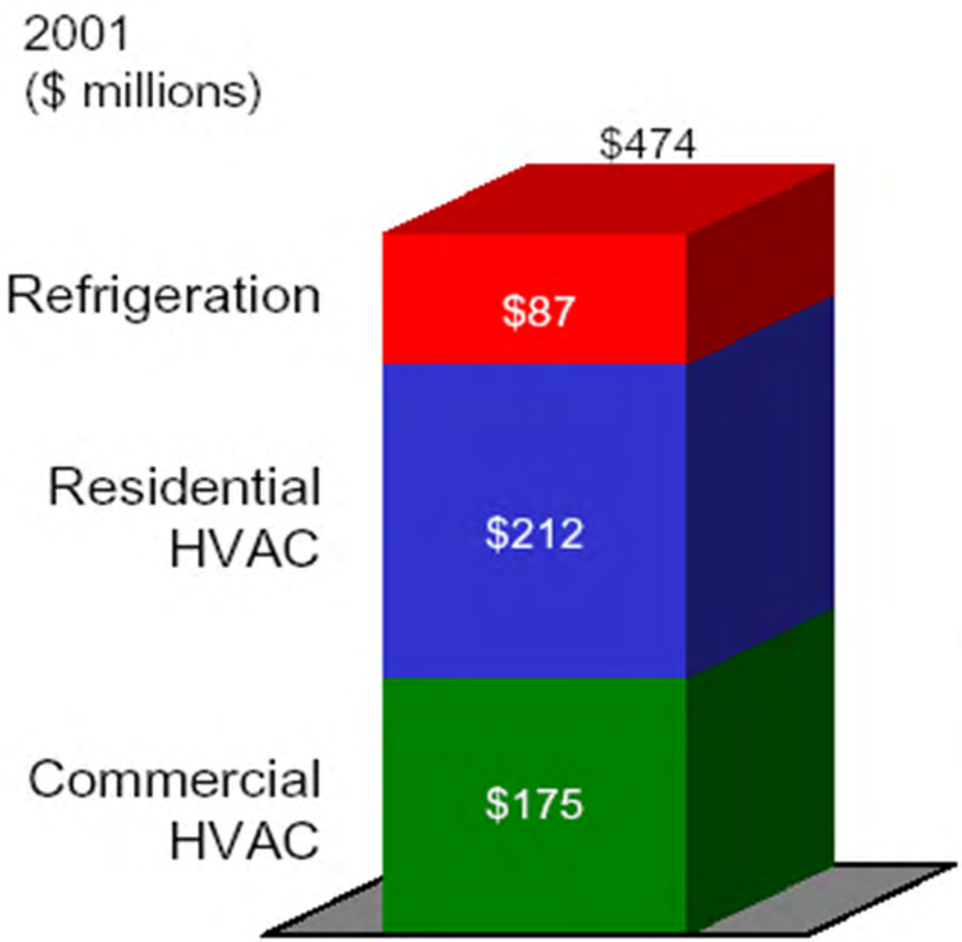

Challenge: Electronics, Controls and Software
Shifting the Basis of Competition in Vehicles
-More functions & features
-Less hardware
-Faster
Potential inflection point. Now!
Value from Electronics & Software
Fuel Cell
Wheel Motor
ACC
Passive Er
Side Airba
Head Airba
Electric Ignition
Electric Fan
Software $ 2%
Other $ 9%
Electronics $ 13%
Mechanical $ 76%
Other $ 8%
Software $ 13%
Electronics $ 24%
Mechanical $ 55%
$1182 (+196%)
50 ECUs (+150%)
100M Lines of Code (+9900%)
1M Lines
AVG.
1970s
1980s
2000s
2020s
Vehicle Integration
System Connection
Subsystem Controls & Features
Forefront of Innovation

GM SAC Vehicular Electronics, Controls and Software Study

- Software content in automobiles could increase by 100 X over the next 5-6 years. Challenges will include:
  - Software system architecture
  - Partitioning for modularity & system reliability
  - Reuse
  - Standardization of interfaces

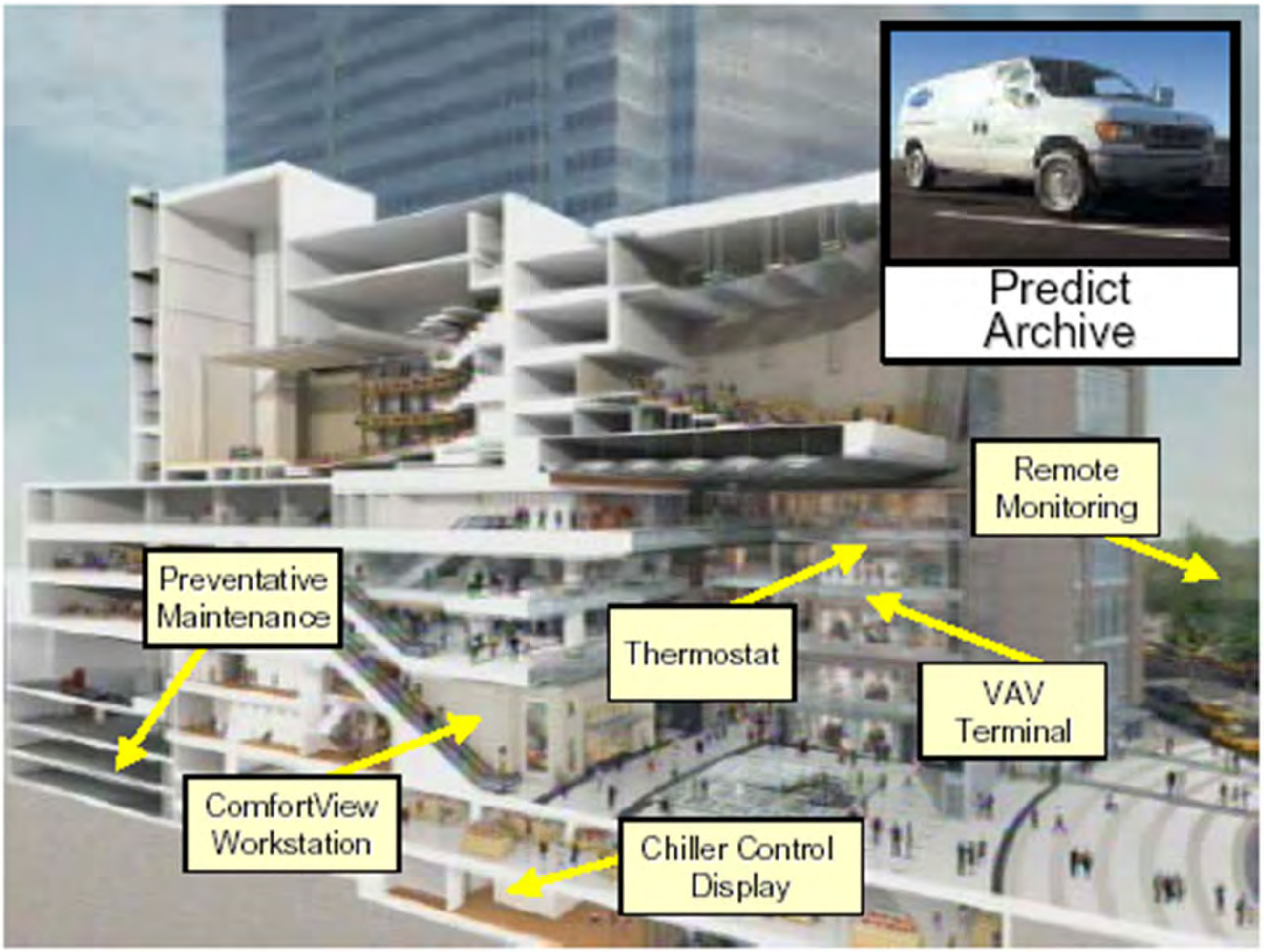
CARRIER CONTROLS BUSINESS

Market segments



FUNCTION OF CONTROLS

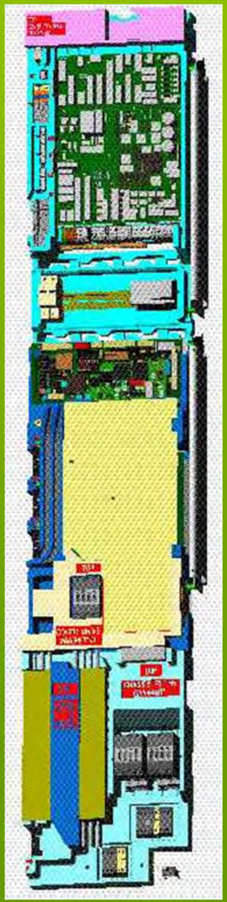
Typical commercial HVAC application



- Configure
- Sense
- Actuate
- Regulate
- Display
- Trend
- Diagnose
- Predict
- Archive

OTIS Elevators

1. EN: GeN2-Cx



2. ANSI: Gen2/GEM

3. JIS: GeN2-JIS

Segments

Attribute	Type 1	Type 2	Type 3
Stops/Rise	< 20 stops Opportunity: < 6 stops (20m)	< 64 stops	< 128 stops
Group Size	Simplex	1 – 8 cars	1 – 8 cars
Speed	< 4m/s <= .75 m/s (ANSI)	< 4 m/s	< 15 m/s
Op Features	Basic	Advanced	Hi-End Dispatch
Motion Features	Basic Perf. Basic FM	Limited Perf. Advanced FM	Advanced Perf. Advanced FM
Code	EN, ANSI, JIS	EN, ANSI, JIS	EN, ANSI, JIS
Remote Service	Yes	Yes	Yes
Price Sensitivity	High	High, Med	Med
Market	Utility	Utility, Design	Design

System Above Chip - SAC

Consumer segments
Common technology elements

aming

Bro

'Systems within systems'

- Multimedia processors
- Embedded µP
- Wireless connectivity
  Baseband processing, RF transceivers
- Power Amps
- Flat panel displays
- Digital signal processor technologies
- VOIP

Locality

Internet

e-commerce

Auto electronics

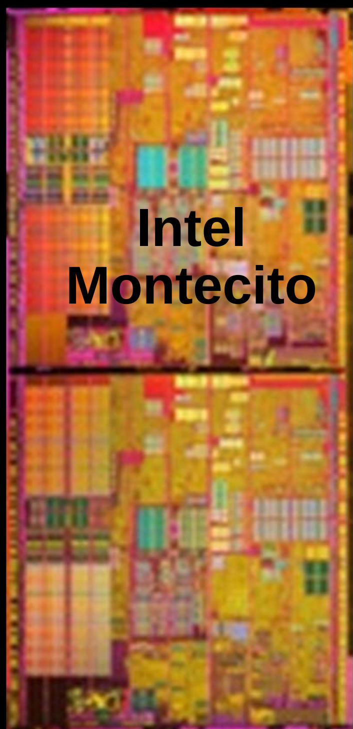
Common Situation in Industry

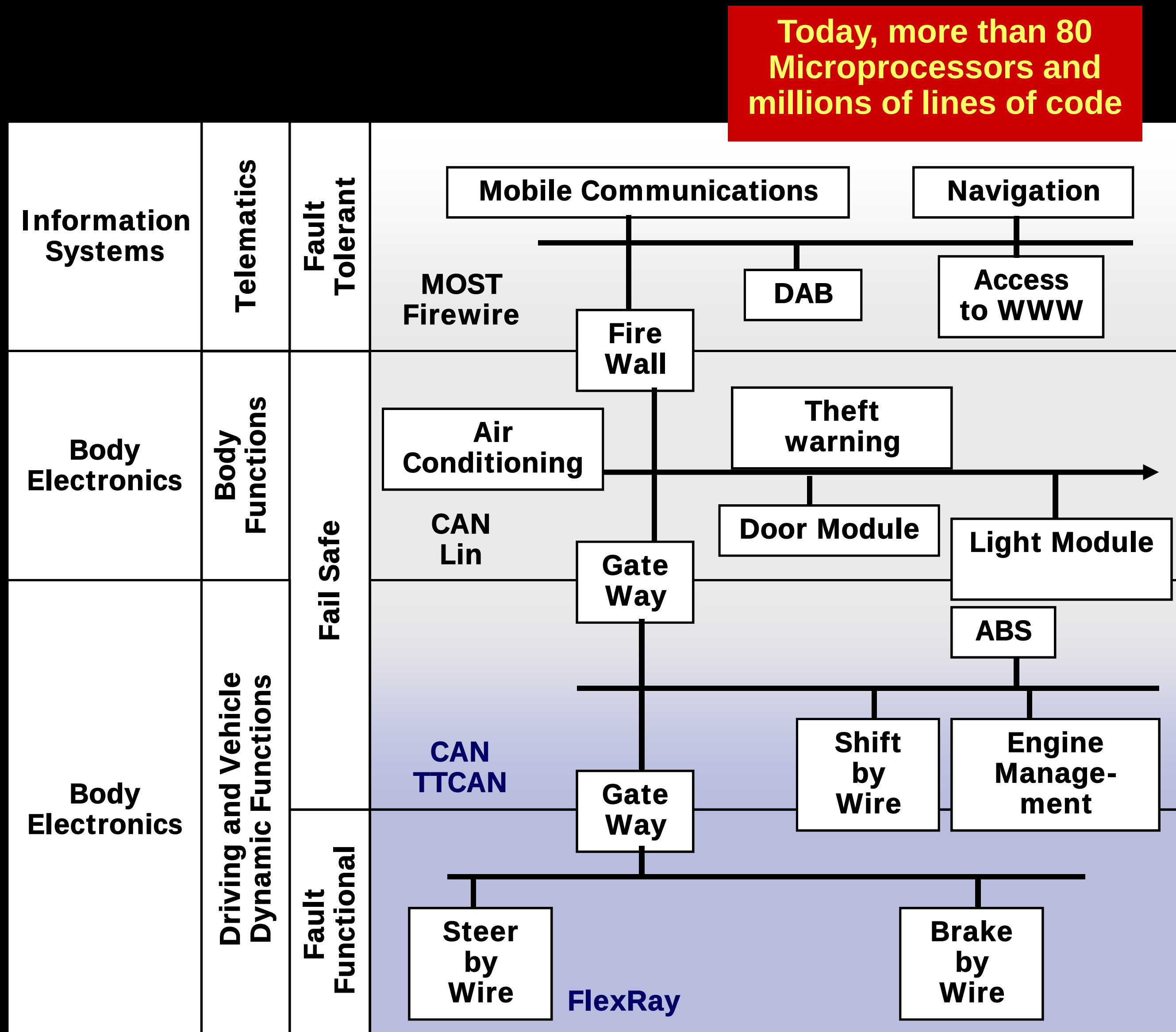
- Different hardware devices and architectures
- Increased complexity
- Non-standard tools and design processes
- Redundant development efforts
- Increased R&D and sustaining costs
- Lack of standardization results in greater quality risks
- Customer confusion

Outline for the Introduction

- Examples of Embedded Systems
- The Future of Embedded Systems and Their Impact on Society
- Design Challenges
- Embedded Software and Control

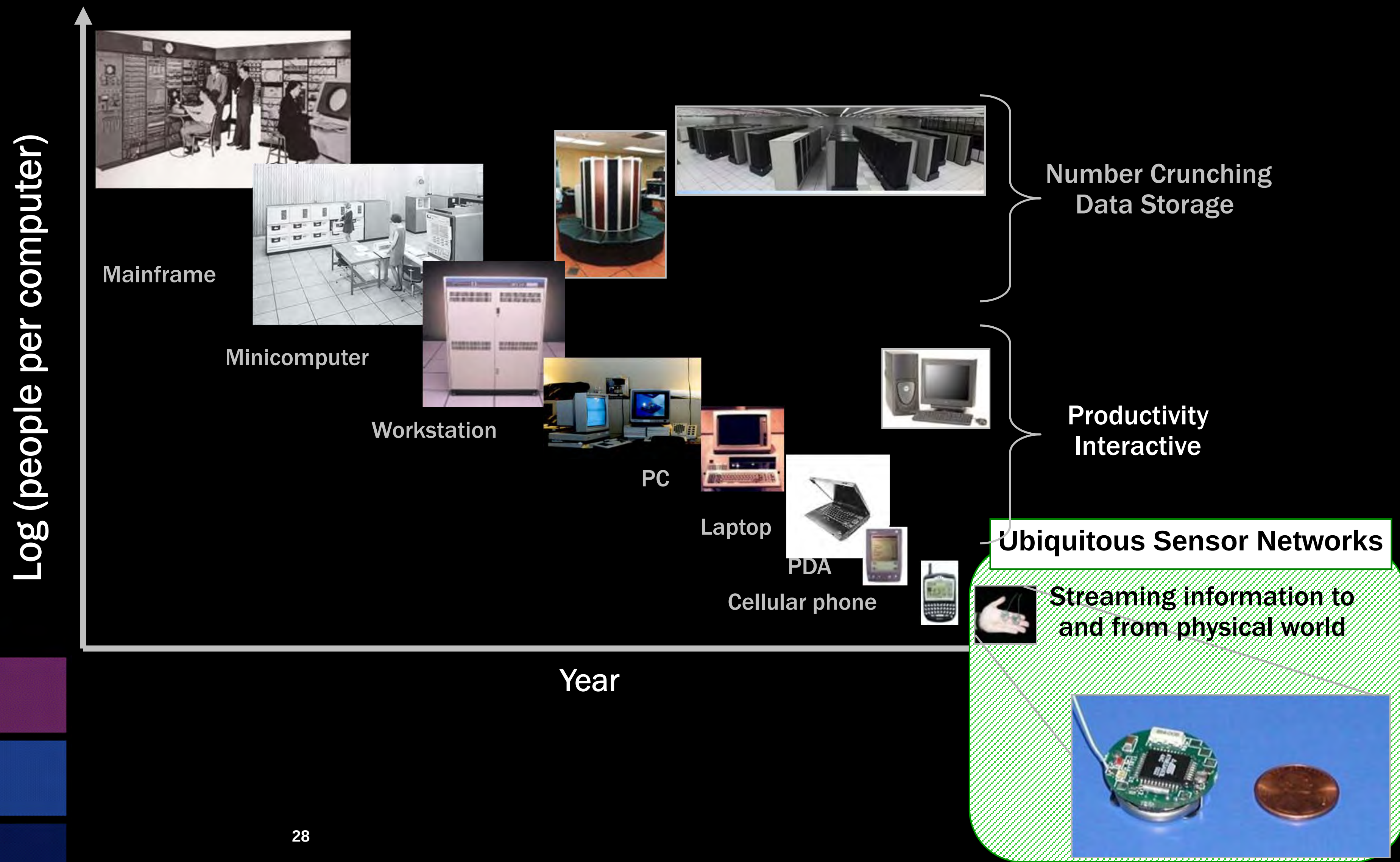
Concurrency and Heterogeneity





Source: Bosch

Challenge: The Physical Internet



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Exponentials Bound to Continue

EE Times: Latest News

Wireless is everywhere; ignore it at your peril

Bolaji Ojo

Page 1 of 2

EE Times

(01/07/2008 9:00 AM EST)

PRINT THIS STORY

SEND AS EMAIL

REPRINTS

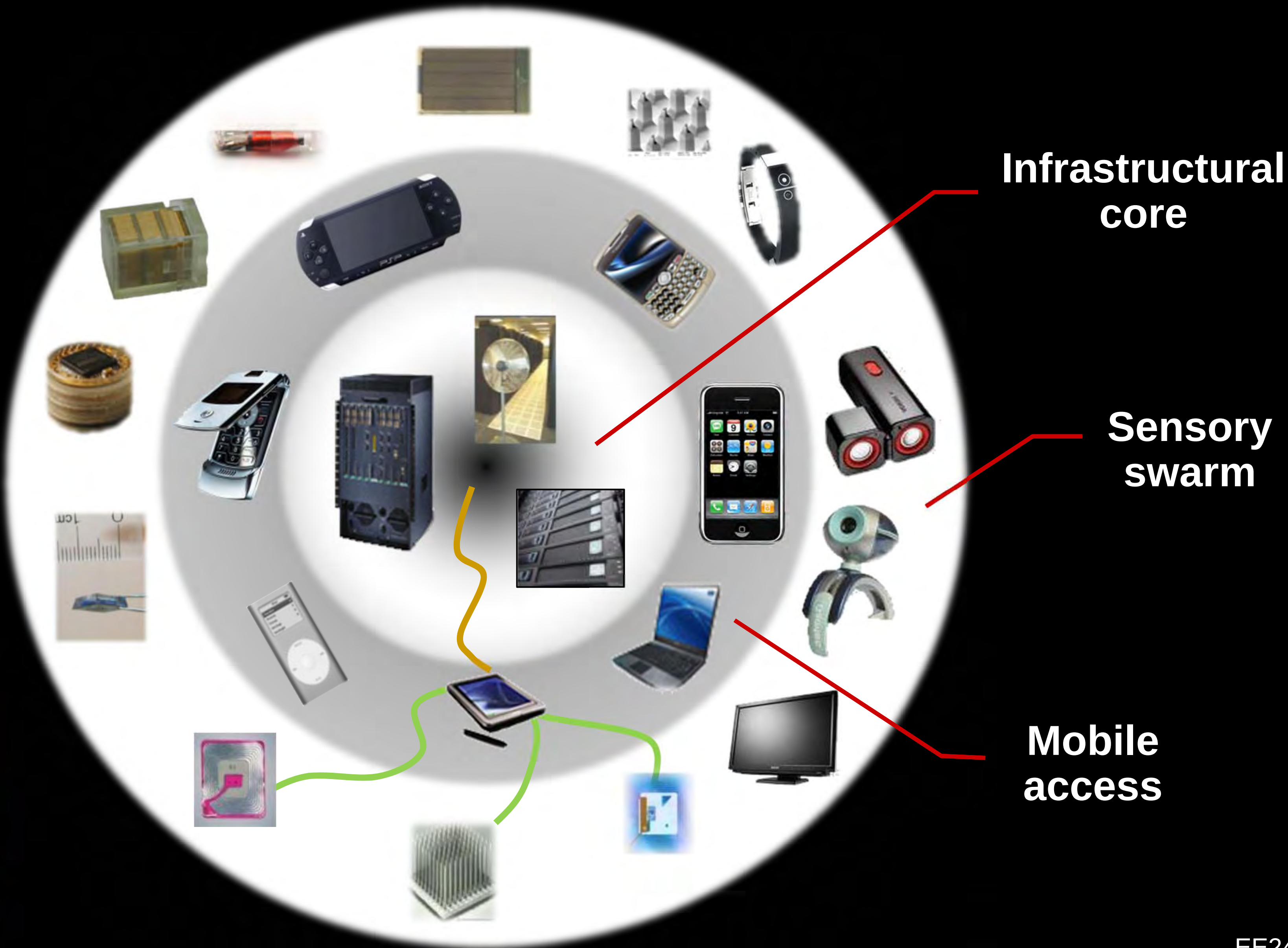
The search is over for the next killer app. It is wireless, it is all around you, and it will leave no sector of the global economy untouched.

EE Times, January 07, 2008

- 5 Billion people to be connected by 2015 (Source: NSN)
- The emergence of Web2.0
  - The “always connected” community network
- 7 trillion wireless devices serving 7 billion people in 2017 (Source: WirelessWorldResearchForum (WWRF))
  - 1000 wireless devices per person?

[Courtesy: Niko Kiukkonen, Nokia]

The Emerging IT Scene



The Technology Gradient: Computation

Driven by Moore's Law

Driven by "More Than Moore" and "Beyond Moore"

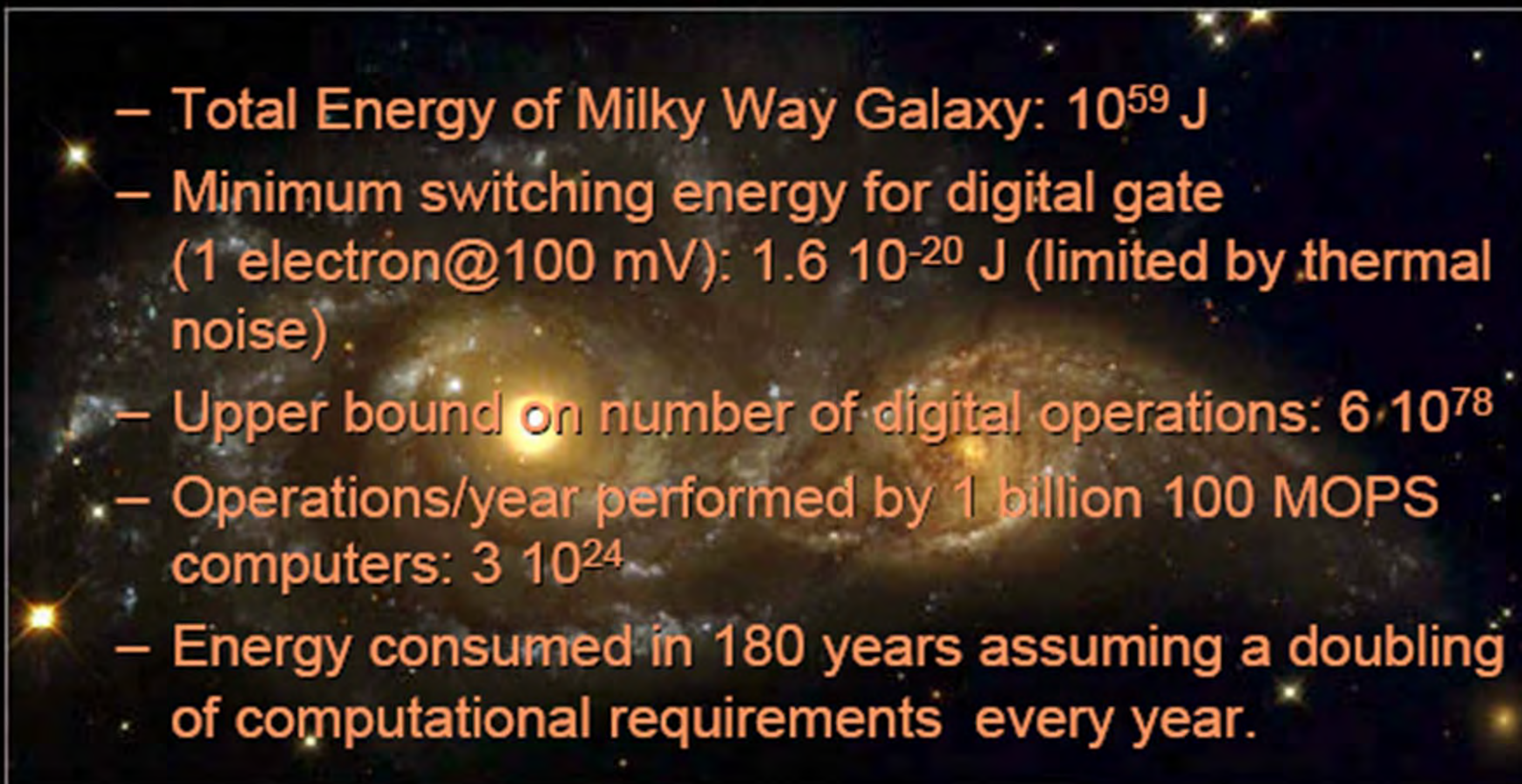
The Technology Gradient: Communication

Mostly wired

Almost uniquely wireless

Challenge: Power

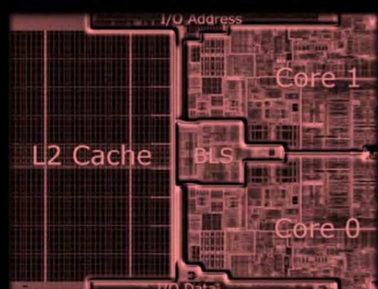
Energy = upper bound on the amount of available computation



- Total Energy of Milky Way Galaxy: 10^{59} J
- Minimum switching energy for digital gate (1 electron@100 mV): 1.6 10^{-20} J (limited by thermal noise)
- Upper bound on number of digital operations: $6 \cdot 10^{78}$
- Operations/year performed by 1 billion 100 MOPS computers: 3 10^{24}
- Energy consumed in 180 years assuming a doubling of computational requirements every year.

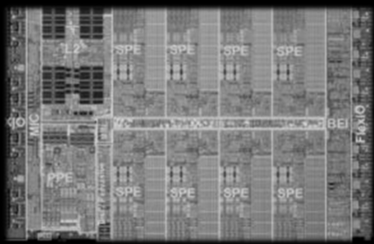
Challenge: Parallel Architectures

Scaling enabled integration of complex systems with hundreds of millions of devices on a single die



Intel KEROM dual core
ISSCC 07, 290M trans.

SUN Niagara-2
ISSCC 07, 500M trans.



IBM/Sony Cell
ISSCC 05, 235M trans.

Challenge: Design Chain Integration
Automotive Industry

Automakers

GM
Ford
TOYOTA
HONDA
DAIMLERCHRYSLER
VW

2005 Revenue
$1.1T

CAGR 2.8%
(2004-2010)

Tier 1 Suppliers

Visteon
DENSO
JOHNSON CONTROLS
BOSCH
DELPHI

90%+ of revenue from automotive

2004 Revenue
~$200B

CAGR 5.4%
(2004-2010)

IC Vendors

freescale semiconductor
RENESAS
ST
Infineon
NEC

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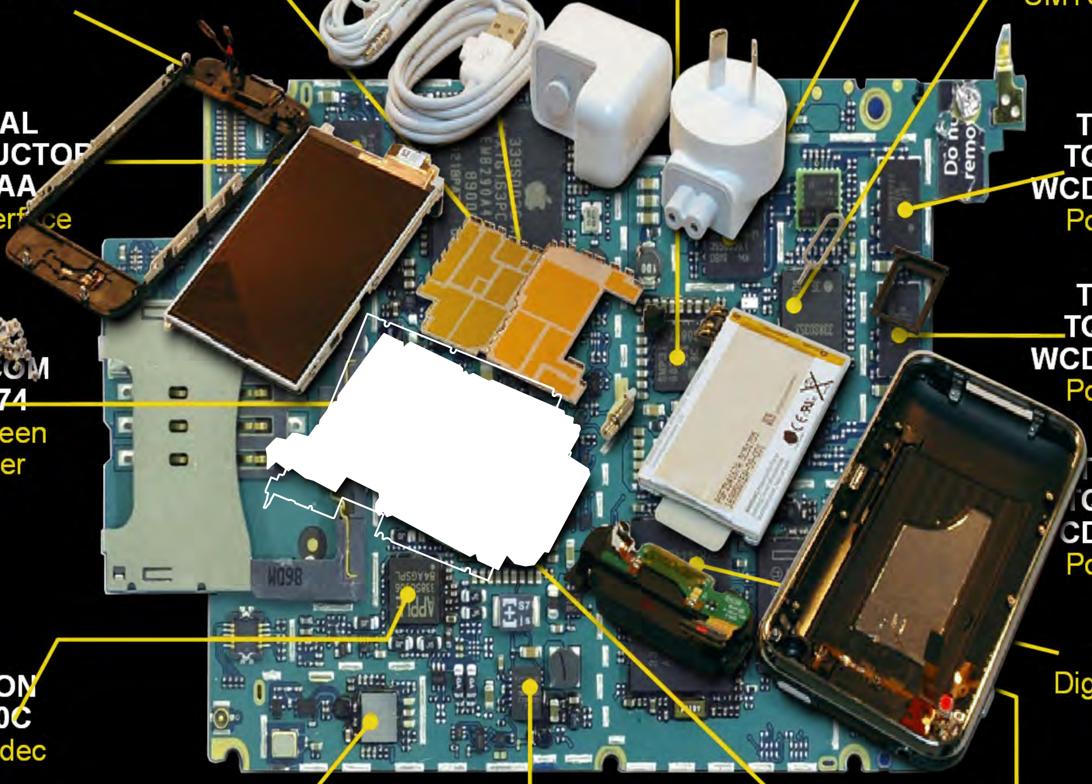
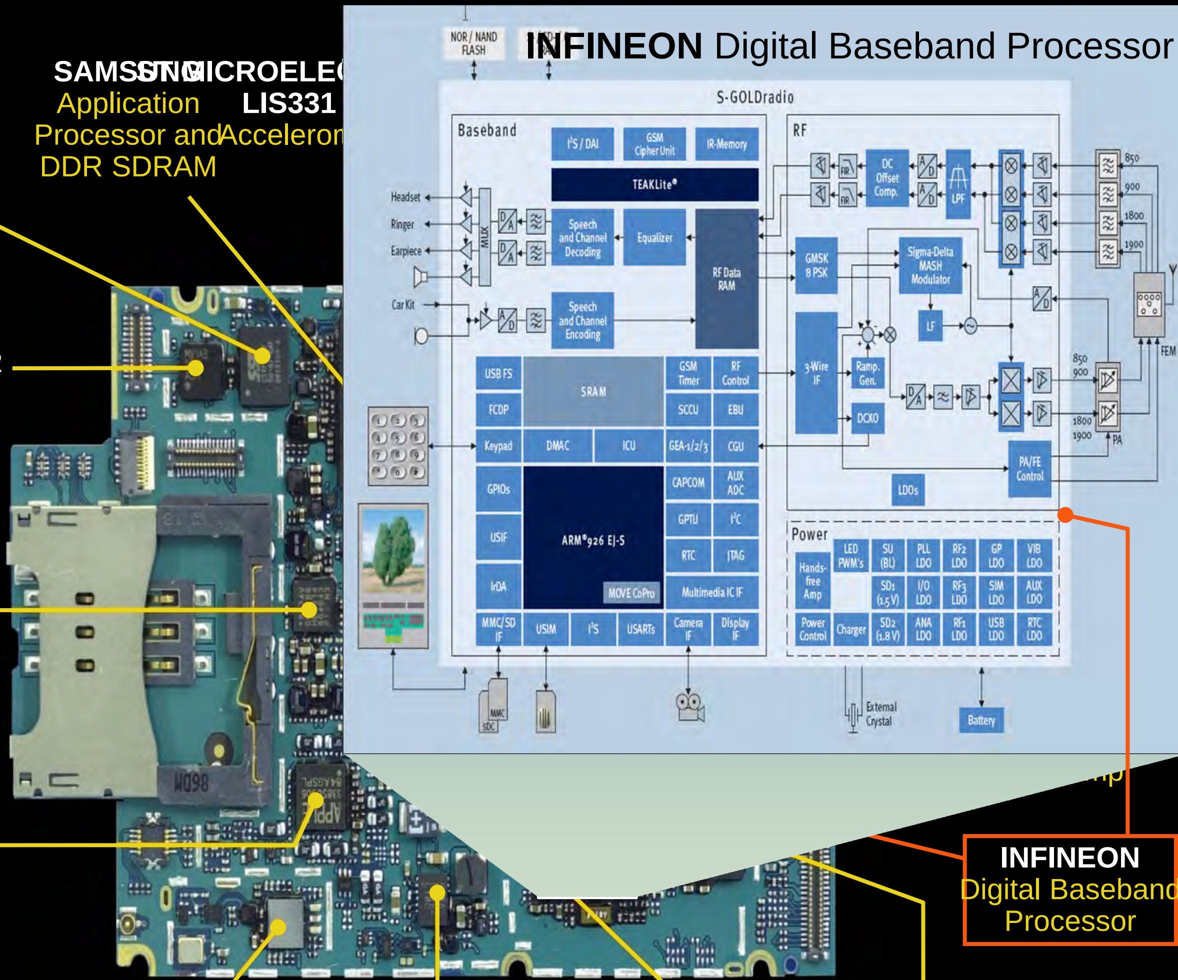
Source: Public financials, Gartner 2005

Collaborating to Create the iPhone



Collaborating to Create the iPhone



SST
SST25VF080B
1 MB Serial Flash

SAMSUNG
Application Processor and DDR SDRAM

STMICROELEC
LIS331
Acceleron

NATIONAL SEMICONDUCTOR
LM2512AA
Display Interface

BROADCOM
BCM5974
Touchscreen Controller

WOLFSON
WM6180C
Audio Codec

INFINEON
Digital Baseband Processor

INFINEON
PMB2525
Hammerhead II GPS

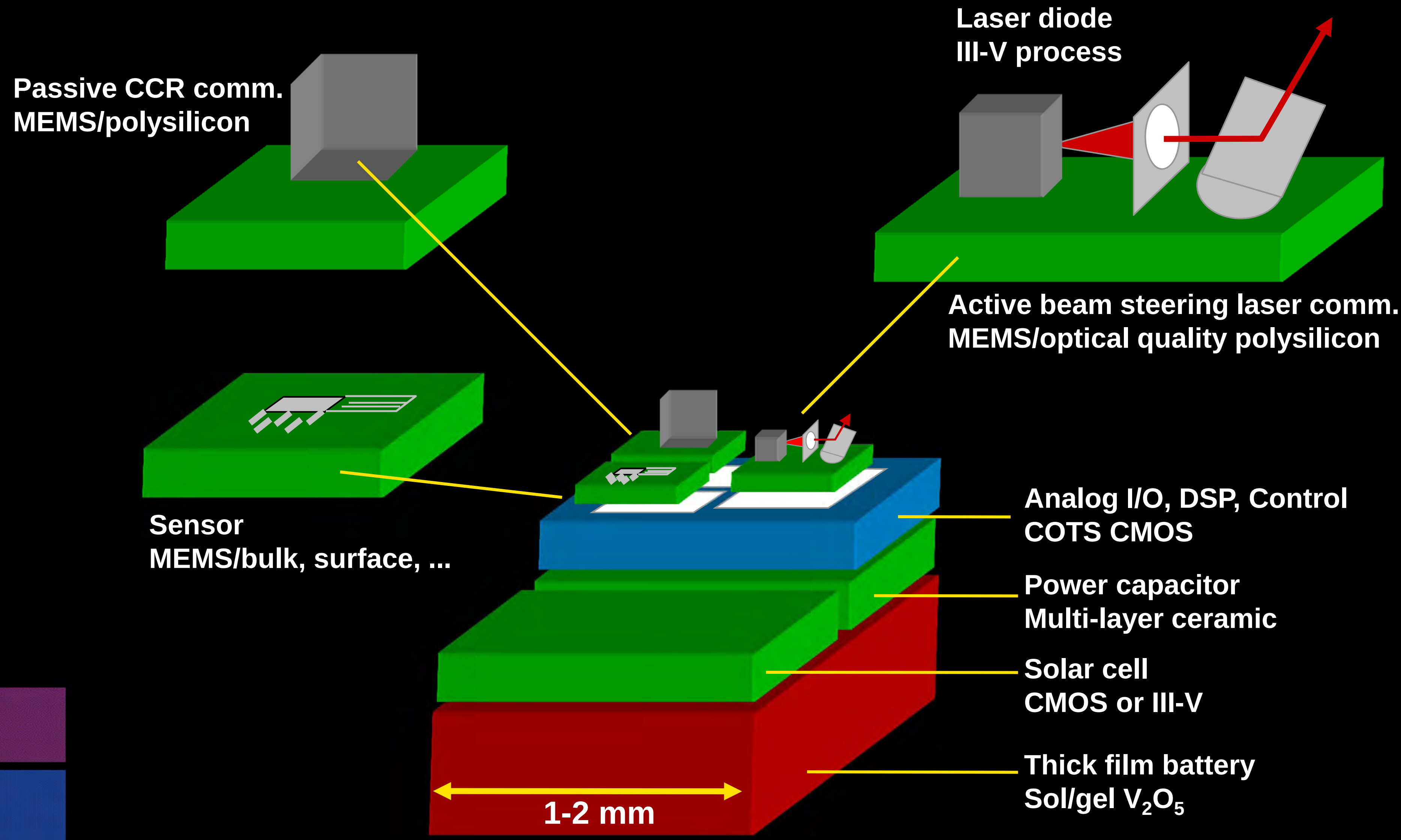
LINEAR TECHNOLOGY
LTC4088-2
Battery Charger/ USB Controller

NXP
Power Management

NUMONYX
PF38F3050M0Y0CE
16 MB NOR + 8 MB Pseudo - SRAM

Semiconductor insights

Smart Dust

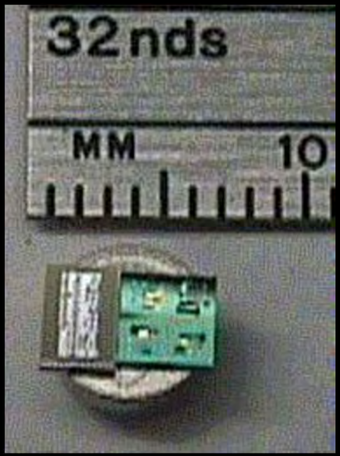


Source: K. Pister, Berkeley

Wireless Sensor Networks

The use of wireless networks of embedded computers "could well dwarf previous milestones in the information revolution" - National Research Council Report: Embedded, Everywhere", 2001.

Berkeley Dust Mote[1]



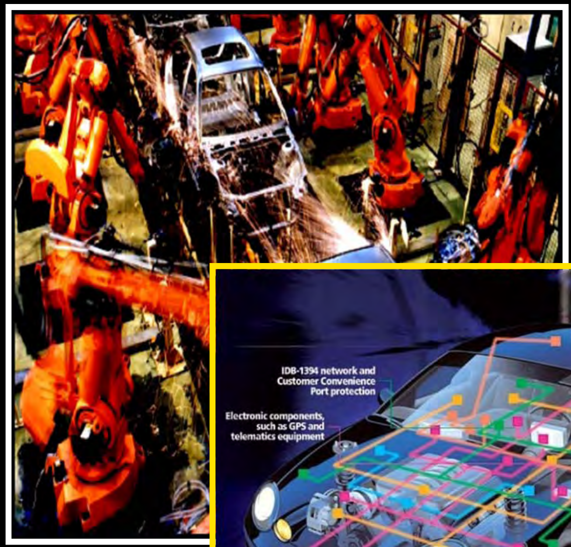
Berkeley Mote[1]

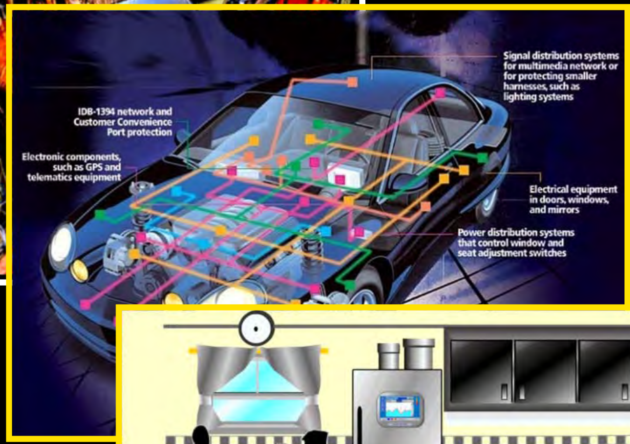
[1]**From Pister *et al.*, *Berkeley Smart Dust Project***

Creating a Whole New World of Applications

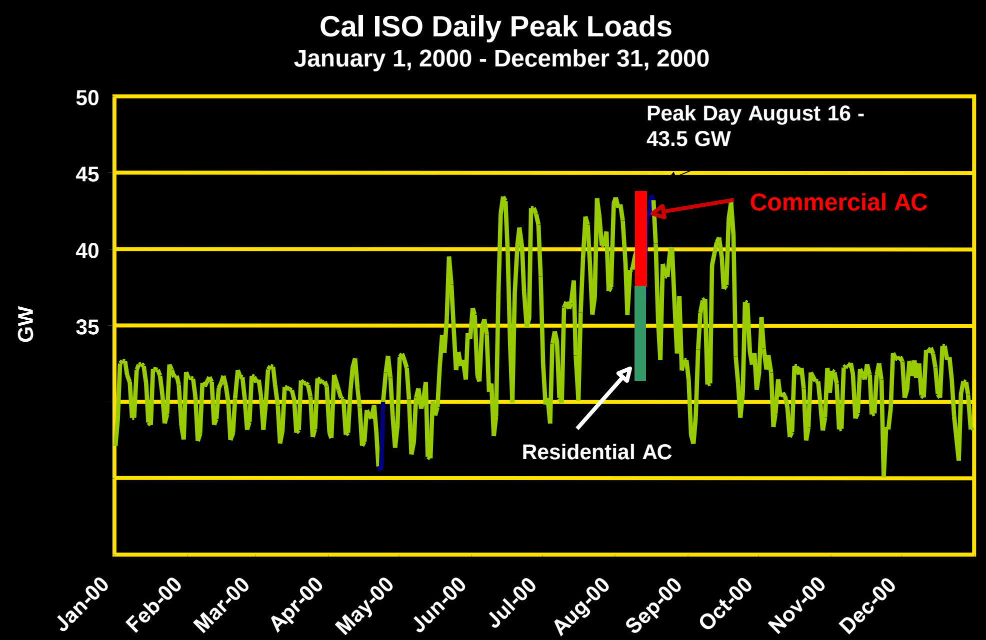
From Monitoring

To Automation



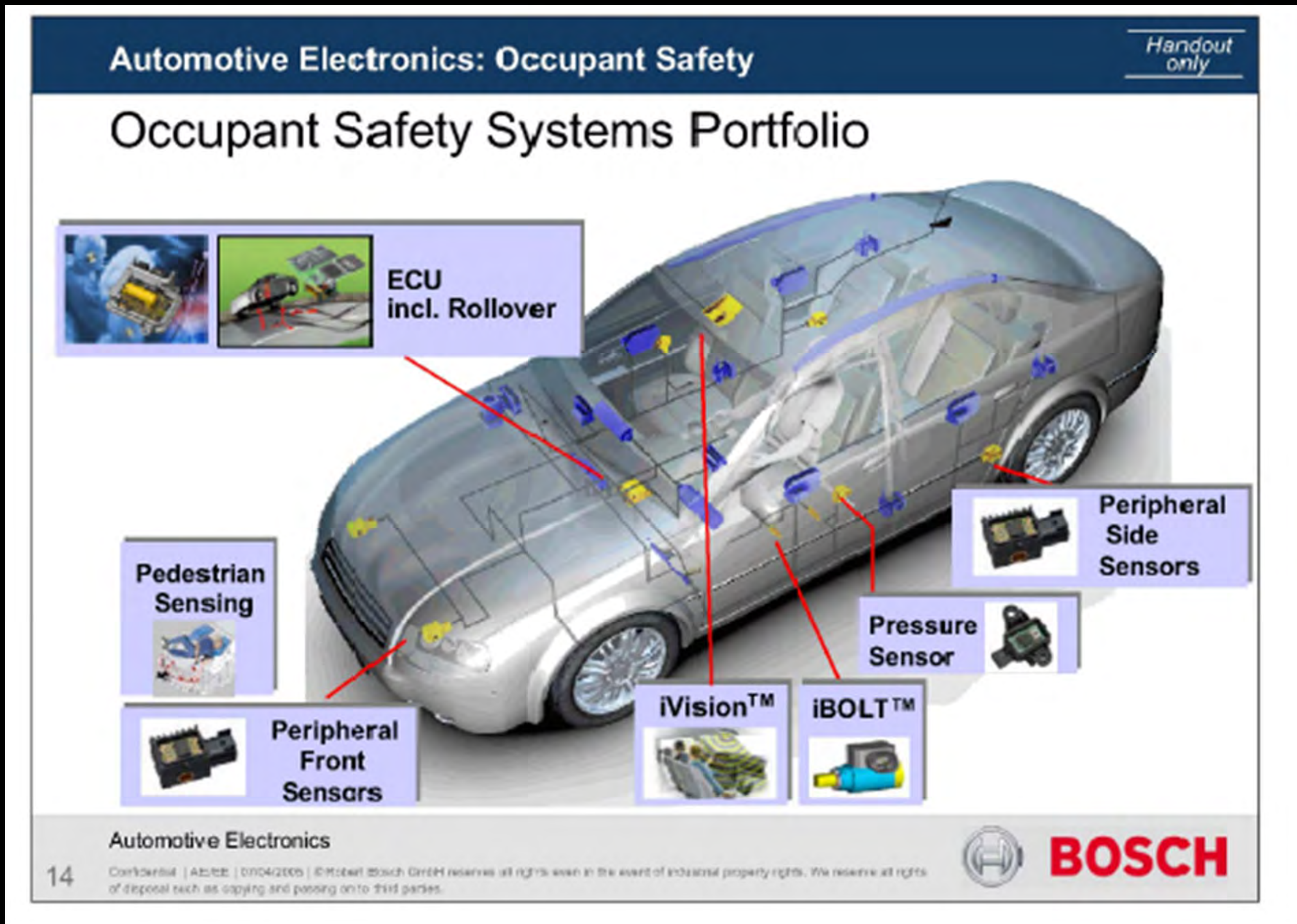


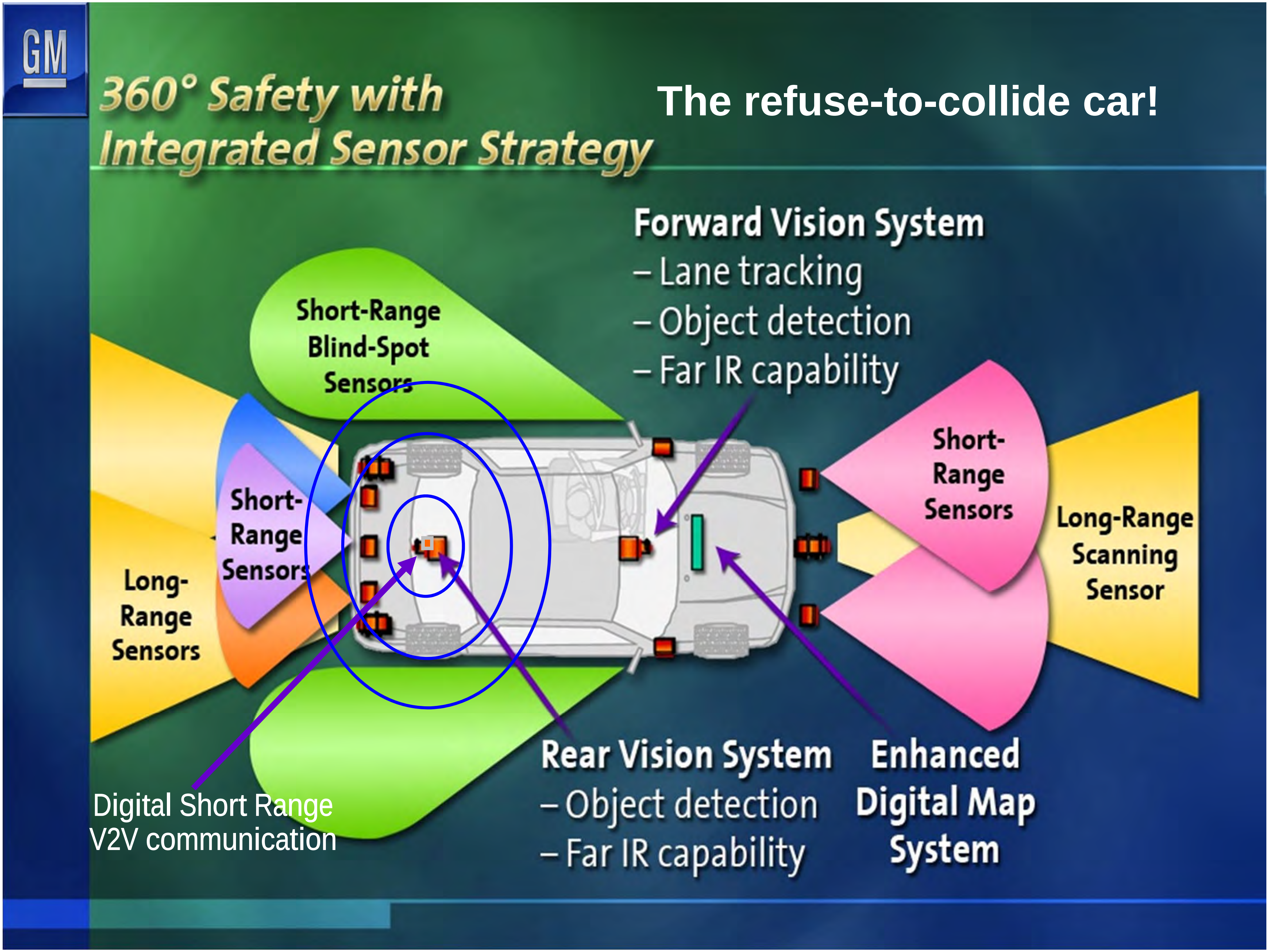
Energy Management and Conservation



Demand response:
Make energy prices dependent upon time-of-use

- Advanced thermostats operate on required level of comfort, energy cost, weather forecast and distributed measurements to offload peak times
- Appliances are energy and cost aware


Automotive Electronics: Occupant Safety
Handout only
Occupant Safety Systems Portfolio
ECU incl. Rollover
Pedestrian Sensing
Peripheral Front Sensors
iVisionTM
iBOLTTM
Pressure Sensor
Peripheral Side Sensors
Automotive Electronics
14
BOSCH


GM
360° Safety with
Integrated Sensor Strategy
The refuse-to-collide car!
Forward Vision System
– Lane tracking
– Object detection
– Far IR capability
Short-Range
Blind-Spot
Sensors
Short-
Range
Sensors
Long-
Range
Sensors
Short-
Range
Sensors
Long-Range
Scanning
Sensor
Digital Short Range
V2V communication
Rear Vision System
– Object detection
– Far IR capability
Enhanced
Digital Map
System

The Tire of the Future

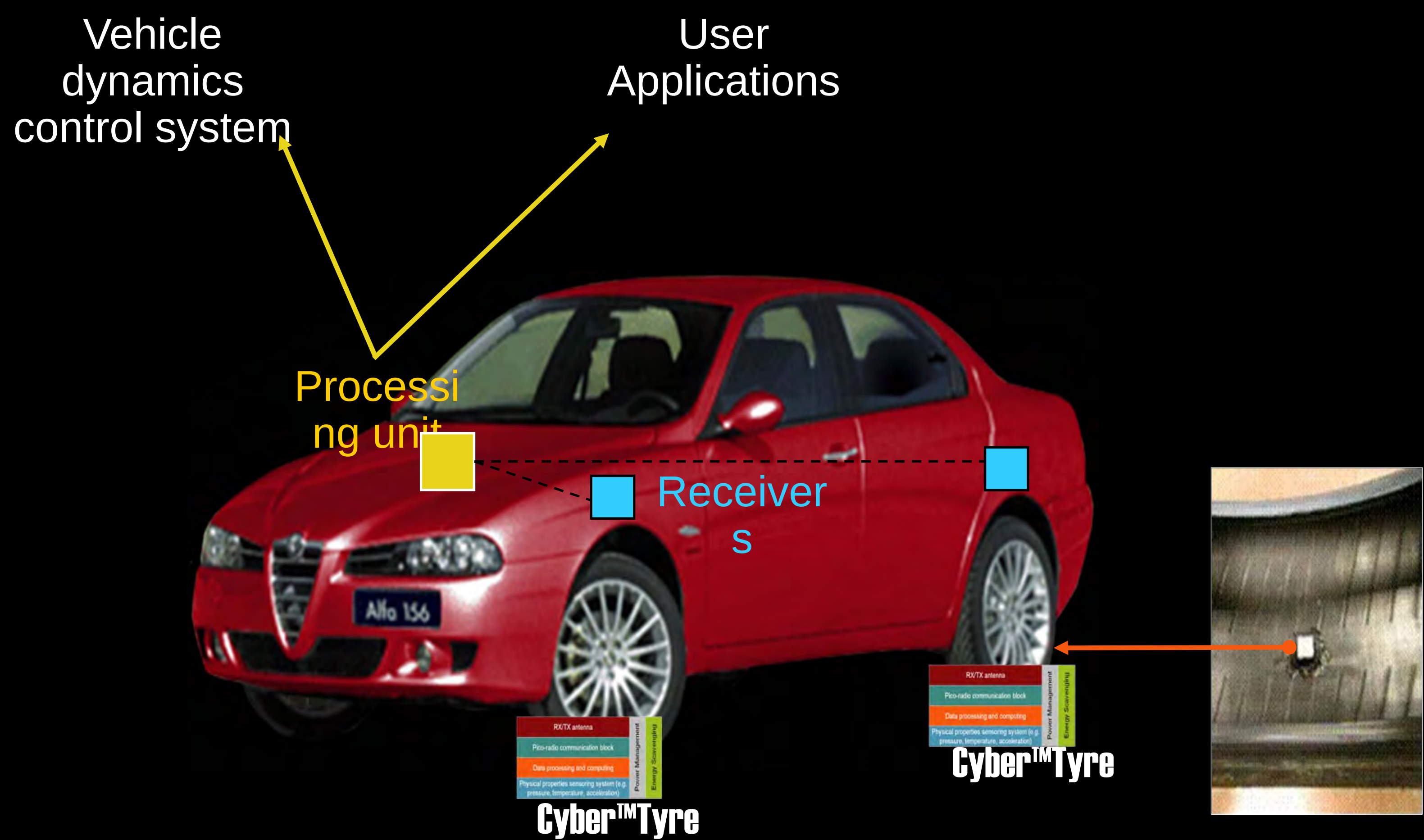
New materials: enhanced performances, reduced rolling resistance, lower noise, reduced puncture risk, nanotechnologies, new compounds, new tread design, "self sealing" technologies.

New design technologies: virtual engineering for reducing time to market & engineering costs.

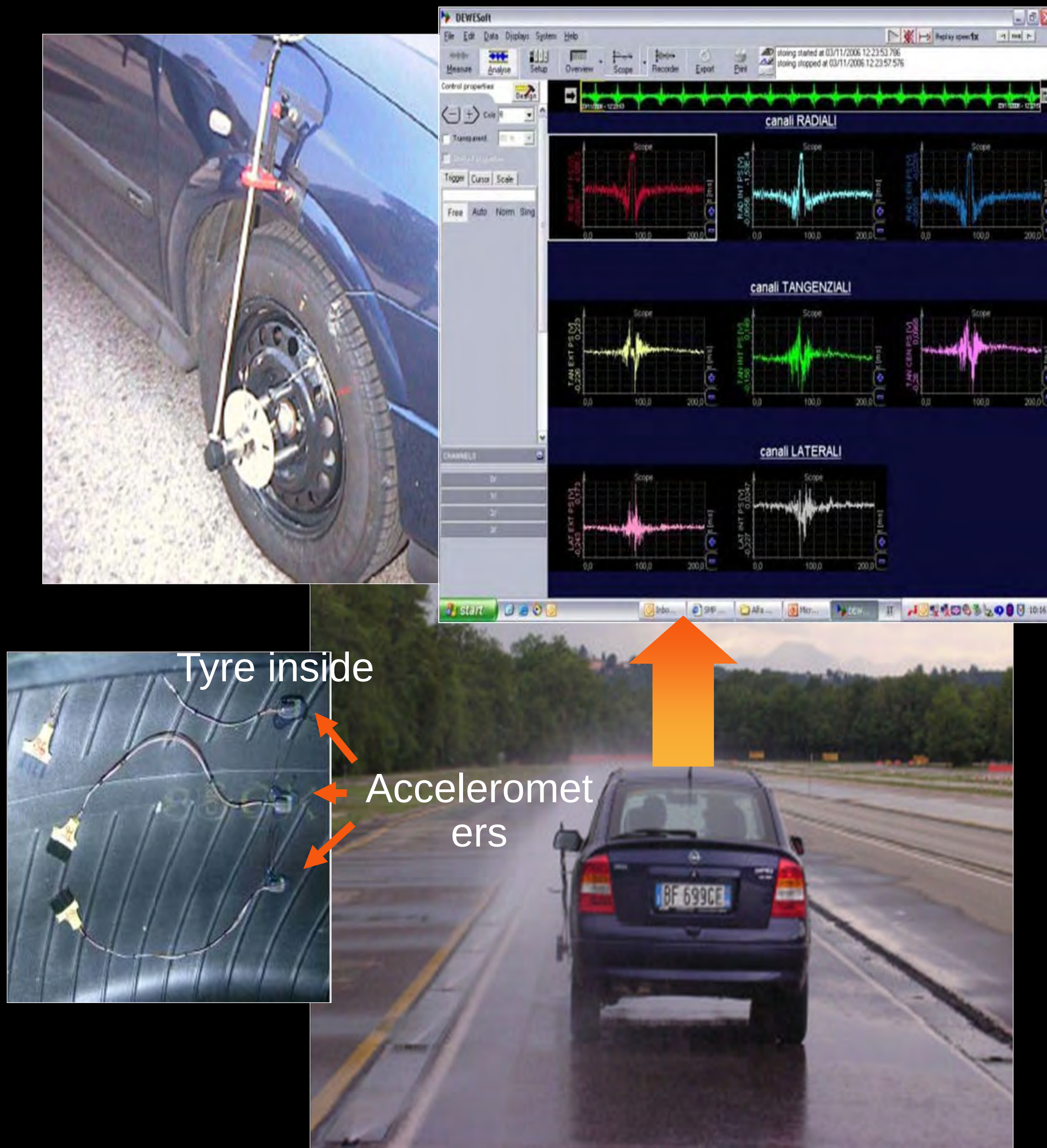
New electronics technologies inside the tire: pressure monitoring, friction, slip, tire consumption, contact force, "health" check-up information extraction & transmission....

The Tire as an Intelligent Sensor!

Cyber™ Tyre Intelligent Tire System



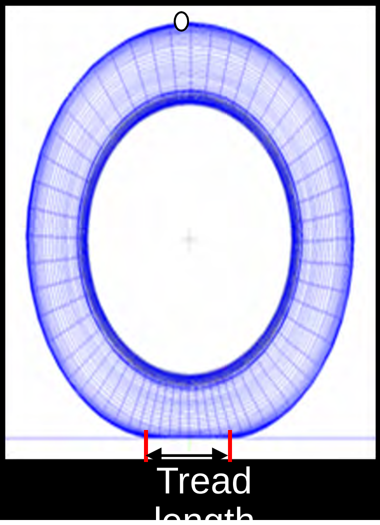
Experimental Tests

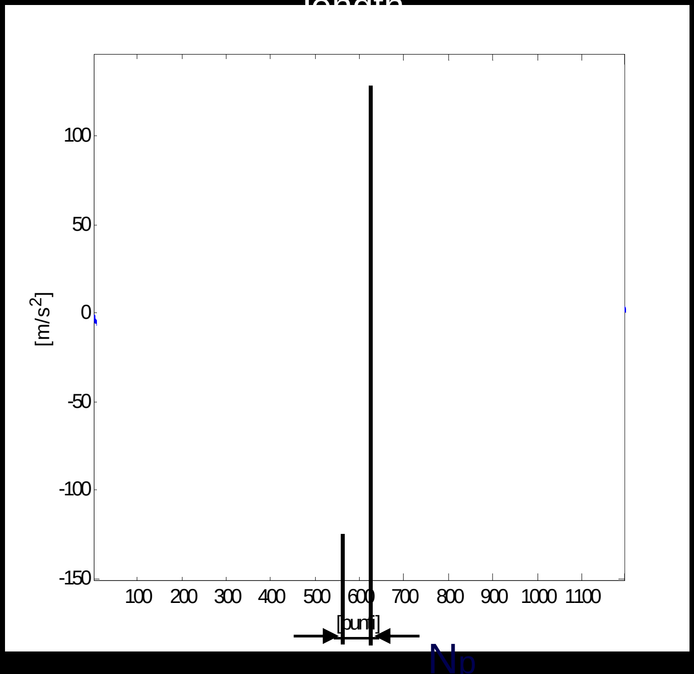


Wide database

- Different tires
- Different sensor positioning
- Different speeds
- Different tracks
  - Steering pad
  - Straight line
  - Braking
  - Acceleration
  - ...
- Different conditions
  - Dry
  - Wet
  - Ice

Tread Length Estimation





- Minimum of the tangential component signal: tread area entry
- Maximum of the tangential component signal: tread area exit

$$PL = N_p / f_c \cdot \omega \cdot R_{rot}$$

PL : tread length

R_{rot} : rolling radius

ω : angular speed

f_c : sampling rate

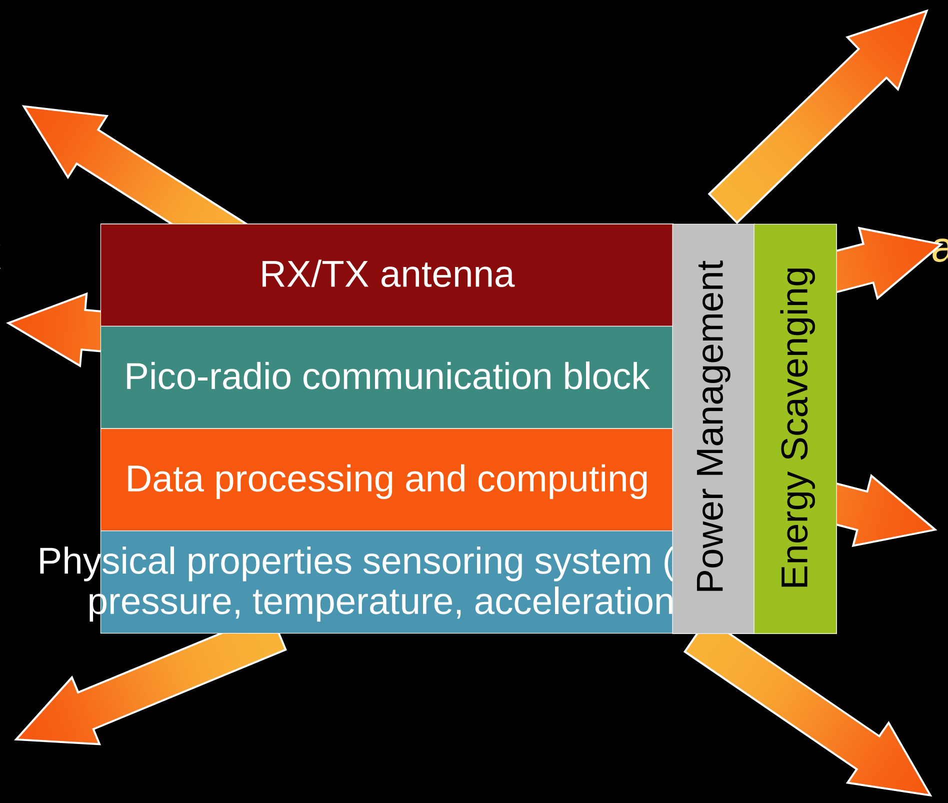
Cyber™Tyre Development Partners

Politecnico di Torino
Prototype Vehicle Integration, Engineering Support

Politecnico di Milano
Feature Extraction, kinematics pre-conditioner

UMC
IP and chip manufacturing

University of California, Berkeley
Ultra low power radio
....
Advanced new communication protocols



Valtronic Technologies SA
assembly and packaging technologies

Encrea S.r.L.
Breakthrough energy supply and power management technologies

Accent S.p.A.
acquisition, processing and advanced architectural technologies

Industrial Plants

Monitoring:
Vibrations, Temperature,
Humidity, Position, Logistics

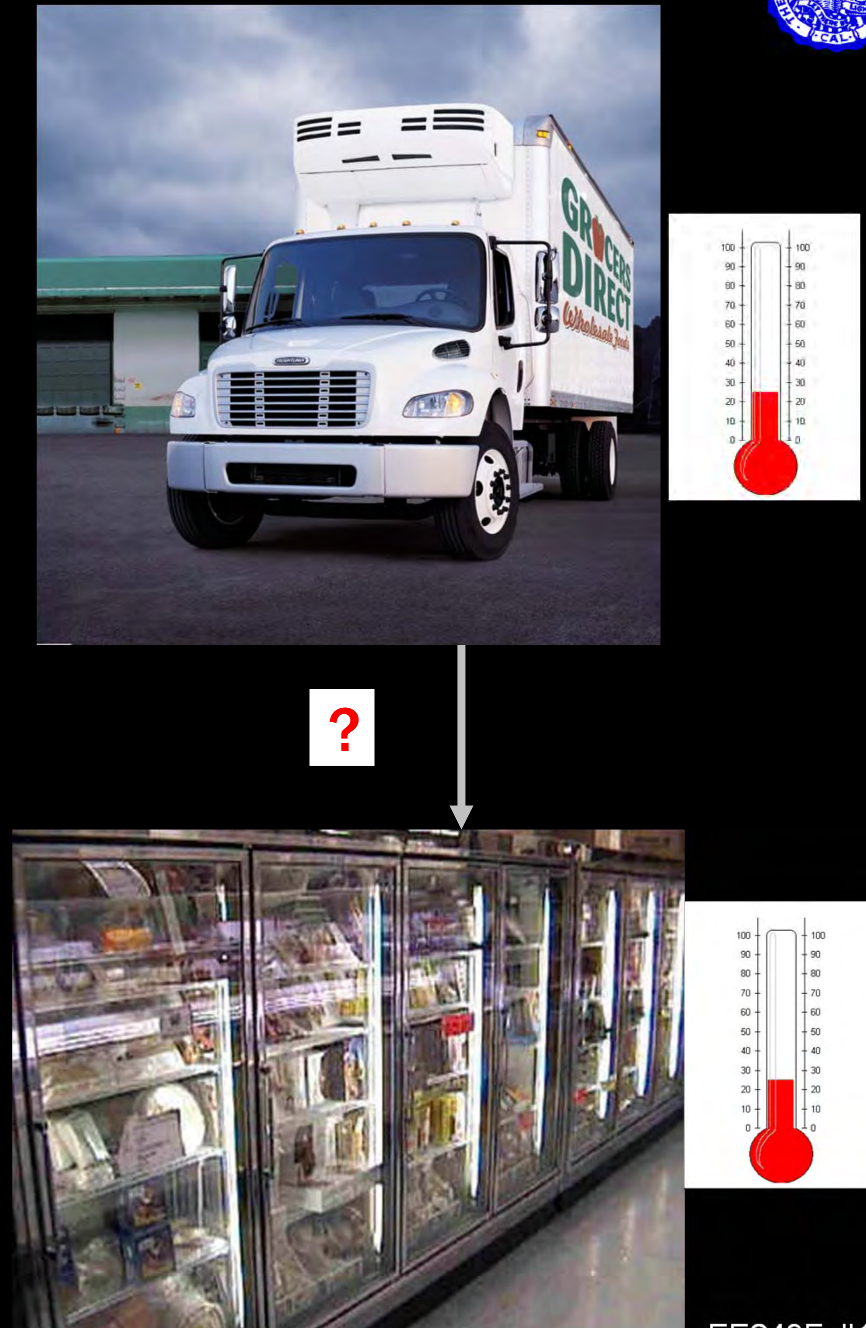
Current solution:
Wired Infrastructure

Future solution:
WIRELESS

Wireless advantages:
Reduce cabling
Enhance flexibility
Easy to deploy
Higher safety
Decreased maintenance costs

Temperature Tracking

- No or little real-time data on assets, environment, or activity
  - Inventory/supply management
    - Pharmaceutical
    - Foods
  - Automated meter reading



Source: Xbow

Preventative Maintenance Program on Oil Tankers

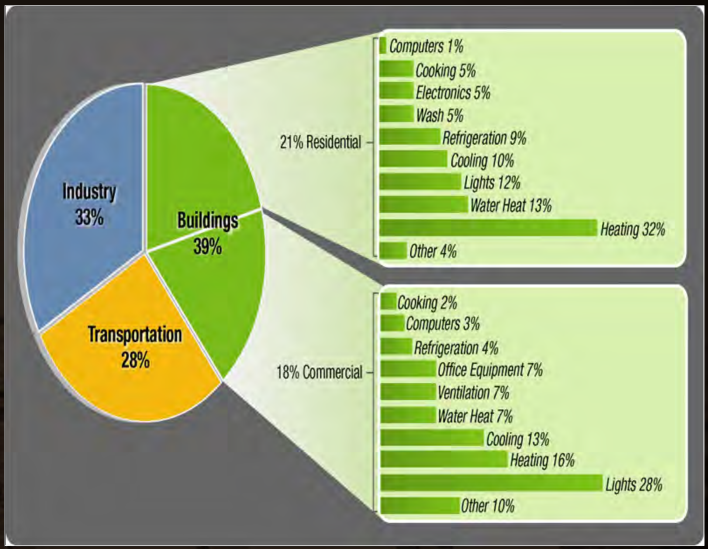
- The task:
  - Engine monitoring is critical for both keeping the ship operational and complying with insurance policy.
- Old Methods
  - Manually record vibration profile with data loggers.
  - Post process data for engine health and diagnostics.

Source: Xbow

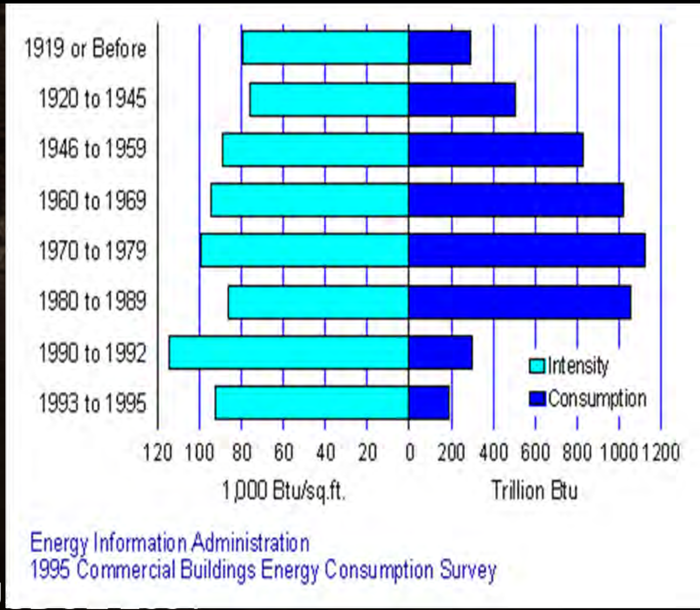
Building Energy Demand Challenge

- Buildings consume
  - 39% of total U.S. energy
  - 71% of U.S. electricity
  - 54% of U.S. natural gas
- Building produce 48% of U.S. carbon emissions
- Commercial building annual energy bill: $120 billion
- The only energy end-use sector showing growth in energy intensity
  - 17% growth 1985 - 2000
  - 1.7% growth projected through 2025

Energy Breakdown by Sector



Energy Intensity by Year Constructed



Sources: Ryan and Nicholls 2004, USGBC, U

Systems of Systems Approach to Energy Efficiency

Buildings Design Energy and Economic Analysis

Windows and Lighting

HVAC

Domestic/International Policies, Regulation, Standards, Markets

Demonstrations, Benchmarking, Operations and Maintenance

Natural Ventilation, Indoor Environment

Networks, Communications, Performance Database

Sensors, Controls, Performance Metrics

Power Delivery and Demand Response

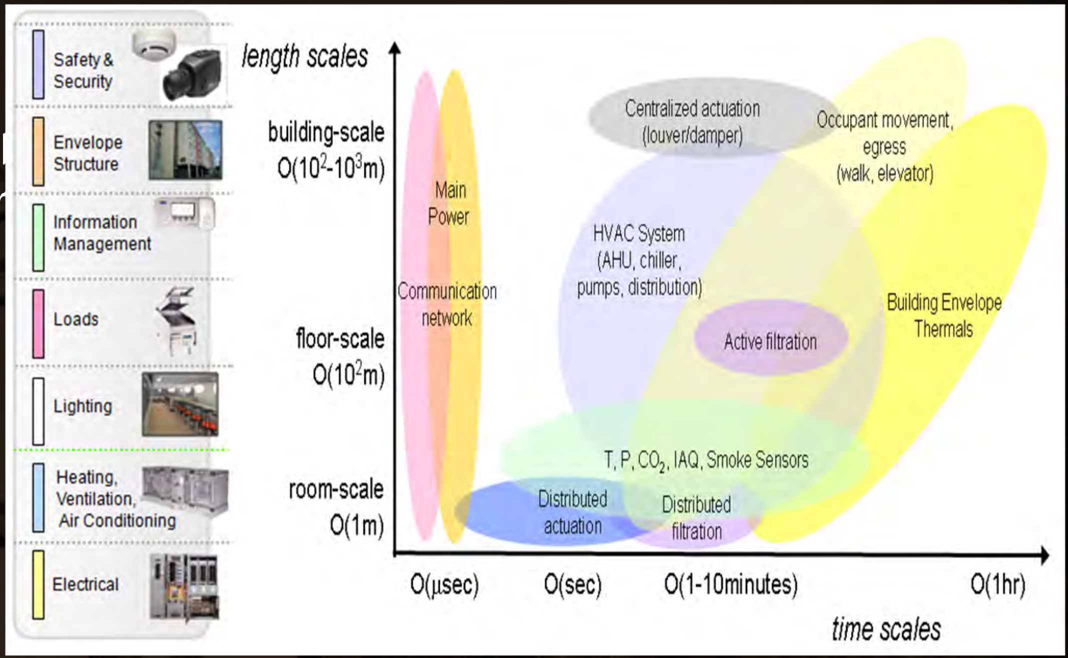
Building Materials, Misc. Equipment

Integration: *The Whole is Greater than the Sum of the Parts*

Building Systems Integration Challenges

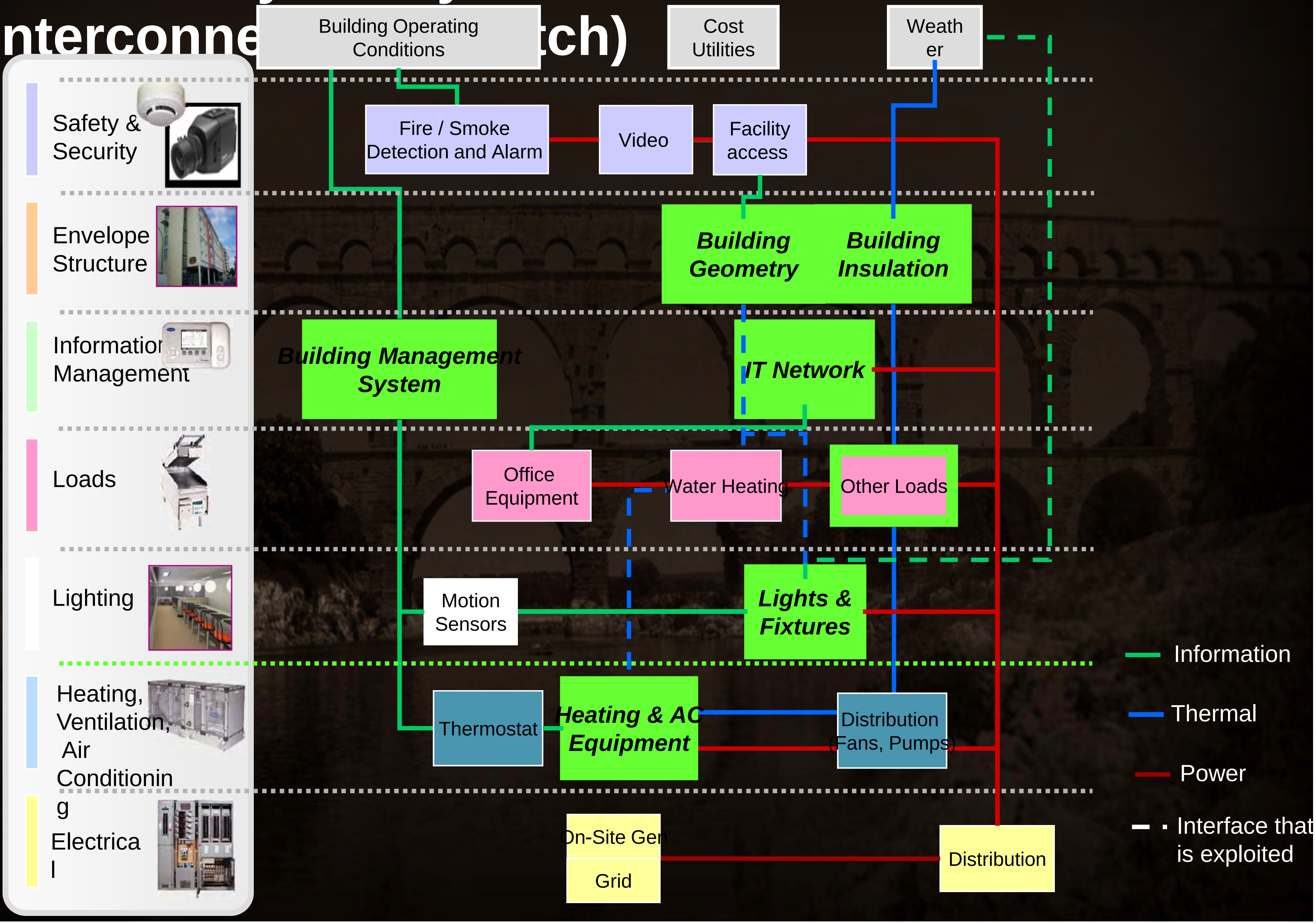
Complex* interconnections among building components

- HETEROGENEITY
  - Components do not necessarily mathematically similar structur… may involve different scales in time or space
- SIZE
  - The number of components may be large/enormous
- DISTRIBUTED NETWORKED SYSTEMS
  - Components can be connected in a variety of ways, most often nonlinearly and/or via a network. Local and system wide phenomena may depend on each other in complicated ways
- EMERGING BEHAVIOR IN COMPOSITION
  - Overall system behavior can be difficult to predict from the behavior of individual components. May evolve along qualitatively different pathways that may display great sensitivity to small perturbations at any stage



* D.L. Brown, J. Bell, D. Estep, W. Gropp, B. Hendrickson, S. Keller-McNulty, D. Keyes, J. T. Oden and L. Petzold, Appled Mathematics at the U.S. Department of Energy: Past, Present and a View to the Future, DOE Report, LLNL-TR-401536, May 2008.

Full Facility Subsystems and their Interconne tch)



Engineering Tomorrow's Designs

Synthetic Biology

The creation of novel biological functions and tools by modifying or integrating well-characterized biological components into higher-order systems using mathematical modeling to direct the construction towards the desired end product.

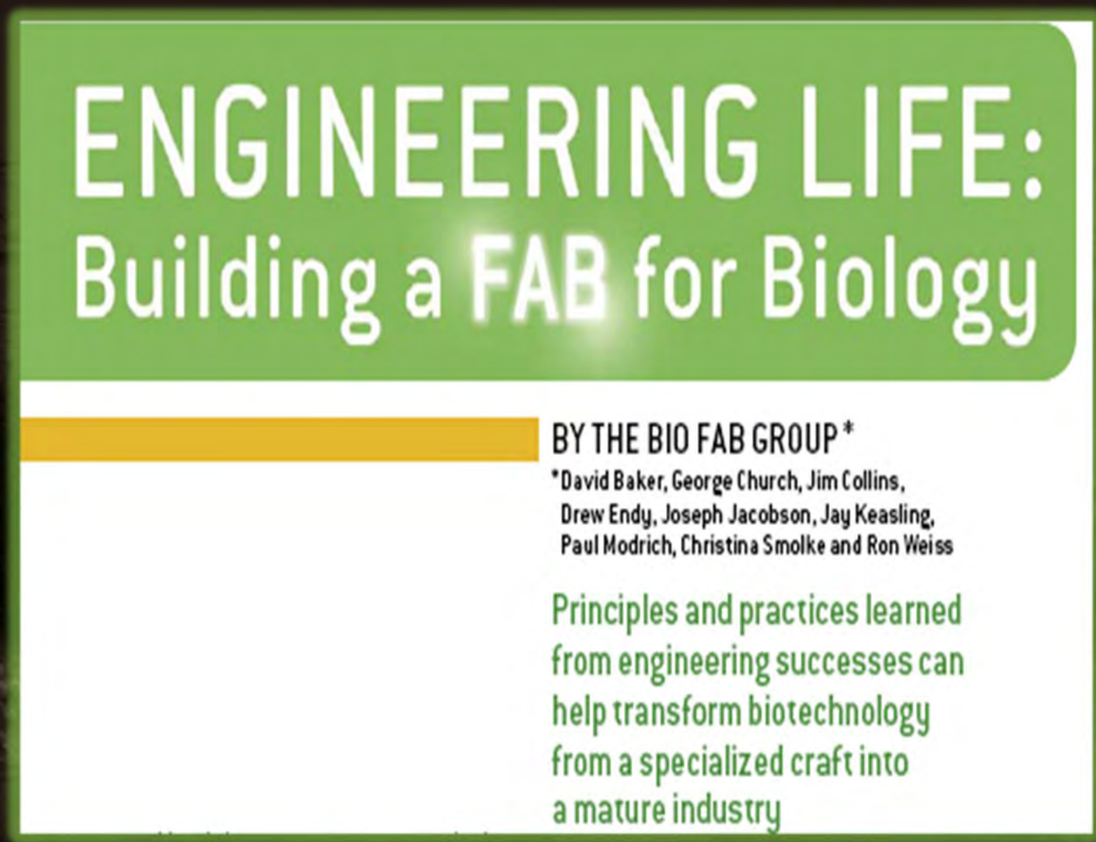
"Building life from the ground up" (Jay Keasling, UCB)
Keynote presentation, World Congress on Industrial Biotechnology and Bioprocessing,
March 2007.

Development of foundational technologies:

Tools for hiding information and managing complexity

Core components that can be used in combination reliably

Pioneering Synthetic Biology



ENGINEERING LIFE:
Building a FAB for Biology

BY THE BIO FAB GROUP*
*David Baker, George Church, Jim Collins, Drew Endy, Joseph Jacobson, Jay Keasling, Paul Modrich, Christina Smolke and Ron Weiss

Principles and practices learned from engineering successes can help transform biotechnology from a specialized craft into a mature industry

Moving from ad-hoc to structured design

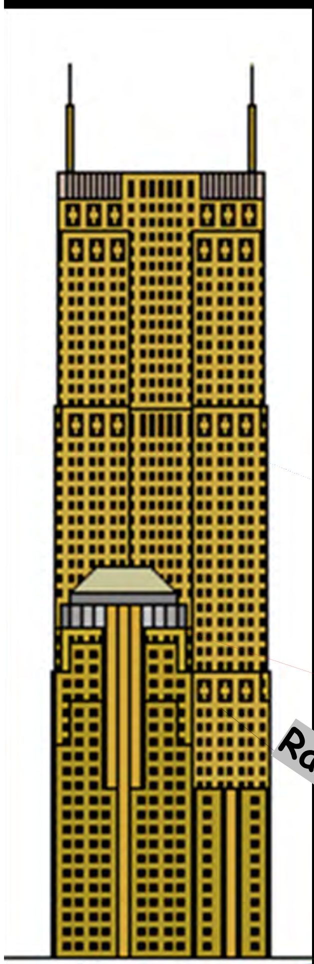
[Reference: Scientific American, June 2006]

Applications

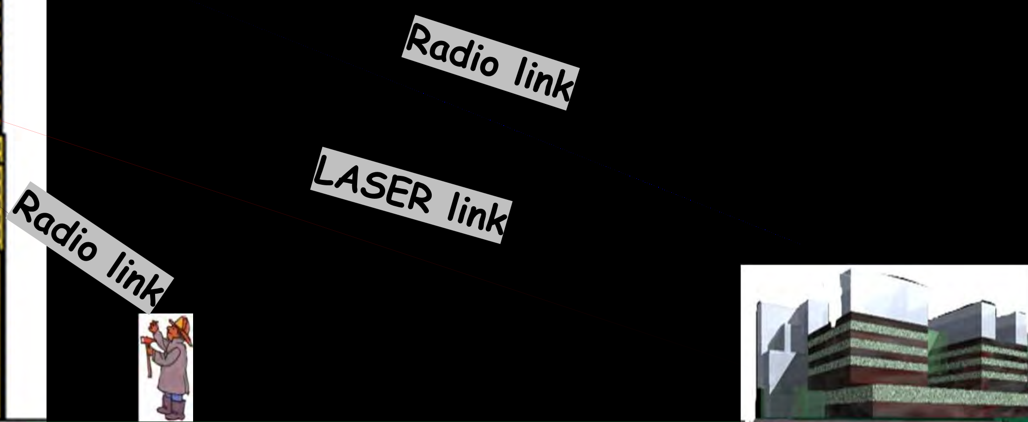
Disaster Mitigation (natural and otherwise)

- Monitor buildings, bridges, lifeline systems to assess damage after disaster
- Provide efficient, personalized responses
- Must function at maximum performance under very difficult circumstances

What is Disaster Response?

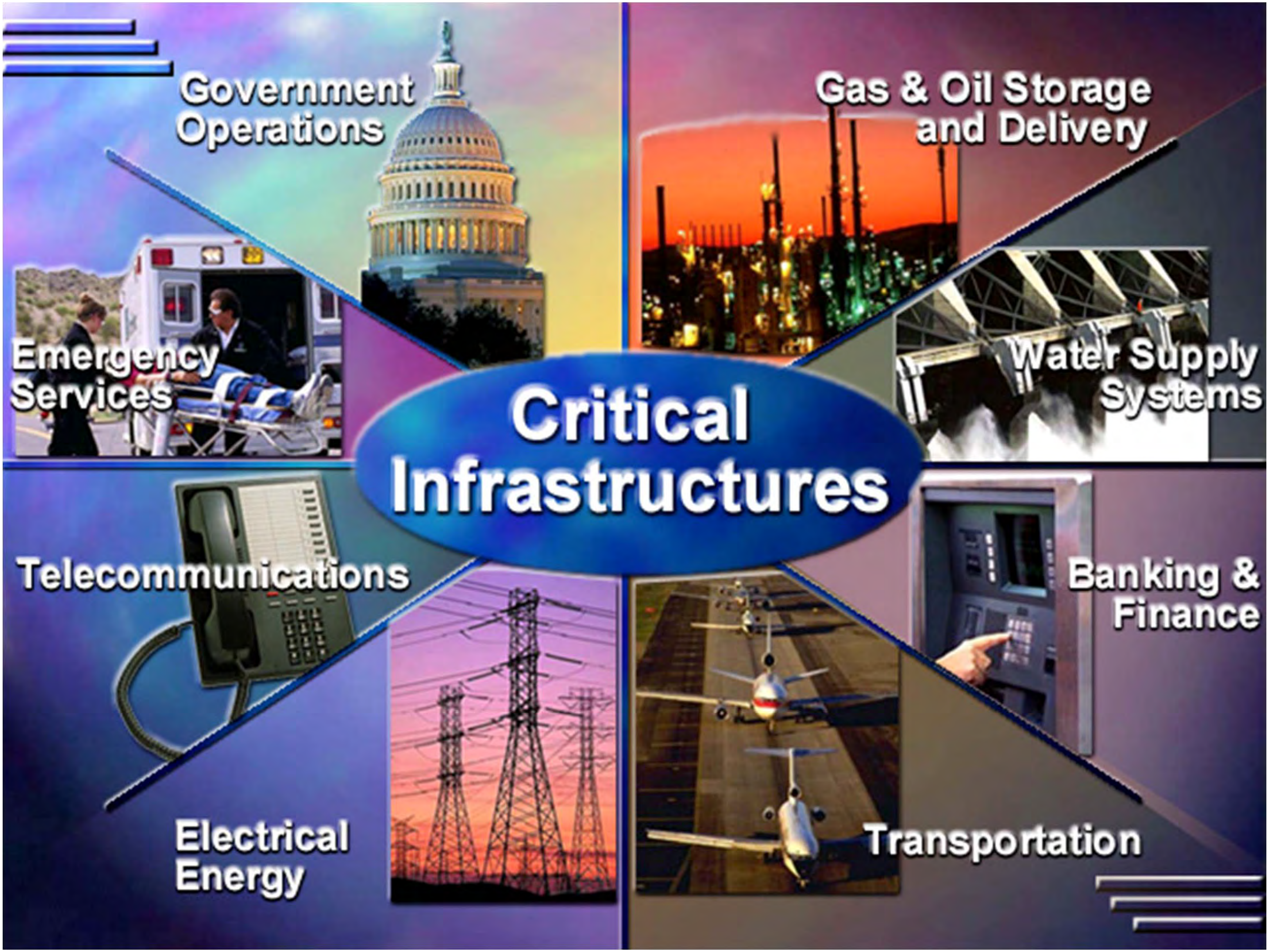


- **Sensors installed near critical structural points**
- **Sensor measure motion, distinguish normal deterioration and serious damage**
- **Sensors report location, kinematics of damage during and after an extreme event**
  - Guide emergency personnel
  - Assess structural safety without deconstructing building



Discussion

- What are the most challenging aspects of these applications (and how does a company make money) ?
  - Interaction mechanisms: sensors, actuators, wireless networks
  - Reliability and survivability
  - Infrastructure
  - Services
  - Legislation
  - ……


Government
Operations
Gas & Oil Storage
and Delivery
Emergency
Services
Critical
Infrastructures
Water Supply
Systems
Telecommunications
Banking &
Finance
Electrical
Energy
Transportation

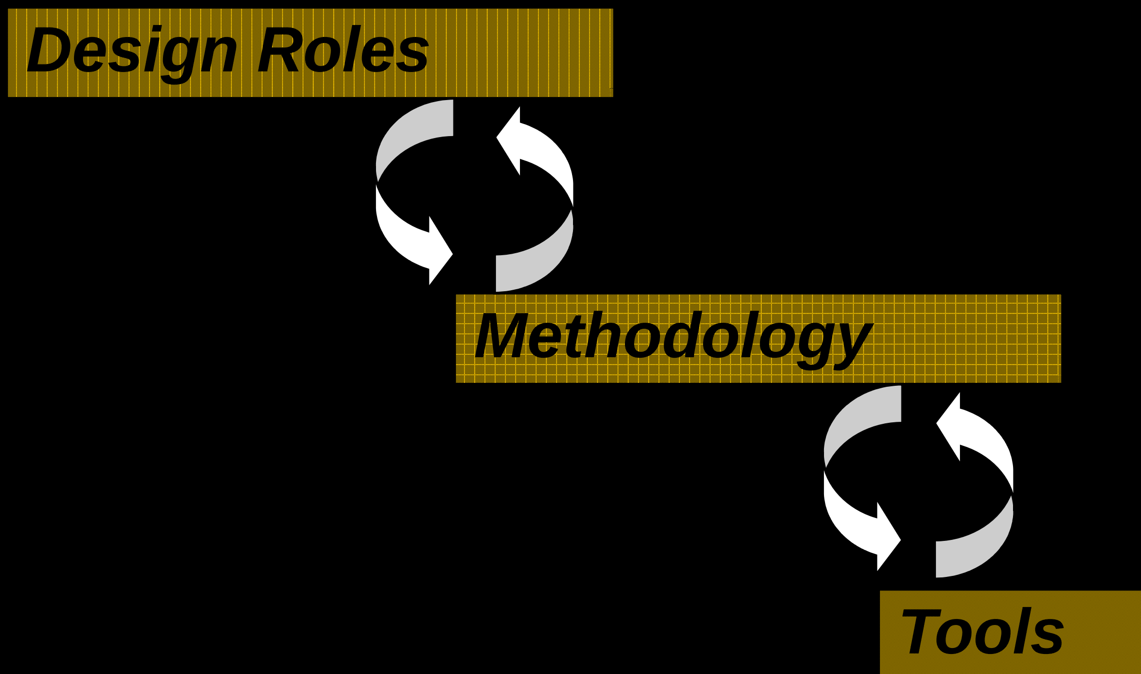
Secure Network Embedded SystEms (SENSE)

- Networked embedded systems and distributed control creates a new generation of future applications: new infrastructures
- We need to think about how to prevent the introduction of vulnerabilities via this exciting technology
- Security, Networking, Embedded Systems

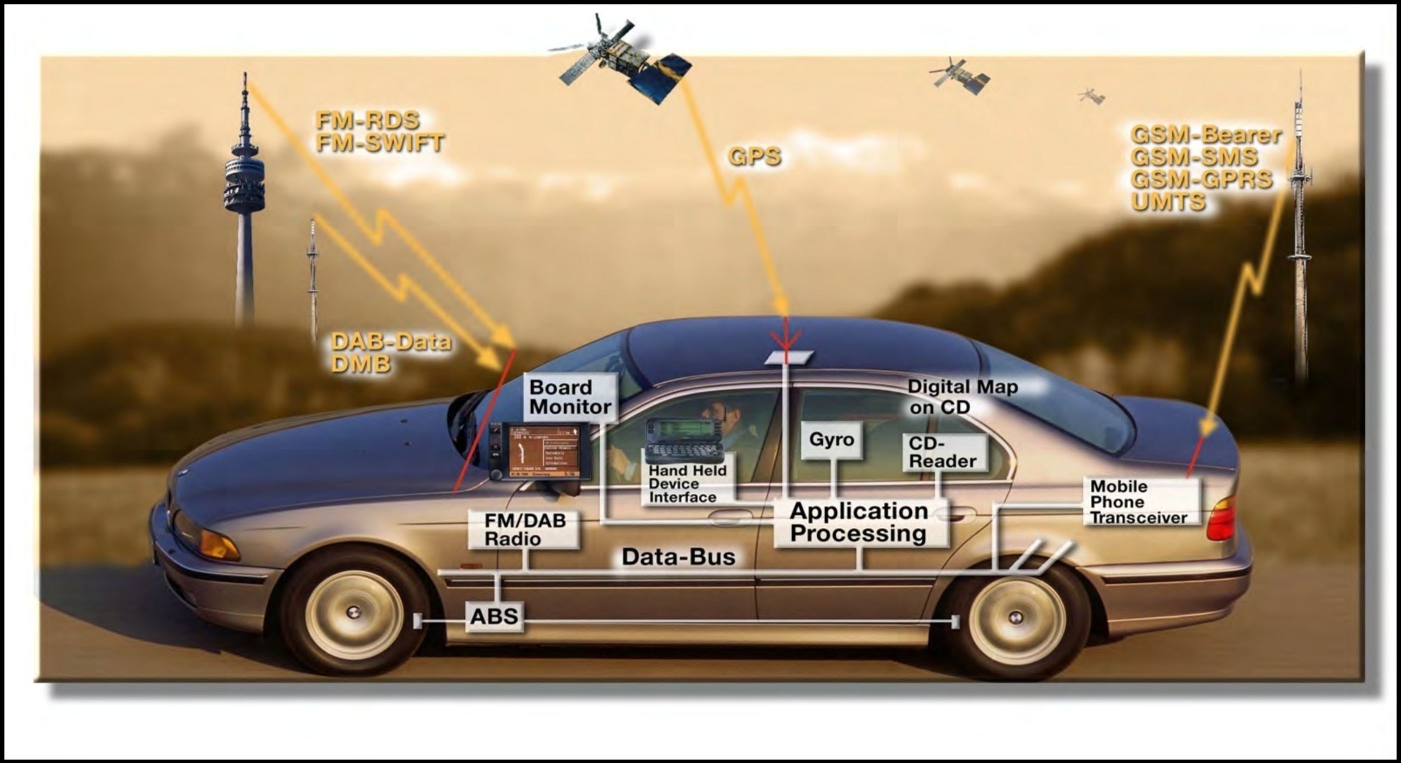
Outline for the Introduction

- Examples of Embedded Systems
- Their Impact on Society
- Design Challenges
- Embedded Software and Control

Supply Chain:
Design Roles-> Methodology->Tools

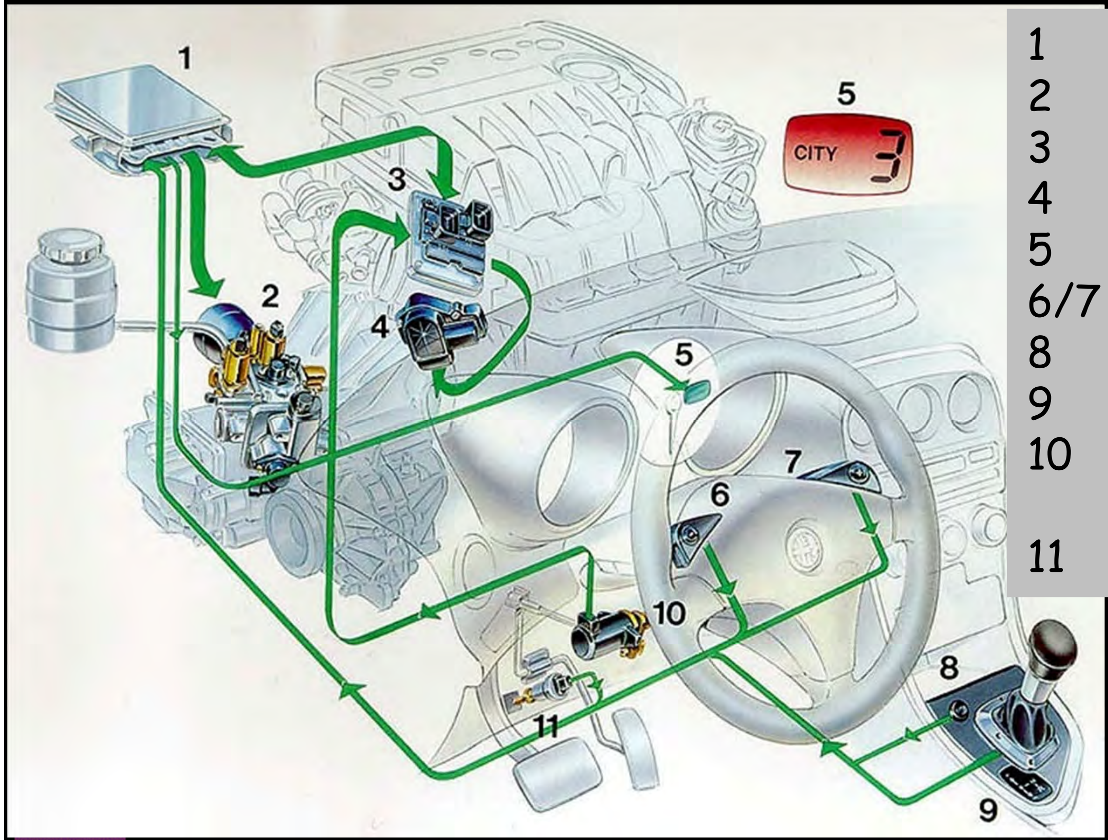


Automotive Supply Chain:
Car Manufacturers



- Product Specification & Architecture Definition (e.g., determination of Protocols and Communication standards)
- System Partitioning and Subsystem Specification
- Critical Software Development
- System Integration

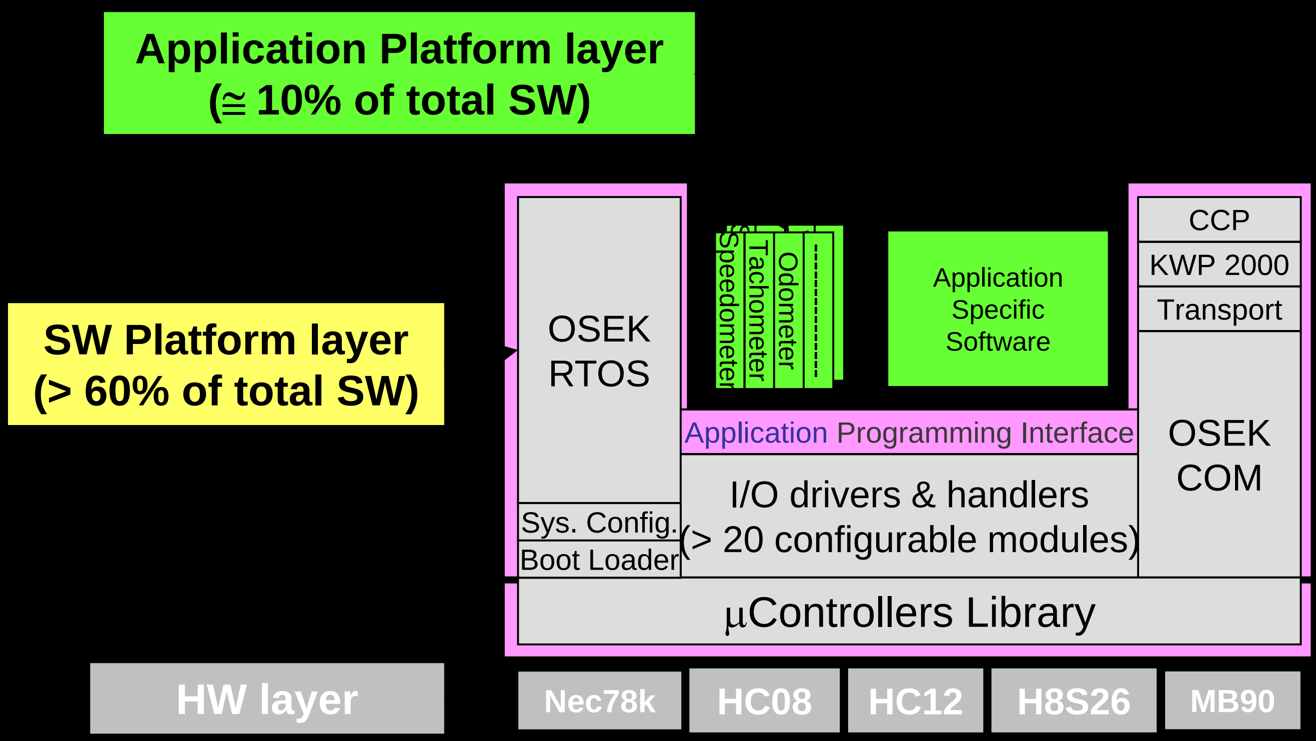
Automotive Supply Chain:
Tier 1 Subsystem Providers



1	Transmission ECU
2	Actuation group
3	Engine ECU
4	DBW
5	Active shift display
6/7	Up/Down buttons
8	City mode button
9	Up/Down lever
10	Accelerator pedal position sensor
11	Brake switch

- Subsystem Partitioning
- Subsystem Integration
- Software Design: Control Algorithms, Data Processing
- Physical Implementation and Production

Automotive Supply Chain: Subsystem Providers

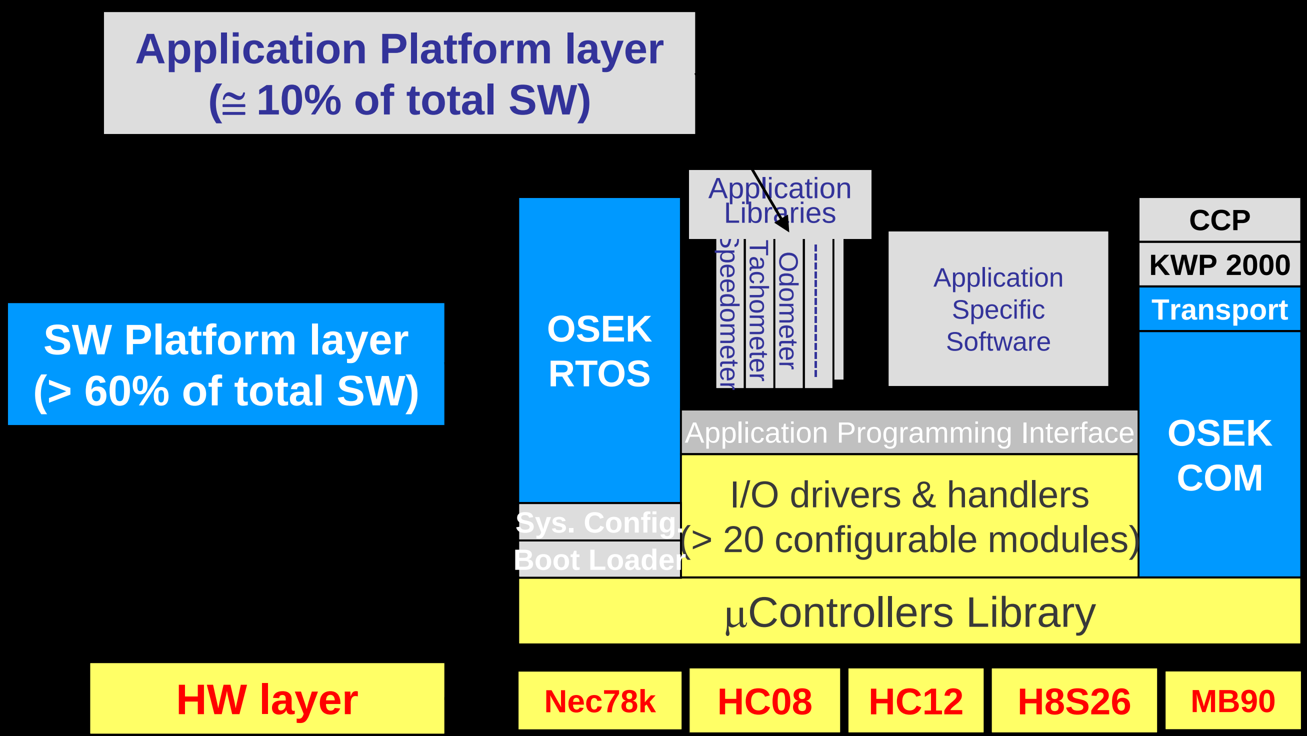


Platform Integration
Software Design

“firmware” and “glue software”

“Application”

Automotive Supply Chain: Platform & IP Providers



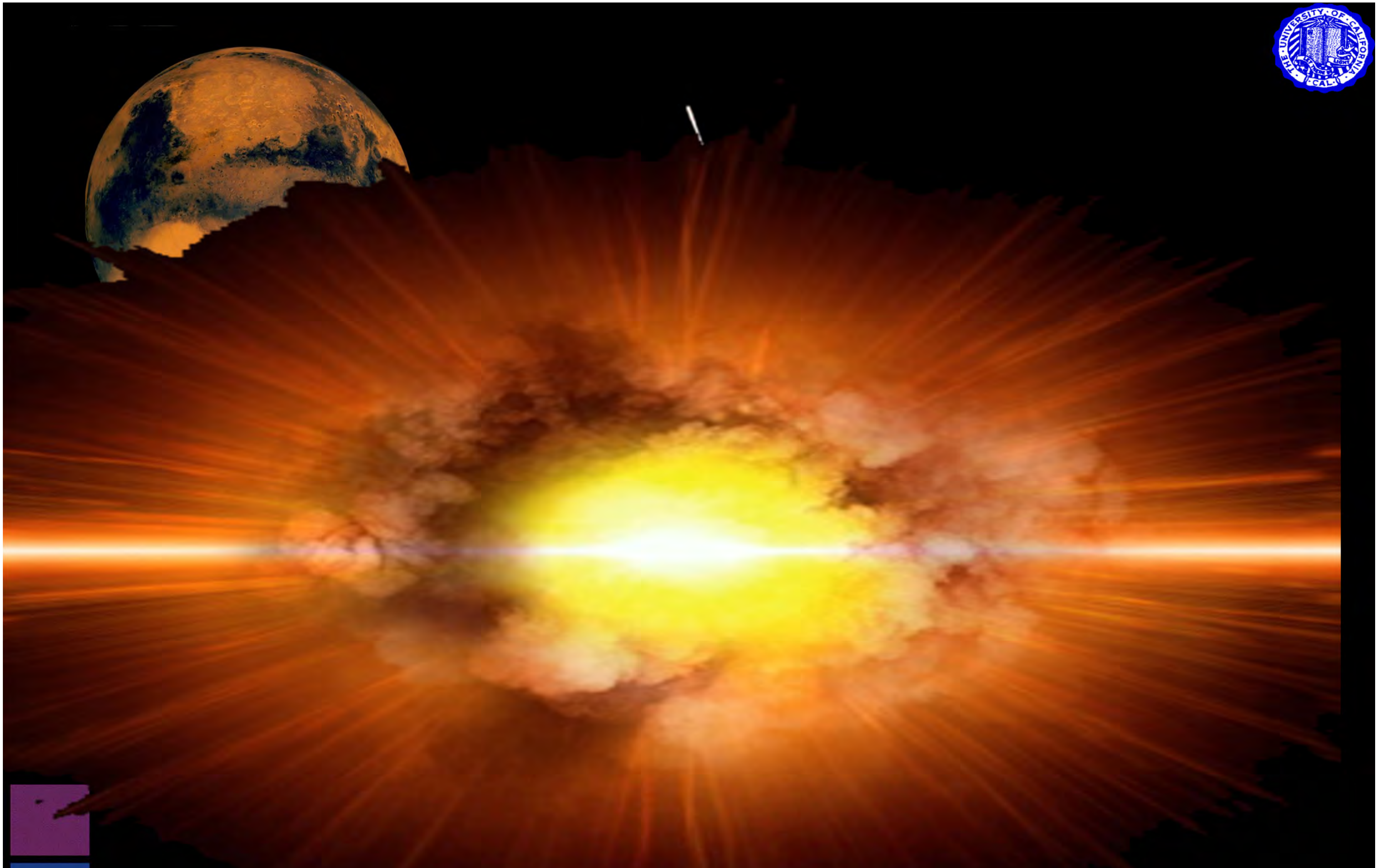
- "Software" platform — RTOS and communication layer
- "Hardware" platform — Hardware and IO drivers

Outline for the Introduction

- Examples of Embedded Systems
- Their Impact on Society
- Design Challenges
- Embedded Software and Control

How Safe is Our Real-Time Software?

Computing for Embedded Systems



Mars, December 3, 1999
Crashed due to un-initialized variable


$4 billion development effort
40-50% system integration & validation cost

Complexity, Quality, & Time To Market today

	PWT UNIT 	BODY GATEWAY 	INSTRUMENT CLUSTER 	TELEMATIC UNIT 
Memory	256 Kb	128 Kb	184 Kb	8 Mb
Lines Of Code	50.000	30.000	45.000	300.000
Productivity	6 Lines/Day	10 Lines/Day	6 Lines/Day	10 Lines/Day*
Residual Defect Rate @ End Of Dev	3000 Ppm	2500 ppm	2000ppm	1000 ppm
Changing Rate	3 Years	2 Years	1 Year	< 1 Year
Dev. Effort	40 Man-yr	12 Man-yr	30 Man-yr	200 Man-yr
Validation Time	5 Months	1 Month	2 Months	2 Months
Time To Market	24 Months	18 Months	12 Months	< 12 Months

*** C++ CODE**

FABIO ROMEO, Magneti-Marelli
DAC, Las Vegas, June 20th, 2001

Software Bugs Cost $59.5 Billion a Year

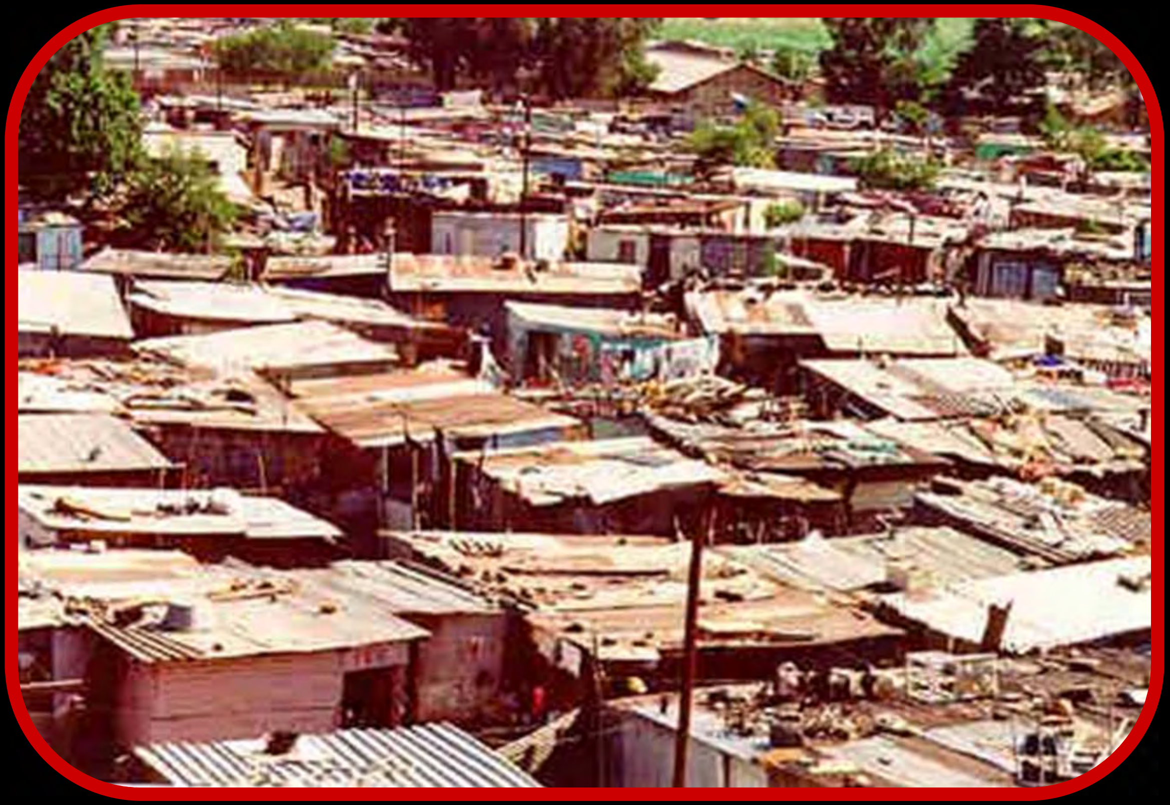
INFOWORLD, JUNE 28, 2002 – BY PAUL KRILL

Software bugs cost $59.5 billion a year, study says

Software bugs cost the U.S. economy an estimated $59.5 billion per year, or 0.6 percent of the gross domestic product, according to a newly released study by the U.S. Department of Commerce National Institute of Standards and Technology (NIST). In a statement released on Friday, NIST said more than half the costs are borne by software users and the remainder by software developers and vendors.

Additionally, the study found that although errors cannot be removed, more than a third of the costs, or an estimated $22.2 billion, could be eliminated by improved testing that enables earlier and more effective identification and removal of defects. Currently, more than half of errors are not found until “downstream” in the development process or during post-sale use of software, according to NIST.

Embedded Software Architecture Today



We Live in an Imperfect World!

PAGE 14 – SUNDAY, FEBRUARY 6, 2005 – THE NEW YORK TIMES (by Tim Moran)

What's Bugging the High-Tech Car?

On a hot summer trip to Cape Cod, the Mills family minivan did a peculiar thing. After an hour on the road, it began to bake the children. Mom and Dad were cool and comfortable up front, but heat was blasting into the rear of the van and it could not be turned off.

Fortunately for the Mills children, their father – W. Nathaniel Mills III, an expert on computer networking at I.B.M. – is persistent. When three dealership visits, days of waiting and the cumbersome replacement of mechanical parts failed to fix the problem, he took the van out and drove it until the oven fired up again. Then he rushed to the mechanic to look for a software error.

Additionally, the study found that although errors cannot be removed, more than a "It took two minutes for them to hook up their diagnostic tool and find the fault," said Mr. Mills, senior technical staff member at I.B.M.'s T.J. Watson Research Center in Hawthorne, N.Y. "I can almost see the software code; a sensor was bad."

Indeed, the high-tech comfort sys... confused... the 2001... sending... freezing... loyal van... up. third... billion, c...

MOTOR TREND

NHTSA To Probe Reports Of Sudden Engine Stalls In Prius Hybrids

The National Highway Traffic Safety Administration said yesterday it is investigating reports that a software problem can cause the engine of Toyota's Prius hybrid to stall without warning at highway speeds. No accidents have been reported thus far.

NHTSA has received 33 reports of stalling in Prius cars from model years 2004 and 2005, according to the agency's initial report. More than 85 percent of the cars that stalled did so at speeds between 35 and 65 miles per hour.

How is Embedded Software Different from Ordinary Software?

- It has to work
- One or more (very) limited resources
  - Registers
  - RAM
  - Bandwidth
  - Time

Source: Alex Aiken

Devil's Advocate

- So what's different?
- All software works with limited resources
- We have compiler technology to deal with it
  - Various forms of program analysis

Source: Alex Aiken

Example: Registers

- All machines have only a few registers
- Compiler uses the registers as best as it can
  - *Spills* the remaining values to main memory
  - Manages transfers to and from registers
- The programmer feels she has 1 registers

 Source: Alex Aiken

The Standard Trick

- This idea generalizes
- For scarce resource X
  - Manage X as best as we can
  - If we need more, fall back to secondary strategy
  - Give the programmer a nice abstraction

Source: Alex Aiken

The Standard Trick

- This idea generalizes
- For scarce resource X
  - Manage X as best we can
  - *Any correct heuristic is OK, no matter how complex*
  - If we need more, fall back to secondary strategy
  - *Focus on average case behavior*
  - *Give the programmer a nice abstraction*

Source: Alex Aiken

Examples of the Standard Trick

- Compilers
  - Register allocation
  - Dynamic memory management
- OS
  - Virtual memory
  - Caches

Summary: abstract and hide complexity of resources

Source: Alex Aiken

What's Wrong with This?

- Embedded systems have limited resources

- Meaning hard limits
  - Cannot use more time
  - Cannot use more registers

- The compiler must either
  - Produce code within these limits
  - Report failure

- The standard trick is anathema to embedded systems
  - Can't hide resources

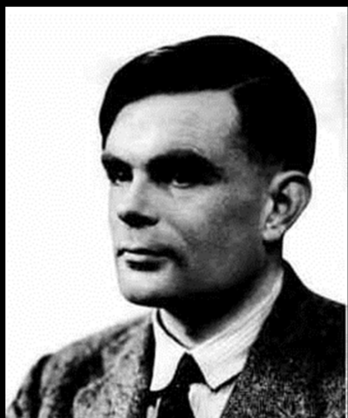
 Source: Alex Aiken

Revisiting the Assumptions

- *Any correct heuristic is OK, no matter how complex*
  - Embedded programmer must understand reasons for failure
  - Feedback must be relatively straightforward
- *Focus on average case behavior*
  - Embedded compiler must reason about the worst case
  - Cannot improve average case at expense of worst case
- *Give the programmer a nice abstraction*
  - Still need abstractions, but likely different ones

Source: Alex Aiken

Another Traditional Systems Science - Computation, Languages, and Semantics

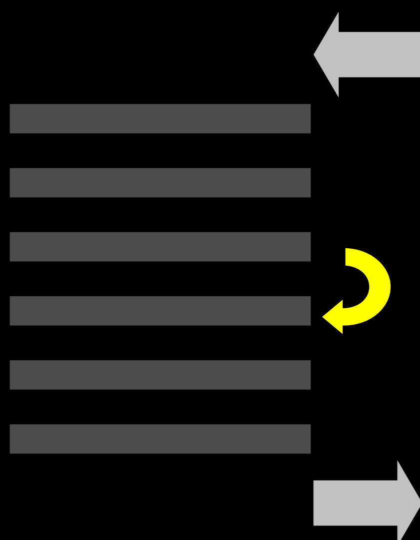


Alan Turing

Everything "computable" can be given by a terminating sequential program.

- Functions on bit patterns
- Time is irrelevant
- Non-terminating programs are defective

sequence

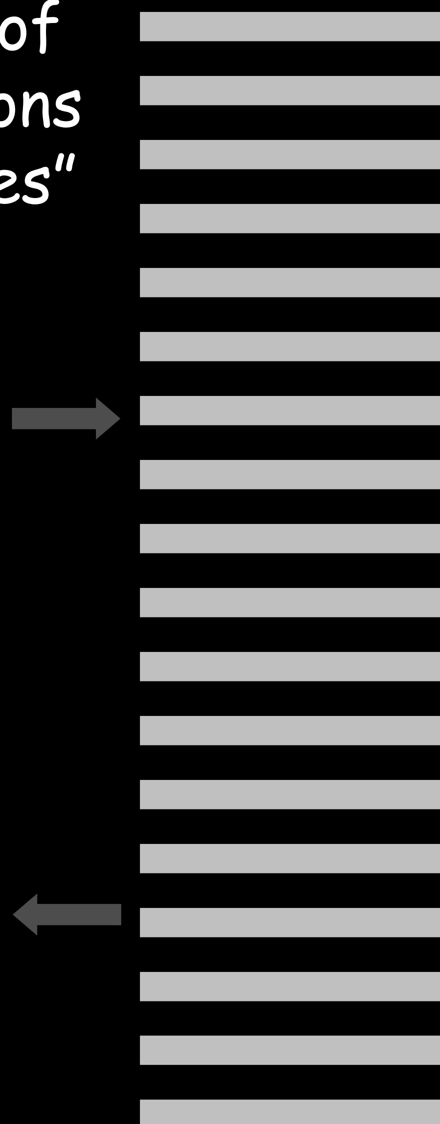


Source Ed Lee

Processes and Process Calculi

Infinite sequences of state transformations are called "processes" or "threads"

incoming message



outgoing message

In prevailing software practice, processes are sequences of external interactions (total orders).

And messaging protocols are combined in ad hoc ways.

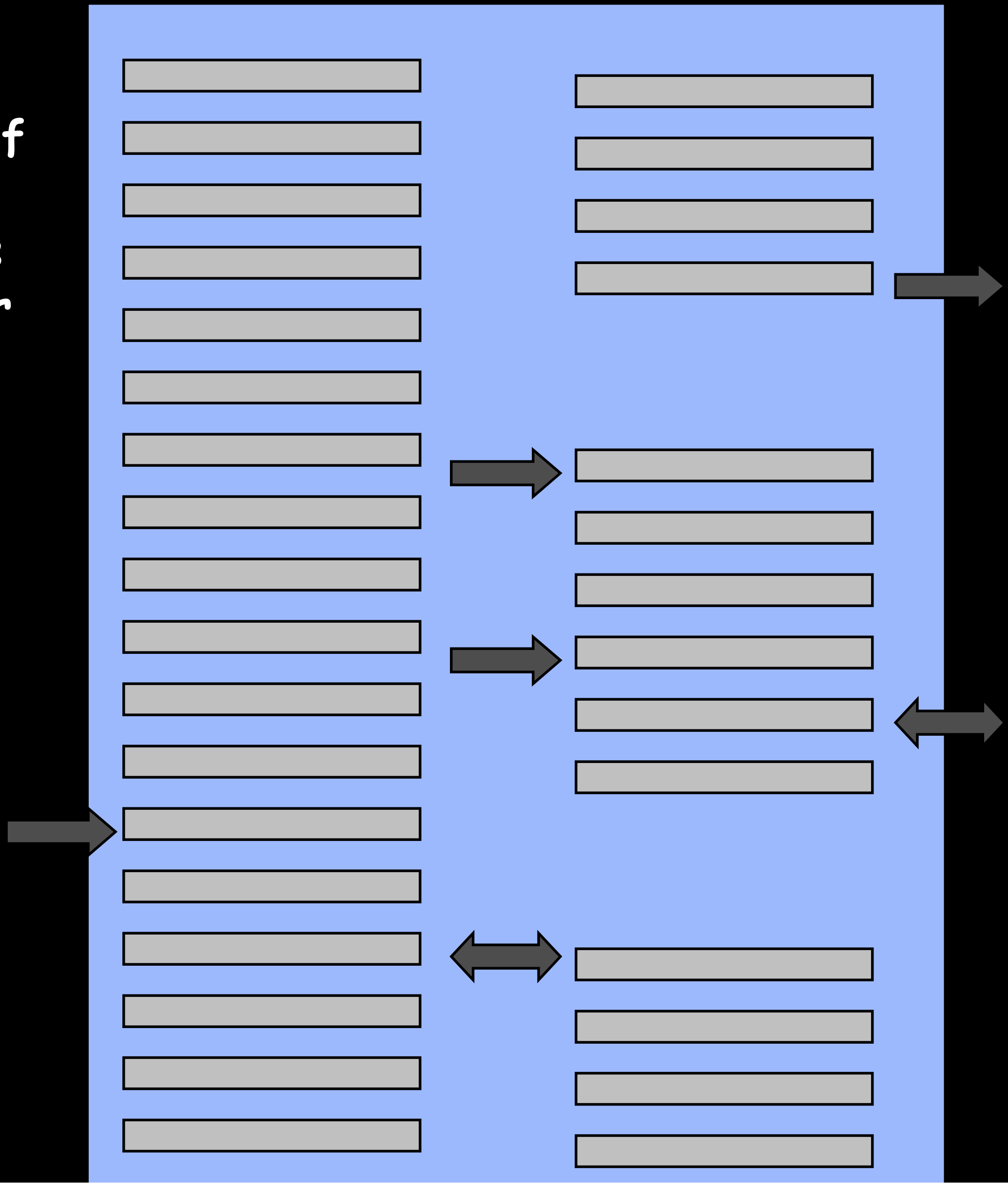
Interacting Processes – Concurrency as Afterthought

Software realizing these interactions is written at a very low level (e.g., semaphores). *Very* hard to get it right.

Interacting Processes – Not Compositional

An aggregation of processes is not a process (a total order of external interactions). What is it?

Many software failures are due to this ill-defined composition.

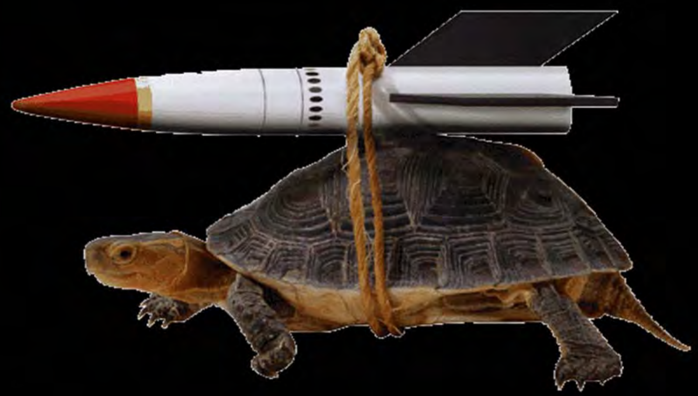


Source Ed Lee

Compositionality

Non-compositional formalisms lead to very awkward architectures.

What About Real Time?



"Make it faster!"

First Challenge on the Cyber Side: Real-Time and Power-aware Software

Correct execution of a program in C, C#, Java, Haskell, etc. has nothing to do with how long it takes to do anything. All our computation and networking abstractions are built on this premise.

Timing of programs is not repeatable, except at very coarse granularity.

Programmers have to step outside the programming abstractions to specify timing and power behavior.

Second Challenge on the Cyber Side: Concurrency

Threads dominate concurrent software.

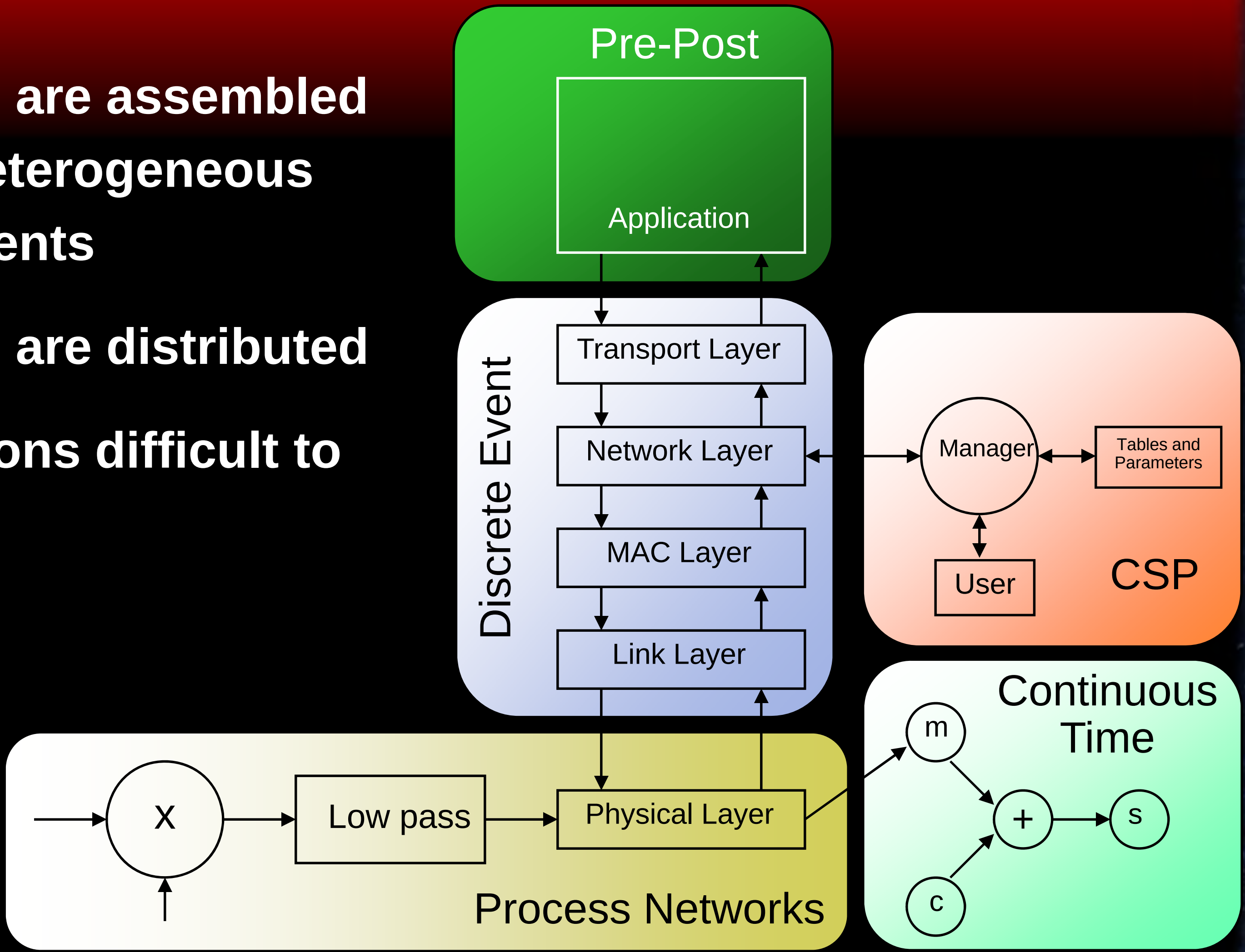
- ***Threads*: Sequential computation with shared memory.**
- ***Interrupts*: Threads started by the hardware.**

Incomprehensible interactions between threads are the sources of many problems:

- **Deadlock**
- **Priority inversion**
- **Scheduling anomalies**
- **Nondeterminism**
- **Buffer overruns**
- **System crashes**

Common Features

- Systems are assembled out of heterogeneous components
- Systems are distributed
- Interactions difficult to define



The Intellectual Agenda

To create a modern computational systems science and systems design practice with

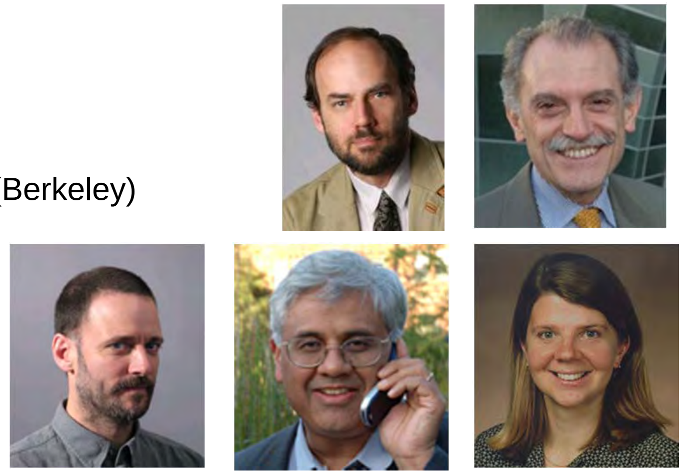
- **Concurrency**
- **Composability**
- **Time**
- **Hierarchy**
- **Heterogeneity**
- **Resource constraints**
- **Verifiability**
- **Understandability**

Chess: Center for Hybrid and Embedded Software Systems

Principal Investigators
- Thomas Henzinger (EPFL)
- Edward A. Lee (Berkeley)
- Alberto Sangiovanni-Vincentelli (Berkeley)
- Shankar Sastry (Berkeley)
- Janos Sztipanovits (Vanderbilt)
- Claire Tomlin (Berkeley)

Executive Director
- Christopher Brooks

Associated Faculty
- David Auslander (Berkeley, ME)
- Ahmad Bahai (Berkeley)
- Ruzena Bajcsy (Berkeley)
- Gautam Biswas (Vanderbilt)
- Ras Bodik (Berkeley, CS)
- Bella Bollobas (Memphis)
- Karl Hedrick (Berkeley, ME)
- Gabor Karsai (Vanderbilt)
- Kurt Keutzer (Berkeley)
- George Necula (Berkeley, CS)
- Koushik Sen (Berkeley, CS)
- Sanjit Seshia (Berkeley)
- Jonathan Sprinkle (Arizona)
- Masayoshi Tomizuka (Berkeley, ME)
- Pravin Varaiya (Berkeley)

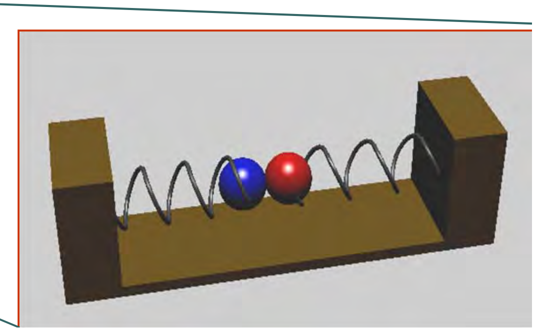


the Berkeley directors of Chess

This center, founded in 2002, blends systems theorists and application domain experts with software technologists and computer scientists.

Some Research Projects
- Precision-timed (PRET) machines
- Distributed real-time computing
- Systems of systems
- Theoretical foundations of CPS
- Hybrid systems
- Design technologies
- Verification
- Intelligent control
- Modeling and simulation

Applications
- Building systems
- Automotive
- Synthetic biology
- Medical systems
- Instrumentation
- Factory automation
- Avionics



Why can’t we make Software Reliable?

Uptime: 125 years

Source: T. Henzinger

Why can't we make Software reliable?

Engineering

Theories of estimation.
Theories of robustness.

R

Computer Science

Theories of correctness.

B

Source: T. Henzinger

Why can't we make Software reliable?

Engineering

Theories of estimation.
Theories of robustness.

Goal: build reliable systems.

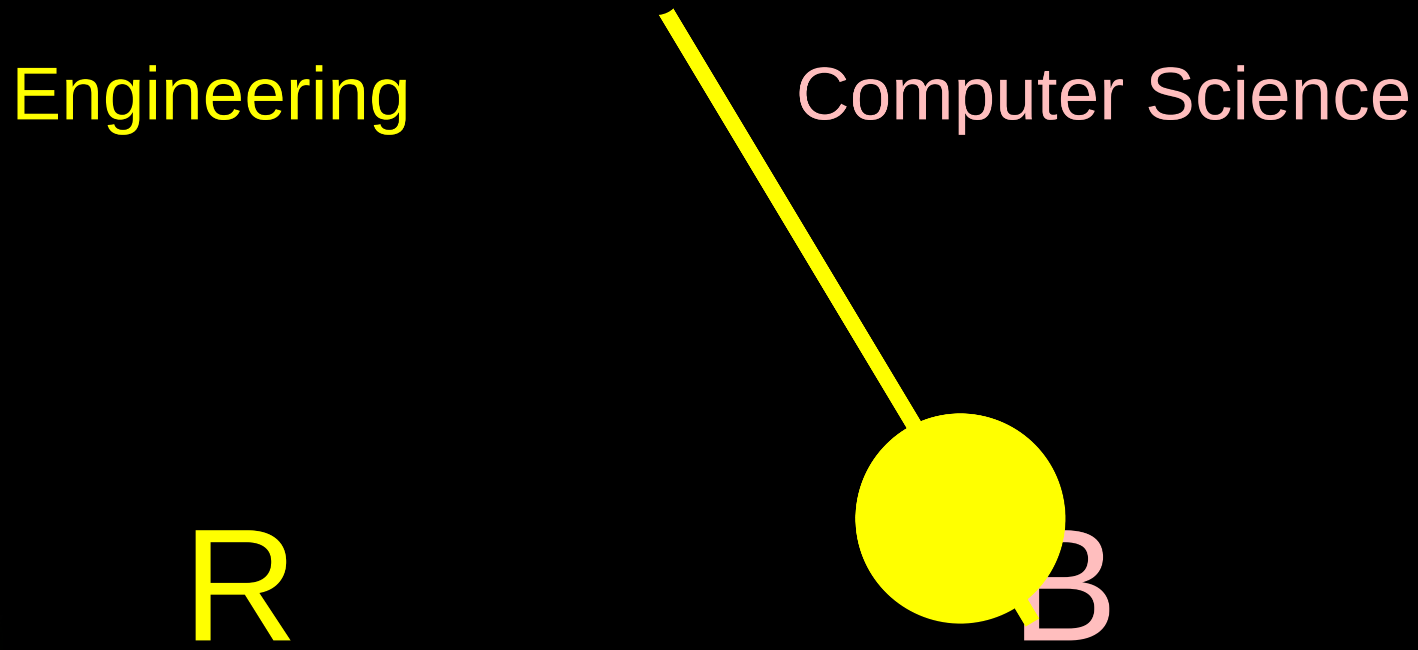
Computer Science

Theories of correctness.

Temptation: programs are mathematical objects; hence we want to prove them correct.

Source: T. Henzinger

The CHESS Premise:
The pendulum has swung too far

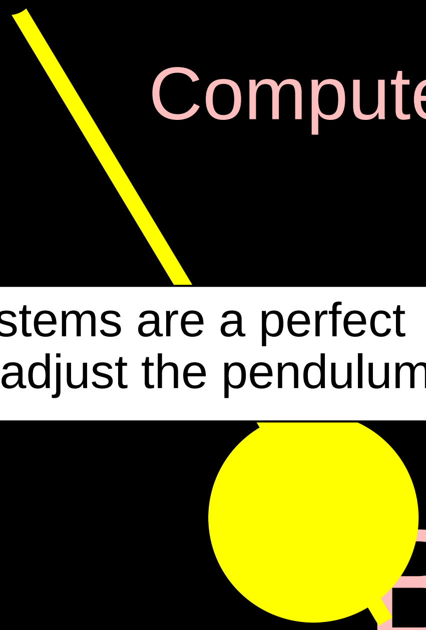


Source: T. Henzinger

The CHESS Premise:
The pendulum has swung too far

Engineering

Computer Science



Embedded Systems are a perfect playground to readjust the pendulum.

R

B

Physicality

Computation

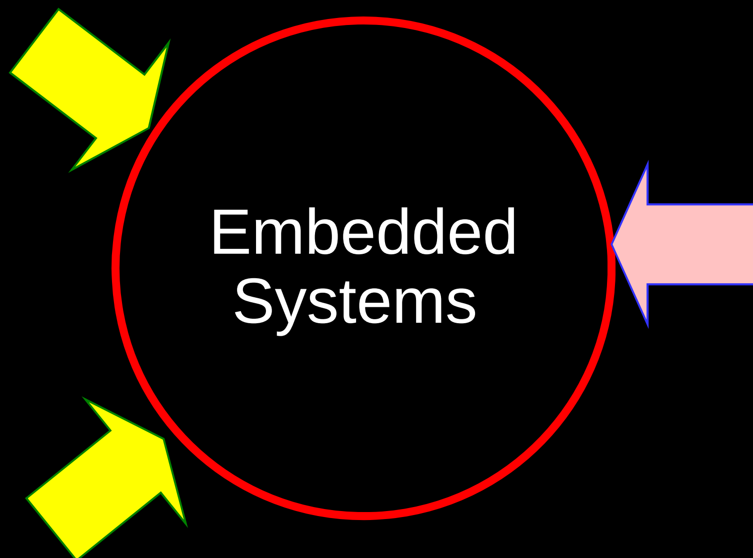
Source: T. Henzinger

Execution constraints

CPU speed
power
failure rates

Reaction constraints

deadlines
throughput
jitter



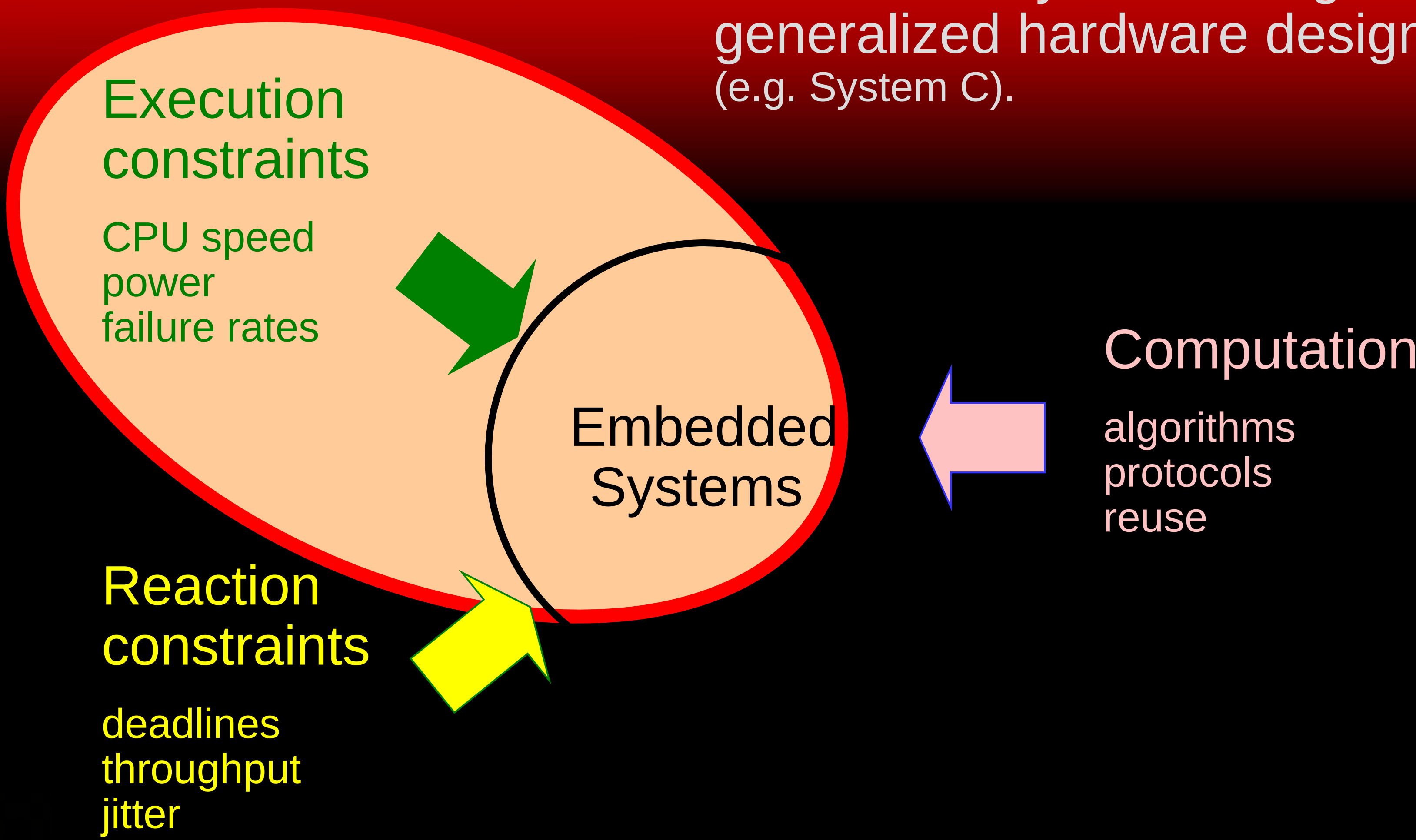
Computation

algorithms
protocols
reuse

Source: T. Henzinger

Embedded System Design is generalized hardware design

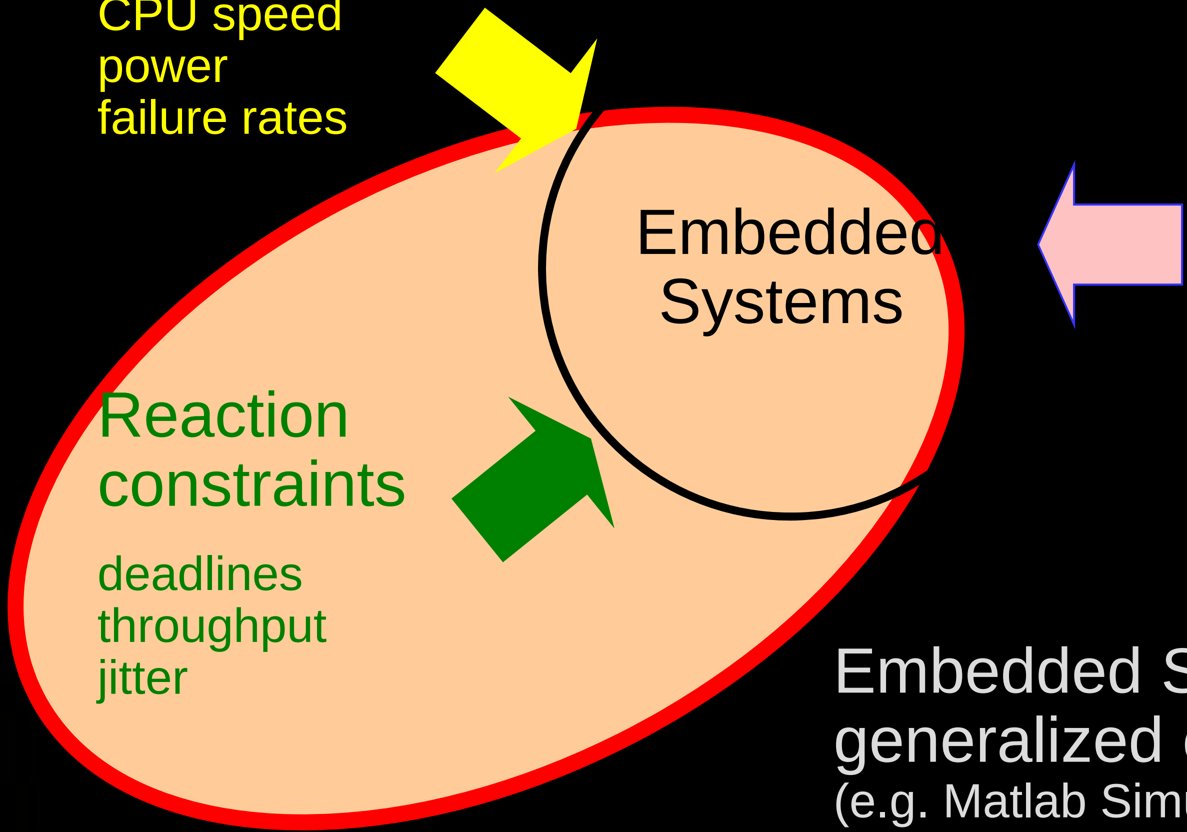
(e.g. System C).



Source: T. Henzinger

Execution constraints

CPU speed
power
failure rates



Computation

algorithms
protocols
reuse

Reaction constraints

deadlines
throughput
jitter

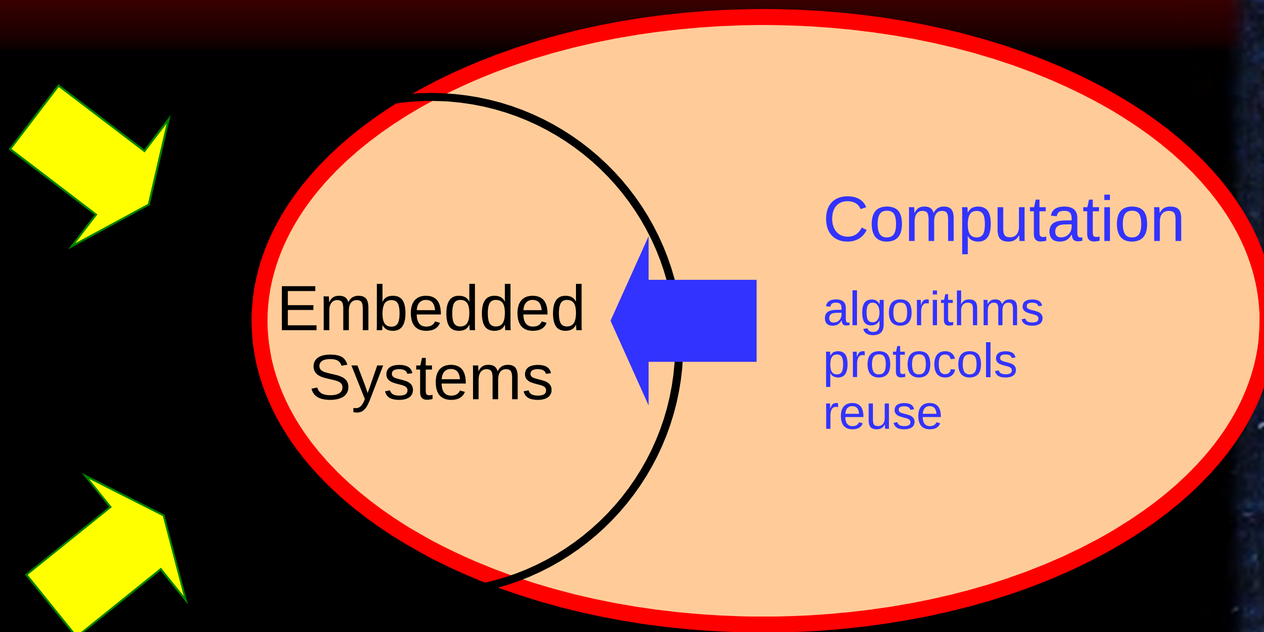
Embedded System Design is generalized control design
(e.g. Matlab Simulink).

Execution constraints

CPU speed
power
failure rates

Reaction constraints

deadlines
throughput
jitter



Embedded System Design is generalized software design
(e.g. RT Java).

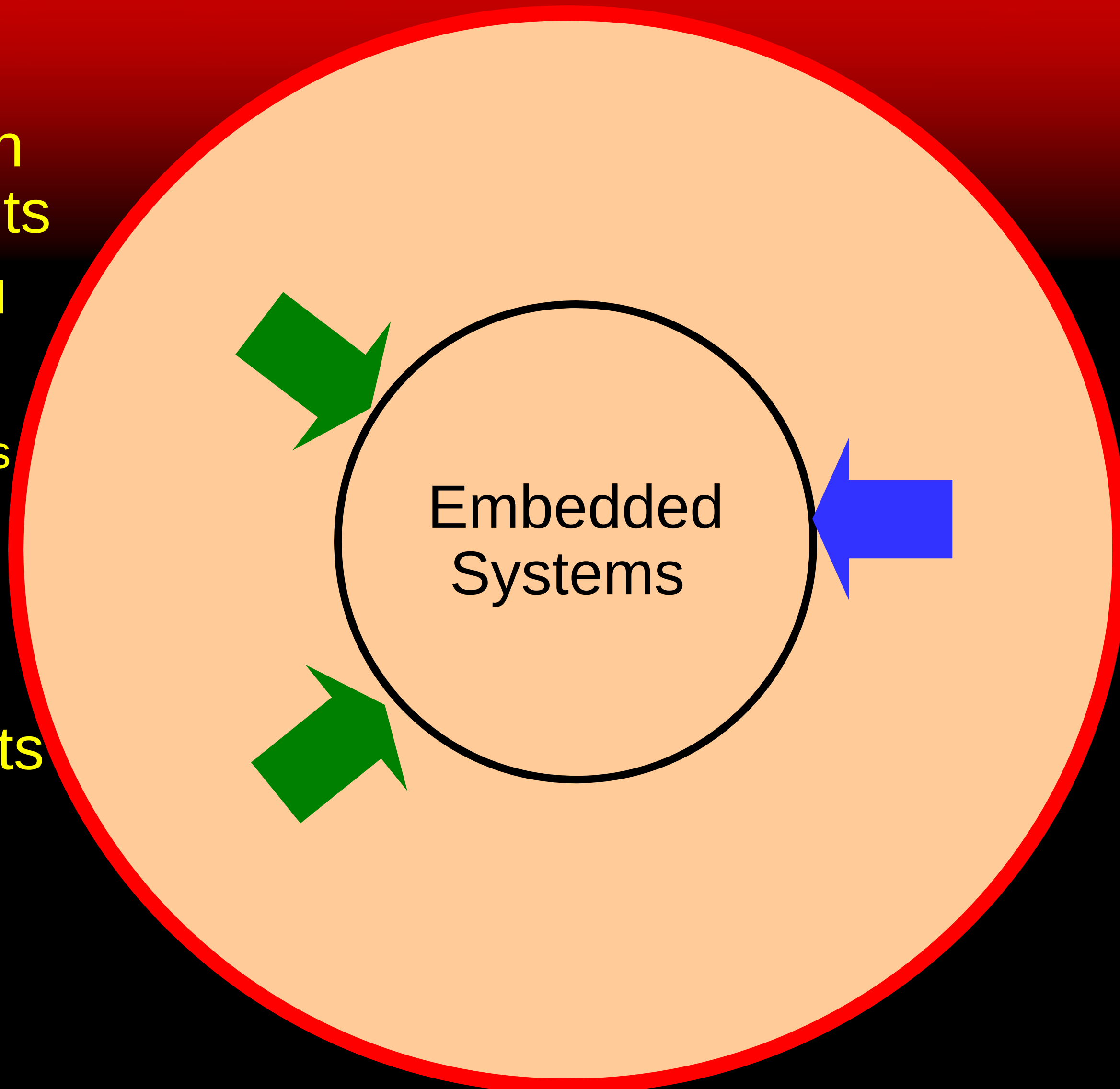
Source: T. Henzinger

Execution constraints

- CPU speed
- power
- failure rates

Reaction constraints

- Deadlines
- throughput
- jitter



Computation

- Algorithms
- protocols
- reuse

Source: T. Henzinger

The CHESS Challenge

We need a new formal foundation for embedded systems, which systematically and even-handedly re-marries

computation and physicality.

Source: T. Henzinger

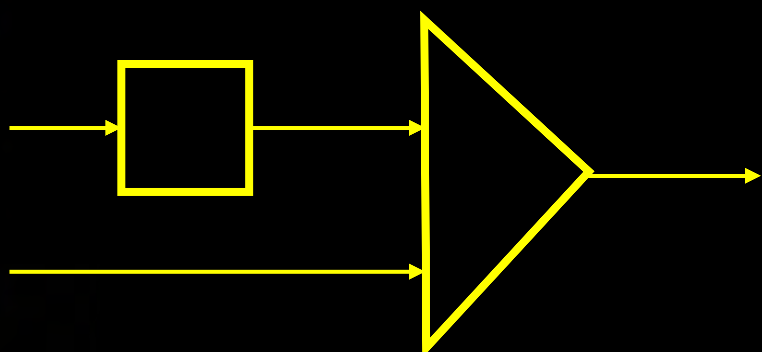
Integration of the Two Cultures

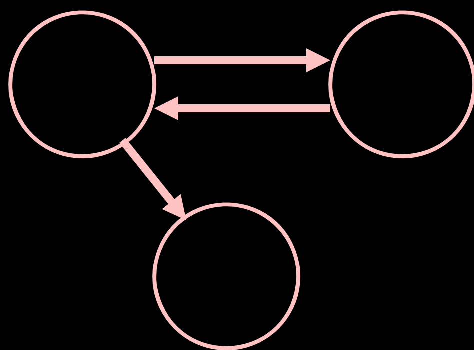
Engineering

Component model: transfer function
Composition: parallel
Connection: data flow

Computer Science

Component model: subroutine
Composition: sequential
Connection: control flow





[Hybrid Systems; Ptolemy; Metropolis; Metamodels]

Integration of the Two Cultures

Equational Models	***Abstract-Machine Models***
Strengths:	
Concurrency Quantitative constraints (time, power, QoS)	Dynamic change Complexity theory
Tool support:	
Best-effort design Optimization	Worst-case analysis Constraint satisfaction

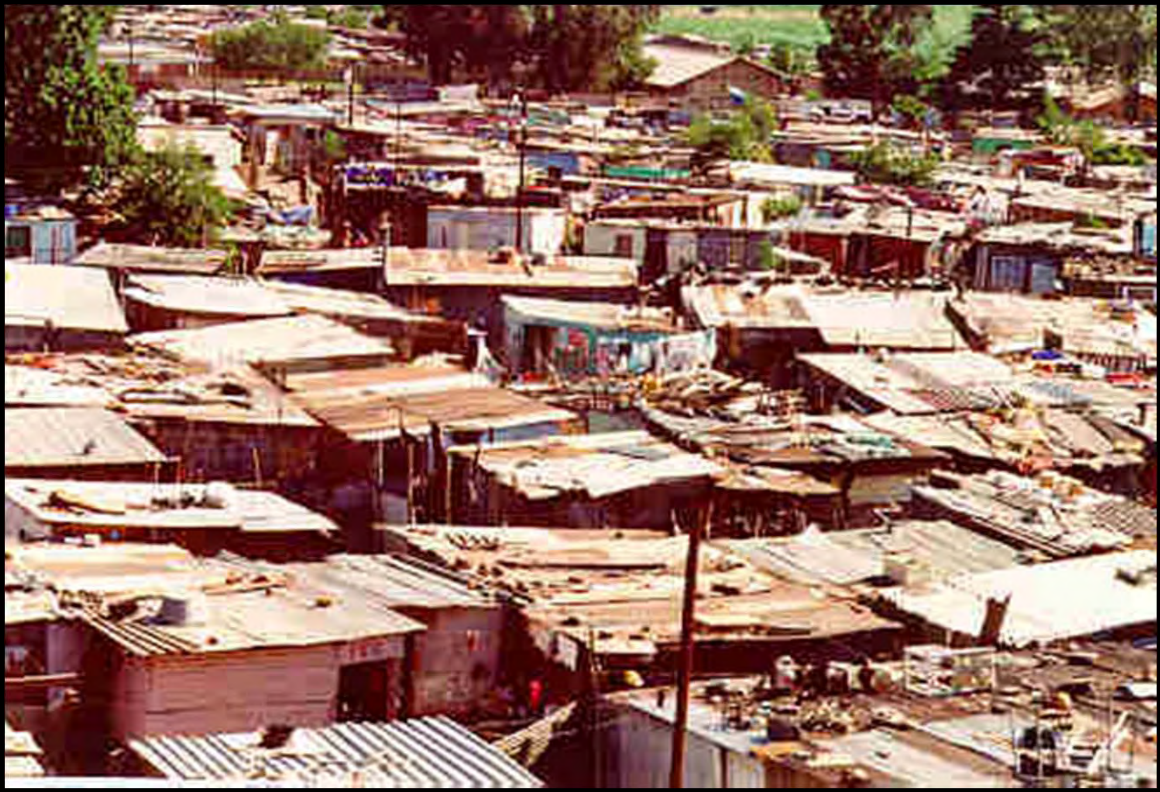
Engineers must understand both complexities and trade-offs .

Source: T. Henzinger

The Embedded Software SCIENCE Dilemma

Raffaello Sanzio, The Athens School

Software Architecture Today



Software Architecture Tomorrow?