LET'S GET PHYSICAL: ADDING PHYSICAL DIMENSIONS TO CYBER SYSTEMS

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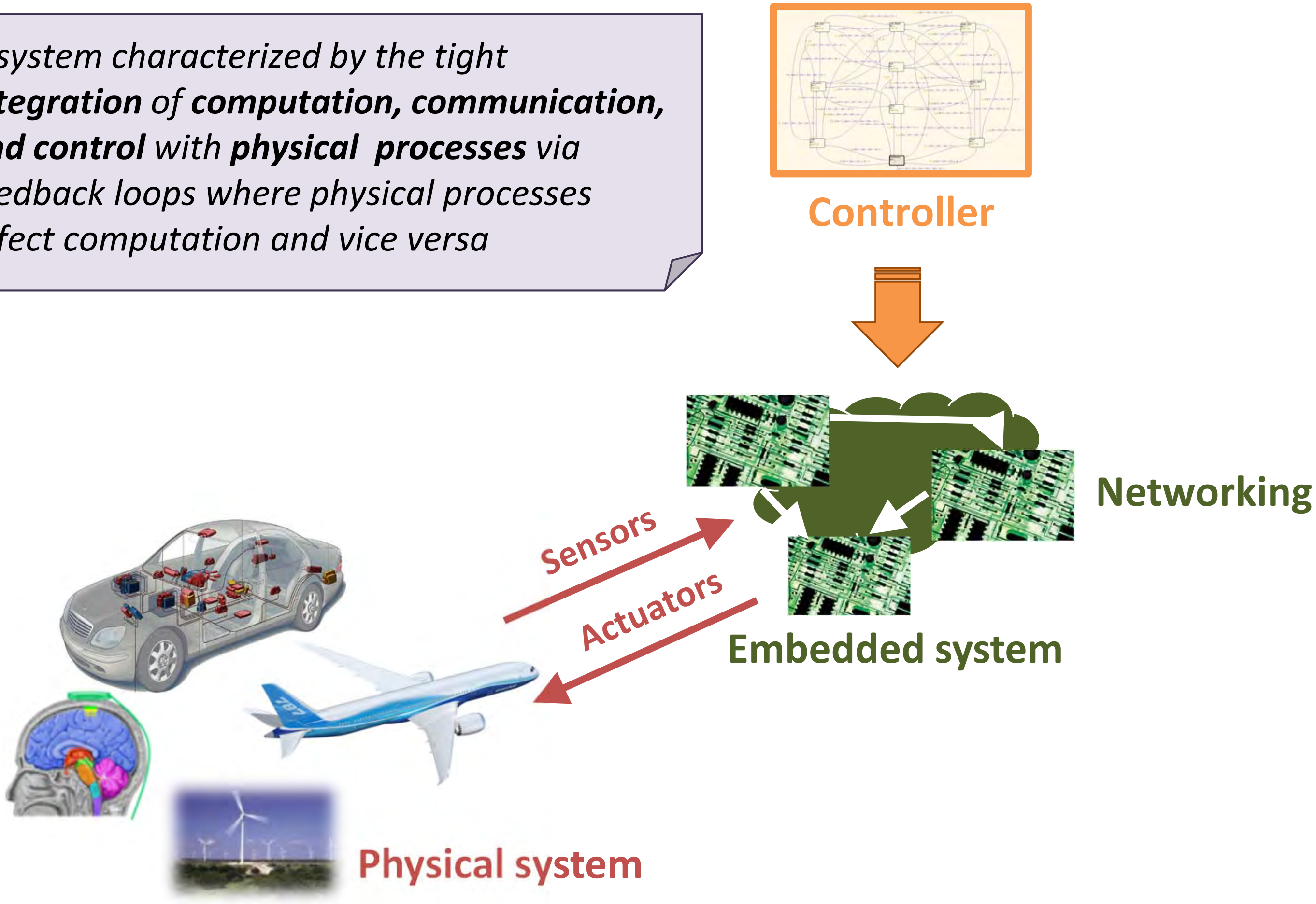
University of California, Berkeley

Outline

- Cyber-physical Systems
  - Societal Scale Systems
  - Automobile of the future
- Design Challenges
- The Far Future
  - Bio-Cyber Systems

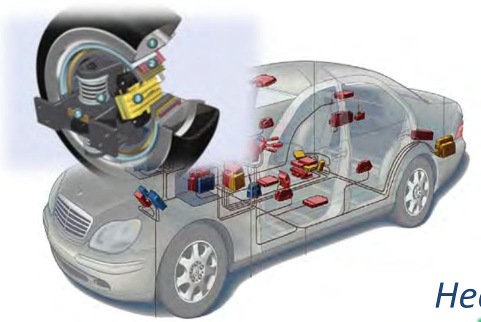
What is a Cyber-Physical System?

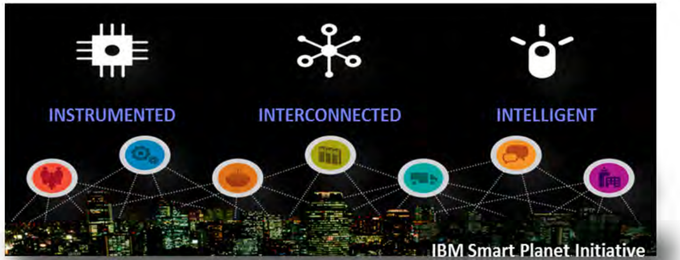
A system characterized by the tight ***integration*** *of* ***computation, communication, and control*** *with* ***physical processes*** *via feedback loops where physical processes affect computation and vice versa*



Cyber-Physical Systems (CPS) Interconnect the World Around Us and Make It “Smarter”

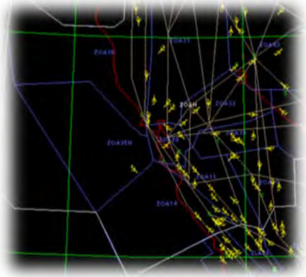
Autonomous Driving





Avionics

Transportation (Air traffic control)



Health care

Telecommunications

Buildings

Power generation and distribution

Factory automation

IBM Smarter Planet Initiative: Something profound is happening… CYBER PHYSICAL SYSTEMS!

INSTRUMENTED

We now have the ability to measure, sense and see the exact condition of practically everything.

INTERCONNECTED

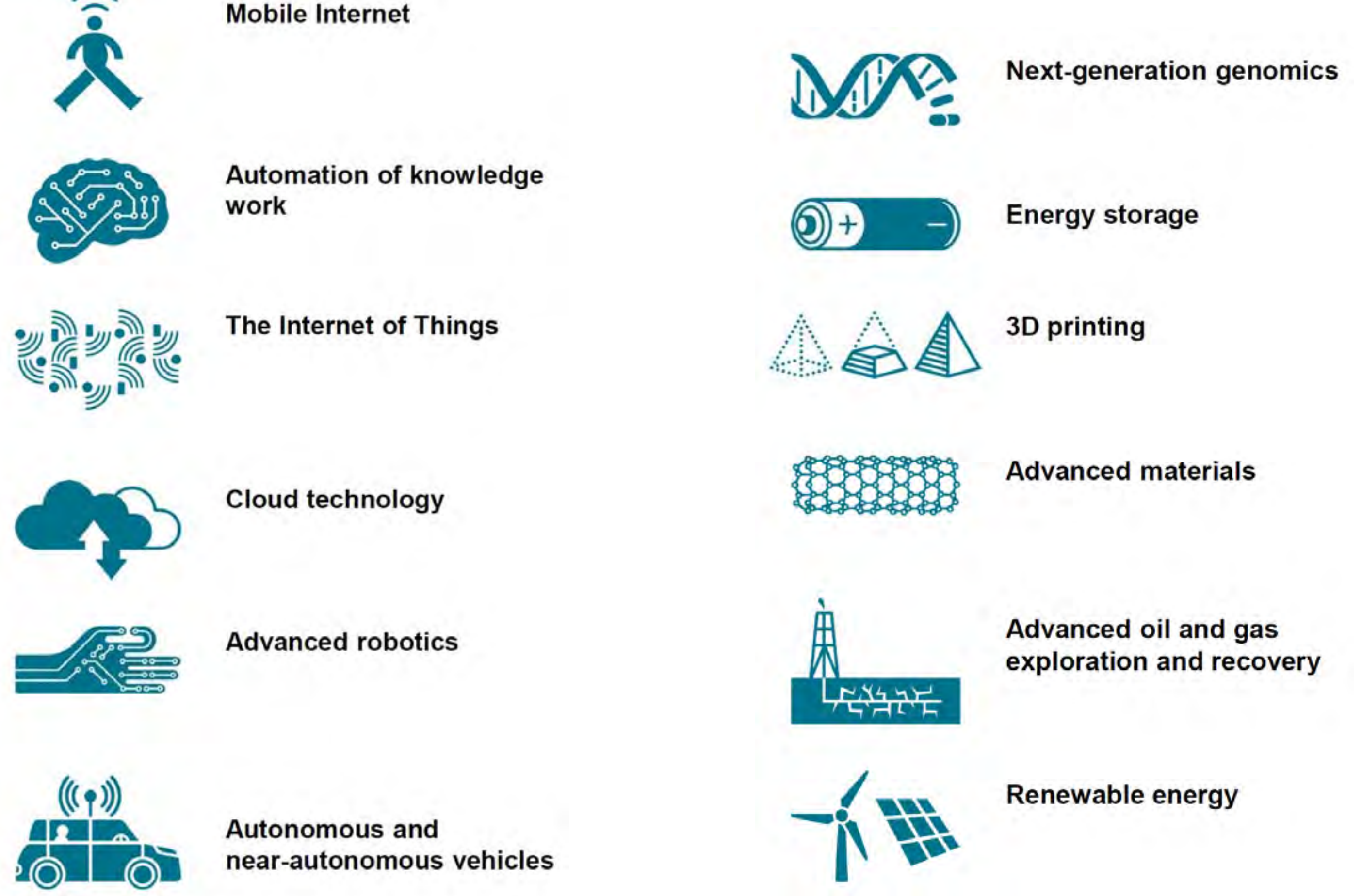
People, systems and objects can communicate and interact with each other in entirely new ways.

INTELLIGENT

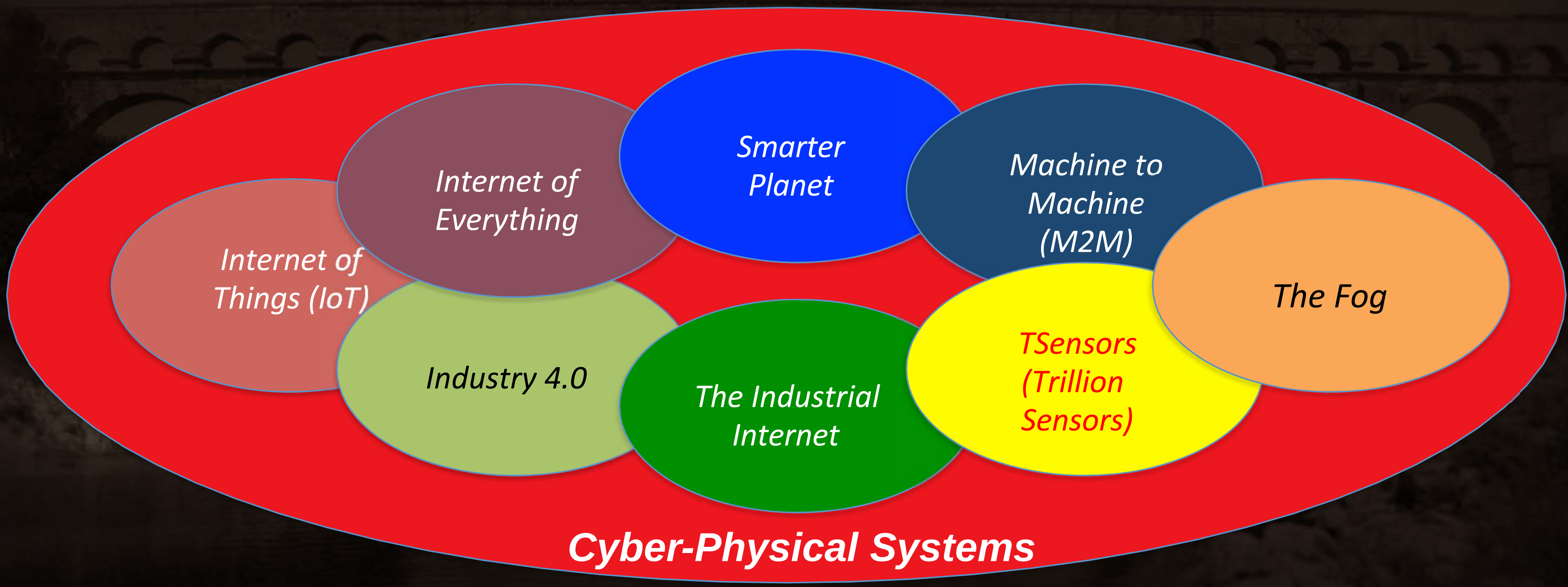
We can respond to changes quickly and accurately, and get better results by predicting and optimizing for future events.

Cyber-Physical System Relevance: McKinsey’s Disruptive Technologies

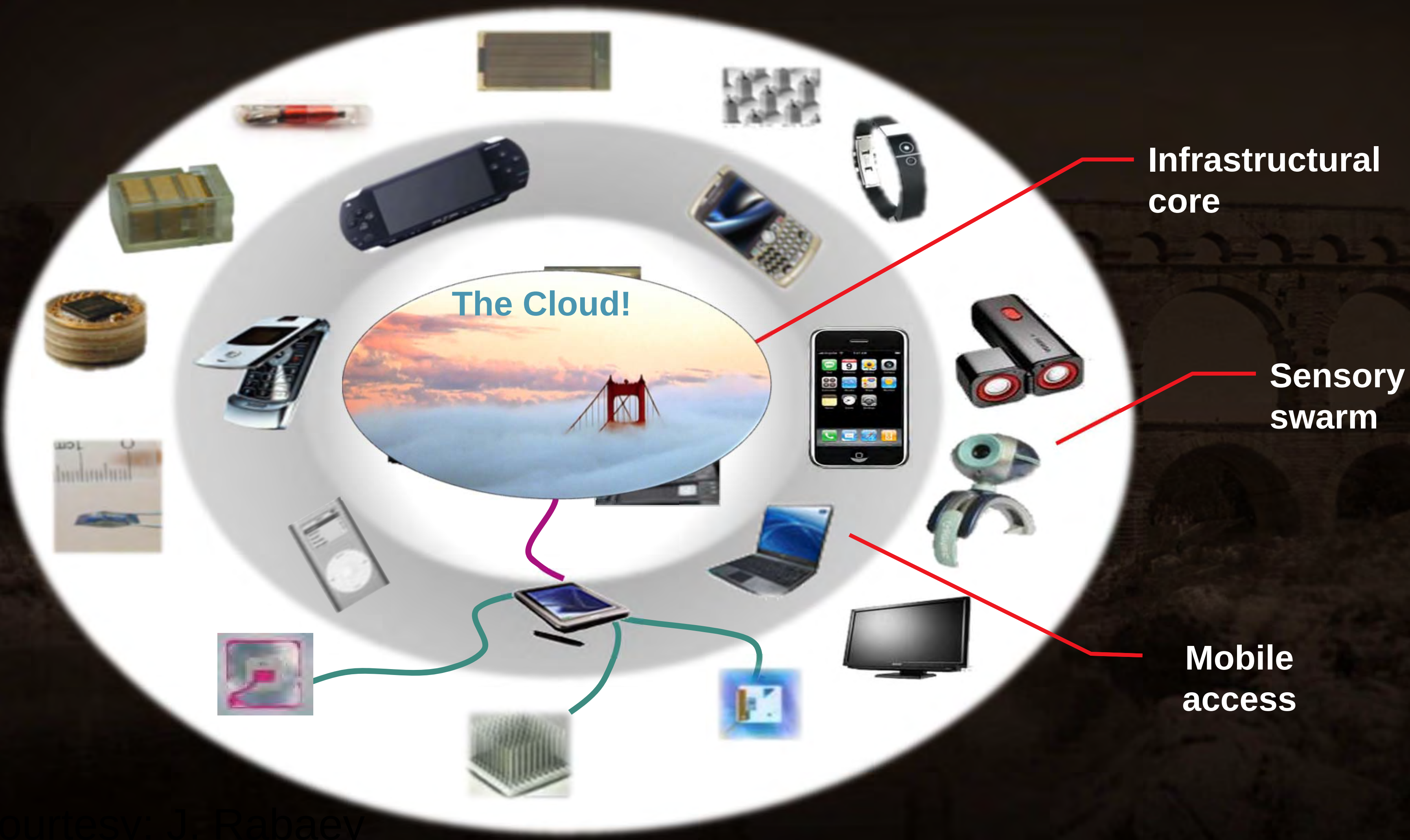
Source: McKinsey&Company



How Buzzwords Relate to CPS

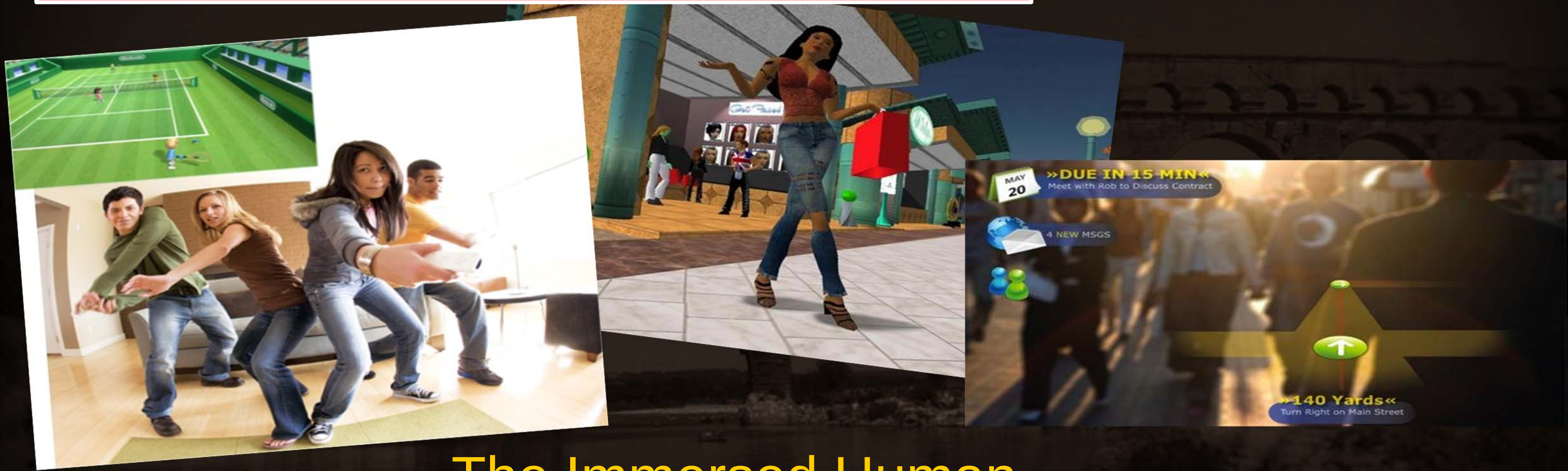


The Emerging IT Scene!



Computers and mobiles to disappear!

Predictions: 7 trillions devices servicing 7 billion people!
1,000 devices per person by 2025



The Immersed Human

Real-life interaction between humans and cyberspace, enabled by enriched input and output devices on and in the body and in the surrounding environment

Courtesy: J. Rabaey

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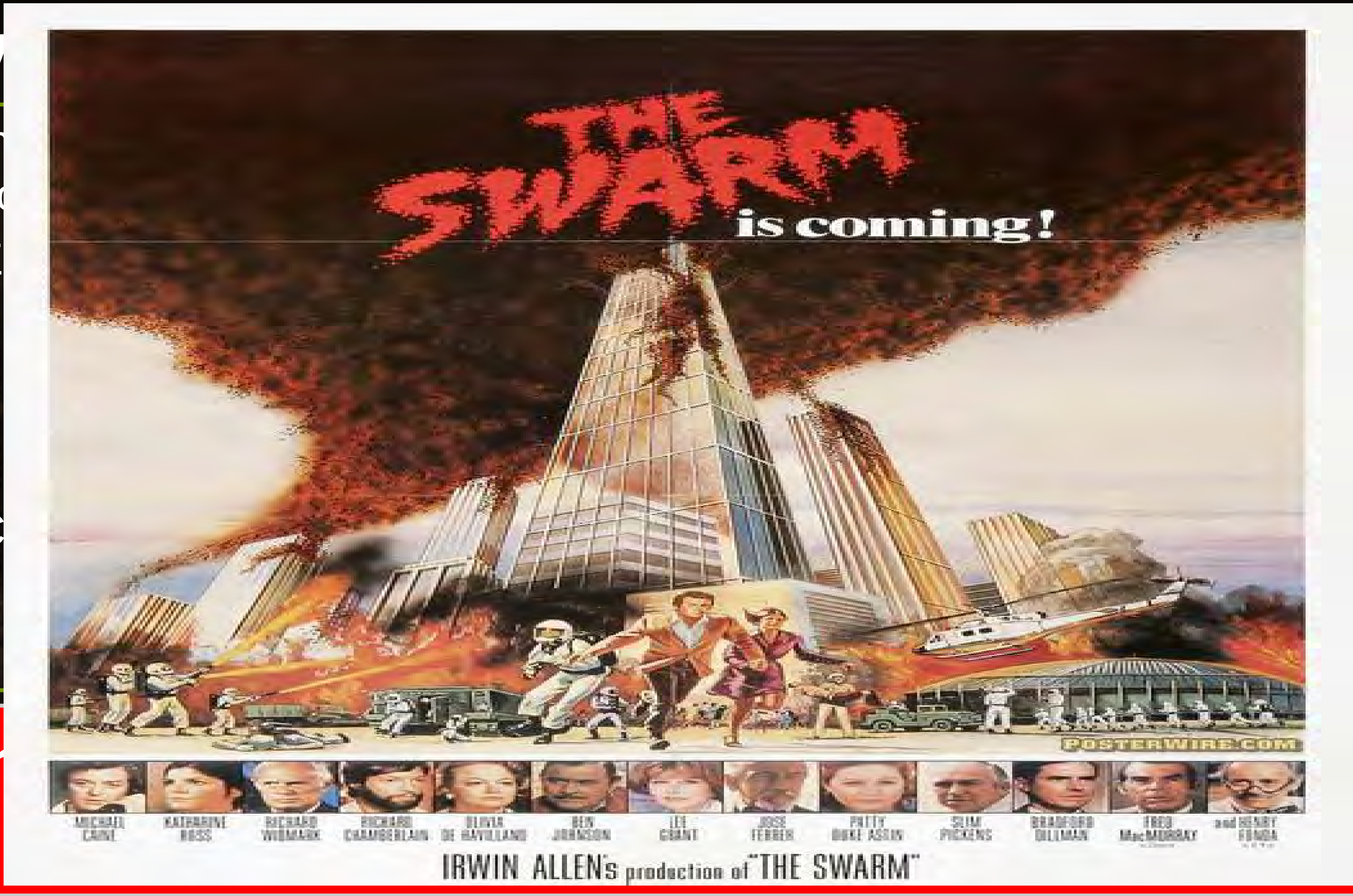

A h ... ve,

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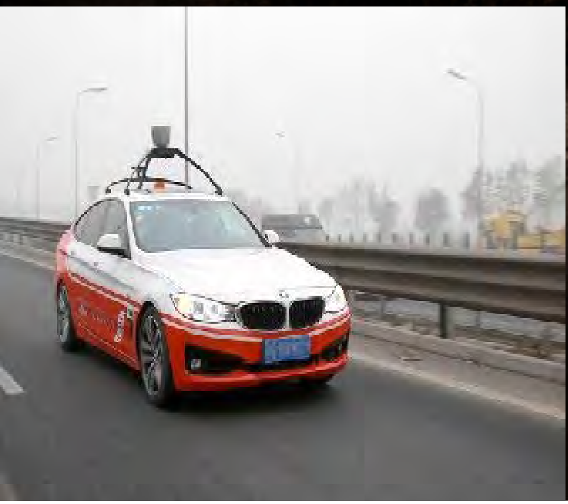


The Evolution of the Automotive DNA

CURRENT DNA	NEW DNA
Energized by Petroleum	Energized by Electricity and Hydrogen
Powered Mechanically by Internal Combustion Engine	Powered Electrically by Electric Motors
Controlled Mechanically	Controlled Electronically
Stand-alone	“Connected”
Totally Dependence on the Driver	Semi/Full Autonomous Driving
Vehicle Sized for Maximum Use - People and Cargo	Vehicle Tailored to Specific Use

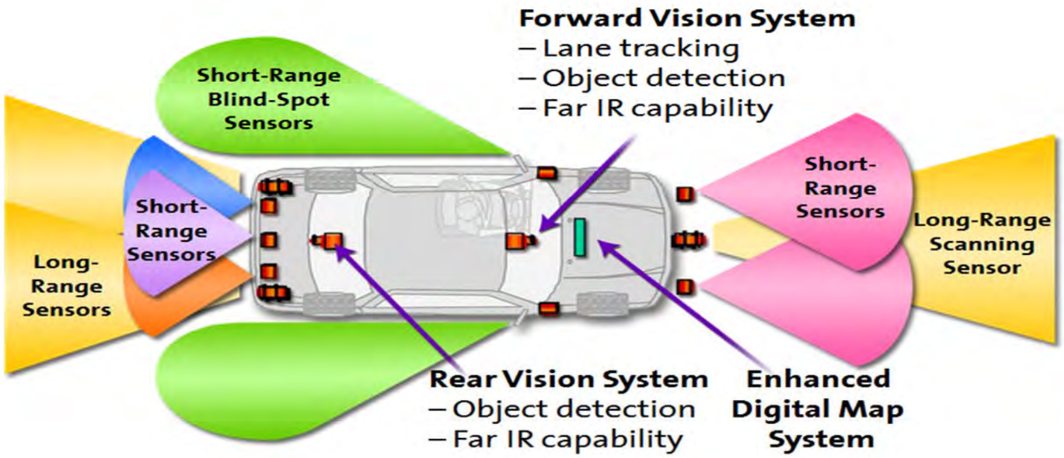
GM SAC Vehicular Electronics, Controls and Software Study

Software content in automobiles could increase by 100 X over the next 5-6 years. Challenges will include:

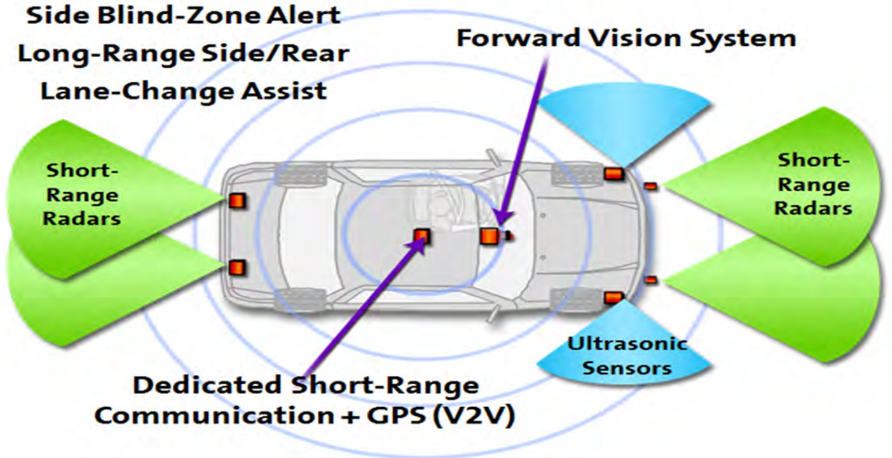
- Software system architecture
- Partitioning for modularity & system reliability
- Reuse
- Standardization of interfaces

360° SENSING CAPABILITY

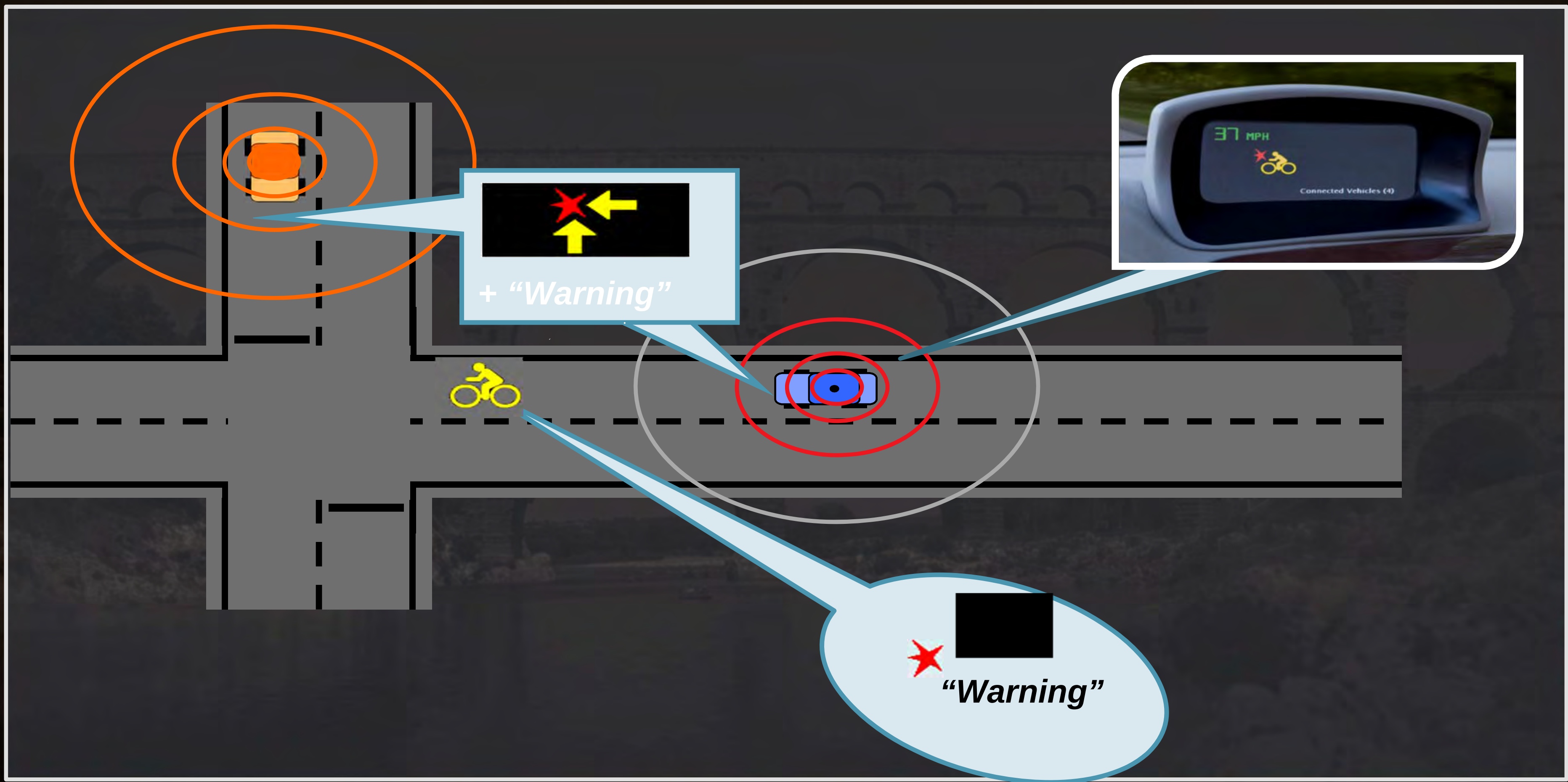
TODAY



FUTURE



V2V/V2X COMMUNICATIONS



Google

CNET › Internet › Google closes $3.2 billion purchase of Nest

Google closes $3.2 billion purchase of Nest

The acquisition brings with it the Learning Thermostat and the Protect smoke and CO detector as Google looks to make its mark in the smart home.

by Lance Whitney @lancewhit / February 12, 2014 5:00 AM PST / Updated: February 12, 2014 5:19 AM PST

theguardian | TheObserver

Search

Google's drive into robotics should concern us all

The company's expansion into robotics was developed in tandem with the US military. Where will its power play stop?

John Naughton
The Observer, Sunday 29 December 2013

Google's robotic cars have about $150,000 in equipment including a $70,000 LIDAR (laser radar) system. The range finder mounted on the top is a Velodyne 64-beam laser. This laser allows the vehicle to generate a detailed 3D map of its environment.
The car then takes these generated maps and combines them with high-resolution maps of the world, producing different types of data models that

Automotive News

2015 AUTOMOTIVE NEWS WORLD CONGRESS

Google in talks with OEMs, suppliers to build self-driving cars

Gabe Nelson
Automotive News | January 14, 2015 - 2:10 pm EST

The New York Times | http://nyti.ms/1zS47wf

TECHNOLOGY

Apple Is Forming an Auto Team

By BRIAN X. CHEN and MIKE ISAAC FEB. 19, 2015

SAN FRANCISCO — While Apple has been preparing to release its first wearable computers, the company has also been busy assembling a team to work on an automobile.

The company has collected about 200 people over the last few years — both from inside Apple and potential competitors like Tesla — to develop technologies for an electric car, according to two people with knowledge of the company's plans, who asked not to be named because the plans were private.

September 21, 2015 - 2:32 pm ET

Silicon Valley technology giant Apple has set a goal of finalizing an electric car in 2019, The Wall Street Journal reported today

Uber's Self-Driving Car Plans Involve a Trucking Startup AUGUST 18, 2016, 8:21 AM EDT

Uber has agreed to acquire Otto, a young startup, it revealed to Bloomberg and later confirmed on its blog. Otto, which developed a kit that lets big-rig trucks drive themselves on highways, was founded by four former Googlers, including Anthony Levandowski, one of the original engineers on the company's self-driving team, and Lior Ron, who headed Google Maps for five years.

The New York Times | http://nyti.ms/2cCrDLf

TECHNOLOGY

No Driver? Bring It On. How Pittsburgh Became Uber's Testing Ground

By CECILIA KANG SEPT. 10, 2016

PITTSBURGH — Any day now, Uber will introduce a fleet of self-driving cars in Pittsburgh, making this former steel town the world's first city to let any passenger hail an autonomous vehicle.

And….

Automotive News

BMW to develop driverless car tech with Intel, Mobileye

Edward Taylor

Automotive News | July 1, 2016 - 9:43 am EST

Automotive News

FCA, Google confirm plan for self-driving prototypes based on hybrid Chrysler Pacifica

From wire reports

Automotive News | May 3, 2016 - 7:40 am EST

Google has agreed to buy 100 plug-in hybrid minivans from Fiat Chrysler to expand its self-driving vehicle testing program, the two companies said today in the most advanced partnership to da Valley and a carmaker.

WASHINGTON/MILAN -- Alphabet Inc.'s Google unit has agreed to buy 100 plug-in hybrid minivans from Fiat Chrysler Automobiles to expand its self-driving vehicle testing companies said today in the most advanced partnership to date between Silicon Valley and a carmaker.

SELF-DRIVING CARS

GM Buying Self-Driving Tech Startup for More Than $1 Billion

Dan Primack, Kirsten Korosec

Mar 11, 2016

Ford Go Further | THE FORD MOTOR COMPANY MEDIACENTER

FORD INVESTS IN ARGO AI, A NEW ARTIFICIAL INTELLIGENCE COMPANY, IN DRIVE FOR AUTONOMOUS VEHICLE LEADERSHIP

Ford is investing $1 billion during the next five years in Argo AI, combining Ford's autonomous vehicle development expertise with Argo AI's robotics experience and startup speed on artificial intelligence software – all to further advance autonomous vehicles.

Press Release

THE VERGE

BUSINESS \ TECH \ TRAN

Samsung i connected

The Korean com tech market

by James Vincent | @jjvin

INTEL

Why Intel Bought Mobileye

Kirsten Korosec
Mar 13, 2017

"As you've heard me say, others predict the future. At Intel, we build it," Intel CEO Brian Krzanich wrote in a letter to employees.

On Monday, Intel bought it.

Intel, the world's largest chipmaker, announced it will acquire Mobileye, a leading automotive supplier of sensor systems that help prevent collisions, for $63.54 per share, which has a fully-diluted equity value of $15.3 billion and an enterprise value of $14.7 billion.

HOWEVER….

BUSINESS DAY

Self-Driving Tesla Was Involved in Fatal Crash, U.S. Says

By BILL VLASIC and NEAL E. BOUDETTE JUNE 30, 2016

Even as the companies conduct many tests on autonomous vehicles at both private facilities and on public highways, there is skepticism that the technology has progressed far enough for the government to approve cars that totally drive themselves.

NSTB Findings

- The National Transportation Safety Board (NTSB) on June 22, 2017 released, after more than a year of suspense, a 500page document or "docket," about a fatal highway crash involving a Tesla S and a tractor-semitrailer truck.
- Given Tesla's ability to link up with its servers and to store data in the car that expands the information contained on the servers, Vision System Iintelligence's Magney was most impressed with Tesla's Over-the-Air (OTA) capabilities. He noted, "Based on our examinations, it is my opinion that the Tesla vehicle architecture is a proxy for future vehicle platforms." He noted, "Albeit Tesla is a maverick in this space, **their OTA architecture plus event handling and data recording is vital for proper Autonomous Vehicle management."**

Apple and Google Slowing down….

The New York Times | http://nyti.ms/2cAPBGv

TECHNOLOGY

Apple Is Said to Be Rethinking Strategy on Self-Driving Cars

By DAISUKE WAKABAYASHI and BRIAN X. CHEN SEPT. 9, 2016

SAN FRANCISCO — Apple is rethinking what it plans to do about self-driving cars, just as other big tech companies appear ready to plow ahead with competing efforts.

In a retrenchment of one of its most ambitious initiatives, Apple has shuttered parts of its self-driving car project and laid off dozens of employees, according to three people briefed on the move who were not allowed to speak about it publicly.

The job cuts are the latest sign of trouble with Apple's car initiative. The

Yesterday and Today News

WallStreetJournal TECH

Uber Suspends Self-Driving Vehicle Program After Accident

Poli

inju

Uber

Uber resumes self-driving car program in San Francisco after crash

Gina Cherelus

Automotive News | March 27, 2017 - 11:55 am EST

self-driving cars after crash

By **Steven Overly** March 25 at 4:14 PM

And again….

Economic Potential

The Internet of Things	**300%** Increase in connected machine-to-machine devices over past 5 years **80–90%** Price decline in MEMS (microelectromechanical systems) sensors in past 5 years	**1 trillion** Things that could be connected to the Internet across industries such as manufacturing, health care, and mining **100 million** Global machine to machine (M2M) device connections across sectors like transportation, security, health care, and utilities	**$36 trillion** Operating costs of key affected industries (manufacturing, health care, and mining)
Cloud technology	**18 months** Time to double server performance per dollar **3x** Monthly cost of owning a server vs. renting in the cloud	**2 billion** Global users of cloud-based email services like Gmail, Yahoo, and Hotmail **80%** North American institutions hosting or planning to host critical applications on the cloud	**$1.7 trillion** GDP related to the Internet **$3 trillion** Enterprise IT spend
Advanced robotics	**75–85%** Lower price for Baxter[3] than a typical industrial robot **170%** Growth in sales of industrial robots, 2009–11	**320 million** Manufacturing workers, 12% of global workforce **250 million** Annual major surgeries	**$6 trillion** Manufacturing worker employment costs, 19% of global employment costs **$2–3 trillion** Cost of major surgeries
Autonomous and near-autonomous vehicles	**7** Miles driven by top-performing driverless car in 2004 DARPA Grand Challenge along a 150-mile route **1,540** Miles cumulatively driven by cars competing in 2005 Grand Challenge **300,000+** Miles driven by Google's autonomous cars with only 1 accident (which was human-caused)	**1 billion** Cars and trucks globally **450,000** Civilian, military, and general aviation aircraft in the world	**$4 trillion** Automobile industry revenue **$155 billion** Revenue from sales of civilian, military, and general aviation aircraft

The $7trillion 'passenger economy'

The $7trillion 'passenger economy' predicted by Intel is not based on the future sales of self-driving cars but on services and emerging applications that will be generated from autonomous cars.

Intel Corp. is forecasting that by 2050, the future of fully automated vehicles will become a $7 trillion "Passenger Economy".

Sensors are key Building Blocks for Smart Driving

Safer | Greener | More Connected

Digital and Satellite radio receivers	Machine Vision ADAS Processors	RADAR LiDAR	32-bit Auto Grade Microcontrollers	Engine control ICs	Secure Gateway Solutions	V2X Communication	Telematics processors
Integrated VDC	HD imaging ICs	GPS/GNSS Low-noise ampl & receivers	Ignition controllers and drivers	Multiple- Phase Motor driver	Analog Audio Processors	EV/HEV Power management ICs	Multiple channel Air Bags
Auto MEMs, gyroscopes, accelerometers	Communication transceivers	Alternator regulators	Door module drivers	Class AB and D Audio Amplifiers	AM/FM tuners	Valve driver ICs	Infotainment voltage regulators
High/Low and configurable side drivers/switches	Voltage regulators	Field Effect Rectifiers	SiC Diodes	SiC MOSFETs	Integrated filter and dataline protection	Micro-batteries	DC and Stepper Motor drivers
Low/High Voltage Planar MOSFET	Planar IGBT	Low Voltage Trench MOSFET	High Voltage Superjunction MOSFET	Ultra Fast & Schottky Diodes	1200V Thyristors	Microphone	Dataline & Load dump protection

increasing complexity

life.augmented

Vision Processing for Autonomous Driving

- Richest source of raw data about the scene – the only sensor that can reflect the true complexity of the scene.
- The lowest cost sensor for the data received
- Cameras are getting better - higher dynamic range, higher resolution
- Combination of RADAR/LIDAR/Ultrasonic for redundancy, robustness

Mobileye

- Mobileye's system-on-chip (SoC) – the EyeQ® family – provides the processing power to support a comprehensive suite of ADAS functions based on a single camera sensor.
- In its fourth and fifth generations, EyeQ® will further support semi and fully autonomous driving, having the bandwidth/throughput to stream and process the full set of surround cameras, radars and LiDARs.

Sensing Challenges:

- Perception of a comprehensive Environmental Model breaks down into four main challenges:
  - **Freespace**: determining the drivable area and its delimiters
  - **Driving Paths**: the geometry of the routes within the drivable area
  - **Moving Objects**: all road users within the drivable area or path
  - **Scene Semantics**: the vast vocabulary of visual cues (explicit and implicit) such as traffic lights and their color, traffic signs, turn indicators, pedestrian gaze direction, on-road markings, etc.

CMOS mmWave Circuits and SoC: 60GHz (2010)

- WirelessHD products available
  - SiBeam (**Berkeley startup**)
  - Wall-powered
  - Dissipate <2W
- A $10 Radar is a possibility!

EE Times Connecting the Global Electronics Community

designlines AUTOMOTIVE

80 Ghz

News & Analysis

NXP to Focus on All CMOS Radar Future

Junko Yoshida

3/9/2015 09:56 AM EDT

5 comments

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Freescale deal spurs automotive push

BARCELONA — In announcing the planned acquisition of Freescale Semiconductor, NXP Semiconductor CEO Rick Clemmer last week explained how he expects the new entity — NXP and Freescale combined — to lead the growing automotive electronics market.

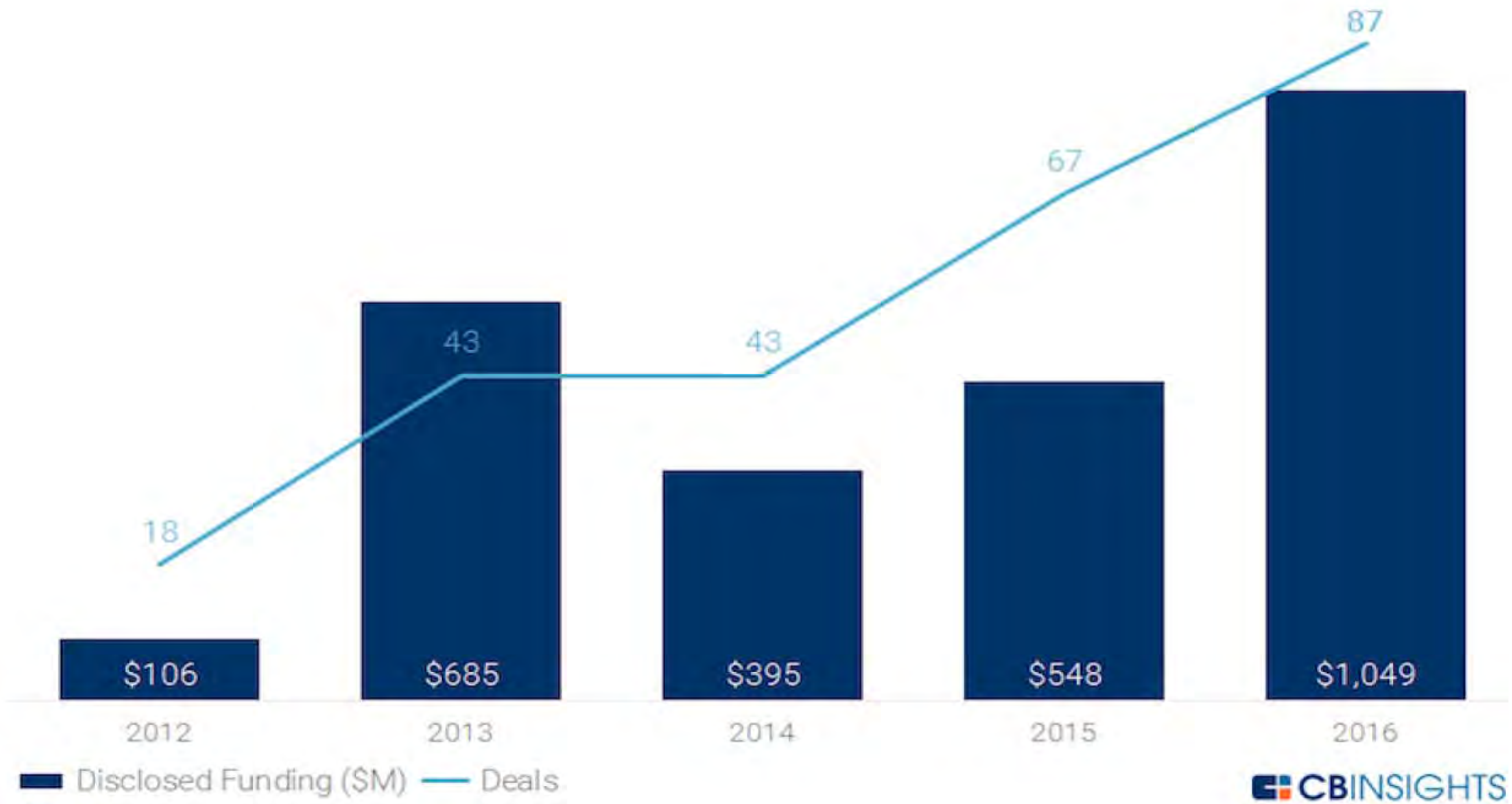
Radars and Cameras

Delphi's industry-first, **integrated Radar and Camera System (RACam)** combines radar sensing, vision sensing and data fusion in a single sophisticated module. The technology integration is helping to provide optimum value to vehicle manufacturers by enabling a suite of active safety features that includes adaptive cruise control, lane departure warning, forward collision warning, low speed collision mitigation, and autonomous braking for pedestrians and vehicles.

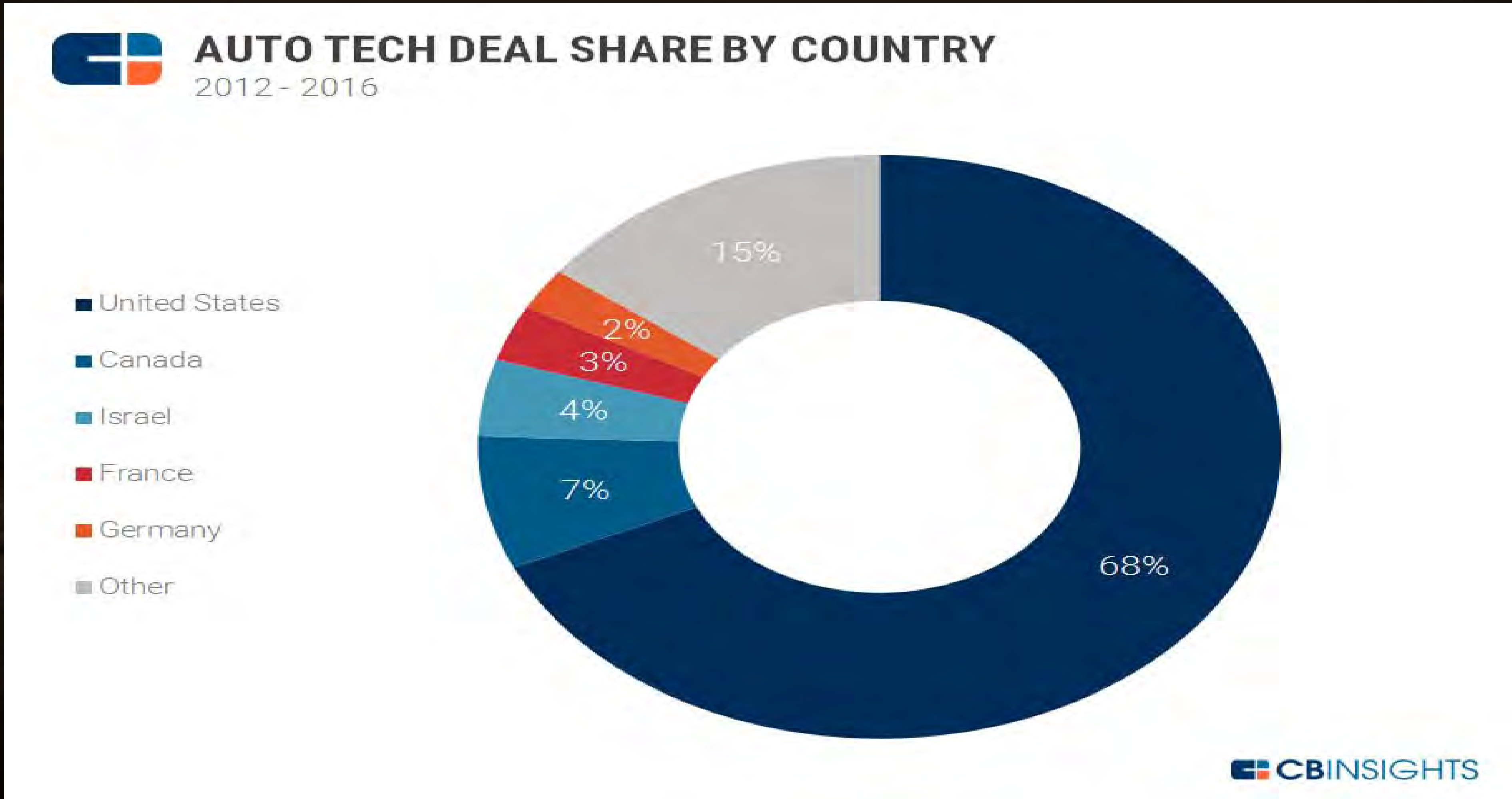
Lidar new entry

The LiDAR Gold Rush

CB Insights estimates $1.049 billion was invested in automotive technology startups last year, involving 87 deals and represen
a 91% increase in funding from 2015. LiDAR represents a growing portion of those investments.



Deal Share by Country



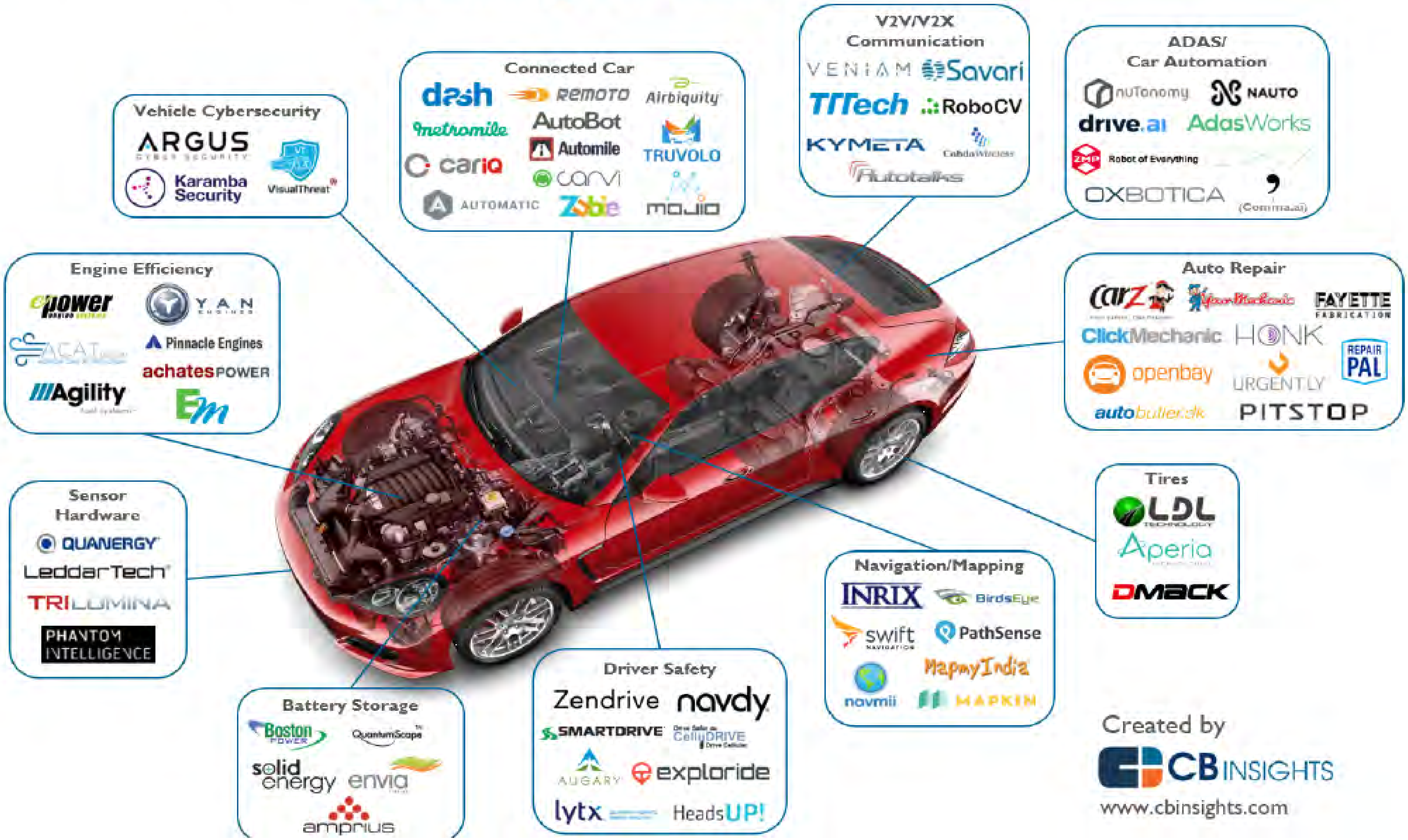
Challenges for the Automotive Ecosystem

- Emerging Markets.
- Demand Constraints.
- Ownership Models.
- Digital Competencies and Differentiation
- The Soul of the Car?
- Centralized traffic control
- SECURITY!!!!

- Legislating Autonomous Driving
- Connectivity
- Mandated Standards
- Engaging the Public
- Insurance Companies: Redefining the Risks and the Customers
- ETHICAL PRINCIPLES

Create free account

Unbundling The Automobile



MARCH 21, 2017

21 Industries Other Than Auto That Driverless Cars Could Turn Upside Down

Affected Industries

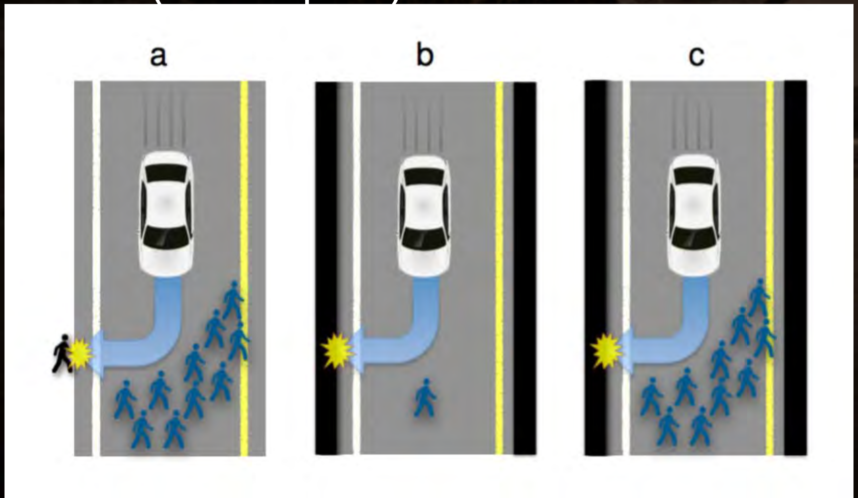
- Insurance
- Auto Repairs
- Professional Drivers and Truckers
- Hotels
- Airlines
- Auto Parts
- Ride Hailing Companies
- Public Transportation
- Parking Garages and Lots
- Fast Food
- Energy and Petroleum
- Real Estate
- Media and Entertainment
- Brick and Mortar Retails
- Auto dealerships
- Health Care
- Driving Schools
- Urban Planning
- Traffic Enforcement

Ethical Issues

Germany Issues Ethics Report on Automated and Connected Cars

Posted on June 22, 2017

On June 20, 2017, the German Federal Ministry of Transport and Digital Infrastructure issued a report on the ethics of Automated and Connected Cars (the "Report").



Ethics

Key points from the Report’s 20 ethical guidelines:

- Automated and connected transportation (driving) is ethically required when these systems cause fewer accidents than human drivers.
- Damage to property must be allowed before injury to persons: in situations of danger, the protection of human life takes highest priority.
- In the event of unavoidable accidents, all classification of people based on their personal characteristics (age, gender, physical or mental condition) is prohibited.
- In all driving situations, it must be clearly defined and recognizable who is responsible for the task of driving – the human or the computer. Who is driving must be documented and recorded (for purposes of potential questions of liability).
- The driver must fundamentally be able to determine the sharing and use of his driving data (data sovereignty).

Vehicle Cybersecurity

- Modern vehicles are complex, networked Information Technology (IT) systems that comprise an increasingly sophisticated array of sensors and control processors connected by internal communication networks

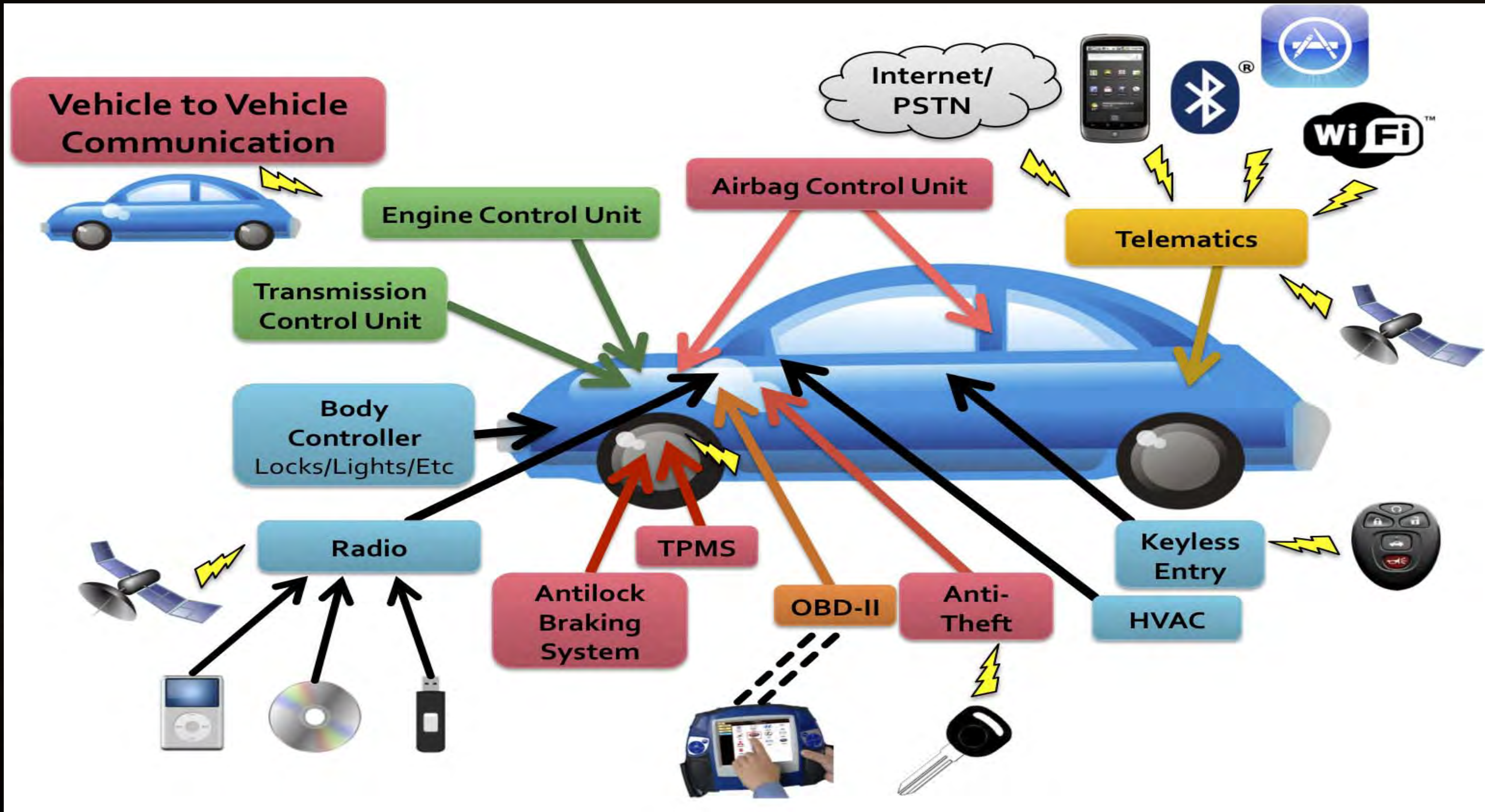
- Vehicles are networked entities that exist in cyberspace much like any other computational node, PC, tablet, or smartphone

- As more and more technology is introduced into automobiles, the threat of malicious software and hardware manipulation increases
  - Increasing connectivity and complexity is greatly expanding the attack surface of our systems

- Recent work has demonstrated potential security weaknesses in vehicles

Comprehensive Experimental Analyses of Automotive Attack Surfaces,
S. Checkoway et al. ,UC San Diego, K. Koscher, et al, U. of Washington
IEEE Symposium on Security and Privacy in Oakland, CA on May 19, 2010.

Surface of attack



Hacking Cars

Robocalypse

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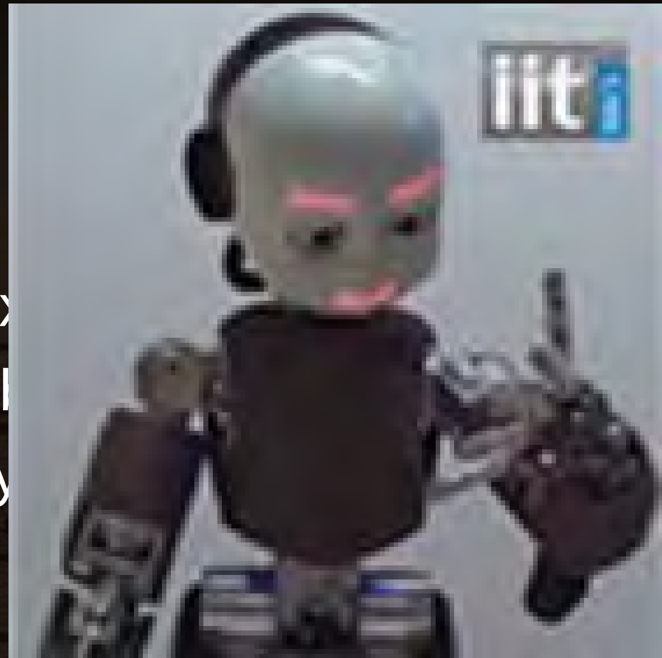

Outline

- What is possible? Cyber-physical Systems
  - Societal Scale Systems
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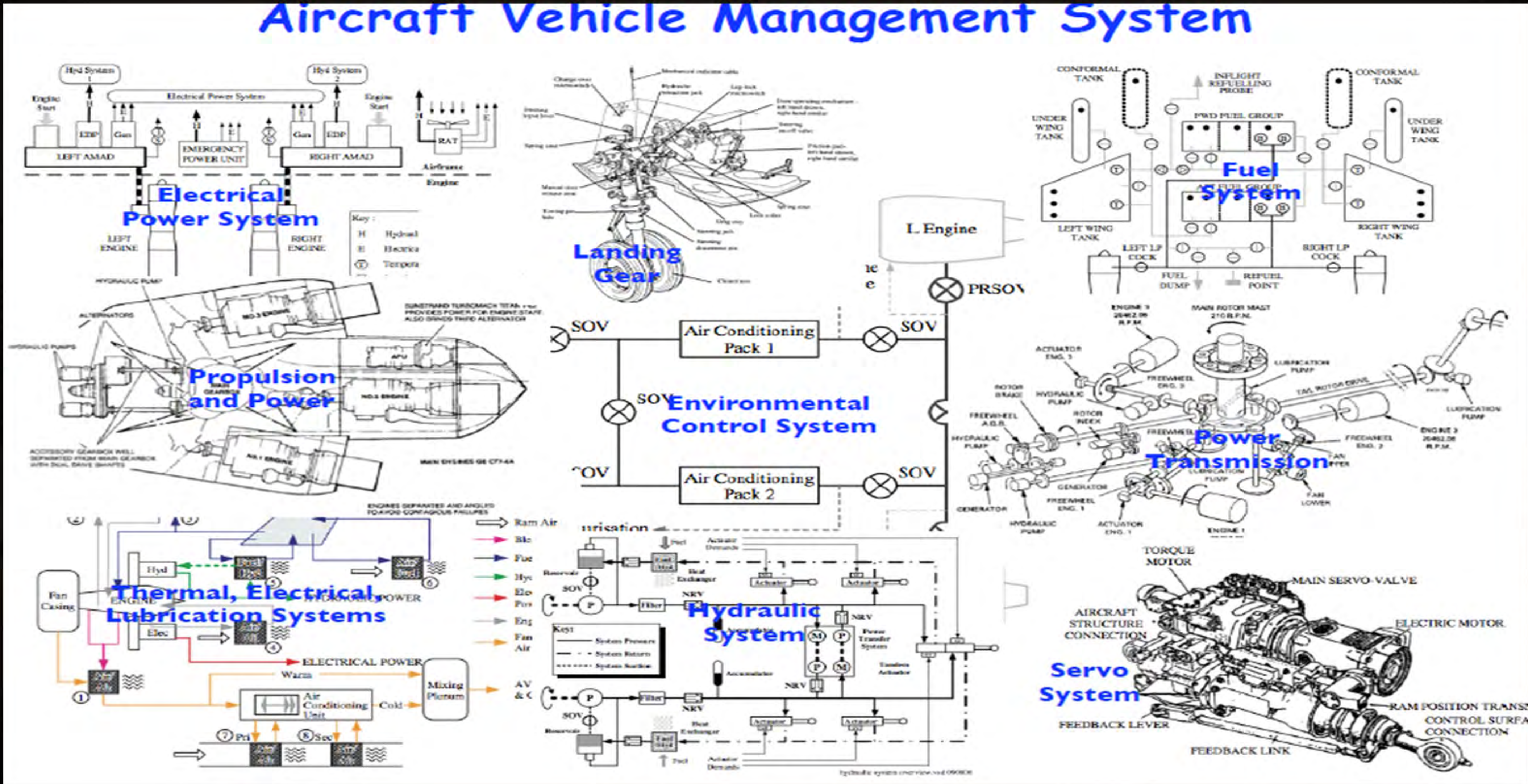
An example of Cyber-Physical System (provided by UTC)



VMS Challenge Problem v1.0 (1Nov2010)

VMS Functions (replace flight engineer)

- Operate and monitor engine/aircraft systems controls and indicators;
- Perform engine starts, monitor run-up, flight operation and engine shutdown;
- Operate engine controls to provide desired efficiency and economy;
- Monitor engine instruments throughout period of operation;
- Control, monitor and regulate some or all aircraft systems: hydraulic, pneumatic, fuel, electronic, air conditioning, pressurization; ventilation; lubrication communication, navigation, radar, etc

VMS architecture (design exploration)

- Implement fully distributed system, with all subsystems integrated across a networked communications interface

System Demonstrations

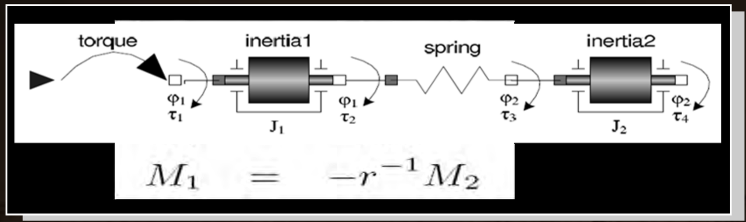
- **System startup**: From a cold start, turn all subsystems on and go into a normal operating mode
- **Transport mission**: pick up ground cargo using winch from hovering configuration, transport cargo as swung load to drop-off location, deposit on ground, and depart from area
- **Landing operations**: support aircraft landing in easy (daylight, clear conditions), moderate (nighttime and/or rainy conditions) and difficult (dusty with icy weather) conditions
- **Safing mode**: perform operations that put vehicle in safe operating mode, depending on condition of vehicle
- **System diagnostics**: during normal operations, log diagnostic data from all subsystems, w/ variable resolution

Where CPS Differs

- *The traditional embedded systems problem*:
  - Embedded system is the union of computing hardware and software immersed in a physical system it monitors and/or controls. The physical system is a given. The design problem is about the embedded system only.
- *Hybrid Systems*
  - Mixed discrete and continuous time systems
- *The CPS problem*:
  - Cyber-Physical Systems (CPS): **Orchestrating** networked computational resources with physical systems
  - Co-design of physical system and controller
  - Computation and networking integrated with physical processes. The technical problem is managing dynamics, time, and concurrency in **networked, distributed** computational + physical systems.

Modeling Cyber-Physical Systems

Model



Equation-based model

Abstraction
“physical modeling”

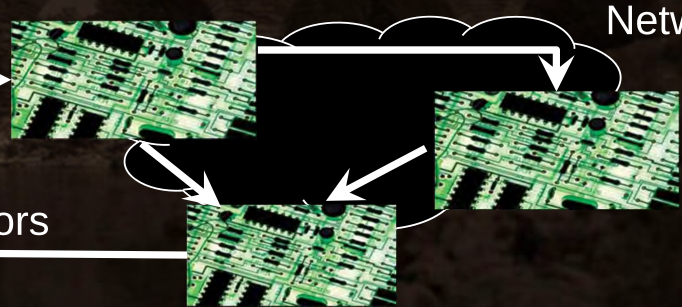
System

Physical system (the plant)

Sensors

Actuators

Networking



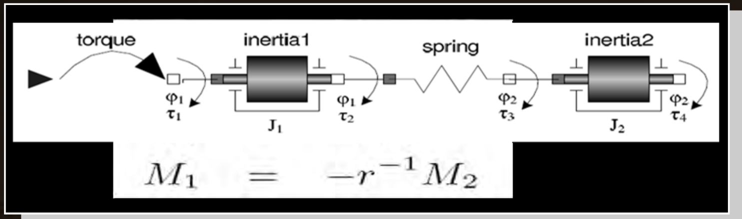
Embedded systems (computation)

Courtesy: D. Broman

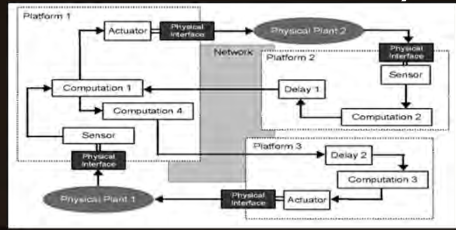
Modeling Cyber-Physical Systems

(Lee, ASV: A framework for comparing models of computation, IEEE Trans. CAD, 1998)

Model



Equation-based model



Different models of computation

Abstraction
"physical modeling"

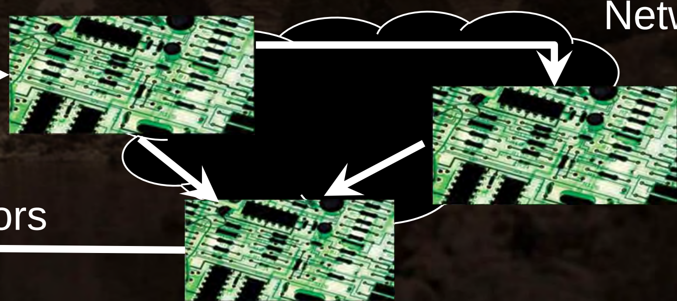
Concept of Time

C-code

System

Sensors

Networking



Actuators

Physical system (the plant)

Embedded systems (computation)

Courtesy: D. Broman

CS modeling challenges for CPS

A richer, systems view of computer science is needed. Ingredients include:

Enriching CS models with relevant physical/resource properties

- Physical, model-based computing
- Resource aware (time/energy) computing

Formal composition of multiple physics, models of computation, languages

- Composition of heterogeneous components

Impact of cyber components on physical components and vice versa

- Physically-aware computing

How Safe is Our Design Today?

The Larger Picture

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

What's Bugging the High-Tech Ca

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

Indeed, the high-tech comfort system confus the 200 sendin freezin loyal v up. thi billion,

MOTOR T

Toyota Problems
The Washington Post, March 7

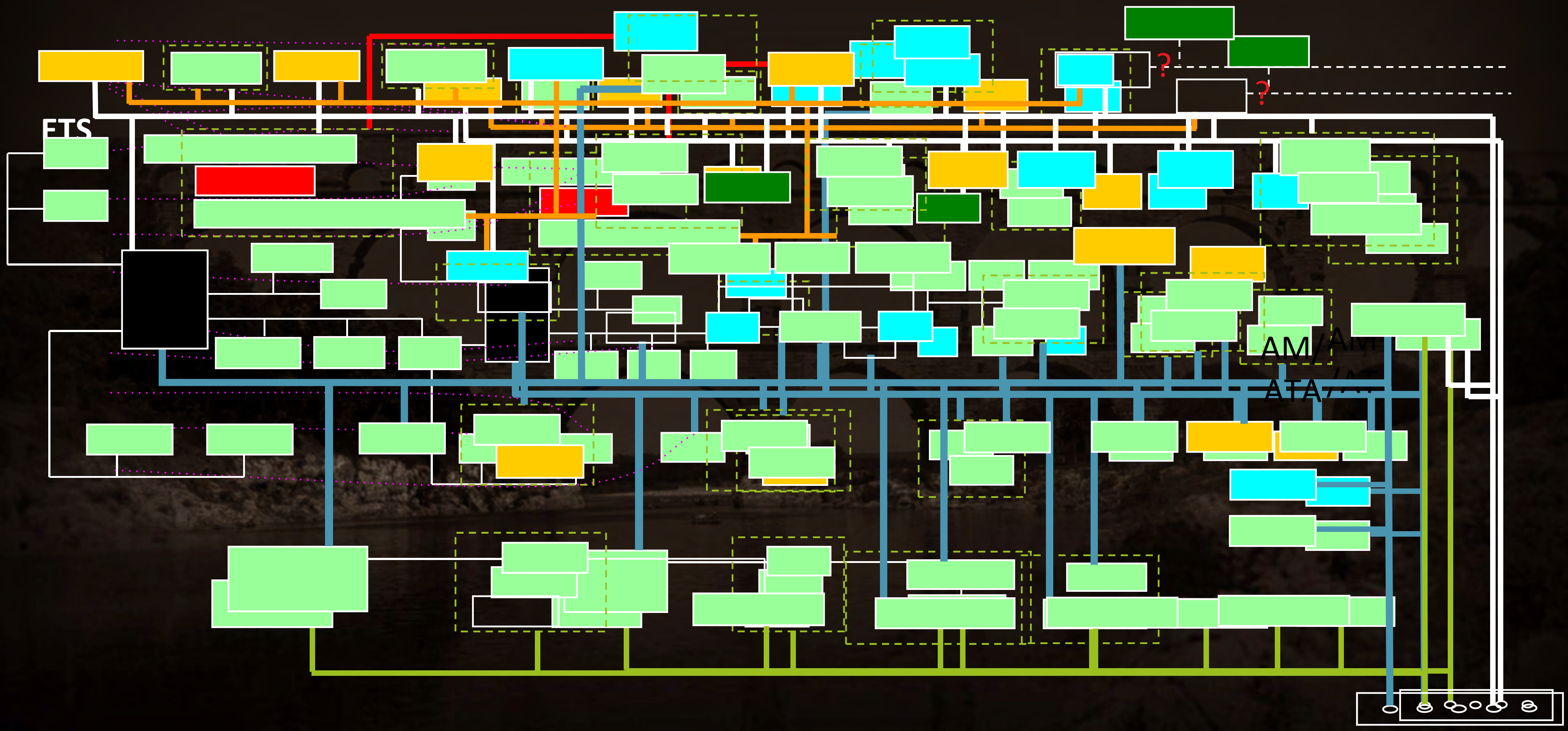
Attention has been focused on mechanical and electronic issues with Toyotas, but another possible cause of the runaway acceleration maybe a software glitch. Each vehicle contains layers of computer code that may be added from one model year to next" that control nearly every system, from acceleration to braking to stability. This software is rigorously tested, but t is well-known in our community that there is no scientific, firm way of actually completely verifying and validating software.

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.

The Problem: Typical Car Electrical Architecture



And What About Airplanes?

Airbus Problems

Initial production of the A380 was troubled by delays attributed to the 530 km (330 mi) of wiring in each aircraft. Airbus cited as underlying causes the complexity of the cabin wiring (100,000 wires and 40,300 connectors), its concurrent design and production, the high degree of customization for each airline, and failures of configuration management … change control … manufactured using aluminum rather than … rules including non-

Boeing Problems

Boeing had originally planned for a first flight by the end of August 2007 and premiered the first 787 at a rollout ceremony on July 8, 2007, which matches the aircraft's designation in the US-style month-day-year format (7/8/07). Although intended to shorten the production process, 787 subcontractors initially had difficulty completing the extra work, because they could not procure the needed parts, perform the subassembly on schedule, or both, leaving remaining assembly work for Boeing to complete as "traveled work". blaming a shortage of fasteners as well as incomplete software. The company expects to write off US$2.5 billion because it considers the first three Dreamliners built are unsellable and suitable only for flight tests. In August 2010, it was announced that Boeing was facing a US$1 billion compensation claim from Air India due to the delays for the 27 787s it has on order

It’s Not Over Yet!

THE WALL STREET JOURNAL.
WSJ.com

BUSINESS | NOVEMBER 25, 2010

Boeing 787 Is Set Back as Blaze Forces Fix

By PETER SANDERS

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

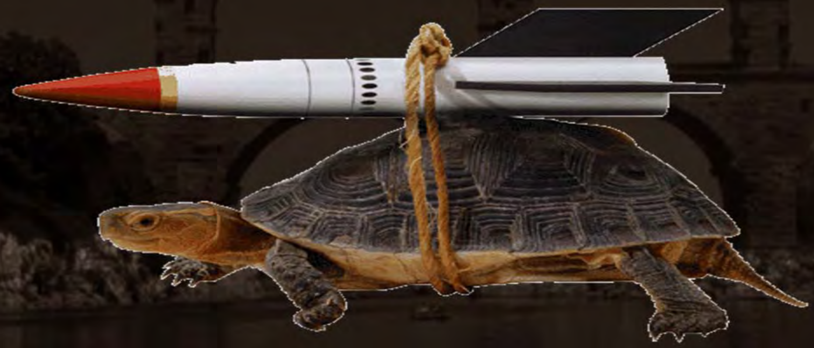
- *Give the programmer a nice abstraction*
  - Still need abstractions, but likely different ones

Source: Alex Aiken

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.

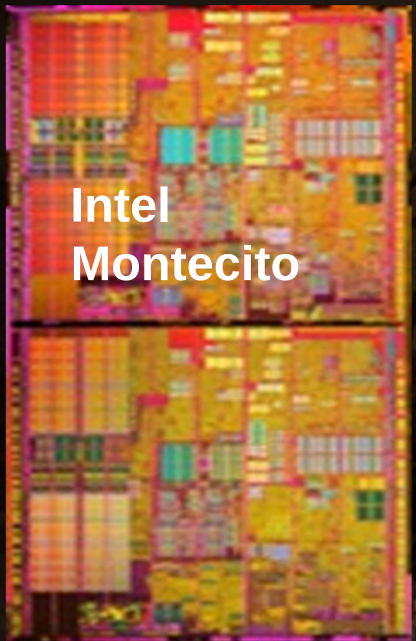
- *Threads*: Sequential computation with shared memory.
- *Interrupts*: Threads started by the hardware.

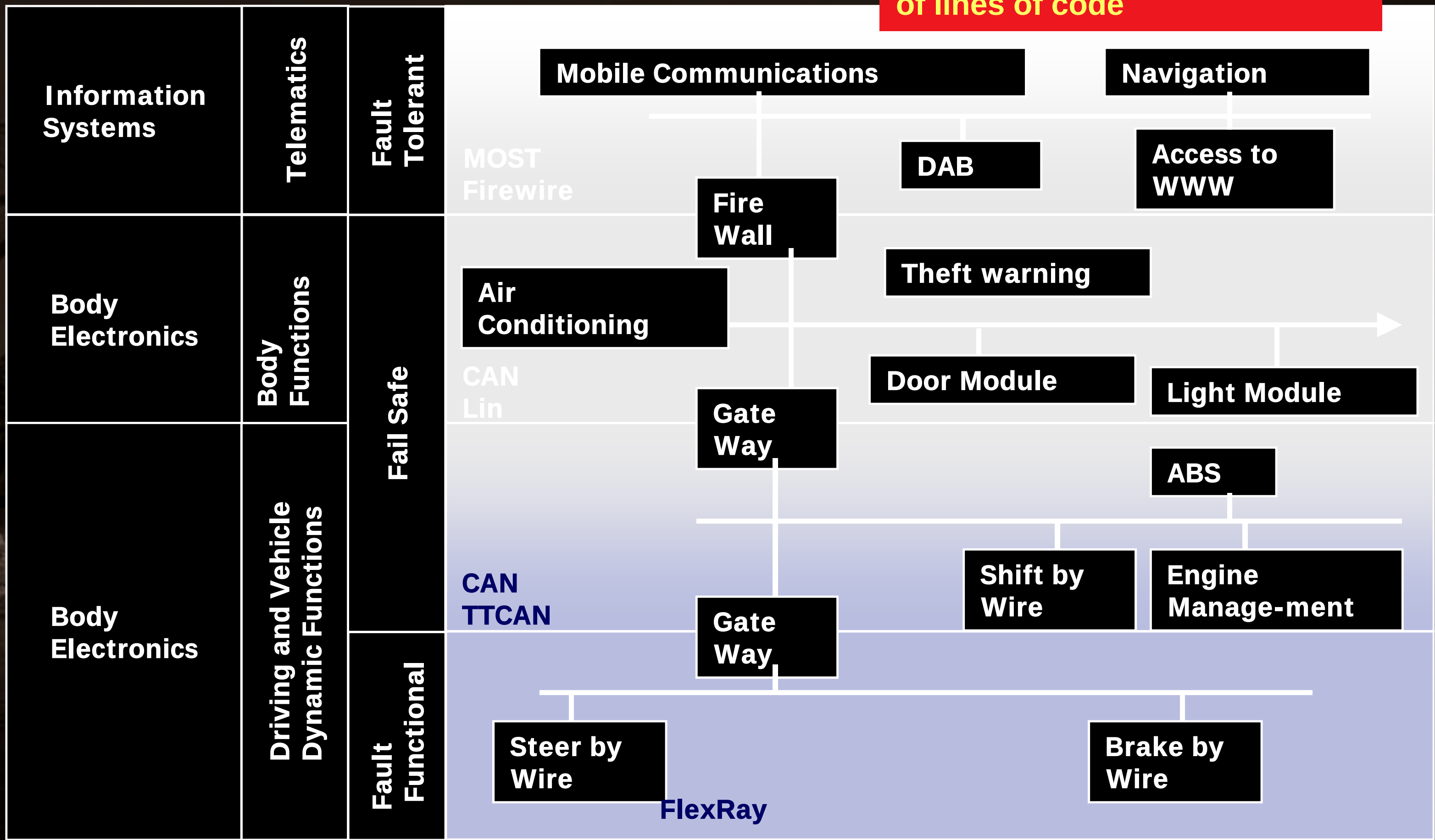
Incomprehensible interactions between threads are the sources of many problems:

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

Concurrency and Heterogeneity

Today, more than 80 Microprocessors and millions of lines of code





Source: Bosch

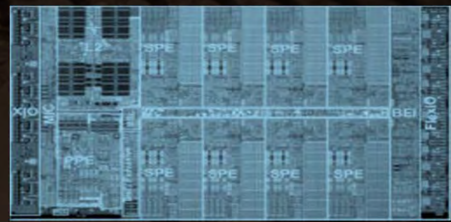
Challenge: Power

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 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.

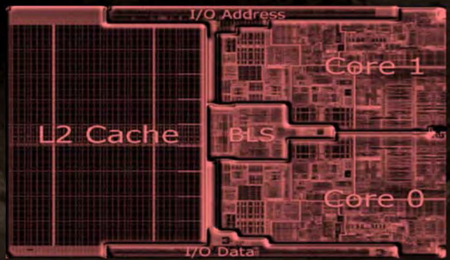
Challenge: Parallel Architectures

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



IBM/Sony Cell
ISSCC 05, 235M trans.

SUN Niagara-2
ISSCC 07, 500M trans.



Intel KEROM dual core
ISSCC 07, 290M trans.

Challenge: Manage the Design and Supply Chain

SST
SST25VF080
B
1 MB Serial
Flash

NATIONAL
SEMICONDU
CTOR
LM2512AA
Display
Interface

BROADCOM
BCM5974
Touchscreen
Controller

WOLFSON
WM6180C
Audio Codec

SAMSUNG
Application
Processor
and
DDR SDRAM

ST
MICROELEC
TRONICS
LI...

INFINEON
SMP3i
SMARTi
Power
Management

SKYWORKS
SKY77340
Power Amp.
Module

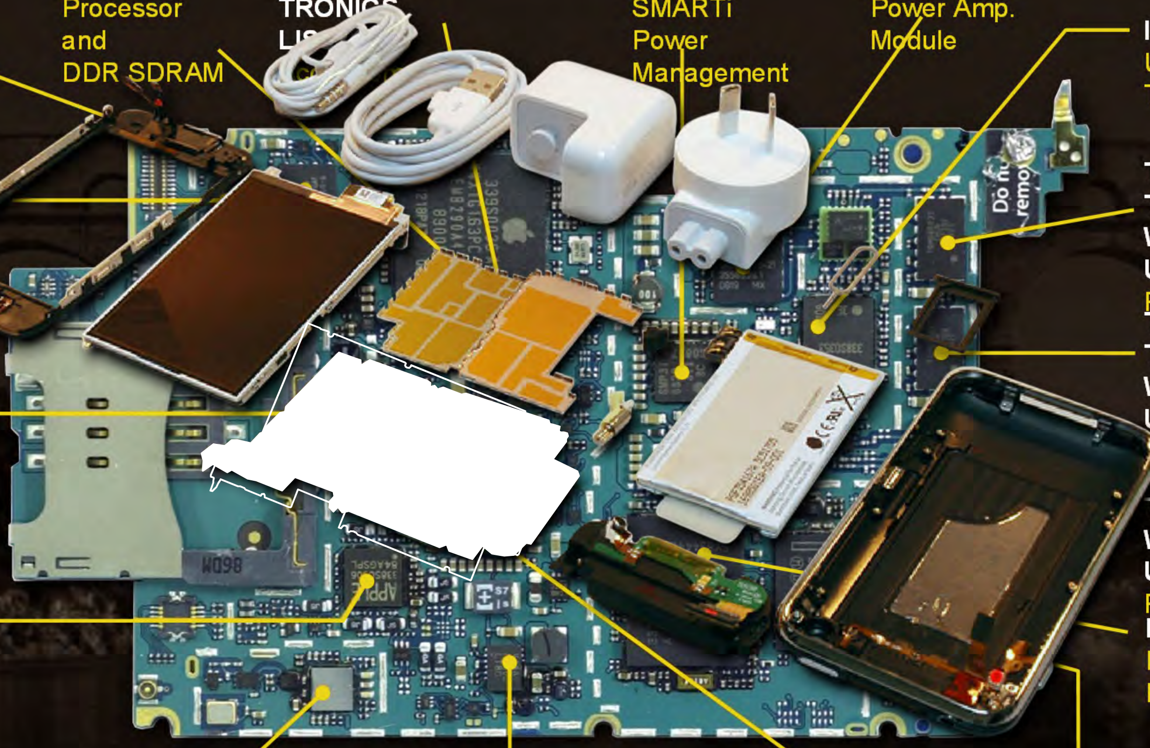
INFINEON
UMTS
Transceiver

TRIQUINT
TQM666032
WCDMA/HS
UPA
Power Amp.

TRIQUINT
TQM676031
WCDMA/HS
UPA
Power Amp.

TRIQUINT
TQM616035
WCDMA/HS
UPA
Power Amp.

INFINEON
Digital Baseband
Processor



Semiconductor insights

INFINEON
PMB2525
Hammerhead
II GPS

LINEAR
TECHNOLO
GY
LTC4088-2
Battery
Charger/

NXP
Power
Management

NUMONYX
PF38F3050M
0Y0CE
16 MB NOR +
8 MB
Pseudo -

Collaborating to Create the iPhone

SST SST25VF080B
1 MB Serial Flash

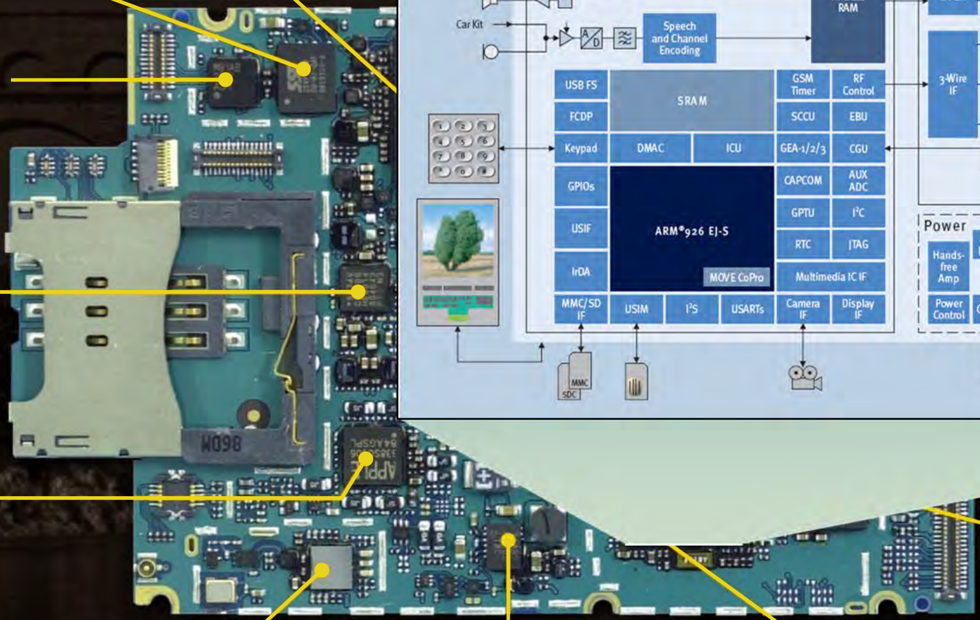
NATIONAL SEMICONDUCTOR LM2512AA
Display Interface

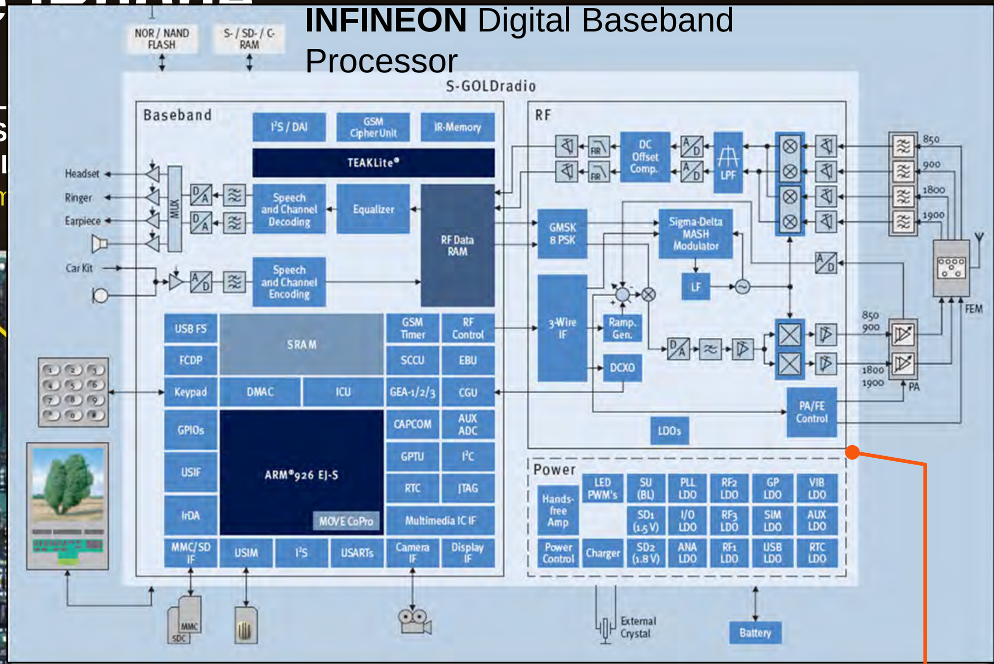
BROADCOM BCM5974
Touchscreen Controller

WOLFSON WM6180C
Audio Codec

SAMSUNG
Application Processor and DDR SDRAM

ST MICROELECTRONICS LIS331 DL
Accelerometer





INFINEON
Power Amp

INFINEON
Digital Baseband Processor

INFINEON PMB2525
Hammerhead II GPS

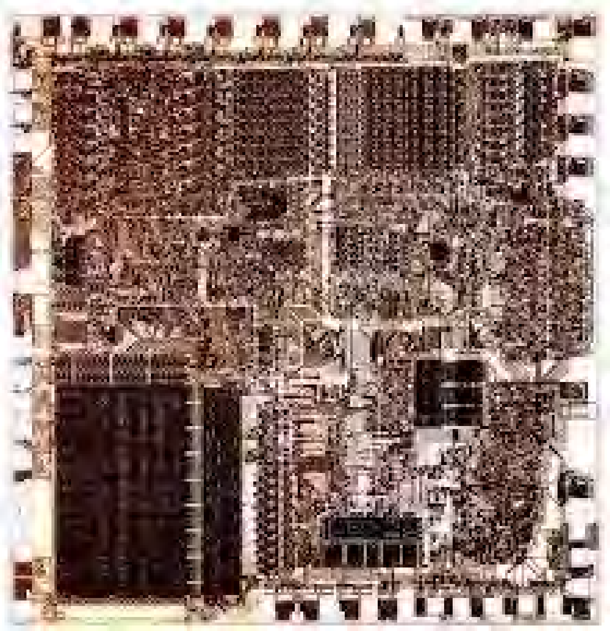
LINEAR TECHNOLOGY LTC4088-2
Battery Charger/

NXP
Power Management

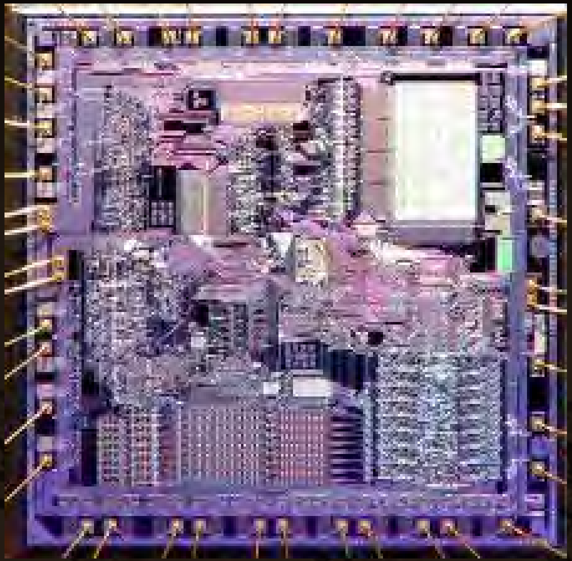
NUMONYX PF38F3050M0Y0CE
16 MB NOR + 8 MB Pseudo -

The Role of Design Methodologies

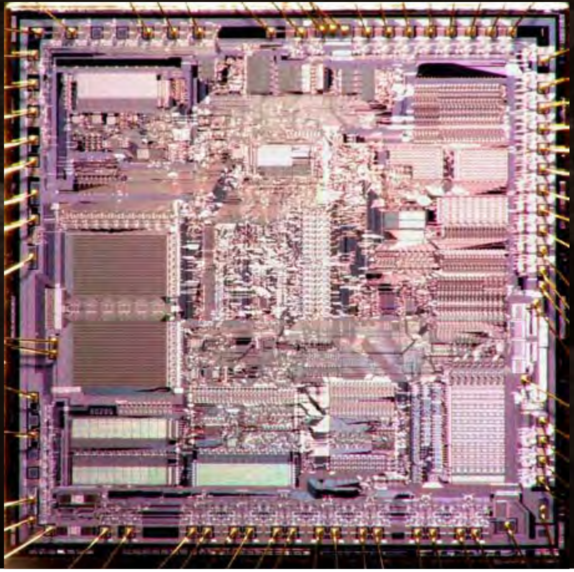
Evolution:
From Handcraft to...



Intel 4004

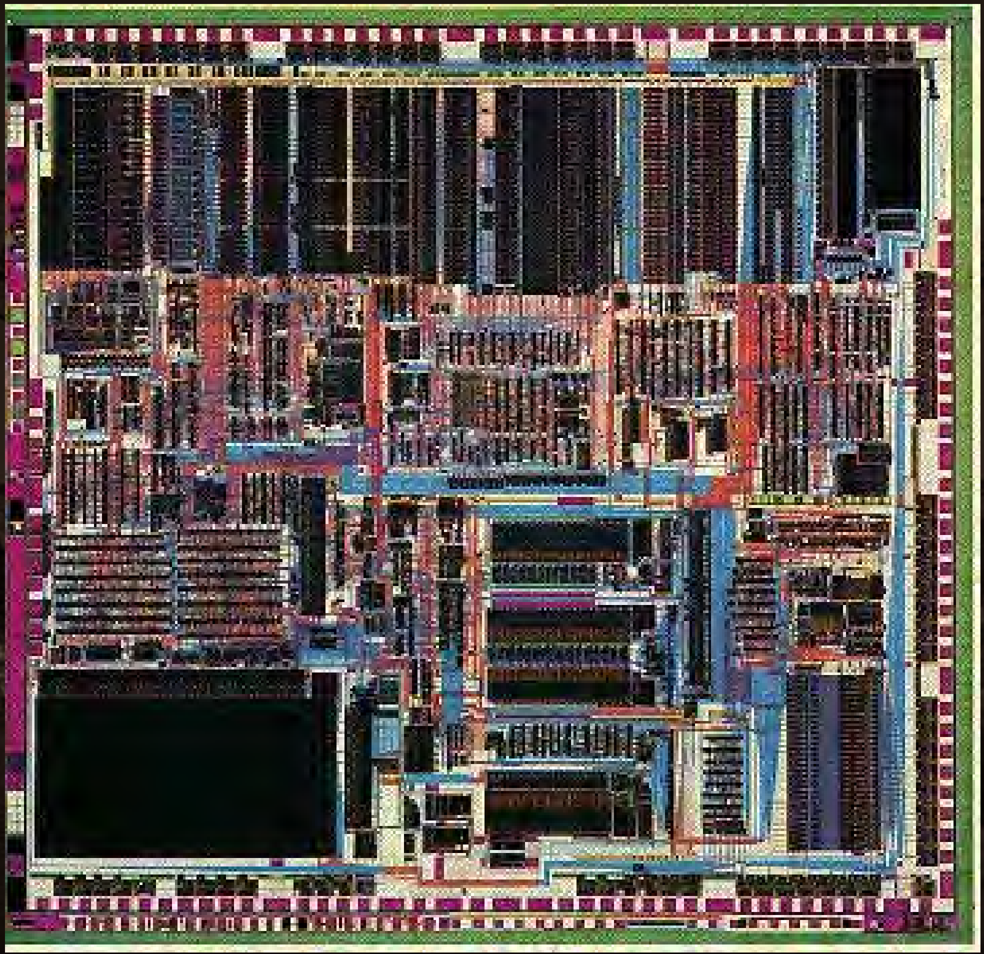


Intel 8086



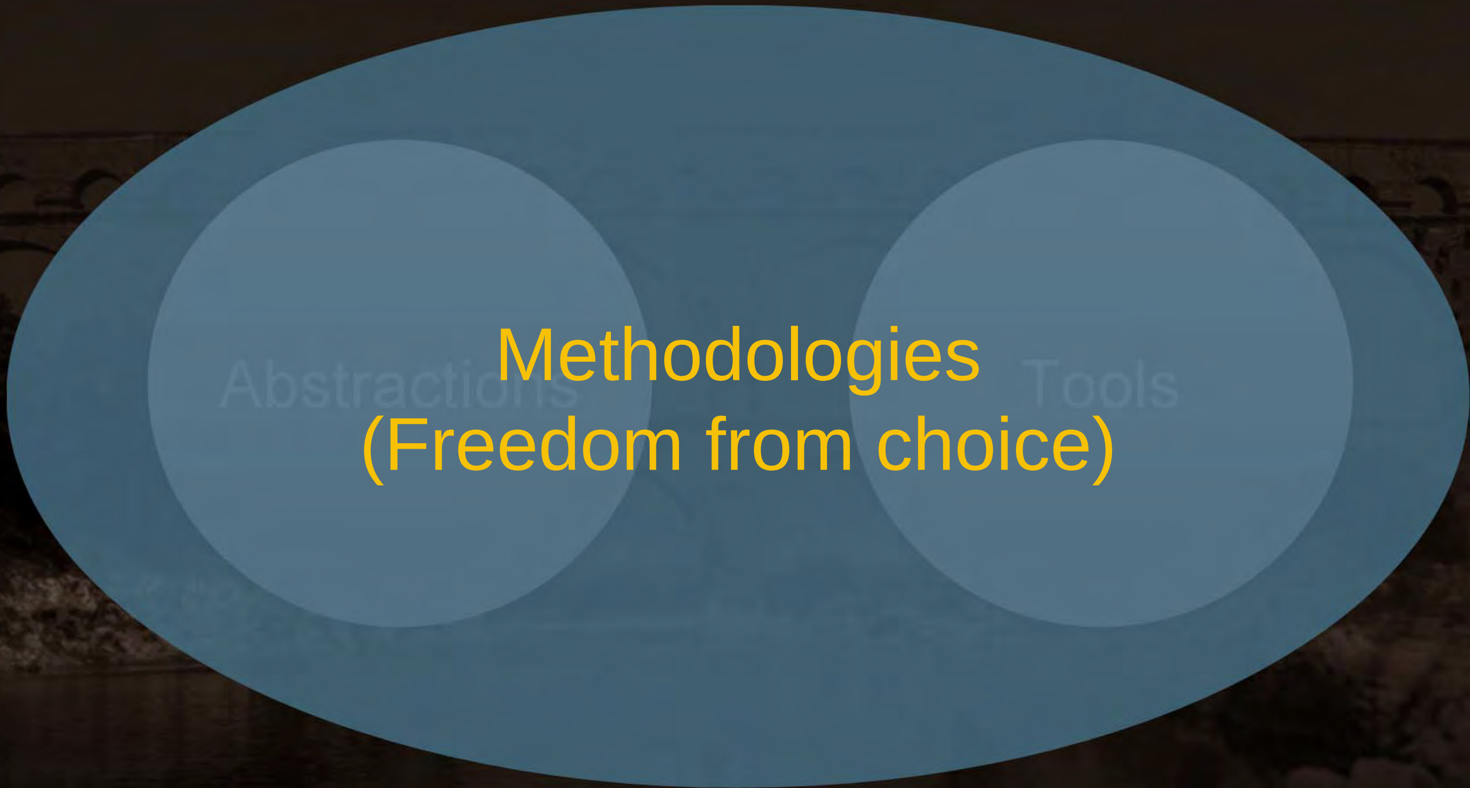
Intel 80286

To....: Regularity, Methodology, Re-usable Parts and Tools!



How did we cope with complexity?

(ASV, Corsi e Ricorsi: The EDA Story, IEEE Solid State Circuits Magazine, 2010)



General principles

Verification complexity is managed by:

- **Abstraction**: reduce the number of items by aggregating objects and by eliminating unnecessary details with respect to the goal at hand
- **Decomposition**: reduce the number of items to consider by breaking the design object into semi-independent parts (*divide et impera)*

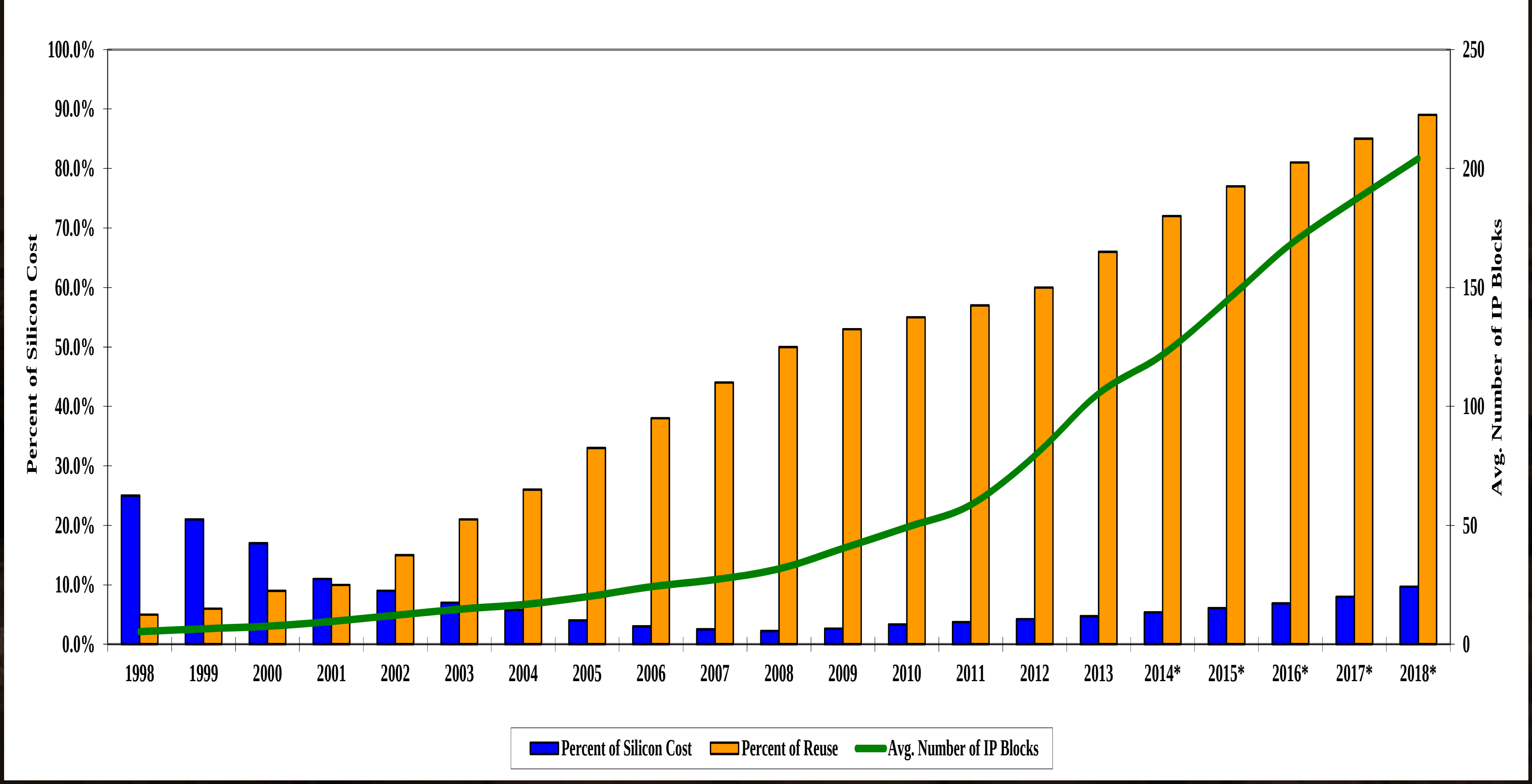
Design Complexity is managed by "construction":

- **Refinement:** Start high in the abstraction layers and define a number of refinement steps that go from the initial description to the
  final implementation
- **Composition:** Assemble designs by composing existing parts

Architecture Design: Formalization

Virtual Design and Refinement

Rise in the Use and Reuse of IP Blocks



Source: Semico SoC Silicon and Software Design Cost Analysis: How Rising Costs Impact SoC Design Starts SC101-15, February, 2015

Integration Challenges: Plug and Play?

Plug and Pray!

The Design Integration Nightmare

Specification:

Implementation:

P. Picasso,
Blue Period

P. Picasso
“Femme se coiffant”
1940

The Way Forward for CPS

- *Everything is Connected:* **Society, Electronic and System Industry facing an array of complex problems from design to manufacturing involving complexity, power, reliability, re-configurability, integration….**
- **Complexity is growing more rapidly than ever seen**
- **Interactions among subsystems increasingly more difficult to predict**
- **Pre-existing systems put to work to provide new services**
- ***Need work at all levels: Methodology, Modeling, Tools, Algorithms***

- **Deep collaboration among**
  - **Governments, industry, and research centers**
  - **Different Disciplines : Control, Communication, Computer Science, Electrical Engineering , Mechanical Engineering, Civil Engineering, Chemistry, Biology.....**

References

Acknowledgements: A. Benveniste, W. Damm, C. Jacobson, E. Lee, R. Murray, P. Nuzzo, R. Passerone

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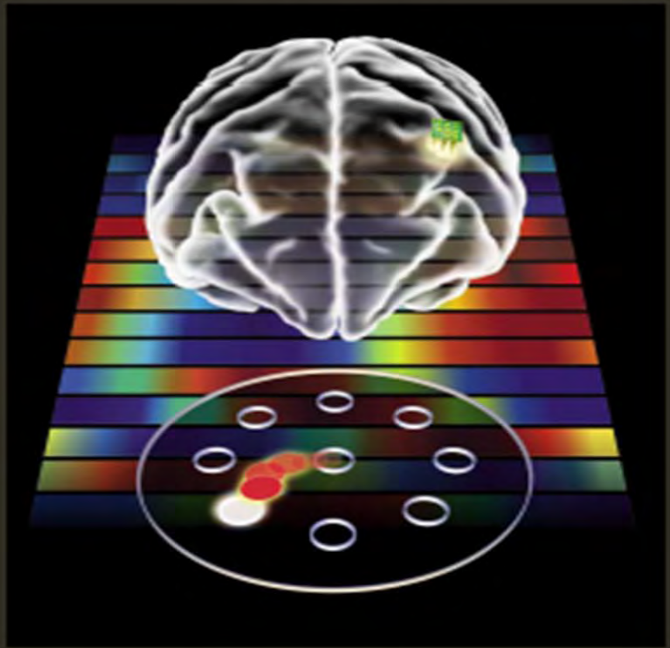
- A. Sangiovanni Vincentelli, W. Damm, R. Passerone, Taming Dr. Frankenstein: Contract-Based Design for Cyber-physical Systems, Semi-plenary presentation CDC 2011, also European Journal on Control, 2012,
- A. Sangiovanni-Vincentelli, Quo Vadis, SLD? Reasoning About the Trends and Challenges of System Level Design, Proceedings of the IEEE, Vol. 95, N. 3, pp. 467-506, March 2007.
- P. Nuzzo, J. B. Finn, A. Iannopollo, and A. Sangiovanni-Vincentelli, "Contract-based design of control protocols for safety-critical cyber-physical systems," ACM/IEEE Design, Automation and Test in Europe (DATE), Mar. 2014.
- P. Nuzzo, A. Sangiovanni-Vincentelli, "Let's get physical: computer science meets systems," From Programs to Systems - The Systems Perspective in Computing Workshop, European Joint Conferences on Theory and Practice of Software (ETAPS), Apr. 2014.
- A. Sangiovanni-Vincentelli, Corsi e Ricorsi: The EDA Story, IEEE Solid State Circuits Magazine, Vol. 2 n. 3,pp. 6-26, Summer 2010 (special issue on work by A. Sangiovanni Vincentelli)

Outline

- Cyber-physical Systems
  – Societal Scale Systems
  – Automobile of the future
- Design Challenges
- The Far Future
  – Bio-Cyber Systems

Another One: BioCyber (?) Systems

Linking the Cyber and Biological Worlds

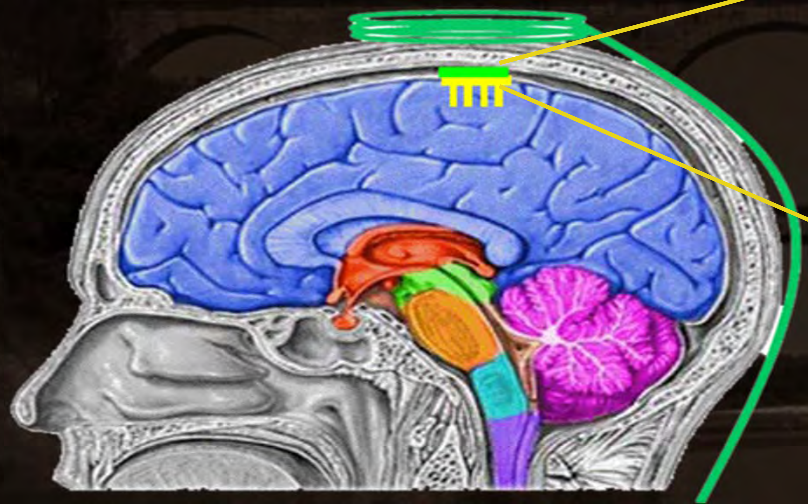


Examples: Brain-machine interfaces and body-area networks

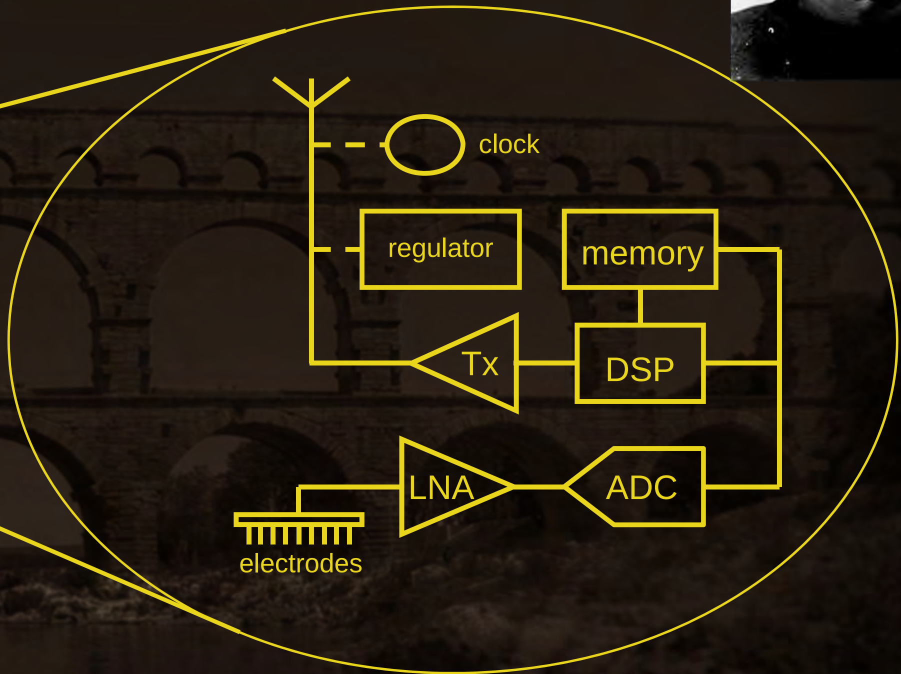
Courtesy: J. Rabaey

Towards Integrated Wireless Implanted Interfaces

Moving the state-of-the-art in wireless sensing



[Illustration art: Subbu Venkatraman]

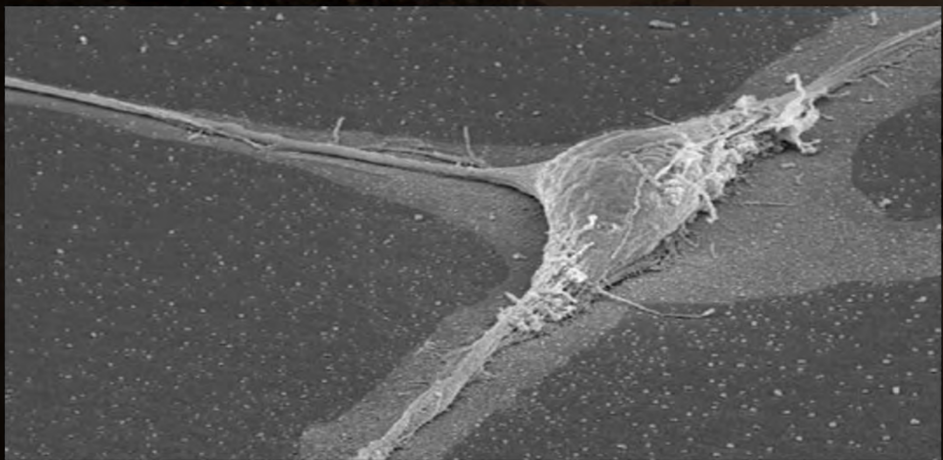


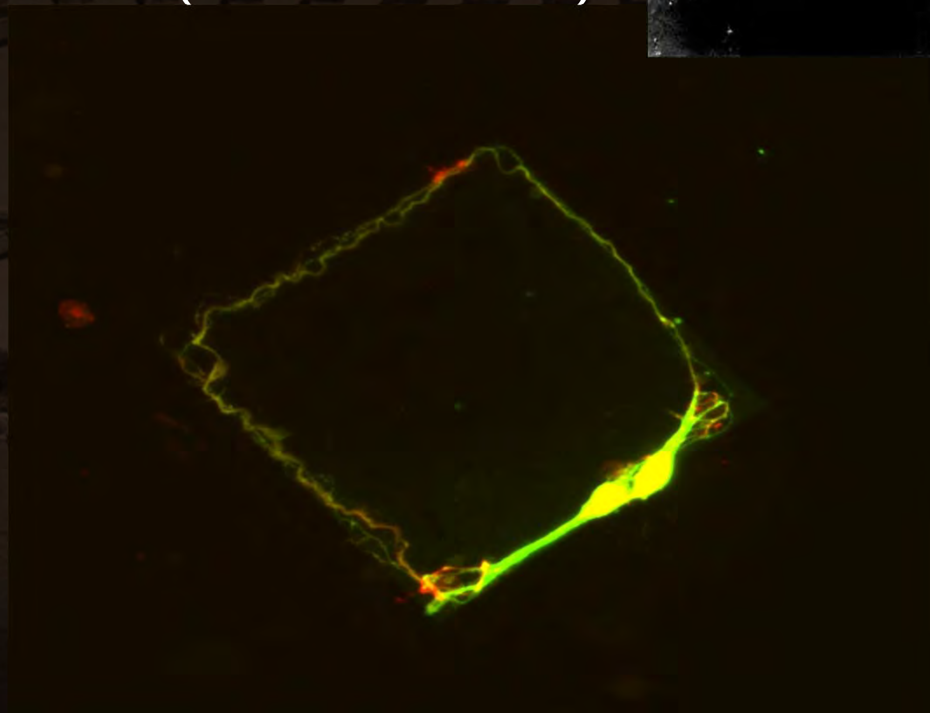
Power budget: mWs to 1 mW

Engineering Tomorrow's Designs:
Neurons drive Electro-Mechanical Systems

Italian Institute of Technology Genova Central Research Center
The Neuroscience Brain Technology Department – Fabio Benfenati's Group

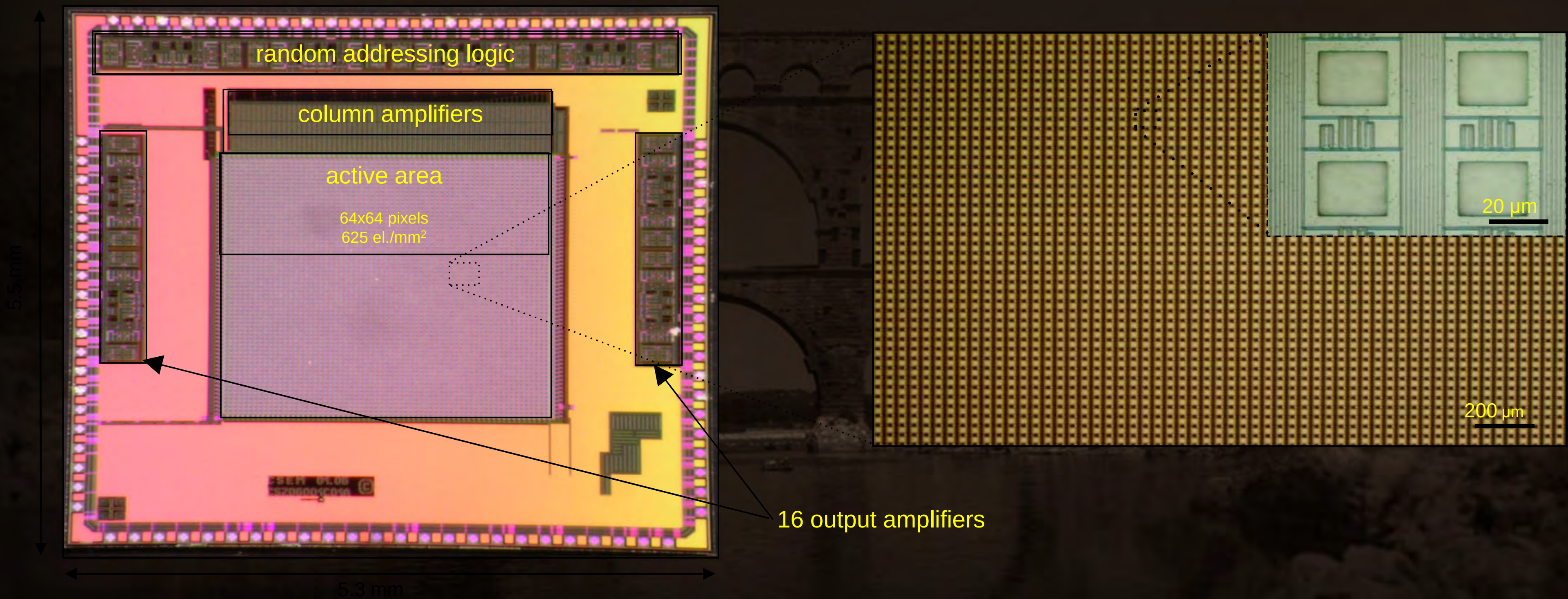
Generate spatially-ordered 2d and 3d neuronal (NON NEURAL) networks





THE HIGH-RESOLUTION NEURON-TO-CHIP INTERFACE

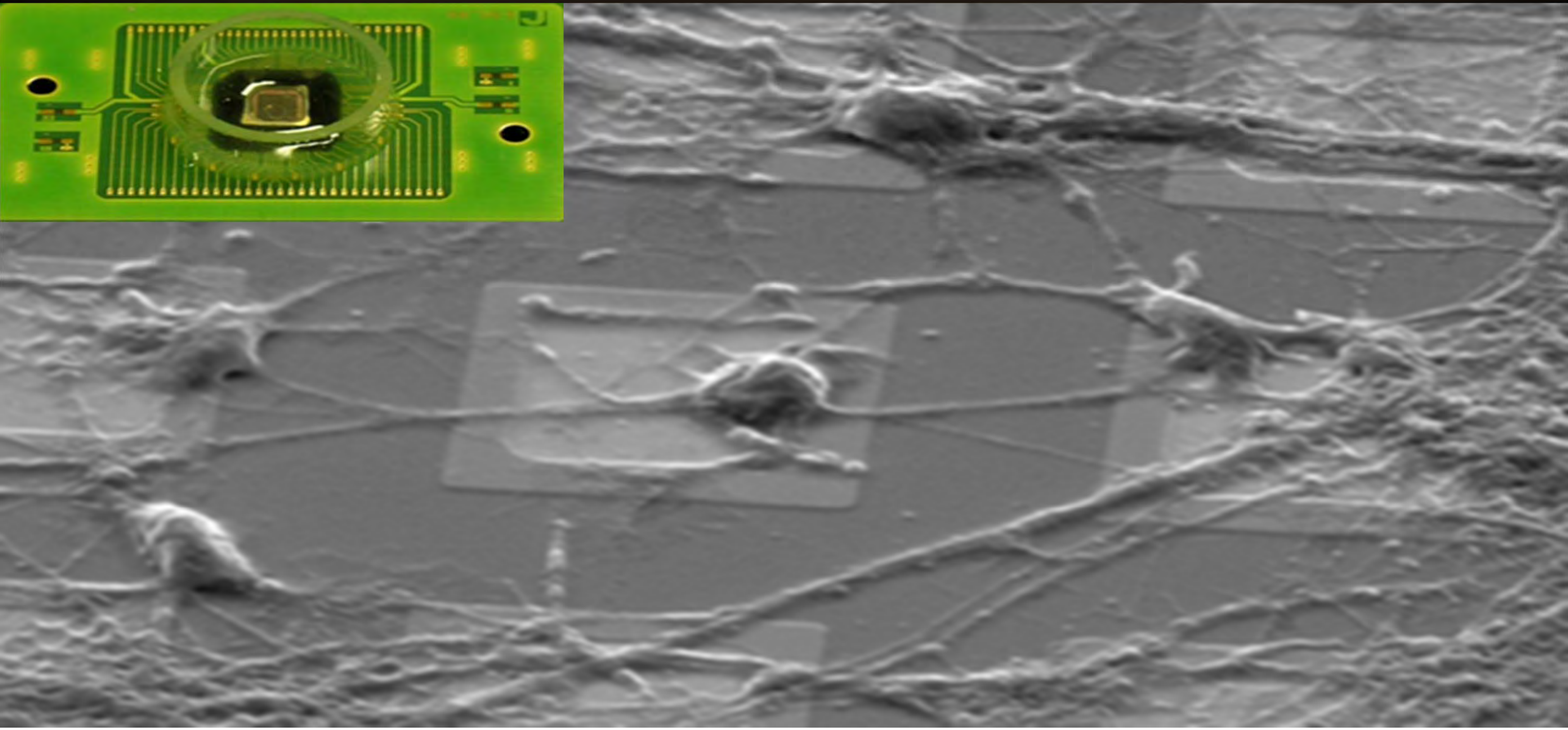
Luca Berdondini



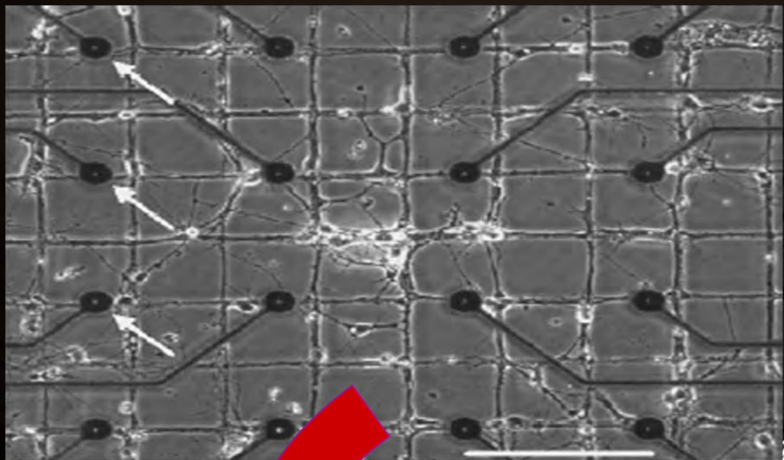
- 625 electrodes per mm^2
- inter-electrode separation of 20 µm

technology: 0.35 µm CMOS (4 metal-layer process by AMS)

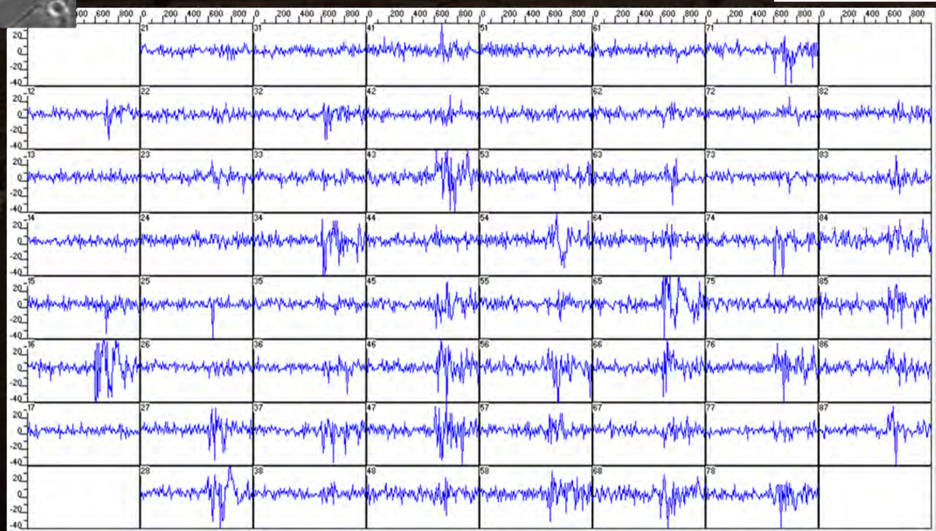
THE 4096 ELECTRODE SPATIAL RESOLUTION



NEURO-ROBOTIC INTERFACES:
from neuronal networks to an external body (Sergio Martinoia)



SENSORY
STIMULATION
(experience)

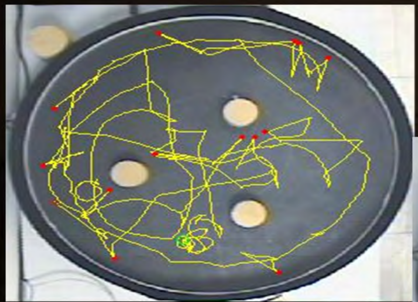


NEURAL
COMPUTATION
(adaptation, plasticity,
emerging properties)

MOTOR
COMMANDS
(purposeful
behavior)

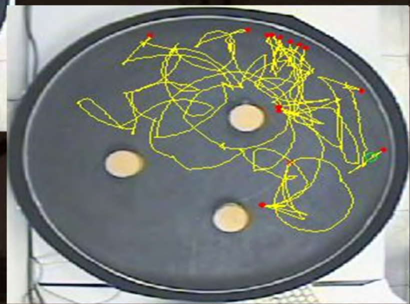
Obstacle avoidance task

10 min per phase



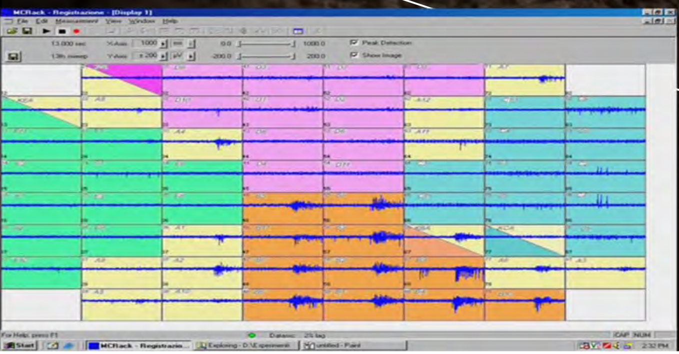
Phase 1
Free running

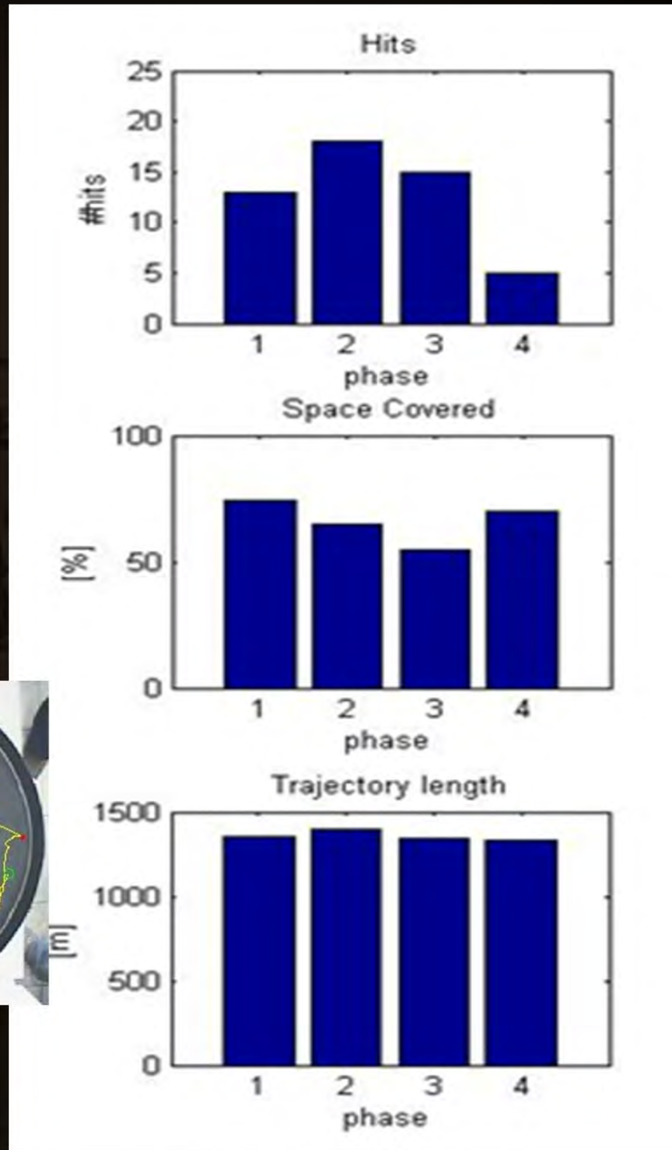
Phase 2
Learning



Phase 3,4
Avoidance

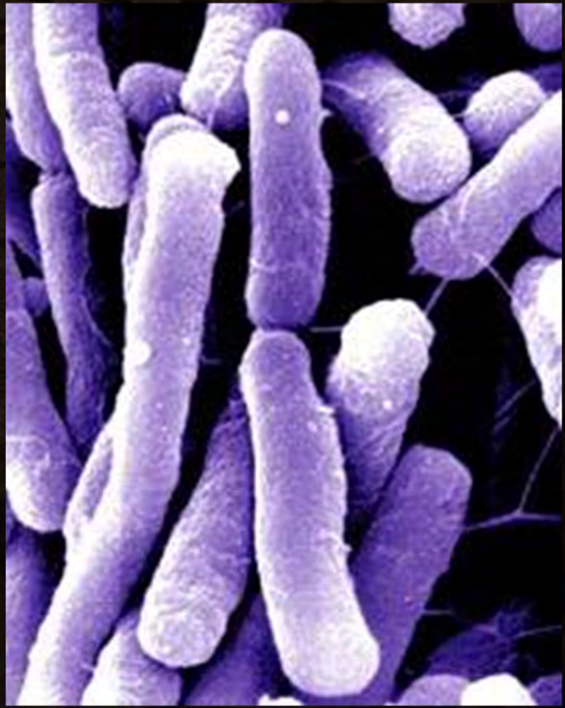
Phase 5
Free running





Synthetic Biology

συν•θη•σισ *n.* 1.a. the combination of separate elements to form a coherent whole.



- Synthetic biology seeks, through understanding, to design biological systems and their components to address a host of problems that cannot be solved using naturally-occurring entities
- Enormous potential benefits to medicine, environmental remediation and renewable energy

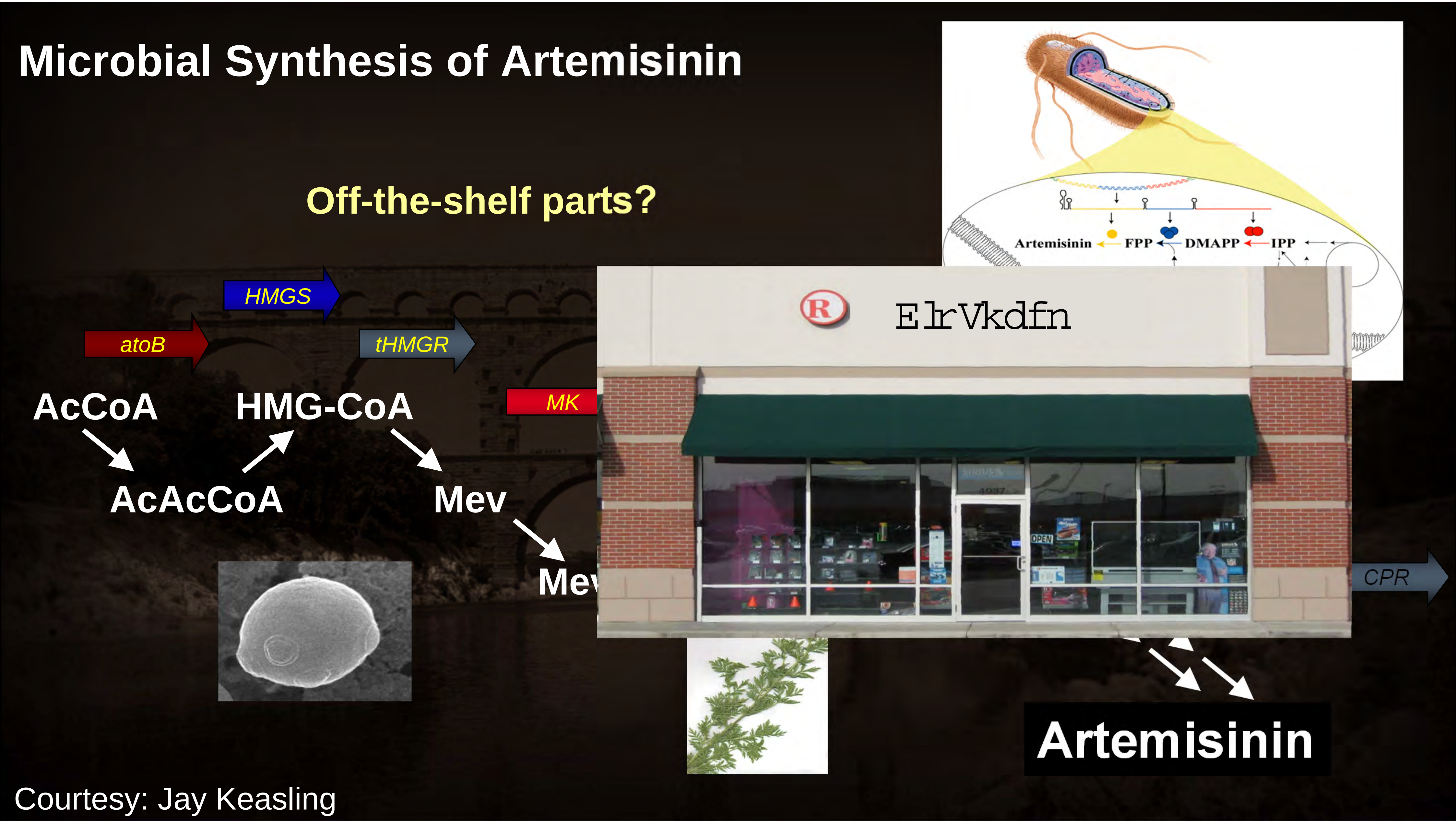
Engineering Tomorrow's Designs
Synthetic Biology

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


Microbial Synthesis of Artemisinin
Off-the-shelf parts?
HMGS
atoB
tHMGR
MK
AcCoA
HMG-CoA
AcAcCoA
Mev
Mev
Artemisinin
FPP
DMAPP
IPP
CPR
Artemisinin
Courtesy: Jay Keasling

Applications of Synthetic Biology

Energy Crop

- Water saving
- No fertilizer
- Doubled photosynthetic efficiency

Biodiesel and bio-jet fuel

- No compromise
- Fully compatible with existing infrastructure

Natural product drugs

- Capture all of the chemistry in nature
- Construct a microbe that can produce any natural product

Courtesy: Jay Keasling

Amyris

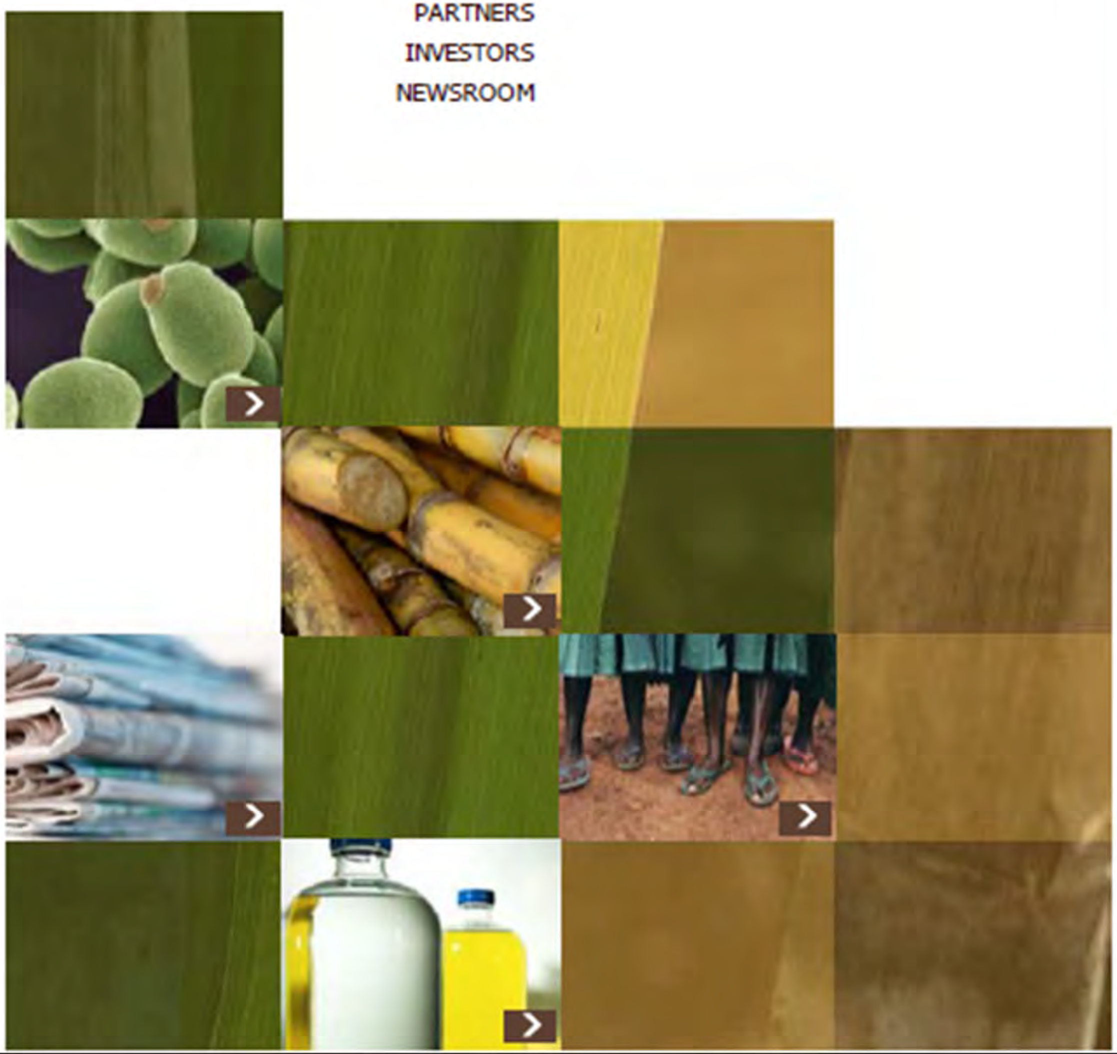
- Amyris had its technological foundation in 2001 in the Keasling lab at Berkeley.
- “Keasling’s magic bug, genetically enhanced from a soup of DNA obtained from bacteria and the plant world, is a five-carbon base chemical and a high-value target in the world of what is now known as the field of renewable chemicals — its a path to isoprenoids, which are themselves a family of some 50,000 molecules that have applications or pathways for pharmaceuticals, fragrances, cosmetics and fuels.”
- Keasling filed the patent in 2001, and Amyris itself was eventually formed and funded by 2006 with $14.1 million in Series A investments from Kleiner Perkins and Khosla Ventures among other early backers.

IPO in 4° Quarter 2010
From 680Mil cap to 1.265Bil today

SCIENCE
MARKETS
PARTNERS
INVESTORS
NEWSROOM

renewable products for the world

AMYRIS IS APPLYING AN INDUSTRIAL SYNTHETIC BIOLOGY PLATFORM TO PROVIDE HIGH-PERFORMING ALTERNATIVES TO PETROLEUM-SOURCED FUELS AND CHEMICALS



Total and Amyris Partner to Produce Renewable Fuels

Total and Amyris strategic partnership expanded to accelerate development and marketing of renewable fuels

PARIS, France and EMERYVILLE, Calif.-- November 30, 2011 - Total (CAC: TOTF.PA) and Amyris, Inc. (NASDAQ: AMRS) signed agreements to expand their current R&D partnership and form a joint venture to develop, produce and commercialize a range of renewable fuels and products.
Total and Amyris have agreed to expand their ongoing research and development collaboration to accelerate the deployment of Biofene® and develop renewable diesel based on this molecule produced from plant sugars. The ambitious R&D program, launched in 2010 and managed jointly by researchers from both companies, aims to develop the necessary stages to bring the next generation renewable fuels to market at commercial scale. Total has committed to contribute $105 million in funding for an existing $180 million program.
In addition, Total and Amyris have agreed to form a 50-50 joint venture company that will have exclusive rights to produce and market renewable diesel and jet fuel worldwide, as well as non-exclusive rights to other renewable products such as drilling fluids, solvents, polymers and specific biolubricants. The venture aims to begin operations in the first quarter of 2012.

Engineered Superbugs Boost Hopes Of Turning Seaweed Into Fuel

SCIENCE VOL 335 20 JANUARY 2012