Pervasive Systems

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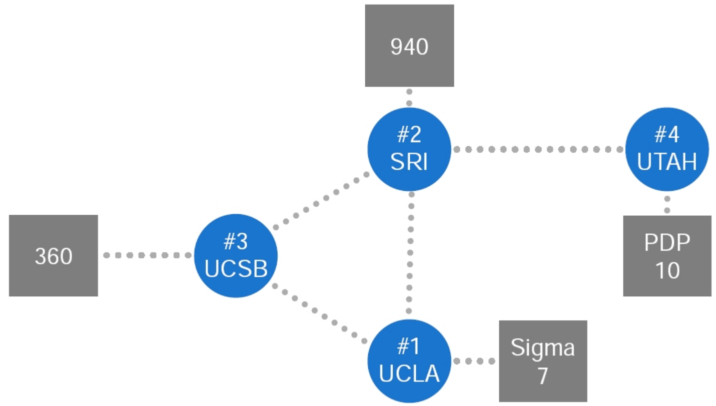
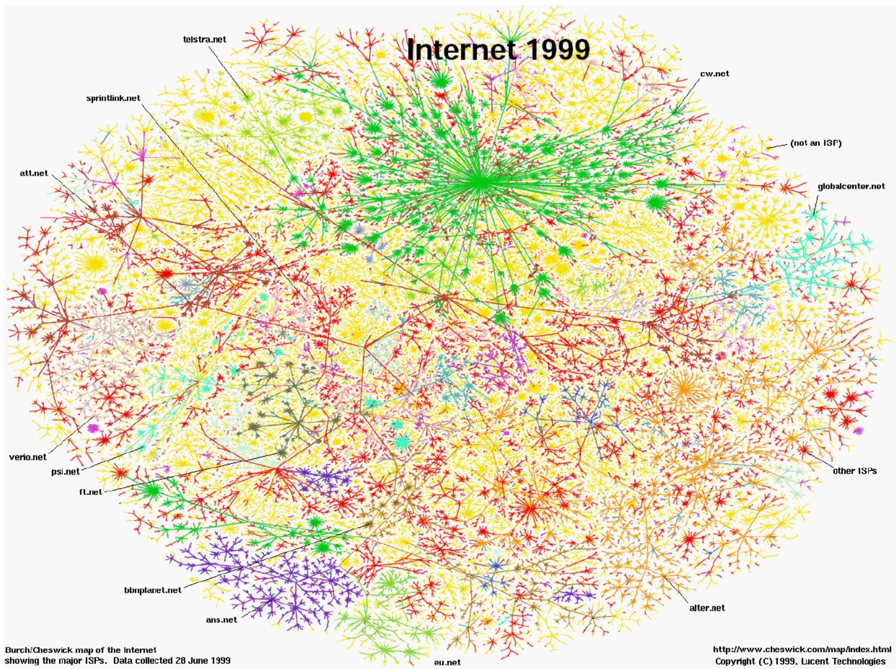
Lecture 1:
Introduction

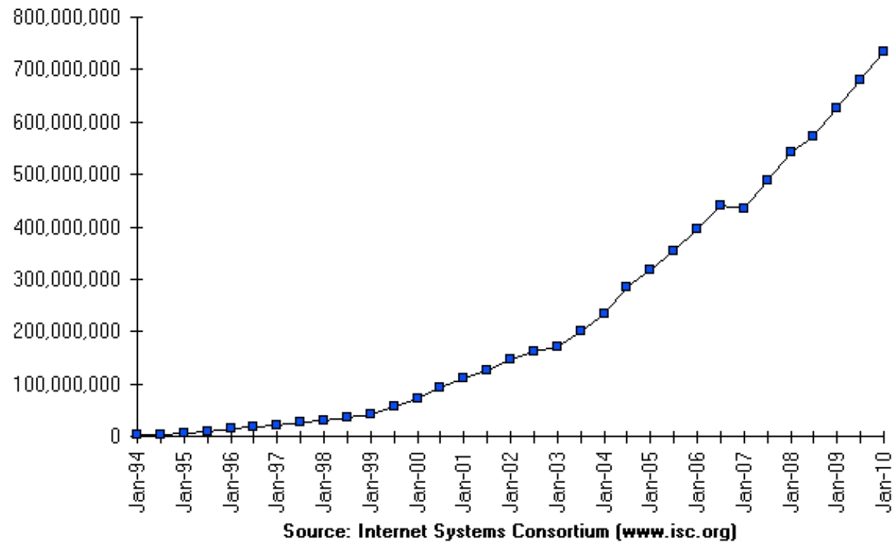
The beginning of Internet (ArpaNet)

- The initial topology of the network on December, 1969
- 4 computers connected via a simple packet switching network





Growth of web sites connected to the Internet

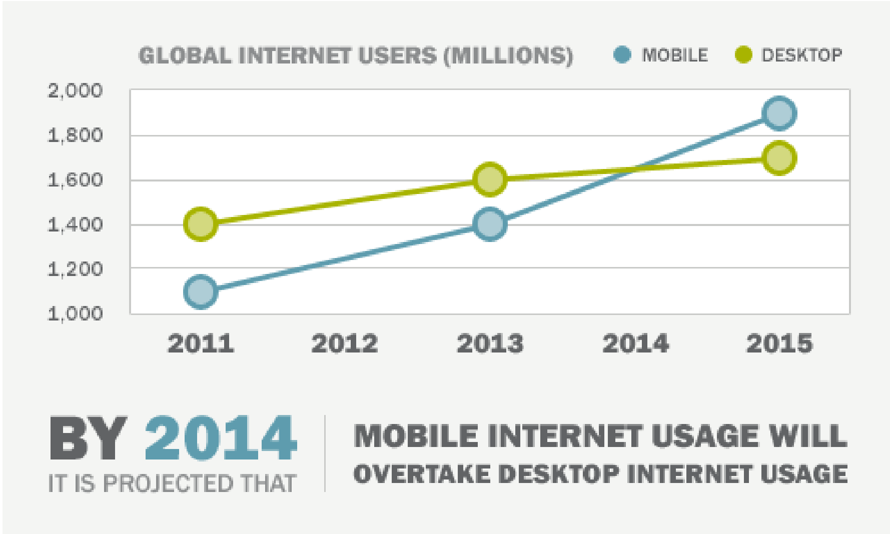


Worldwide Internet Users

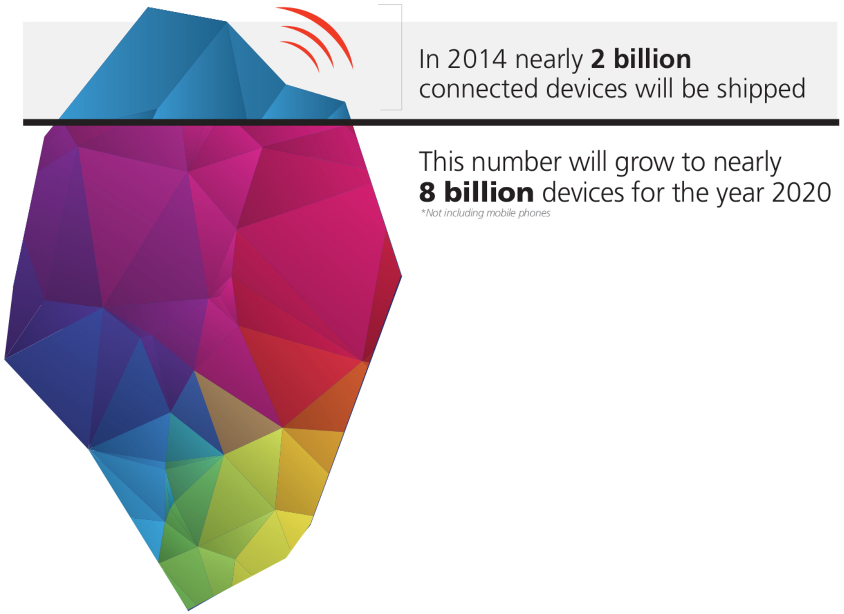
	2005	2010	2013
World population	6.5 billion	6.9 billion	7.1 billion
Not using the Internet	84%	70%	61%
Using the Internet	16%	30%	39%
Users in the developing world	8%	21%	31%
Users in the developed world	51%	67%	77%

Source: International Telecommunication Union official website

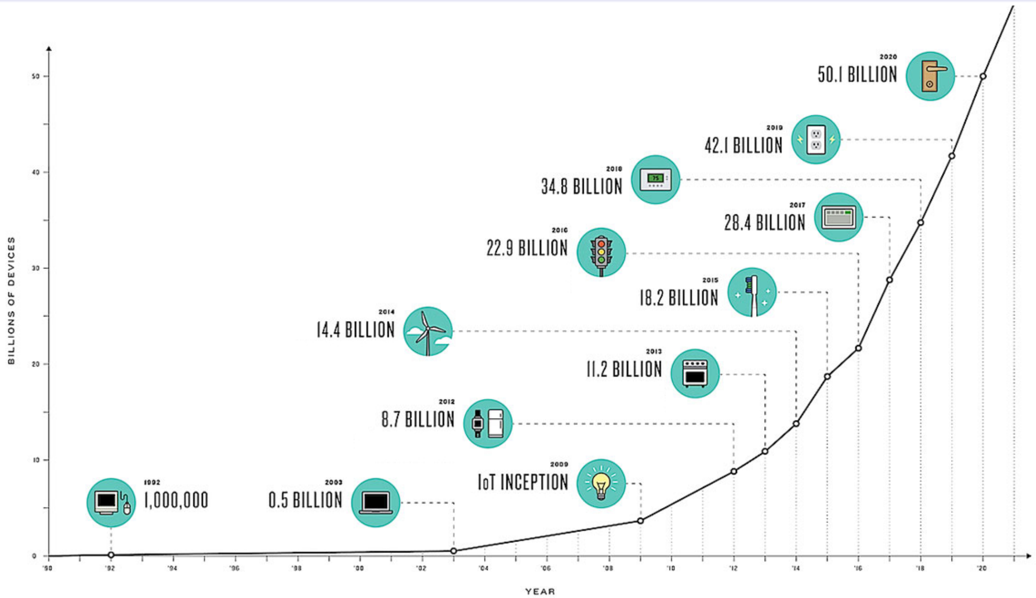
Mobile vs Static Internet Usage



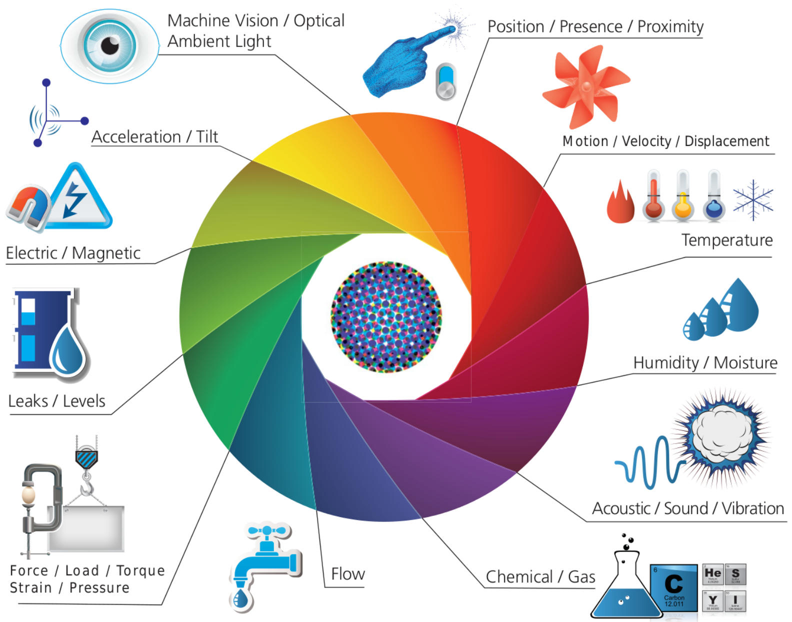
Things, People & Processes are becoming connected



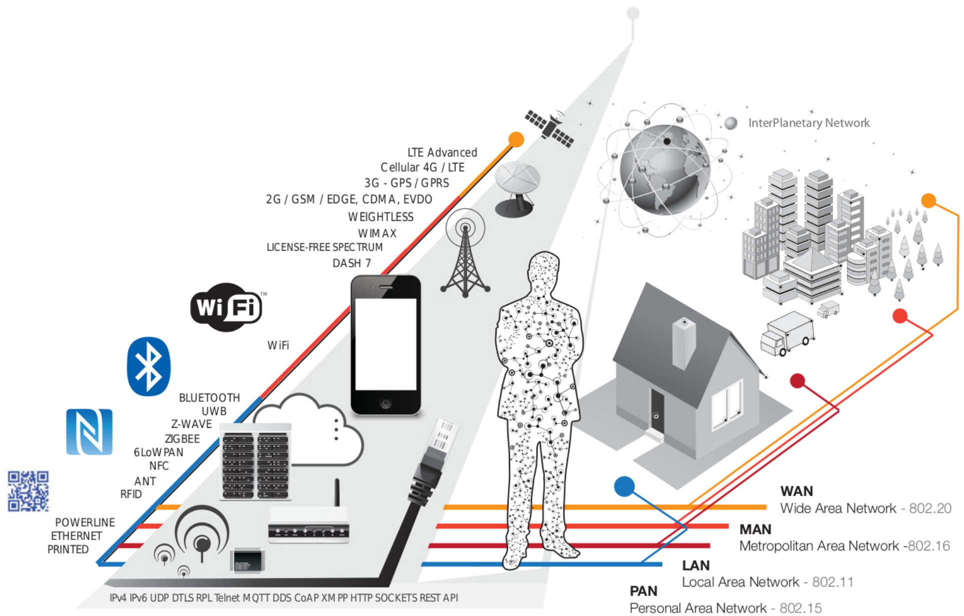
Am explosion of connected possibility



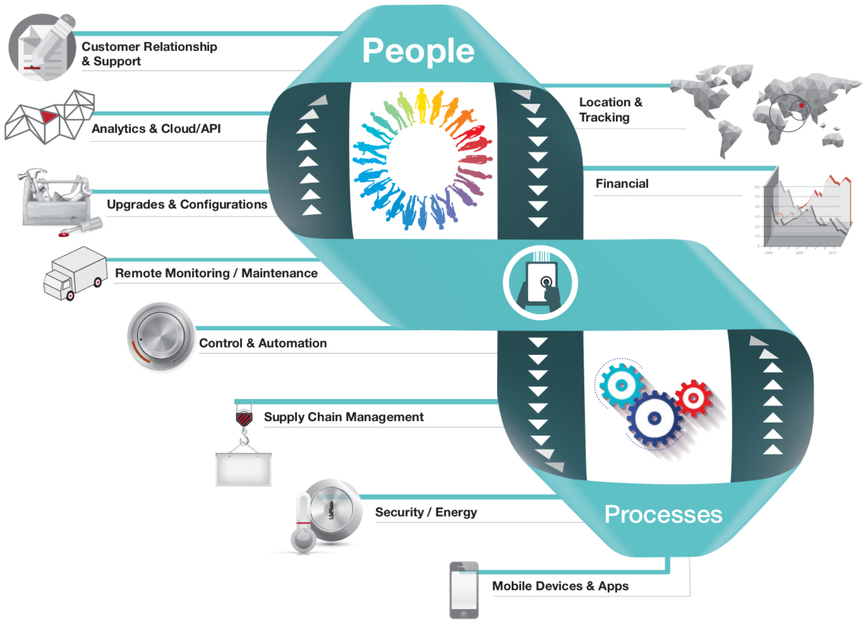
Sensors & Actuators: a digital nervous system



Connectivity: inputs are digitized and placed onto networks



People & Processes: bi-directional systems



The interactions between these
SENSORS + CONNECTIVITY + PEOPLE + PROCESSES
entities are creating new types
of smart applications and services.

Smart Thermostats

Save resources and money on your heating bills by adapting to your usage patterns and turning the temperature down when you're away from home.

Connected Cars

Tracked and rented using a smartphone Car2Go also handles billing, parking, and insurance automatically.

Activity Trackers

Continuously capture heart rate patterns, activity levels, calorie expenditure and skin temperature on your wrist 24/7.

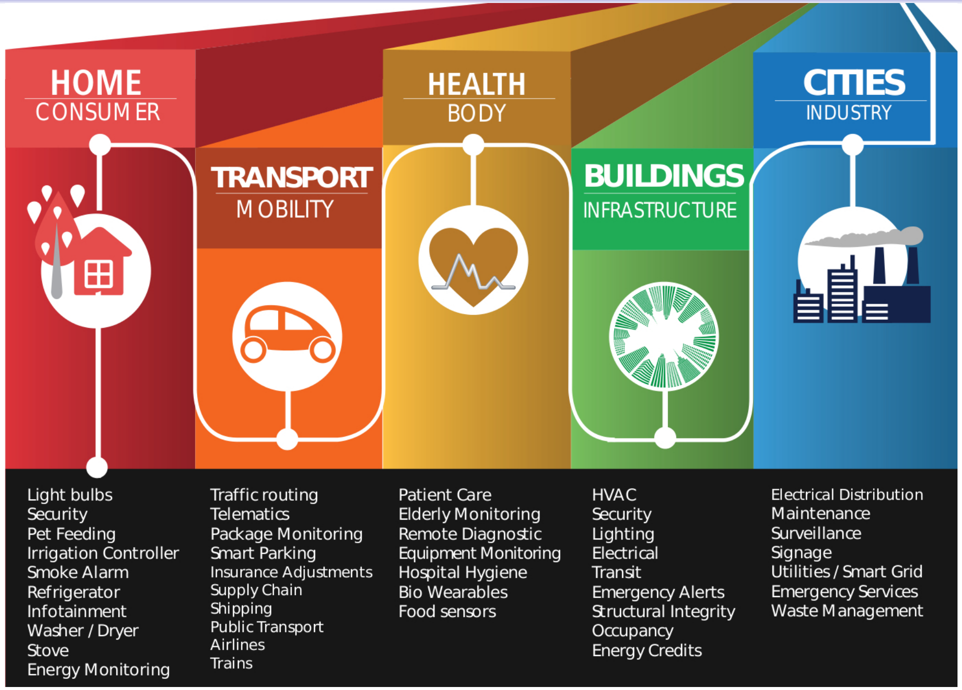
Smart Outlets

Remotely turn any device or appliance on or off. Track a device's energy usage and receive personalized notifications from your smartphone.

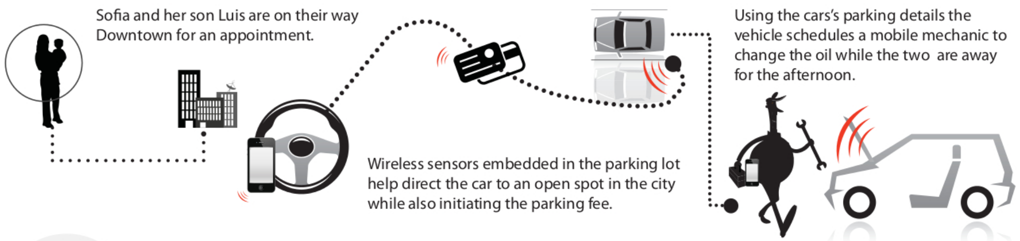
Smart Parking

STREETLINE
CONNECTING THE REAL WORLD

Remotely turn any device or appliance on or off. Track a device's energy usage and receive personalized notifications from your smartphone.

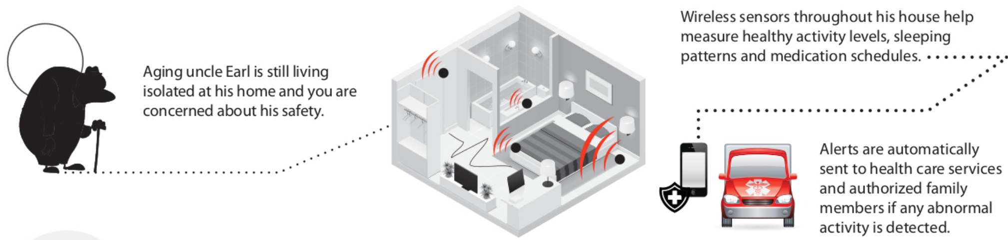


Transportation & Smart Cities



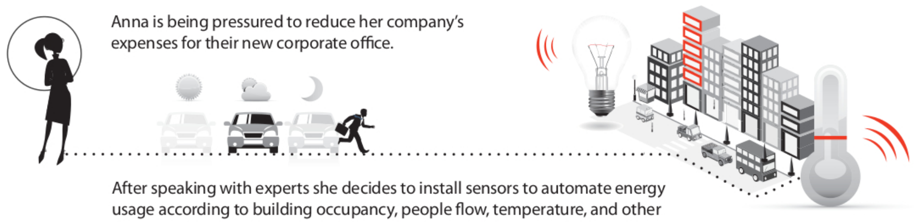
In Downtown San Francisco 20-30% of all traffic congestion is caused by people hunting for a parking spot.
- San Francisco Municipal Transportation Agency (SFMTA)

Healthcare & Smart Home



40 million adults age 65 and over will be living alone in the U.S, Canada and Europe.
- U.S. Department of Health and Human Services: Administration for Community Living (ACL)

Mobility & Smart Buildings



Anna is being pressured to reduce her company's expenses for their new corporate office.

After speaking with experts she decides to install sensors to automate energy usage according to building occupancy, people flow, temperature, and other ambient conditions -- improving the building's overall efficiency.

Energy used by commercial and industrial buildings in the US creates nearly 50% of our national emissions of greenhouse gases.

- United States Environmental Protection Agency

REAL-TIME SERVICE NETWORKS

- Appliance Monitoring
- Predictive Maintenance
- Service Technician / CRM
- Waste Management / Recycling

R Hotel Denver,
Industrial Washer #GHS40-2608

Location: ID: *FC-RM #00243*
Manufacturer: *Appliance Park Louisville, KY ID: #45205343*
Materials: *FC / SUS*
Sensor: *Vibration*
Connectivity: *Wireless LAN*

Connor, the Lead Maintenance Manager at the R Hotel in Denver, receives a sensor notification that the pump body O-ring #6 on washing machine #230243 is starting to fail in the housekeeping laundry room.

On his mobile, Connor prompts the machine to order a new part. This action triggers a bidding opportunity for local service technicians within the product's authorized maintenance network.

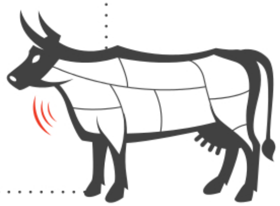
The request lays out:
- *Pricing parameters*
- *Timing requirements*
- *Machine history*
- *Part specs*
- *Predictive sensor measurements & alerts*

Tom from IA Appliances bids on the service request and receives a notification a few moments later that his bid was accepted.

Within 1.5 hours, a service technician from IA Appliances is on site (Using a temporary facility access code for the wireless door lock) to replace the water pump. Connor sends a brief note on the service quality and IA Appliances releases a bid request for the part's raw materials to local recycling centers.

DIGITAL FARM TO TABLE

- Farm & Livestock ID & Sensors
- Food packaging sensors
- Retail Supply Chain Monitoring
- Health Services



Cattle
AIN: 840 003 123 456 789

Location: ID: Braymeadow Farm *FR #00285453543*
Slaughterhouse ID: *#45205343*
Sensor: *Temperature, Accelerometer*
Connectivity: *RFID, NFC, WAN*

Maria and her daughter are picking up groceries for the week. Using packaging with printed sensors, the two can make sure the ground beef they are purchasing has never reached unsafe temperature levels while on the shelf or being transported.

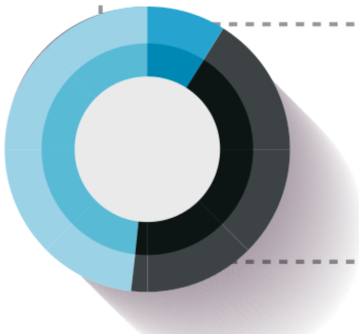
The packaging also contains a QR code which they can use to query the cow's RFID tag and bring up its history:

- *Where it was raised*
- *What it was fed*
- *Where it was slaughtered*
- *How it was transported*
- *Where it was packaged*
- *The last time it was inspected.*

A week later the U.S. Department of Agriculture's Food Safety Service determines ground beef from originating from a regional packing company and sold at a neighboring store is contaminated with E. coli O157:H7. All packages from this distributer change their alert color and notification messages are sent to those shoppers that may have been impacted.

Business Impact & Revenue Opportunities

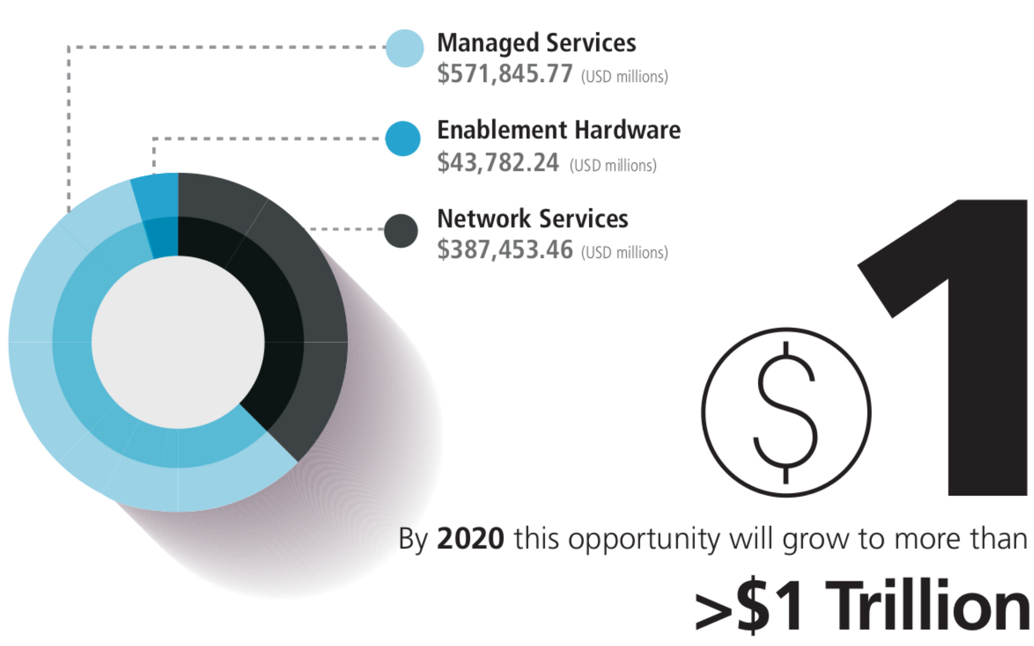
180+ Billion in Revenue in 2014



Managed Services
$86,919.93 (USD millions)
Data and Analytics
Systems Applications
Mobile and Cloud Computing
Value Added Application Services

Enablement Hardware
$16,186.42 (USD millions)
Wireline or wireless module attached to or embedded in each machine to be connected.

Network Services
$77,273.55 (USD millions)



A interesting era

- The Internet gave us the opportunity to connect in ways we could never have dreamed possible.
- The Internet of Things will take us beyond connection to become part of a living, moving, global nerbous system.
- Whether you are an individual, technology developer, or adopter of these technologies, the Internet of Things will strech the boundaries of today's systems.
- Are you prepared for the changes in the way we learn, work and innovate?

Introductory material thanks to ...

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Goal of Course

- Introduce emerging application scenaria
- Study characteristic design approaches of Pervasive systems and networks
  - communication, coordination, fault-tolerance, locality, parallelism, self-organization, symmetry breaking, synchronization, uncertainty
- Examine essential algorithmic techniques and performance limits
- Engineer algorithms in open-design
- Accompany the practical aspects with theoretical topics.
- Present some fundamental aspects of Pervasive Systems

Basic Definitions

- program – code that dictates the behavior of the system.
- process – an instance of the program.
- message – used for inter process communication.
- packet – part of a message, transmitted by the network.
- protocol – a rigorous description of messages, and rules for message exchanges.
- network – infrastructure that connects processing units.
- distributed system – an application that executes a collection of protocols to coordinate the actions of multiple processes on a communication network towards a common goal.
- pervasive system – a combination of protocols and technologies to realize a specific application.

Pervasive Systems & Broad definitions

"Pervasive computing creates an unobtrusive environment with full and integrated Internet connectivity". – *Techopedia*

Pervasive Systems & Broad definitions

"Pervasive computing goes past the arena of desktops so that virtually any device, from apparel to kitchen appliances, could be embedded with microchips, connecting these devices to a boundless network of other gadgets".

Pervasive Systems & Broad definitions

"Most computer software today runs in distributed systems, where the interactive presentation, application business processing, and data resources reside in loosely coupled computing nodes and service tiers connected together by networks." – Buschmann et al., 2007

Pervasive Systems & Broad definitions

"A distributed system consists of a collection of autonomous computer linked by a computer network and equipped with distributed system software. Distributed system software enables computers to coordinate their activities and to share the resources of the system – hardware, software, and data – " – Coulouris et al., 1994

Pervasive Systems & Broad definitions

"A distributed system is one in which the failure of a computer you didn't even know existed can render your own computer unusable". – Leslie Lamport, Thu, 28 May 87 12:23:29 PDT

Pervasive Systems & Broad definitions

"Distributed systems need radically different software than centralized systems do.". – Andrew S. Tanenbaum

Computer Networks – Pervasive Systems

- Courses related to Computer Networks:
  - Focus on message/packet transmissions.
  - Do not examine how packets are being handled/processed.
- In this course
  - We assume a mechanism for sending/receiving messages.
  - Focus on the message properties.
  - Design systems that use these messages.

Operating Systems – Pervasive Systems

- Courses related to Operating Systems:
  - Resources are reliable.
  - Resources are used without examining failures.
  - Failures are local and straight forward error handlers are used (e.g., in MINIX, device drivers are restarted to recover from failures).
  - A common global clock is used for process synchronization.
- In this course:
  - Communication over computer network is not always reliable.
  - We may not know when/if a failure has occurred.
  - We do not have access to a common global clock – how are process synchronized?

Parallel Systems – Pervasive Systems

- In courses related to Parallel Systems & Concurrency:
  - Multiple processors are installed in the same processing unit.
  - Communication between processors is very fast & efficient.
  - A common global clock is used for process synchronization.
  - Processing units are high quality – they rarely fail.
- In this course:
  - Communication over computer network is not always fast & efficient.
  - We do not have access to a common global clock – how are process synchronized?
  - Processing units do not always achieve high reliability.

Distributed Systems – Pervasive Systems

- In courses related to Distributed Systems:
  - Abstract the operating conditions of the system.
  - Focus on the message exchanges and the protocol execution.
  - Design systems that use these protocols.
- In this course:
  - The operating conditions are essential for the system design.
  - We focus on the technological platform.
  - Deploy systems in real-world environment and experimentally study performance.

Mobile Computing

- Anywhere, Anytime, Anyhow
- Participating in the pervasive system while on the move.
- Processing is moved from a fixed position to a dynamic position.
- Bring computer communication to areas without pre-existing infrastructure.
- High bandwidth variability.
- Network variability.
- Low power / low resource machines.

Low Power Lossy Networks

- Physical size limitations – short Range communication.
- Battery operation – rate of activity.
- Low power transmissions are affected by environmental noise – high loss rate.
  - Underwater accousting networks
- Reduced capabilities – small footprint.
  - microcontrollers (outnumber microprocessors 25:1) typically have kilobytes of memory, not megabytes or gigabytes.
- Requires rigorous protocol design
  - Cannot just throw resources at it,
  - Cannot just throw bandwidth at it.

Disconnected Operation

- Devices are not always connected – no accessible infrastructure.
- Connectivity may experience long delays.
- Connectivity may be disrupted.
- Techniques for “expanding” connectivity.
- Delay Tolerant Networking.
- Multi-layer interactions.
- Exact vs Partial Scheduling of resources.

Battery Power, Energy Consumption & Prosumption

- Devices become smaller and battery-operated.
- Changing / recharging batteries is redious.
- Lifetime is crucial.
- Techniques to reduce energy consumption – duty cycling.
- Limit unnecessary transmission of data – local processing.
- Limit transmission length – data fusion and compression.
- Rechargable power – who is recharging?
- Renewable energy sources – not just consumer of energy but also producer.
- Energy scavenging techniques.

Participatory & Voluntary Computing

- Smartphones already include a large variety of sensors
- Smartphones, tablets and PCs resources are underutilized.
- People & Communities contributing computational & sensing resources.
- Participatory engagement is vital.
- Global observatories – A new tool for science.

Big Data

- Volume – increasing amounts of sensor data collected.
- Velocity – RFID tags, sensors and smart metering are driving the need to deal with torrents of data in near-real time.
- Variety – data arriving from sensor comes in all types of formats.
- Variability – data flows can be highly inconsistent with periodic peaks. Daily, seasonal and event-triggered peak data loads can be challenging to manage.
- Complexity – data comes from multiple sources: link, match, cleanse and transform data across systems.

Design for Correctness

- Current Software & Network infrastructures already pervade our everyday life.
- We rely deeply on software-based infrastructure and when it fails to function, there can be serious side effects.
- We become aware of our dependence only when the infrastructure is down.
- Future systems will be constantly present monitoring all aspects of our life.
- Clearly, society expect future systems to be dependable, robust and resilient to sudden environmental changes.
- It is important to understand the impact of our systems when we design & implement them.

Dependence to Infrastructure

- A common theme we hear in many conversations is concern for the fragility or brittleness of our networked-and software-driven world.
- Most of us do not lie awake worried that the power will go out.
- When the power does go out, we suddenly become aware of the finiteness of battery power or the huge role that electricity plays in our daily lives.
- Mobile phones went out during Hurricane Sandy because the cell towers and base stations ran out of power either because of battery failure or because the back-up generators could not be supplied with fuel or could not run because they were underwater.

Robustness and Resilience

"I therefore propose a development project to make our system more robust." – Leslie Lamport, Thu, 28 May 87 12:23:29 PDT

What's a Robot ?

"I believe it would be a contribution to our society to encourage deeper thinking about what we in the computing world produce, the tools we use to produce them, the resilience and reliability that these products exhibit and the risks that they may introduce."
– Vinton G. Cerf, ACM President, Jan 2013

What's a Robot ?

"For decades now, Peter Neumann has labored in this space, documenting and researching the nature of risk and how it manifests in the software world. We would all do well to emulate his lead and to think whether it is possible that the three or four laws of robotics might motivate our own aspirations as creators in the endless universe of software and communications."
– Vinton G. Cerf, ACM President, Jan 2013

Safety, Validation & Robustness

Edmund M. Clarke and E. Allen Emerson, Joseph Sifakis, laureates of the 2007 Turing Award, for their roles in developing model checking into a highly effective verification technology, widely adopted in the hardware and software industries.

Barbara Liskov, laureate of the 2008 Turing Award, for her contributions to practical and theoretical foundations of programming language and system design, especially related to data abstraction, fault tolerance, and distributed computing.

Hierarchical Analysis of Systems Performance

A fundamental method for studying the performance of a system is the top-down approach

- Initially we abstract all technical details and study the system at high level (i.e., bird's eye view)
- Then, we look into specific modes of operations and investigate the most important parameters that affect performance.
- Step - by step, we introduce additional levels – until we end up to our final system, operating in the actual conditions

This approach leads to good results for organizing and analyzing a broad range of systems

Contemporary Systems

Hierarchical, centralized, top-down approaches have allowed us to design very good contemporary systems

- e.g., database management systems, mobile telephony networks

However our always-connected world is becoming more complex

- We should not ignore the fact that many contemporary systems have a totally different structure.
- e.g., the stability and effectiveness of contemporary politico-economic models relies on decentralized, distributed mechanisms that are independent and self-regulated
- The Internet is another example of a similar approach, at a techno-social level.
- How to efficiently organized extremely huge collections of unstructured or structured data ?

Limitations of Top-down approach

Studying a pervasive system from a theoretical perspective contributes to a basic level of understanding its behavior and rigorously defining its performance bounds.

However, it entails certain pitfalls:

- Abstracting certain technical details may lead to totally unrealistic / non-implementable solutions.
- Measuring complexity does not take into account the so-called "hidden" constants.
- A "poor" complexity solution may be very efficient in almost all practical case.
- It is very hard (if not impossible) to analyze the performance of a system using theoretical tools.

Performance evaluation by Experimentation

A different approach is the implementation of the system and its evaluation using practical means:

- The implementation may use an experimental framework – e.g., simulator, testbed facilities, ...
- The performance study is done using well-defined evaluation scenaria
- Measure performance of the "actual" performance.
- Immediate validation of the applicability of a solution in existing technologies.
- Results can be deployed to devices in real-world deployments.

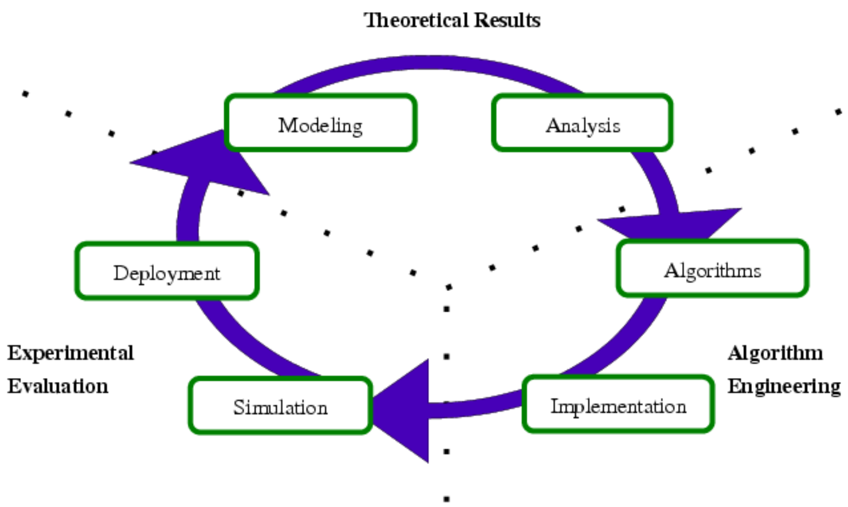
Dual Approach

Each approach has certain benefits and handicaps:

- A theoretical approach allows to develop solutions that are correct by proof, efficient ... may not be applicable (or very hard) in current technologies.
- A practical approach immediately deals with all technological issues and provides effective solutions ... may not result in innovative solutions that are efficient in large scale systems.

We need to be both efficient and effective.

Theoretical – Practical Approach Cycle



Necessity of Dual Approach

- Surprisingly, the need for association between theory and practice has been identified long before the computer science era.
- Philosophers of the antiquity, already, state that the notion of effectiveness requires two components: design an efficient prototype, an *ideal version* that is used to plan the goal; then, *apply* this plan in practice.
- According to Plato, $\nu o \eta \sigma \iota \varsigma$ (cognition) "captures optimal" plans, and $\theta \epsilon \lambda \eta \sigma \iota \varsigma$ (goodwill) is required to apply the ideal plans in reality.
- This is defined by Aristotle as $\phi \rho o \nu \eta \sigma \iota \nu$, the process of associating the ideal with its application, thus reducing the gap between these two approaches.

Part 1: Smartphones

1. Infrastructure Networking & Cloud services
2. Ad-hoc Networking mechanisms
   - IEEE 802.11 (WiFi, WiFi-Direct)
   - IEEE 802.15.1 (Bluetooth)
3. Network communication & control protocols
   - Dissemination (Flooding, Gossiping)
   - Agreement, Commit
   - Localization
4. Open-source frameworks
   - Android
5. Case-studies
   - Participatory sensing
   - Physical interaction sensing
   - Pervasive gaming

Part 2: Sensor Networks

1. Ad-hoc Networking mechanisms
   - IEEE 802.15.4
2. Network communication & control protocols
   - Broadcast & Convergecast
   - Routing
   - Clustering
3. Open-source frameworks
   - Arduino – codebender.cc
   - TinyOS
   - Wiselib
4. Case-studies
   - Energy-efficient buildings
   - Monitoring Elderly

Part 3: Internet of Things

1. Machine-to-machine Communication
   - ZigBee, ZWave
   - 6LowPan (RPL, COAP)
   - MQTT
2. Byzantine Failures & Data
3. Real-world Testbeds
   - Wisebed Testbed Runtime
   - Smart Santander
4. Open-source frameworks
   - Libelium
5. Case-studies
   - Air-quality monitoring
   - Traffic monitoring
   - Smart citizen kit