The Cloud Will Change Everything

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Rorschach Test for Computer Architects
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Global mobile cellular subscriptions, total, 2000-2010*

*Estimates
Source: ITU World Telecommunication /ICT Indicators database
Presentation Roadmap

What are the technology trends shaping the future – hardware, software, experiences?

How can computing change today’s life experiences – computers that become ‘assistants’?

What is XCG doing to drive innovation in this new world?
It’s Easy To Forget That Not Very Long Ago ...

There were few or no experiences with:

- Web sites, email, spam, phishing, computer viruses
- e-commerce, digital photography or telephony

Cell phones were rare and expensive

A portable cassette player was still cool

HiFi was more common than WiFi

A “friend” was someone you actually knew
Understanding the Future

Some rules of thumb

- In the near term, we \textit{overestimate} change
- In the long term, we \textit{underestimate} change

Outside their field of expertise

- Experts are often better at predictions

Recognize exponentials

- Quantitative change brings qualitative change
- Multidisciplinary coupling shifts the balance

Technological and social change

- Different rates with differing consequences
Orders of Magnitude Always Matter

Tools must empower, not frustrate

These are systemic problems
An insight from Jim Gray …

A computation has four characteristic demands:

<table>
<thead>
<tr>
<th>Networking</th>
<th>Computation</th>
<th>Data access</th>
<th>Data storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivering questions and answers</td>
<td>Transforming information to produce new information</td>
<td>Access to information needed by the computation</td>
<td>Long term storage of information</td>
</tr>
</tbody>
</table>

The ratios among these *and their costs* are critical
Computing Eras: Exponential Change


21\textsuperscript{st} century implicit and natural computing

- Increasingly natural interfaces
- Embedded intelligence in everyday objects
- Ubiquitous network access and cloud services
What Is Changing?

- System on a chip designs
  - Powerful mobile devices
- Graphics processing units
  - High quality graphics
- Explosive data growth
  - Ubiquitous sensors and media
- Inexpensive embedded computing
  - Everyday smart objects, CIP, ...
- Wireless spectrum pressure
  - Mobile device growth
- New software models
  - Social networks, clients+clouds ...

[Diagram showing desktop, mobile, and server devices]
Paucity to Plethora

• Paucity drives certain behaviors
  • Hoarding, conservatism, limitation

• Plethora also drives certain behaviors
  • Speculation, risk taking, profligacy

• Psychologically we still believe in paucity ...

That World View Is Changing …
Megatrends: The Many Device World

- System on a Chip Designs
  Powerful Mobile Devices

- Graphics Processing Units
  High Quality Graphics

- Explosive Data Growth
  Ubiquitous Sensors and Media

- Inexpensive Embedded Computing
  Everyday Smart Objects, CIP

- Mobile Device Growth
  Smart Phones and Feature Phones

- New Software Models
  Social Networks, Clients + Clouds…
Moore’s “Law” and Limiting Exponentials ...

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 66,000 components on a single silicon chip.

By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor
Division of Fairchild Camera and Instrument Corp.

The future of integrated electronics is the future of electronics itself. The advantages of integration will bring about a proliferation of electronics, pushing this science into many new areas.

Integrated circuits will lead to such wonders as home computers...automotive controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.

The trigger potential lies in the production of large systems. In telephone communications, integrated circuits are already appearing on multiple equipments. Integrated circuits will also switch telephone circuits and perform data processing.

Computers will be more powerful, and will be organized in different ways. In particular, memory and control functions of integrated electronics may be distributed throughout the machine instead of being concentrated in a central unit. In addition, the improved reliability made possible by integrated circuits will allow the construction of larger processing units. Machines similar to those in existence today will be built at lower costs and with larger turn-arounds.

Present and future

The integrated electronics, I mean all the various technologies which are referred to as microelectronics today as well as any additional ones that result in electronics functions supplied to the user asitable units. These technologies were first investigated in the late 1950's. The object was to develop electronics equipment to include increasingly complex electronic functions in limited space with minimum weight. Several approaches evolved, including microelectronic techniques for individual components, thin-film electronics, and semiconductor integrated circuits. Each approach evolved rapidly and converged so that each borrowed techniques from another. Many researchers believe the way of the future is to be combination of the various approaches.

The advancement of semiconductor integrated circuits is already leading us into the improved characteristics of thin-film electronics by applying film directly to an active semiconductor substrate. Advances in this technology are being developed at a pace which has surprised many researchers today. Both approaches have worked well and are being used in equipment today.

From K. Olukotun, L. Hammond, H. Sutter, and B. Smith

Trouble in River City

Intel 4004

Intel Core i7
Chip Performance 101

- Delivered processor performance
  - Frequency × Instructions/Cycle

- Overall power consumption (basic physics, see below)
  - Proportional to CdV2F + S

- Where
  - Cd is the capacitance of switched elements
  - V is the voltage
  - F is the frequency
  - S is the static current leakage (stay tuned)

- Implications
  - Reducing V and F yields cubic power reduction
  - However, voltage is bounded below by zero 😊

- Remember the basic physics (capacitors and work)
  - \( C = \frac{Q}{V} \) and \( W = \int q=0 \int Vdq = \int q=0 \int q/\int C dq = \frac{1}{2} CV^2 \)

- Dennard scaling by constant $k (\sqrt{2})$
  - Length, width, gate oxide thickness
  - Doping concentration
- Via scaling, transistors are
  - $k^2$ times smaller and $k$ times faster
  - Dissipate $k^2$ less power

$T_{ox}$ is now
- ~5 atoms thick (1.2 nm)
- Major source of static current leakage

Silicon Scaling Challenges The Extant Ecosystem

- Embrace heterogeneity
  - Functional and performance
  - Optimize for function

- We’re surrounded by “opportunities”
  - Devices and architectures
  - Algorithms and applications
  - Usage models and behaviors

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**Energy Efficiency (MOPS/mW or OP/nJ)**

**Better**

Single, General Purpose Processor

Multiple, Specialized Processors

Pentium


3 orders of magnitude!
Multicore and SoCs: Think Chocolates And Cookies

Sugar Cookies Alone
- Similar, modulo process variation
- You must eat lots to be satisfied

Designer Chocolates
- Diversity is a feature
- Forrest Gump was right

Multicore and SoC Implications
- Legacy and new code
- Programming heterogeneity
- System software and services
System on a Chip (SoC): The New Motherboard
- Core(s), memory controller, I/O
- Function-specific accelerators
  - Graphics, communications, sensors, security

Internet of Things (IoT)
- Embedded intelligence in everyday objects
- Experiences and natural user interfaces (NUIs)
- Resource discovery, security, services, programming
System on a Chip (SoC) Implications
Multicore and SoCs: What’s An Application?

An FFT?
• No, it’s an algorithm

A rendering pipeline?
• No, it’s a software library

A feature recognition system?
• No, it’s a building block

Our notion of “application” is increasingly complex
• Integrated and interoperating components

Our tools must enable creativity
• Creation of integrated experiences
Integrated Capabilities Are Increasingly Common

Applications
Languages, Compilers, Operating Systems
Specialization (ASIC, GPUs, FPGAs)
Architecture (ISA) (x86, ARM, EDGE)
Microarchitecture
Chip Fabrication

Hardware Companies
Software Companies
New Bytes of Information in 2010

Source: IDC, as reported in The Economist, Feb 25, 2010

$1.2 \times 10^{21}$
Economics of Storage

Disk Storage (per gigabyte)

2000 $24.0576
2001 $1,250
2002 $0.07
2003 $0.15
2004
2005
2006
2007
2008
2009
2010

Web Storage (per gigabyte)

2001 $10,215.0

… free storage is like free puppies …

Source: Wired Magazine April 2010; Figures represented in USD
The Data Explosion

Deliver the capability to mine, search and analyze this data in near real time.

Discovery itself is evolving
In 2000 the Sloan Digital Sky Survey collected more data in its 1st week than was collected in the entire history of Astronomy.

By 2016 the New Large Synoptic Survey Telescope in Chile will acquire 140 terabytes in 5 days - more than Sloan acquired in 10 years.

The Large Hadron Collider at CERN generates 40 terabytes of data every second.
Genetics Gets Really Personal
CMOS Sensing and Computing

$45,000 per Genome
$100 per Genome?

3e09 bytes per person x 6e09 people
= 1.8e19 bytes
= 10K petabytes

Source: George Church, Harvard Medical School, as reported in IEEE Spectrum, Feb '10. Figures represented in USD
The Changing Nature Of Research: Data Driven

Experimental

Thousand years ago

Description of natural phenomena

Theoretical

Last few hundred years

Newton’s laws, Maxwell’s equations…

Computational

Last few decades

Simulation of complex phenomena

The Fourth Paradigm

Today and the Future

Unify theory, experiment and simulation with large multidisciplinary data

Using data exploration and data mining (from instruments, sensors, humans…)

Distributed communities
What’s A Cloud?
Clouds: There Are Lots of Shapes

Amazon Web Services
User deploys and runs software; retains control over operating system and deployed applications

Windows Azure & Office 365
Cloud provider offers infrastructure and permits users to create or run applications

Google Apps
Applications run in the cloud
What’s Causing The Cloud Excitement?

Cost Optimization
- Reaping economies of scale
- Including virtualization

Business Efficiencies
- Focus on core competencies

Transfer of Responsibilities
- To cloud service provider

Just-in-time Provisioning
- Pay only when you need it
What’s A Cloud? The Traditional View
Microsoft’s Data Center Evolution And Economics

- **Data Center Co-Location Generation 1**
- **Quincy and San Antonio Generation 2**
- **Chicago and Dublin Generation 3**
- **Modular Data Center Generation 4**

**Deployment Scale Unit**

- **Server**
  - Capacity
- **Rack**
  - Density & Deployment
- **Containers**
  - Scalability & Sustainability
- **IT PAC**
  - Time to Market Lower TCO

Facility PAC
Generation 3 - Chicago Data Center

- $500M+ investment
- 707,000 sq ft
- 1.5 million person hours-of-labor
- 3000 construction related jobs
- 7.5 miles of chilled water piping
- 3400 tons of steel
- 2400 tons of copper
- 26,000 cubic yards of concrete

Each data center is approximately 17 times the size of a football field and uses containers.
1 + 1 = 10
A Transition: Computing Power + Data

As individuals, we have more computing power than the fastest supercomputers once provided to a select few.

We have enough computing and enough data that when combined with the power of the cloud, new kinds of experiences can emerge.
Working At Your Command

Working On Your Behalf
Not Everyone Can Have An Assistant... Or Can They?

I’ll research options, and let you know what will work.

There is only one connection that will work, but it requires you to stay an extra day.

I’ll adjust your schedule, so that meetings don’t conflict.

A Good Assistant:
- Leverages “Memory”
- Anticipates
- Holistically Completes Tasks
- Senses Emotion
- Recognizes Patterns

I’m running late due to clients & staff meetings. Can you reschedule for next week for me?

I need to be in London by the 5th. Can you arrange a flight for me?

The team will be in London by the 5th.
VIDEO: The Future

http://www.officelabs.com/projects/futurevisionmontage/Pages/default.aspx
Work/Office

Ambient, translucent displays (OLED)
Rich visualization, natural gesture 3-D space, touch and speech recognition
Fully active workspace, leveraging sensors and projectors
Rich graphics
Integrated workflows, ability to access and share work via the cloud
Seamless interface with devices and cloud services
Simple devices on surface to access and share data
Mobile

Integrated life experience: smart device + cloud = shared calendars, social spaces, next-gen interface

Location-based services, device projector within phone combined with sensor networks, context info retrieval, GPS, compass to “assist” in finding location

Smart device + cloud—preference-based communication routing (no decision-making)

Digital boarding pass, touch from beneath, dynamic information from the cloud
Different form factors, seamlessly integrated

Digital paper, OLED flexible displays, form factor – conductive battery set-up

“Smart” Home…

Switch to task pane for work; tasks pushed via personal profiles and data sharing in cloud

Switch surface, interconnected devices, Internet of Things
The Connected Home and Lifestyle

- Managed Circuits:
  - HVAC Systems
  - Hot Water
  - Pool Pump
  - Comfort lighting
  - Accessories
  - Other loads

- Local Distributed Generation (Wind, Solar, etc...)

- Home Energy Management System

- Hybrid/Electric Vehicle Interface

- Cloud Energy Services:
  - Remote Control
  - Reporting, Analytics, Alerts
  - Remote Diagnostics
  - CRM/Billing
  - Competitive Retail Offerings
  - Appliance Diagnostics and offers
  - Smart Energy Wizards

- Utility Z
- Meter (bi-directional power flows)
- DOE 2007 Solar Competition Darmstadt winning entry
Security and Privacy: The Threat Ecosystem

www.microsoft.com/sir
Security, Privacy and End-to-End Trust
Systems Evolution: Convergent Invisibility
The Future of Experiences

EXPERIENCES

Private Data Services
Augmented Interaction
Sensory Inputs
Anticipatory Processing
Adaptive Behavior
Context Awareness
Environment Awareness
Trust & Security Services
Public Data Services

CLIENT

HYBRID

CLOUD
eXtreme Computing Group (XCG)

- Data Center Improvement
- Client Experience
- Security and Privacy
XCG Vision: Rethinking Everything

**Philosophy:** Cloud infrastructure must be designed and programmed as an integrated system.

- Chip stacking
- Modularity
- Novel cooling
- Over-provisioned
- Introspection
- Tier-splitting
- Adaptation
- Resilience and Security

- Optics
- Distributed routing
- Optics
- Distributed routing
- On-chip
- Non-TCP/IP
- Low power
- FLASH
- Virtualization
- PCM
- Optical Interconnect
- Manycore
- Heterogeneity
Rethinking Node Architecture

- System on a chip (SoC)
  - Learn from the embedded space
  - Embrace heterogeneity
    - Functional and performance
- Operations/joule
  - Low power, in order wins
- Memory-processor balance
  - Do not fixate on core counts
  - Optimize for workloads
    - TCO, not just ops or FLOPS

Rethinking Node Architecture

- Low power systems for web search
  - Workload adaptation and SLAs

- Intel Cloud Chip
  - 48 x86 cores
  - Software power control
    - Energy management
  - On-chip mesh network
    - Low latency
    - High bandwidth
Rethinking Storage: Beyond Disks/FLASH

• The tyranny of disks
  • Last mechanical component
  • Most common failure mode
  • Capacity/bandwidth mismatch

• Rethink the storage hierarchy
  • Mixed processes and DRAM
  • Chip stacking and PIM
  • NVRAM futures
    • FLASH (transition)
    • Phase change memory (PCM)
      • Crystalline (1) and amorphous (0) states
      • Word/byte addressable with lower latency
Current Cloud Data Center Networks

Key:
• CR (L3 Border Router)
• AR (L3 Access Router)
• S (L2 Switch)
• LB (Load Balancer)
• A (20 Server Rack/TOR)
Rethinking LAN/WAN Networking

- Break the LAN hierarchy
  - Multiple paths, commodity components
  - High bisection bandwidth
- We build WAN islands, not continents
  - Isolated facilities with limited connectivity
- Change the landscape
  - Serious, multiple terabit WANs
  - Many lambdas entering a facility
  - Fused node/LAN/WAN infrastructure
Rethinking Packaging and Cooling

• People and hardware need not mix
• Hardware cooling standards are conservative
  • Reliable at high temperature/humidity

• Optimize for efficiency
  • Cooling is (often) unnecessary
    • Design for ambient environments
  • Energy reliability is (often) unnecessary
    • Design for power outages
• Use larger building blocks
  • Accept component failures
Rethinking Reliability: Fail In Place

- Factory sealed units (FRUs)
- Over-provisioned for failure
- Dynamic reconfiguration
- Real-time, adaptive control
Rethinking Energy Provisioning

• Power redundancy is a major cost
  • Batteries to supply up to 15 minutes

• Use multiple sites, based on energy cost and carbon footprint
  • Electrical grid, solar, wind, fuel cell, ...
  • Workload dispatching based on models

• Real-time optimization and prediction
  • Workload demand
  • Weather and seasonal models
  • Auction-based energy pricing
  • Infrastructure
    • UPS, optical fiber and computing
Micro Datacenter Prototype

• Early test vehicle
  • 1500 W target
    • Solar and wind renewables
    • Grid as backup

• Power smoothing
Rethinking Trust: End-to-End Balance
Rethinking Data Center Software: Orleans

- Key concepts
  - Grains
  - Activations
  - Message passing
  - Promises
  - Transactions
Rethinking SLAs: Multivariate Balance

• Clear specification and separation of concerns
  • Consumer, commercial, NGO, government

• Roles, rights and responsibilities
  • Direct and derived

• Service classes and expectations
  • Security and privacy
  • Performance, reliability and cost

• Claims-based access
  • Roles and intervals
A Vision of the Future

- A web of modular cloud infrastructure
  - Intelligent energy management
  - Adaptive failure resilience
  - Rugged environment tolerant
  - Configurable components
  - Designer hardware

- Flexible enabling software
  - Device agnostic adaptation
  - Fine grained mobility
  - SLA driven resource management
  - Secure, attested environment

- Rich and diverse client experiences
  - Mediated by wired and wireless devices
  - Contextually aware and responsive
  - Supported by rich infrastructure