

# The Impact of Exponentials on Information and Communications Technology

Rodney Brooks

MIT Computer Science and Artificial Intelligence Laboratory



**CSAIL**



The experts look ahead

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# **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 65,000 components on a single silicon chip**

By Gordon E. Moore

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

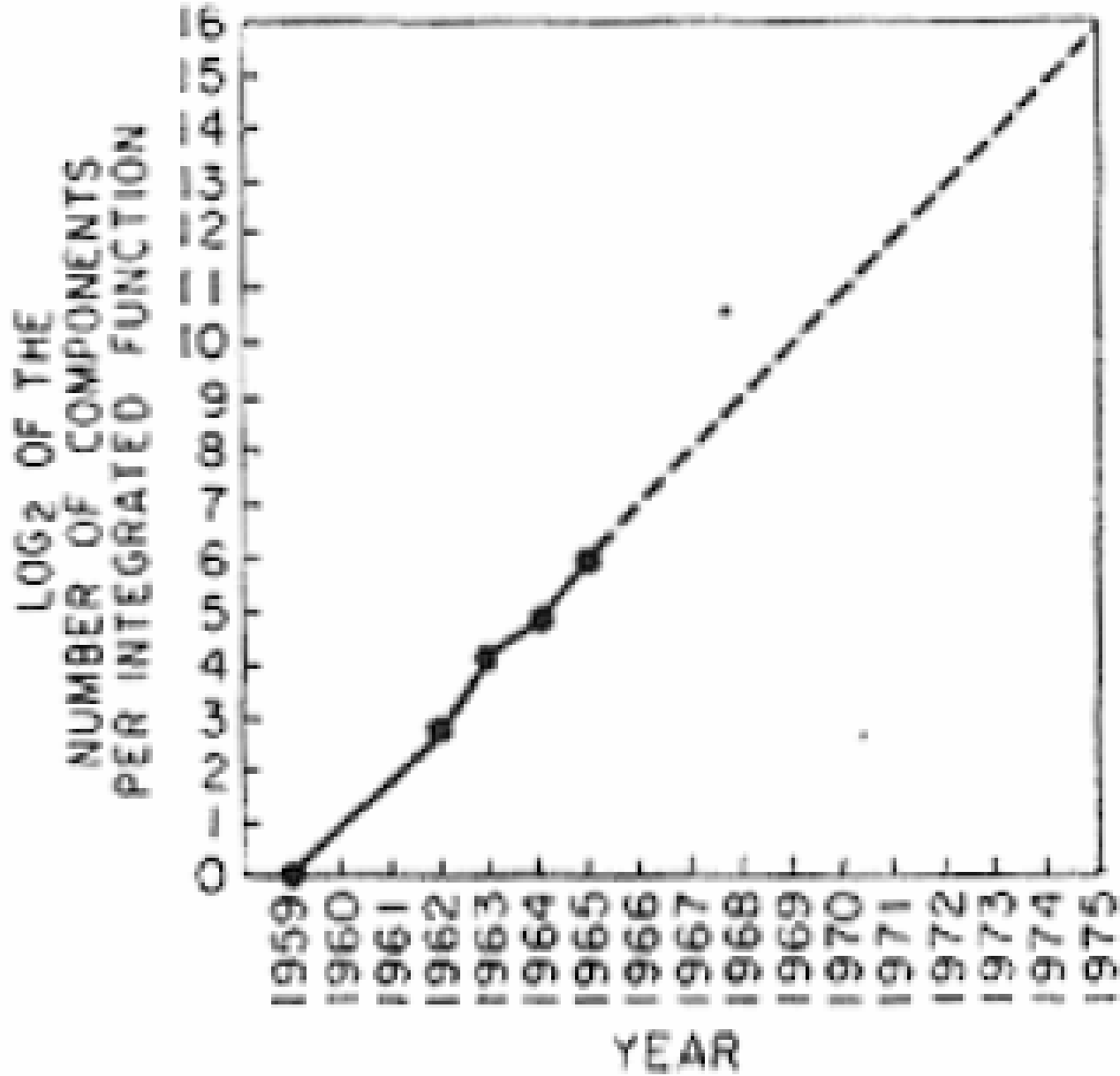
# Radical Insights

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—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment. The electronic wristwatch needs only a display to be feasible today.



# The Key Graph



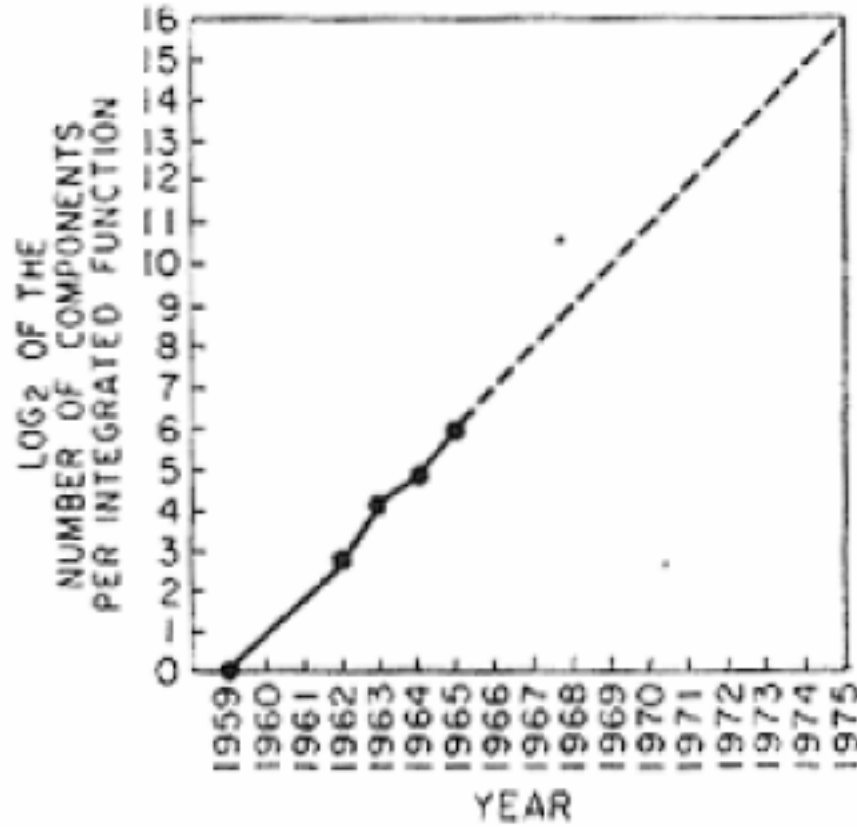
# What Defines an Exponential?



$$\frac{ds}{dt} = \alpha s$$

- The rate of change of “stuff” is proportional to the instantaneous amount of “stuff” that is around already
- Is this the explanation for how computer power has been an exponential?
- Does the presence of computers of power  $P$  make it easier to build a computer of power  $wP$ , where  $w > 1$ ?

# But Not in Play in 1965



# So What Makes Exponentials?



- The existing level of adoption
- The expectation of an exponential
- The cross-transfer from another exponential



The existence of the “law” helped to drive the exponential at the predicted rate.



# Other Exponential Stories

# A (Typical) Convoluted Example (I)



- Computer vision research used to require really expensive equipment and compared to today was in the stone age--a few small isolated bands of researchers, barely getting a flame to catch
- Exponentials came to the rescue
  - **Exponential** increase in computer power
  - Home VCR's **exponentially** bringing down the cost of a 1/4 Megapixel CCD
- Computer vision now flourishes and useful contributions can come from any research lab in the world--the barriers to entry have gone

# A (Typical) Convoluted Example (II)



- After CCD commoditization, there was a new development:
  - exponential growth in Megapixels
  - enabled digital cameras to replace film

# Kodak CEO Dan Carp (out in June)



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are needed to see this picture.

# Hard To Understand Until Too Late



**1976:** Kodak had 90% of the US film market and 85% of the US camera market.

**1983:** Leo J. Thomas, senior vice president and director of Kodak:

*"[but] it's very hard to find anything [with profit margins] like color photography that is legal."*

**1993:** Kodak had spent \$5B on digital R&D but had no products.

**1993:** Had 23 different digital scanner projects scattered across its divisions.

# From January 2005:



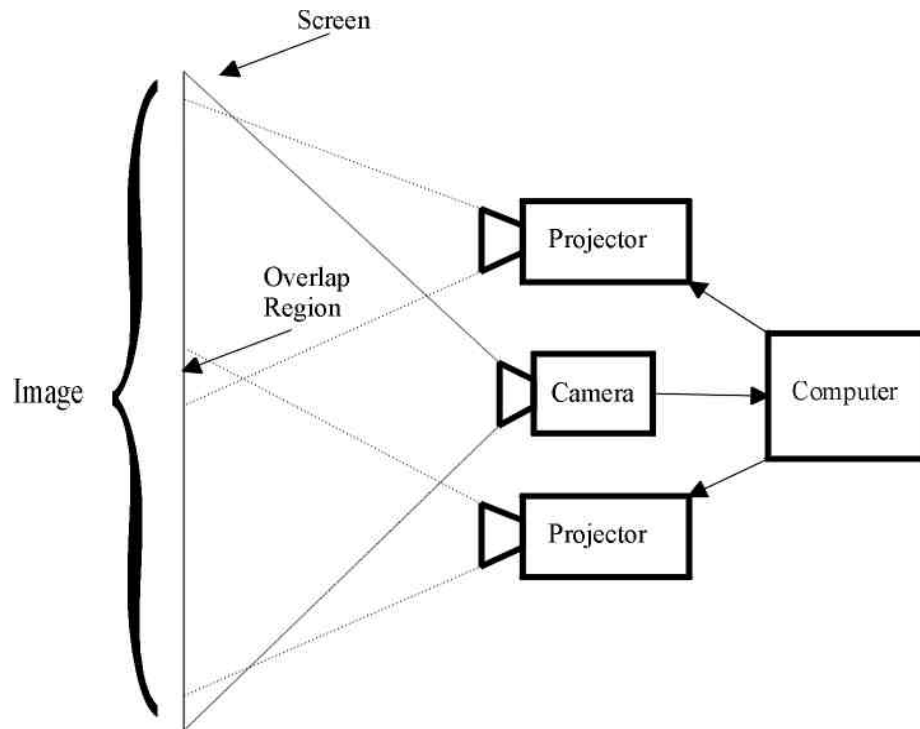
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# A (Typical) Convoluted Example (II)



- After CCD commoditization, there was a new development:
  - exponential growth in Megapixels
  - enabled digital cameras to replace film
- Megapixel growth is now saturated
  - 8 Megapixels gets you movie screen resolution
  - bits per pixel is better than display technology
  - now multiple cameras per device!
- The **value** is now in the processing before the human eye gets involved--new research!!!
- How will this new exponential drive the display business???

# Replacing Precision with Computation



# Multiple Cores on a Chip



- Intel, AMD, Freescale going to two cores on consumer PC chips
- Tensilica, Freescale, others, already have a “handful” of cores on a chip for embedded applications
- This number is going to increase exponentially

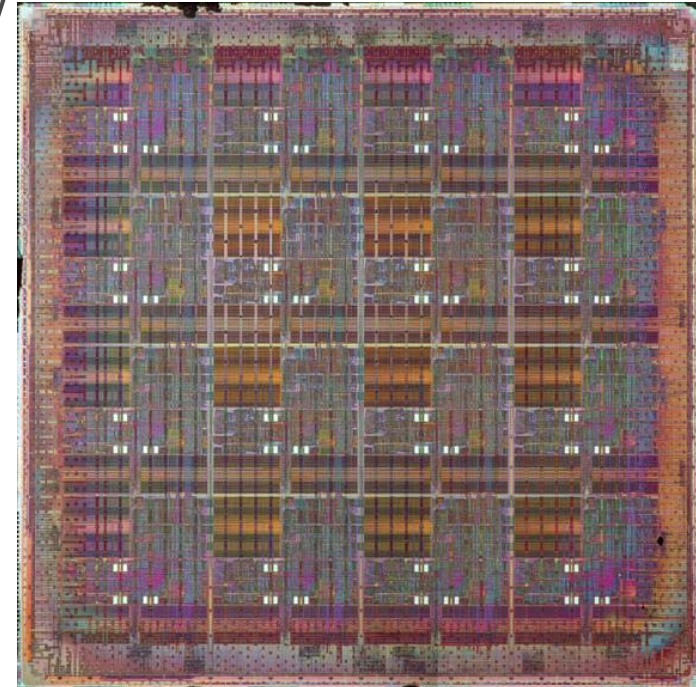
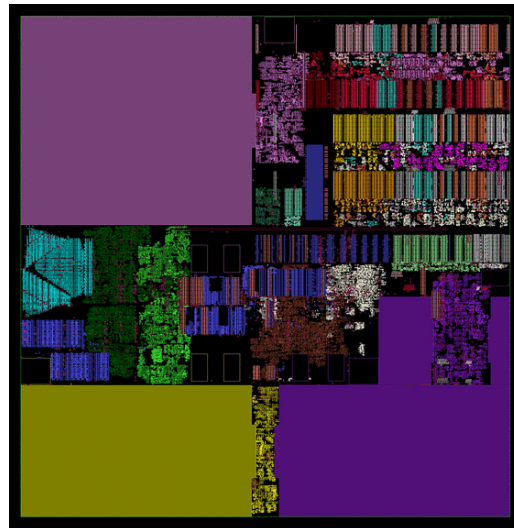
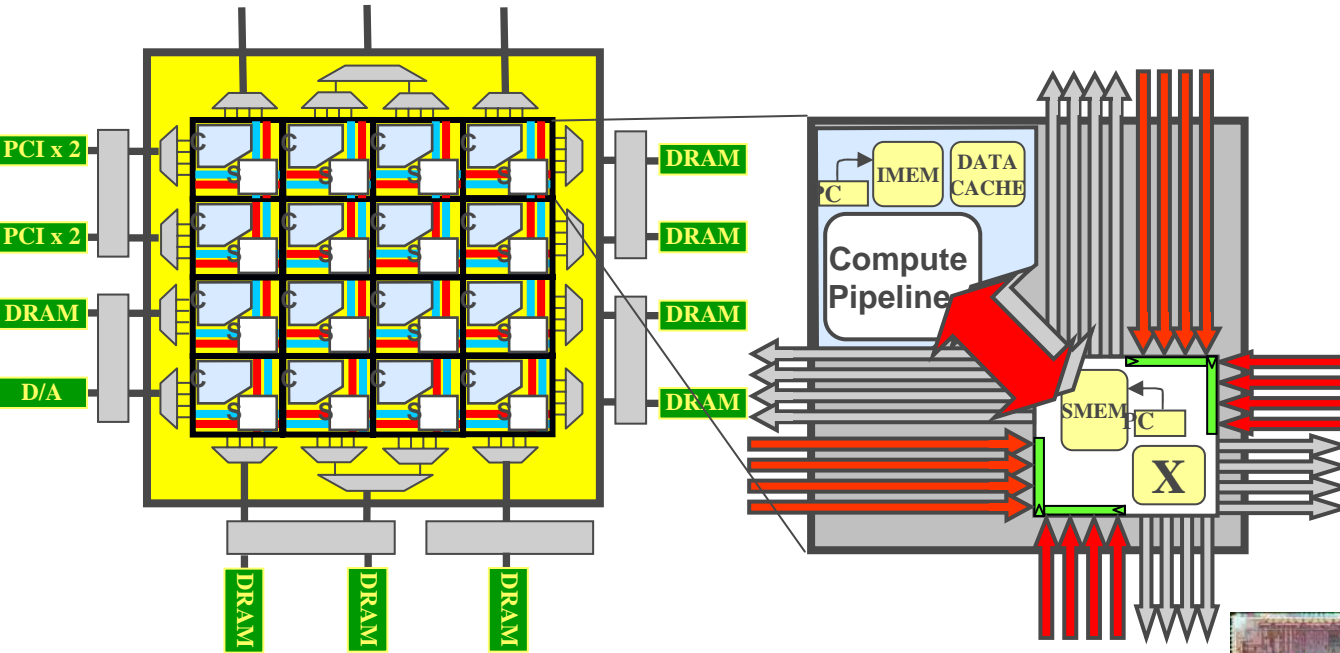
# IBM/Toshiba/Sony CELL



- Each chip
  - 64 bit PowerPC at 4GHz
  - 8 independent SIMD machines
    - » 16 way byte integer parallelism
    - » 4 way single precision float prllism
  - 256 Gflops per chip peak
- Sony Play Statio 3 will contain four such chips
  - 1 Tflop peak performance
- Compiler/caching model is not conventional!

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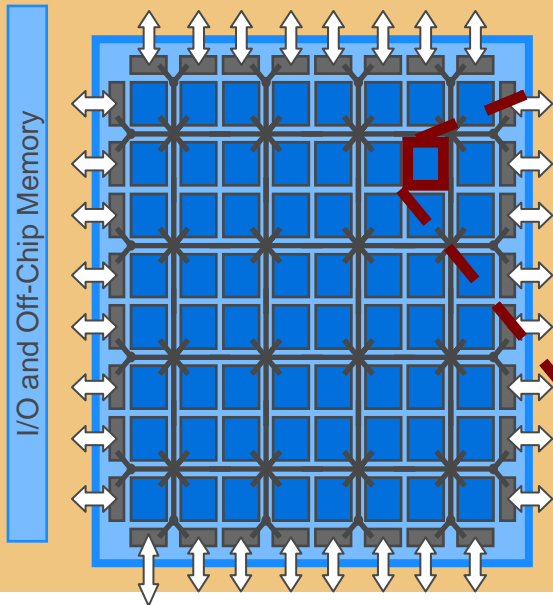
# RAW -- Tiled Processors -- 16



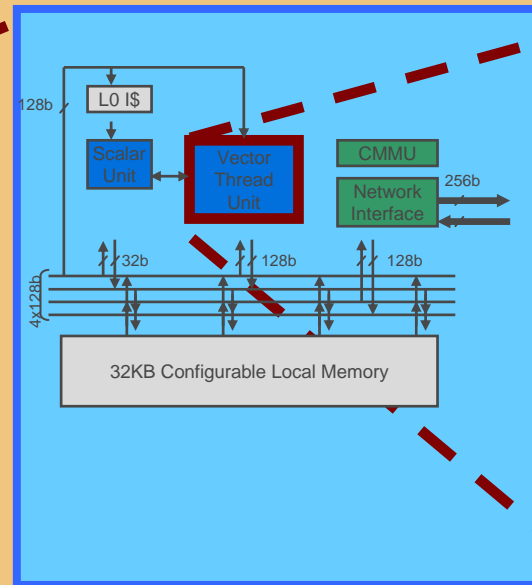
# SCALE -- Tiled Processors -- 64



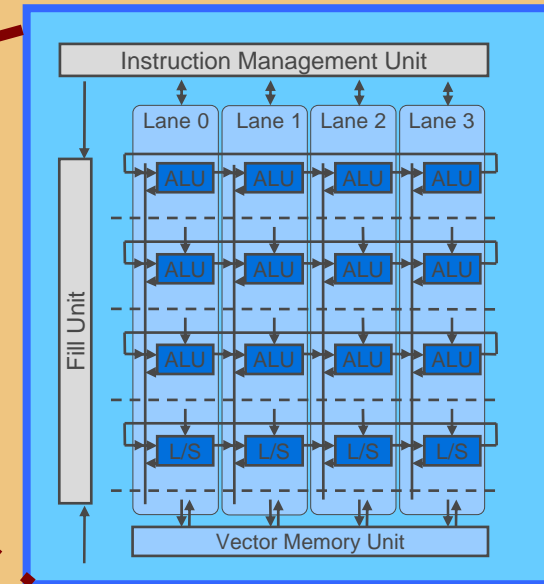
Multi-Tile SCALE Chip



Single SCALE Tile



Vector-Thread Unit



- As # of tiles grow exponentially, the way in which software must be written needs to be changed
- The value shifts from the hardware to the software

# The StreamIT Compiler Project



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- The designs at the lower levels will eventually shake out into a few dominant approaches
- The silicon becomes more of a commodity
- Compilation and optimization become more critical
- The boundary to the “outside” world will move
- Companies will have to change the game that they play if they want to remain high on the value chain

# iPod as Current Storage Standard



- 2004: 20 Gigabytes -- teenager price (\$400), fits in pocket Enough for most people's personal music collection.
- Today (on Apple Web site):
  - 20 Gb = \$249
  - 30 Gb = \$349
  - 60 Gb = \$449 (sold as iPod Photo)
- Approximately doubling every year
- 20 years from now that means an iPod, \$400, pocket sized, will have
  - 40,000,000 Gigabytes
  - or 40 Petabytes



# The Million Book Project

- Digitization centers in India, China, Egypt
- Aim is 1,000,000 books digitized and freely available
- 500 Gigabytes as text (= iPod in 2009)
- 50 Petabytes as image files
- Library of Congress has 20 million books
  - 10,000 Gigabytes as text (= iPod in 2013)
- Current iPod = four full movies
- 319,937 movies on IMDB (500K including Bollywood)
- iPod in 2024 (all the ones worth caring about: <2020)

# Pervasive Lo-Level Wireless



- Now: bar-codes are pervasive
- Soon: RFID tags will be pervasive
- Ad-hoc networks will start to form in the home
  - 802.15.4 and Zeebig
  - and everywhere else
- There will be more and more sensor collection and aggregation

# Hi-level Wireless Networks



- 802.11b is becoming pervasive
  - in the US: hotspots in Starbucks, Borders, airports
  - citywide in places
    - » San Francisco: free, amateur, ad-hoc, organic
    - » Philadelphia, etc. (fought by TelCo's)
- South Korea: pervasive cell based broadband
- Bandwidth is increasing: 802.11g is five times faster
- 802.16 (WiMax) gives broader area and higher bandwidth
- Over 10 years there will be a merger with GSM/3G to new standards
- Will be more pervasive than current cell phone service

# Exponentials



- Personal storage is more than doubling per year; constant \$
- Number of processor cores on a chip is rising (AMD, Intel, Freescale, IBM,... CSAIL)
  - dedicated speech/vision
  - new software methodologies
- Bandwidth between processors and memory is increasing
- Wireless becoming pervasive at many scales; 802.11, 802.16 and 802.15.4
- Location awareness following
- Remote presence possibilities
- Digital cameras everywhere
- Display technologies are both expanding and dropping price
- Speech systems are multi-lingual and increasing vocabulary size
- Real-time vision systems are proliferating on PC-class arch.
- Cost of microphone arrays and high resolution cameras drops
- Enterprise-wide ontologies are being exploited and world-wide being developed
- Statistical machine learning techniques pervading CS&AI
- Brain-silicon interfaces
- Expectations of change



# A Few Exponential Successes

# Better Digital Photography



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# Better Than Human Acuity



- Currently runs in 10 hours
- In 13 doublings of computation will run in real time
- Work of:
  - Bill Freeman QuickTime?and a Cinepak decompressor are needed to see this picture.
  - Fredo Durand
  - Ted Adelson
  - Ce Lui
  - Antonio Torralba

# Multilingual Speech Input



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# Practical Multi-Modal Interfaces



# Synthesize Human...



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QuickTime?and a  
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**Where Does This Lead?**

# What We See Users Doing Today



- Voice communication
- Text messages (SMS, paging, email, instant msg)
- Tele/video/web conferencing
- Digital photography/video
- Music/video storage and play
- Games, personal and multi-player
- Calendar/contacts/scheduling
- Using the Web for information + commerce
- Making presentations
- Business applications (spreadsheets, word processing, project planning, CAD, etc.)
- General purpose computing

# What Will They Want Tomorrow?



- Collaboration
- Expansion of pen-based interactions
- Personal digital video libraries
- New forms of communication once someone invents them
- Remote presence
- Access to more on-line information (e.g., Google's announcement of digitizing great libraries)
- Electronic book reading...finally
- On-demand access to entertainment content
- Multi-lingual conversion
- Personal medical monitoring
- Things yet to be invented...

# Market Trends...

- PDA becoming more notebook-like
- PDA becoming more telephone-like
- Phone becoming more PDA-like
- Phone becoming more camera-like
- Notebook becoming more DVD-player-like
- Notebook becoming more “note book”-like
- MP3 players becoming more PDA-like
- Digital cameras becoming more video camera-like
- Notebook becoming more desktop-like
- Notebook becoming more super computer-like
- Everything becoming network connected

# Where Does This End?

- What form of device will “win”?
  - Will everything converge?
  - Will everything diverge?
  - How will trends be disrupted by new “inventions”?
- 
- JUMP PAST THE TRENDS
  - IT'S ALL ABOUT INTERACTIONS



In the future, information and communications technology will be about the space of interactions.

# What This Implies...



- There will be many sorts of devices for component services:
  - authentication
  - input and output
  - storage
  - networking
  - computation
- There will be private and public components
- They will need to come together dynamically to serve a user's current needs

# The Interaction Space and the User



- The interaction space will be defined by the user's personal data
- Key developments that this needs
  1. private and secure agglomeration of devices into smoothly functioning ensembles
  2. software that adapts the user interface to the physical configuration in place from moment to moment
  3. software that adapts the user interface to what the user is doing from moment to moment

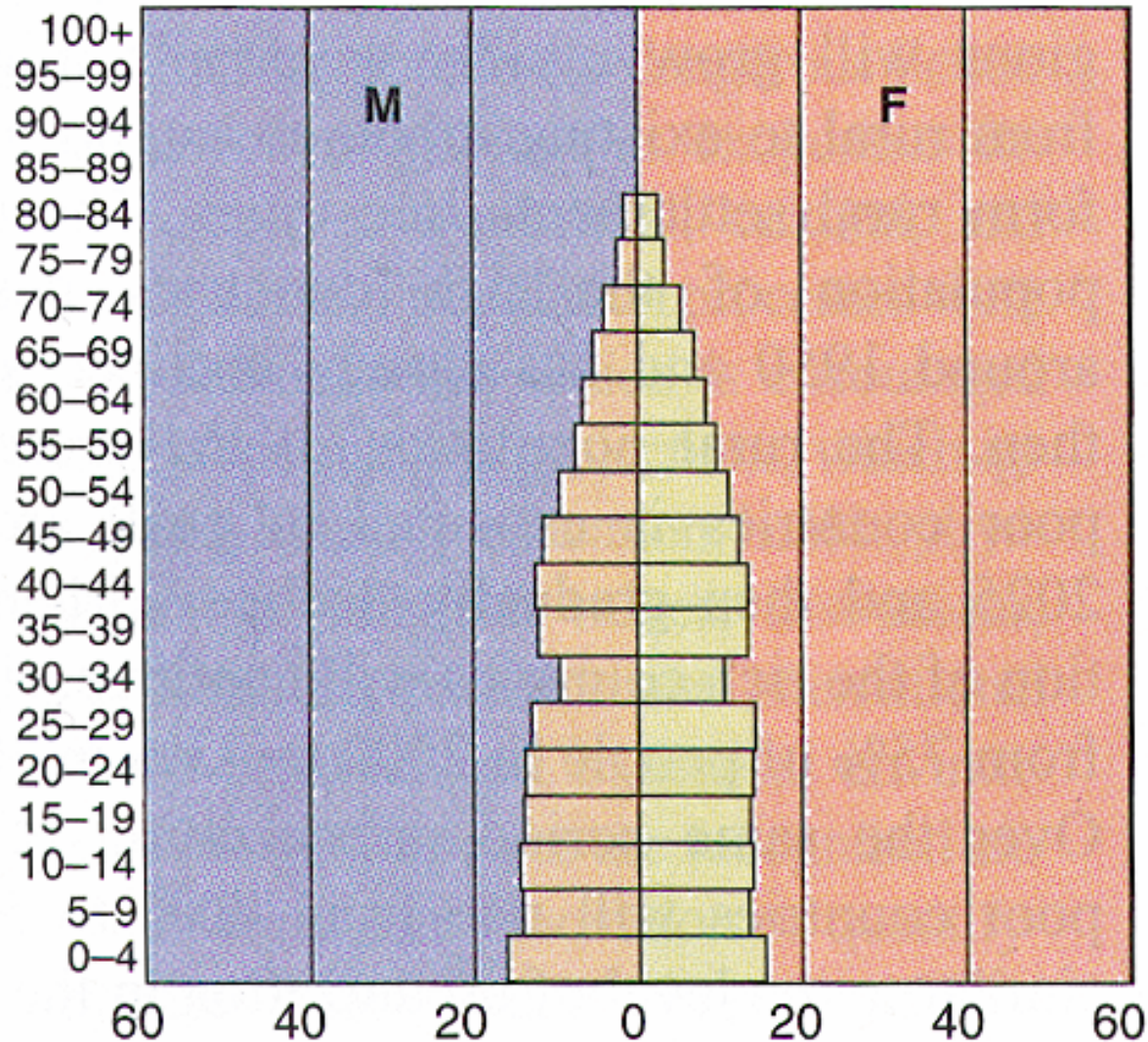


# The Future

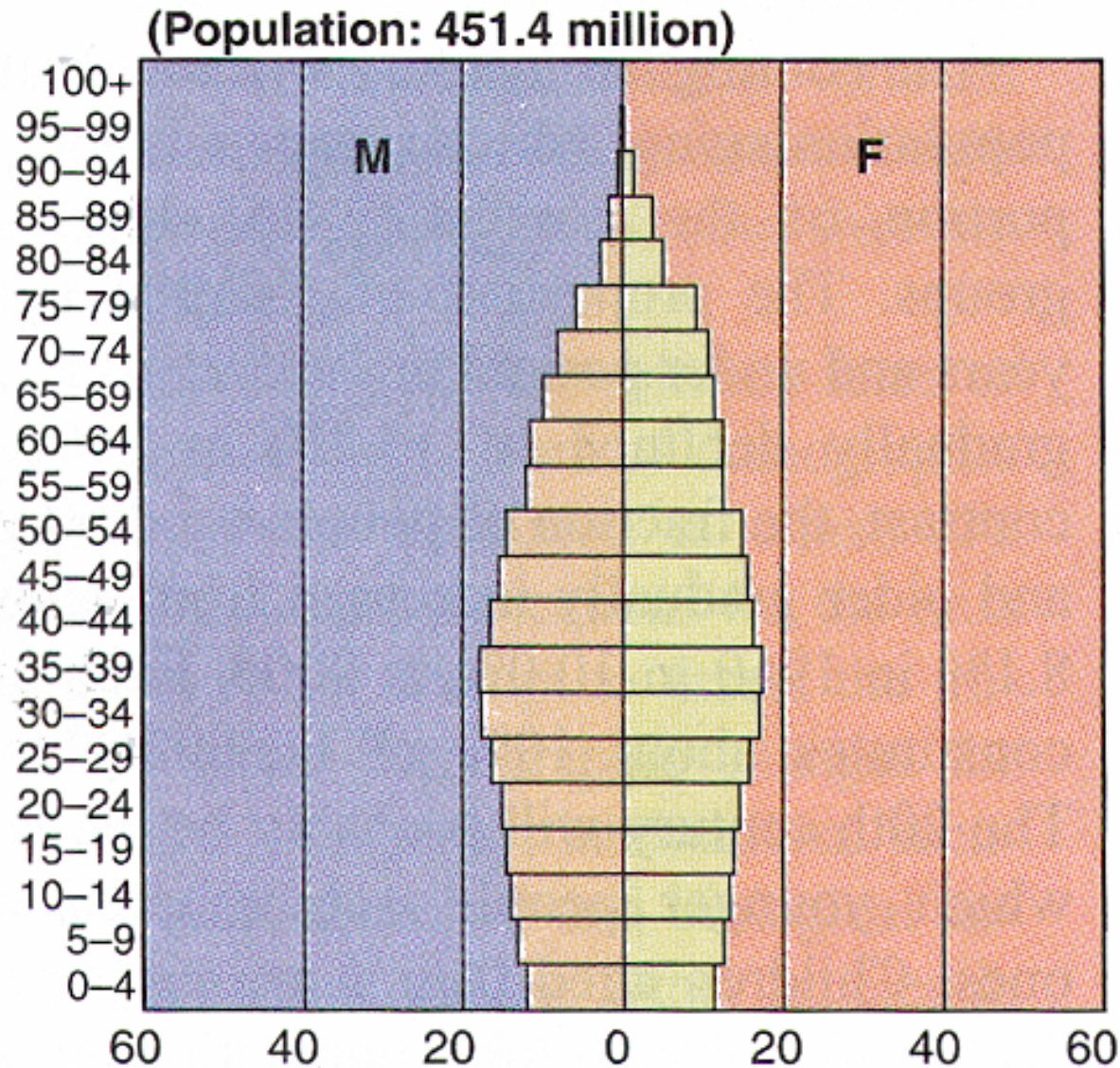
# Europe - 1950



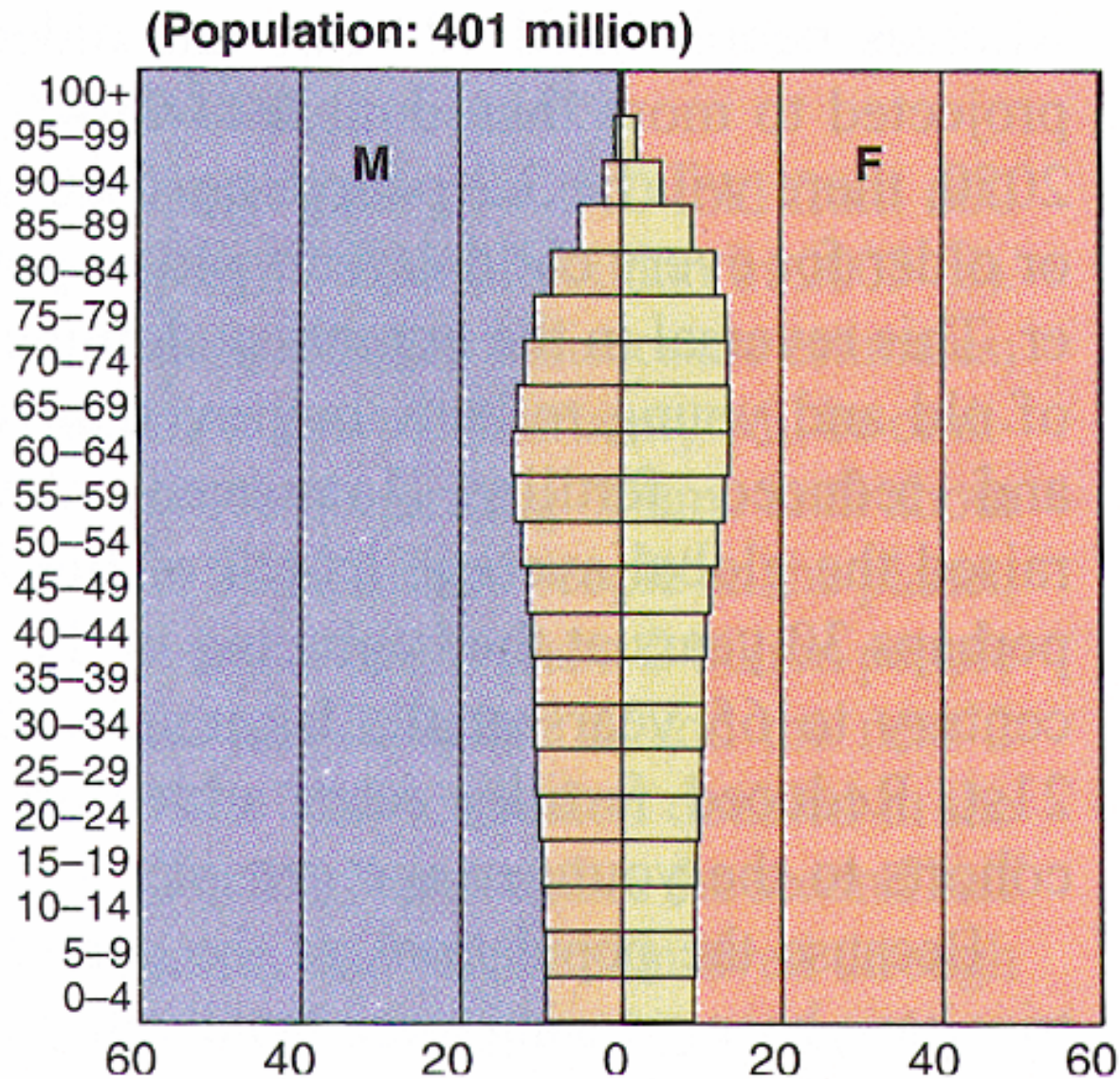
(Population: 349.8 million)



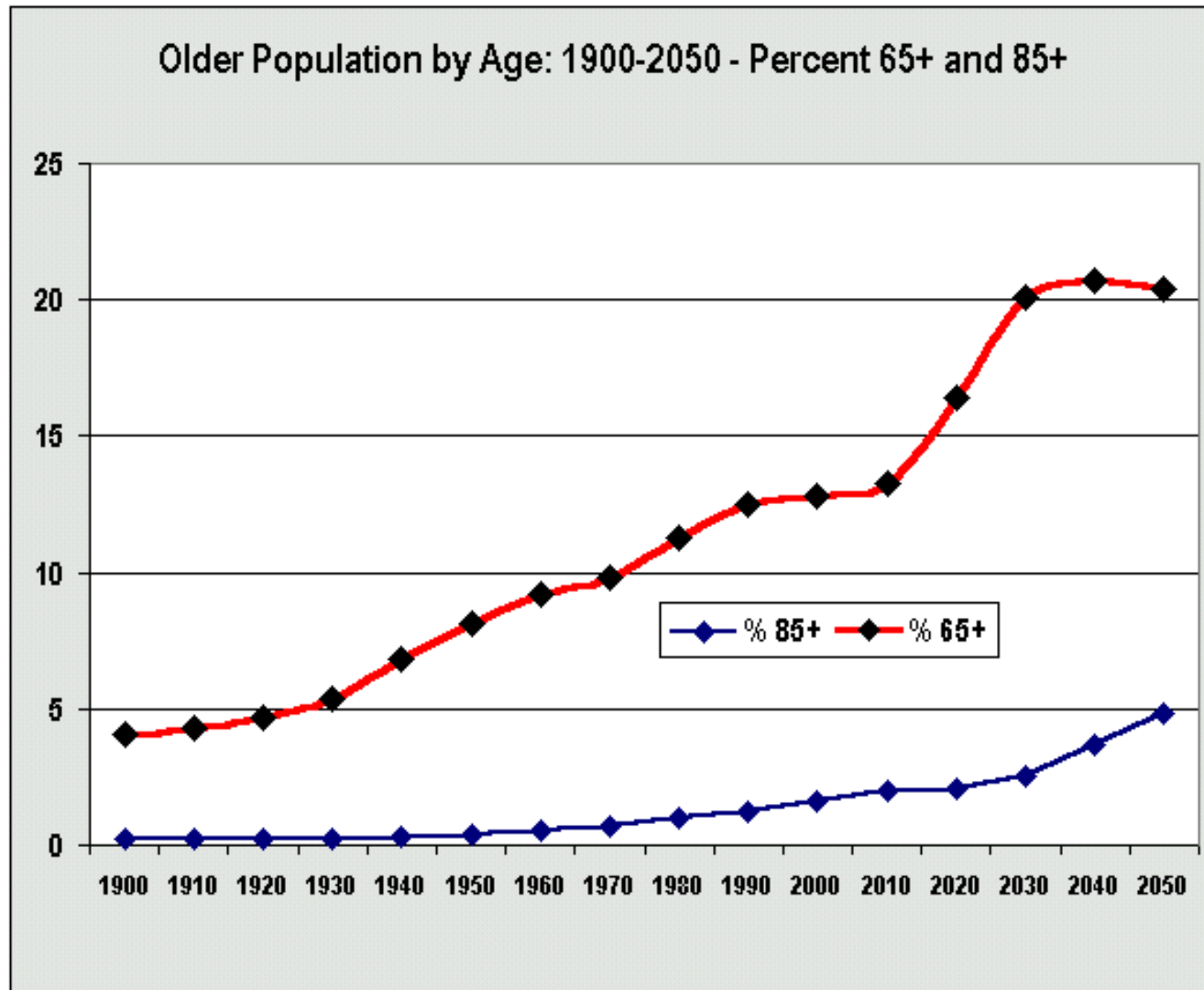
# Europe - 2000



# Europe - 2050



# US Statistics



# Changing Demographics



- The ratio of 20-65 year olds to 65+ year olds will change dramatically
- The elderly will be healthier, fitter, mentally active, work longer, and will be ICT accepting
- There will be less people to do the very physical jobs that support society
  - replacement labor or physical assists will be crucial
- There will be a pull for assistance in the home
  - allowing people to stay in their own homes longer

# Today's Robots...



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# What Can Modern Robots Do?



- Can navigate around unstructured environments
  - observe
  - recall
  - build maps
- Can wave their arms around and sometimes hit things
- Perform group behaviors
  - sometimes they push each other
  - sometimes they play soccer
- Can have social interactions
  - observing people
  - speaking and moving their body parts

# Four Fundamental New Capabilities



- I. The object recognition capabilities of a two year old child
- II. The manual dexterity of a six year old child
- III. The ability to move around freely and to work in built-for-human environments
- IV. Intuitive human interfaces

# Big Application - Agriculture



- currently: roboticizing large agricultural machines
- future: maintenance of individual plants
  - pruning, picking, etc.
  - currently Europe and US import low cost labor, Japan has higher cost agriculture
  - what are the technical challenges?

# Big Application - Manufacturing



- currently: robot arms for “fixed automation”
- future: flexible low-cost manufacture
  - dexterous assembly/fabrication of small low cost products
  - currently we outsource this to low cost developing-world labor
  - what are the technical challenges?

# Big Application - Elder Care



- currently: no automation
- future: robotic assistants
  - in-house care and nursing care
  - currently Europe and US import low cost labor, Japan is facing immediate challenges
  - what are the technical challenges?

# Big Issue #1



- Dogs have better autonomous manipulation capabilities than any of our robots
- Manipulation at the 6 year old child level would open up applications tremendously

# Some Exploratory Research...



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# Big Issue #2



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- **General purpose vision has not been achieved**
  - even though we're good at faces, 3d, motion, image-matching, etc.
- **Object recognition at the 2 year old child level would open up applications tremendously**

# Big Issue #3



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are needed to see this picture.

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- Elder care will be in built-for-human spaces
- Spaces designed for adult human bodies

# Big Issue #4



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- For robots to be pervasive they must be easy to use
- People must immediately sense the robots intentions, and vice versa

# Summary



- Simple trends get swamped by exponentials
  - they open up new ways of thinking about problems
  - they cause demands for new services
  - they alter the landscape of who the important players are
- In ICT there will be big research issues in
  - security, privacy, networking, user interfaces, wireless device communication
- In robotics there are research issues in
  - vision, manipulation, mobility, and user-interfaces