Bell's Law; P,M,S Structures; Rules of thumb; and Taxonomies

1957-1998. 41 yrs. 4 generations:
Tubes > transistors > ICs, VLSI (micros) > clusters - winner take all

How computer classes form, evolve …and die (according to economically based laws)

Gordon Bell
Microsoft Research, Silicon Valley Laboratory

References

Moore's Law

http://www.computerhistory.org/semiconductor/timeline/1965-Moore.html

Bell's Law:

http://research.microsoft.com/research/pubs/view.aspx?0rc=p&type=technical+report&id=1389

Bell, C. G., R. Chen and S. Rege, "The Effect of Technology on Near Term Computer Structures," Computer 2 (5) 29-38 (March/April 1972).

IEEE History Center's Global History Network:

http://ieeeghn.org/wiki/index.php/STARS:Rise_and_Fall_of_Minicomputers

In retrospect…by 1971, the next 50 years of computing was established

1. Moore's Law (1965) transistors/die double every 18 mos.
2. Intel 4004, Processor-on-a-chip (1971)

   Clearly, by 1978 16-bit processor-on-a-chip
3. Bell et al 1971 observation...computer evolution
   1. Computers evolve at constant price (Moore's Law)
   2. Computer clases form every decade (Bell's Law)

      New technology, manufacturers, uses and markets

How I think about computers

- P,M,S describes architectures i.e. the components and how they are interconnected and interact
  - Reveals structure (size, cost, performance, power, etc.)
  - Parallelism, bottlenecks, and rules of thumb
  - Functional evolution to compete with larger computers
- Bell’s Law determines classes birth & death
- Rules of thumb determine goodness
- Taxonomies enumerate alternatives

A Walk-Through Computer Architectures from The Largest & Fastest to the Digestible

Computers have evolved from a bi-furcation of:

- calculating (P) aka scientific and record keeping (M) aka commerce to
- control (K),
- interfacing (T/Transduction) including GUIs, NUI, and
- Communication (L), switching (S) and networking (N) Every information carrier from greeting cards to phones is an embedded computer. Similarly, physical carriers from networks to autos can be viewed as computers with wheels, UIs, memory, etc. In each area the choice may be cost, power, reliability, specialization for the task, etc.. Computer structures will include:
- Cloud and HPC supercomputers are almost indistinguishable. They are both scalable and constructed from many low cost computing nodes interconnected to each other and to storage (disks). A proposed triple crown measures their Top500, Graph500, and Green500 rankings. Cray Research, Fujitsu, IBM, as well as China all compete for these titles. In 2012 a single HPC computer operates at almost 20 petaflops. The goal of an exa-flops is after 2020.
- Communications and network computers are a special breed. Within this category, companies compete for the ability to execute stock trades electronic with the lowest latency. One company Zeptronics claims a delay of less than 10 ns.
- Game computers for better performance/price than supercomputers. Graphics Processing Units were introduced in games and have become an HPC component. What makes each special?
- Wireless Sensor Nets en route to IoT Industrial control, building automation, and scientific and engineering data acquisition usually boils down to interconnecting a variety of highly distribute, sensors and effectors to some central or distributed computers for control or record keeping. Wireless Sensor Networks provide reliable communication in the face of electrical noise, sharing communication channels with Bluetooth, 802.11x, wireless phones, etc.
- Body Area Networks and Home Networking for Health Monitoring.
- Ingestible and in body from pill-cams to pacemakers. One of the smallest is designed to remain in the eye for measuring pressure is a 1 mm^3 that includes sensing, battery, and telemetry.

P,M,S (Functional) for Computer Structures

- **P/Processor or central Processor Pc. The element for fetch-execute**
- **Mp/Primary Memory …where instructions are stored and the data operated on.**
- **Ms/Secondary Memory … place where data are stored**
- **S/Switch … multiple port to allow multiple units to communicate**

C/Computer := P-Mp;

- **multiprocessor P…-S-Mp…;**
- **multicomputer C…-S**

- **K/Control… evokes action in other components. Control is the program or hardware within a processor that defines a system's e.g. processor, computer behavior. Control is contained in a memory or combinatorial logic plus its state.**
- **T/Transducer…unit to transform the form of data e.g. electric to light**
- **L/Link … the interconnection of just two components**
- **D/Data… unit to transform data value**
- **N/Network := {C's, S's}**
- **H/Human… a particular kind of information processor**

PDP-8 P,M,S
Structure 1971 and 1982

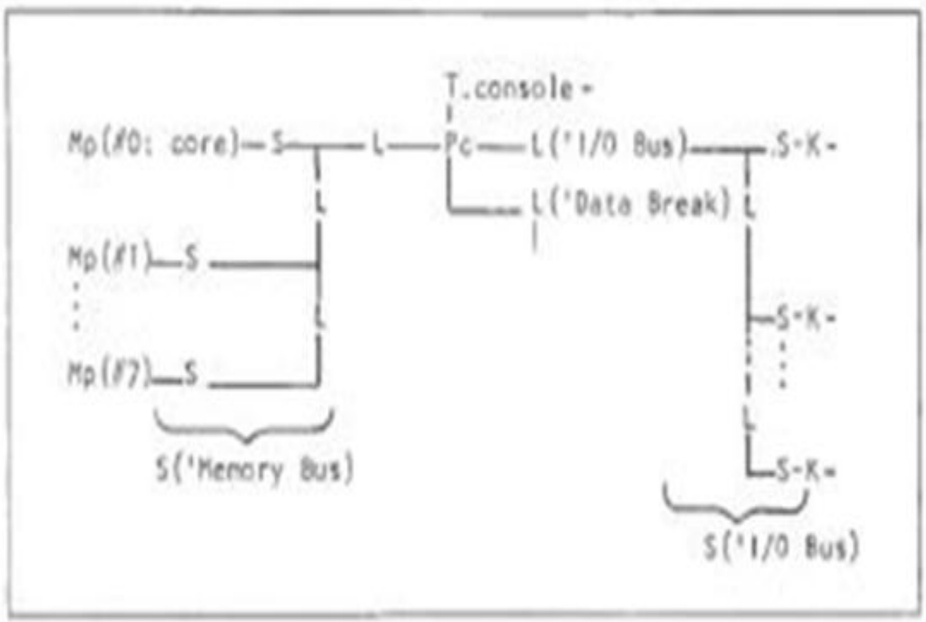
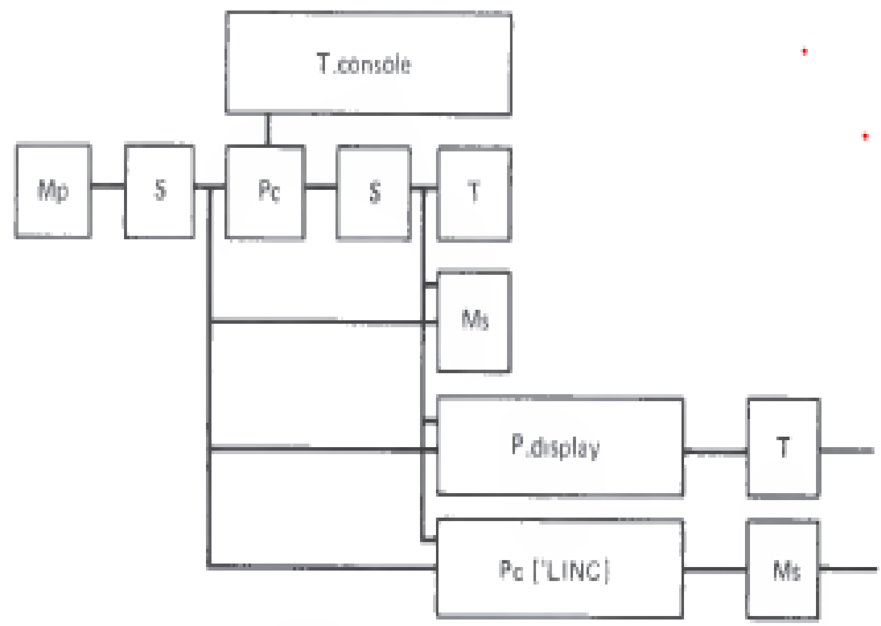
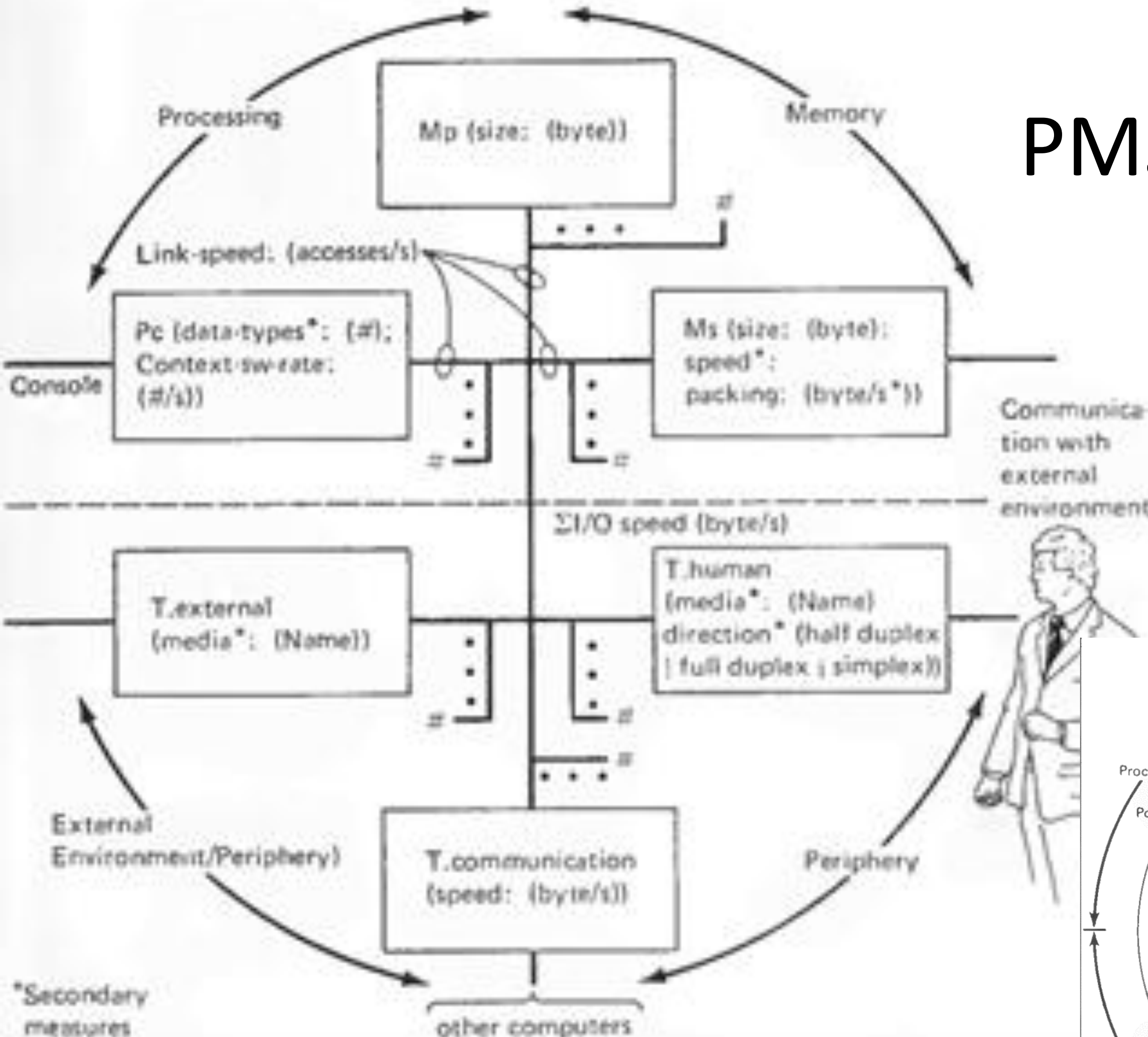
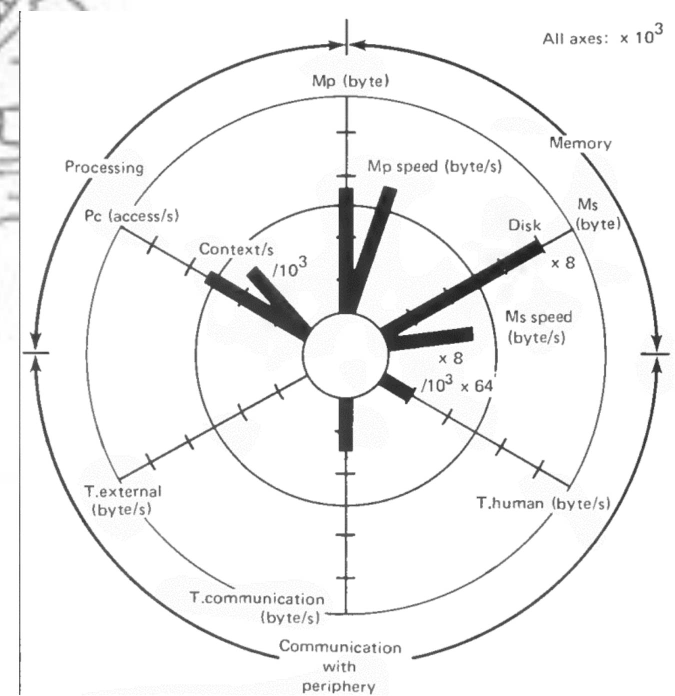


Fig. 3. DEC PDP-8 PMS diagram (simplified).



PMS Structure





PMS Model of A Computer

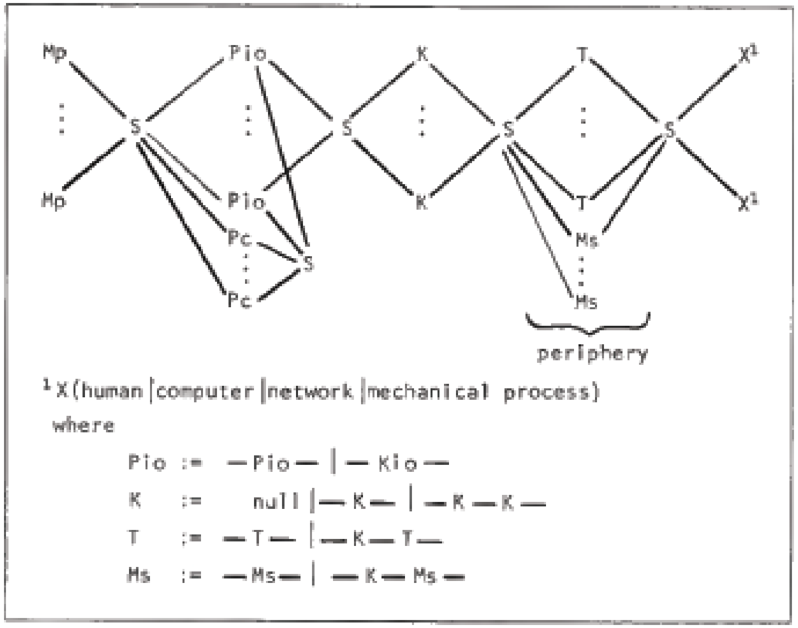


Fig. 10. General computer model (multiprocessors) PMS diagram.

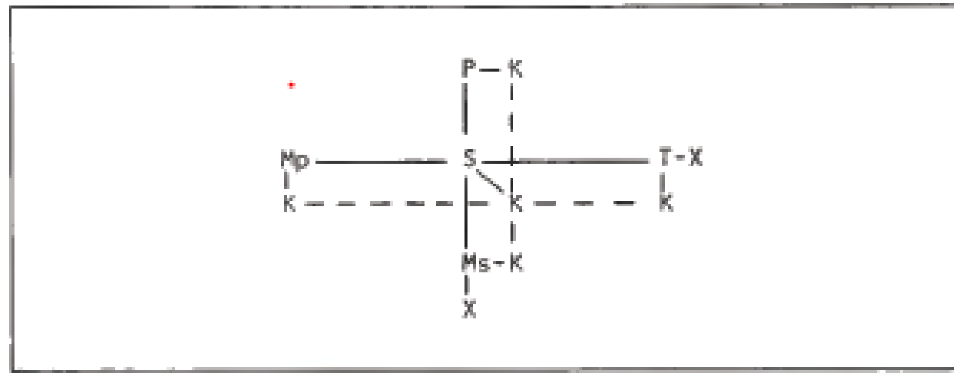


Fig. 7. General computer model (with distributed control) PMS diagram.

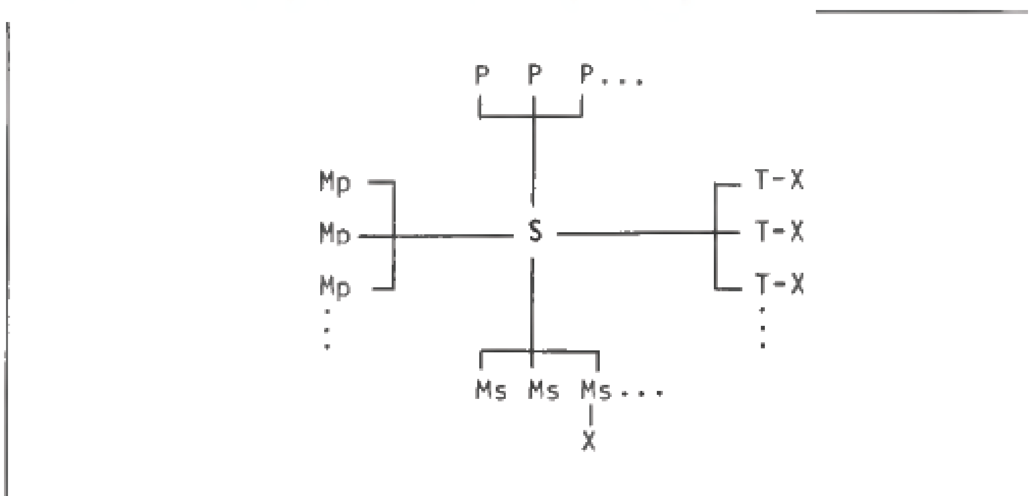


Fig. 9. General computer model (with multiple components)

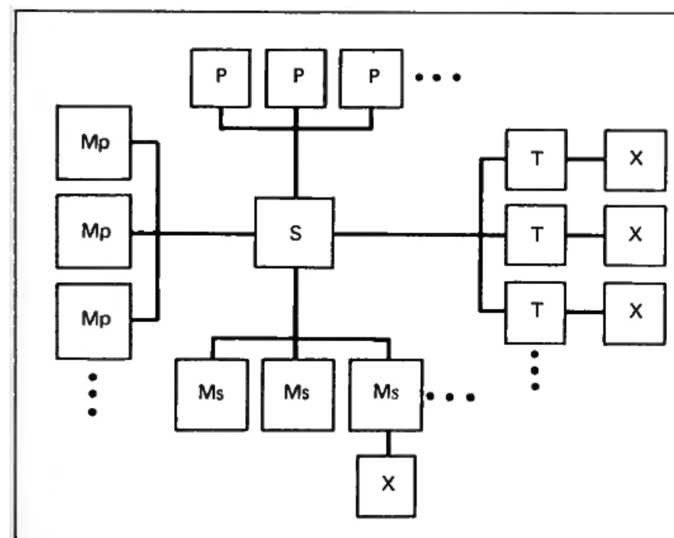
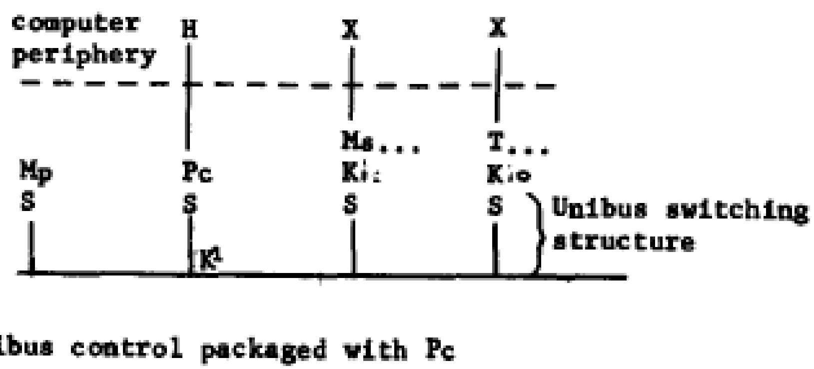


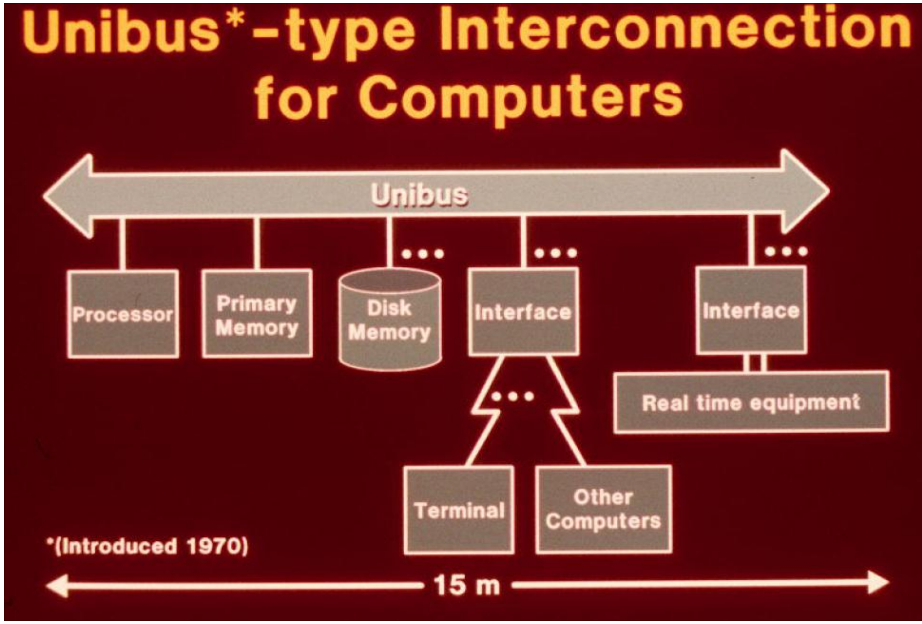
Fig. 11. General computer model (with multiple components) PMS diagram.

General model applied to PDP-11 c1970



1 Unibus control packaged with Pc

Figure 2—PDP-11 physical structure PMS diagram



```
MARK1 :=
    begin

! The Manchester Mark-I architecture is described.

! The Mark-I was an early (circa 1948) computer.

**MP.State**

    M[0:8191]<0:31>,

**PC.State**

    PI\Present.Instruction<0:15>,
        f\function<0:2> := PI<0:2>,
        s<0:12> := PI<3:15>,
    CR\Control.Register<0:12>,
    ACC\Accumulator<0:31>,

**Instruction.Execution**{tc}

    icycle\instruction.cycle{main} :=
        begin
        REPEAT
            begin
            PI ← M[CR]<0:15> next
            DECODE f =>
                begin
                #0 := CR ← M[s],
                #1 := CR ← CR + M[s],
                #2 := ACC ← - M[s],
                #3 := M[s] ← ACC,
              #4:#5 := ACC ← ACC - M[s],
                #6 := IF ACC lss 0 => CR ← CR + 1,
                #7 := STOP()
                end next
            CR ← CR + 1
            end
        end
    end
```

Instruction-set Architecture ISP Definition

Manchester Mark I c1948

C.Mmp CMU first mP project c1972

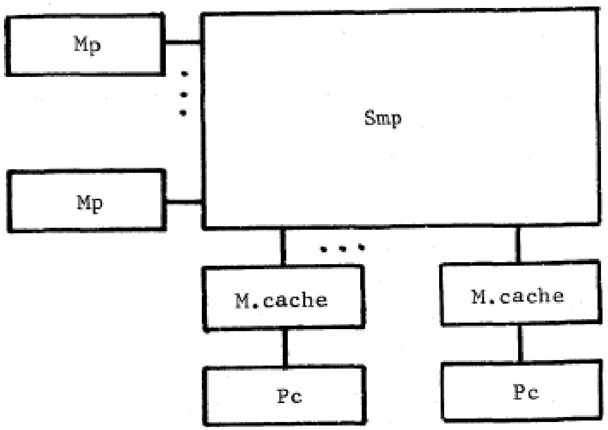


Figure 3—Multiprocessor computer with cache associated with each Pc.

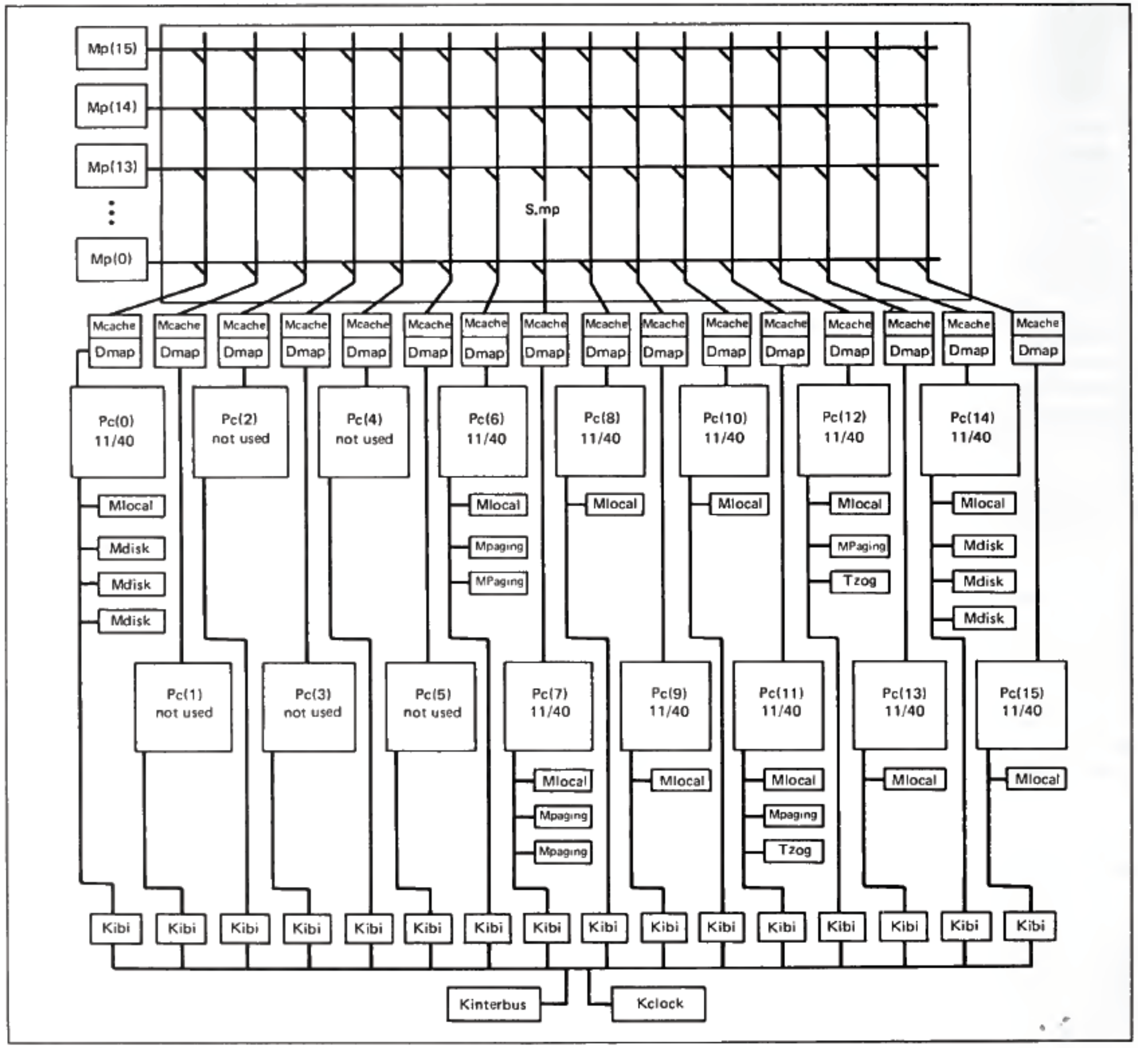


Fig. 2. The PMS structure of C.mmp.

Cm* … where a computer is the building blocks for bigger computers

Idea was generally outlined: 1973, LSI-11 available:1975

Architecture: March 1975, Design: fall1975

One cluster operating: July 1976

10 processor, 3 cluster system and OS :June 1978.

50 processor, 5 cluster: 9/1979

Decommissioned: January 1986

27 papers, 24 PhD, 14 MS

8 faculty, 10 staff,

Many alumni …

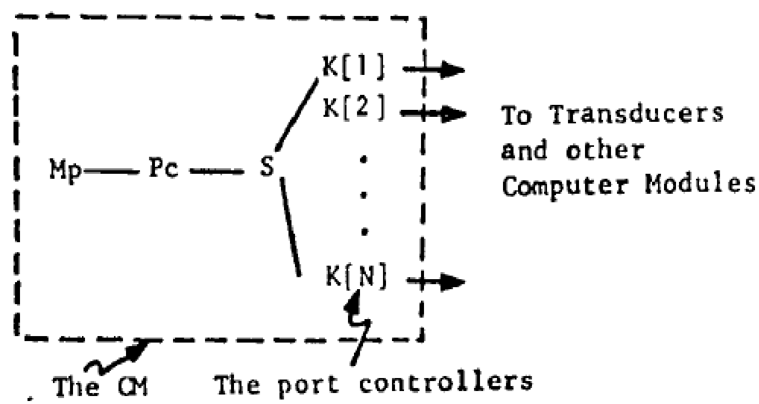


Figure 1. PMS Diagram of a CM

Cost 5 million over 10 year. Gov't was spending 100M/yr.

Therefore 20 books a year…

Computer types taxonomy

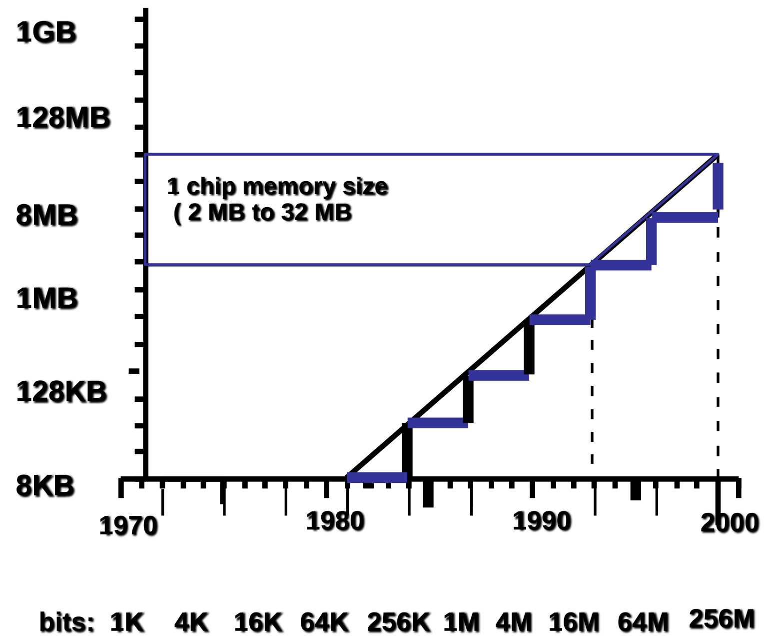
		Record, TP	Mainframes & Departmental Minis > Web serving clusters	
		Calculate	Supercomputers, minisupercomputers > Clusters	
		Control (embeded)	Microcomputers, Minicomputers, superminicomputers > Clusters	
		Cloud (Store, Proc., I	Web Servers	
	Shared*	Internet & WWW		
		Comm. & Network Processors (Routers, Gteways, etc.)		
		Wireless Sensor Nets (WSN)		
Computer apps & functions				
	Personal	*Calculate*	Calcutators, Spreadsheets	
	& Client	Records--	PC, PDA	
			Camera*	SmartPhone (converged)
			Phone, GPS > Smart Phone	
			PC (email, web)	
*Unseen infrastr.				
**incl. SenseCam			Personal Audio/Video Devices (e.g. iPOD)	
		Entertain/	PC	
		Retain	TV, Media Centers, Home Servers	
			Handheld & Game computers	
		Home Netrork for Entertainment, Automation & Control		
		Body Area Nets (Health,fitness,recording)		
	Embeded	Appliances		
		Automobiles	Engine	
			Guidance	
			Enterainment	
			Communicaton	
		-		
		Robots		
	--			

The two great inventions of 20th Century

- The computer (1946).
  Computers supplement and substitute for all other info processors, including humans
  - Computers are built from other computers in a recursive fashion
  - Processors, memories, switching, and transduction are the primitives
- The Transistor (1946) and subsequent Integrated Circuit (1957).
  - Computers are composed of a set of well-defined hardware-software levels

Moore's First Law

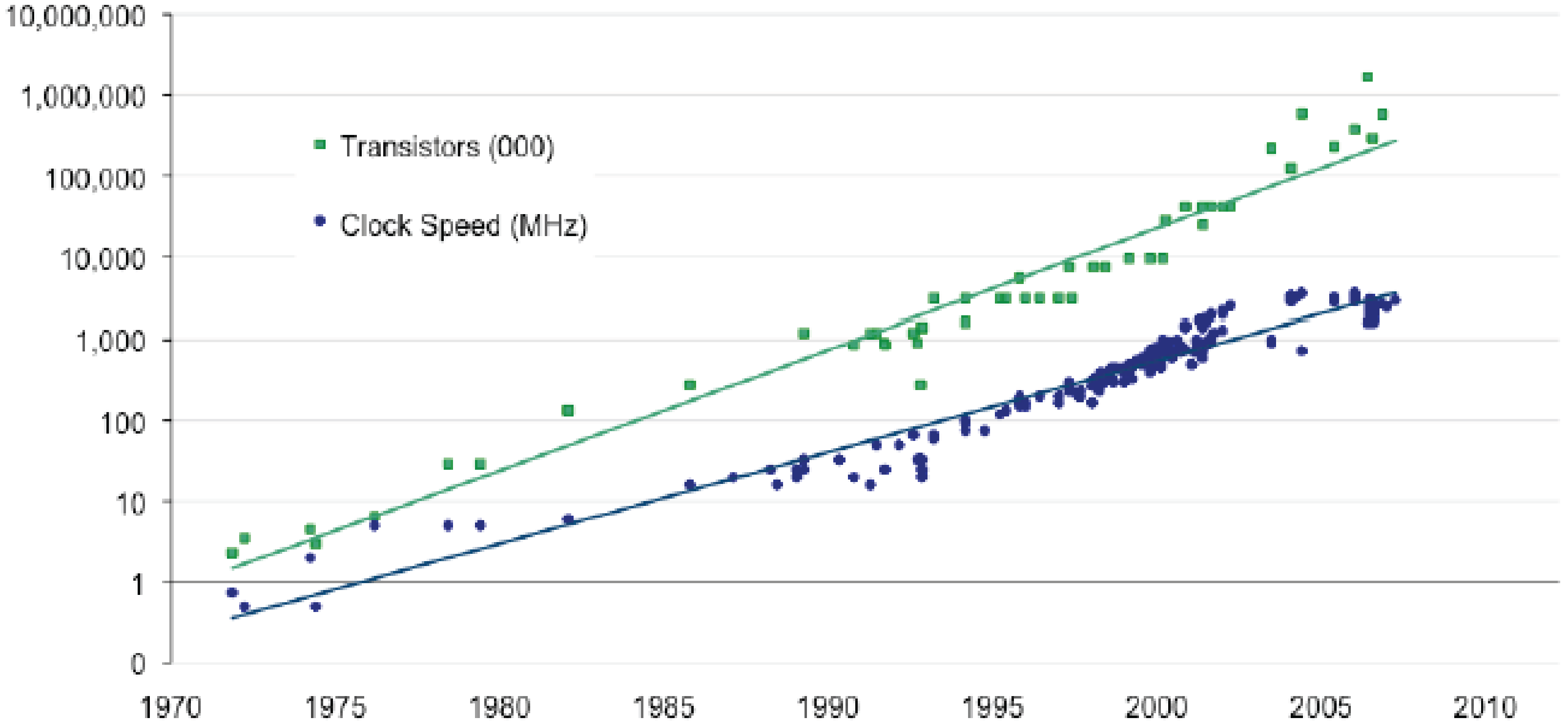
- Transistor density doubles every 18 months
  60% increase per year
  - Chip density transistors/die
  - Micro processor speeds



- Exponential growth:
  - The past does not matter
  - 10x here, 10x there … means REAL change
- PC costs have declined faster than any other platform EXCEPT smart phones
  - Volume and learning curves
  - PCs are the building bricks of all future systems

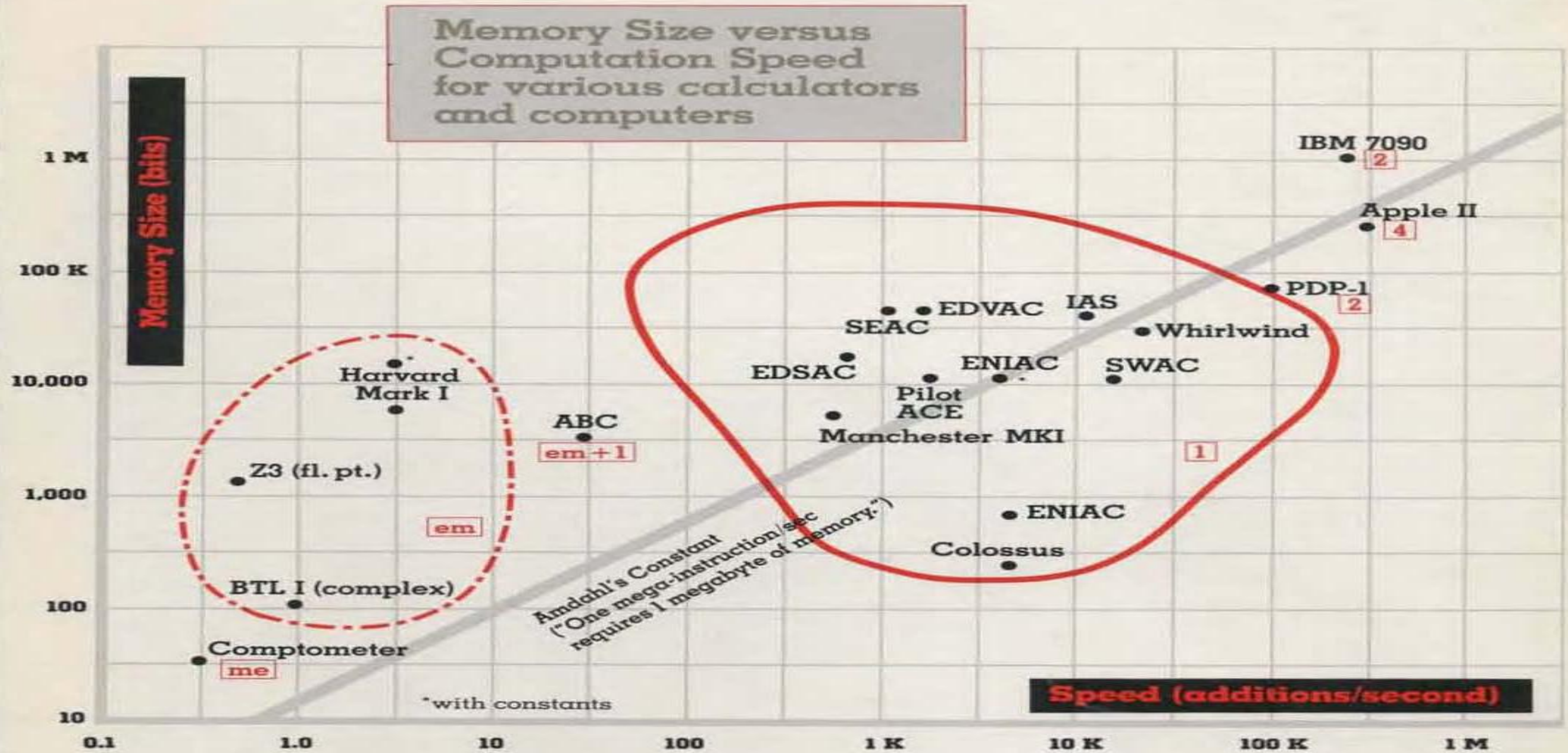
Moore's Law

Clock speed and Moore's law



Efficiency

Copyright Jonathan Koomey 2011



GENERATIONS:

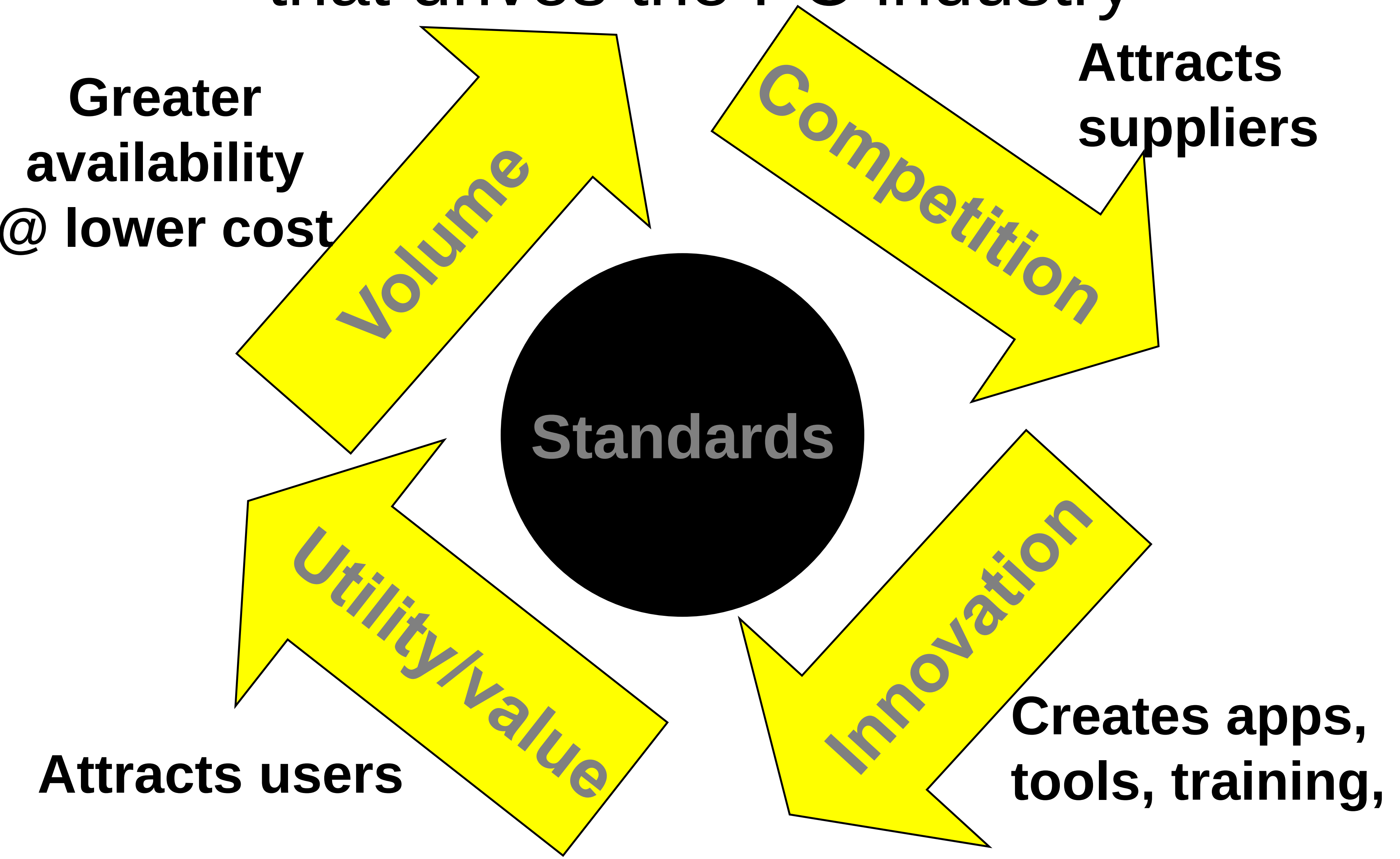
m = manual
me = mechanical
em = electromechanical

1 = electronic—vacuum tube
2 = transistor
3 = integrated circuit
4 = large scale integrated circuit

Economics-based laws determine the market

- **Demand: doubles as price declines by 20%**
- **Learning curves: 10-15% cost decline with 2X units that enable Moore's Law and other hardware technology evolution**
- **Bill's Law for the economics of PC *software***
- **Nathan's Laws of Software -- the virtuous circle**
- **Metcalfe's Law of the "value of a network"**
- **Computer classes form and evolve just like modes of transportation, restaurants, etc.**

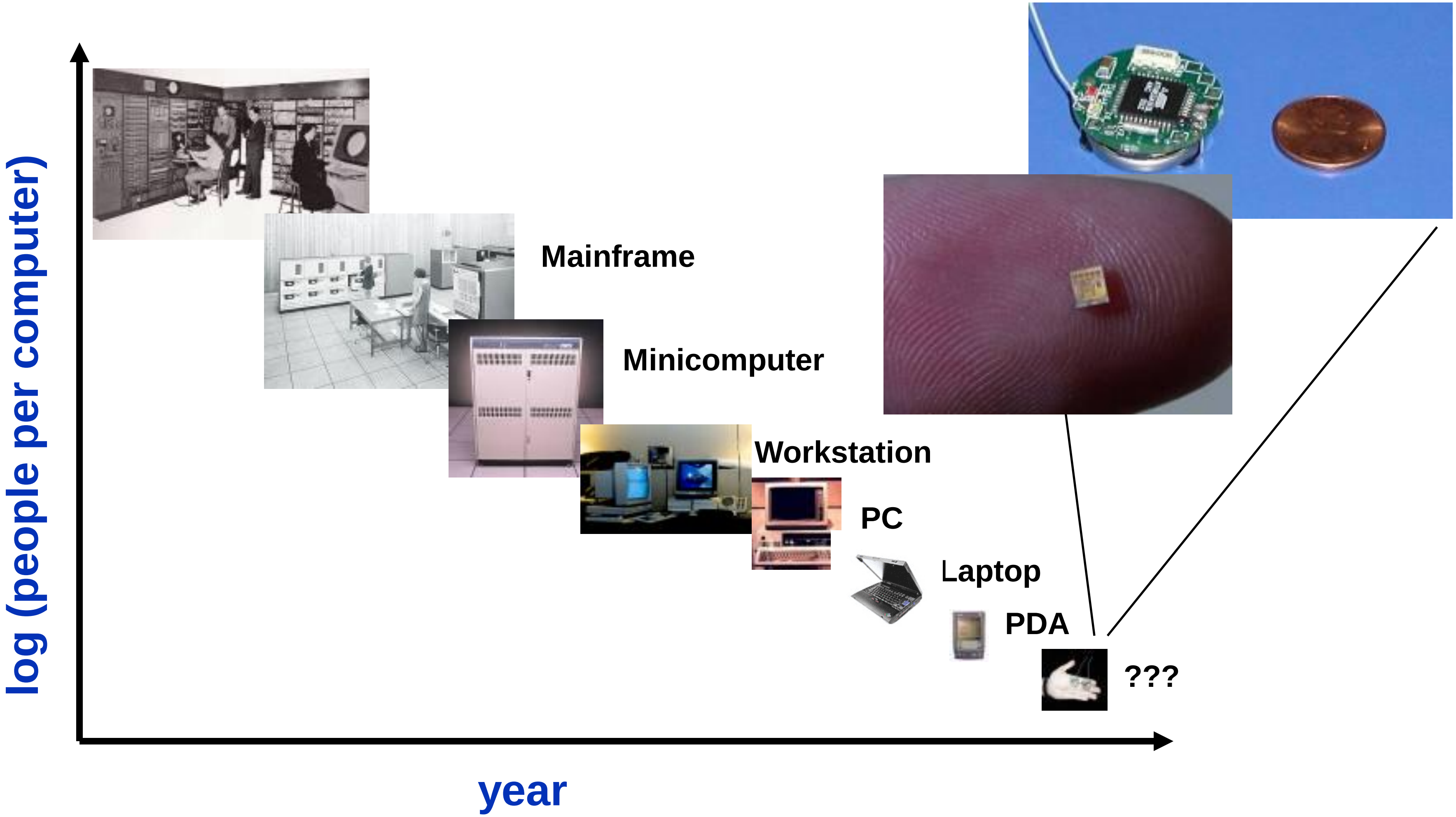
The Virtuous Economic Cycle that drives the PC industry



Computer components must all evolve at the same rate

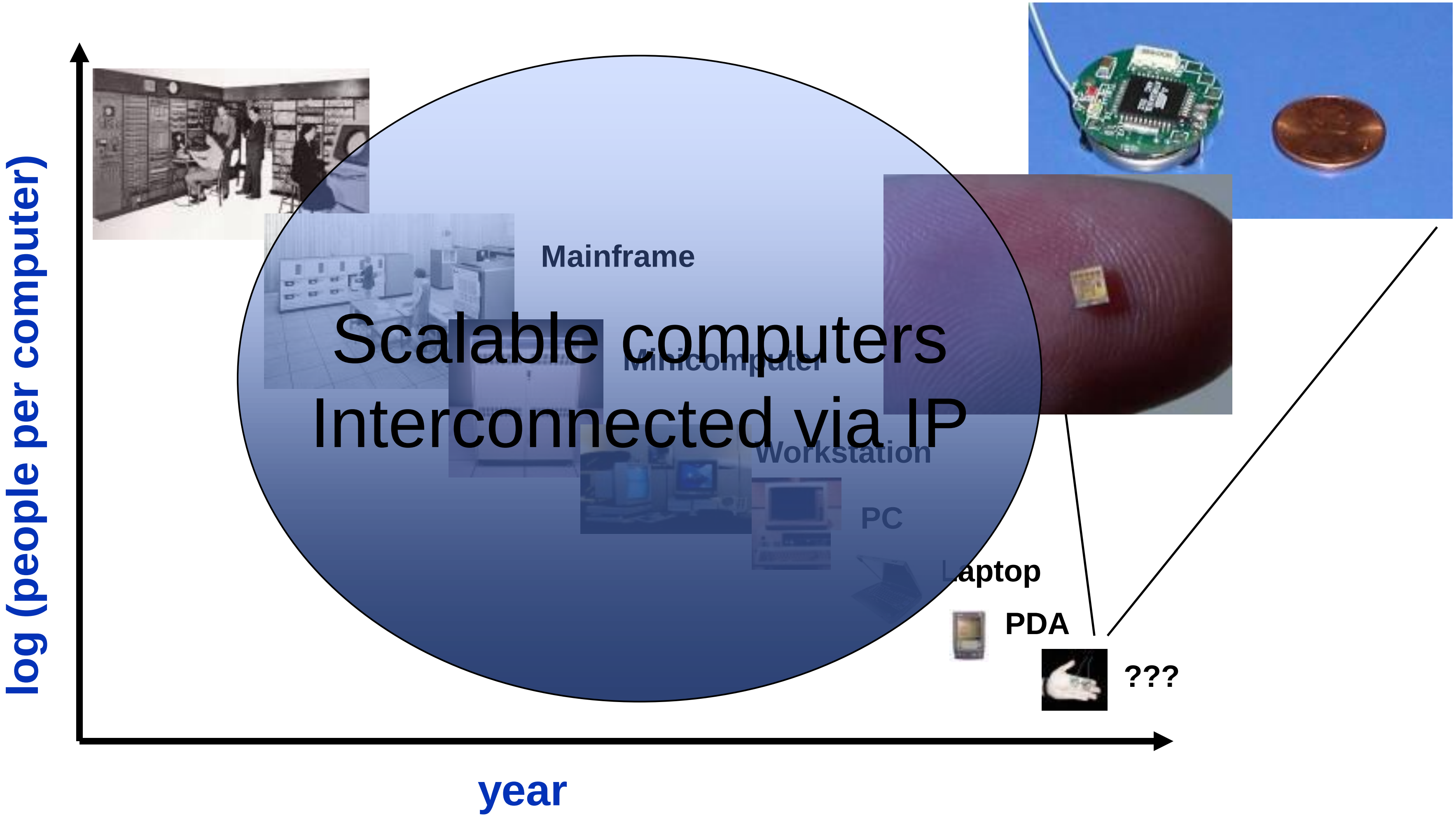
- Amdahl's law: one instruction per second requires one byte of memory and one bit per second of I/O
- Storage evolved at 60%; after 1995: 100
- Processor performance evolved at 60%.
  - Clock Performance flat >1995 until multi-cores
  - Multi processors.
  - Graphics Processing Unit to exploit parallelism
- Wide Area Network speed evolved at >60%
- Local Area Network speed evolved 26-60%
- Grove's Law: Plain Old Telephone Service (POTS) thwarts speed

The classes, sans phones, 2006



David Culler UC/Berkeley

The classes, sans phones, 2006

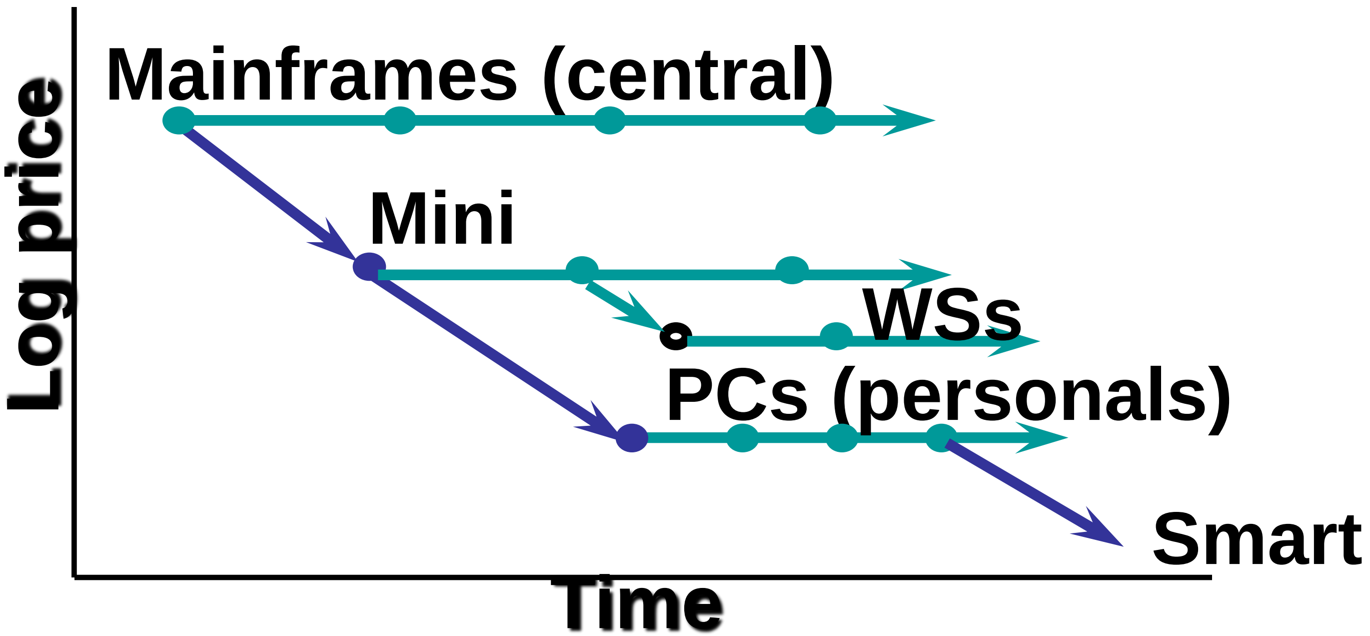


David Culler UC/Berkeley

Bell's Law of Computer Classes

Technology enables two evolutionary paths:

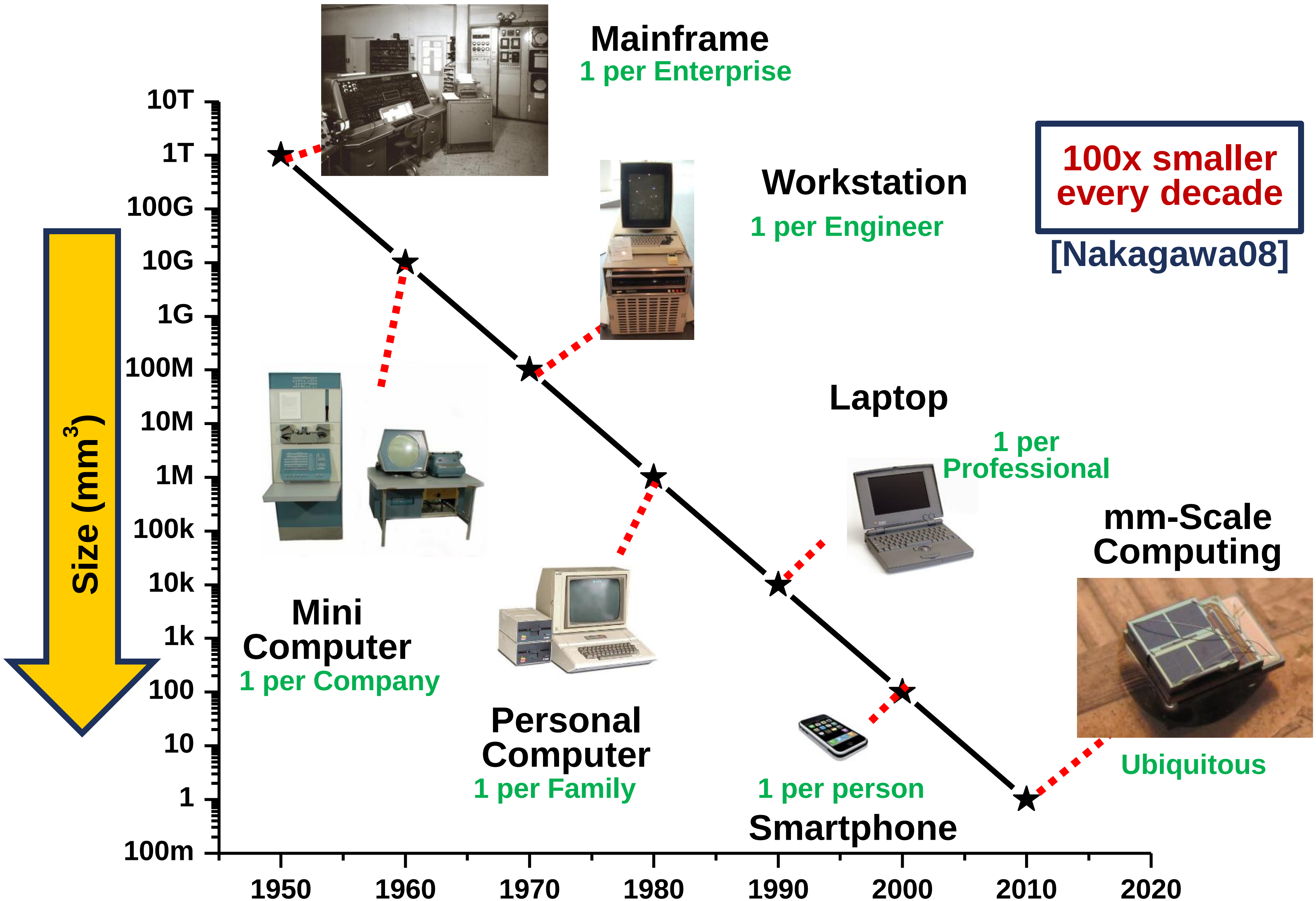
1. constant price, increasing performance
2. constant performance, decreasing price



1.26 = 2x/3 yrs -- 10x/decade; 1/1.26 = .8

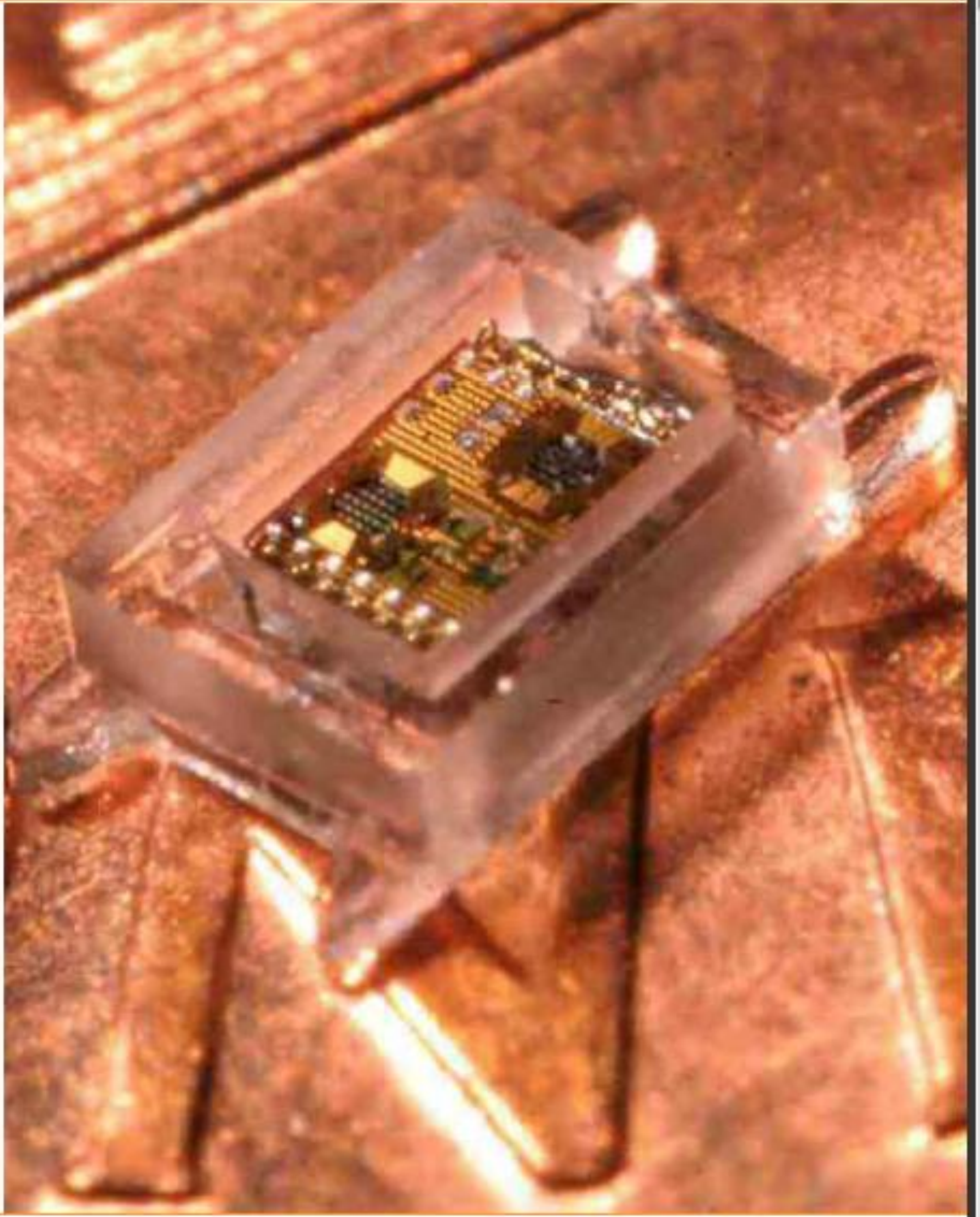
1.6 = 4x/3 yrs --100x/decade; 1/1.6 = .62

Bell’s Law – Production Volume



1.5 mm^3 Intraocular Pressure Monitor

- Continuous IOP monitoring
- Wireless communication
- Energy-autonomy
- Device components
  - Solar cell
  - Wireless transceiver
  - Cap to digital converter
  - Processor and memory
  - Power delivery
  - Thin-film Li battery
  - MEMS capacitive sensor
  - Biocompatible housing



Q: What do these have in common?

Tianhe 1A

~4PFLOPS peak

2.5PFLOPS sustained

~7,000 NVIDIA GPUs

About 5MW

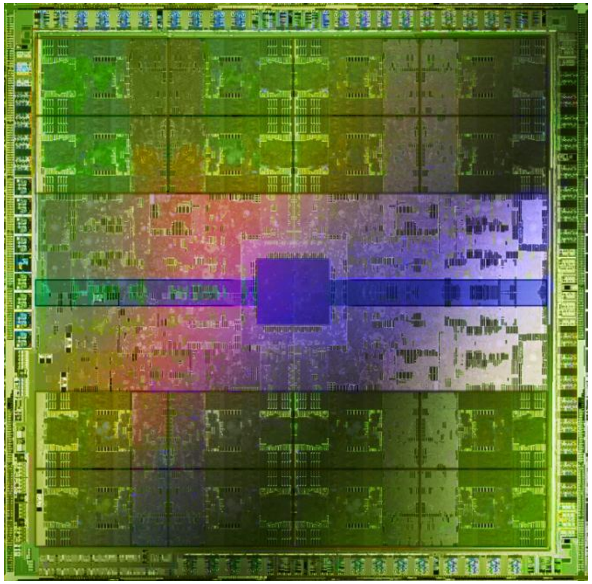
3G smart phone

Baseband processing 10GOPS

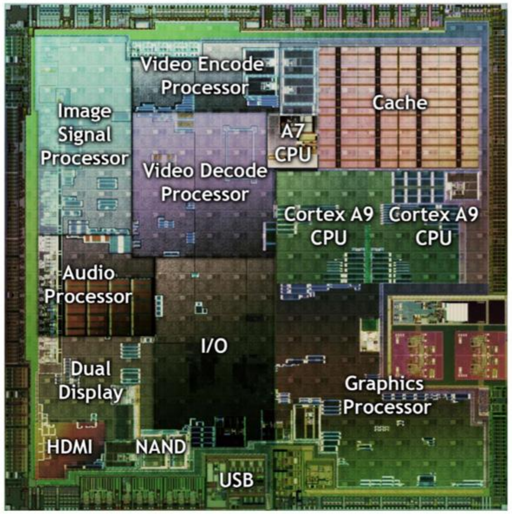
Applications processing 1GOPS and increasing

Power limit of 300mW

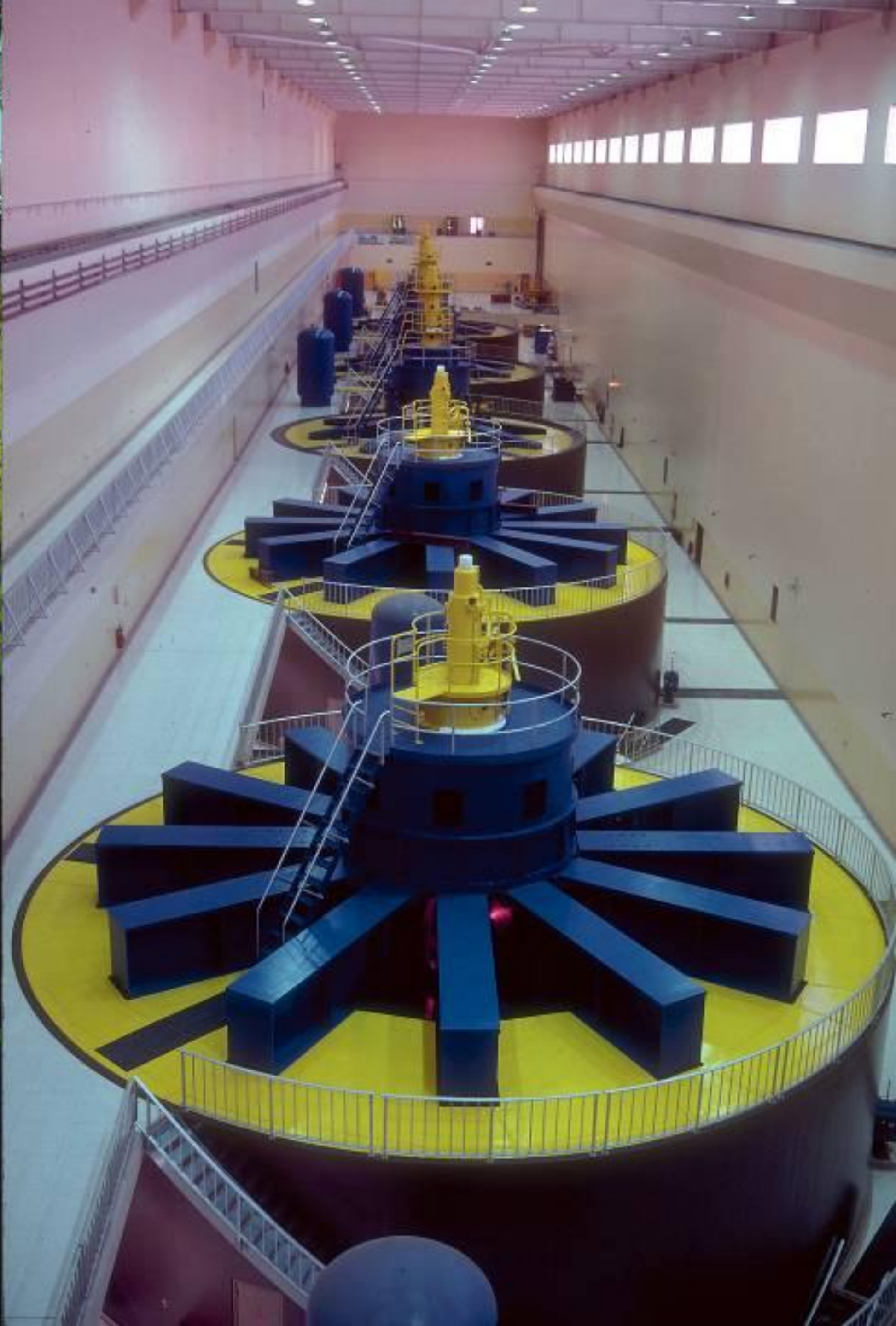
Both are Based on NVIDIA Chips



Fermi
3 x 10^9 Transistors
512 Cores

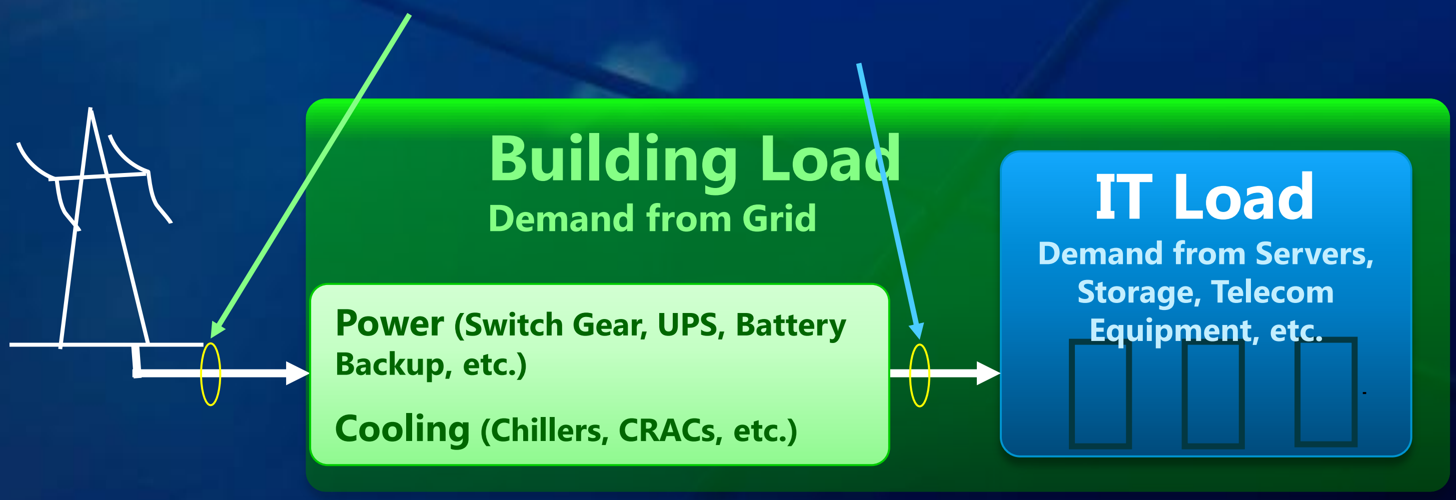


Tegra-2 (T20)
3 ARM Cores
GPU
Audio, Video, etc…

Why Power is Important?

- **Energy Consumption: US power rate 10.27 cents per Kilowatt hour) in 2008 according to DOE/eia** (http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html)
- **In a typical data center: for every watt in server power there can be another 0.5 to 1 watt consumed for power distribution losses and cooling**



PUE = Total Facility Power / IT Equipment Power


Generators
Substation
Evaporators
Pumps/Pipes
Electrical Distribution
Chiller Tower
Battery Room
Operations

Traditional Datacenter Builds

Monolithic design & construction	Typical large datacenter = 11 football fields 20 to 50 Megawatts
Huge $$$	Typical construction costs = $10M to $20M per Megawatt
Long lead time	18 to 24 months from design to online

Microsoft Data Center Scale

Microsoft has more than 10 and less than 100 DCs worldwide housing 100s of thousands of servers

Multiple global CDN locations

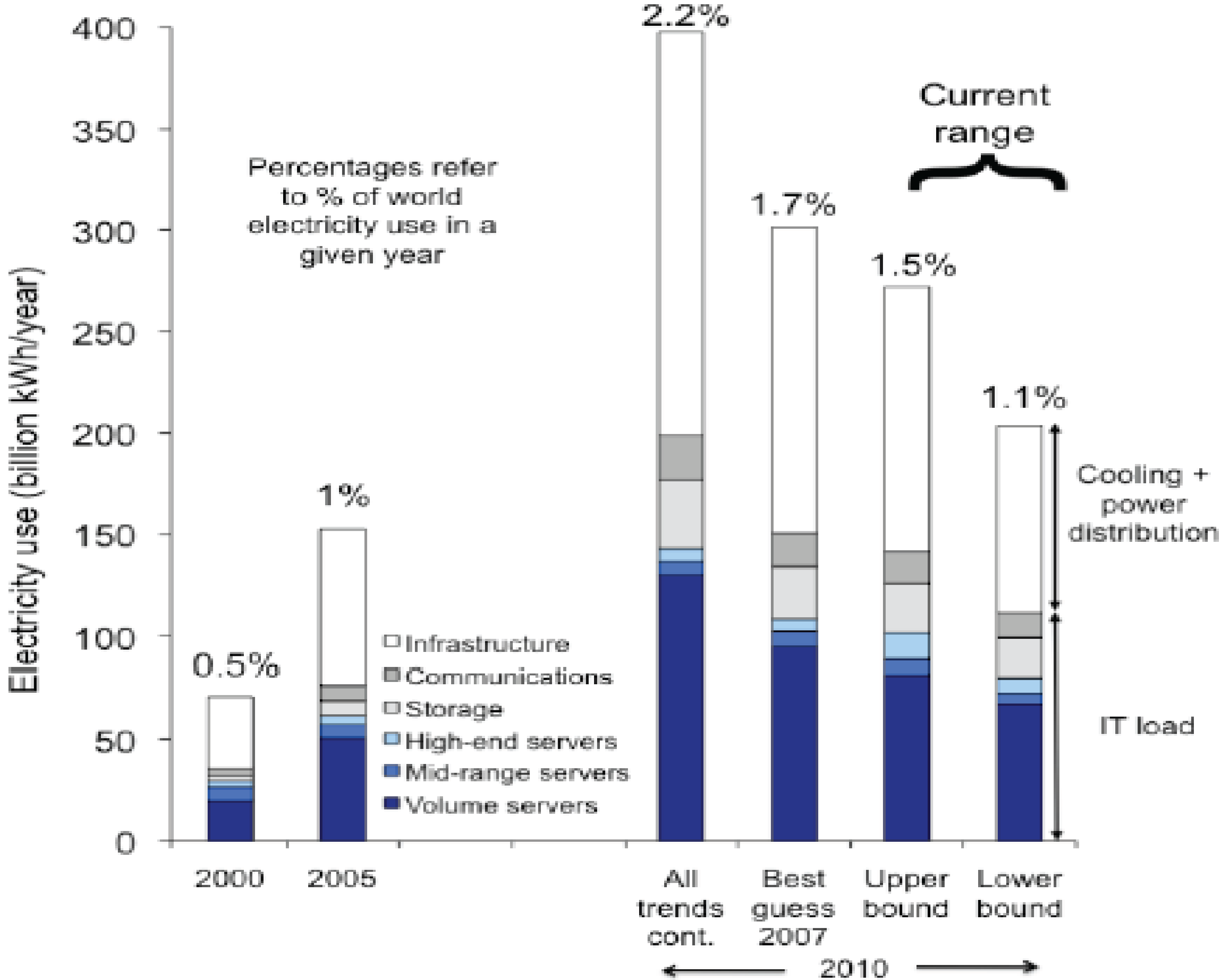
Quincy, Washington	27 MW + ITPACs	100% Hydro power, free air cooled ITPACs
San Antonio, Texas	27 MW	Recycled water for cooling
Chicago, Illinois	30 MW	Water side economization, Containers
Dublin, Ireland	29 MW	Outside air cooling, PODs

"Data Centers have become as vital to the functioning of society as power stations."

The Economist

Dublin Data Center in 2012

- Single story construction expansion
  - Concrete slab and roof
  - Steel frame and cladding
- Hot aisle isolated PODs
- Free air cooling with outside air
- No raised floor
- No chillers
- No adiabatic assist
- 13.2 MW in 4.4 MW modules


Electricity use (billion kWh/year)
400
350
300
250
200
150
100
50
0
Percentages refer to % of world electricity use in a given year
0.5%
1%
2.2%
1.7%
1.5%
1.1%
Current range
Infrastructure
Communications
Storage
High-end servers
Mid-range servers
Volume servers
Cooling + power distribution
IT load
2000
2005
All trends cont.
Best guess 2007
Upper bound
Lower bound
2010

ORNL Titan Cray Supercomputer

- 18,688 AMD 16-core Opteron 6274 CPUs. 2.2 GHz
  - Pc: 18.7K proc x 16 core/proc. x 2.2 GHz. = 658 Tticks; ?? Flops per tick
  - Mp: 600 TB
  - 200 cabinets retrofitted with nearly ten thousand XK7 blades… 2 processors/blade?
- 18,688 Nvidia 2.5K-core K20 GPUs. 732 MHz 46.5 M cores
  - 1.3 TFlops per chip??
  - Mp: 112 Tbytes; 37 GB/proc? …1/40 of a byte per FLOP on GPU
- Ms: 13.6 PB driven by 140-Dell servers
- 9 MW; PUE=??
- <u>1-5 weather years per day of simulation</u>

Bell’s Law for the formation of The Birth & Death of Computer Classes

Hardware technology improvements i.e. Moore’s Law for semiconductors,… disks, enable two evolutionary paths(t) for computers:

1. **constant price, increasing performance**
   direct consequence of Moore’s Las

2. **Constant or decreasing performance,**
   decreasing cost by a factor O(10)X

.. Leads to new structures & new computer class!

Bell's Law of Computer Classes…
Every Decade a new class emerges

- **Every decade a new, lower (1/10) cost class of computers emerge to cover cyberspace with a**
  - **New computing platform (e.g. chip density evolution)**
  - **New Interface to humans or a part of physical world**
  - **New networking and/or interconnect structure**
  - **New class --> new function & apps --> new industry with potentially disintegrated structure**
- **The classes… a decade in price every decade**

60s	**$millions**	**mainframes**
70s	**$10K-100K**	**minis**
80s	**$10K**	**workstations & PCs; MICROs**
90s	**$1K**	**PCs >> NetBooks >> Tablets**
00s	**$100s**	**PDAs >> Smart phones**
10s	**$10**	**WSNs????**

Platform, Interface, Network Computer Class Enablers

What	"The Mainframe"	Minicomputer >> Timesharing	Super	WS & PC
When	1950-'64-…	1965-1985	1965, '75, '95	1982-…
How	tube, core, drum, tape, batch O/S	SSI-MSI, disk, timeshare O/S	Vector mP, Clusters/ GPU/… Proc-in-Mem.	"microproc'r" floppy, display, mouse, dist'd O/S
USE	direct > batch	terminals via commands	Batch	WIMP
FCN	M	K, T	P	T, P&M
Net.	--, POTS	POTS, WAN	WAN	LAN
Who	IBM & 7	Digital	Cray, IBM	IBM & SUN

Future Computer Classes

When, who	1997+ client-side platforms	2000 Wintels "upsizing"	2010 embedded apps	??
what	net computer telecomputer tv computer	SNAP scalable network & platforms	do what I say chips for 1000s of apps	helpful robots, ns in cyber & real space
platform	low cost term. Telephone, TV & computer	commodity platform & nets	common sense	mobility to for home & office
user inter'f	point to, speech, audio & video	browser access	Speak to it! Radar & vision	vision
netwk	Internet via phone & cable	System Area Net	IP dial-tone, home, body nets	no new tech.

Cell aka Mobile >> Smart Phone evolution

Smart phone functionality evolves to accomplish every available task, thereby potentially replacing more complex computers e.g tablets, PCs

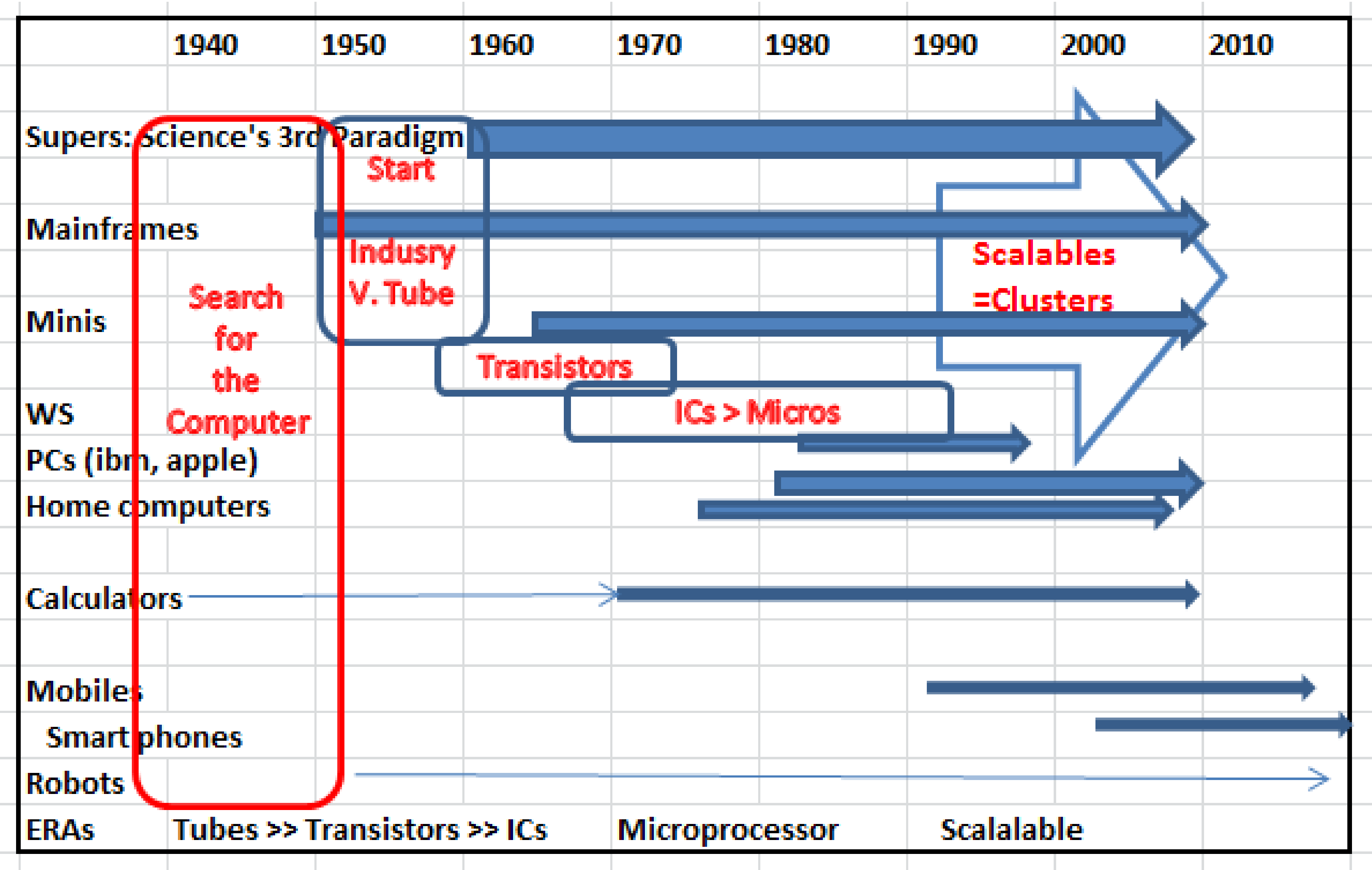
Product	Functionality	Year
Gameboy	handheld games	1979
Cellular net	US mobile phones licensed (AMPS)	1983
SMS	SMS Service	1992
Palm	PDA Functionality	1995
GPS service	GPS service Availability	1995
Imaging	Camera addition	1997
Rio & Music svc	Digital Audio Player	1998
PocketPC	Programmable platform -PC with apps	1999
BlackBerry	Email	2000
Web Browsing	WWW.	2002
Windows Mobile	Smartphone & PC with apps	2002
iPod	Multimedia player	2002
BodyMedia	Health monitor	2003
GeoVector	Pointing anywhere*	2007
eBook	eBook, TV	2010
TV	location svcs	

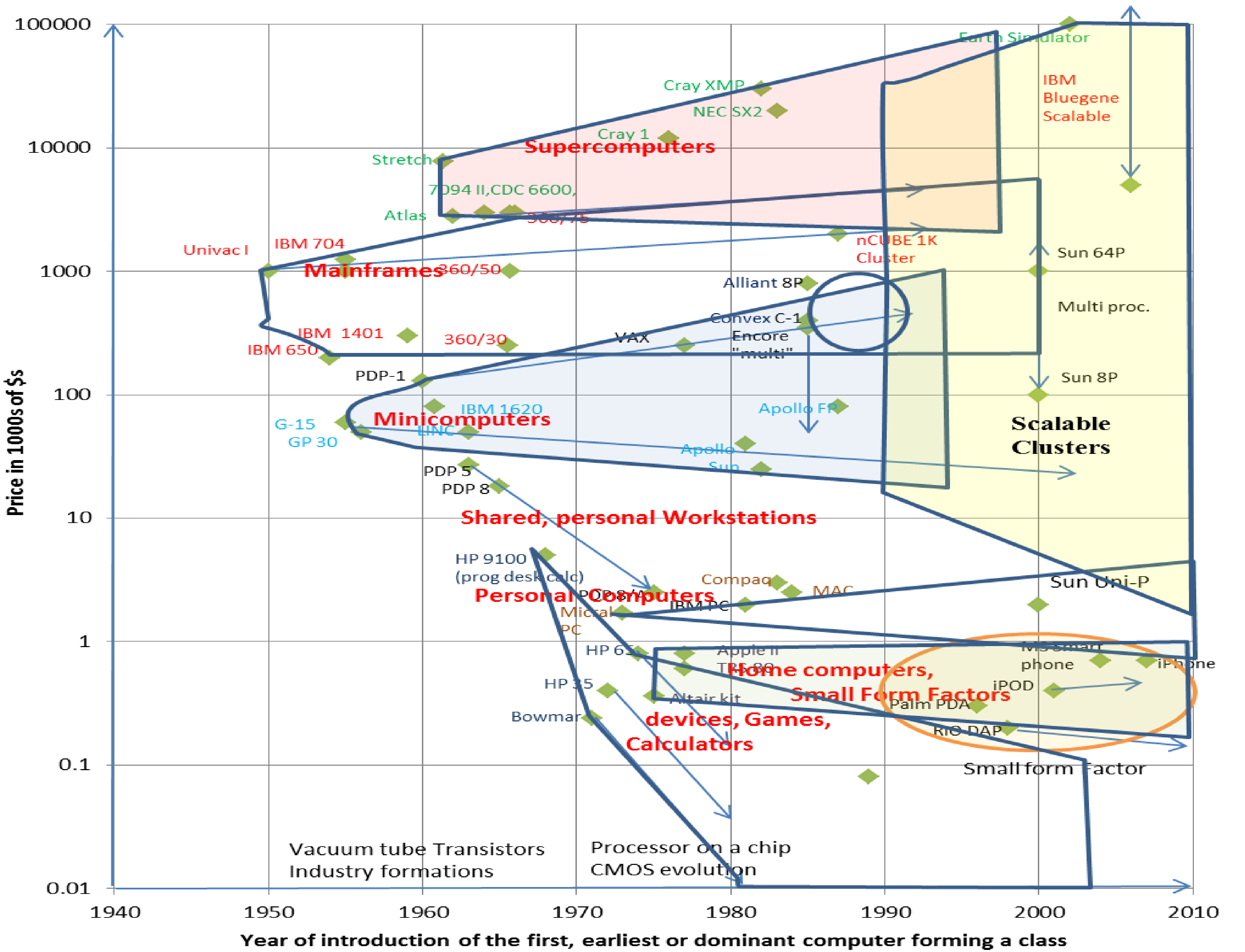
Notes: Increasing bandwidth protocols e.g. GSM, service generations enabler not shown

Audio recording, video capture, videophone, and mobile TV not shown

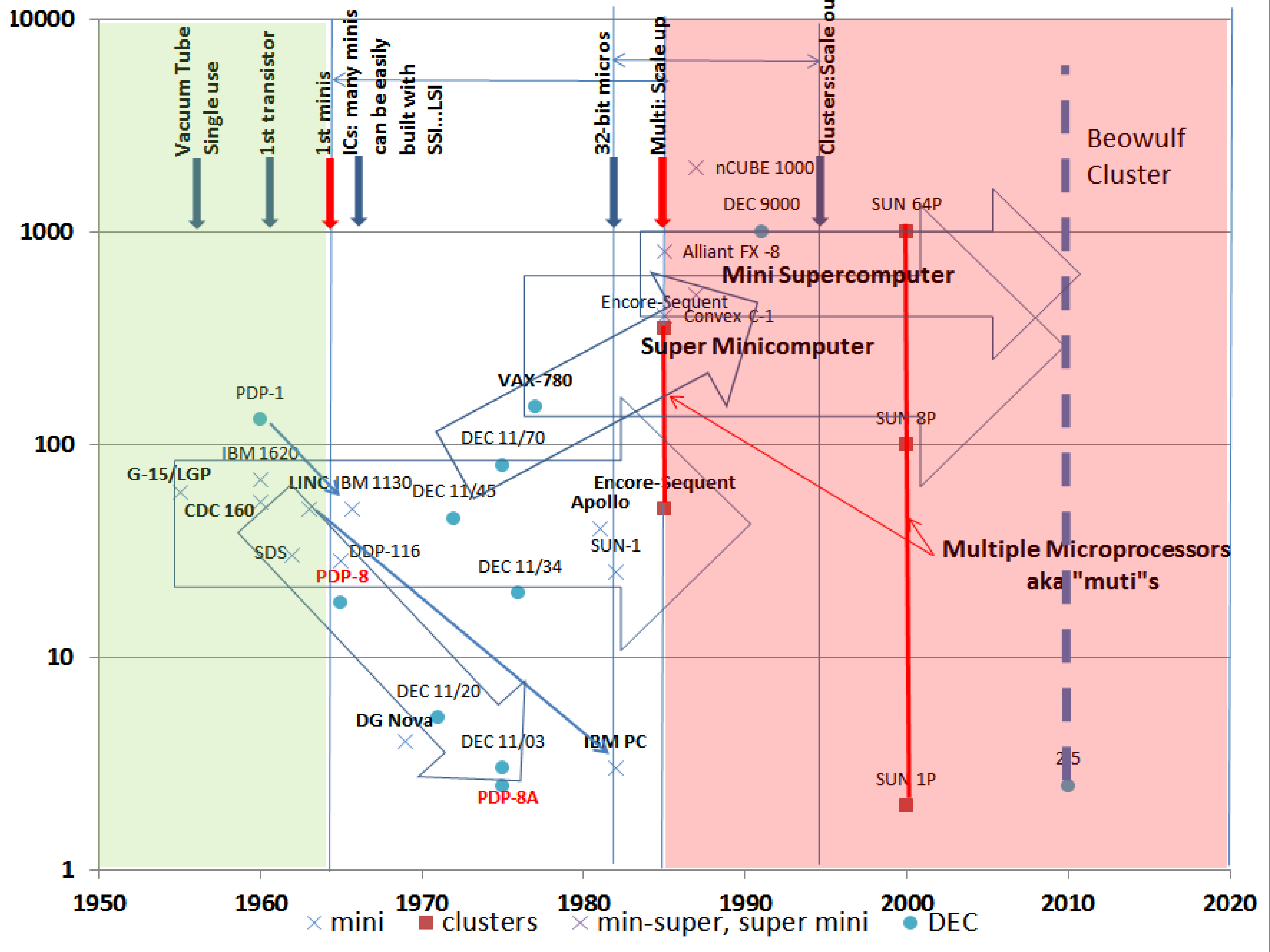
*GPS: location lat, long, alt. 3 axis compass; 6 axis accel.

Timeline of Computer Classes





Price in 1000s of $s
100000
10000
1000
100
10
1
0.1
0.01
1940
1950
1960
1970
1980
1990
2000
2010
Year of introduction of the first, earliest or dominant computer forming a class
Supercomputers
Mainframes
Minicomputers
Shared, personal Workstations
Personal Computers
Home computers,
Small Form Factors
devices, Games,
Calculators
Scalable
Clusters
Earth Simulator
IBM
Bluegene
Scalable
Cray XMP
NEC SX2
Cray 1
Stretch
7094 II,CDC 6600,
Atlas
nCUBE 1K
Cluster
Sun 64P
Univac I
IBM 704
360/50
Alliant 8P
Multi proc.
Convex C-1
Encore
"multi"
VAX
IBM 1401
IBM 650
360/30
PDP-1
Sun 8P
IBM 1620
G-15
GP 30
LINC
Apollo FP
Apollo
Sun
PDP 5
PDP 8
HP 9100
(prog desk calc)
Compaq
MAC
Sun Uni-P
Micral
PC
IBM PC
MS Smart
phone
iPhone
Apple II
TRS 80
iPOD
HP 35
Altair kit
Palm PDA
Bowmar
RIO DAP
Small form Factor
Vacuum tube Transistors
Industry formations
Processor on a chip
CMOS evolution



10000
1000
100
10
1
Vacuum Tube
Single use
1st transistor
1st minis
ICs: many minis
can be easily
built with
SSI...LSI
32-bit micros
Multi: Scale up
Clusters:Scale ou
Beowulf
Cluster
nCUBE 1000
DEC 9000
SUN 64P
Alliant FX -8
Mini Supercomputer
Encore-Sequent
Convex C-1
Super Minicomputer
VAX-780
PDP-1
SUN 8P
DEC 11/70
IBM 1620
G-15/LGP
LINC
IBM 1130
DEC 11/45
Encore-Sequent
Apollo
CDC 160
SUN-1
SDS
DDP-116
Multiple Microprocessors
aka "muti"s
PDP-8
DEC 11/34
DEC 11/20
DG Nova
DEC 11/03
IBM PC
2.5
SUN 1P
PDP-8A
1950
1960
1970
1980
1990
2000
2010
2020
mini
clusters
min-super, super mini
DEC

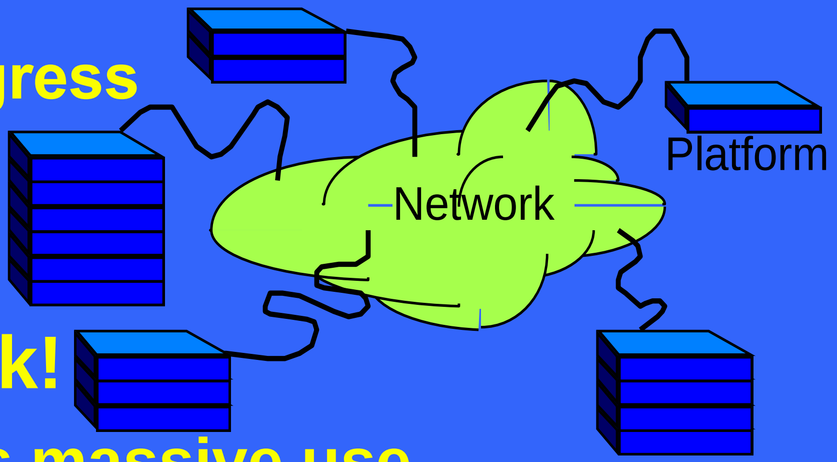
1994: Computers will All be Scalables

Thesis: SNAP: Scalable Networks as Platforms

- upsize from desktop to world-scale computer
- based on a few standard components

Because:

- Moore's law: exponential progress
- standards & commodities
- stratification and competition



When: Sooner than you think!

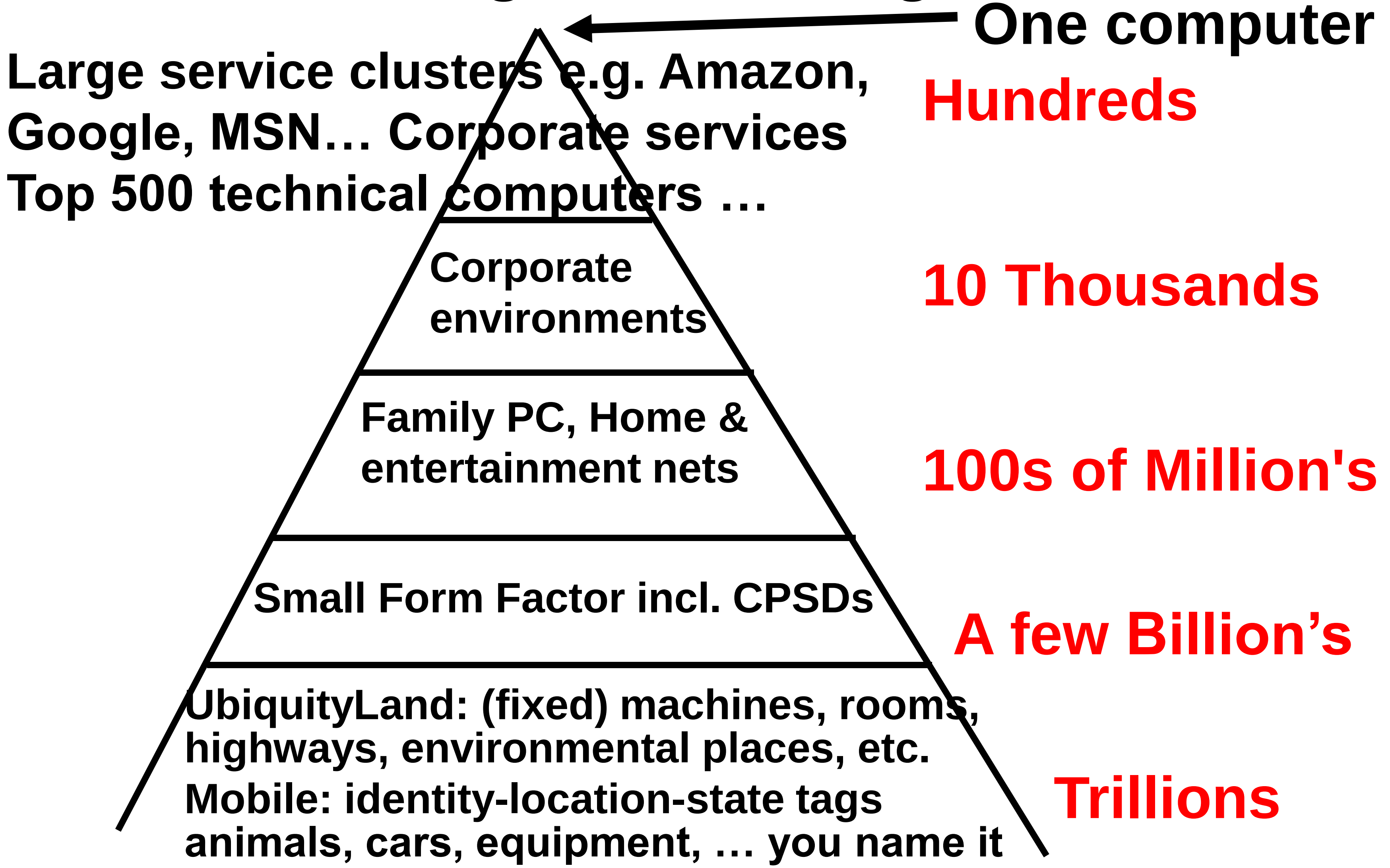
- massive standardization gives massive use
- economic forces are enormous

Bell's Nine Computer Price Tiers

1$:	embeddables e.g. greeting card
10$:	wrist watch & wallet computers
100$:	pocket/ palm computers
1,000$:	portable computers
10,000$:	personal computers (desktop)
100,000$:	departmental computers (closet)
1,000,000$:	site computers (glass house)
10,000,000$:	regional computers (glass castle)
100,000,000$:	national centers

Super server: costs more than $100,000
"Mainframe": costs more than $1 million
an array of processors, disks, tapes, comm ports

Pyramid of networked - computing, communicating, and storage devices



Bell’s Law of Computer Classes: Their Formation and Death

End

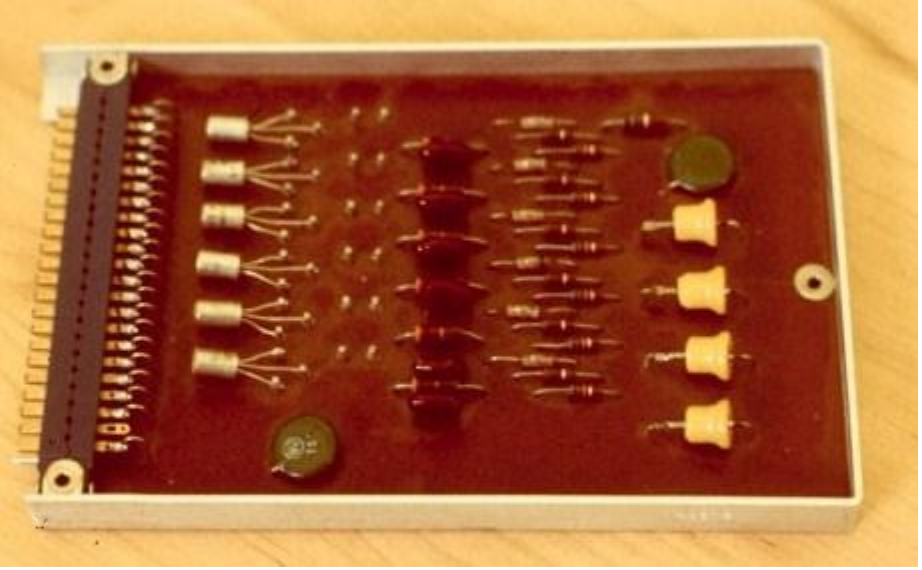
How did minicomputers form and die

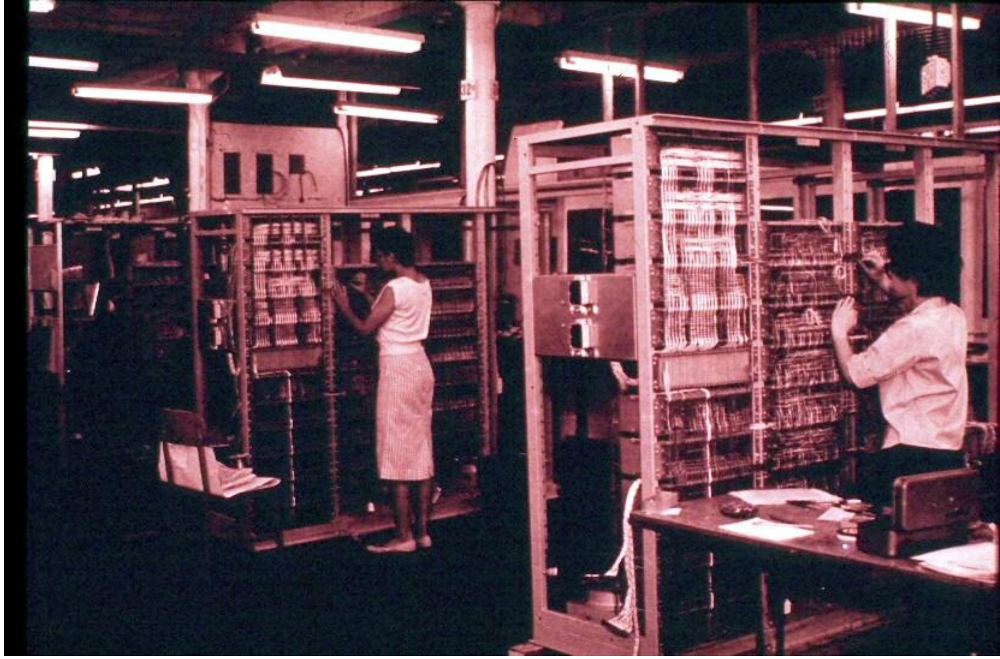
Enable by small scale integrated circuits whereby 100 companies designed and built their own, proprietary architecture computers successfully for:

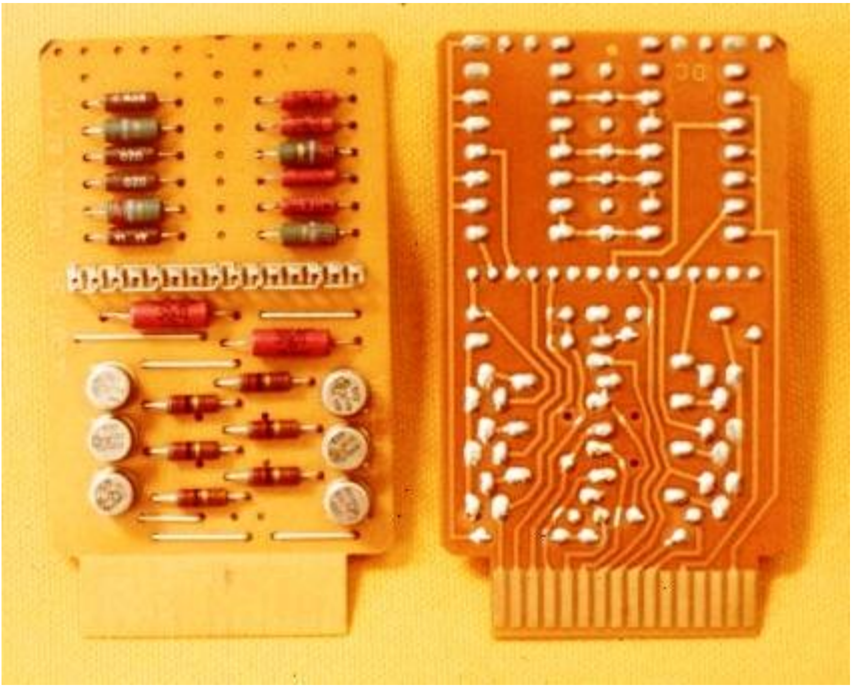
1. Control, switching, and interfacing (thereby avoiding mainstream computing and business)
2. Sold through Original Equipment Manufacturer market channel
3. Significantly smaller or minimal.
   Named for "mini" auto and mini-skirt c.1967

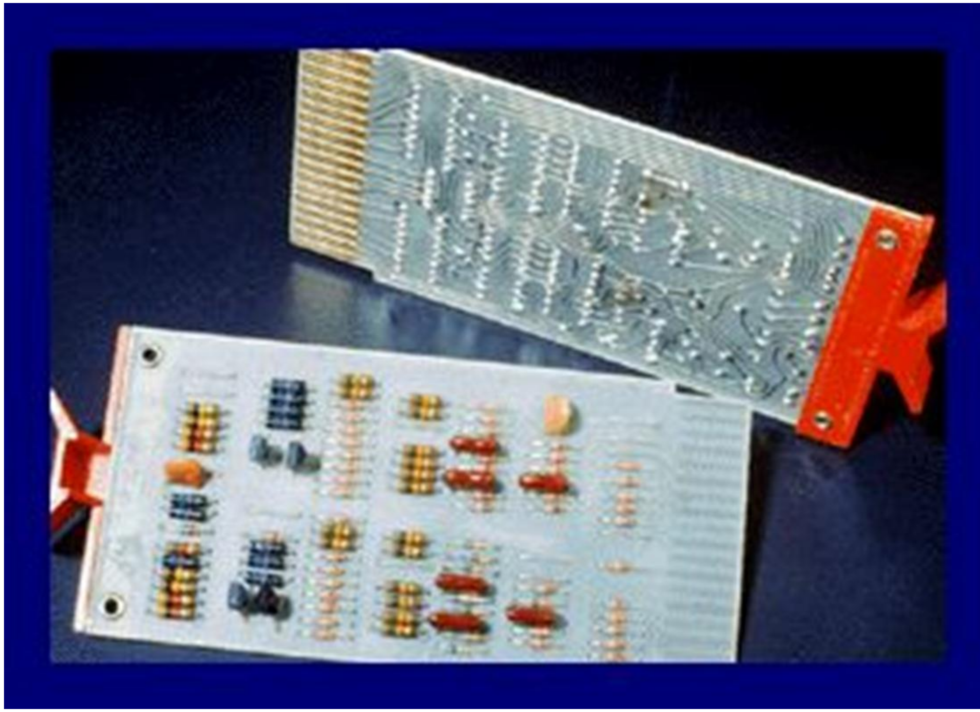
Digital Equipment Corporation PDP-8

1965 introduction
12 bit word (1.5 bytes)
4,096 word memory
1.5 usec memory cycle time, or
300,000 ops per sec.
$18,000 including Teletype ASR printer, paper tape reader and punch

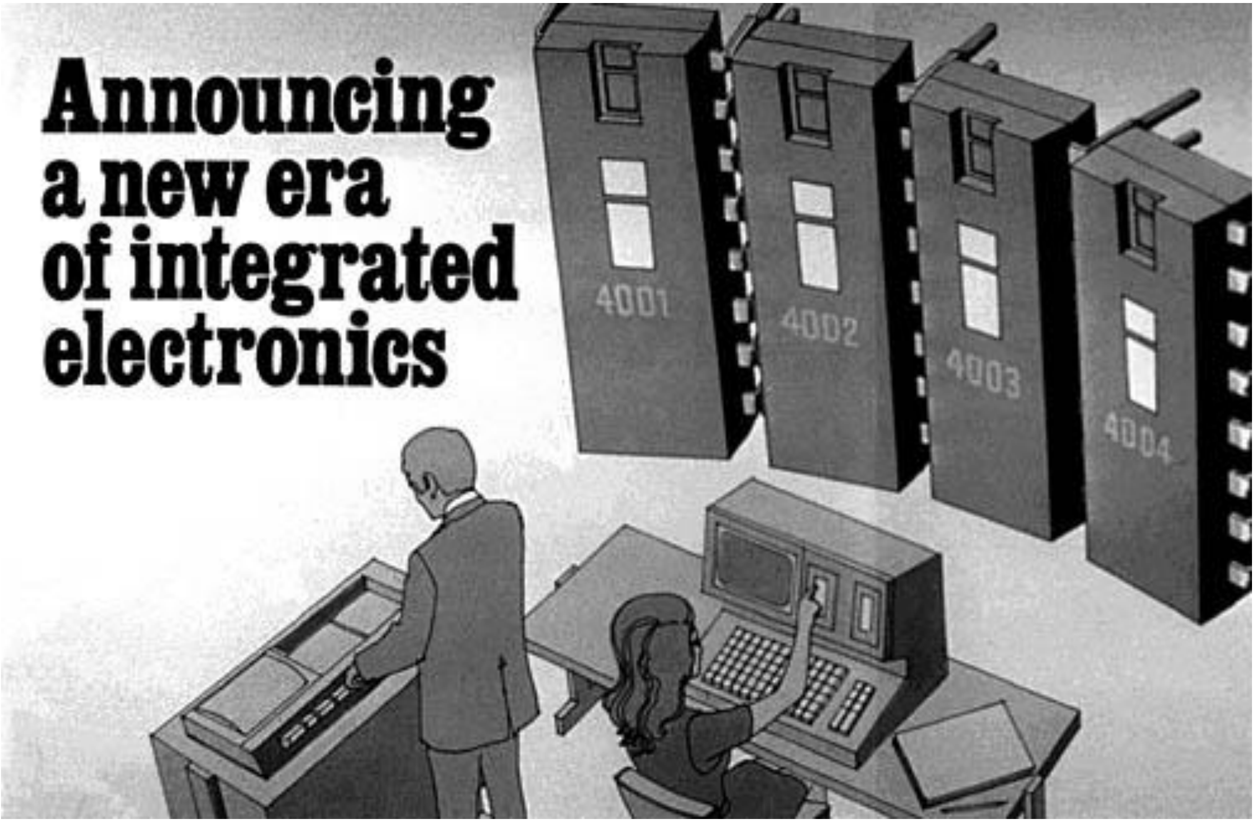


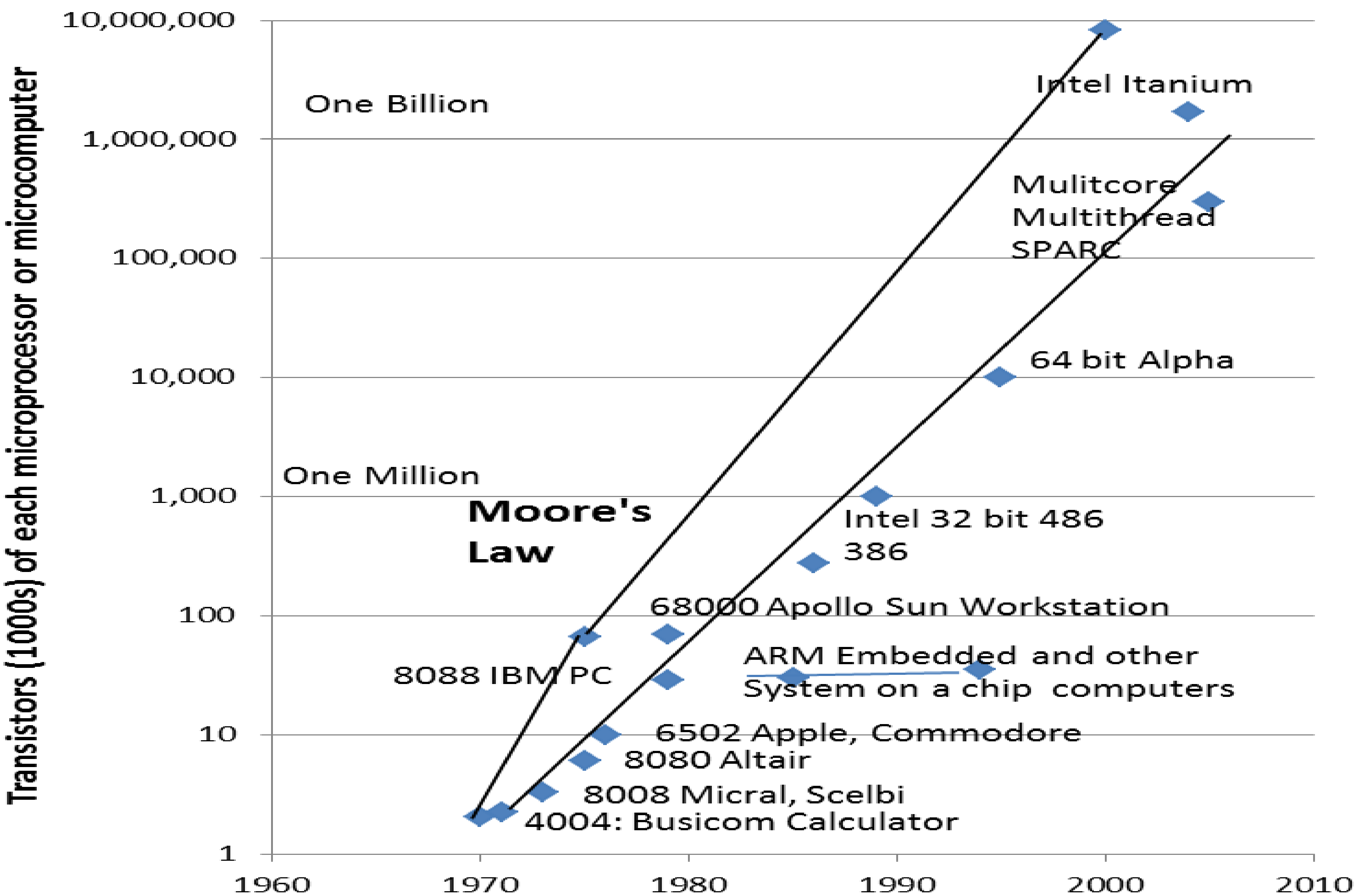






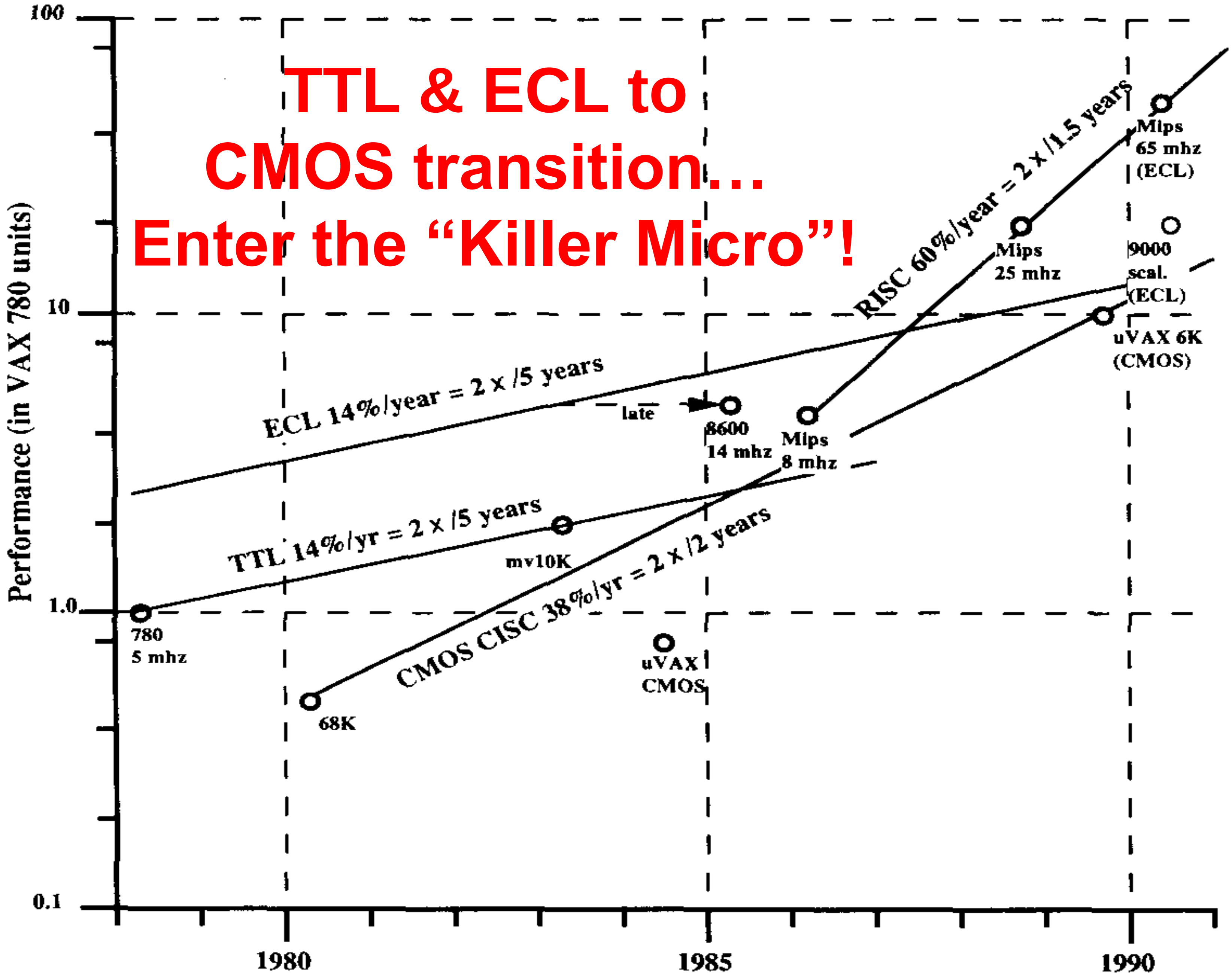
1971 4004 Introduction: The beginning of the end & The end of the beginning





Transistors (1000s) of each microprocessor or microcomputer
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
1960
1970
1980
1990
2000
2010
One Billion
One Million
Moore's Law
Intel Itanium
Mulitcore Multithread SPARC
64 bit Alpha
Intel 32 bit 486
386
68000 Apollo Sun Workstation
ARM Embedded and other System on a chip computers
8088 IBM PC
6502 Apple, Commodore
8080 Altair
8008 Micral, Scelbi
4004: Busicom Calculator

TTL & ECL to CMOS transition… Enter the "Killer Micro"!



VAX-11/780 c1978
32 bit super minicomputer

32 bit word
VAX = virtual address extension
$250,000
1-2 Mbytes

Serial 3? delivered to CMU's John Pople for Computational Chemistry
As a PC.

CMOS microprocessor effects in 1985 to destroy & eliminate Minicomputer industry

Technology cross-over of vanity architectures in favor of Intel and Motorola microprocessors

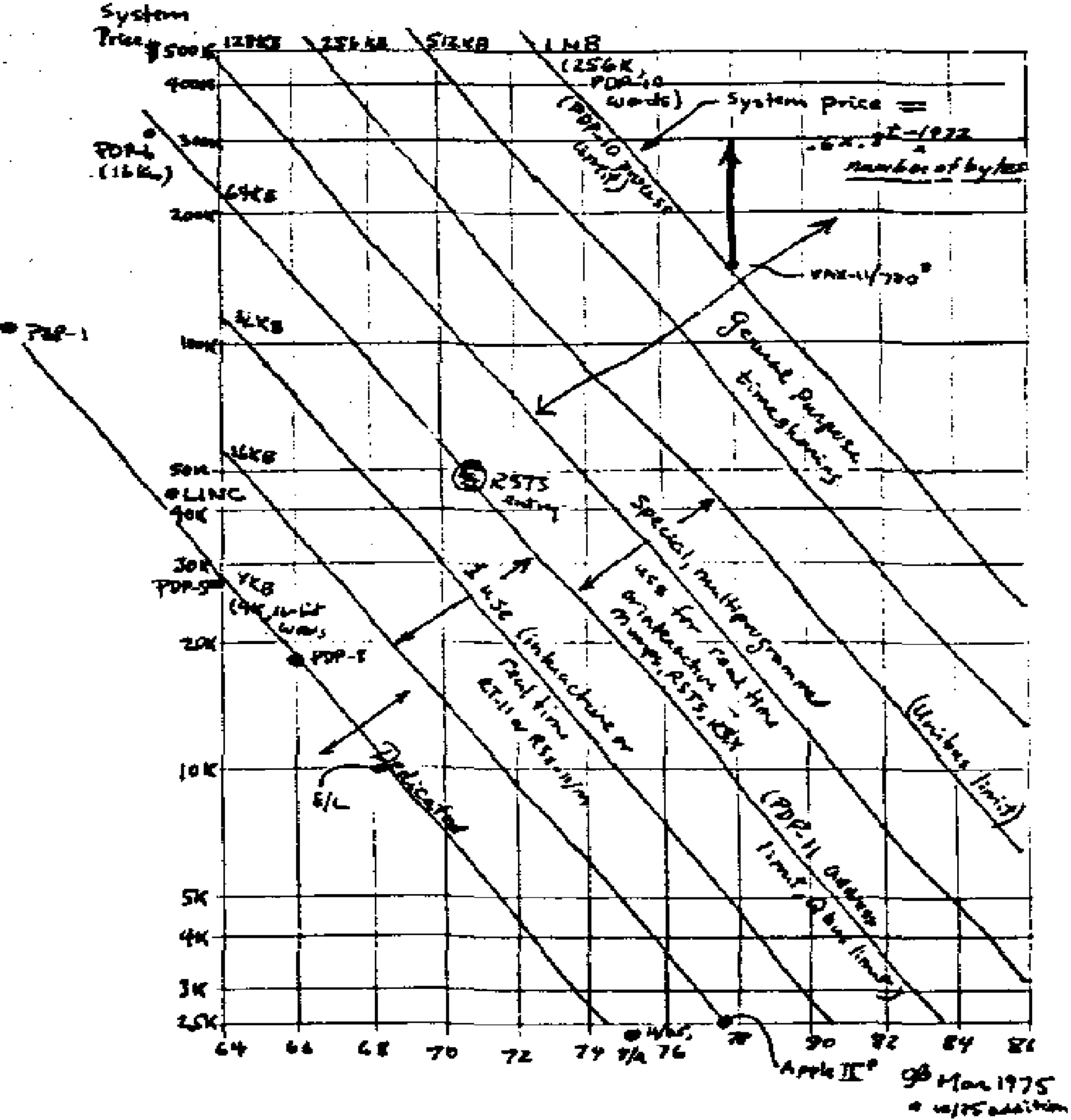
1. Bell's Law of a new class. 1982 introduction of PCs at good enough performance & lower cost
2. Workstations introduced in 1981 at minicomputer cost and same performance
   a. Microprocessor computers standards
   b. Complete disintegration
3. Multiple microprocessors i.e. multis in 1985
   1) More performance at price of supermini
   2) High redundancy, high reliability

VAX-A Bluebook 1 April 1975
Bell, Cutler, Hastings, Lary, Rothman, Strecker

Had we the foresight, it was clear the pure, 16-bit 11 was born to have a short, happy, prolific, profitable life. In 1969, an address of 16-18 bits, and a system size being sold of 13-15 bits, left only 3 bits of address growth left. At the constant-price historical memory growth rates of 26 to 41 percent per year, only 6 to 9 years of comfortable lifetime is allowed, bringing it to 1975-1978.

“There is only one mistake that can be made in a computer design that is difficult to recover from – not providing enough address bits for memory addressing and memory management. The PDP-11 followed the unbroken tradition of nearly every known computer.

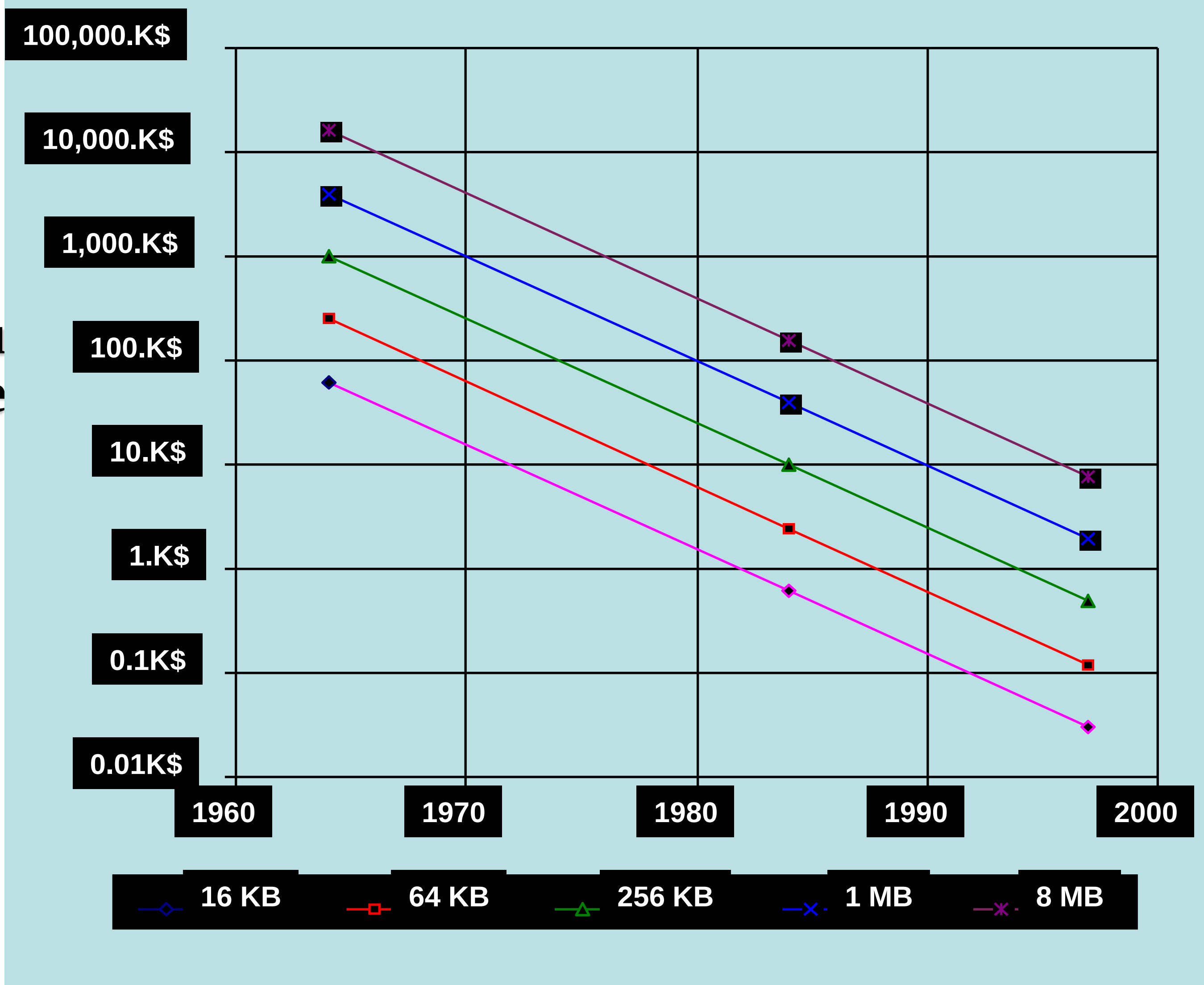
VAX Planning Model



Gordon Bell's 1975 VAX Planning Model... I Didn't Believe It!

System Price = 5 x 3 x .04 x memory size/ 1.26 $^{(t-1972)}$ K$

- 5x: Memory is 20% of cost
  3x: DEC marku
  .04x: $ per byte
- Didn't believe: the projection $500 machine
- Couldn't comprehend implications



IBM PC c1982 …older than graduates

A perfect storm killed minicomputers formed from proprietary architectures and implemented with TTL semiconductors

CMOS technology evolved on a faster track due to higher volume and inherently lower cost, enabling the microprocessor to form new companies for:

1. Personal computers (much lower cost)
2. CMOS microprocessors and UNIX (lower cost, same functions, lower performance)
3. Multiple microprocessors at minicomputer price with greater performance and/or functionality

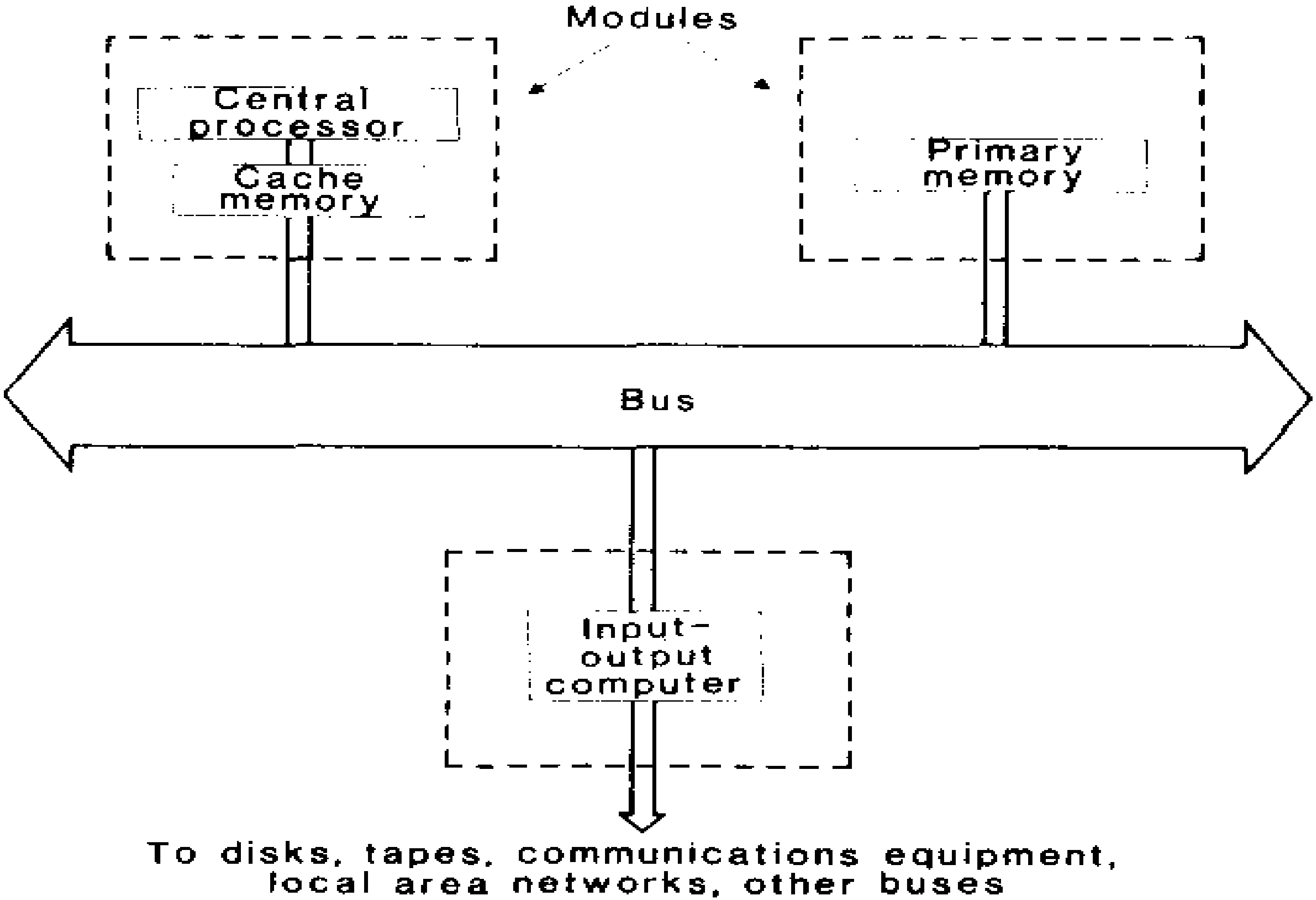
Motorola 68K, UNIX License, PC Standard: Anyone can manufacture computers

```
procedure  Entrepreneur_Venture_Cycle
    begin
    while  Frustration > Reward {Push
             from Old_co} and
           Greed > Fear {Pull to New
             company} do
           begin
           get (PC, spreadsheet);
           IF System_Company then
             write  (Beat_Vax_Plan)
             ELSE
             write (Plan)_
                 New_Company
           get (Venture_capital);
             {from Old_Venture_Co}
           exit {job};
             start (New_Company);
```

get (UNIX License, developers)

```
           get (Vax, development_tools);
           build (product); sell (product);
           sell (New_Company);
             {@ 100 × sales}
           venture_funds := Co._Sale
           start (New_Venture_Co.);
           end
         end
```

Multis: Multiple, shared memory Microprocessors (Bell, Science 4/25/1985)



The Challenge: Dealing with technology *transitions* and any ensuing standards
Technology = Change = Disruption

- 1957: Vacuum tube to Transistor circuits (high bar)
- 1965: Transistors to ICs… 100 mini companies
- 1971: 8 bit Microprocessor >> master VLSI;
  1981: IBM PC >> failure to embrace, only extend
- 1983: VLSI overtakes TTL AND ECL>> 9000 fail
- 1984+?+: UNIX and 32-bit micros >> standards fail
  "Either make the standard, or follow the standard.
  If you fail to set the standard, you get to do it twice."
- 1992: WWW, Altavista, servers, clients. Mrkt'ng fail.

To think about

- Given an environment e.g. body area, home, car, small business, an industrial structure, what is the structure and IT taxonomy of the network, computers, storage, etc. showing function
  - Now, in 5 years, in 10 years
- How will Moores's Law change computing
  - In 5 years, in 10 years
- What new computers could you envision that Bell's Law might enable
  - In 5 years, in 10 years

More to think about

- Name, classify, and construct a taxonomy of all the platforms i.e. dominant programming environments after the PC, WIMP*
  - What year
  - Programming environment
  - Key apps
- What will IoT add to the platform and classes?

*These could encompass Internet 1.0 and 2.0

The End