Computer Processing

Case Studies

NBAY 1620

March 7, 2016
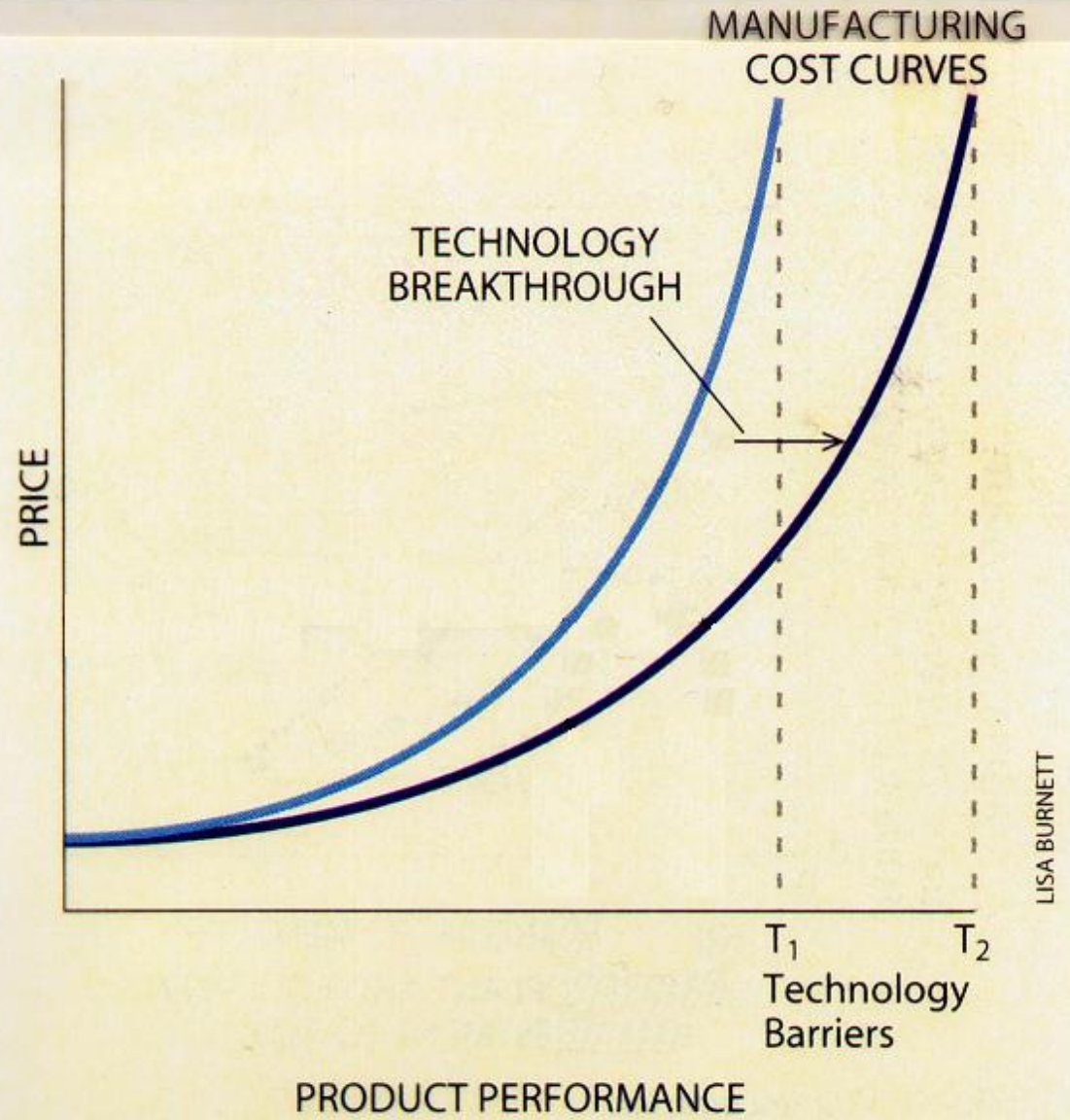
Donald P. Greenberg

Lecture 3

Required Reading

- G. Dan Hutcheson and Jerry D. Hutcheson. Technology & Economics in the Semiconductor Industry, Scientific American, January 1996.

- Shimpi, Anand Lal. "The ARM Diaries, Part 1: How ARM's Business Model Works." *Anand Tech*. N.p., 28 June 2013. Web. 31 Aug. 2015.

- Hardy, Quentin. "Intel Faces Uphill Battle to Live by Moore's Law." January 15, 2016. The New York Times.

Economics of the Semiconductor Industry

- **G. Dan Hutcheson and Jerry D. Hutcheson. Technology & Economics in the Semiconductor Industry, <u>Scientific American</u>, January 1996.**
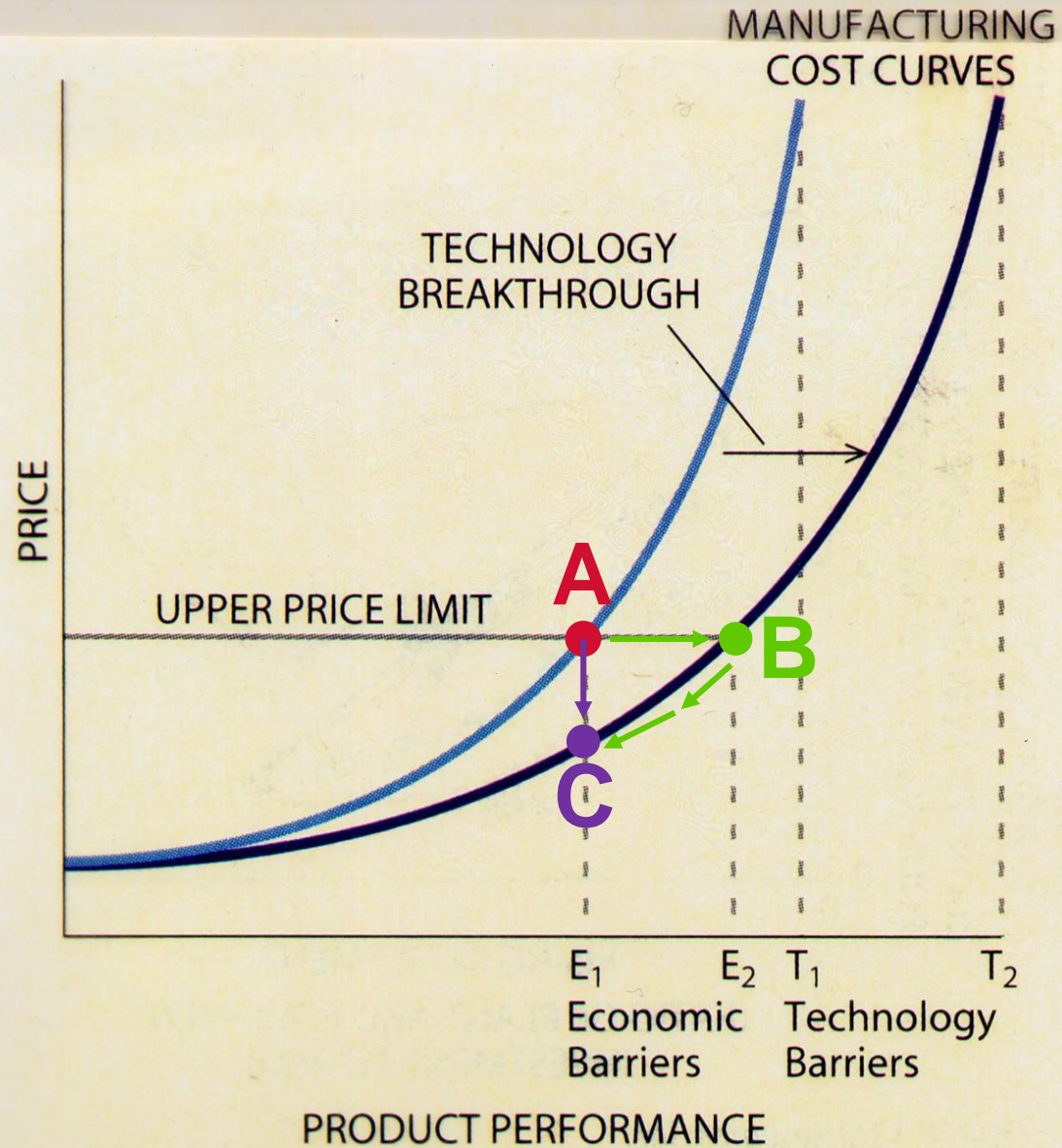
PRICE VERSUS PERFORMANCE

MANUFACTURING COST CURVES

TECHNOLOGY BREAKTHROUGH

PRICE

PRODUCT PERFORMANCE

T₁   T₂
Technology Barriers

LISA BURNETT

SOURCE: VLSI Research, Inc.

Return on Investment (ROI)

Assumptions:

Payback period (time)

Net Present Value
Value of future benefits in today's money

Internal Rate of Return

How do you predict what the technology, manufacturing cost, market demand, market supply, and competition will be five years in the future?

Return on Investment (ROI) Model does not work well

Difficulties:

- **How long does the product last?**

- **What is the price (revenue)/unit?**

- **Exponential change**

- **Non-linear pricing behavior**

- **Competition (monopoly pricing)**

- **Prediction of demand**

- **Technical obstacles**

Profitability vs. Investment in the Computer Industry
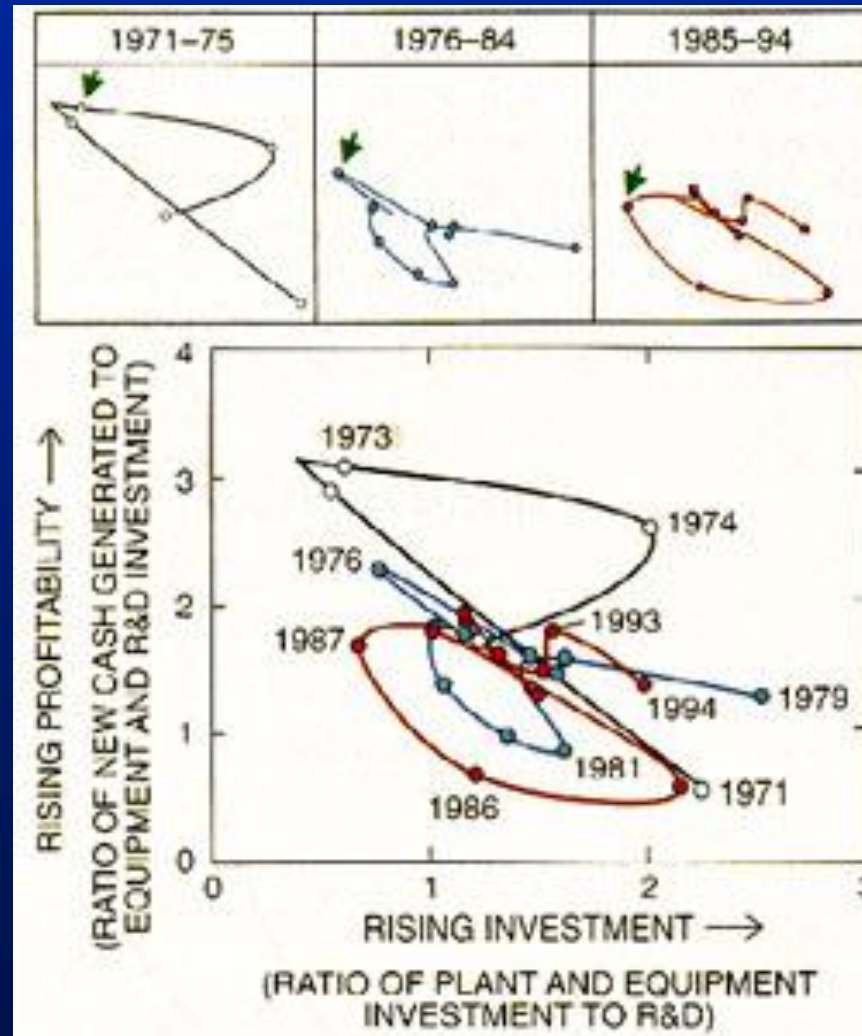
Profitability vs. Investment in the Computer Industry

Rising Profitability

$$\text{Measured by ratio} = \frac{\text{cash generated during year}}{\text{investments made in new technology previous year}}$$
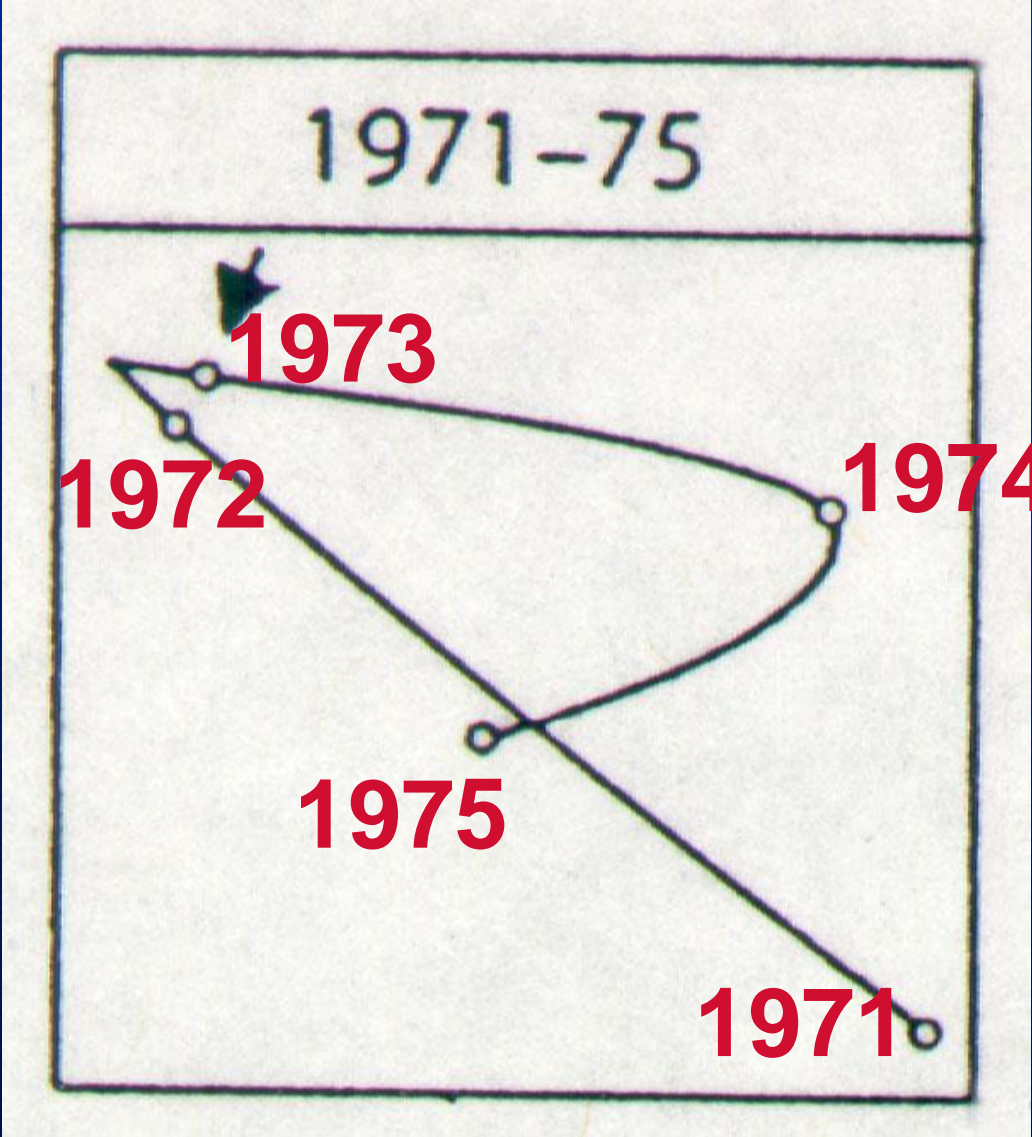
$$\text{where new technology} = \text{new equipment} + \text{R \& D}$$

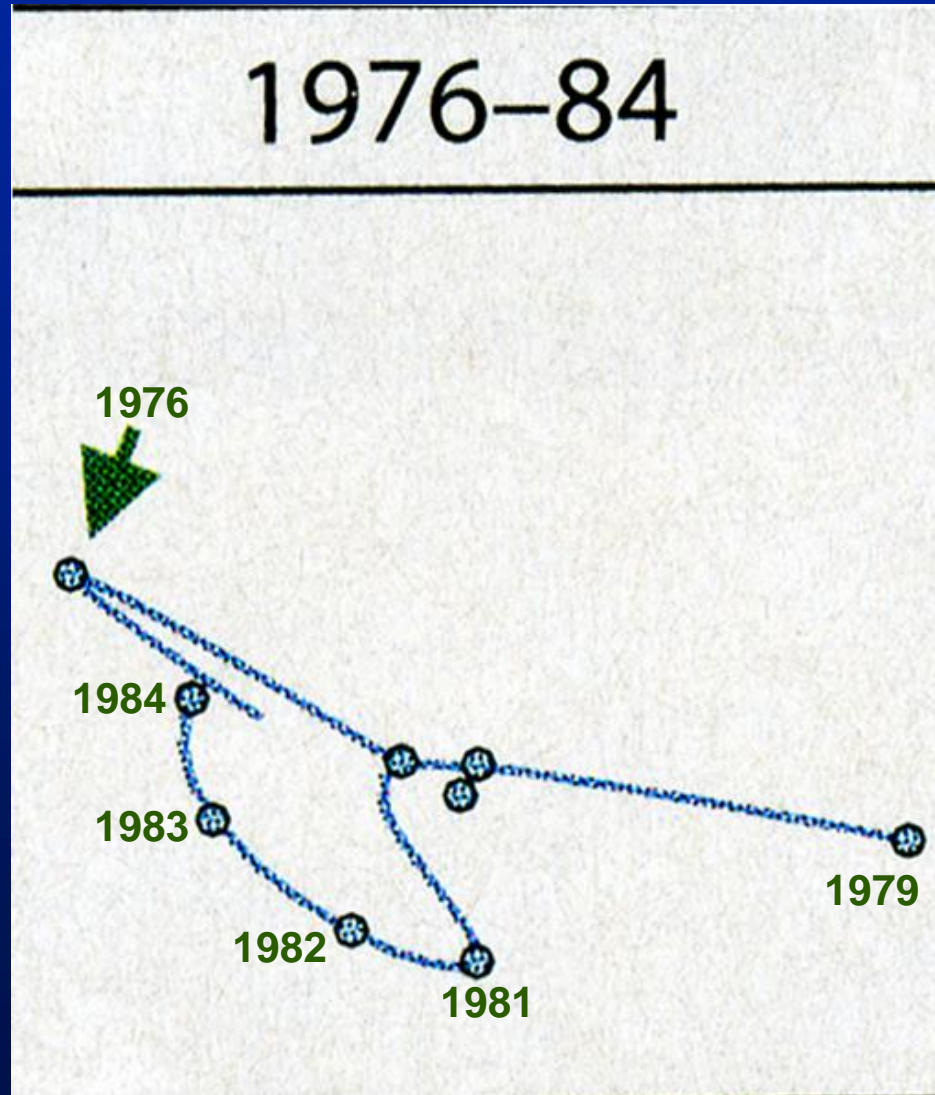$$\text{cash} = \text{gross profit (including R \& D)}$$

Rising Investment

$$\text{Measured by ratio} = \frac{\text{plant \& equipment investment}}{\text{R \& D}}$$
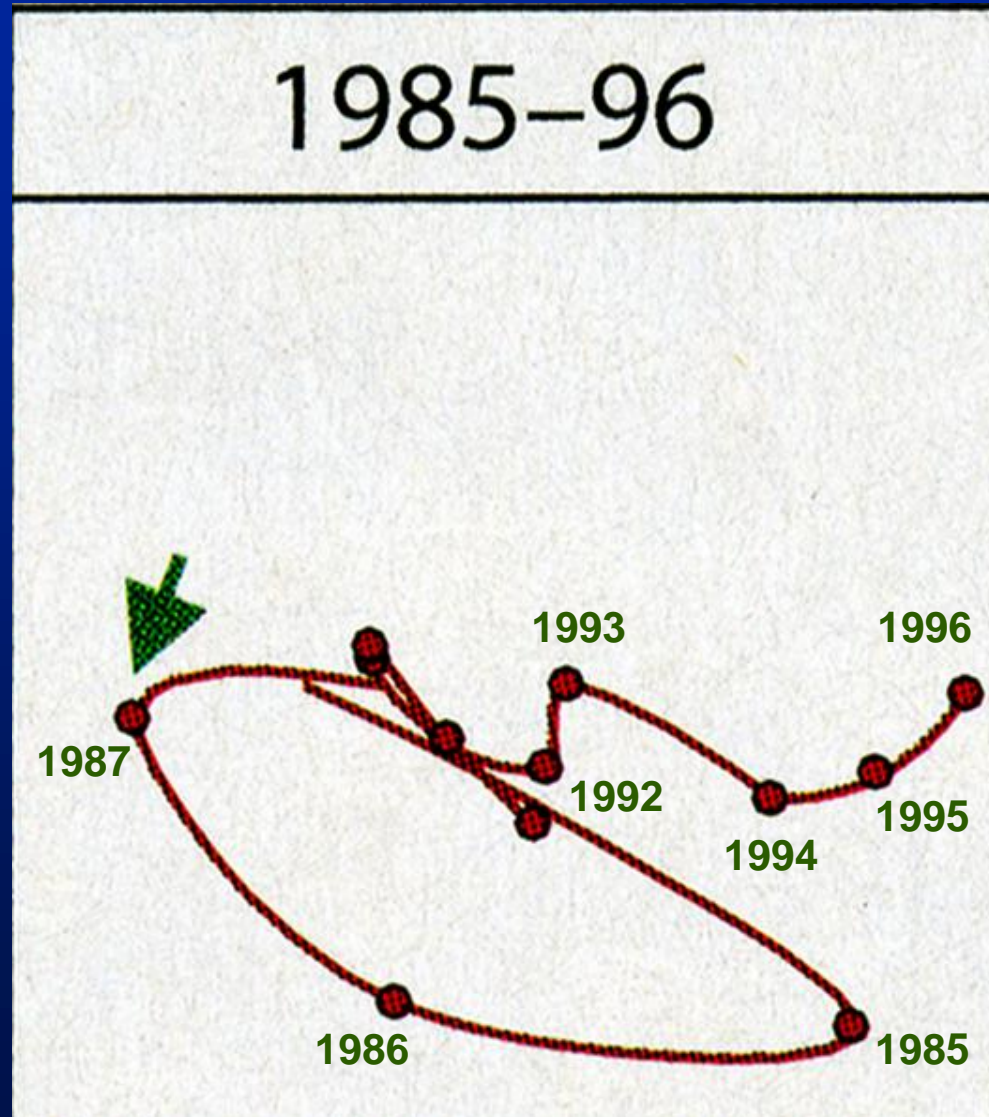
Profitability vs. Investment

# Profitability vs. Investment

Profitability vs. Investment

Profitability vs. Investment in the Computer Industry

- It is obvious that with the shrinking technology, it is getting more expensive to move to the next generation process technology.

- It is also obvious that the manufacturing cost as well as the sales price of processing chips is decreasing rapidly.

Price vs. Performance
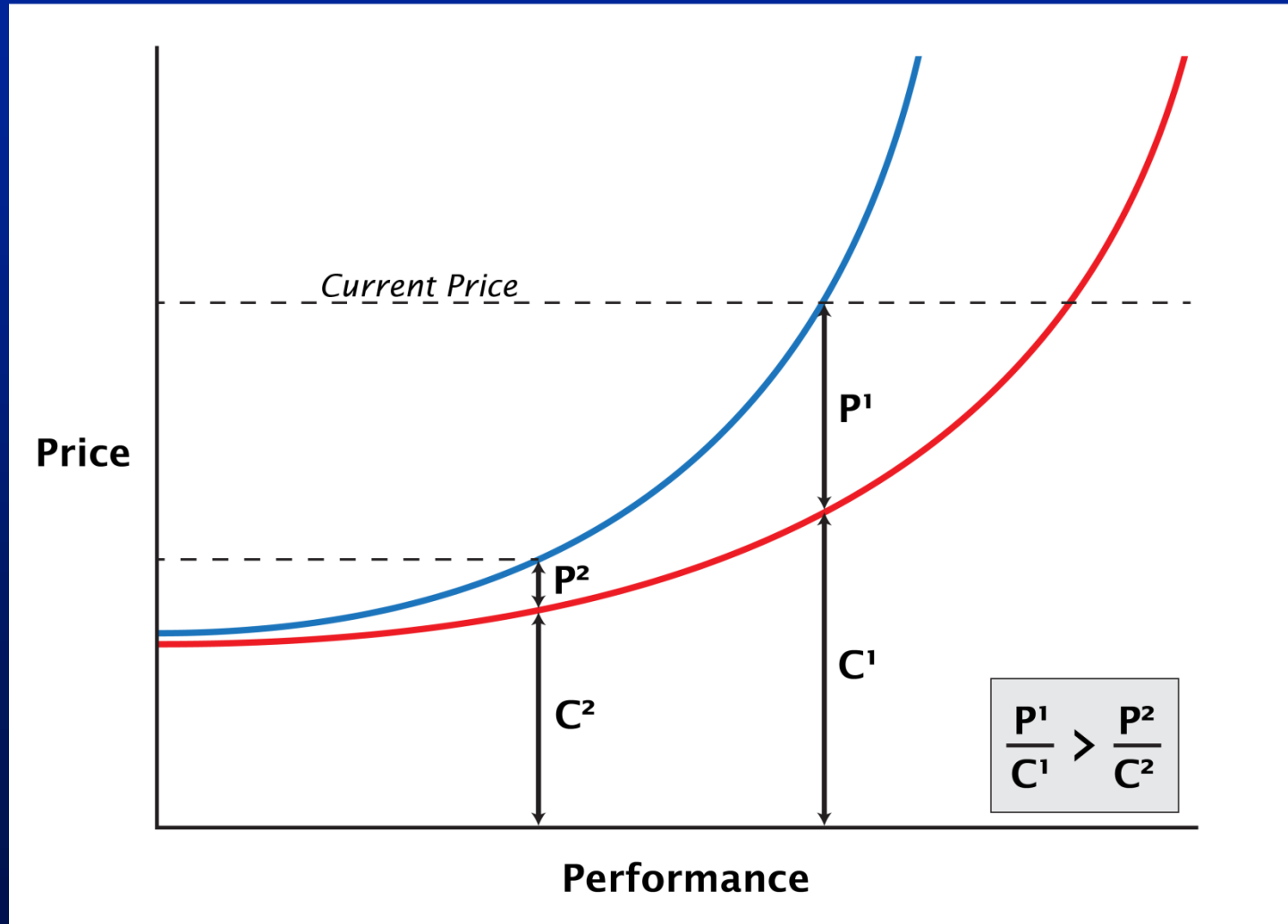
With these observations, what should the dominant chip manufacturers (Intel, IBM, TI Samsung, etc.) do?

New Gross National Product Accounting

- On July 31, 2013, the U.S. Bureau of Economic Analysis restated the size & composition of the GNP

- R&D will no longer be treated as an expense (original work of art, film, music & books will also be treated as "long-lived assets"

- U.S. Gross National Product will get an immediate 2.7% boost

New Gross National Product Accounting

- Intangible investment is not a faddish new idea

- In the 1930's & 1940's economist Joseph Schumpeter made intangibles the centerpiece of his theory that economies grow through innovation

- Ben Bernanke in a 2011 speech also promoted this idea to stimulate innovation

Intel 2007

- The growth in mobile microprocessors outpaced the growth in desktop microprocessors.

- Systems price points have migrated to lower levels and average selling prices indicate continued erosion.
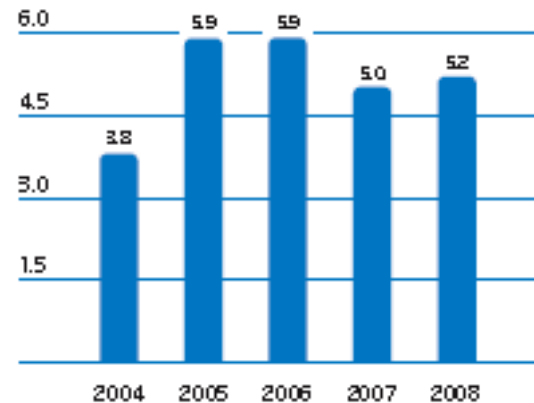
Intel 2007

- Mobile microprocessors ASP's are less than desktop microprocessor ASP's.

- In 2007 gross margins were negatively impacted by declining ASP's and higher start-up costs for the new 45nm process technology.

- At the end of 2007, Intel had roughly $20B cash.

Intel   2008

- In 2008 the average selling price for all products continued to decline

- The revenues for the mobility group as contrasted to the digital enterprise group continued to increase
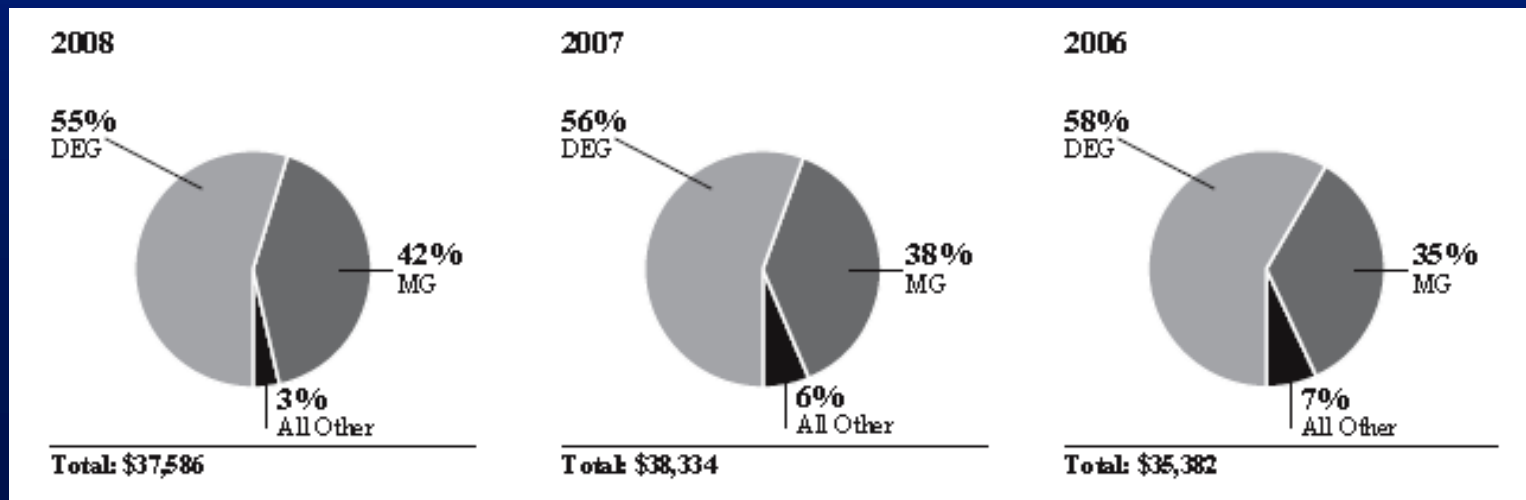
Percentage of Revenue (Dollars in Millions)

Intel Research and Development
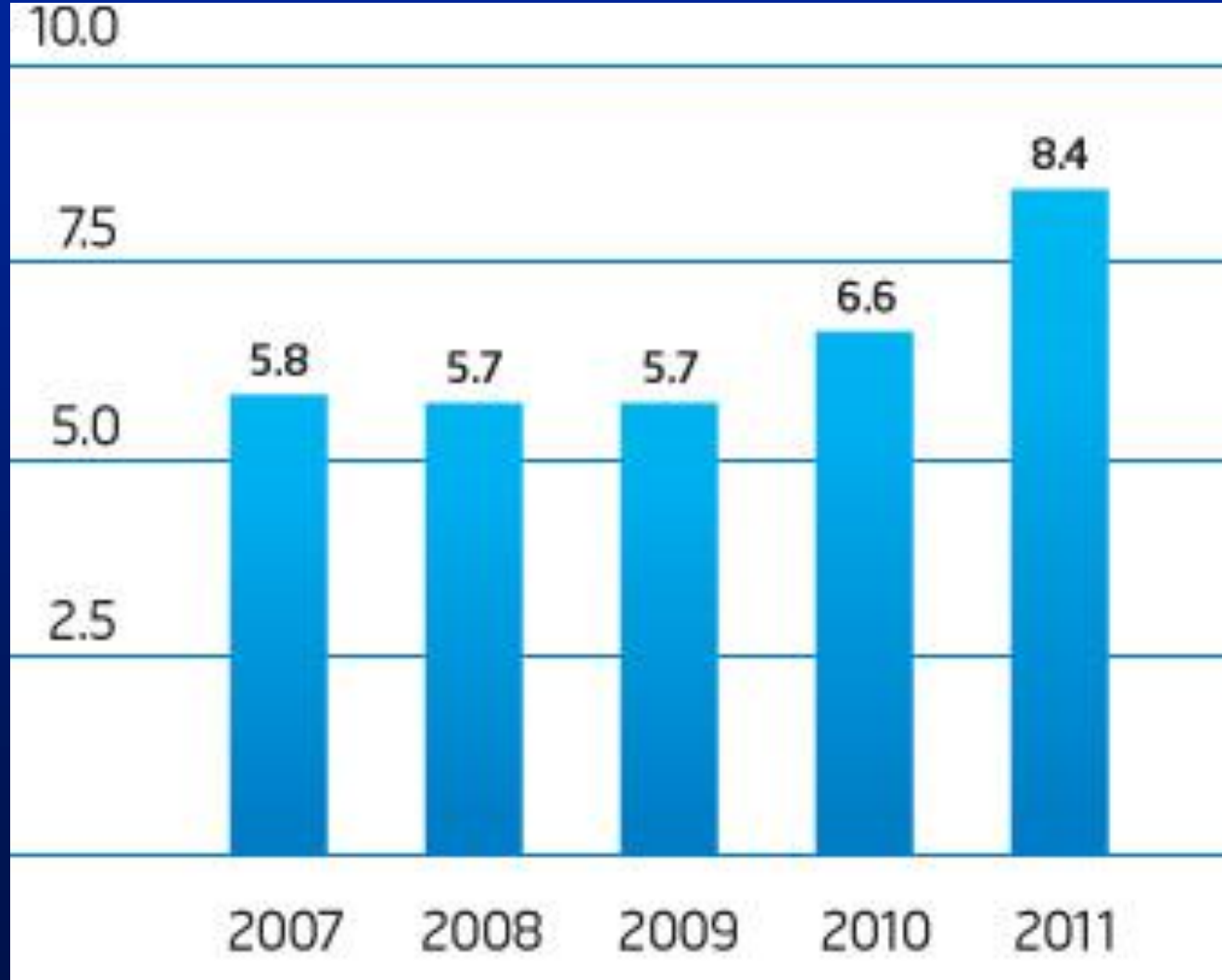
Intel Capital Additions to Property, Plant and Equipment
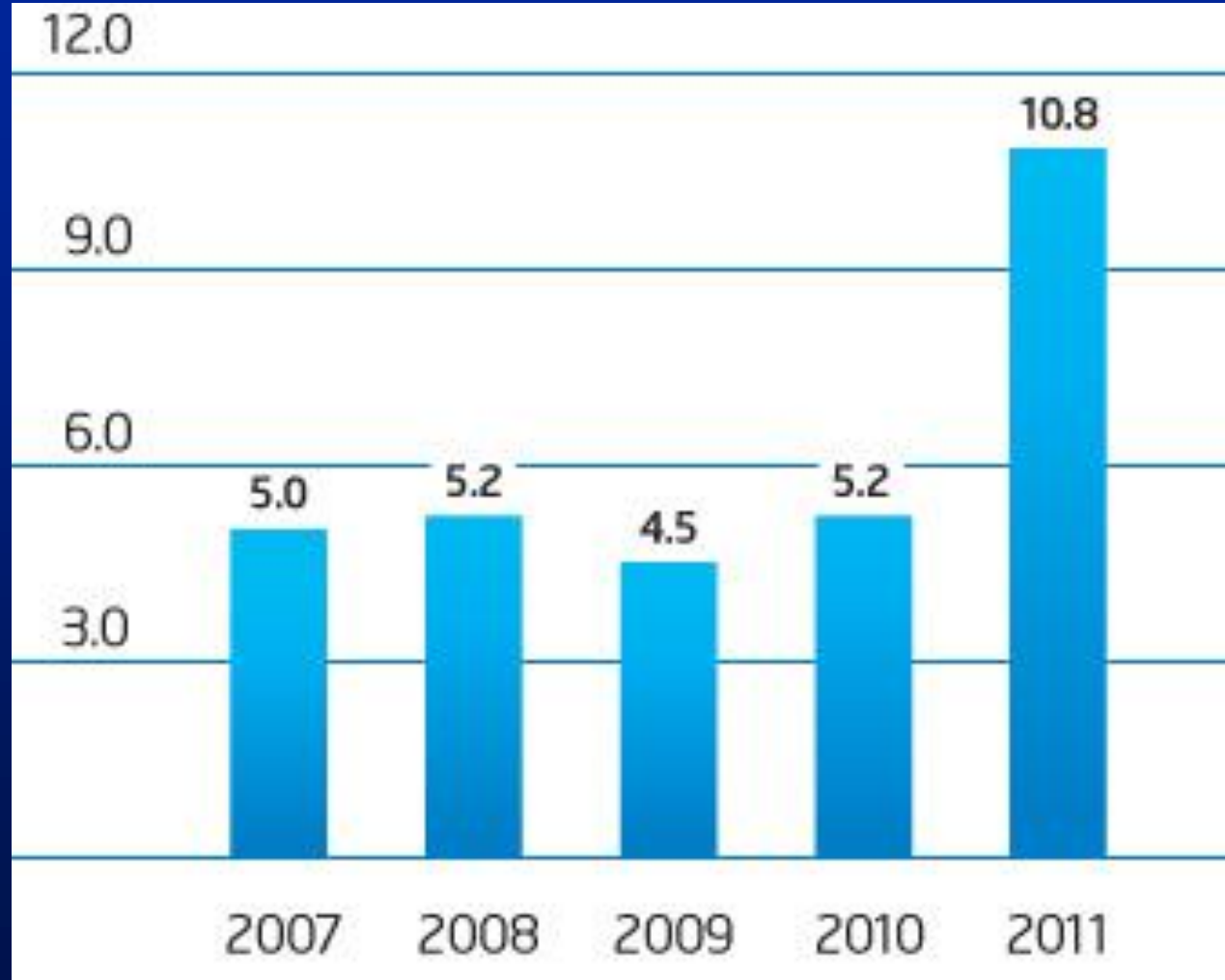
Intel's In a Sweet Spot   2011

- Having invested in its 32nm fab, Intel achieved higher than expected efficiencies and introduced new chips faster than expected.

- Sandy Bridge, their latest microprocessors was introduced in 2011.

- AMD, even if it designed better chips, was stuck with its 45nm production and couldn't compete. Their chips were more expensive to produce.

- Intel's new chips possibly eroded the graphics market for competitors (nVidia & AMD) as PC makers no longer needed stand-alone graphics processors.

Intel Net Revenue   2011

Intel Geographic Breakdown of Revenue   2011
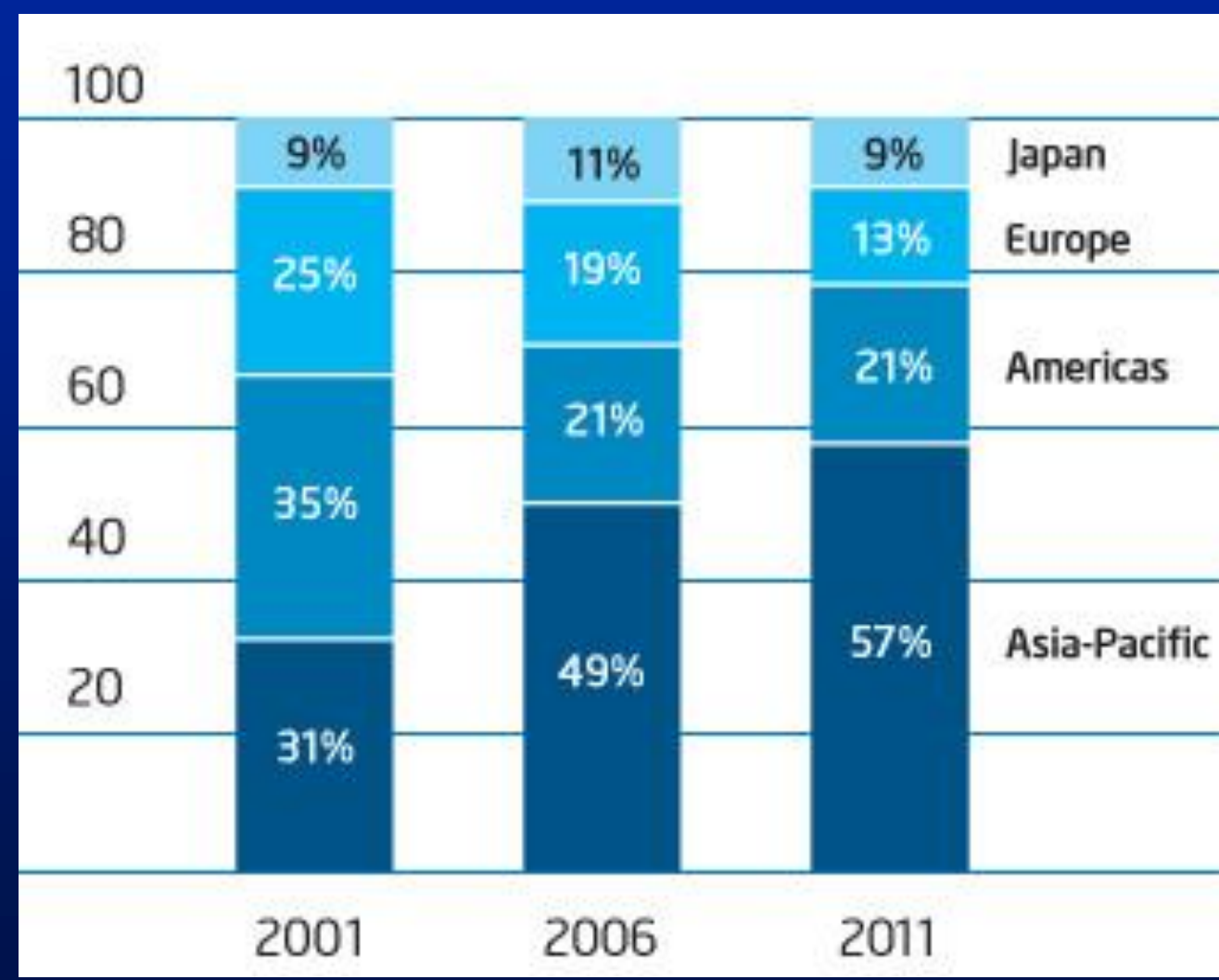
Intel 2011

- A new fab costs approximately $3-4B or more

- Should Intel Continue to Invest In Creating New Fabrication Facilities?

Intel Net Revenue   2012

Net Revenue
Dollars in billions

Year	Revenue
03	30.1
04	34.2
05	38.8
06	35.4
07	38.3
08	37.6
09	35.1
10	43.6
11	54.0
12	53.3
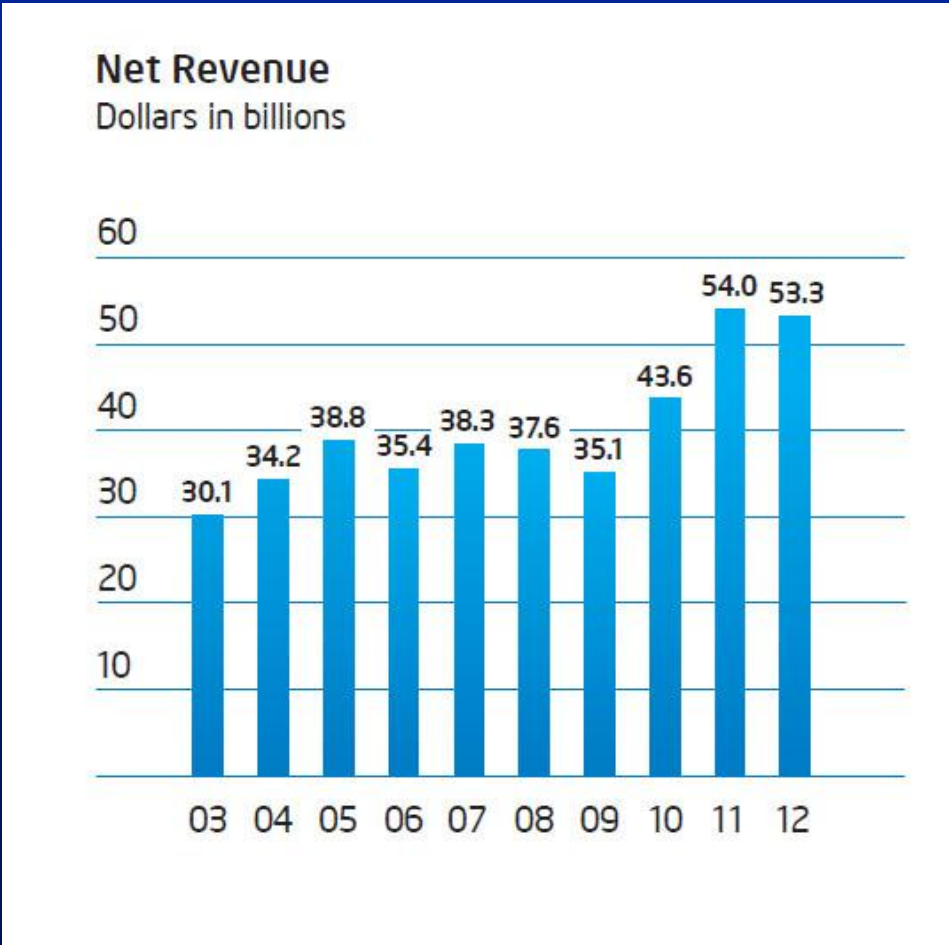
Capital Additions to Property, Plant and Equipment
Dollars in billions
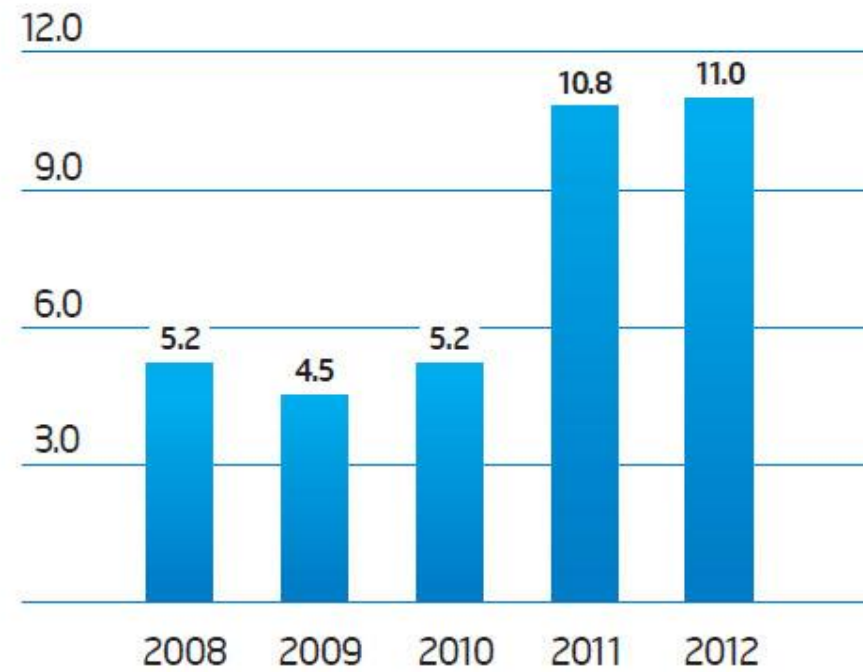
Intel Research & Development   2012

Intel   2012
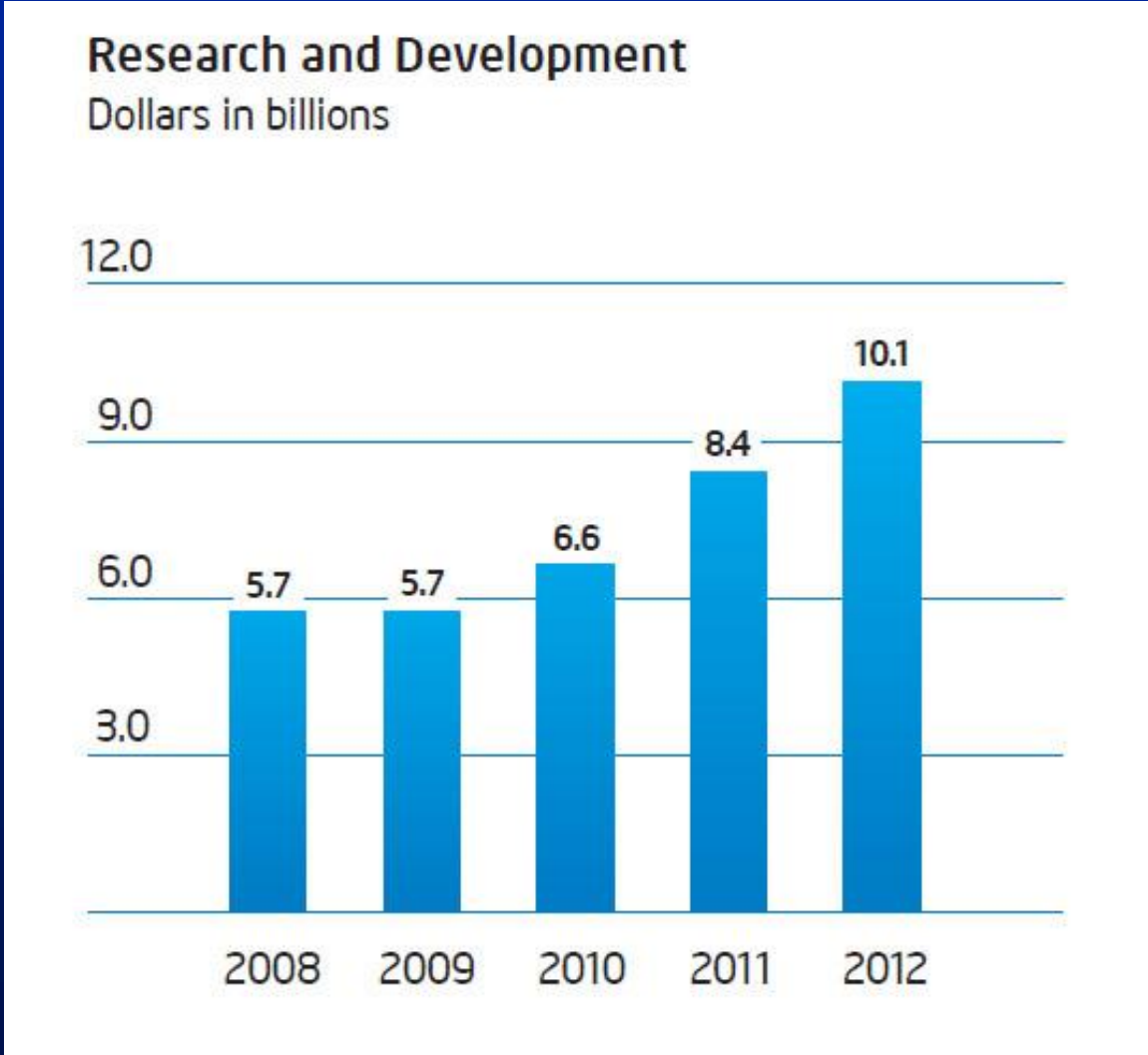
- Intel announced that it would spend $9B to upgrade four fabrication plants to move to 22nm technology (one in Israel).

- ARM and IBM announced a joint agreement to move to 14nm technology.

Computer Industry Problem   2013

- The high price servers are representing a much smaller percentage of revenue stream

- The prices of laptops and netbook computers are continuing to decrease

- Competition and price wars in the mobile computing segments (mobile phones, smart devices, tablets) are fierce

Intel 2014

- In 2011 Intel had announced it would build a $5B high-tech manufacturing plant, Fab 42, in Arizona.

- 2012 President Obama visited the plant and mentioned Fab 42 in his State of the Union Address.

- January 14, 2014, Intel puts the new Arizona chip factory on back burner.

- Why did Intel PAUSE?

How did Intel maintain it's revenue stream?

It Retrofitted two existing plants in Chandler Arizona

- 22nm >>> 14 nm (Fab 22 & Fab 32)

Intel   2015

- Intel again delays 10nm technology. It will depend on revenue increase from Windows 10 and its new Skylake processor.

- The second generation of 14nm production technology had significant yield improvements.

- At the same time, Intel moved to purchase Altera so it could shift from PC's to mobile devices.

Intel's Hillsboro   2015
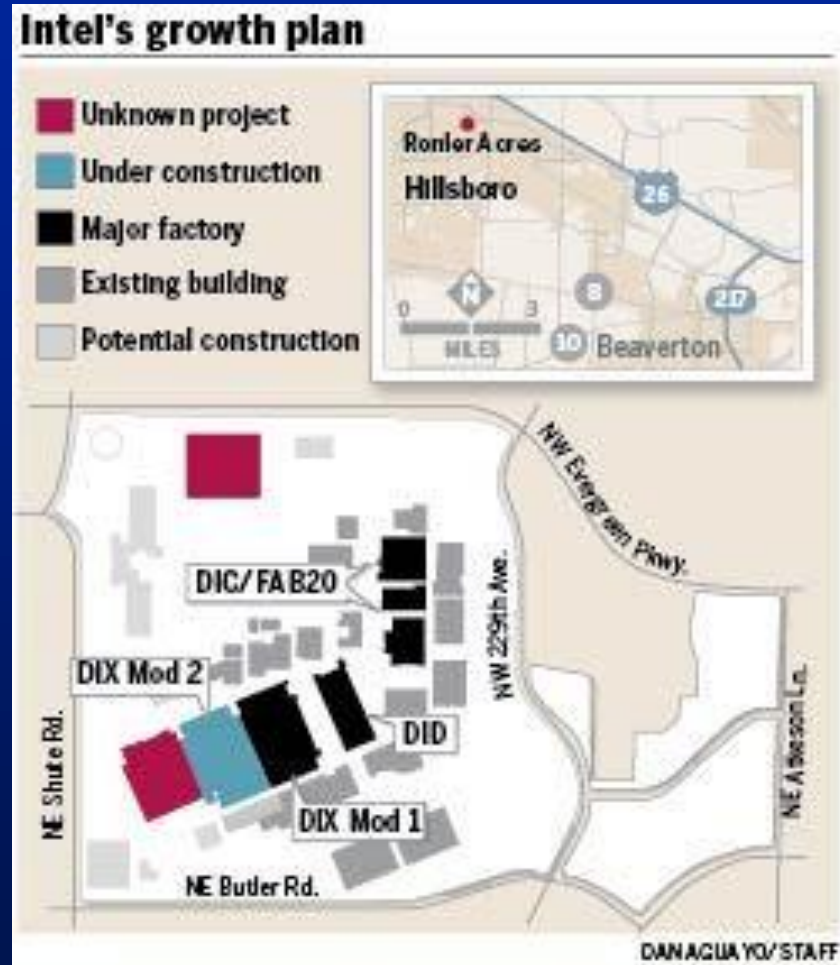
Is there another business model?

Foundry Model

- Many companies (Integrated Device Manufacturers, IDMs) design and manufacture integrated circuits (efficiency through vertical integration)

- Today, there are many companies that:

    - only design devices (fabless semiconductor companies),

    - as well as *merchant foundries* that only manufacture devices.

- The *foundry model* is a business vision that seeks to optimize productivity.

- In 1987, the world's first dedicated merchant foundry opened its doors: Taiwan Semiconductor Manufacturing Company (TSMC)

source: https://en.wikipedia.org/wiki/Foundry_model

TSMC's Customers

- Manufacture's chips for
    - Qualcomm
    - Nvidia
    - Advanced Micro Devices (AMD)
    - Broadcom, Altera
        > (even some for Intel & Texas Instruments)
    - Apple's A5, A6 for iPad & iPhone
    - Apple's new A8

TSMC's Revenue   2014

- In 2014 TSMC's Revenue reached 25 Billion USD.

- They are particularly at producing low power mobile devices at 28nm.
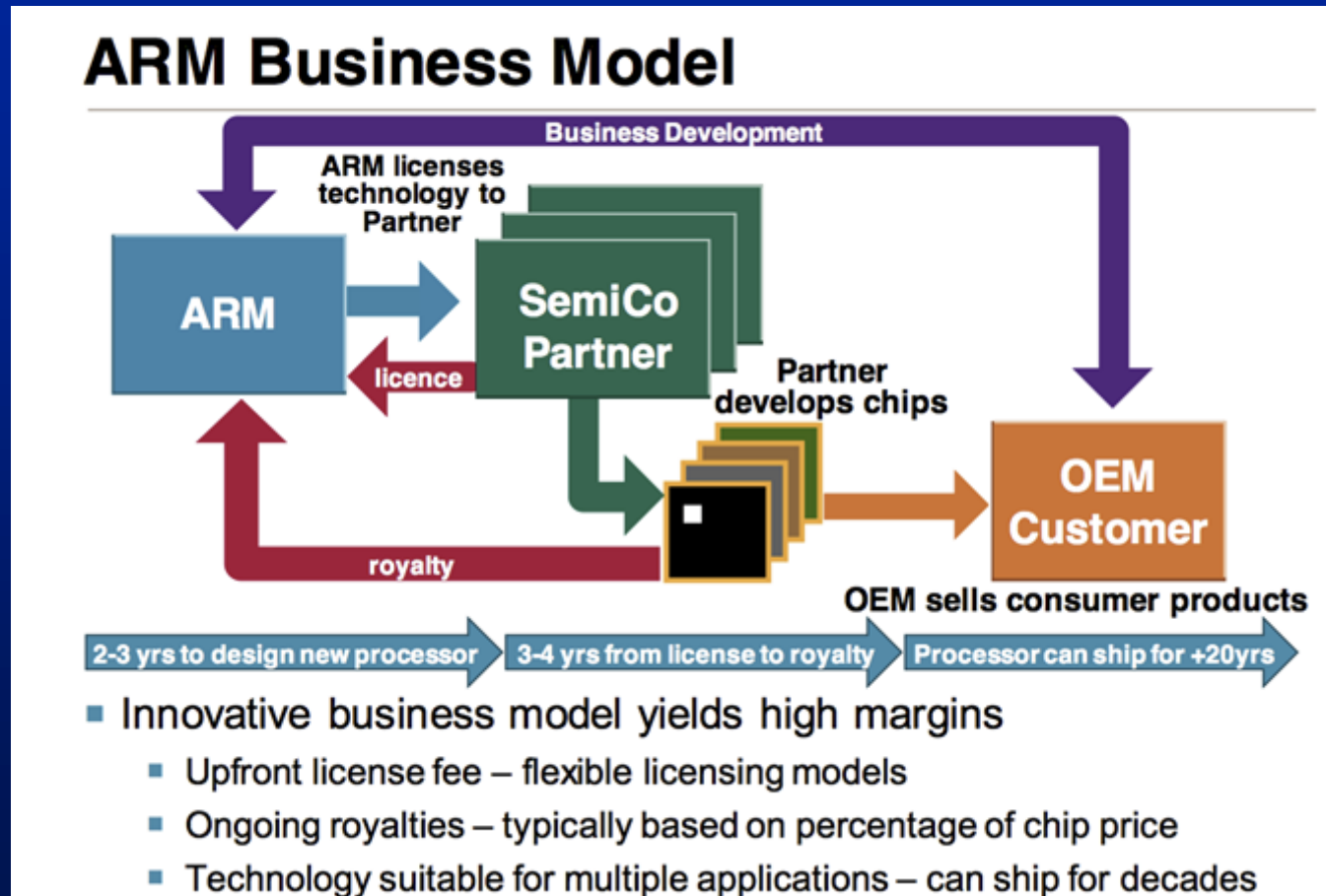
- They capital spending was between 10.5 – 11 Billion USD.

TSMC's Fabrication Plants 2014

- TSMC had four 300mm wafer plants in Taiwan

- TSMC had four 200mm wafer plants in Taiwan

- TSMC had one 200mm wafer plant in Shanghai, Washington State, Singapore, and other smaller plants.

Is there another business model?

ARM Holdings - Business Model

ARM Business Model

Business Development

ARM licenses technology to Partner

ARM → SemiCo Partner

licence

Partner develops chips

royalty

OEM Customer

OEM sells consumer products

2-3 yrs to design new processor | 3-4 yrs from license to royalty | Processor can ship for +20yrs

- Innovative business model yields high margins
  - Upfront license fee – flexible licensing models
  - Ongoing royalties – typically based on percentage of chip price
  - Technology suitable for multiple applications – can ship for decades

Shimpi, Anand Lal. "The ARM Diaries, Part 1: How ARM's Business Model Works." *Anand Tech*. N.p., 28 June 2013. Web. 31 Aug. 2015.

ARM Holdings

- Original name was Acorn Computers

- In 1990 a new customer arrived, Apple: and company was renamed Advanced RISC Machines (ARM)

ARM Holdings   2014

- By 2014, ARM dominated the smartphone market and had the following market share

    - 95% smartphone market
    - 10% mobile market
    - 35% digital TV's
    - 23% PC's

- In 2014 ARM cores were licensed for 12 Billion chips

ARM's Customers

- Apple (iPhone 5, iPad, iPhone 5s, iPhone 6, etc.)

- Samsung (Galaxy S4, S5, etc.)

- Qualcomm (Snapdragon)

Will the cost of new fabrication plants lead to an oligopoly in this industry?

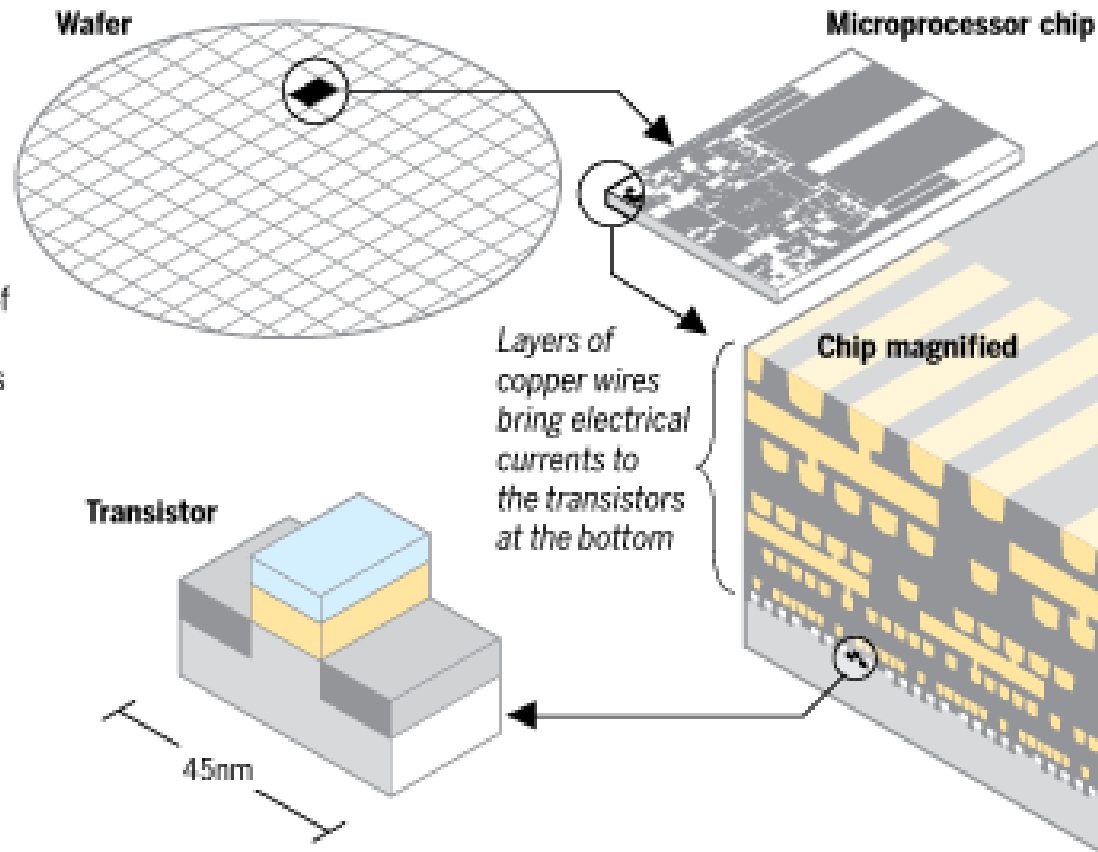# Fewer companies can deliver smaller and more powerful chips (July 20, 2009)

Fewer companies can deliver smaller and more powerful chips

Microprocessor
The 'brain' of a computer. Contains hundreds of millions of transistors interconnected by fine wires made of copper. Each transistor acts as an on/off switch, controlling the flow of electricity through the chip to send, receive, and process information up to 300bn times a second
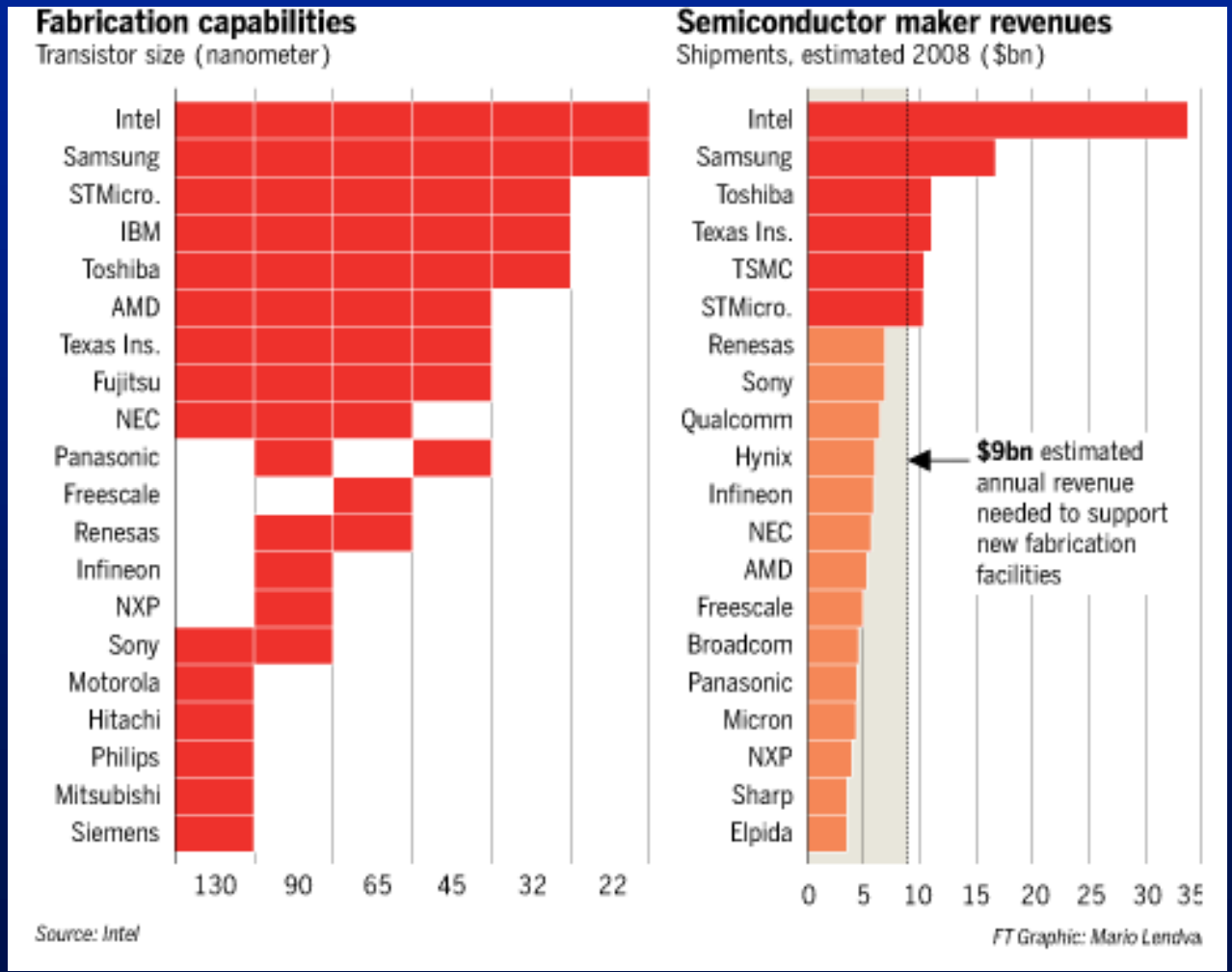
2,000
45 nanometer (nm) transistors can fit across the width of a human hair

Wafer

Microprocessor chip

Layers of copper wires bring electrical currents to the transistors at the bottom

Chip magnified

Transistor

45nm

Fewer companies can deliver smaller and more powerful chips   July 20, 2009

Fabrication capabilities
Transistor size (nanometer)

Semiconductor maker revenues
Shipments, estimated 2008 ($bn)

$9bn estimated annual revenue needed to support new fabrication facilities

Source: Intel

FT Graphic: Mario Lendva

How do you predict what the technology, manufacturing cost, market demand, market supply, and competition will be five years in the future?

CASE STUDY 1:
The Great Chip Glut: Economist August 11, 2001

- **East Asia did not understand the industry's woes**

  - **Oversupply**
  - **Taiwan's "foundries"**
  - **TSMC**
  - **UMC** ⟹ **Operating at 30% of capacity (from 70%)**
  - **Singapore – Charted Semiconductor**
  - **Korea's Hynix (Hyundai) - $1B loss in 2Q01**
  - **Malaysia – new fab, 1st Silicon + 2 more**
  - **China – Shanghai alone, 2 fabs under construction**
    - **2 more on drawing board**
    - **12 more planned**

Case Study #2

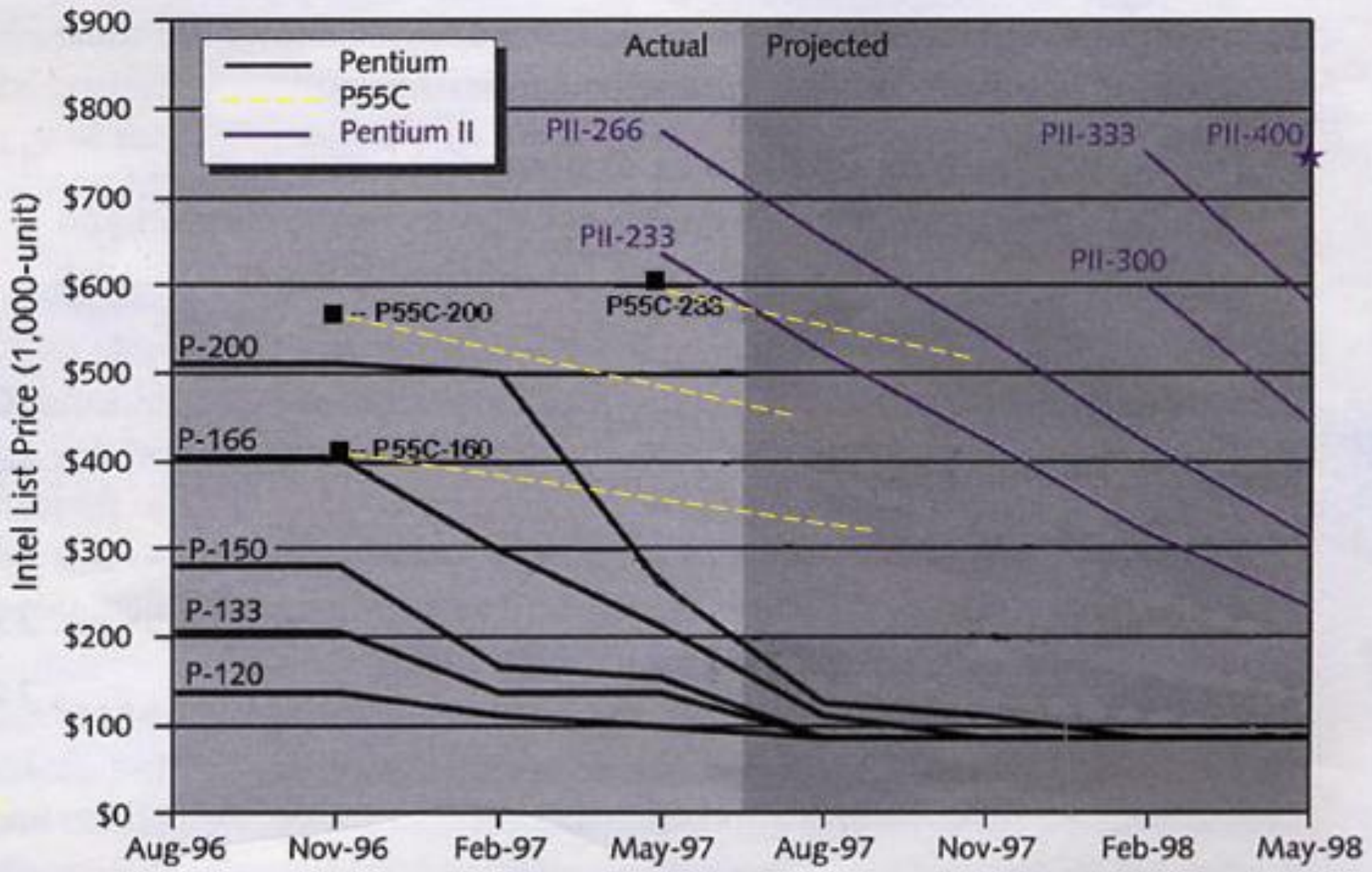Intel's MMX Introduction

Microprocessor Report, July 1997

Marketing & Advertising Strategies in the Computer Industry

> *In a fast moving technology, how do you market your product?*

> *How do you get brand name recognition?*
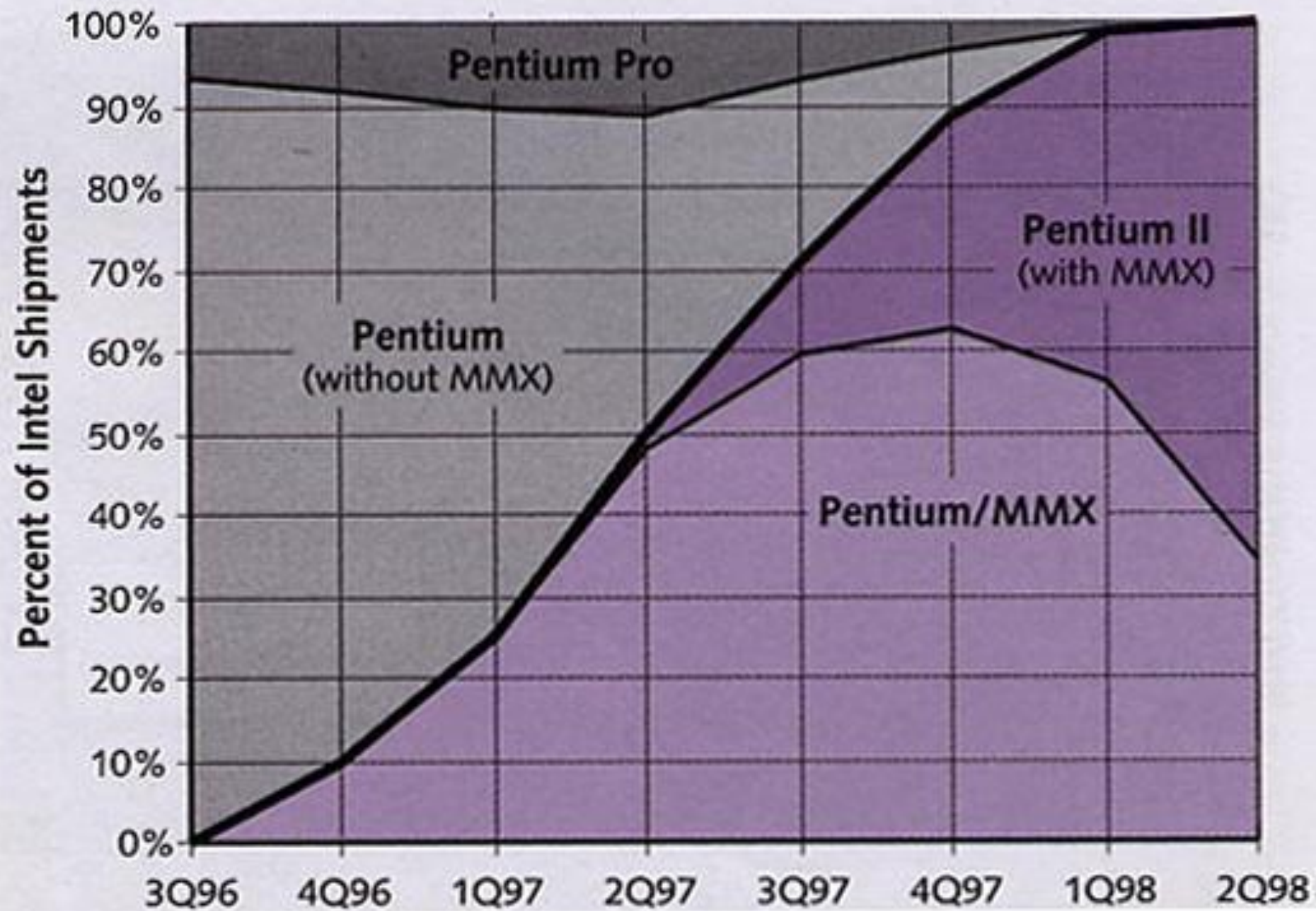
> *When do you start advertising?*

What is MMX?

- First major extension to x86 instruction set since 1985

- 57 new instructions to accelerate:

    2D & 3D graphics

    Video

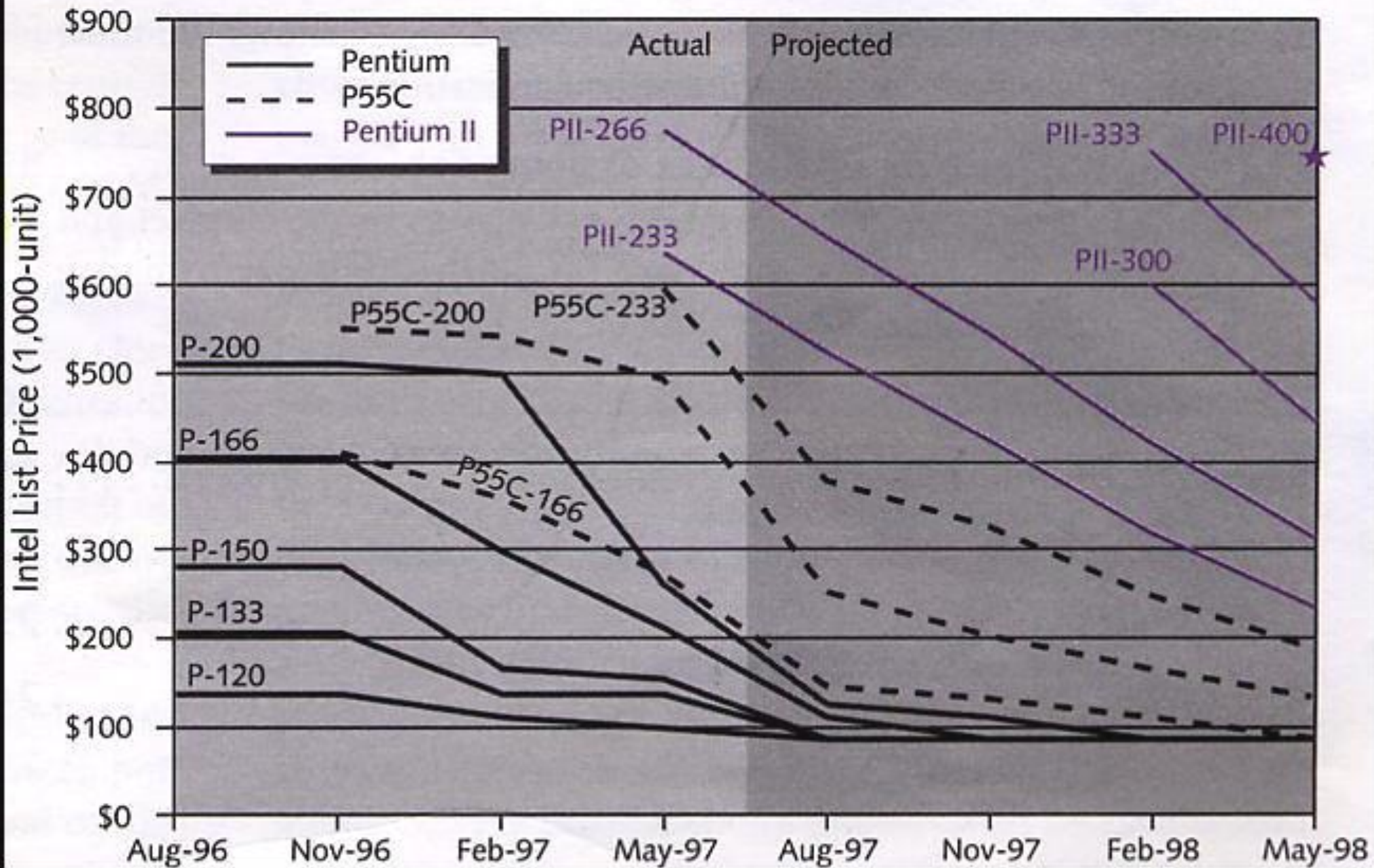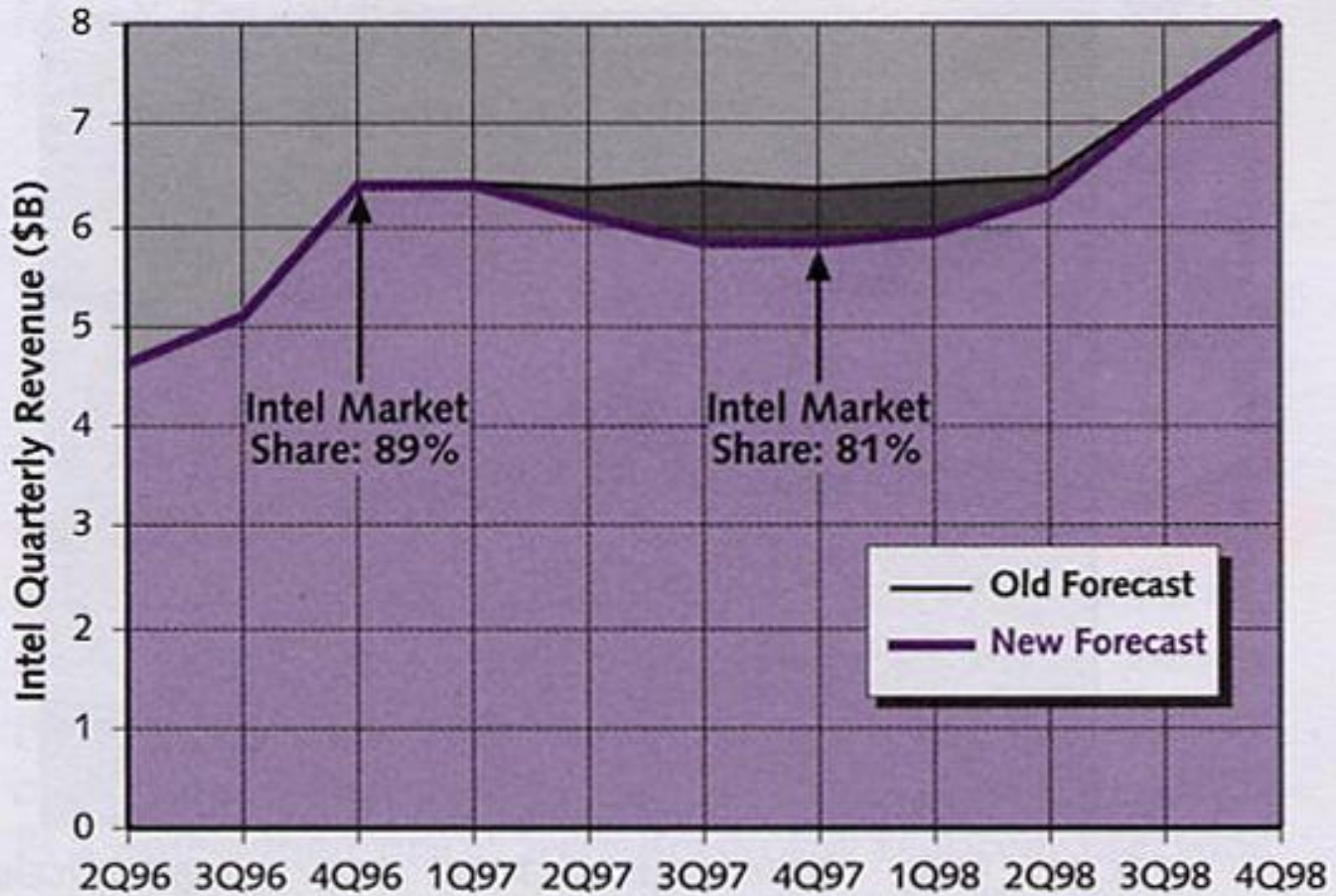   Speech synthesis and recognition
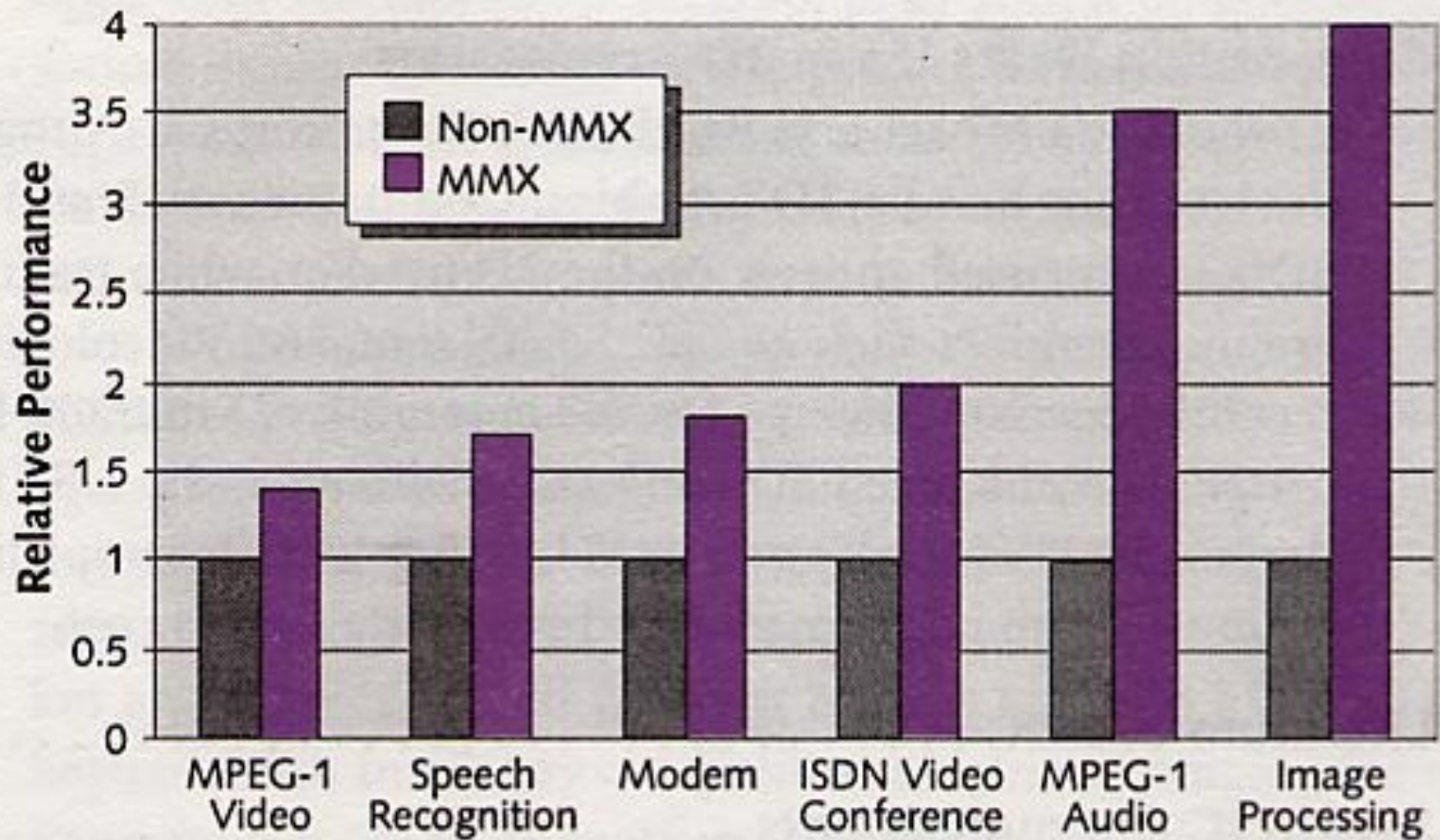
# Video of Intel's Superbowl Ad

Lessons Learned?

- Need to completely integrate new product development, production capacity, advertising and marketing

- New products need to be introduced frequently to keep ASP constant or at high levels

- Case explains the drive for continually shrinking technology

Case Study #3   Product Shelf Life

- In a rapidly changing technology, the product shelf life can exacerbate the problem.

Product Shelf Life Time Is Decreasing
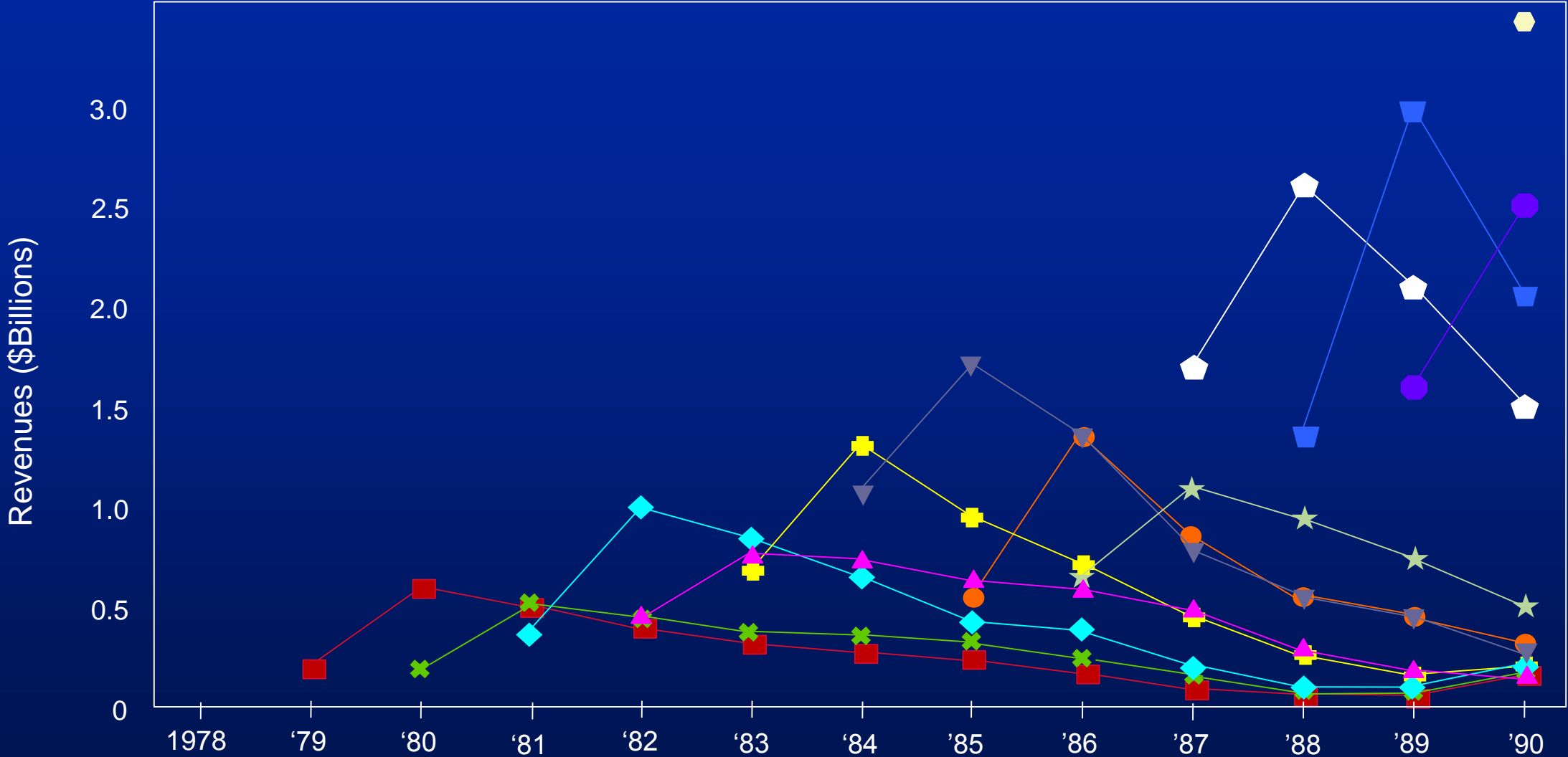
Revenues ($Billions)

3.0
2.5
2.0
1.5
1.0
0.5
0

1978 '79 '80 '81 '82 '83 '84 '85 '86 '87 '88 '89 '90
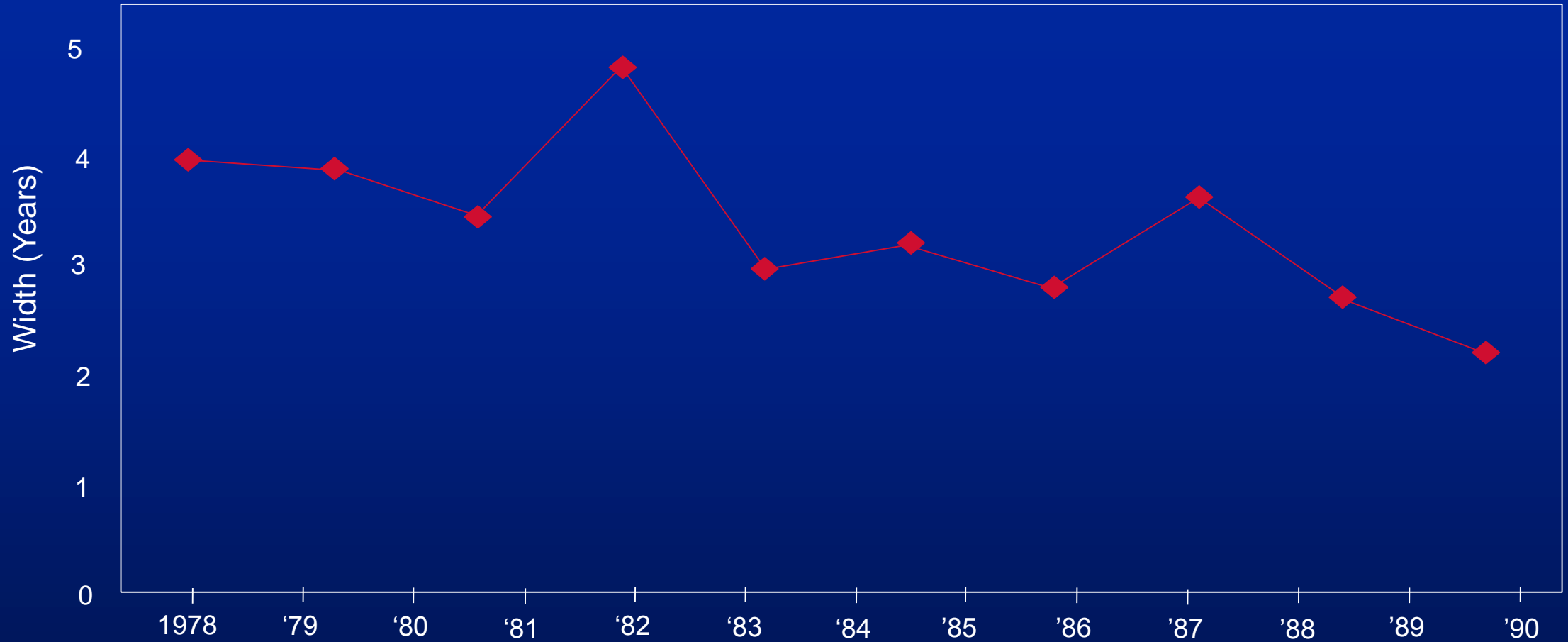
Source: Hewlett-Packard

Note: Each line on the graph represents the sales history over time of all those products launched the year at which the line originates.

Product Selling Price Is Also Decreasing Faster

Source: Hewlett-Packard

Note: Each point on the graph indicates the number of years between (1) the year that sales of a particular cohort of products first reached one-half their subsequent sales peak and (2) the year when sales again fell to that one-half peak level.

Case Study # 4

- **Intel's Weak Celeron Offerings**

Intel's Weak Celeron Offerings

- In late 1998 Intel's weak Celeron offering were being hammered by low-end chips from AMD and Cyrix.

- AMD was suffering at the time with an operating loss of $173M in the second quarter and a 26% decline CPU revenues.

- Intel was also feeling the pain, second quarter revenues and ASP were also down.

- **What should Intel have done?**

Intel's Weak Celeron Offerings

- On the first business day of 1999, Intel cut it's Celeron prices in half and introduced two new speed grades at the same time.

- A result of the aggressive campaign was Intel's market share soared to 81%. AMD lost share and could not sell 2.3 million processors.

- Intel's strategy was to use revenues from its high priced server products to offset declining prices in PC processors.

- Can this strategy be repeated today?

Case Study #5   2005

- One Laptop Per Child (OLPC)

- (The predecessor to Notebooks and Netbooks)

OLPC

Manufacturer: Quanta Computers

Connectivity: Wireless LAN

Media: 1 GB flash memory

Operating system: Linux

Input: Keyboard, Touchpad, Microphone, Camera

Camera: Built –in video camera (640x480; 30 FPS)

Power: Battery removable pack

CPU: AMD

Memory: 256 MB DRAM

Display: Dual-mode 19.1 cm/7.5" diagonal TFT LCD 1200x900

Cost: $188

OLPC

Displays

- Traditional barrier to building cheap laptops

- Need to be readable in bright sunlight and low lighting conditions

- Need power efficiency

OLPC

$100 Laptop Display

- Can be mass produced

- Resolution: 95% of the laptops at that time

- Uses 1/7 the power consumption

- Costs 1/3 price

- Can be read in bright sunlight or room light w/o backlighting

OLPC

Introducing the XO laptop.
Give 1 today

Give 1 Get 1 starting November 12

Starting November 12, 2007 OLPC will offer a

Give 1 Get 1 program

For $399 – purchase 2x10 laptops

One for a child in a developing nation

One for a child at home

OLPC Dismissed

- " A science project"

  Dismissed by Steve Jobs, Apple Computer

- " A Gadget"

  Dismissed by Craig Barrett, CEO Intel

- The idea of a battery-charging cran

  Mocked by Bill Gates, Microsoft

OLPC

- Was this a threat from below?

- Will the entry of low-cost laptops reduce Intel's margins?

- Is this a disruptive technology?

Intel's Classmate   2006

A rugged laptop based on Intel's 900Mhz Celeron with 256MB RAM and 2GB of flash memory, WiFi , Ethernet, and Linux O/S

A Via processor with a 1280 v 768 screen resolution, windows XP or Vista or either a hard drive or a 64GB solid state device.

ASUS's Low Cost Solution   2006

A Linux operating system with 4GB solid state drive, a built in DVD, and a suite of software to replace Microsoft Office.

- When Asustek launched its Eee PC in Fall 2007, they expected their customers to be from poor countries. Instead, their inventory was bought out by middle class consumers.

Budget Laptops of 2015

- http://www.cnet.com/topics/laptops/best-laptops/budget-laptops/

Microsoft Surface 3
$499.00

- 10.8" 1,920 x 1,080 touchscreen
- 1.6 GHz Quad-Core Intel Processor
- 2 GB RAM
- 64 GB SSD

Hisense Chromebook
$149.00

- 11" 1,366x768 touchscreen
- 1.8 GHz Rockchip Processor
- 2 GB RAM
- 16 GB SSD

Toshiba Chromebook 2
$299.00 - $320.09

- 13.3" 1,920 x 1,080 LED display
- 2.16 GHz Dual-Core Intel Processor
- 4 GB RAM
- 16 GB SSD

Acer Chromebook 15
$305.11 - $327.93

- 15.6" 1,920 x 1080 LED display
- 1.5 GHz Dual-Core Intel Processor
- 4 GB RAM
- 16 GB SSD

HP Stream 11.6
$199.00

- 11.6" 1,366 x 768 WLED display
- 2.16 GHz Processor
- 2 GB RAM
- 32 GB SSD

Budget Tablets of 2015

- http://www.cnet.com/topics/laptops/best-tablets/budget-tablets/

Amazon Kindle Fire HDX 7
$235.49

- 7" 1,920 x 1,080 Multi-Touch Display
- 2.2 GHz Quad-Core ARM Processor
- 2 GB RAM
- 16 GB Integrated Storage

Samsung Galaxy Tab A (8-inch)
$179.00 - $ 229.99

- 8" 1,024 x 768 Multi-Touch Display
- 1.2 GHz Quad-Core Qualcomm Processor
- 2 GB RAM
- 16 GB SSD

Dell Venue 7
$129.96

- 7" 1,280 x 800 Multi-Touch Display
- 1.6 GHz Dual-Core Intel Atom Processor
- LPDDR3 SDRAM
- 16 GB Integrated Memory Storage

Amazon Fire HD 6
$99.00

- 6" 1,280 x 800 Multi-Touch Display
- 1.5 GHz Quad-Core ARM Processor
- 2 GB RAM
- 16 GB SSD

Apple iPad Mini 3*
$399.00

- 7.9" 2,048 x 1,536 Retina Multi-Touch
- 1.3 GHz Dual-Core (ARM) Apple A7
- 1 GB RAM – A7
- 16 GB Integrated Storage

Disruptive Technologies?

- Flash memory vs. spinning hard drive

  It uses little power and doesn't break when dropped. Consumer price is 2MB for 1 penny.

- Ingenious LCD panel that detects when onscreen images are static and tells the CPU to shut down
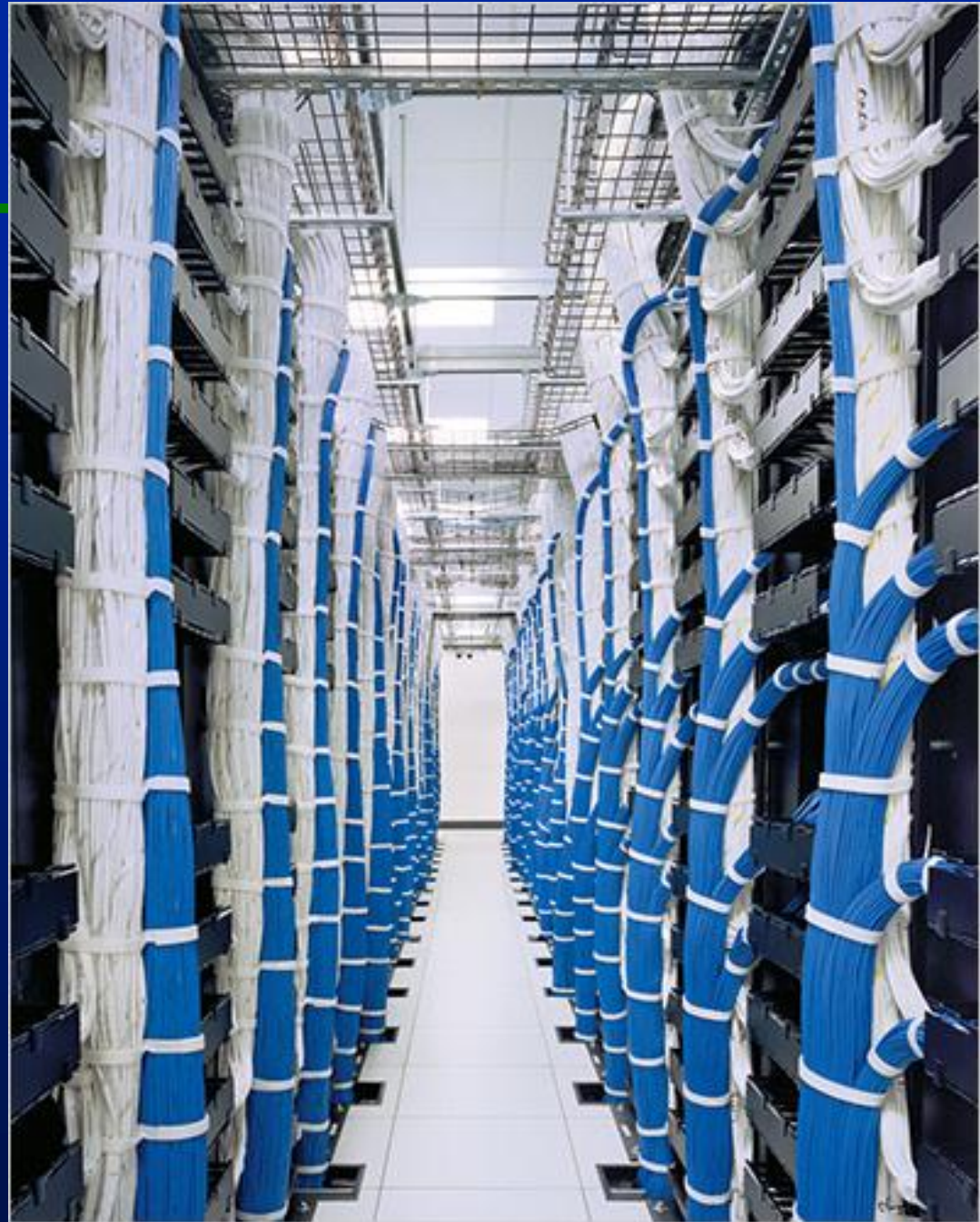
DATATECTURE

Flickr. MySpace. iTunes. Gmail.

In our hyperconnected, superfast age, how can the Internet data centers we've built keep up?

→

Quincy, Wash., home to rows of servers in a 500,000-square-foot data center that Microsoft built in 2006.

(Tom Vanderbilt. "Datatecture," The New York Magazine, 6.14.09)

Water-Powered Computers

"Every economic era is based on a key abundance and a key scarcity."

George Gilder,
Forbes ASAP, 1992

Four Commandments

1. Moore's Law

2. Rock's Law

3. Metcalfe's Law

4. Wirth's Law

Moore's Law

1965 "Cramming More Components onto Integrated Circuits"

(anniversary issue of Electronics, April 1965)

- Predicted an annual doubling of components which could be fabricated on a semiconductor chip.

- Also included a cartoon with a sales booth for "home computers" – another prescient insight

Actually, by 1975, doubling period was 17 months

1985, doubling period was 22 months

1995, doubling period was 32 months

today, doubling period is 23 months

Moore's Law *(continued)*

- Original paper noted that the cost per electronic component was inversely proportional to the number of components/chip

- In 1988 Erich Bloch (then head of IBM's research division), later Chairman of NSF Board, & sponsor for Cornell's Theory Center

  "Moore's law won't work at feature sizes less than a quarter of a micron (250 nanometers)"

- Moore, underestimated the staying power of photolithography, "No exponential trend lasts forever, but forever can be postponed"
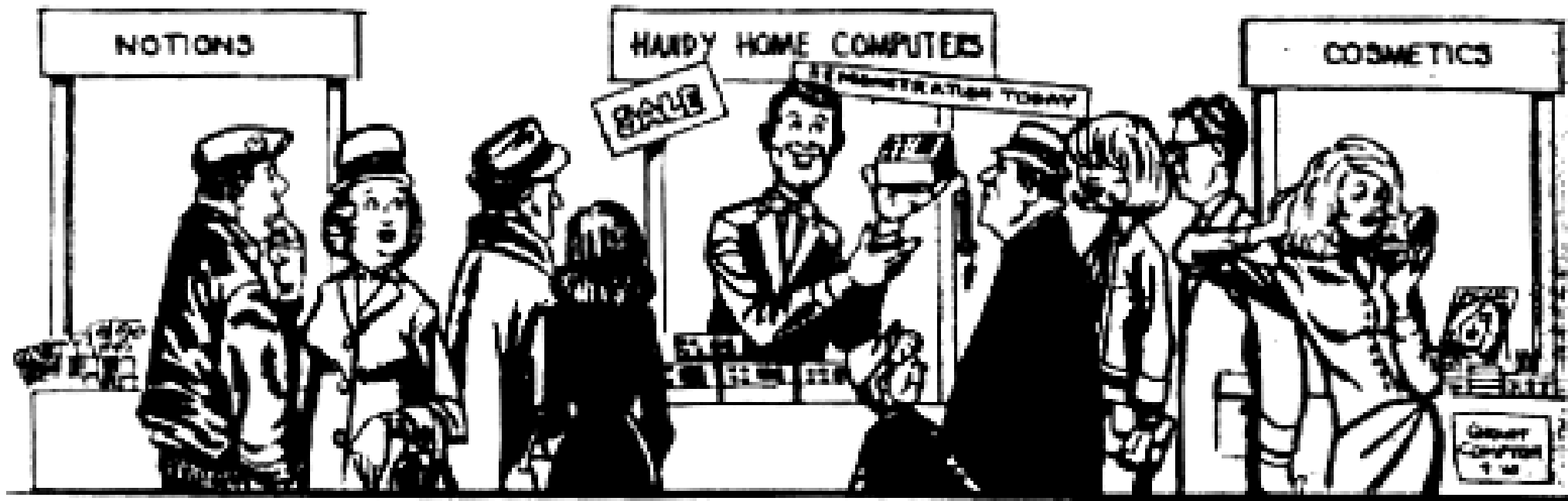
Rock's* Law

"The cost of semiconductor tools will double every four years"

Actually this was not true and current cost is $3 – 4B (slightly more than in the1990's)

What actually happened was:

    1980's. . .increase in yield
    1990's. . .increase in throughput
          (from 20 wafers/hr. $\rightarrow$ 50 wafers/hr.)
    Now, reduced size with 193μm stepper and larger wafers (300mm)

Rock was an initial investor in Intel

Metcalfe's* Law

"The value of a network grows as the square of the number of users"

≈ 1980 - later in "There Oughta be a Law," NY Times 1996

- Unlike the previous laws, this can't be quantified because value (what economists call utility) can't be measured.

- However, note the impact of search engines, and the business model of Google, Yahoo, etc.

Inventor of the Internet standard

Wirth's* Law

"Software is slowing faster than hardware is accelerating"

IEEE Computer 1995

"Were it not for a thousand times faster hardware, modern software would be utter unusable"

- Most of the features that bloated the programs were superfluous for most of the users most of the time

* Niklaus Wirth, Professor of ETH, Zurich and inventor of Pascal

END. . .

Case Study #6 — Cloud Computing

Mobile Internet Outpaces Desktop Internet Adoption
iPhone + iTouch Users = 8x AOL Users 9 Quarters After Launch

Philip Elmer-Dewitt. "Morgan Stanley drinks the Apple Kool-Aid," CNNMoney.com, 12/16/09
http://brainstormtech.blogs.fortune.cnn.com/2009/12/16/morgan-stanley-drinks-apple-kool-aid/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:+fortuneapple20+%28FORTUNE:+Apple+2.0%29
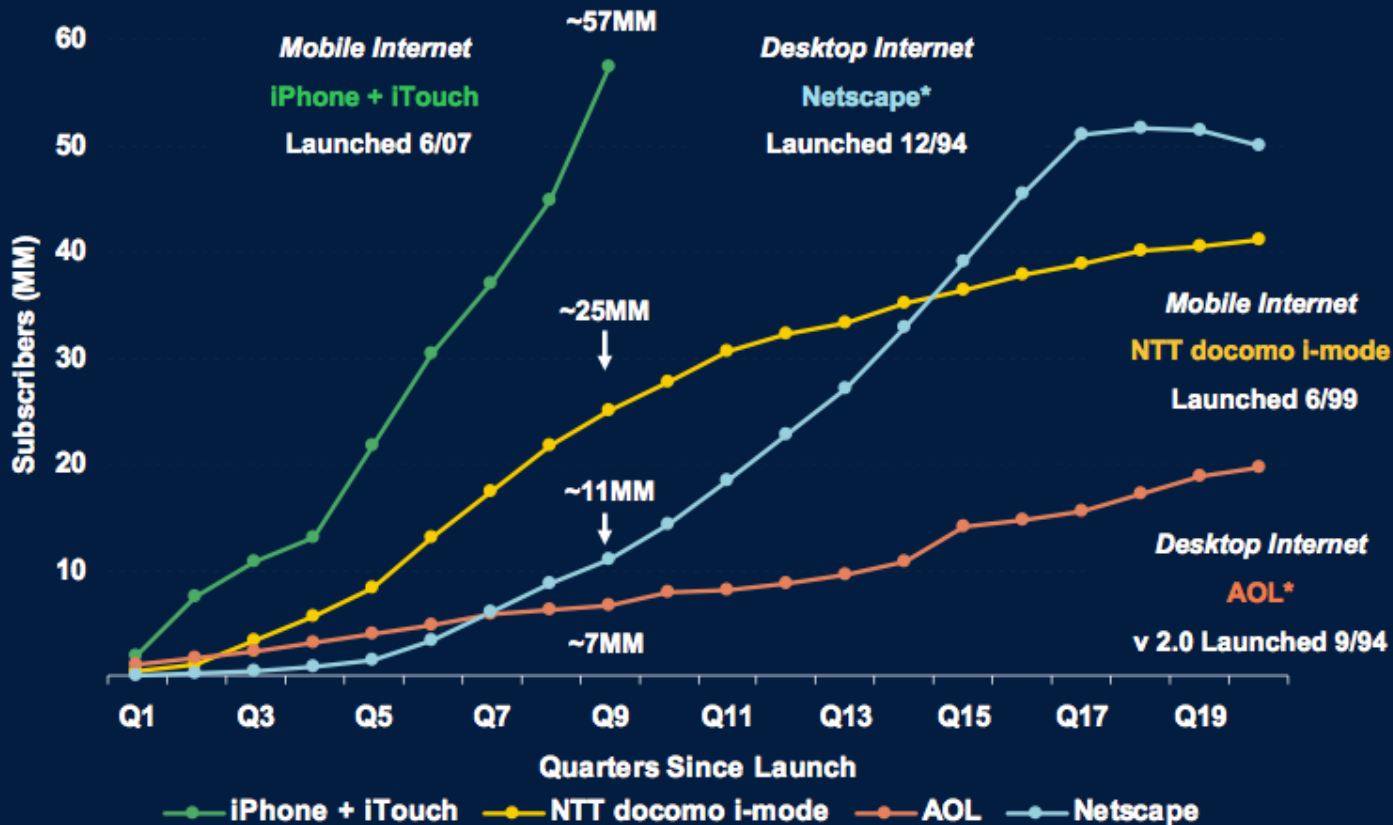
Mobile Internet growth

- International Data Corporation (IDC) predicts 16.6% growth rate for mobile Internet devices between 2010 and 2015

- There will be more mobile users than wireline users with the booming market for smartphones and tablet PCs

Cloud Computing - Pros

- No development program – the infrastructure is already in-place

- Existing data centers (e.g. Amazon, Google, etc.) can rent spare capacity

- Enables start-ups to offer on-line applications immediately without major capital investments

Cloud Computing - Cons

- Integrity and security of user's data is not guaranteed

- Lack of standards to allow companies to move from one provider to another

- The entire system depends on available bandwidth

Conjuring Clouds

BIG SEVEN
A survey of 1,771 firms showed they plan on using these public cloud vendors by mid-2009

- Google — 20%
- Microsoft — 15%
- IBM — 15%
- Amazon — 13%
- Salesforce.com* — 12%
- Sun Microsystems — 8%
- VMware — 8%
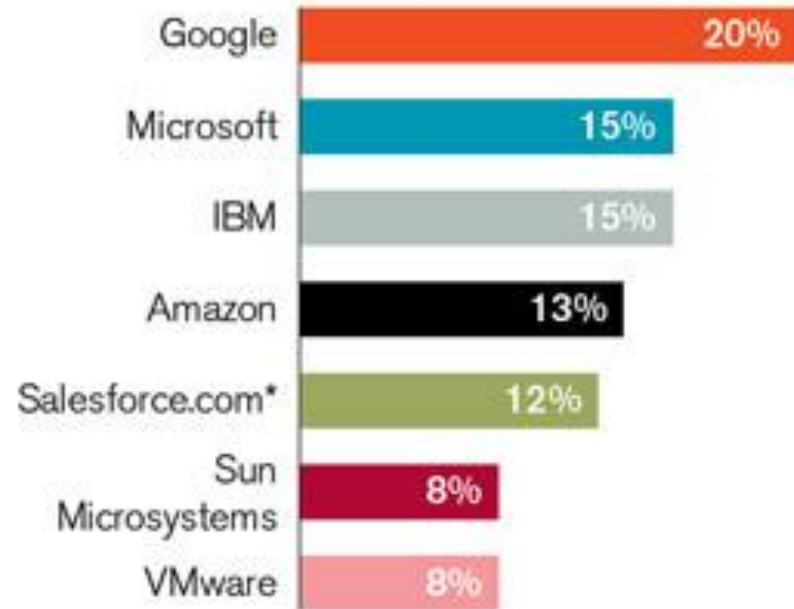
Source: The 451 Group

Conjuring Clouds
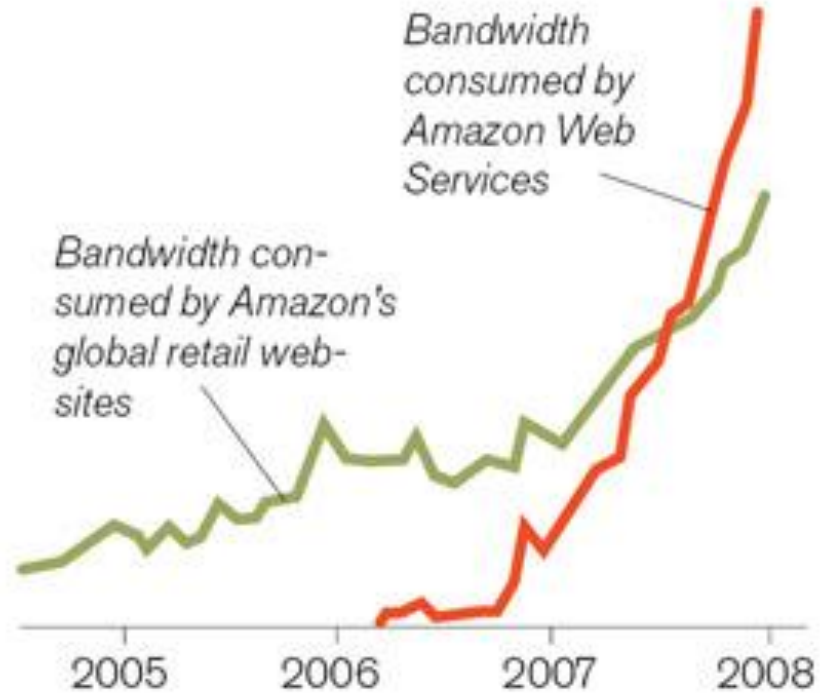
(Platform as a service)
Allows developers to run applications

DATABASE | WEB SERVER

APPLICATION RUN-TIME ENVIRONMENT

IaaS
VIRTUAL INFRASTRUCTURE
(Infrastructure as a service)

MANAGEMENT LAYER
Customer can choose required resources as needed

P P P P P
S S S S S

VIRTUALIZATION LAYER
Each physical server can host a number of virtual servers

P P P P P
S S S S S

HARDWARE LAYER
Physical servers, disk arrays & network hardware

Virtual Computers, Real Money

TOP USES FOR CLOUD COMPUTING
Based on an October 2008 survey of 1,771 companies

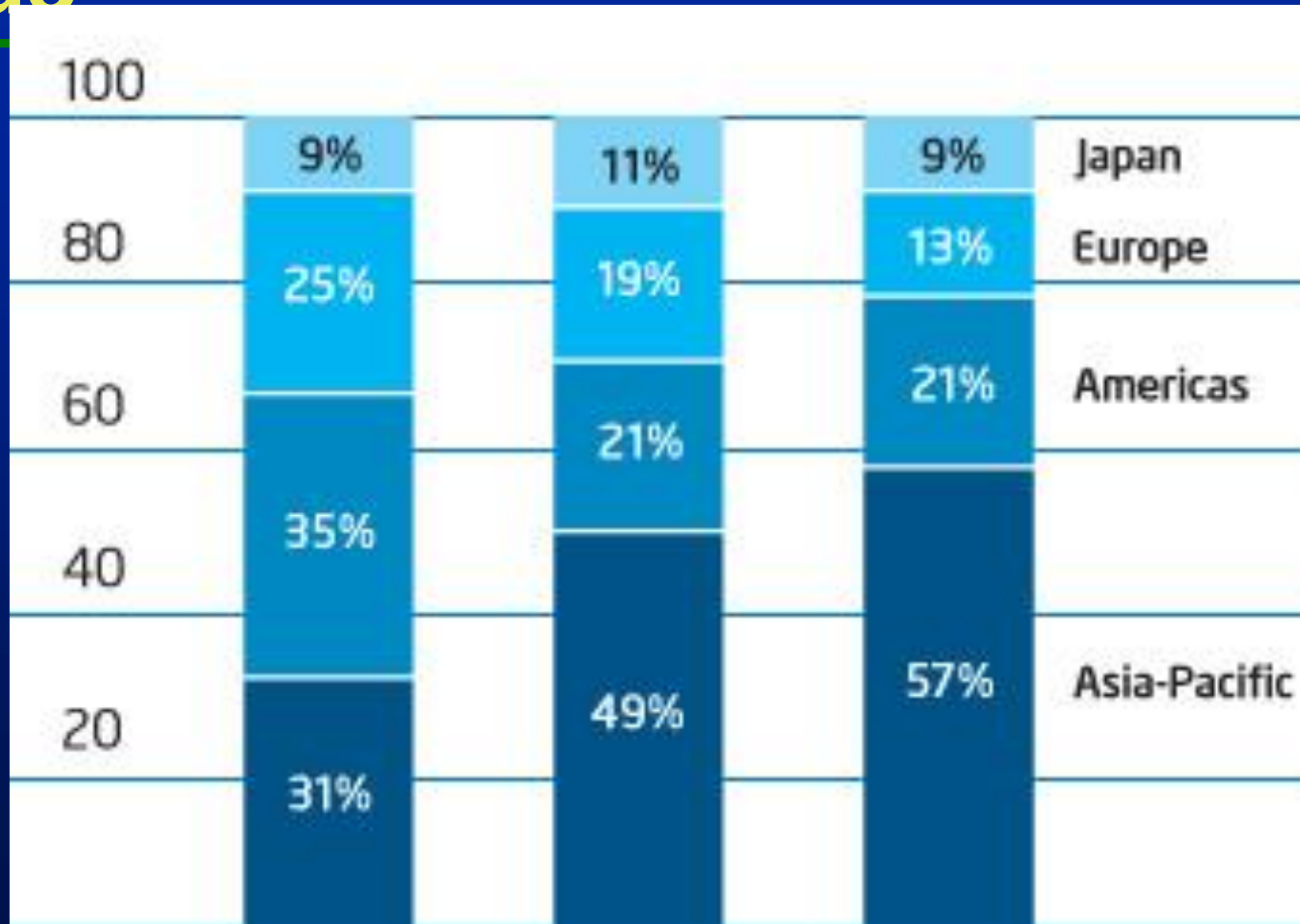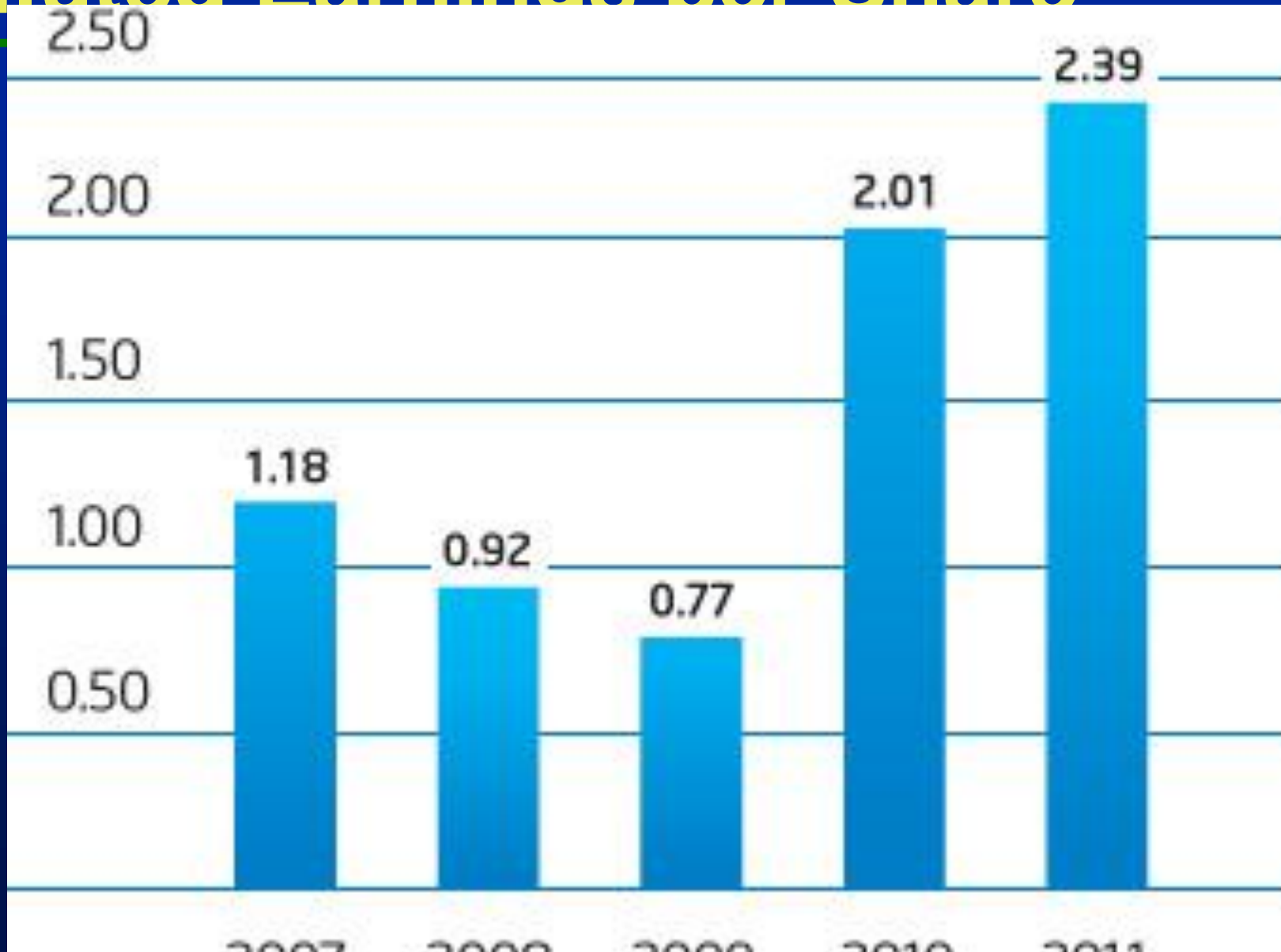| Use	Percentage
Internet application hosting	50%
Databases	32%
Disaster recovery	26%
Remote storage	26%
Application testing & development	22%
Batch computing jobs	9%
Billing	4%
Log processing	1%
Don't know	4%
Other	13%
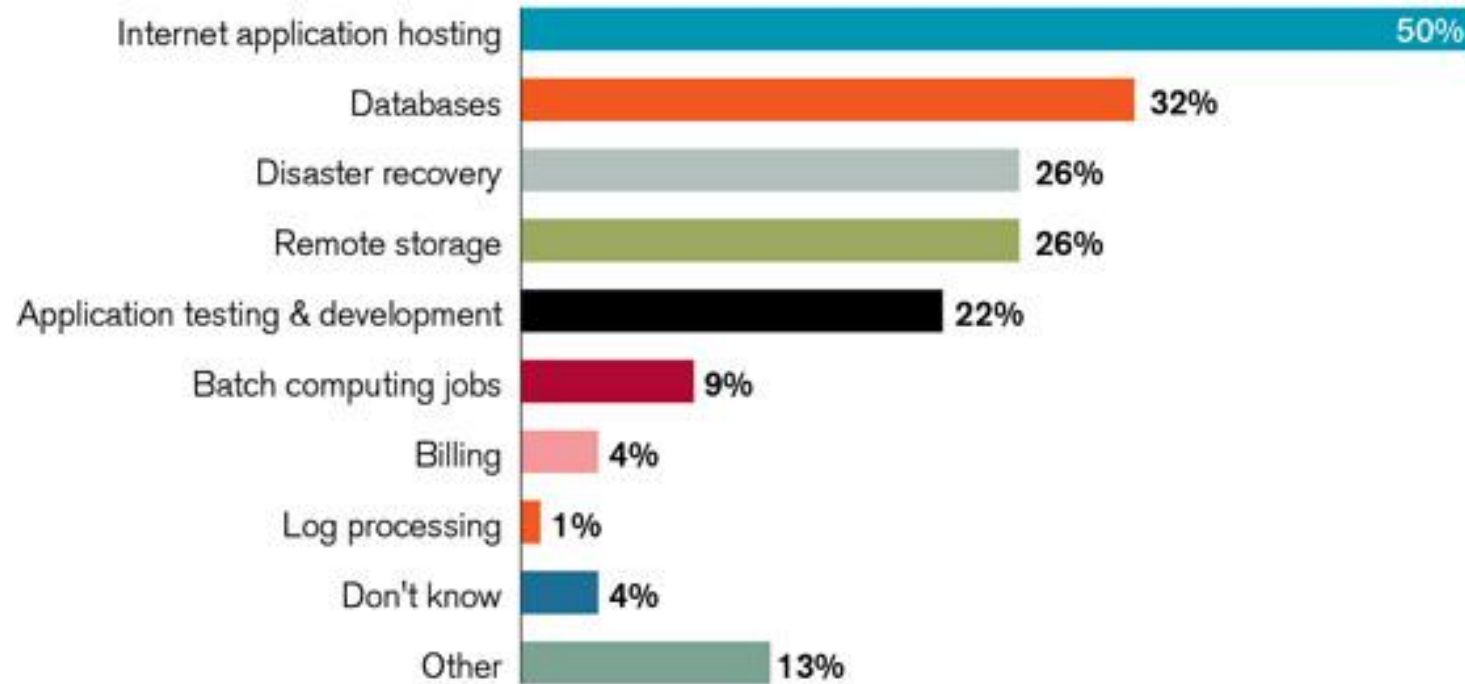
Source: The 451 Group

Intel Net Revenue
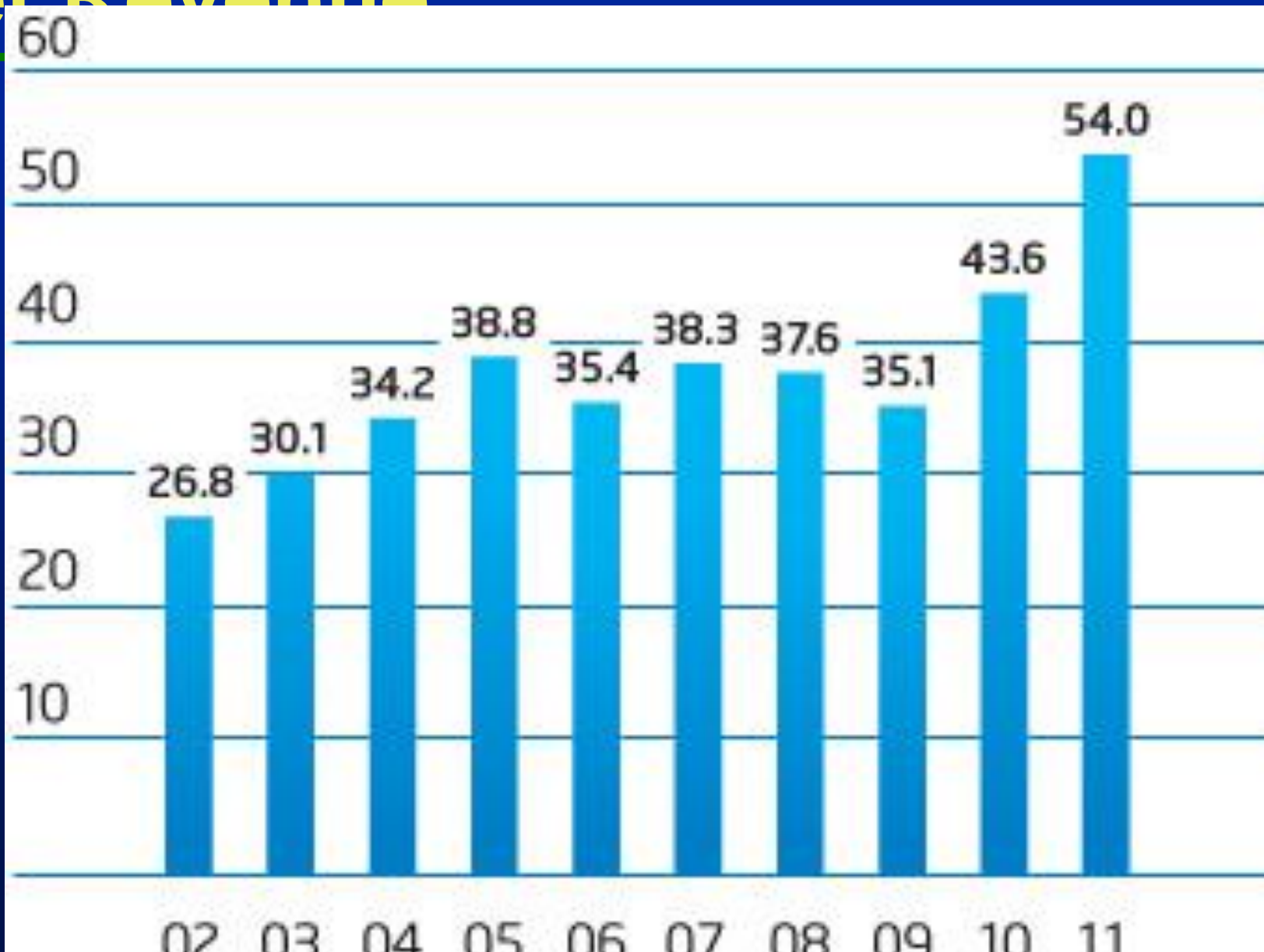
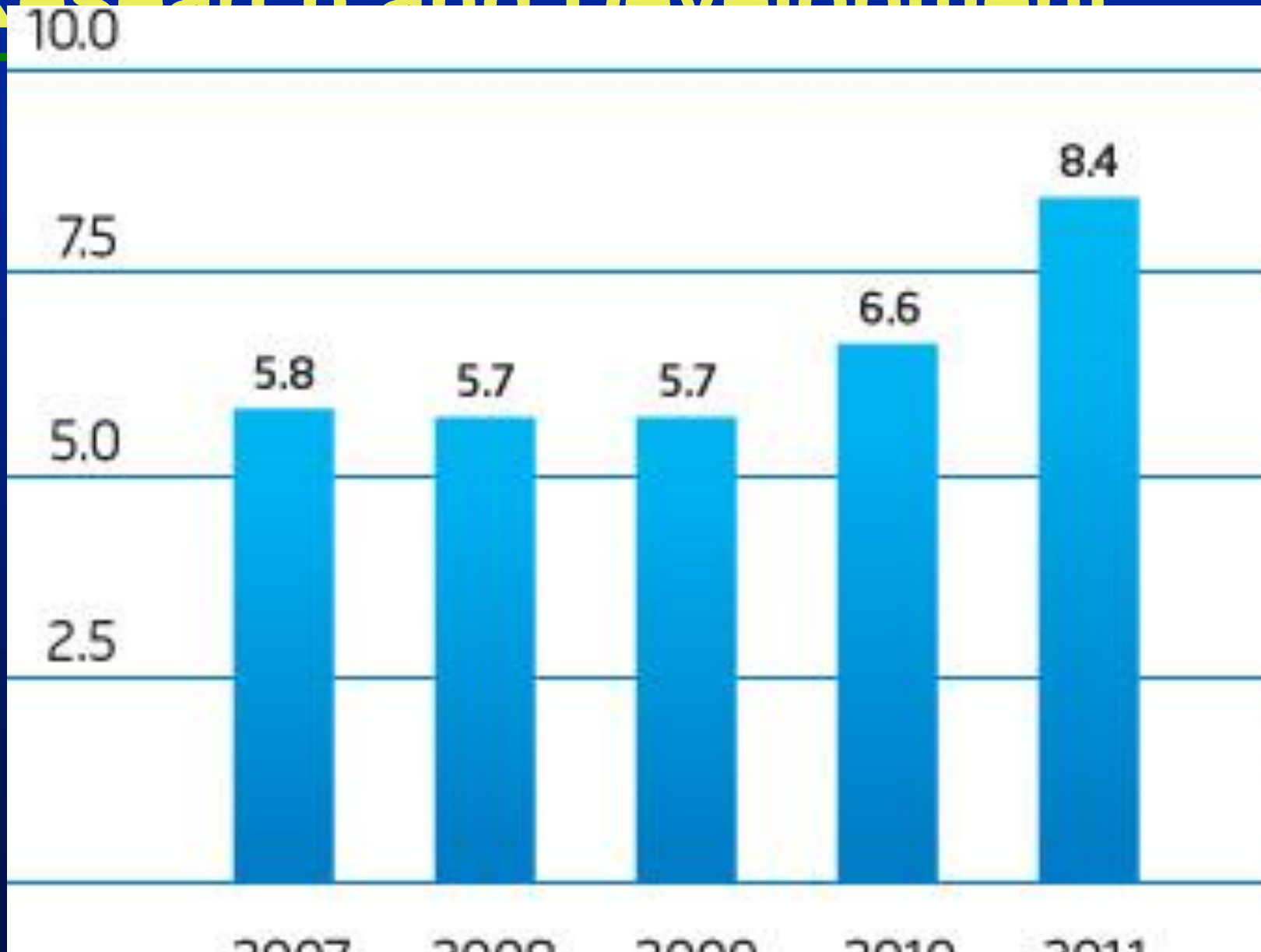# Intel Geographic Breakdown of Revenue

Intel Diluted Earnings per Share

Intel Capital Additions to Property, Plant and Equipment
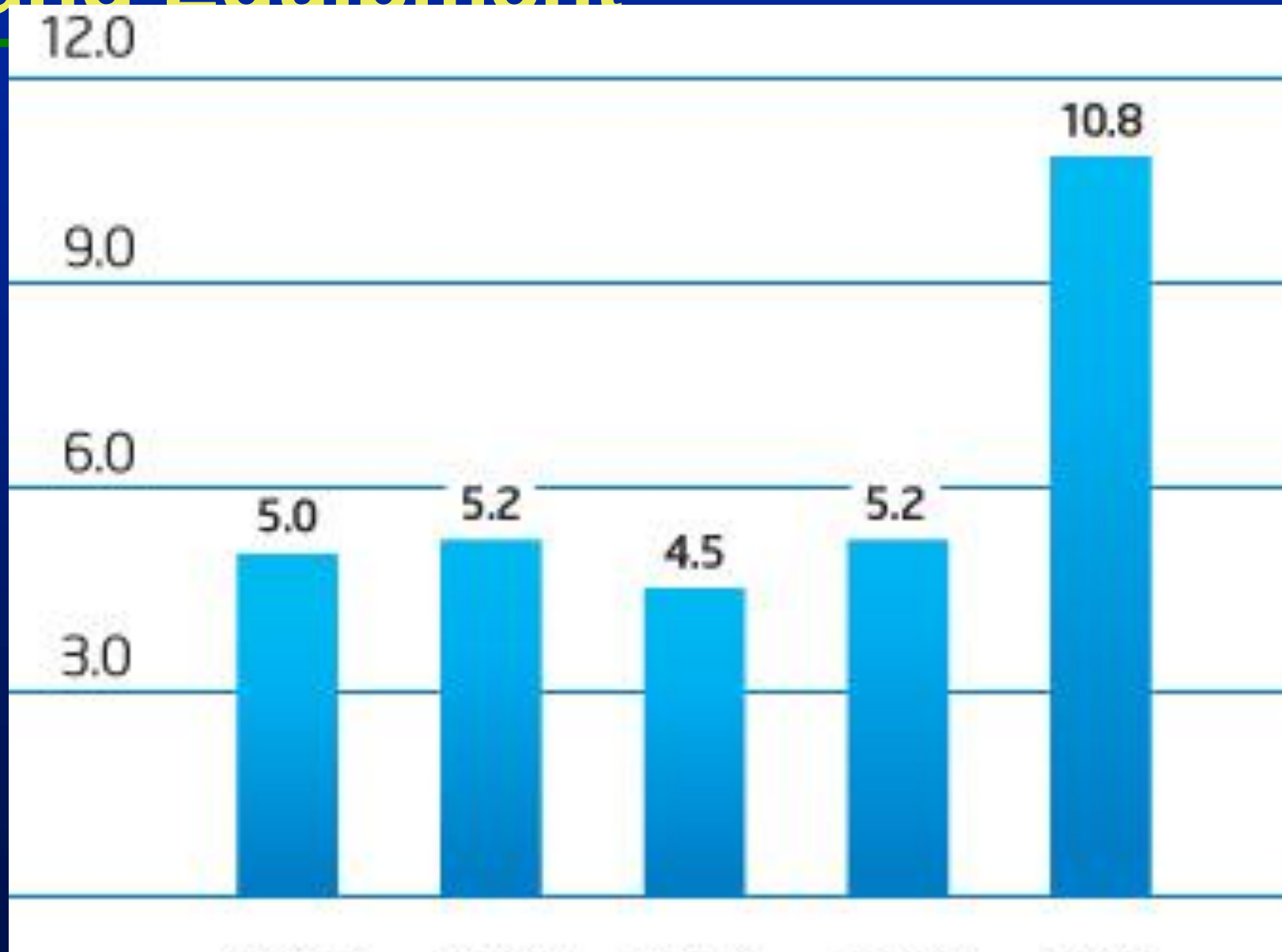
Intel Research and Development

Intel's Antitrust Behavior

|	
Before 2009	For many years AMD has claimed that Intel rewarded computer makers that used <u>only</u> Intel chips and punished those who bought from AMD.
May 2009	European Union fines Intel a record $1.45B for anti-trust practices.
November 2009	New York attorney general Andrew Cuomo filed a wide-ranging anti-trust suit against Intel.
November 2009	Intel, facing antitrust challenges around the world, announced it would pay AMD $1.25 B.

Yahoo sites

140

Microsoft sites

120

100 ——— AOL
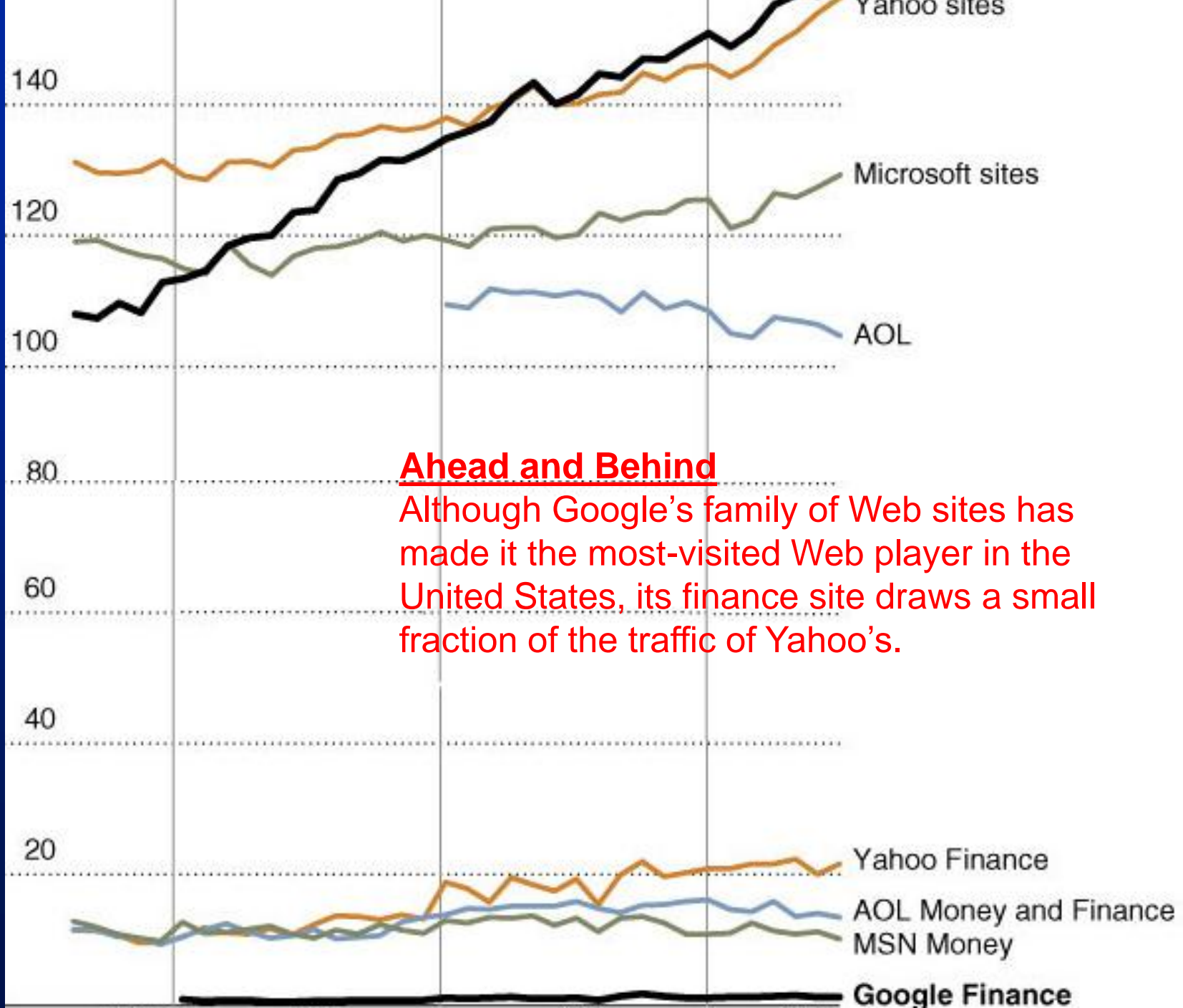
80   **Ahead and Behind**
Although Google's family of Web sites has
60   made it the most-visited Web player in the
United States, its finance site draws a small
fraction of the traffic of Yahoo's.

40

20 ——— Yahoo Finance

——— AOL Money and Finance
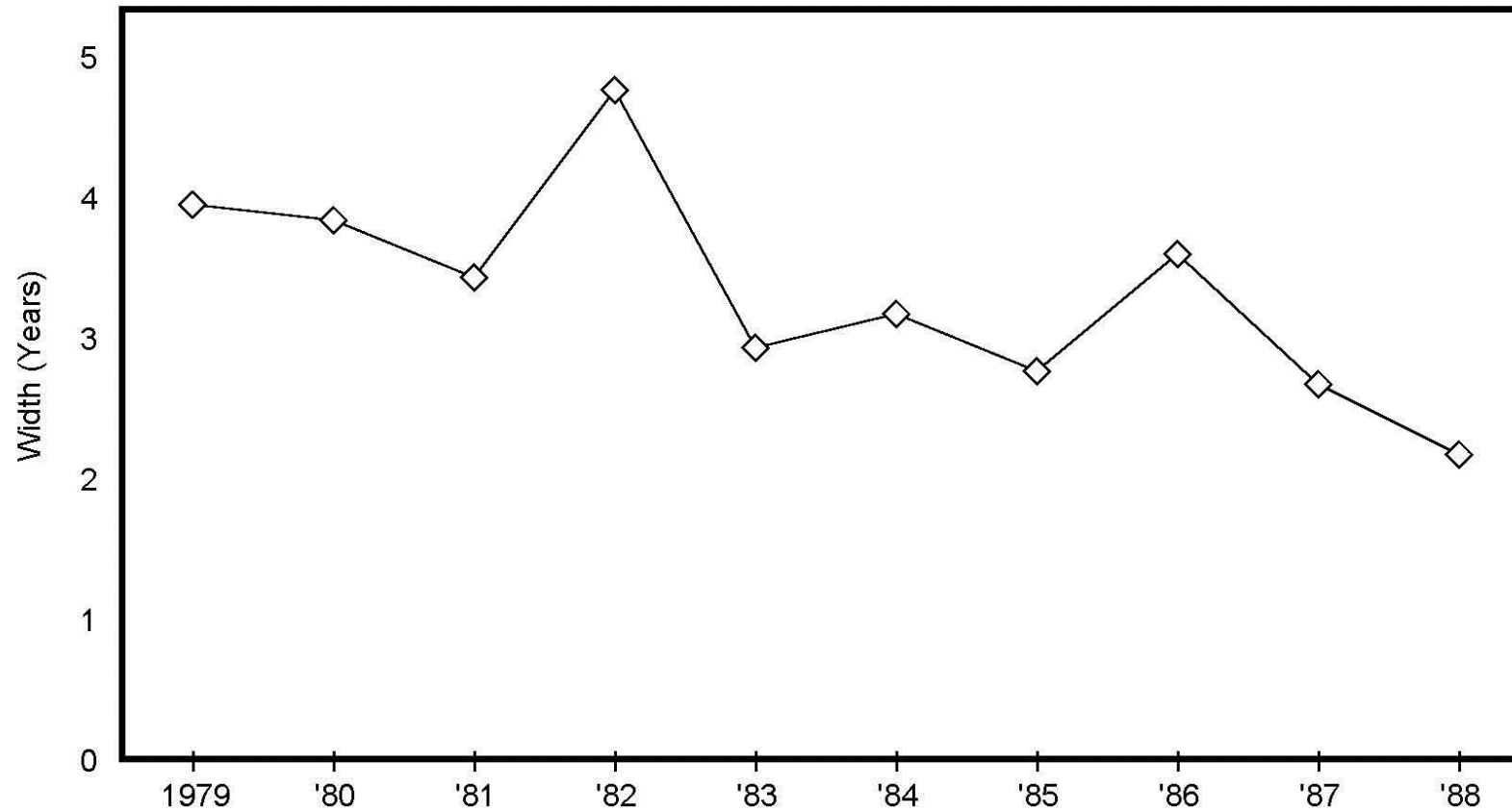MSN Money

Google Finance

Exhibit 1   Product Sales History
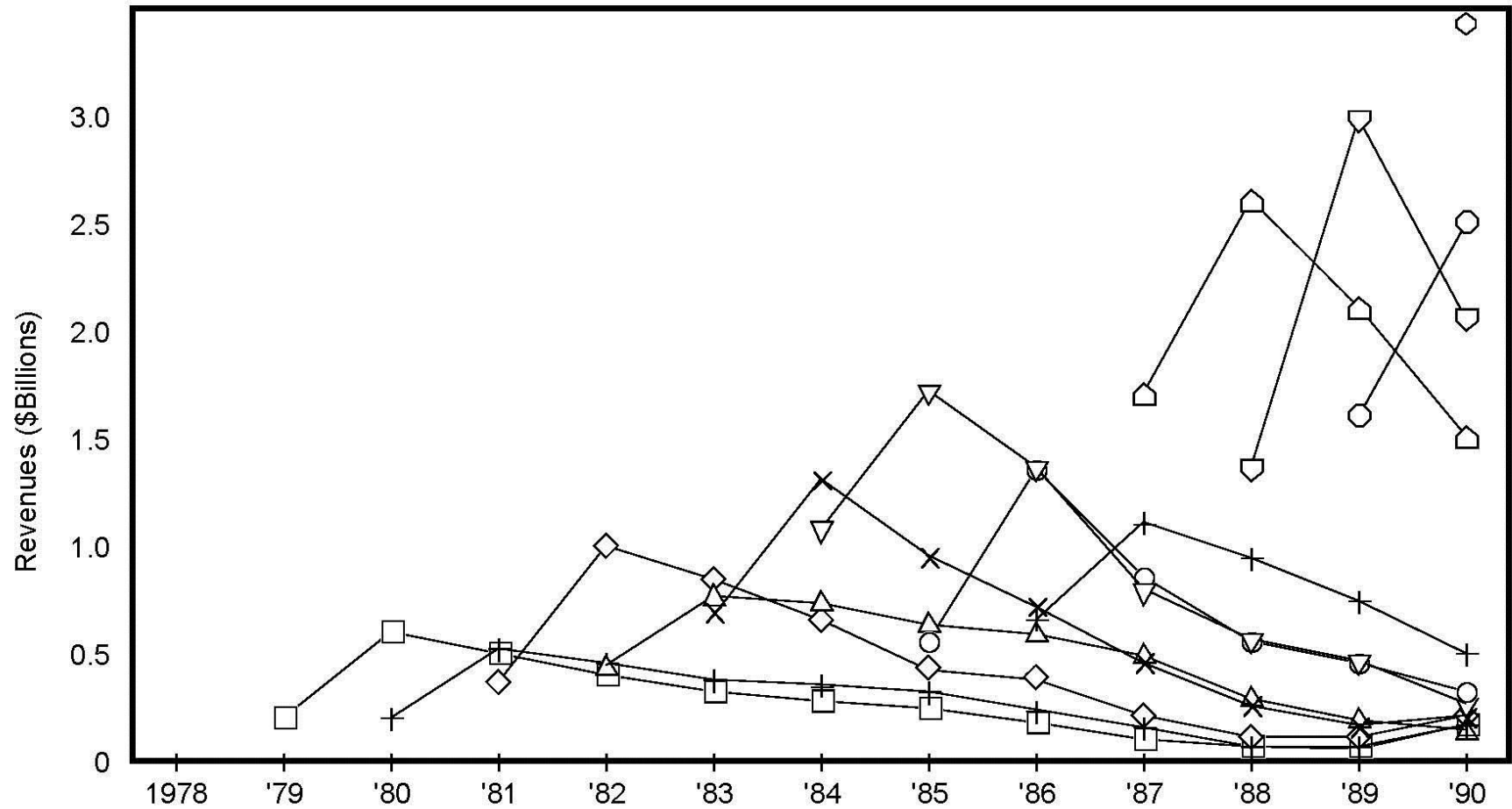
Source: Hewlett-Packard

Note: Each line on the graph represents the sales history over time of all those products launched the year at which the line originates.

**Exhibit 2**   Sales Windows for Product Cohorts

Source: Hewlett-Packard

Note: Each point on the graph indicates the number of years between (1) the year that sales of a particular cohort of products first reached one-half their subsequent sales peak and (2) the year when sales again fell to that one-half peak level.

END. . .

"Every economic era is based on a key abundance and a key scarcity."

George Gilder,
Forbes ASAP, 1992

Windows and Intel, Kings of the PC: Divided They Fall?
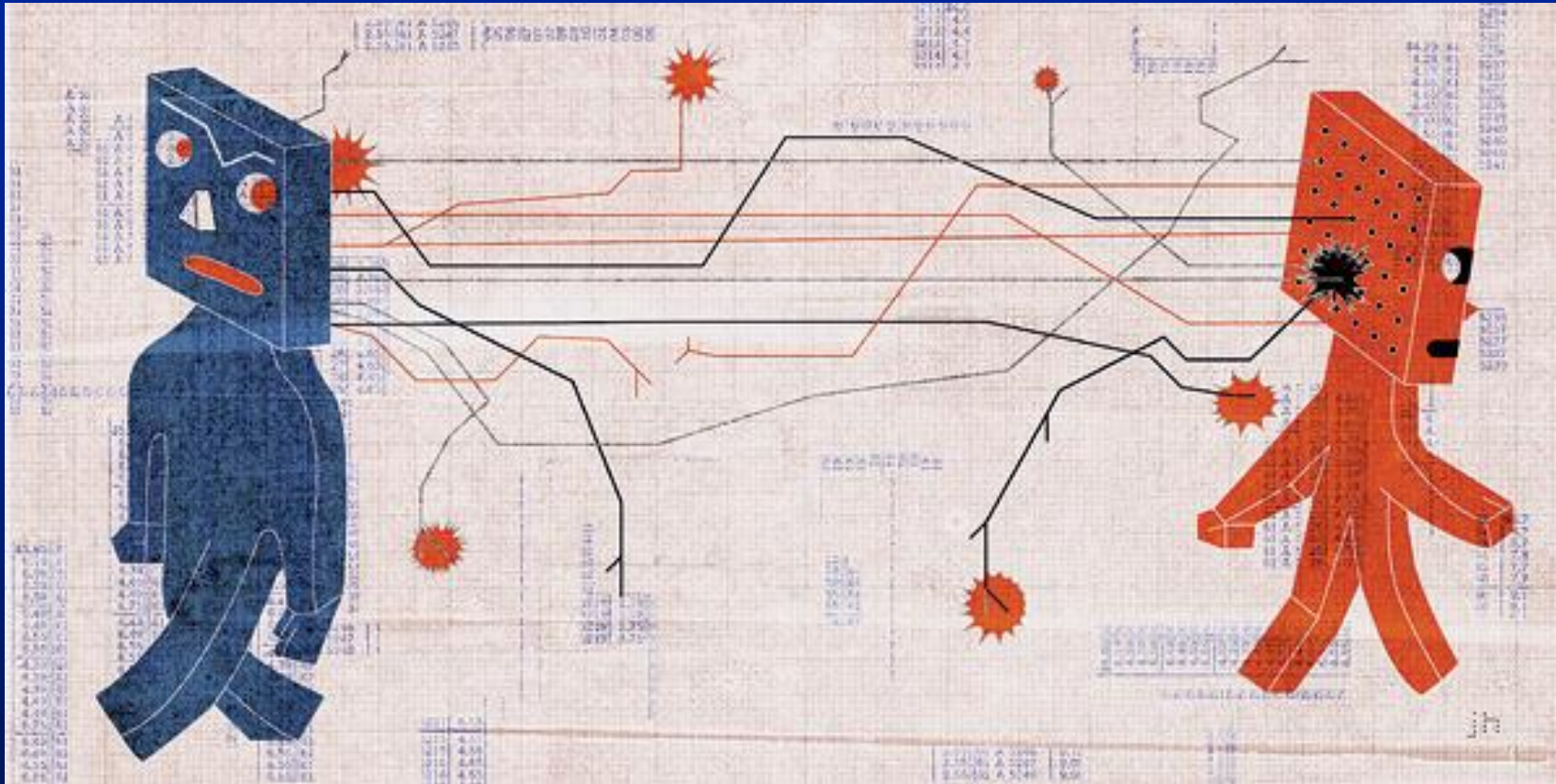
- A legendary partnership is strained by the rise of mobile and Web computing, and the companies' own outside ventures
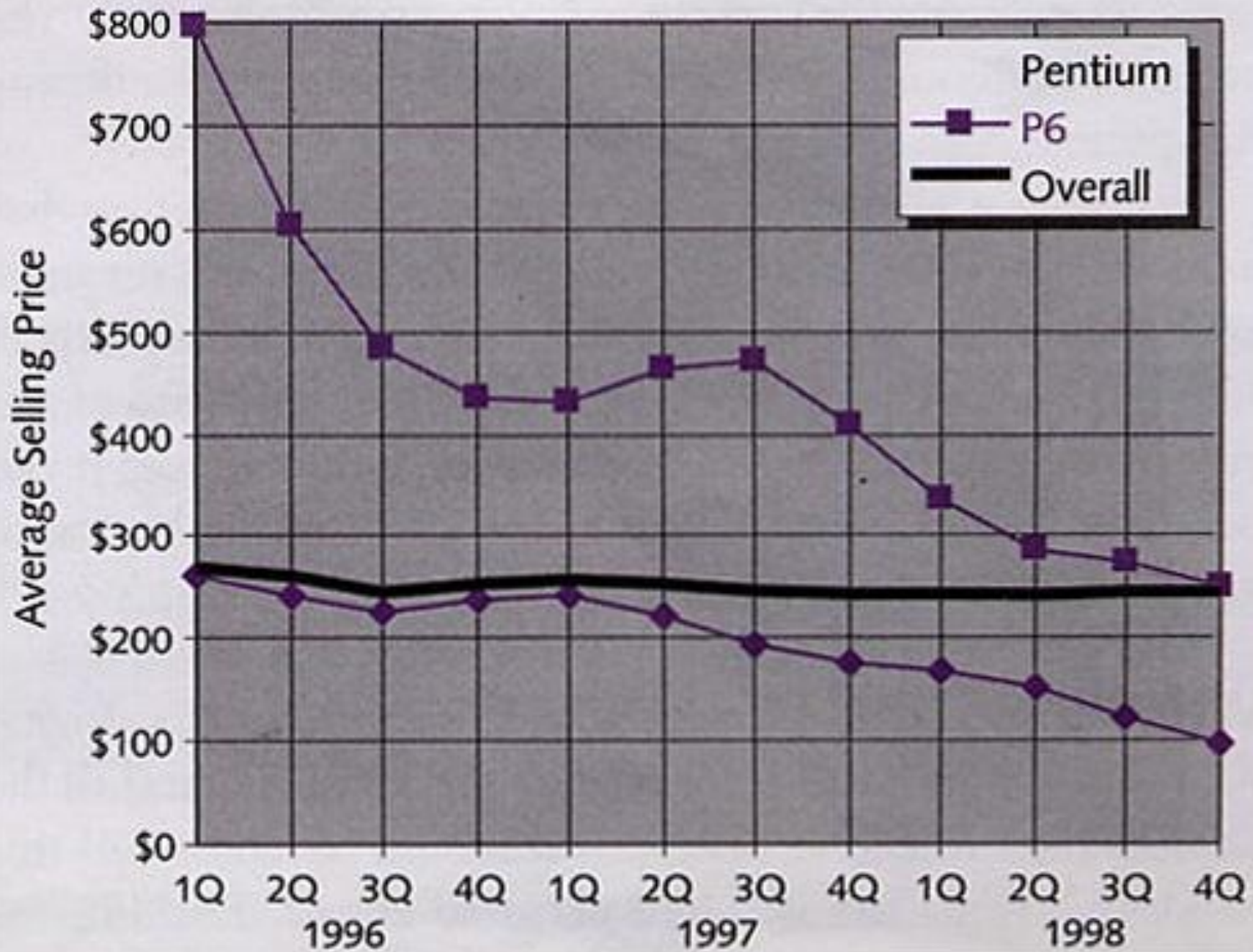
Microprocessor Price Wars

AMD can't sell 2.3M K6 processors
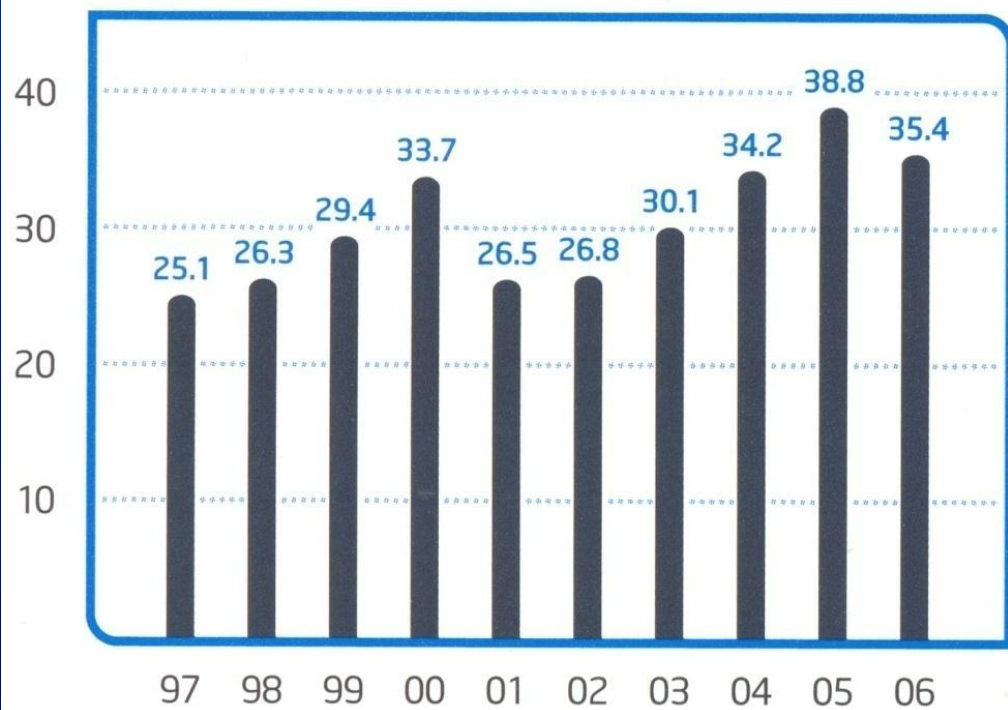   Starts to lose money

Intel's ASP holds by using revenues from high end Xeon products to offset declining low end prices
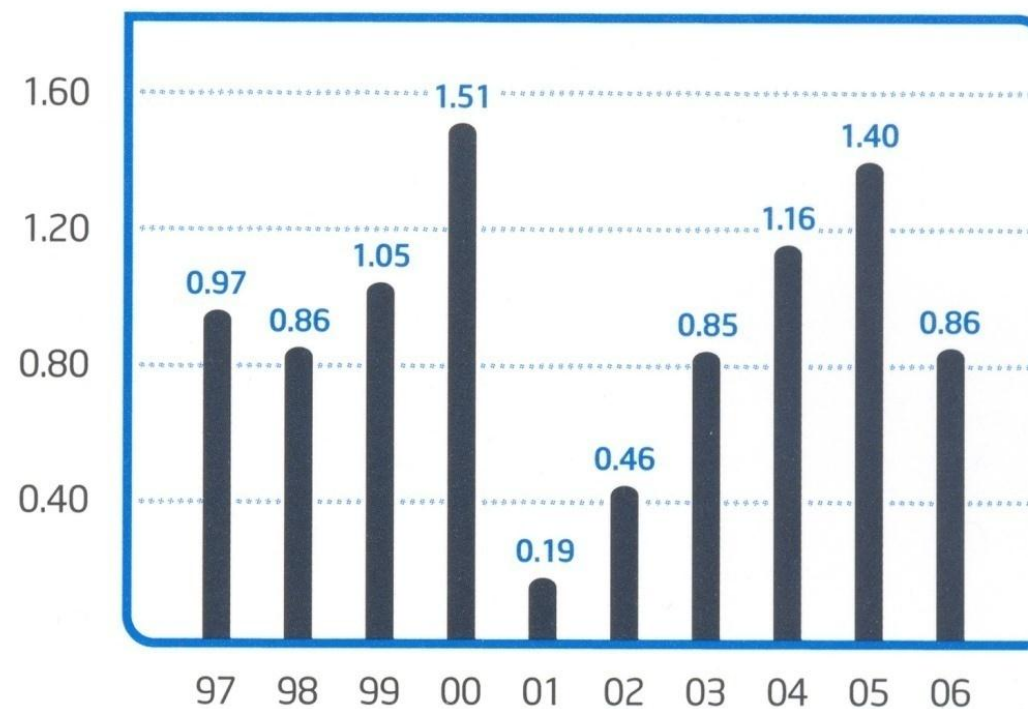
END. . .

Net Revenue
Dollars in billions

Year	Value
97	25.1
98	26.3
99	29.4
00	33.7
01	26.5
02	26.8
03	30.1
04	34.2
05	38.8
06	35.4

Diluted Earnings Per Share
Dollars, adjusted for stock splits

Year	Value
97	0.97
98	0.86
99	1.05
00	1.51
01	0.19
02	0.46
03	0.85
04	1.16
05	1.40
06	0.86

Case Study #5

Top PC Vendors Adopt Transmeta's Crusoe

Transmeta's Magic Show – IEEE Spectrum – May 2000

Microprocessor Report, July 10, 2000
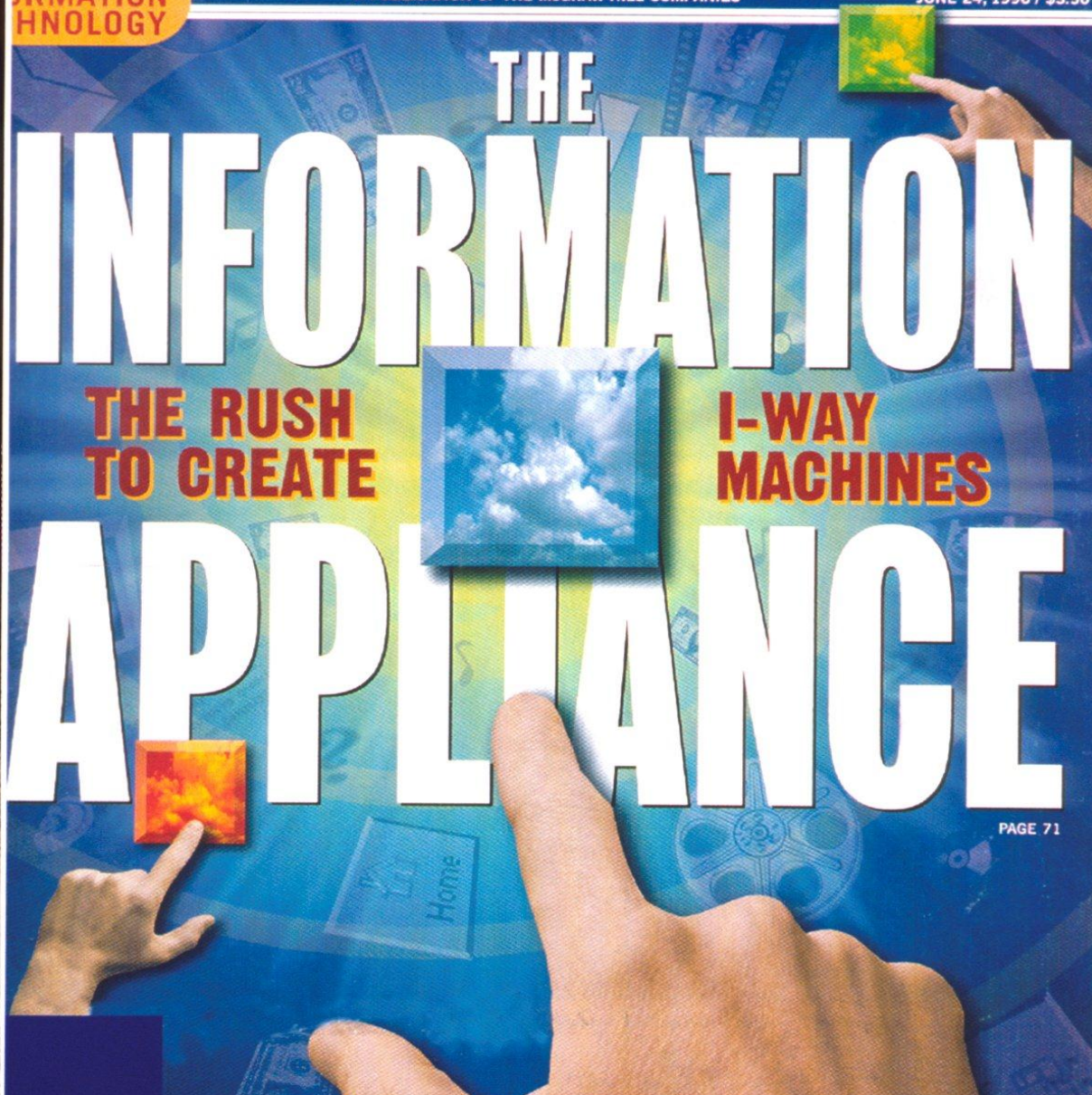
BusinessWeek

THE INFORMATION APPLIANCE

**THE RUSH TO CREATE**

I-WAY MACHINES

PAGE 71

Home

"To grasp the new era, you must imagine that bandwidth will be free and watts scarce. If the law of thrift in the old paradigm <u>was waste watts and transistors</u>, the law of thrift in the new paradigm will <u>be waste bandwidth and save watts</u>."

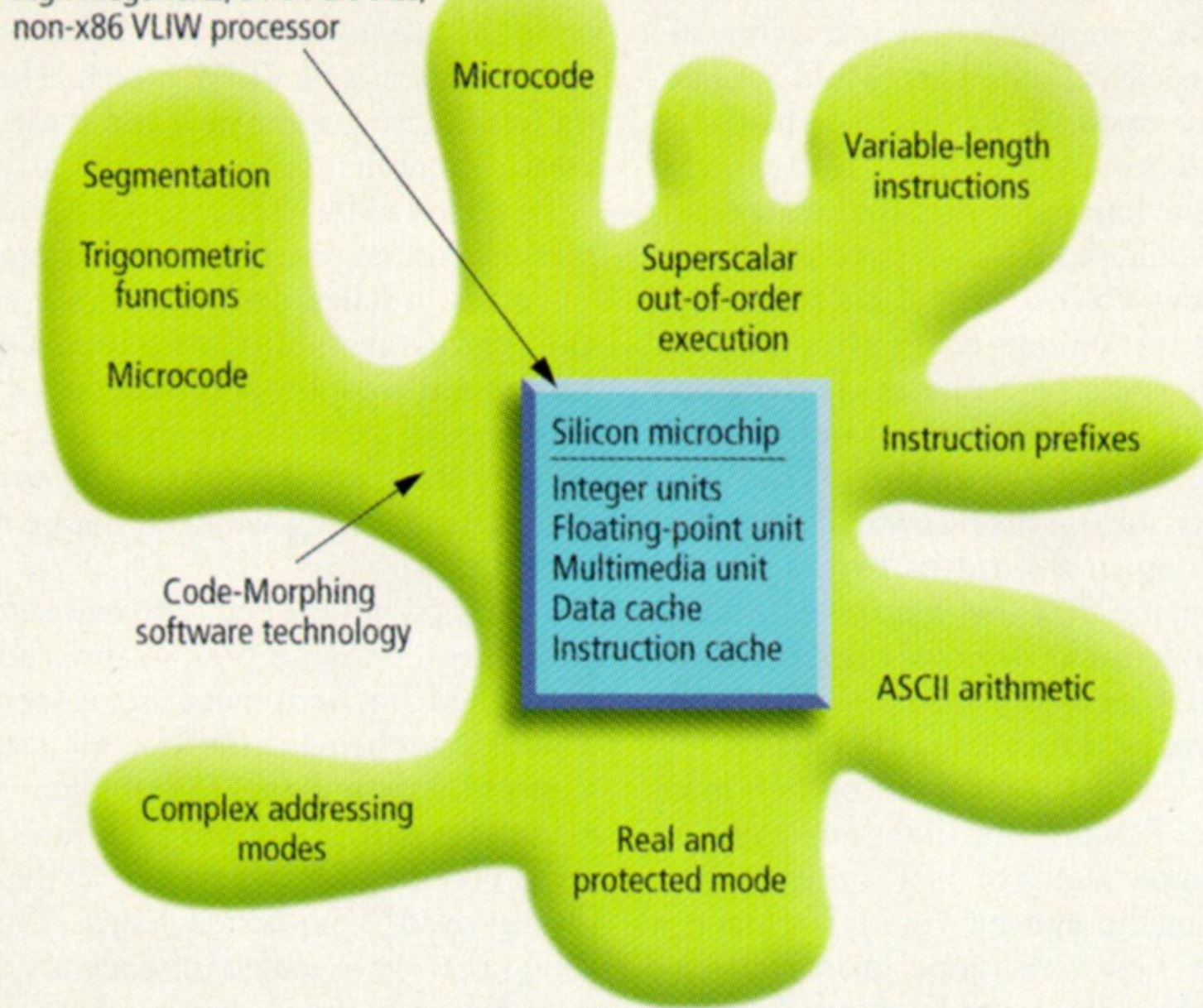*<u>Gilder Technology Report</u>, F'98*
-Special Report,
*"Grow Rich on the Coming Technology Revolution",*

Transmeta's Crusoe Chip
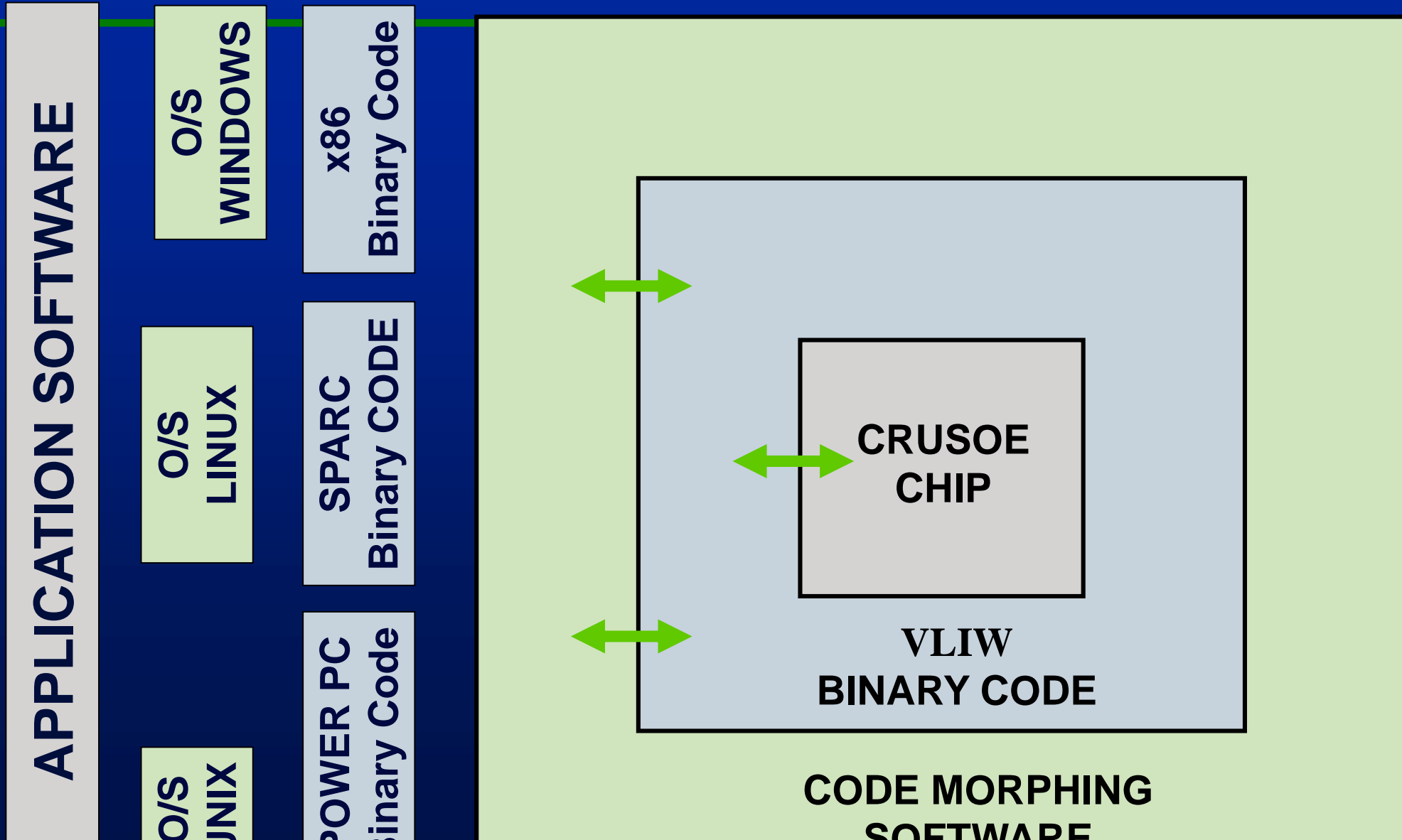
Uniqueness of Oracle Hardware Architecture

- A novel method (hardware/software) for "commit & rollback"

- Extra set of "shadow registers" to mimic the data

- If the program creates a fault, it doesn't have to recompute on "rollback"

- After commit, can erase and start again

- Moving data is expensive - a single instruction can modify 130 bytes in memory

non-x86 VLIW processor

Microcode

Variable-length instructions

Segmentation

Trigonometric functions

Microcode

Superscalar out-of-order execution

Silicon microchip

Integer units
Floating-point unit
Multimedia unit
Data cache
Instruction cache

Instruction prefixes

Code-Morphing software technology

ASCII arithmetic

Complex addressing modes

Real and protected mode

[3] The Transmeta founders credit a simplified sketch of their proposed architecture, which they called the "amoeba," with convincing the financial community that their idea could work. In this concept, the x86 architecture is an ill-defined amoeba containing such fea-

TM 5400
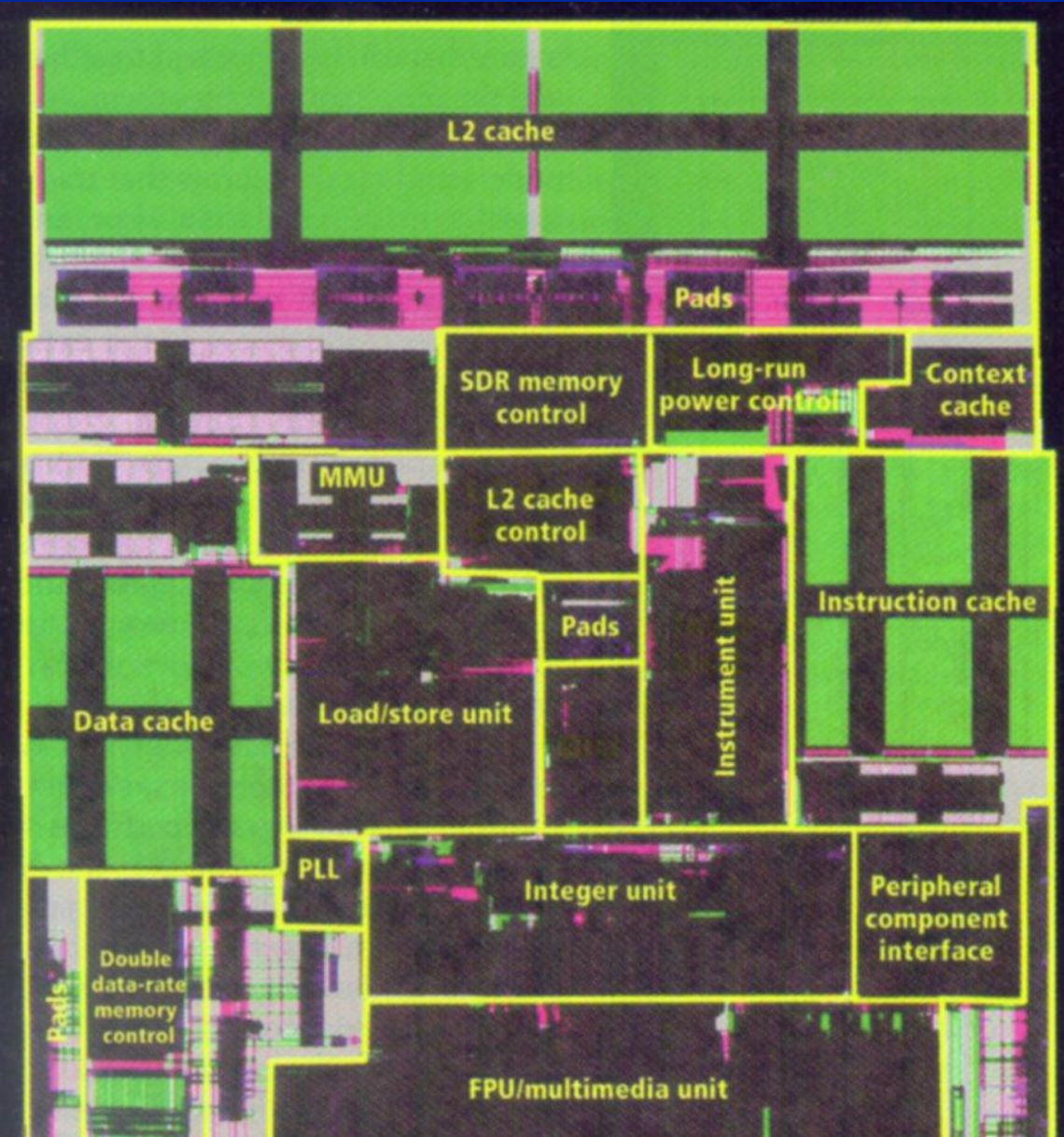
Area = 73 mm²

$$L_1 \text{ cache} = 128\text{KB}$$
$$L_2 \text{ cache} = 256\text{ KB}$$

Long run power control
Memory Bandwidth –
**   double standard rate**
Copper interconnects
0.18μ technology
Fabrication by IBM

Power Crusoe consumption

- 1/2 transistors of x86 chip

- the code morphing (done in software) reduced hardware size (virtual devices)

- put clocks in functional units, $\therefore$ only appropriate parts were turned on

- developed Longrun software - which monitors programs and adjusts both supply voltage and frequency (e.g. dimmer switches on every light)

- **Result:** 1/3 to 1/30 power consumption

Transmeta Advantages

- **Combination of dynamic binary recompilation inherent efficiency and parallelism of VLIW**

- **Unique hardware/software which can dynamically vary its voltage and clock frequency**

- **<u>Results:</u> Very low power usage**

  Very high efficiency

  Portability

  Easily upgradeable

  Compatibility with different systems

Transmeta Risks

- **Products have not been shipped**

- **Competition in semiconductor industry is intense**

- **Competitors are larger**

- **Revenues may be derived from small number of customers**

- **Lengthy and variable sales cycles**

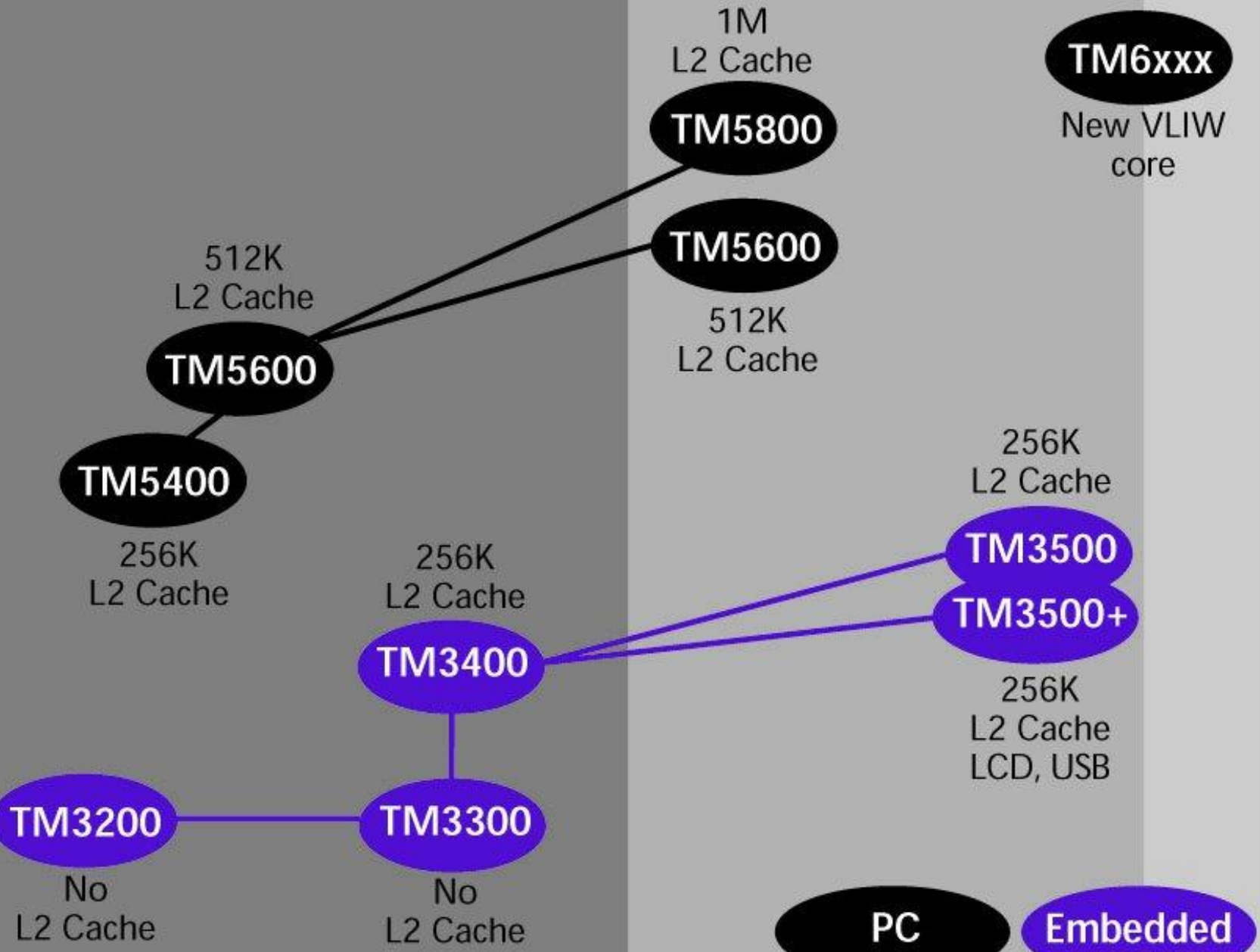- **No guarantee of supply and delivery of products (Fabless problem)**

END. . .

How do you predict what the technology, manufacturing cost, market demand, market supply, and competition will be five years in the future?

Is this a "puzzle" or is this a mystery? (Malcolm Gladwell, New Yorker,   January 8, 2007)
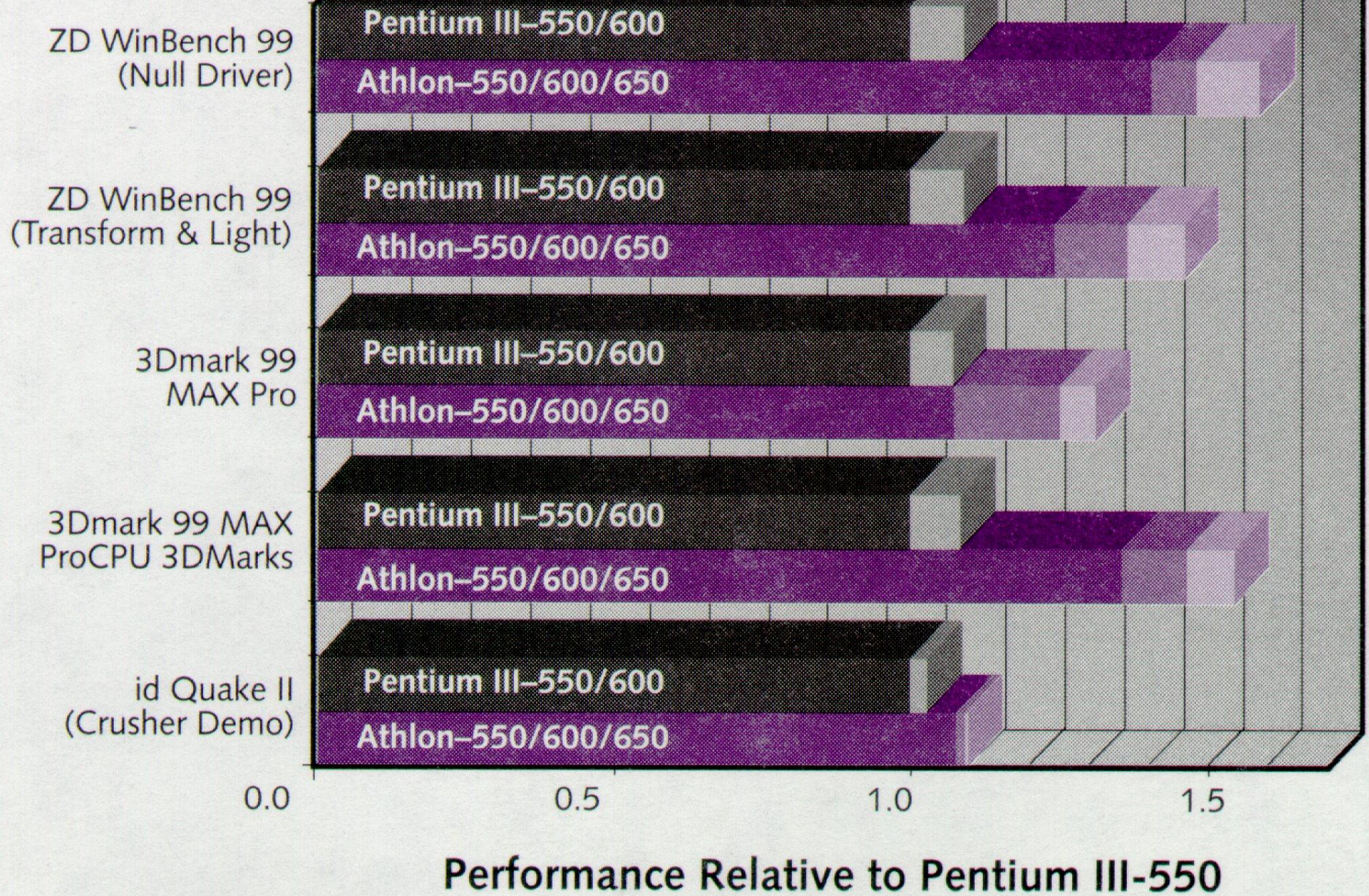
Figure 8. 3D benchmarks indicate Athlon's 3DNow implementation
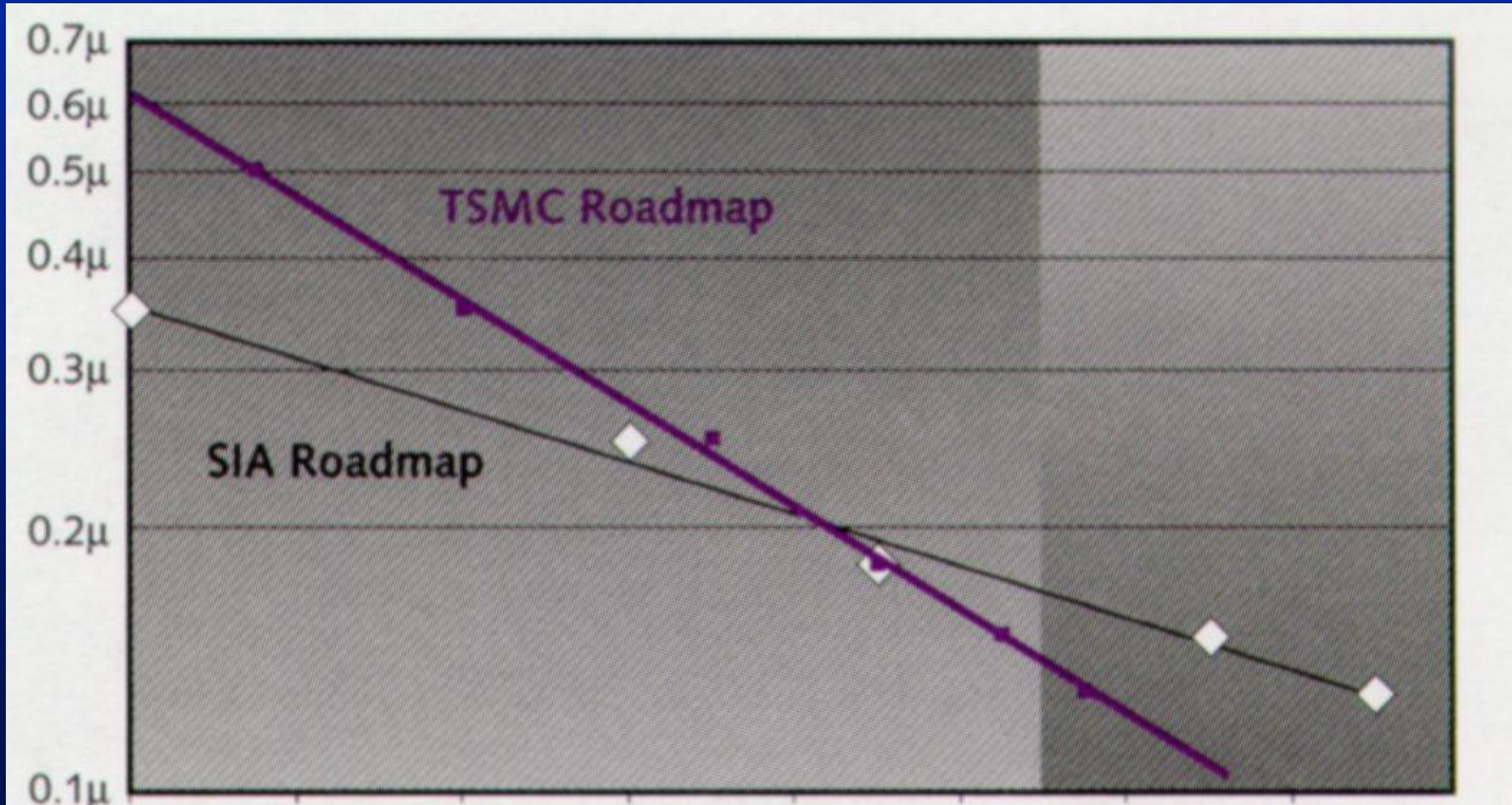
Case Study #2

Intel's weak Celeron offerings being hammered by AMD, Cyrix

Microprocessor Price Wars

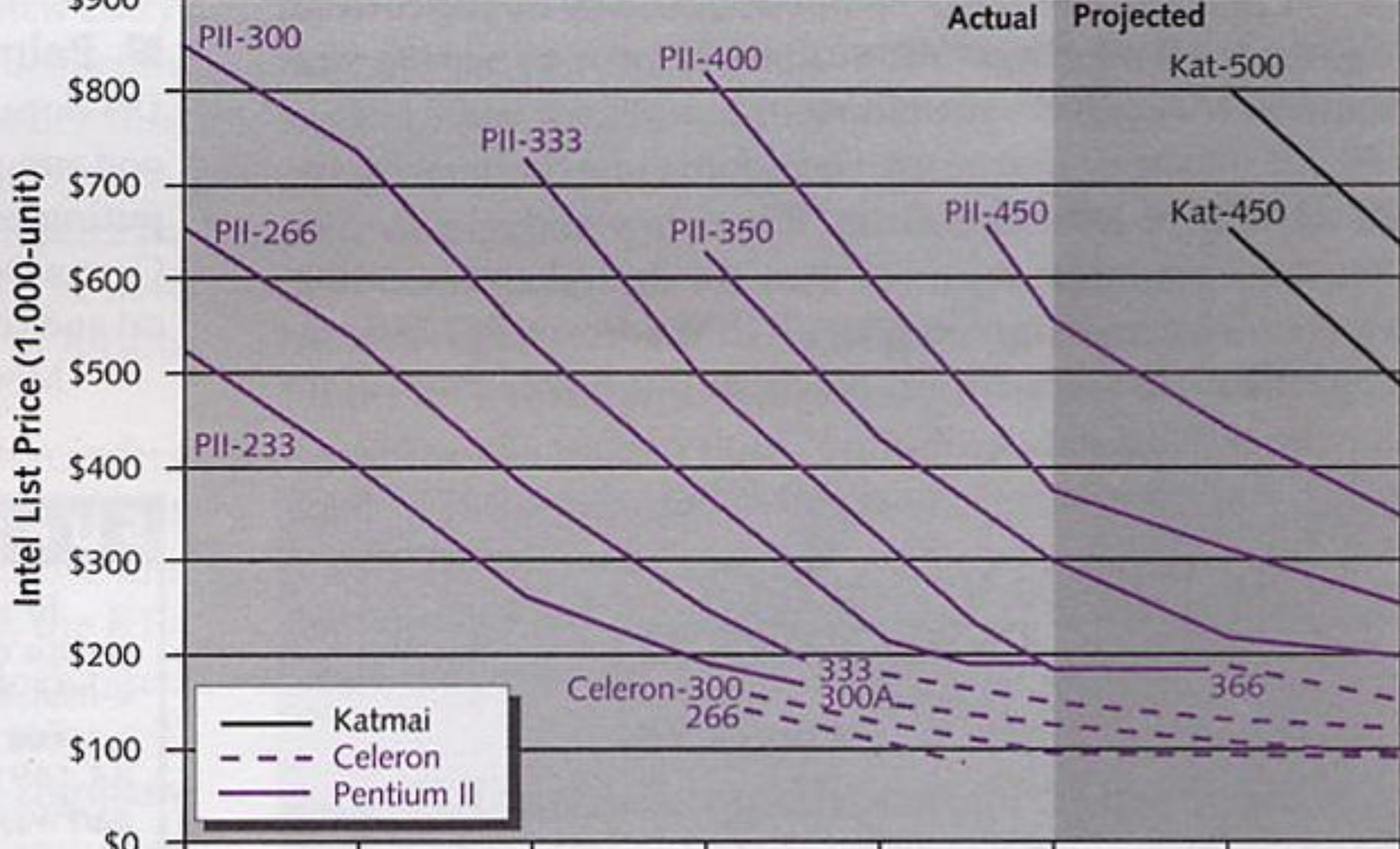Intel's weak Celeron offerings being hammered by AMD, Cyrix

Intel launches price war
    Cuts Celeron prices in half
    Introduce 2 new speed grades

Intel's market share $\rightarrow$ 81%
AMD's market share $\rightarrow$ 13%

A line graph titled with axes labeled "Intel List Price (1,000-unit)" on the y-axis ranging from $0 to $900. The chart shows three product lines (Katmai, Celeron, Pentium II) with an "Actual" and "Projected" division.

Labeled data series: PII-300, PII-266, PII-233, PII-333, PII-400, PII-350, PII-450, Kat-500, Kat-450, Celeron-300, 333, 300A, 266, 366.

Legend:
- Katmai (solid black line)
- Celeron (dashed line)
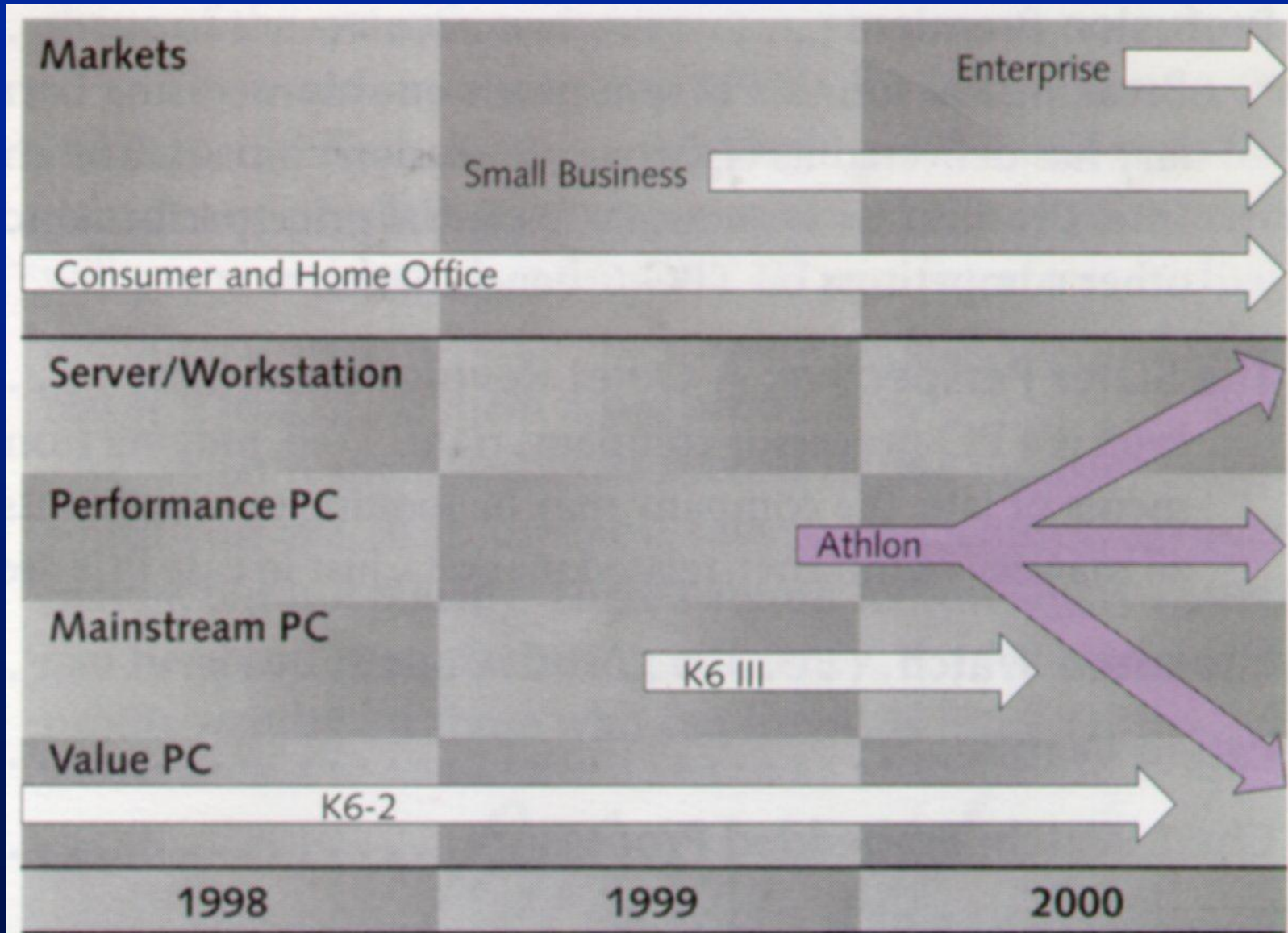- Pentium II (solid purple line)

Case Study #3
AMD's Athlon Outruns Pentium III

Microprocessor Report, August 3, 1999

AMD's Athlon Strategy

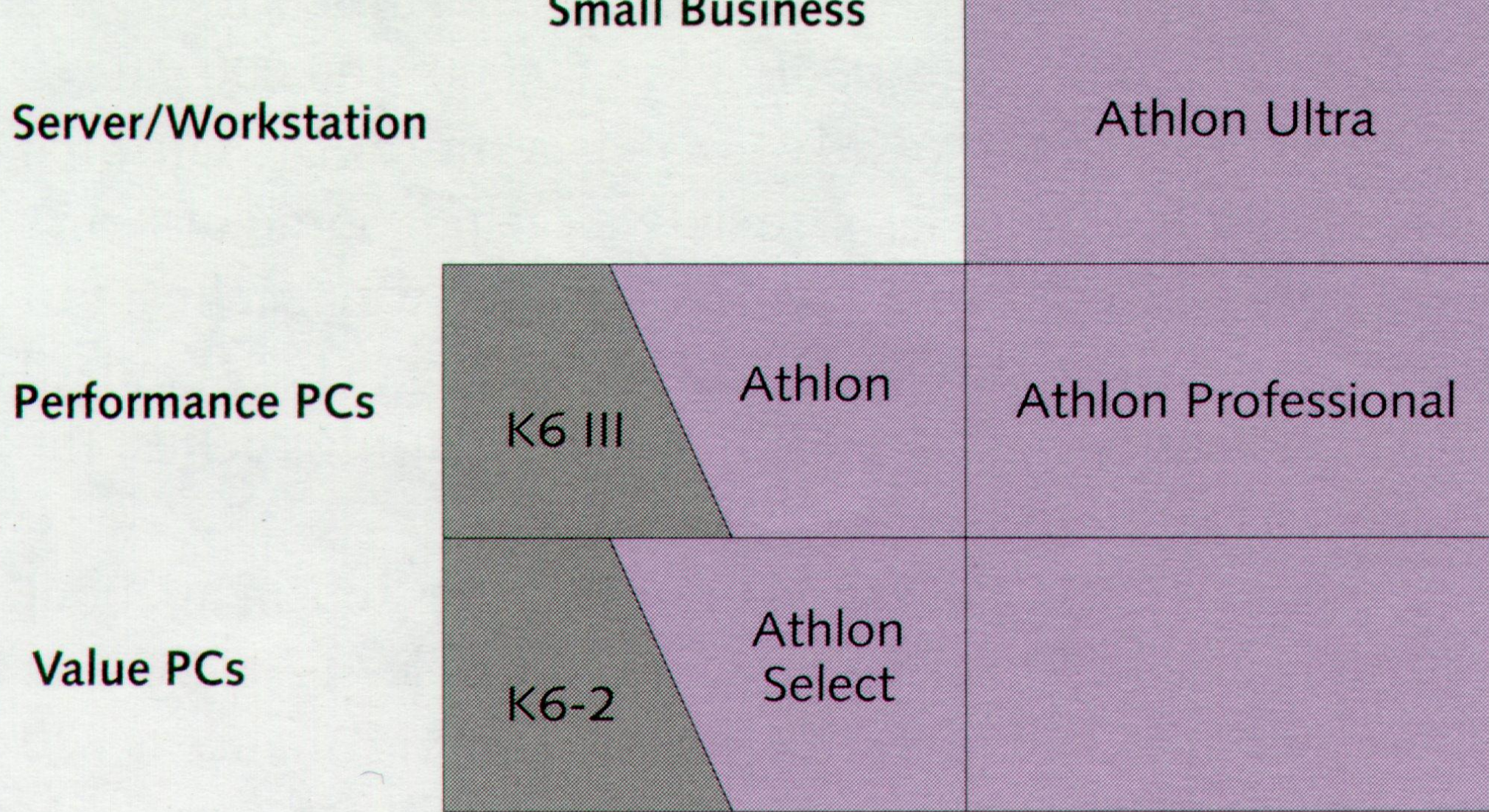**Figure 2.** AMD will introduce three new Athlon sub-brands—Ultra, Professional, and Select—to differentiate its products in dif-

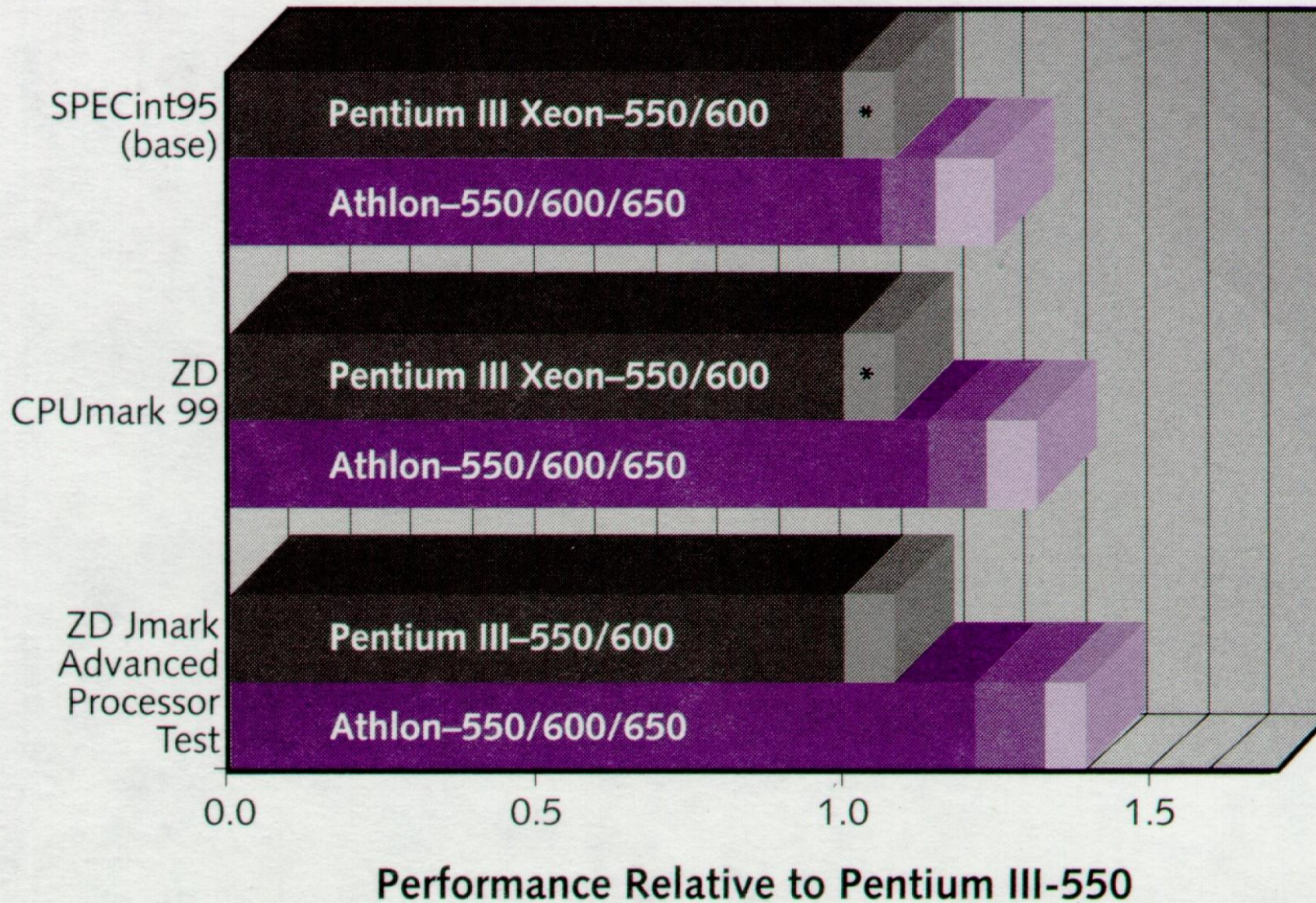**Figure 6.** These benchmarks show how Athlon beats Pentium III on CPU-intensive integer code. (Source: AMD, except *MDR estimates)

SPECfp95 (base)
- Pentium III Xeon–550/600 *
- Athlon–550/600/650

ZD FPU WinMark 99
- Pentium III Xeon–550/600 *
- Athlon–550/600/650

AutoCAD 2000
- Pentium III Xeon–550/600 *
- Athlon–550/600/650

0.0 0.5 1.0 1.5
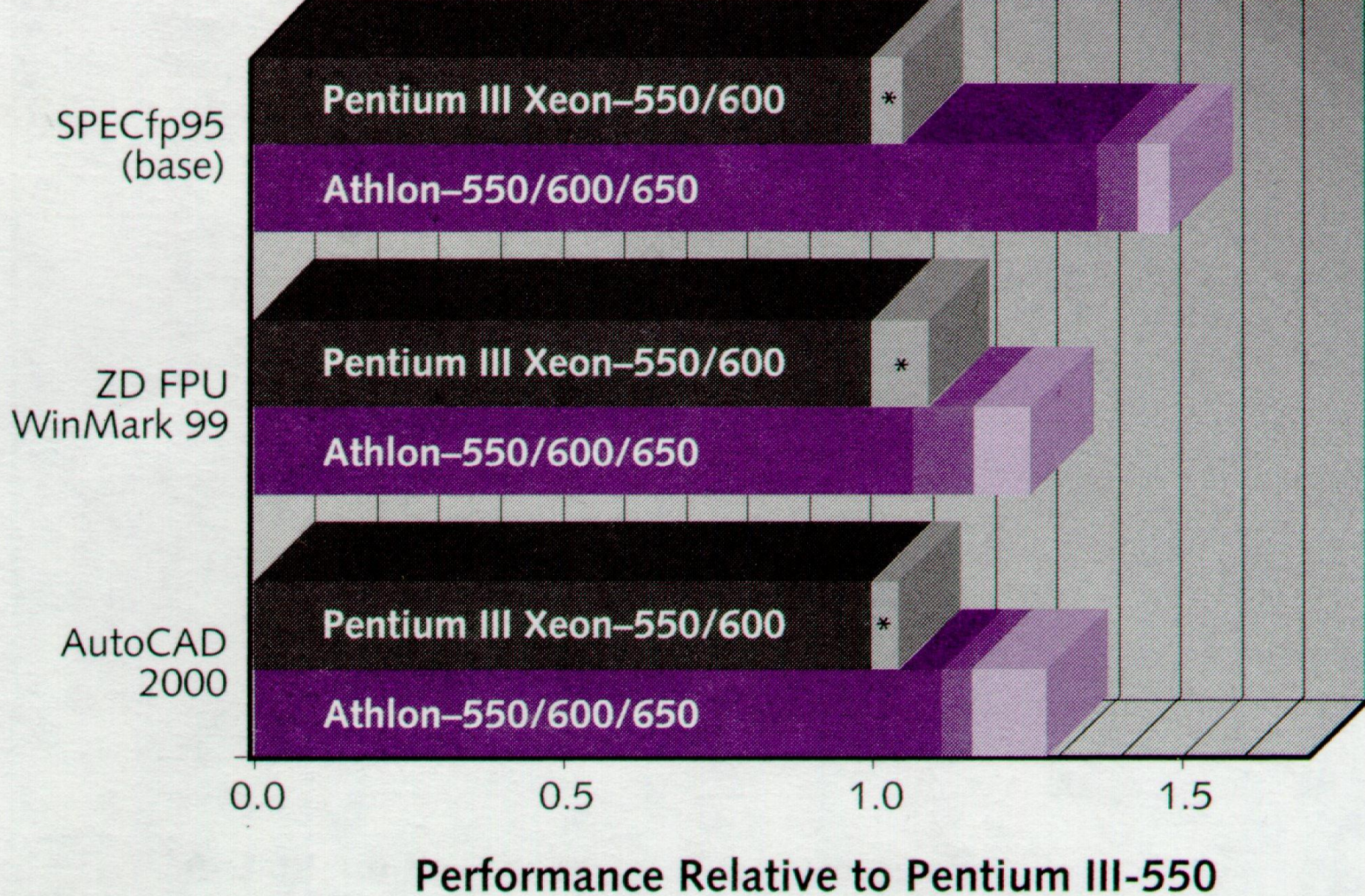
Performance Relative to Pentium III-550

Figure 7. Athlon's three pipelined FPUs give it a big advantage over P III on floating point. (Source: AMD, except *MDR estimates)
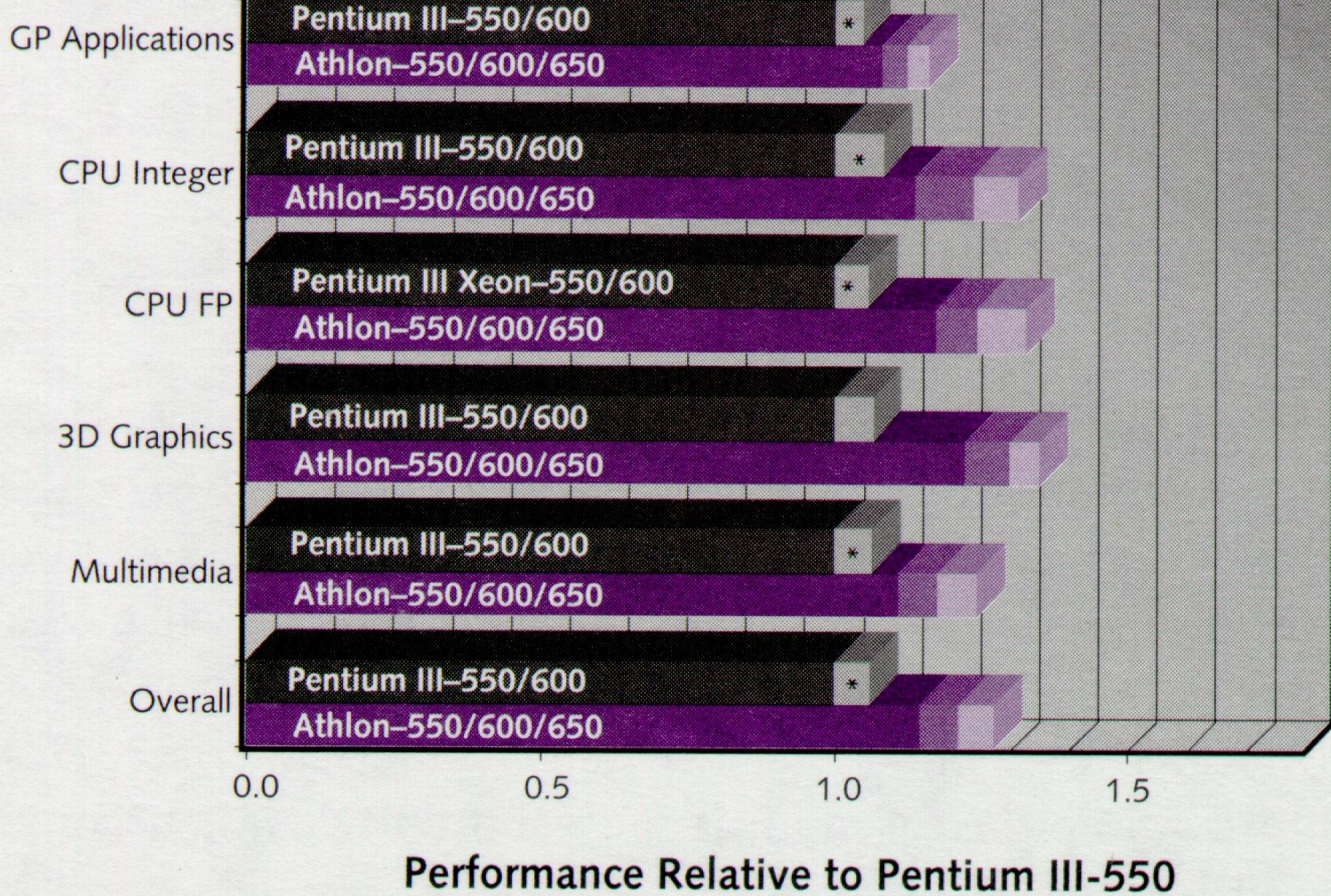
Figure 11. Athlon clearly outperforms Pentium III in every cate-
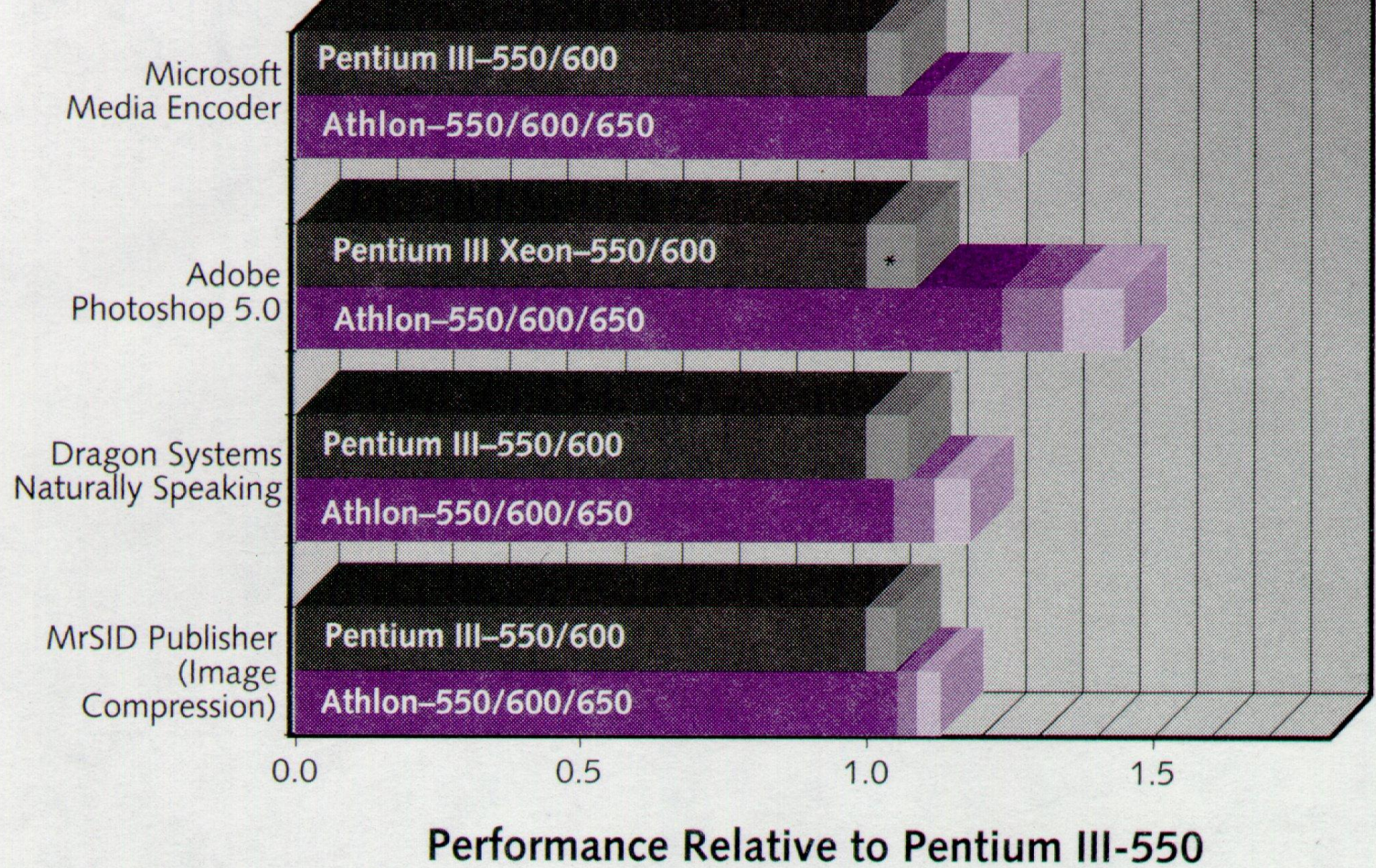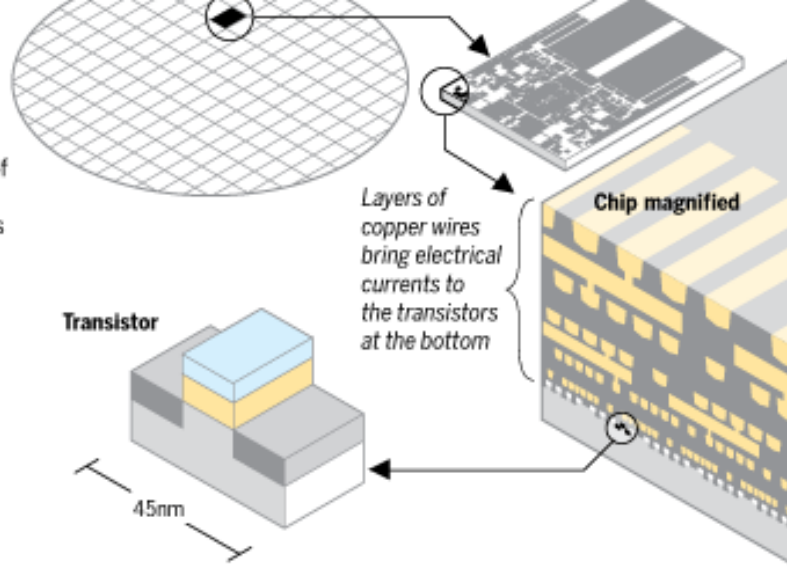
Figure 9. On multimedia-rich benchmarks, Athlon outperformed P III by 5% to 25%. (Source: AMD, except *MDR estimates)

Return On Investment (ROI Models)

It is this non-linearity (and unpredictability) which renders the ROI models unsuitable.
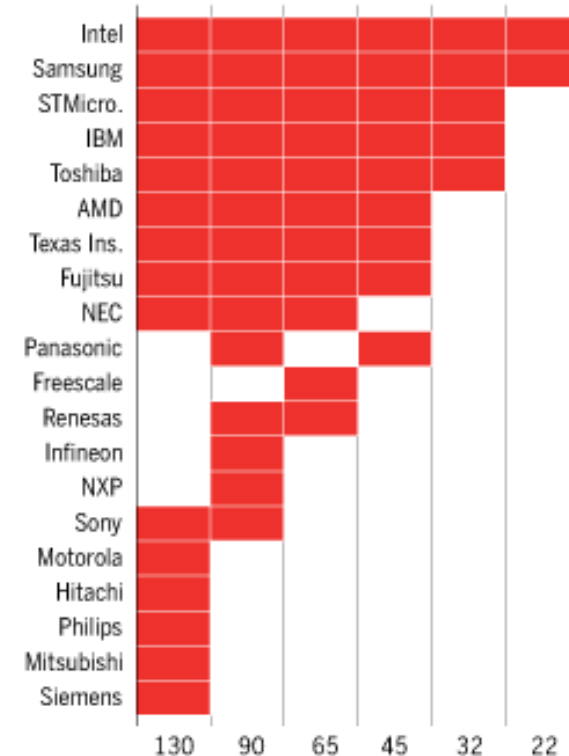
The 'brain' of a computer.
Contains hundreds of millions of transistors interconnected by fine wires made of copper. Each transistor acts as an on/off switch, controlling the flow of electricity through the chip to send, receive, and process information up to 300bn times a second

2,000
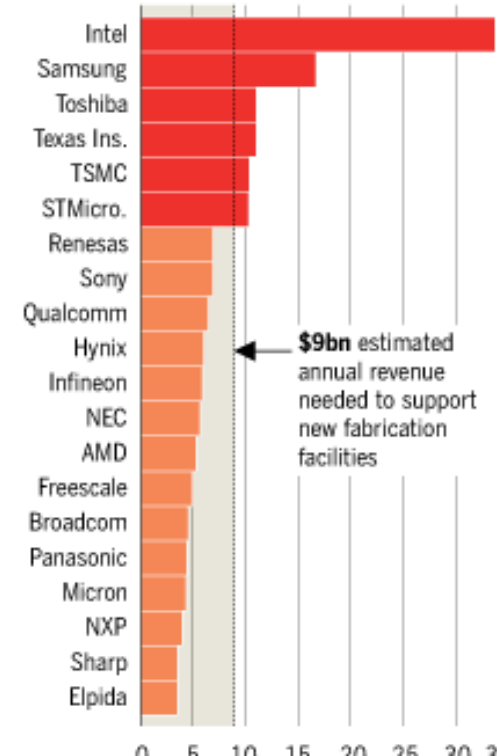45 nanometer (nm) transistors can fit across the width of a human hair

Transistor

45nm

Layers of copper wires bring electrical currents to the transistors at the bottom

Chip magnified

Fabrication capabilities
Transistor size (nanometer)

	130	90	65	45	32	22
Intel						
Samsung						
STMicro.						
IBM						
Toshiba						
AMD						
Texas Ins.						
Fujitsu						
NEC						
Panasonic						
Freescale						
Renesas						
Infineon						
NXP						
Sony						
Motorola						
Hitachi						
Philips						
Mitsubishi						
Siemens						

Semiconductor maker revenues
Shipments, estimated 2008 ($bn)

Intel
Samsung
Toshiba
Texas Ins.
TSMC
STMicro.
Renesas
Sony
Qualcomm
Hynix
Infineon
NEC
AMD
Freescale
Broadcom
Panasonic
Micron
NXP
Sharp
Elpida

0 5 10 15 20 25 30 35

$9bn estimated annual revenue needed to support new fabrication facilities

Lenovo's Ideapad Yoga

Consumer Electronics Show, January 2012

"Every economic era is based on a key <u>abundance</u> and a <u>key</u> scarcity."

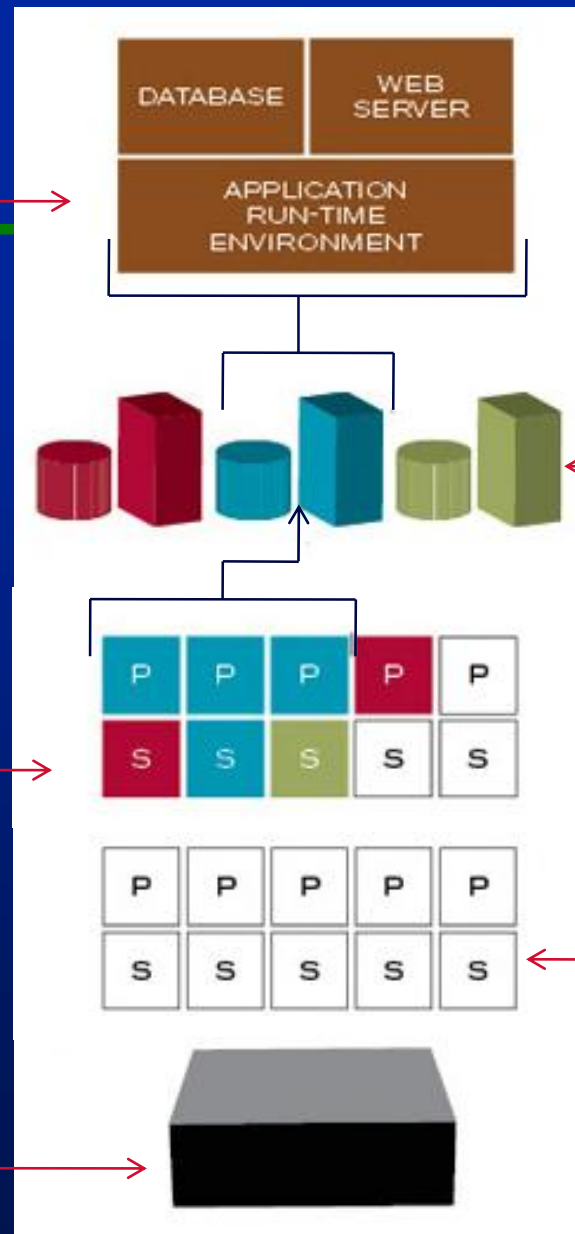*"Half of the world's children have no access to electricity."*

"Watts are more important then MIPS of FLOPS"

- George Gilder

(Platform as a service) Allows developers to run applications

DATABASE | WEB SERVER

APPLICATION RUN-TIME ENVIRONMENT

IaaS
VIRTUAL INFRASTRUCTURE
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S S S S S

HARDWARE LAYER
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Virtual Computers, Real Money

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Batch computing jobs	9%
Billing	4%
Log processing	1%
Don't know	4%
Other	13%

Source: The 451 Group

Cloud Computing Services

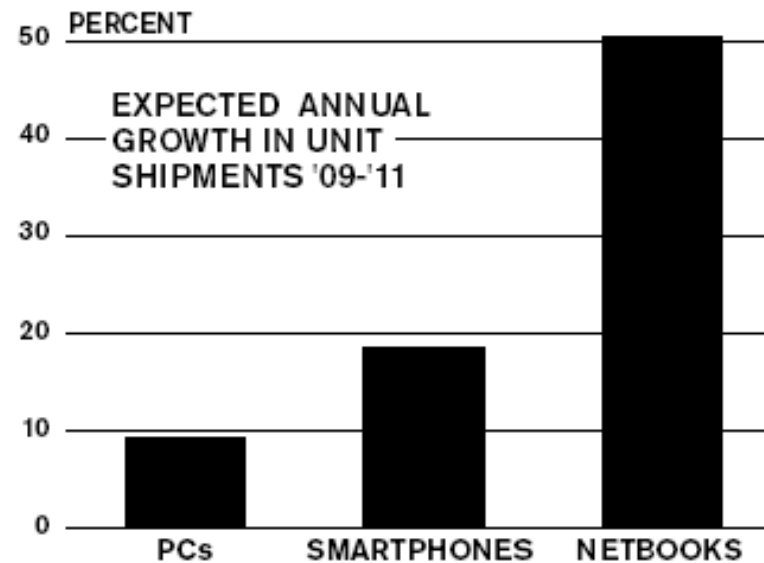- Are highly efficient, which is one reason they're growing fast
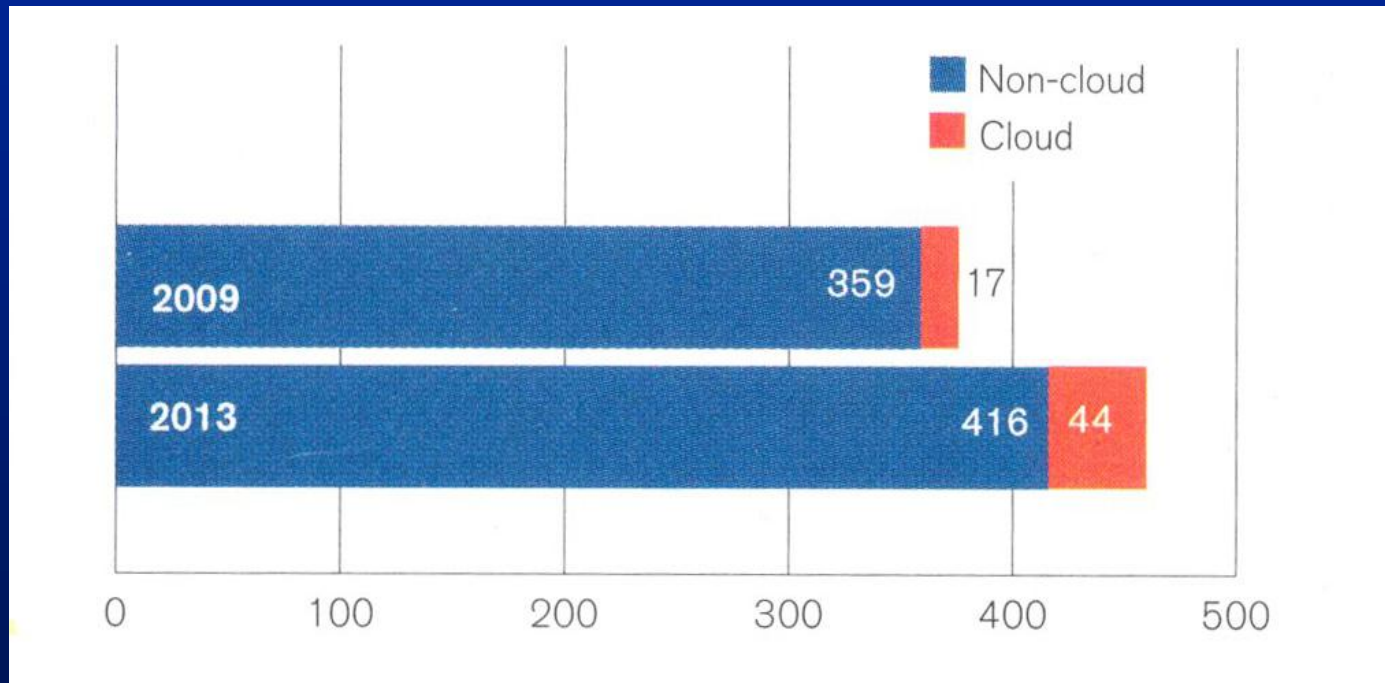
Case Study #6
Trading Shares in Milliseconds

- Five years ago automated trading was approximately 30% of the market

- Today, high frequency automated trading accounts for 67% of the market (10 billion shares daily)

- Profits go to the company with the fastest hardware and best algorithms

Trading Shares in Milliseconds

- One market for huge volume high speed players

- A second market for retail investors

Congress Is Worried!