Computer Processing
Case Studies

NBAY 1620

March 6, 2017

Donald P. Greenberg

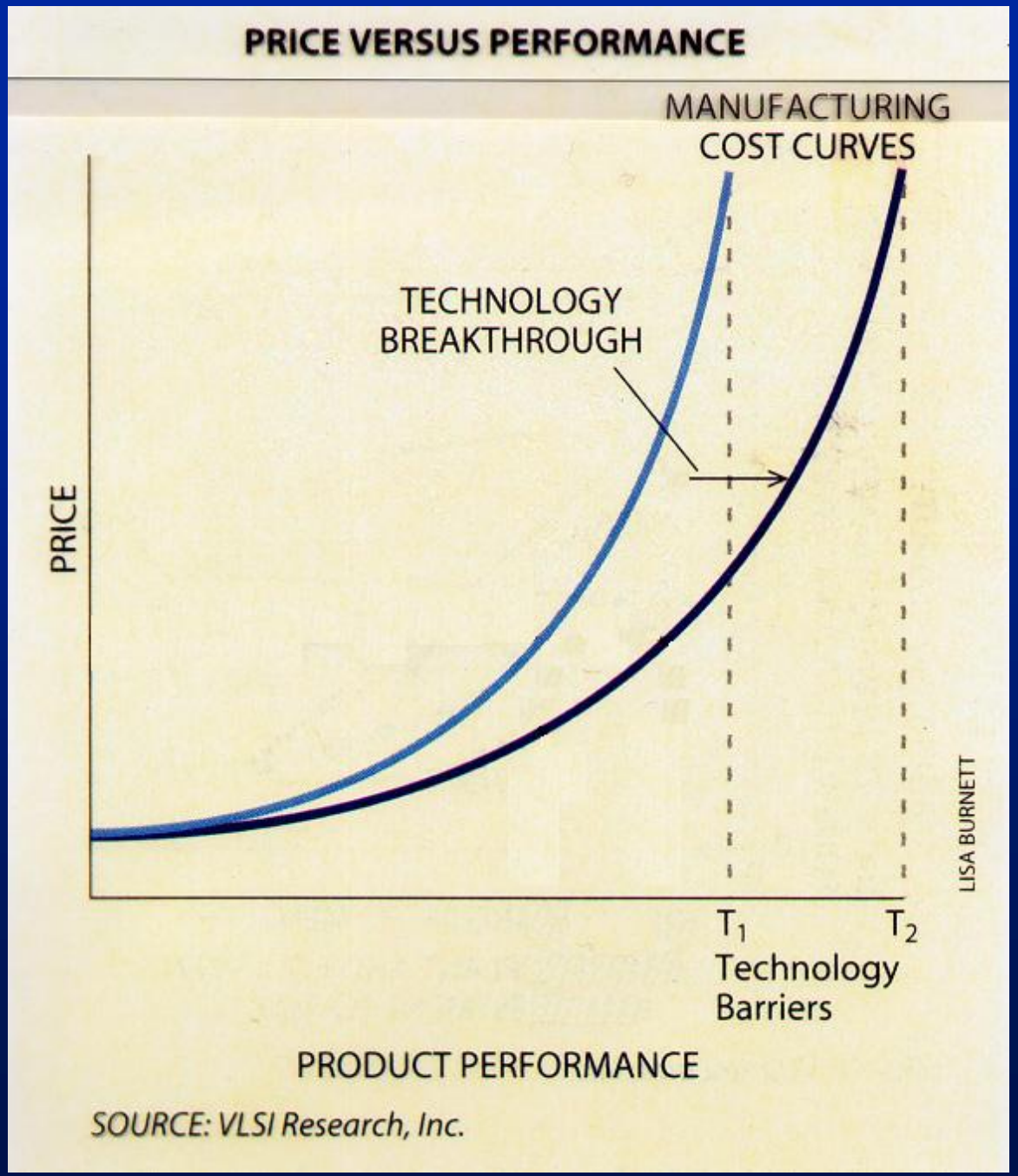
Lecture 3

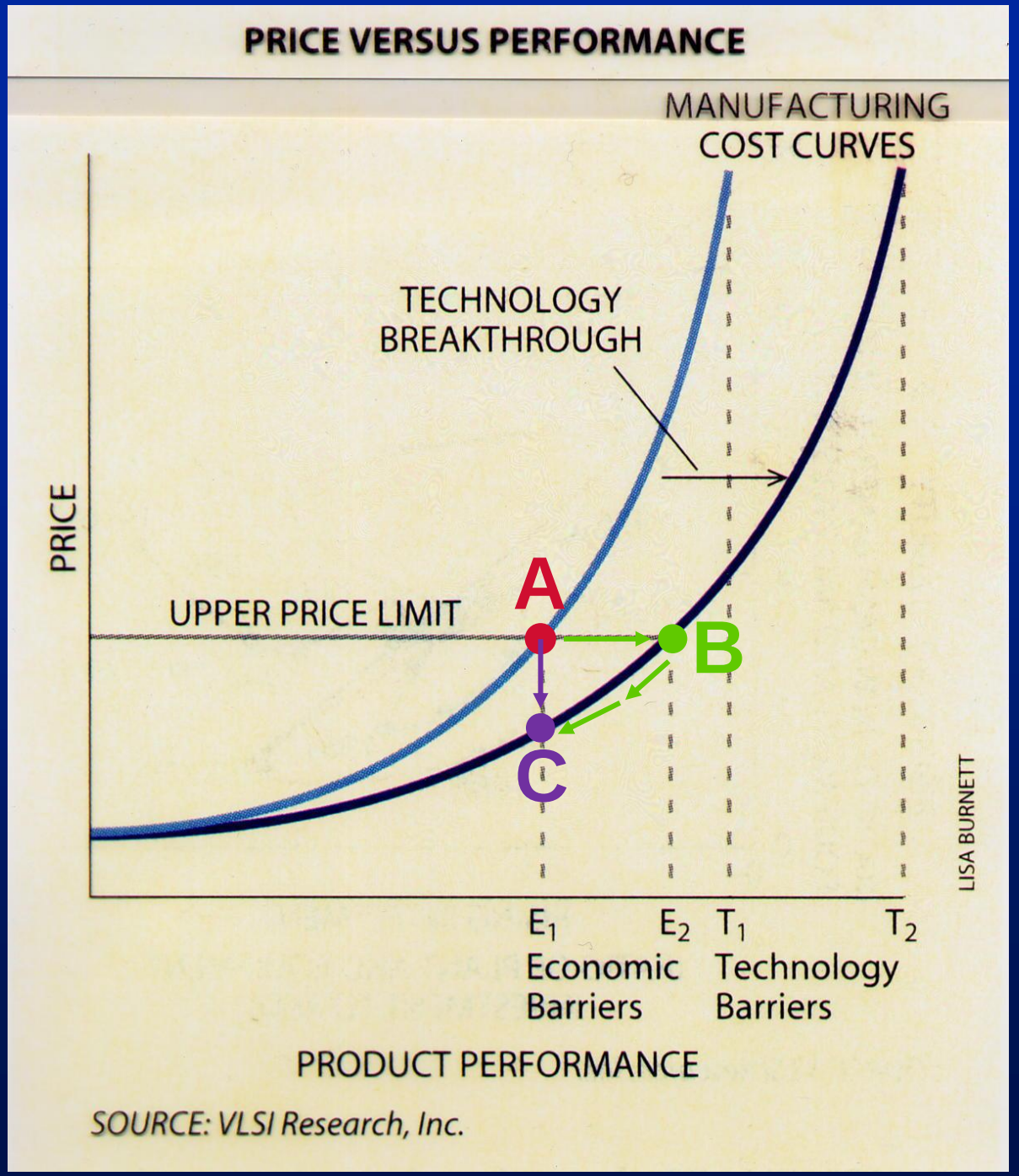
Required Reading

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

Optional Reading

- Michael Armbrust, Armando Fox, Rean Griffin, Anthony D. Joseph, Randy H. Katz, Andrew Konwinski, Gunho Lee, David A. Patterson, Ariel Rabkin, Ion Stoica, Matei Zaharia. "Above the Clouds: A Berkeley View of Cloud Computing," Electrical Engineering and Computer Sciences, University of California at Berkeley, Technical Report No. UCB/EECS-2009-28, February 10, 2009.
- **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.**


PRICE VERSUS PERFORMANCE
MANUFACTURING
COST CURVES
TECHNOLOGY
BREAKTHROUGH
PRICE
LISA BURNETT
T1
T2
Technology
Barriers
PRODUCT PERFORMANCE
SOURCE: VLSI Research, Inc.


PRICE VERSUS PERFORMANCE
MANUFACTURING
COST CURVES
TECHNOLOGY
BREAKTHROUGH
PRICE
UPPER PRICE LIMIT
A
B
C
LISA BURNETT
E1
E2
T1
T2
Economic
Barriers
Technology
Barriers
PRODUCT PERFORMANCE
SOURCE: VLSI Research, Inc.

Return on Investment (ROI)

Assumptions:

Payback period (time)

Net Present Value

Value of future benefits in today's money

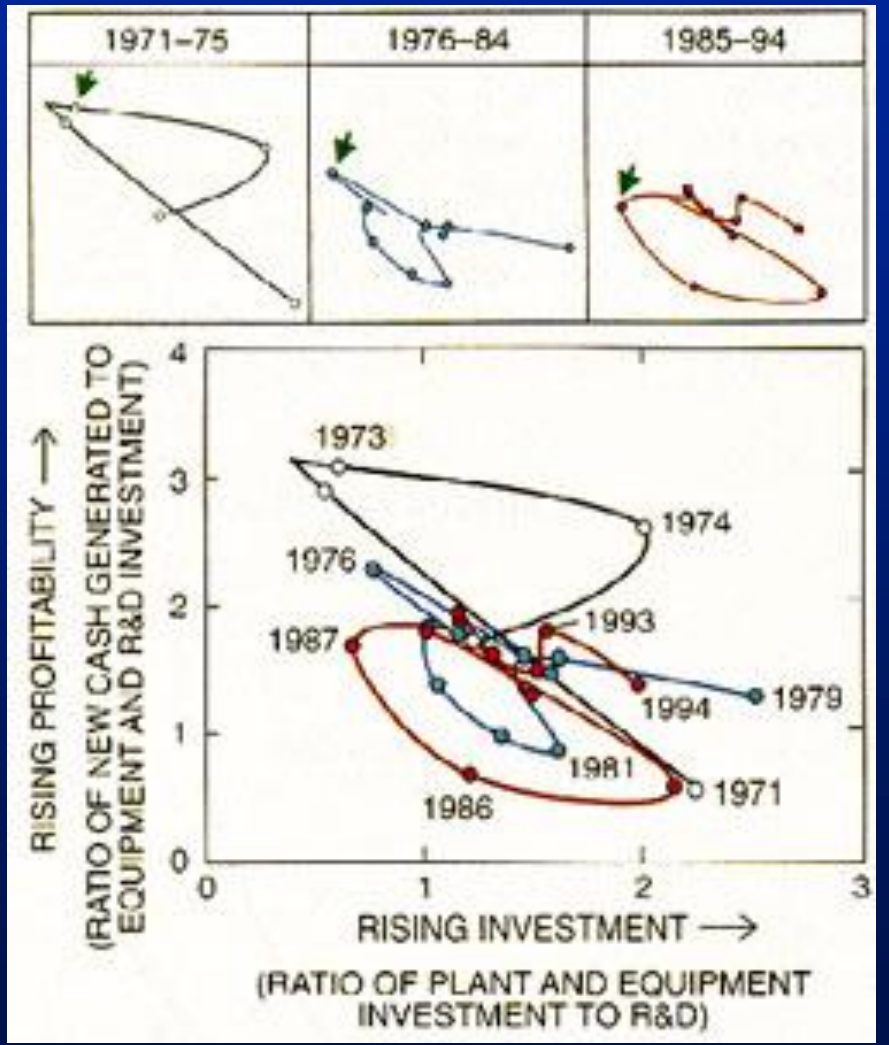
Internal Rate of Return

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

$$\text{Measured by ratio} = \frac{\text{cash generated during year}}{\text{investments made in new technology previous year}}$$

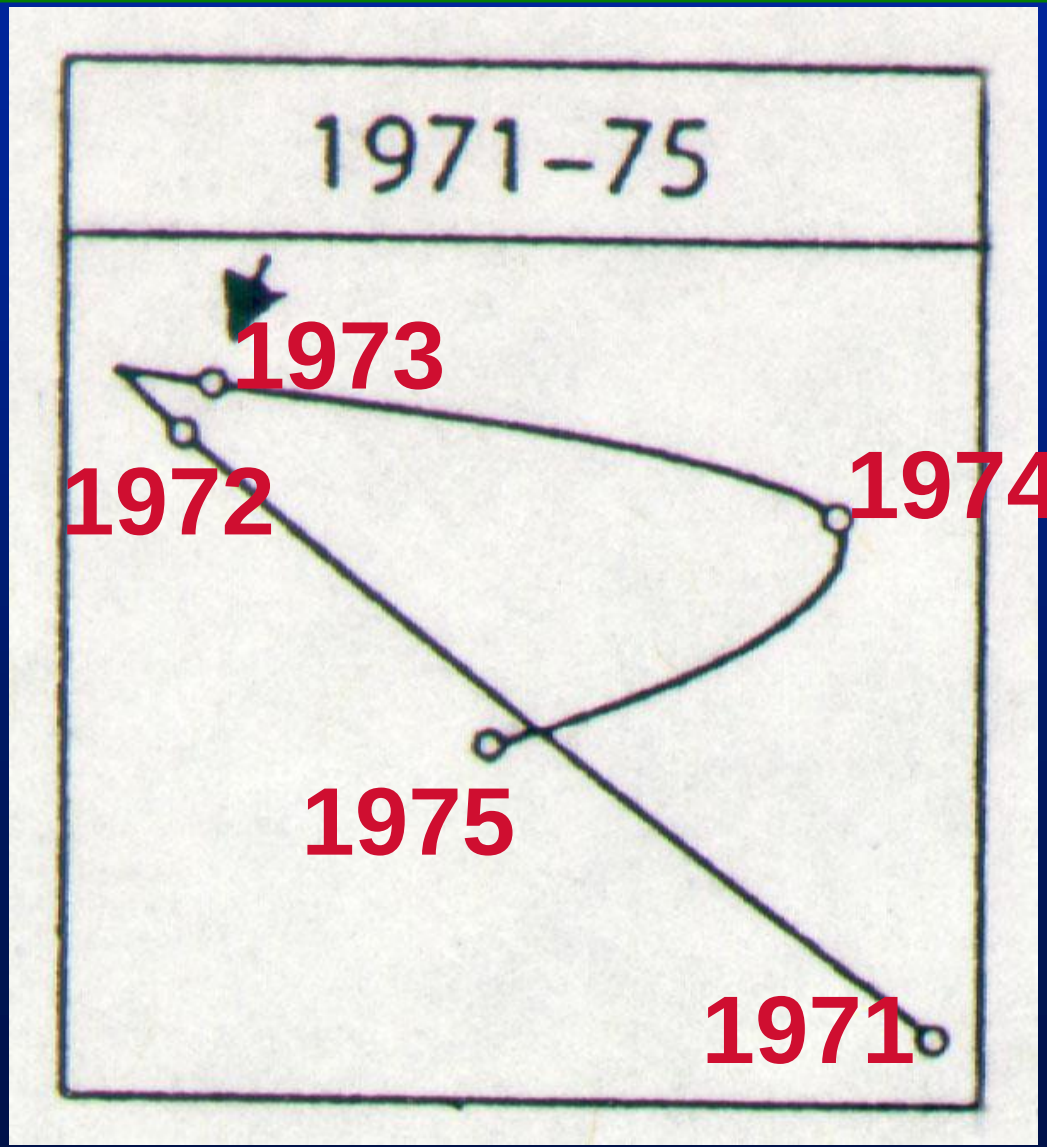
where new technology = new equipment + R & D

cash = gross profit (including R & D)

Rising Investment

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

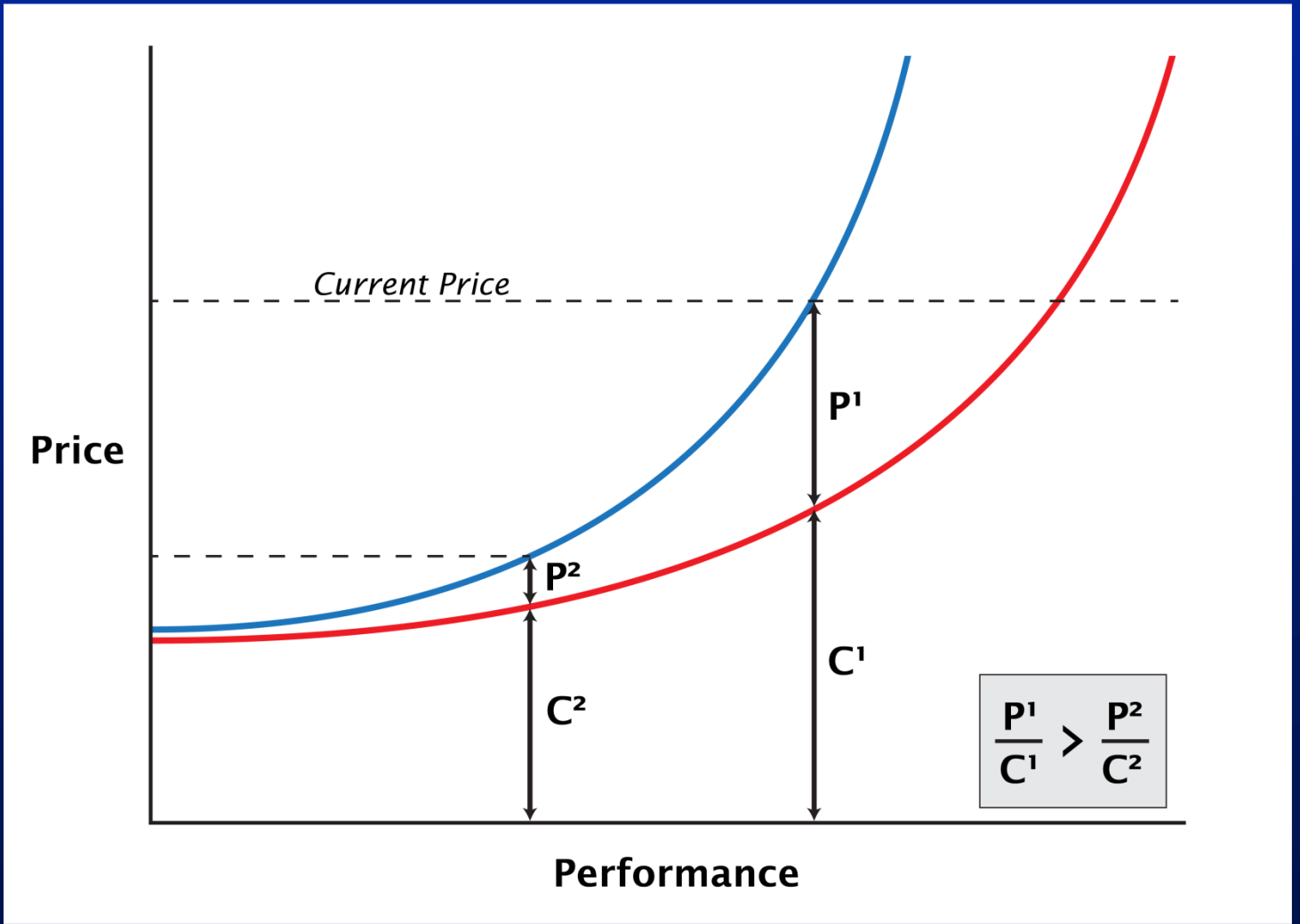
Profitability vs. Investment



Profitability vs. Investment in the Computer Industry

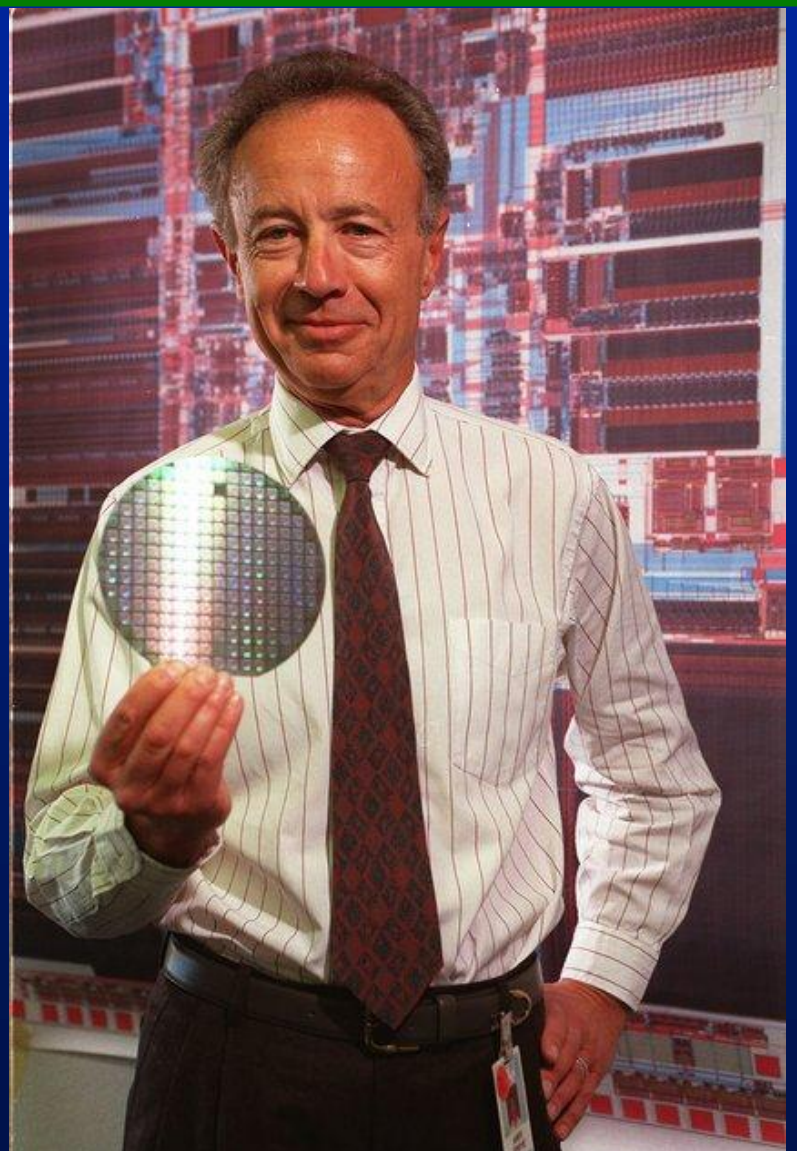
- It is obvious that with the shrinking technology, it is getting more expensive to move to the next generation process technology.
- It is also obvious that the manufacturing cost as well as the sales price of processing chips is decreasing rapidly.

Diminishing Profitability



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

Andrew S. Grove, Chief Executive and Chairman of Intel Corporation



From the New York Times, caption: “Mr. Grove in 1991 with a silicon wafer, part of the process to make Intel’s 386 microprocessor.”

9/2/1936 - 3/21/2016

Intel 2007

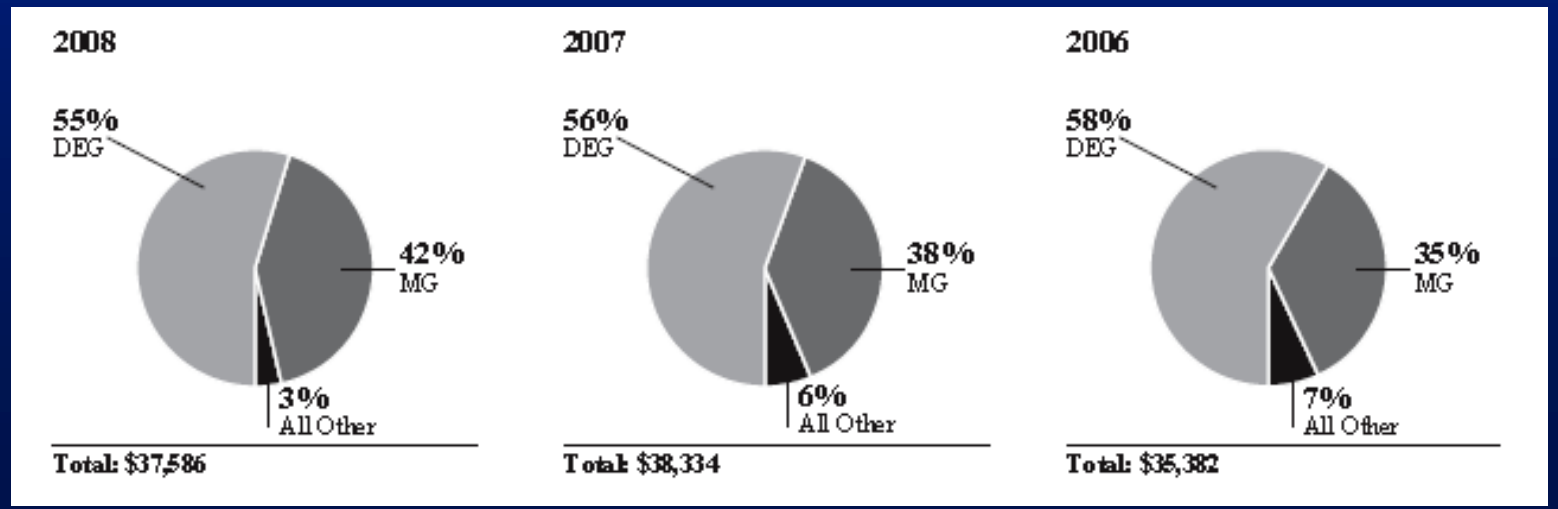
- The growth in mobile microprocessors outpaced the growth in desktop microprocessors.
- Systems price points have migrated to lower levels and average selling prices indicate continued erosion.

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.

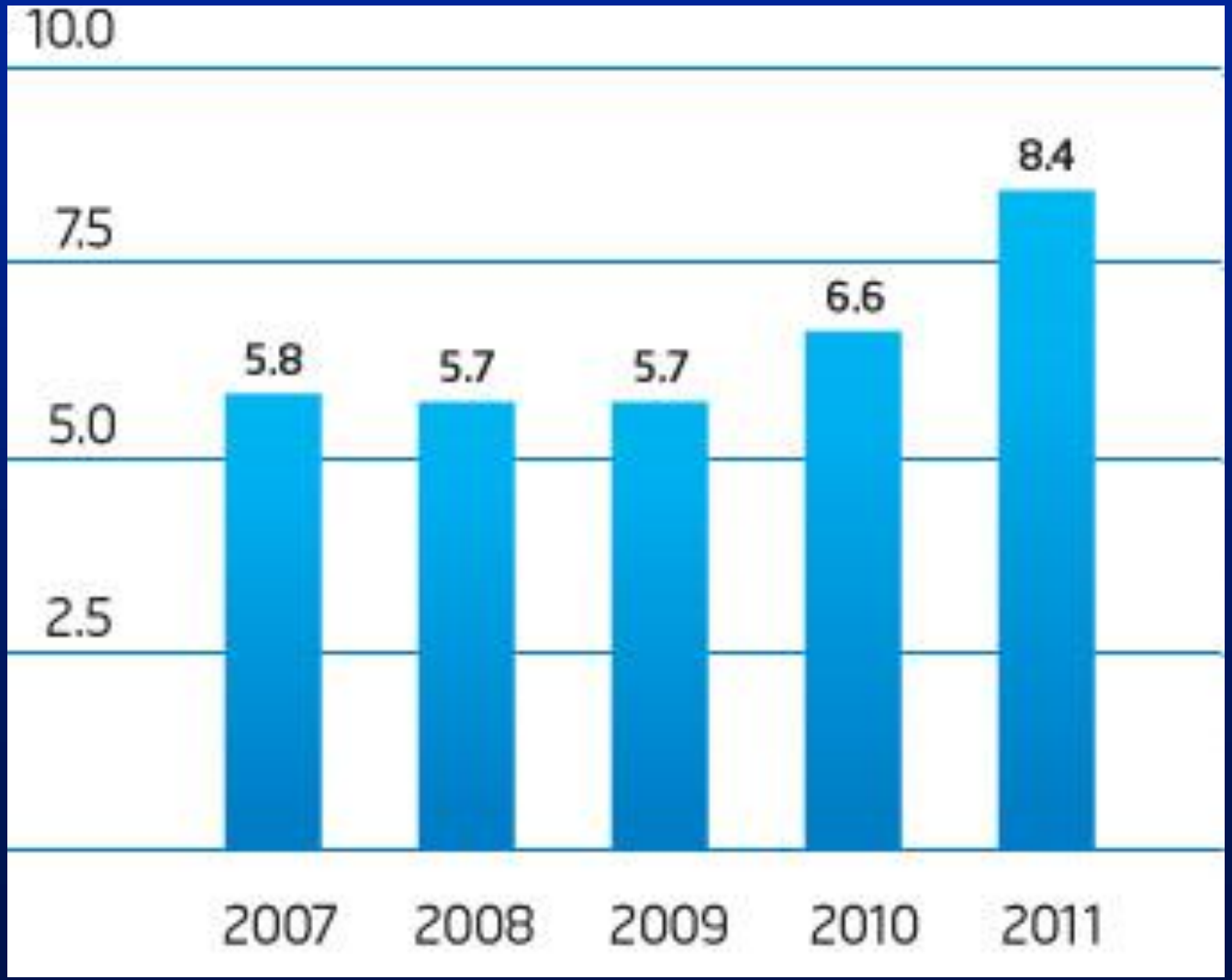
Intel 2008

- 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

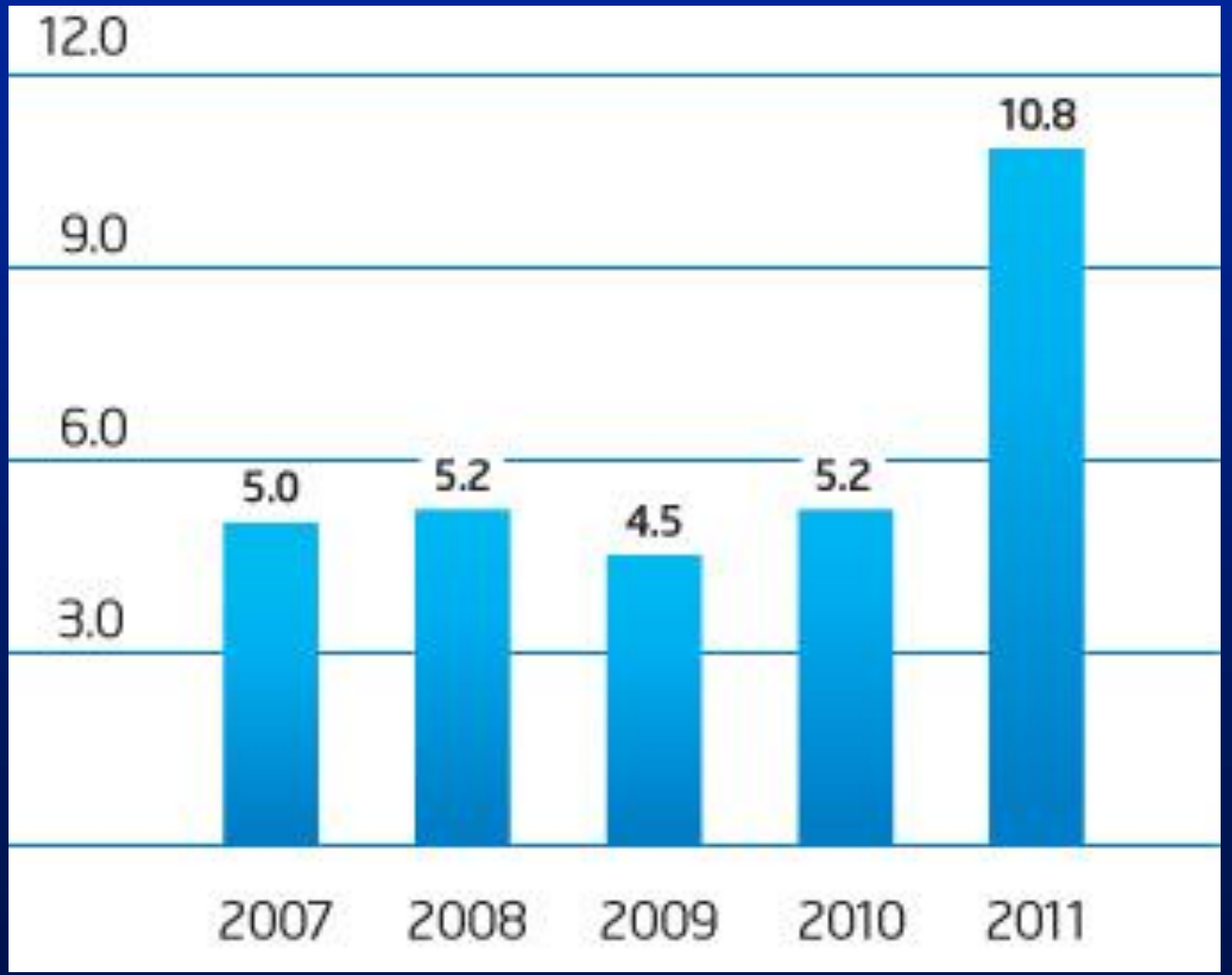


Percentage of Revenue (Dollars in Millions)

Intel Research and Development 2011



Intel Capital Additions to Property, Plant and Equipment 2011



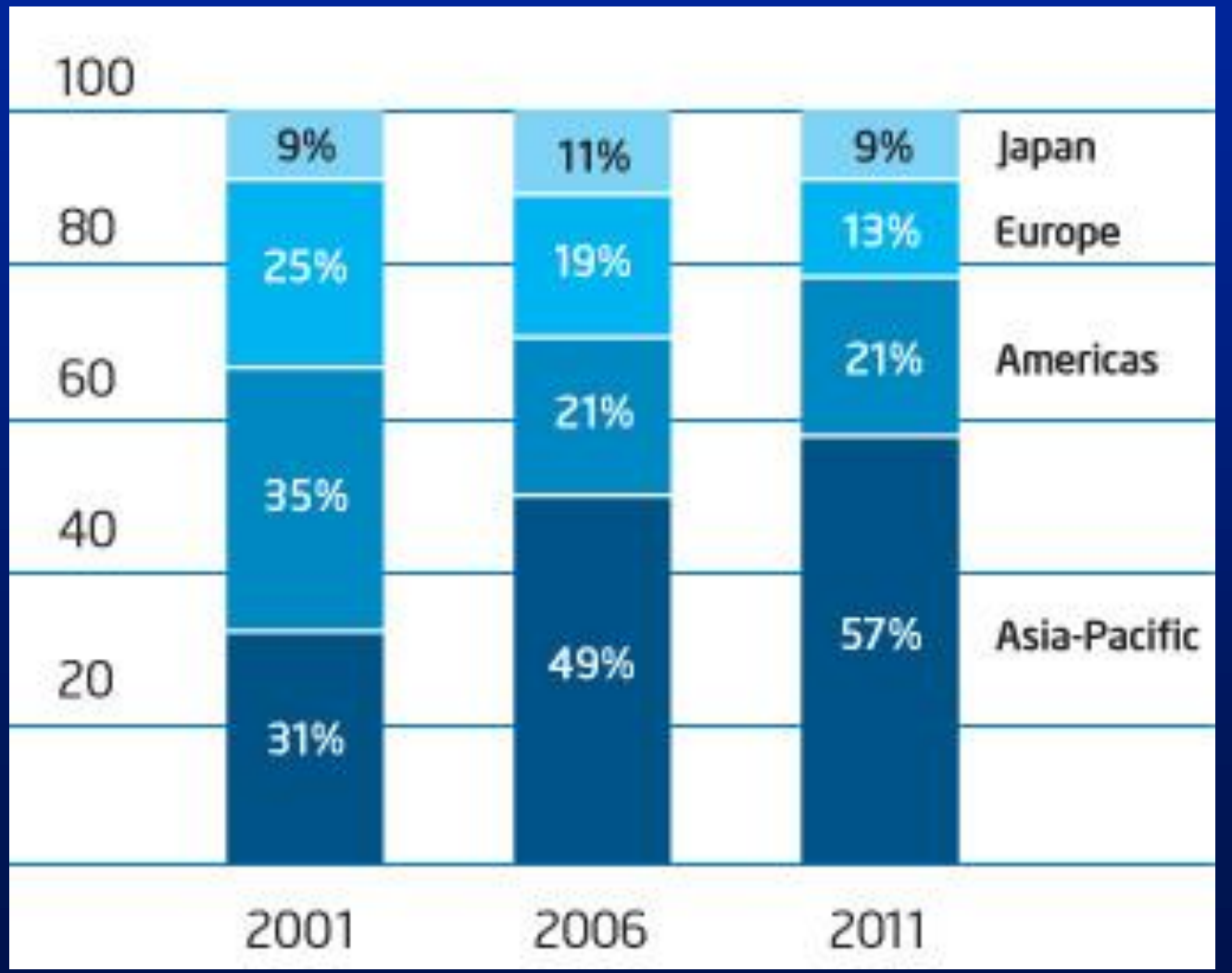
Intel 2011

- A new fab costs approximately $3-4B or more
- Should Intel Continue to Invest In Creating New Fabrication Facilities?

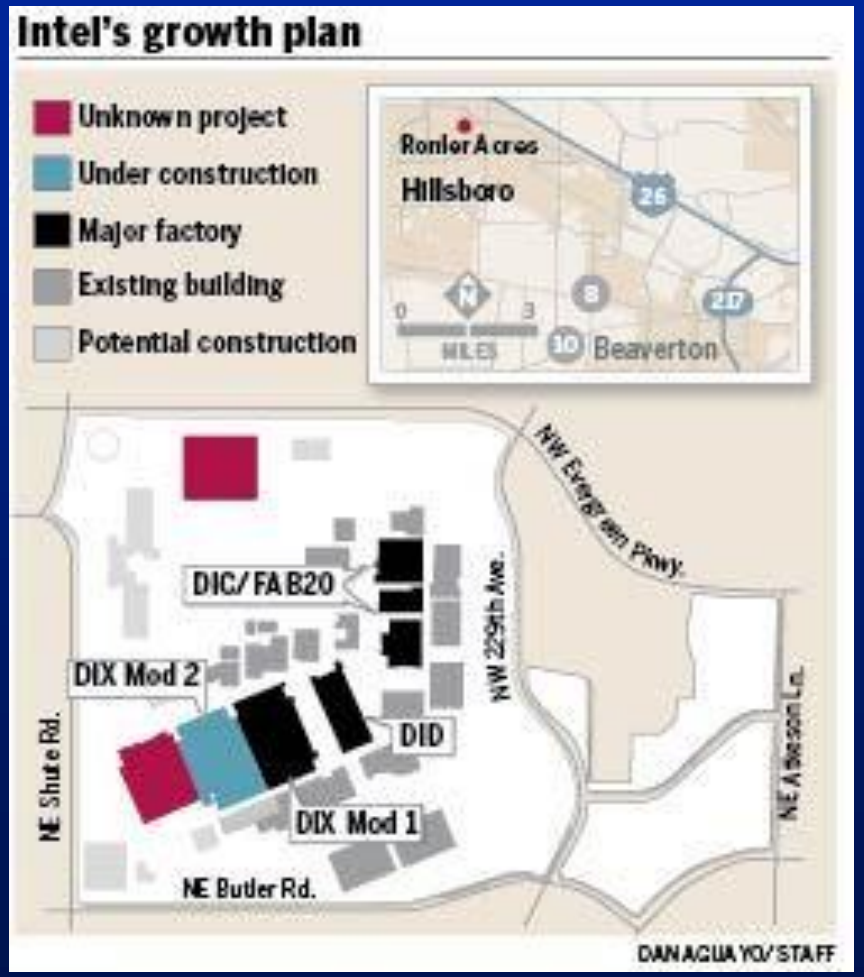
Intel's In a Sweet Spot 2011

- 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 Geographic Breakdown of Revenue 2011



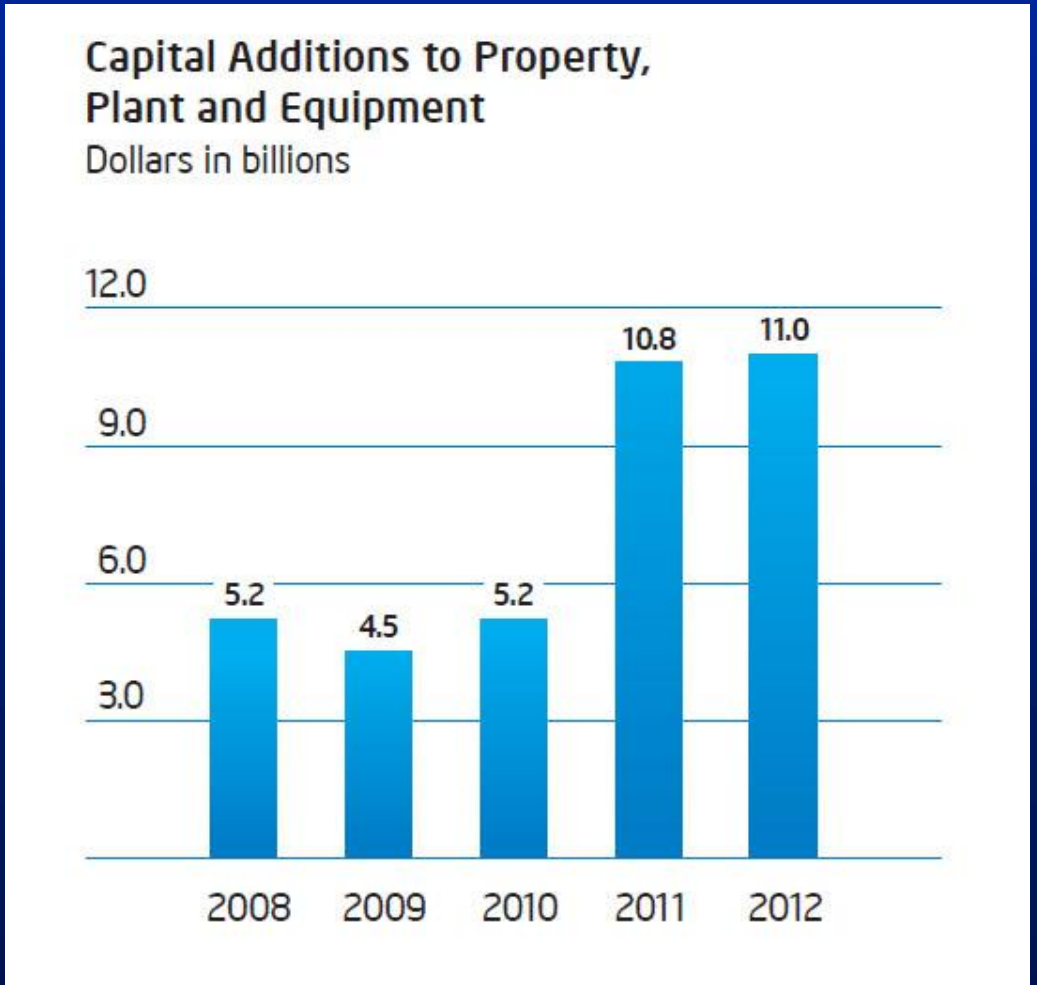
Intel's Hillsboro



Oregonian/OregonLive, Mike Rogoway | The. "Intel Map Shows Long-term Plan for Humongous Hillsboro Expansion." *Oregonlive.com*. The Oregonian, 19 Feb. 2015. Web. 31 Aug. 2015

Intel

2012


Capital Additions to Property, Plant and Equipment
Dollars in billions
12.0
9.0
6.0
3.0
5.2
4.5
5.2
10.8
11.0
2008
2009
2010
2011
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?

Intel cancels 14nm Fab 42 in AZ, due to increasing competition from ARM

January 2014, ExtremeTech.com

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.

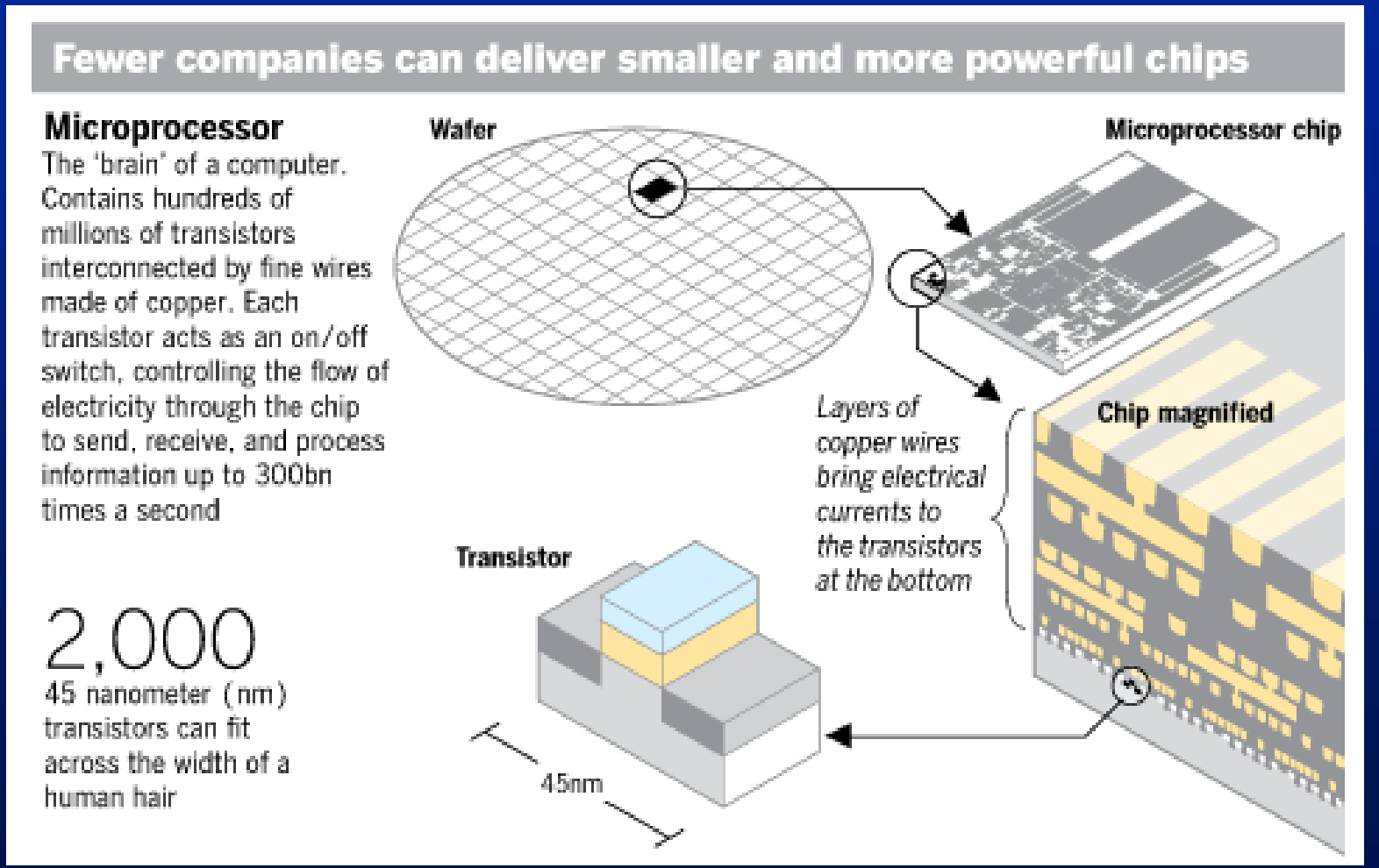
Intel's $7B Investment

Wall Street Journal, Feb. 8th, 2017

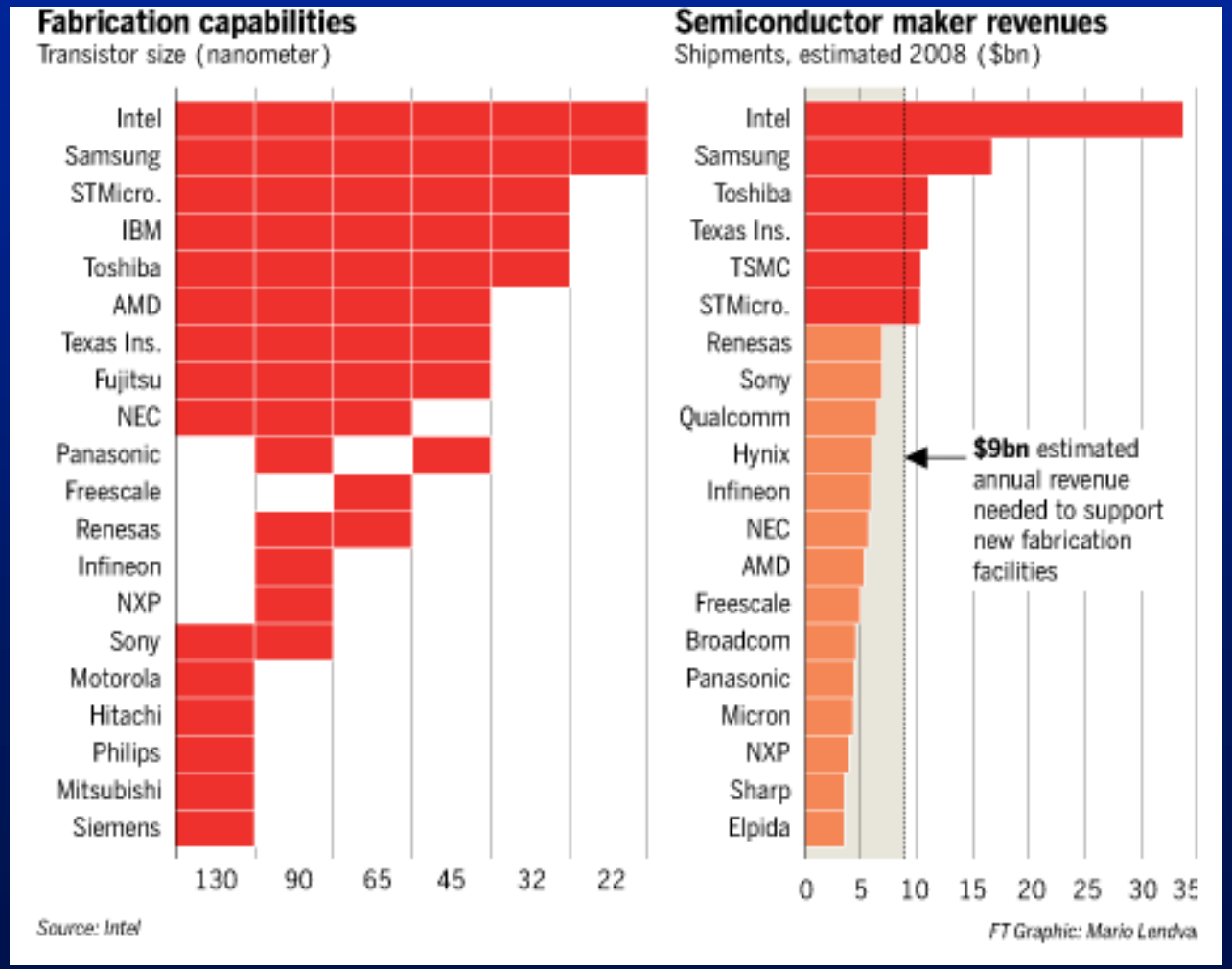
Potential Plans

- 7 nanometer chip technology
- 5 G Networks
- Drones

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



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



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

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

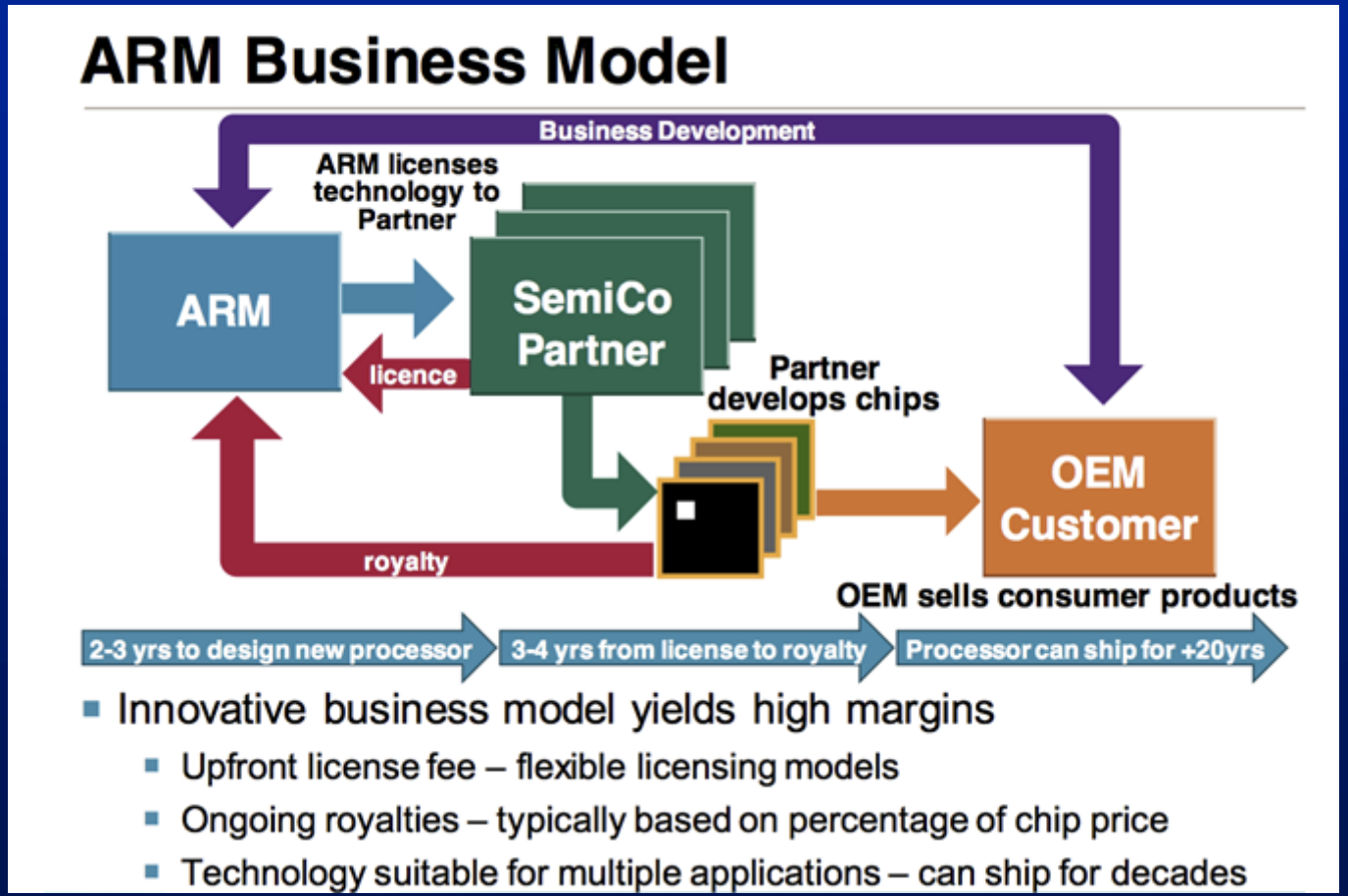
TSMC's Revenue 2014

- In 2014 TSMC's Revenue reached 25 Billion USD.
- They are particularly good 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.

ARM Holdings - Business Model



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)

"Watts are more important then MIPS of FLOPS"

- George Gilder

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)

Japan's Softbank Purchased ARM For $32B 2016

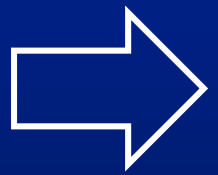
- Influenced by the growing "Internet of Things" (IOT)
- Price was greater than 40% over the closing stock price

Predicting Demand

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?*

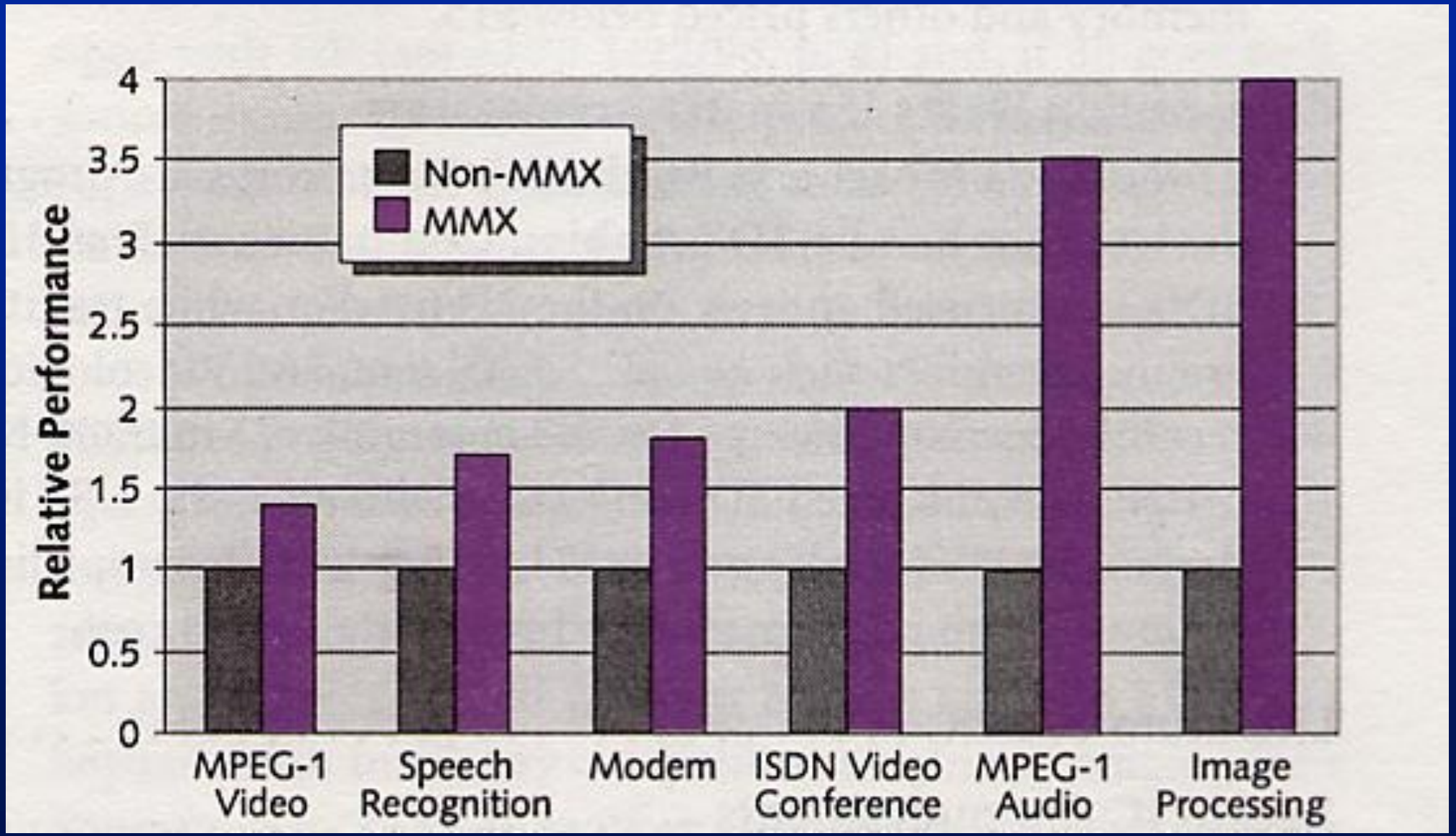
What is MMX?

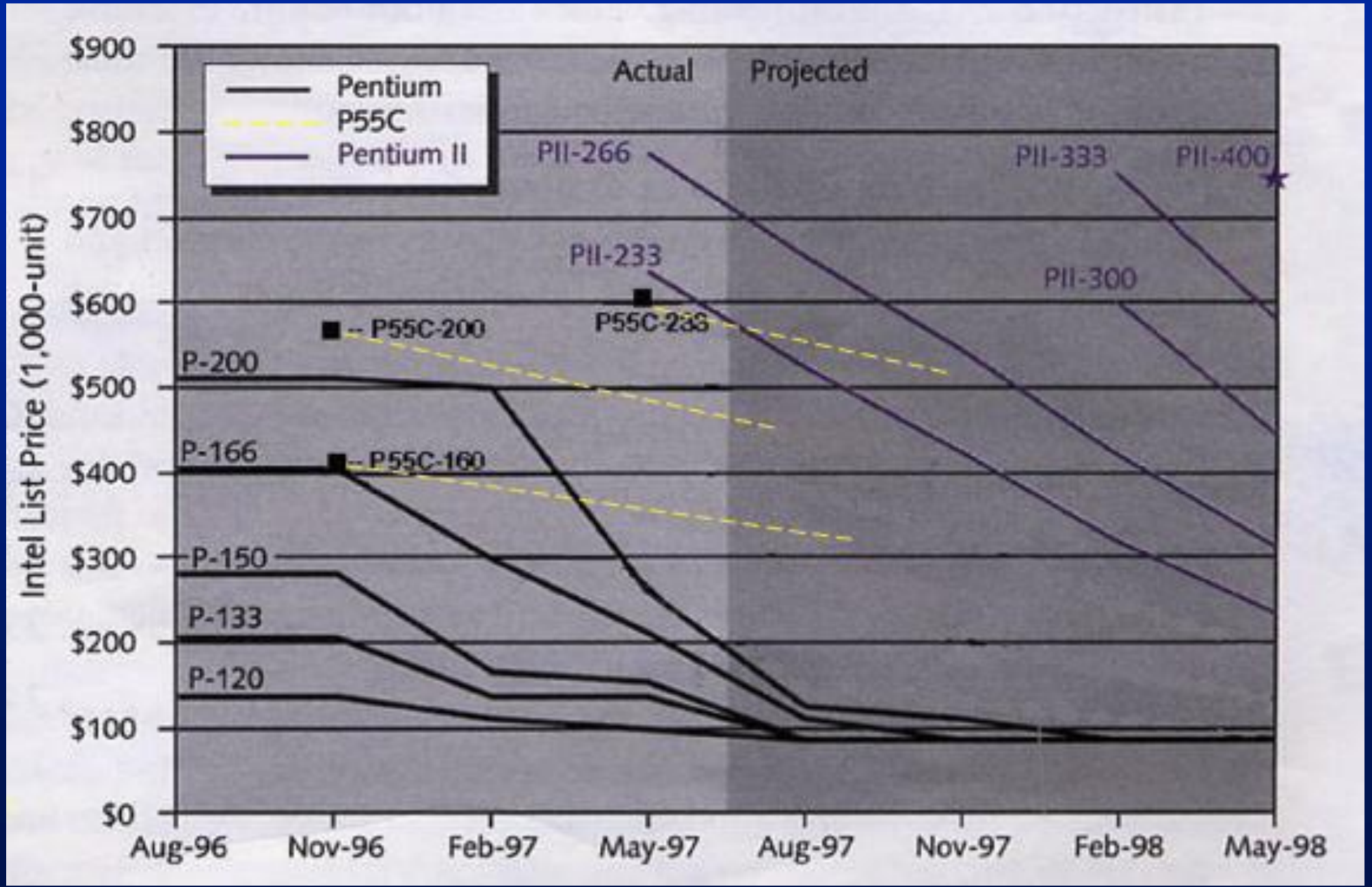
- First major extension to x86 instruction set since 1985
- 57 new instructions to accelerate:

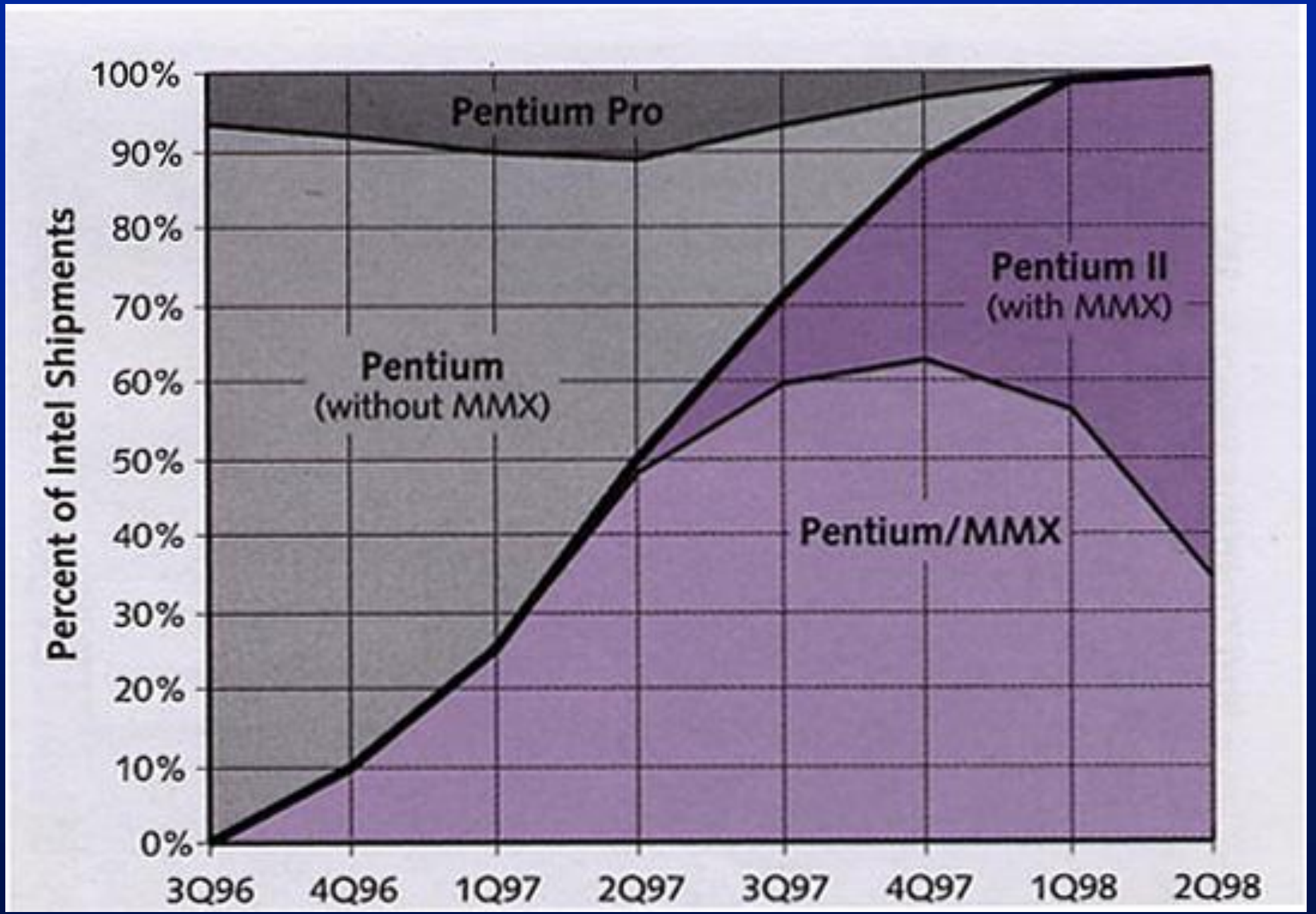
  2D & 3D graphics

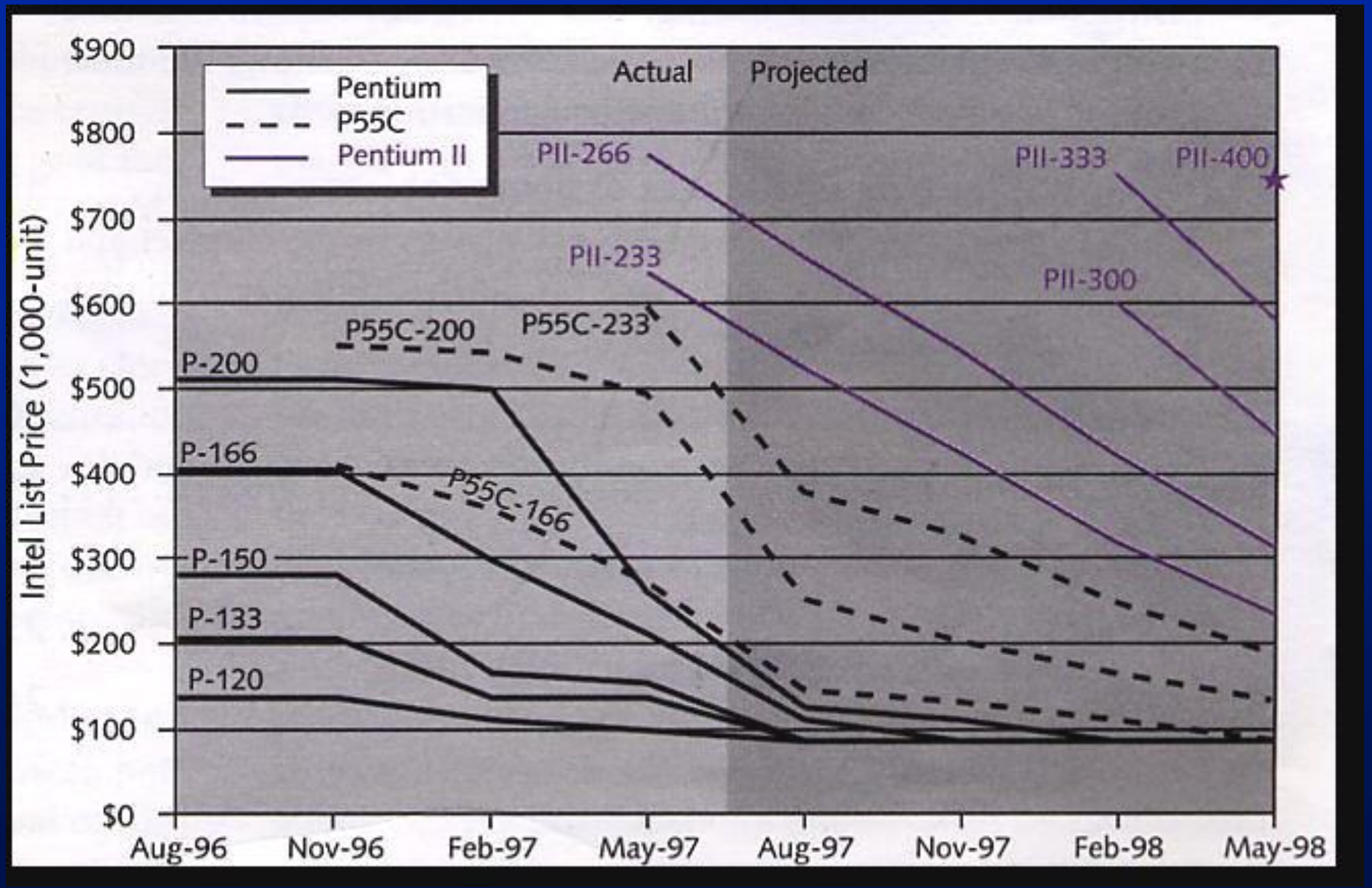
  Video

  Speech synthesis and recognition


Relative Performance
4
3.5
3
2.5
2
1.5
1
0.5
0
Non-MMX
MMX
MPEG-1 Video
Speech Recognition
Modem
ISDN Video Conference
MPEG-1 Audio
Image Processing


Intel List Price (1,000-unit)
$900
$800
$700
$600
$500
$400
$300
$200
$100
$0
Aug-96
Nov-96
Feb-97
May-97
Aug-97
Nov-97
Feb-98
May-98
Actual
Projected
Pentium
P55C
Pentium II
PII-266
PII-333
PII-400
PII-233
PII-300
P55C-200
P55C-233
P55C-160
P-200
P-166
P-150
P-133
P-120


Percent of Intel Shipments
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
3Q96
4Q96
1Q97
2Q97
3Q97
4Q97
1Q98
2Q98
Pentium Pro
Pentium
(without MMX)
Pentium II
(with MMX)
Pentium/MMX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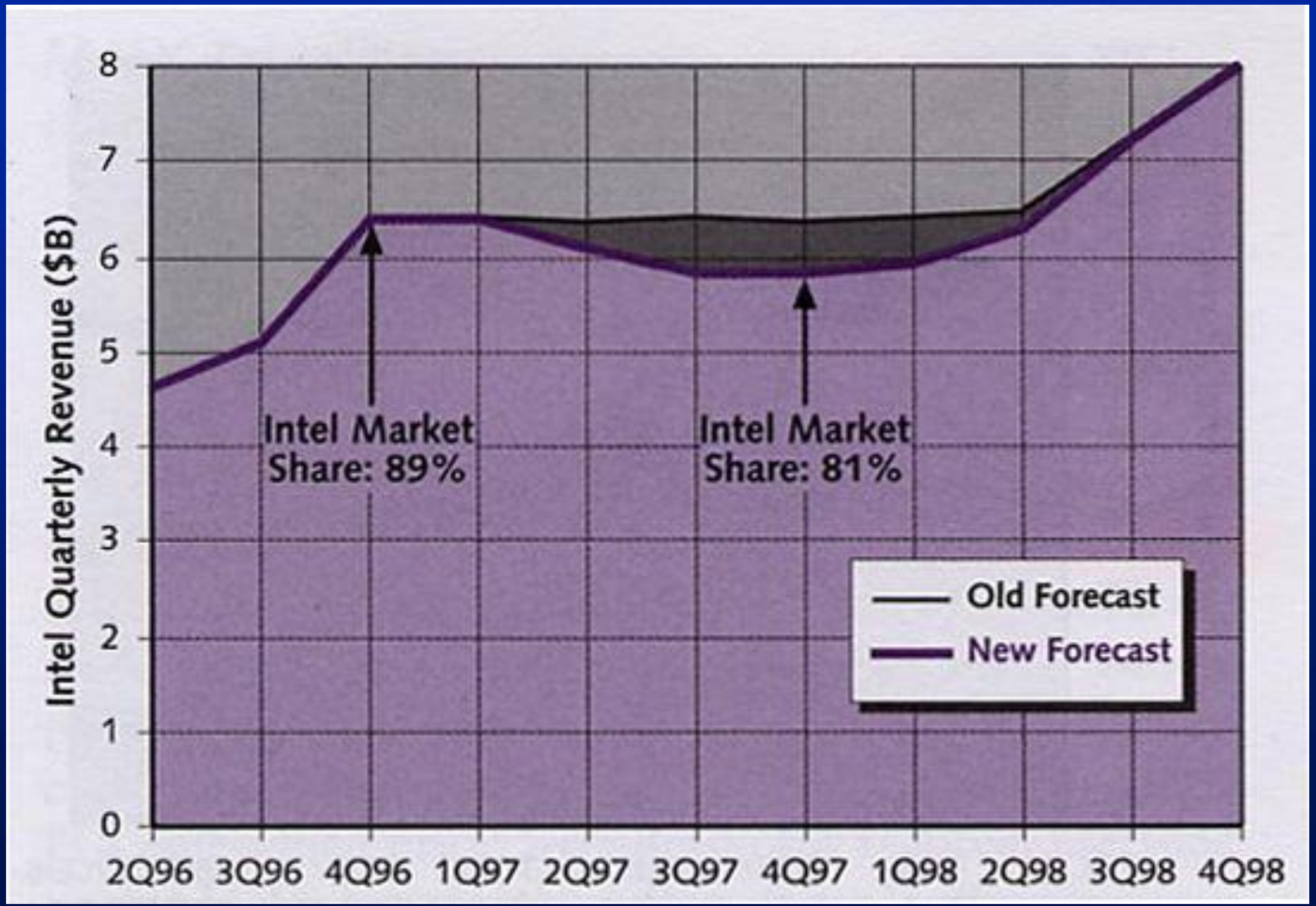
P55C-166
P-150
P-133
P-120


Intel Quarterly Revenue ($B)
8
7
6
5
4
3
2
1
0
2Q96
3Q96
4Q96
1Q97
2Q97
3Q97
4Q97
1Q98
2Q98
3Q98
4Q98
Intel Market Share: 89%
Intel Market Share: 81%
Old Forecast
New Forecast

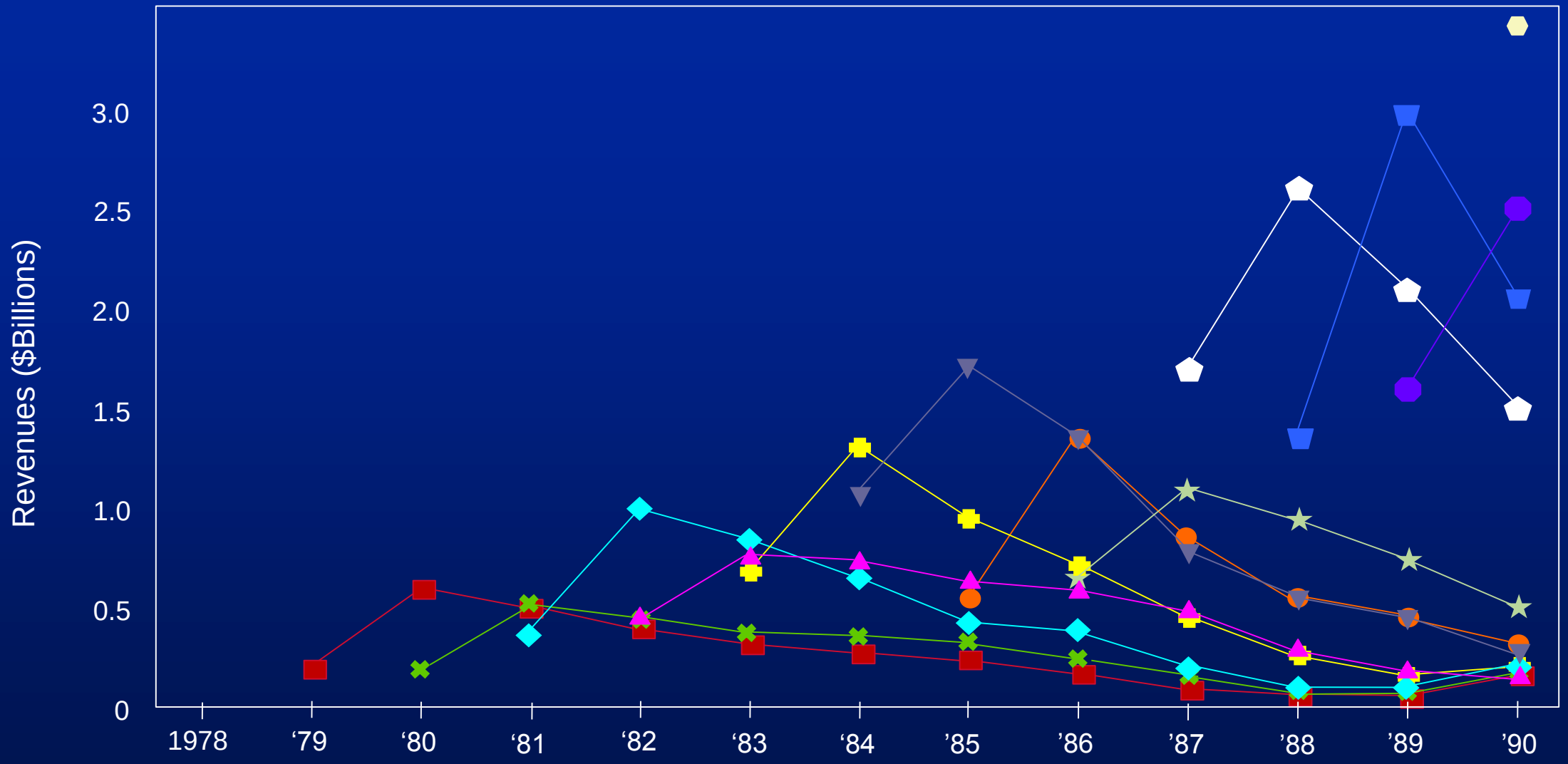
Lessons Learned?

- 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.

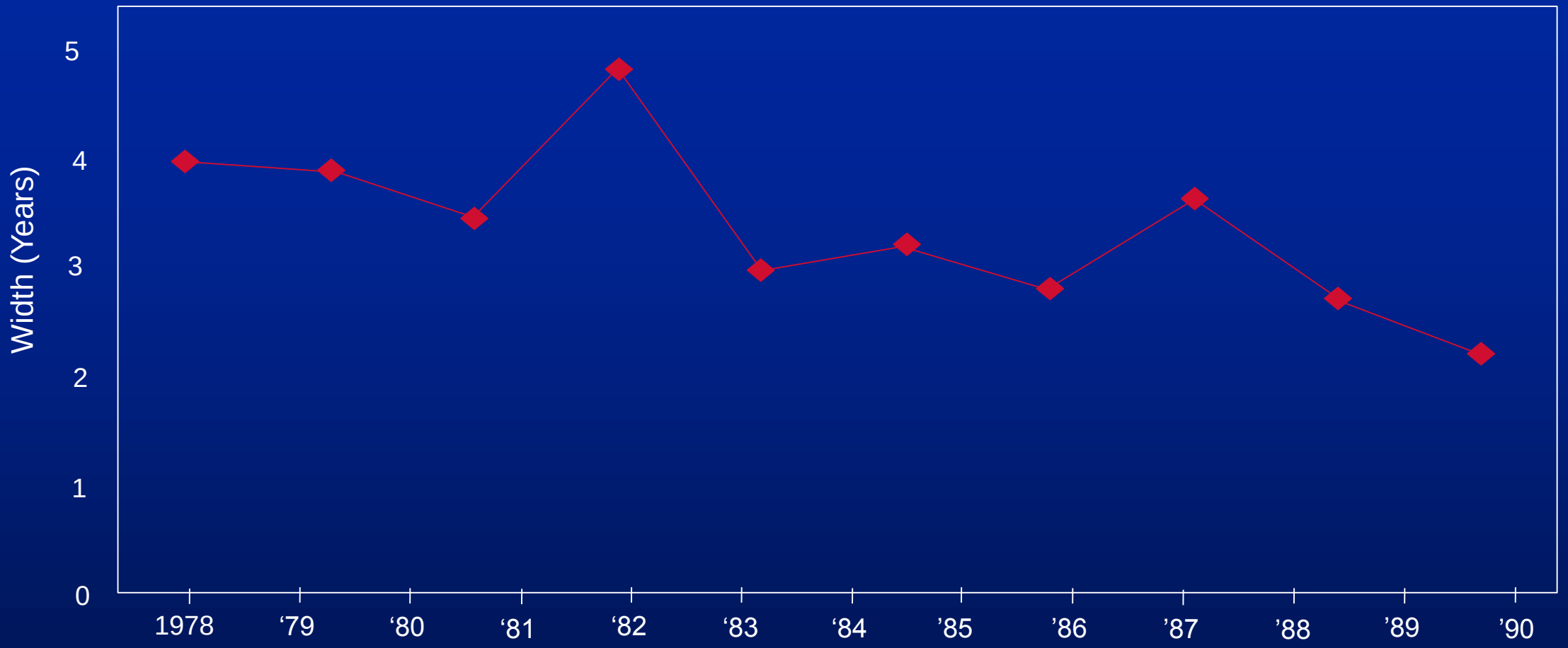
Product Shelf Life Time Is Decreasing



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.

Ralph E. Gomory. From the ‘Ladder of Science’ to the Product development Cycle,” Harvard Business Review, November – Vol. 67 Issue 6 December 1989.

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 could Intel have done?**

Case Study #5 2005

- One Laptop Per Child (OLPC)
- (The predecessor to Notebooks and Netbooks)

OLPC 2005

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 2005

Displays

- Traditional barrier to building cheap laptops
- Need to be readable in bright sunlight and low lighting conditions
- Need power efficiency

OLPC 2005

$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 2005

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

Disruptive Technologies? 2005

- 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

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

HP’s Mini-Note 2006

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

* http://www.cnet.com/topics/tablets/best-tablets/mini-tablets/

DATATECTURE

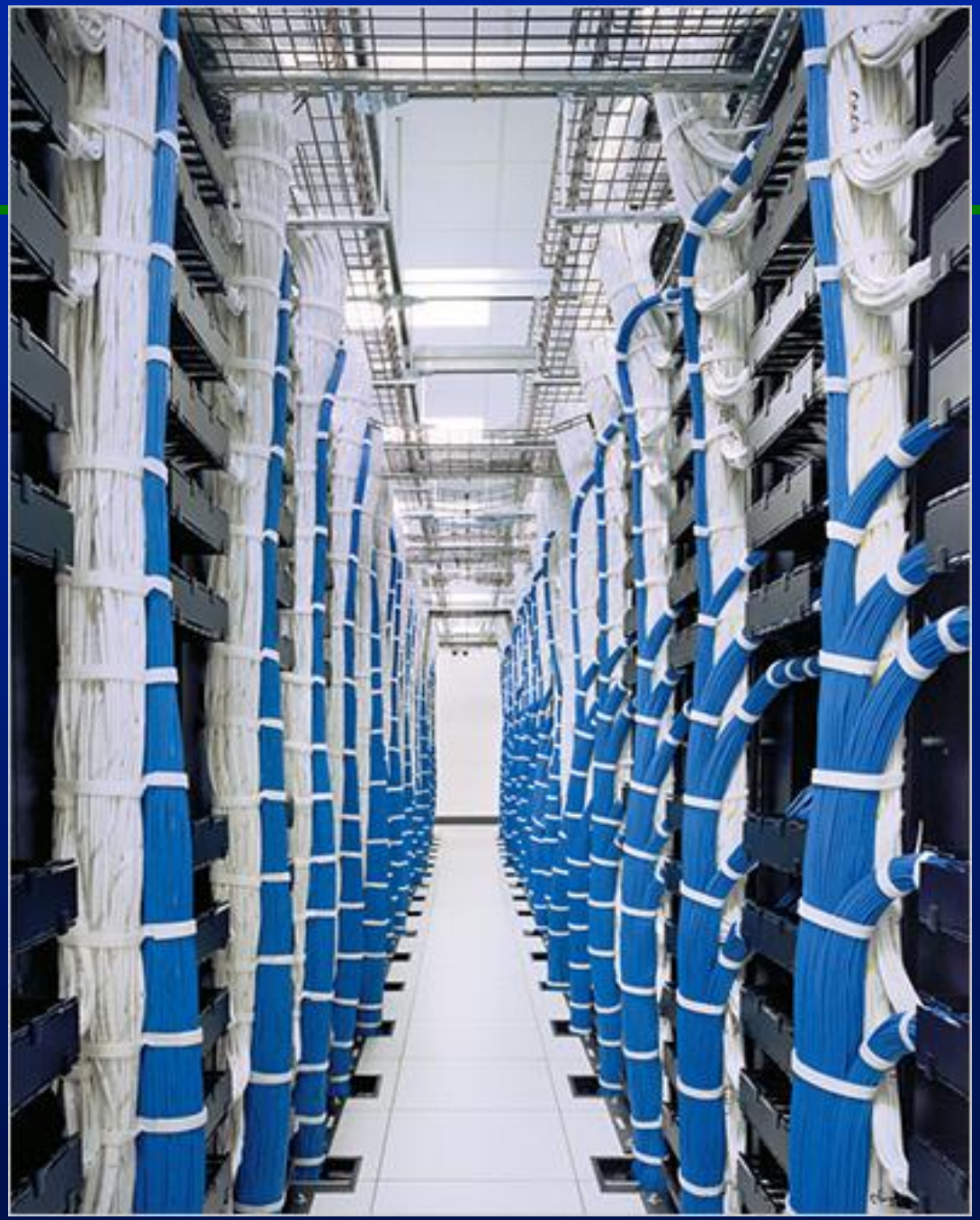
Flickr. MySpace. iTunes. Gmail.

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

"Chip density doubles every 18 months."

Processing Power (P) in 15 years:

$$P = P_{today}(2)^{\frac{15\ years}{18\ months}} = P_t(2)^{\frac{15}{1.5}}$$

$$= P_t(2)^{10} = 1000P_t$$

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)*

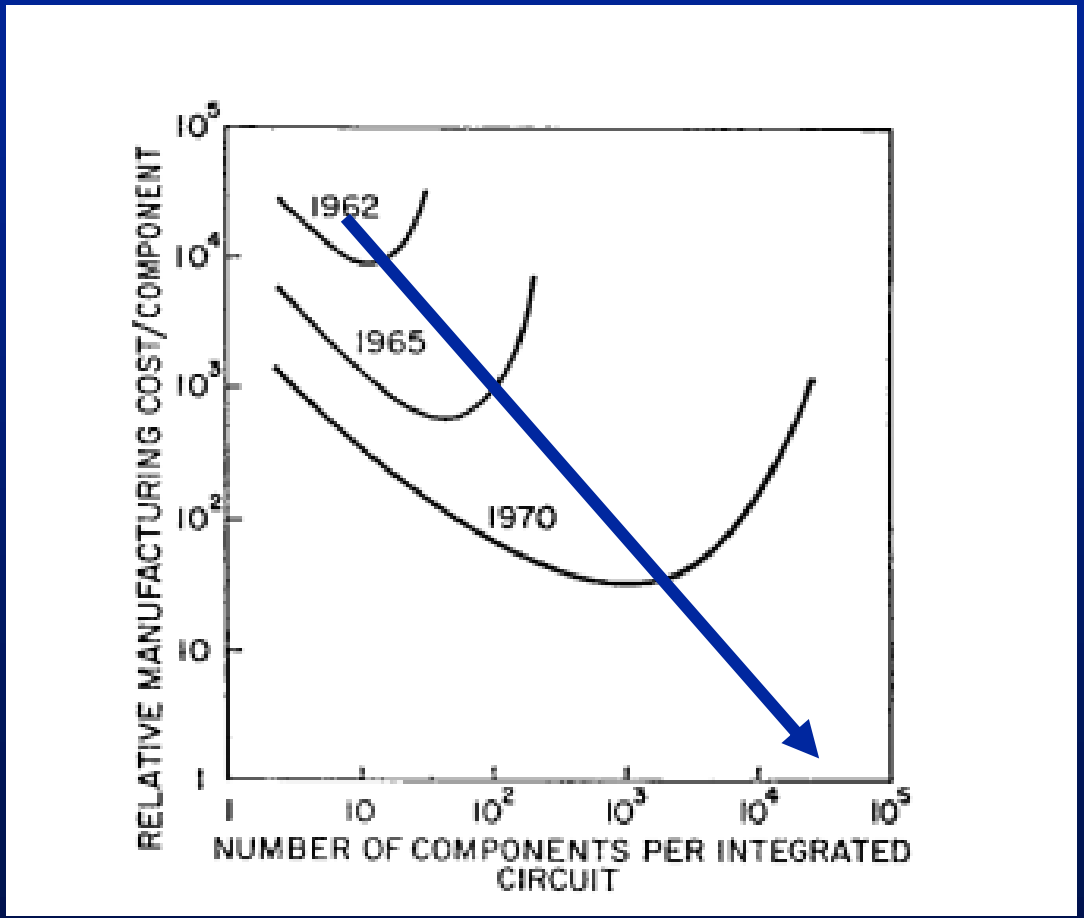
- Original paper noted that the cost per electronic component was inversely proportional to the number of components/chip
- In 1988 Erich Bloch (then head of IBM's research division), later Chairman of NSF Board, & sponsor for Cornell's Theory Center

  "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"

Moore's Original Article 1965

Source: http://web.eng.fiu.edu/npala/eee6397ex/gordon_moore_1965_article.pdf

Moore's Original Prediction 1965



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. →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"

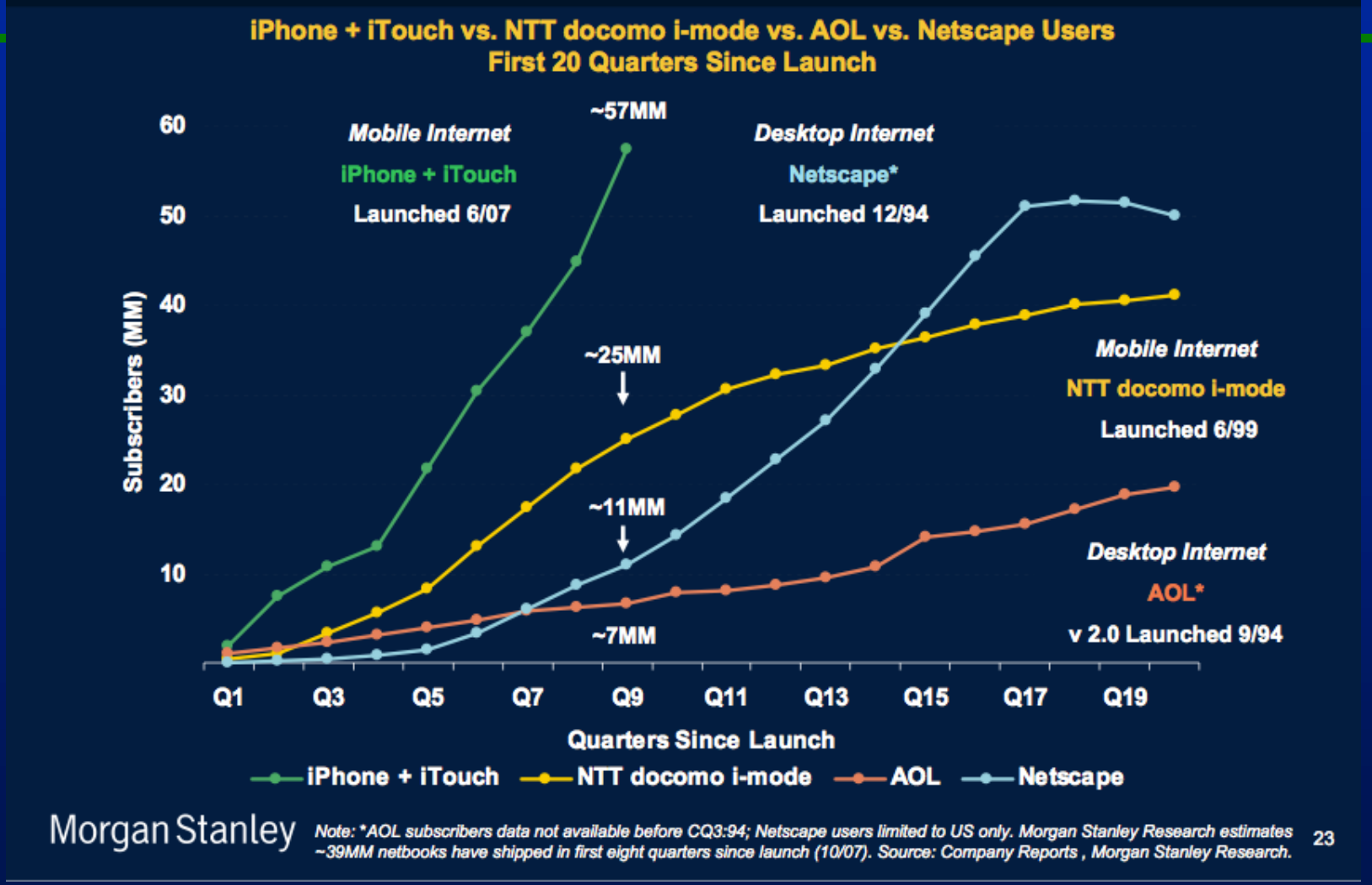
- Most of the features that bloated the programs were superfluous for most of the users most of the time

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

Case Study #6 Cloud Computing

Mobile Internet Outpaces Desktop Internet Adoption

iPhone + iTouch Users = 8x AOL Users 9 Quarters After Launch



Morgan Stanley

*Note: *AOL subscribers data not available before CQ3:94; Netscape users limited to US only. Morgan Stanley Research estimates ~39MM netbooks have shipped in first eight quarters since launch (10/07). Source: Company Reports , Morgan Stanley Research.*

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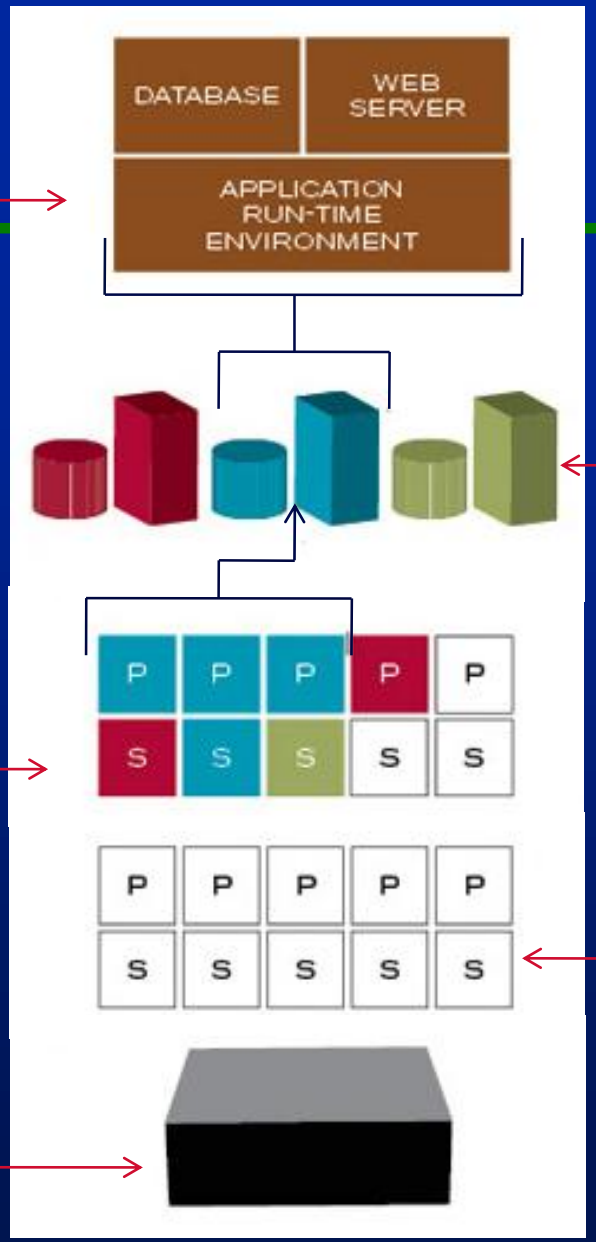
Philip Elmer-Dewitt. “Morgan Stanley drinks the Apple Kool-Aid,” CNNMoney.com, 12/16/09
http://brainstormtech.blogs.fortune.cnn.com/2009/12/16/morgan-stanley-drinks-apple-kool-aid/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:+fortuneapple20+%28FORTUNE:+Apple+2.0%29

(Platform as a service)
Allows developers to run applications



IaaS
VIRTUAL INFRASTRUCTURE
(Infrastructure as a service)

MANAGEMENT LAYER
Customer can choose required resources as needed

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

HARDWARE LAYER
Physical servers, disk arrays & network hardware

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

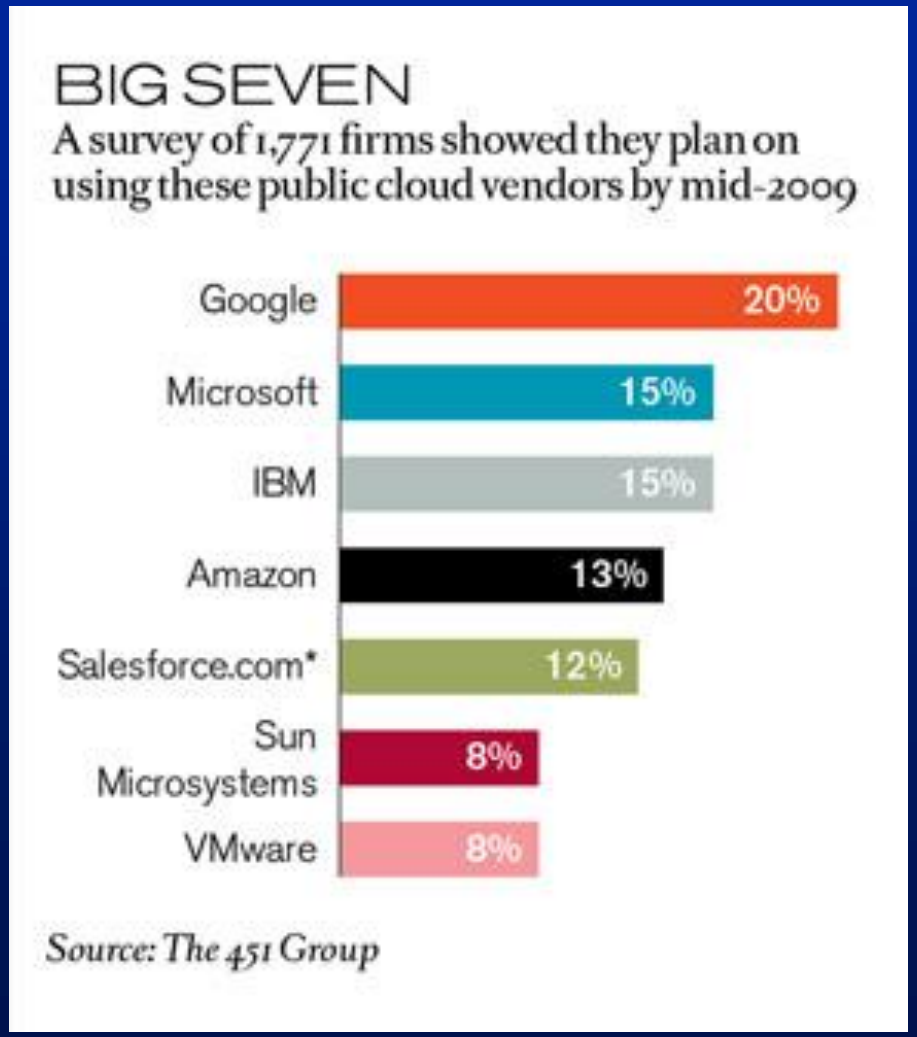
Cloud Computing - Pros

- 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

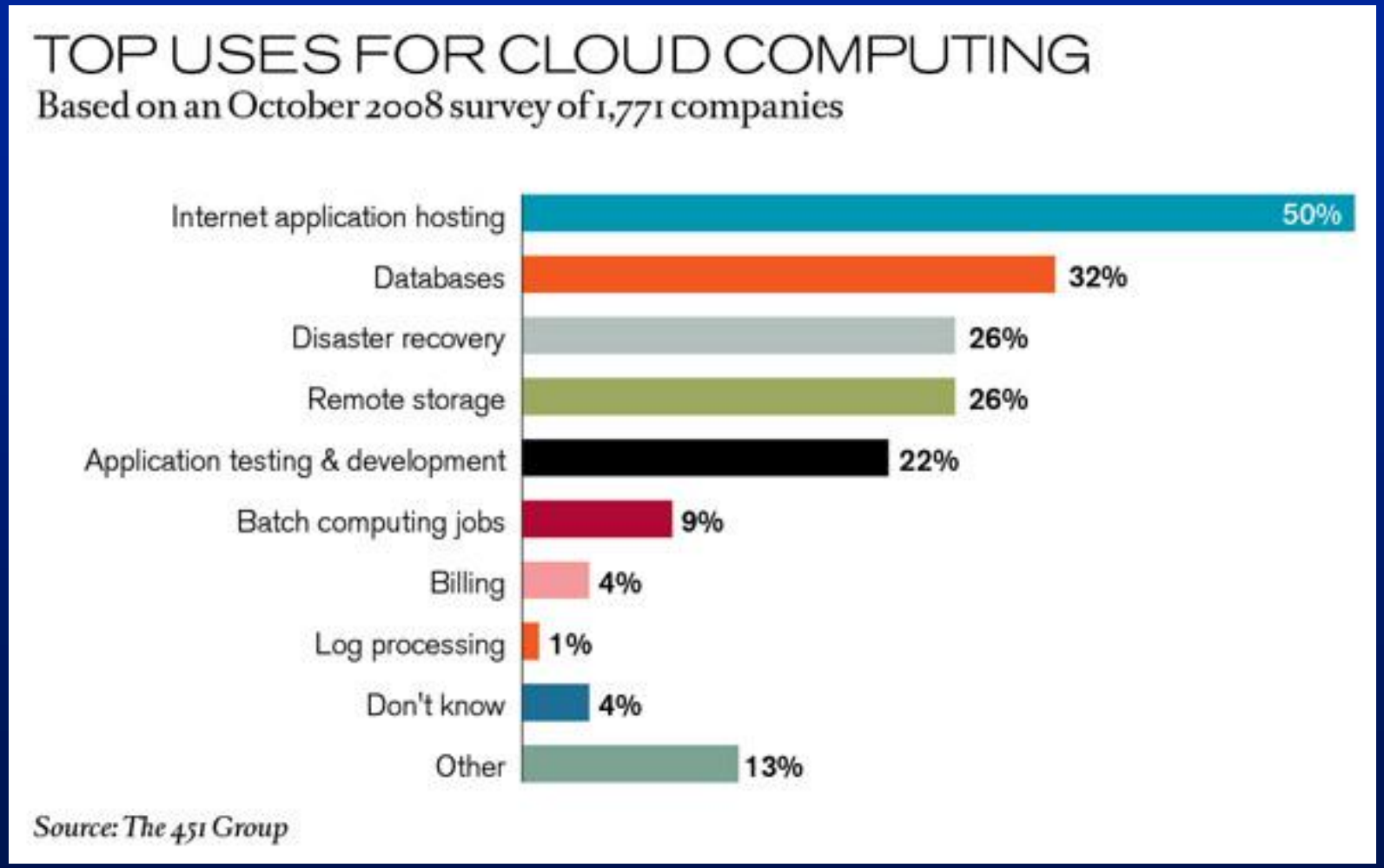
Cloud Computing - Cons

- 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



Virtual Computers, Real Money



Conjuring Clouds

Recent Bandwidth Usage

- Netflix Bandwidth Usage Climbs to Nearly 37% of Internet Traffic at Peak Hours (2015)
- Fascinating Number: Google Is Now 40% Of The Internet (2013)
- Streaming services now account for over 70% of peak traffic in North America (Facebook accounts for 15.96%) (2015)

END. . .