Computer Processing
Case Studies

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Lecture #3
Required Reading


Economics of the Semiconductor Industry

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

[Graph showing trends in profitability and investment from 1971-75, 1976-84, and 1985-94.]
Profitability vs. Investment in the Computer Industry

Rising Profitability
Measured by ratio = \( \frac{\text{cash generated during year}}{\text{investments made in new technology previous year}} \)

where new technology = new equipment + R & D

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

Rising Investment
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.
Price vs. Performance

![Graph showing the relationship between Price and Performance with a current price barrier and two performance levels denoted as C² and C¹. The price ratio for the two levels is indicated as $\frac{p^1}{c^1} > \frac{p^2}{c^2}$]
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
• 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.
• 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
Intel Research and Development

![Bar chart showing research and development expenditures from 2007 to 2011. The expenditures are as follows: 2007: 5.8, 2008: 5.7, 2009: 5.7, 2010: 6.6, 2011: 8.4.](image)
Intel Capital Additions to Property, Plant and Equipment
• 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.
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

60
50
40
30
20
10
0

03 04 05 06 07 08 09 10 11 12

30.1 34.2 38.8 35.4 38.3 37.6 35.1 43.6 54.0 53.3
Capital Additions to Property, Plant and Equipment
Dollars in billions

- 2008: 5.2
- 2009: 4.5
- 2010: 5.2
- 2011: 10.8
- 2012: 11.0

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
• 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?
<table>
<thead>
<tr>
<th>Intel</th>
<th>2015</th>
</tr>
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<tbody>
<tr>
<td>• Intel again delays 10nm technology. It will depend on revenue increase from Windows 10 and its new Skylake processor.</td>
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<tr>
<td>• The second generation of 14nm production technology had significant yield improvements.</td>
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<tr>
<td>• At the same time, Intel moved to purchase Altera so it could shift from PC’s to mobile devices.</td>
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</tbody>
</table>
Intel’s Hillsboro

2015

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)
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
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.
ARM Holdings - Business Model

ARM Holdings

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

July 20, 2009
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
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

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.

Source: Hewlett-Packard

Case Study # 4

• 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.
Case Study #5

- 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 back lighting
OLPC

• Was this a threat from below?

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

• Is this a disruptive technology?
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 x 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.
## Budget Laptops of 2015


<table>
<thead>
<tr>
<th>Laptop</th>
<th>Price</th>
<th>Screen Size</th>
<th>Resolution</th>
<th>Processor Details</th>
<th>RAM</th>
<th>SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microsoft Surface 3</td>
<td>$499.00</td>
<td>10.8”</td>
<td>1,920 x 1,080</td>
<td>10.8” 1,920 x 1,080 touchscreen, 1.6 GHz Quad-Core Intel Processor, 2 GB RAM, 64 GB SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hisense Chromebook</td>
<td>$149.00</td>
<td>11”</td>
<td>1,366x768</td>
<td>11” 1,366x768 touchscreen, 1.8 GHz Rockchip Processor, 2 GB RAM, 16 GB SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toshiba Chromebook 2</td>
<td>$299.00 - $320.09</td>
<td>13.3”</td>
<td>1,920 x 1,080</td>
<td>13.3” 1,920 x 1,080 LED display, 2.16 GHz Dual-Core Intel Processor, 4 GB RAM, 16 GB SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acer Chromebook 15</td>
<td>$305.11 - $327.93</td>
<td>15.6”</td>
<td>1,920 x 1080</td>
<td>15.6” 1,920 x 1080 LED display, 1.5 GHz Dual-Core Intel Processor, 4 GB RAM, 16 GB SSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HP Stream 11.6</td>
<td>$199.00</td>
<td>11.6”</td>
<td>1,366 x 768</td>
<td>11.6” 1,366 x 768 WLED display, 2.16 GHz Processor, 2 GB RAM, 32 GB SSD</td>
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</tbody>
</table>
## Budget Tablets of 2015


<table>
<thead>
<tr>
<th>Tablet Model</th>
<th>Price</th>
<th>Display Size</th>
<th>Resolution</th>
<th>Processor</th>
<th>RAM</th>
<th>Storage</th>
<th>Additional Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon Kindle Fire HDX 7</td>
<td>$235.49</td>
<td>7”</td>
<td>1,920 x 1,080</td>
<td>Multi-Touch Display</td>
<td>2 GB RAM</td>
<td>16 GB Integrated Storage</td>
<td>7” 1,920 x 1,080 Multi-Touch Display</td>
</tr>
<tr>
<td>Samsung Galaxy Tab A (8-inch)</td>
<td>$179.00 - $229.99</td>
<td>8”</td>
<td>1,024 x 768</td>
<td>Multi-Touch Display</td>
<td>1.2 GHz Quad-Core Qualcomm Processor</td>
<td>2 GB RAM</td>
<td>16 GB SSD</td>
</tr>
<tr>
<td>Dell Venue 7</td>
<td>$129.96</td>
<td>7”</td>
<td>1,280 x 800</td>
<td>Multi-Touch Display</td>
<td>1.6 GHz Dual-Core Intel Atom Processor</td>
<td>2 GB RAM</td>
<td>16 GB SSD</td>
</tr>
<tr>
<td>Amazon Fire HD 6</td>
<td>$99.00</td>
<td>6”</td>
<td>1,280 x 800</td>
<td>Multi-Touch Display</td>
<td>2 GB RAM</td>
<td>16 GB SSD</td>
<td>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</td>
</tr>
<tr>
<td>Apple iPad Mini 3*</td>
<td>$399.00</td>
<td>7.9”</td>
<td>2,048 x 1,536</td>
<td>Multi-Touch Display</td>
<td>1.3 GHz Dual-Core (ARM) Apple A7</td>
<td>16 GB SSD</td>
<td>16 GB Integrated Storage</td>
</tr>
</tbody>
</table>

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.

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 the 1990’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 193 µm 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

“We are 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