EEL 4768: Computer Architecture

Introduction

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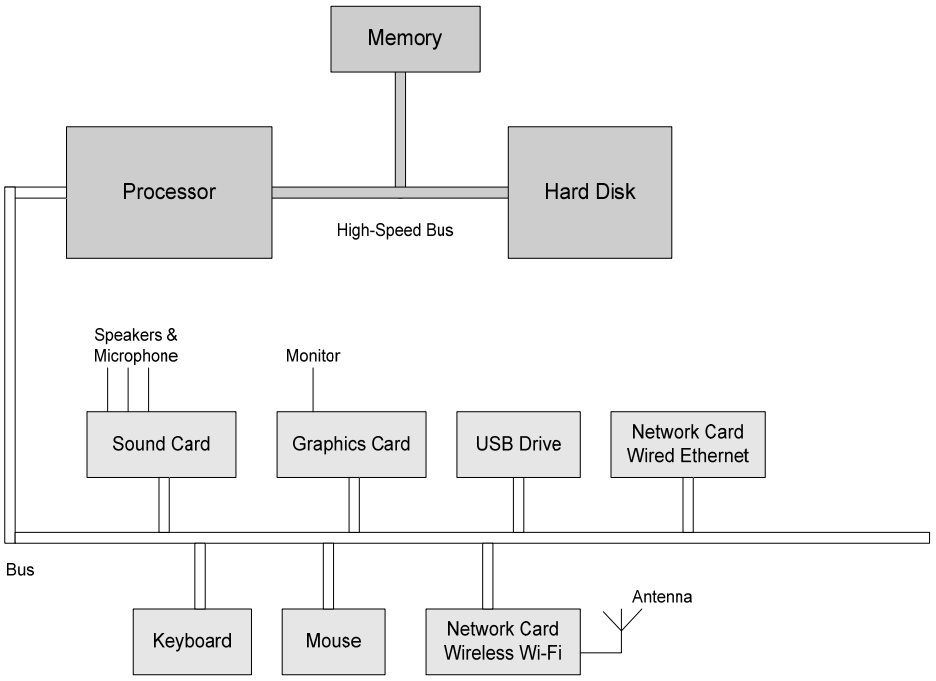
Basic Computer Organization



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Computer Architecture

- The figure in the previous slide shows the basic layout of a computer with the components found most often
- The computer architecture is mostly involved with the CPU
- *What is the definition of computer architecture?*

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Computer Architecture

- *Definition:* The architecture describes the low-level software environment
- Think of assembly language
  - How many bits is a word (32 bits?)
  - How many registers are there on the CPU?
  - What are the supported instructions?
  - What are the addressing modes?
- The architecture describes the environment in which the assembly language runs

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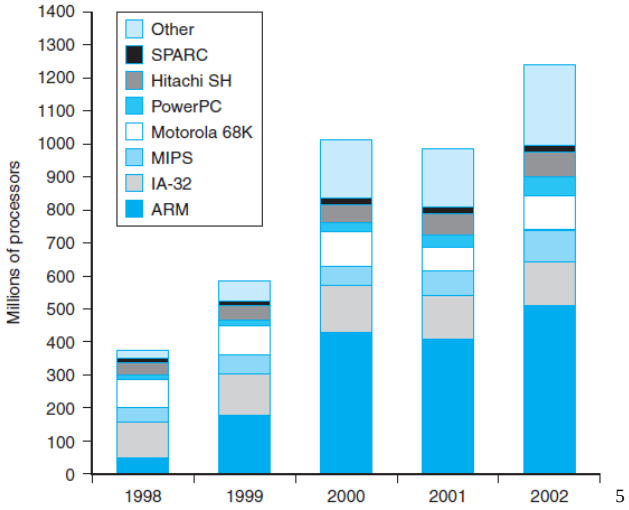
Most Popular Architectures

- ARM are the most popular CPUs by number of CPUs sold
- However, a lot of these CPUs have low computation power; they're used in products, such as phones, calculators, home monitoring, printer…

- You can you find more information on ARM's CPUs at this link:
- http://www.arm.com/products/processors/



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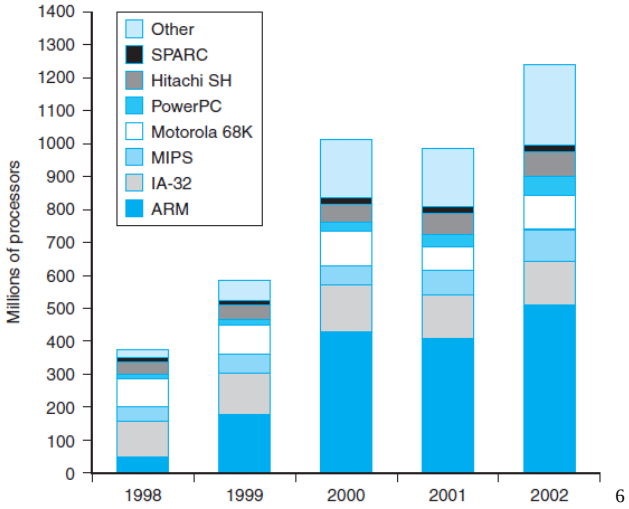
Most Popular Architectures

- The next popular architecture is the IA-32 (Intel Architecture 32-bit)
- It's part of the Intel x86 family of architectures
- It's used in the Intel-based CPUs in laptops, desktops and servers



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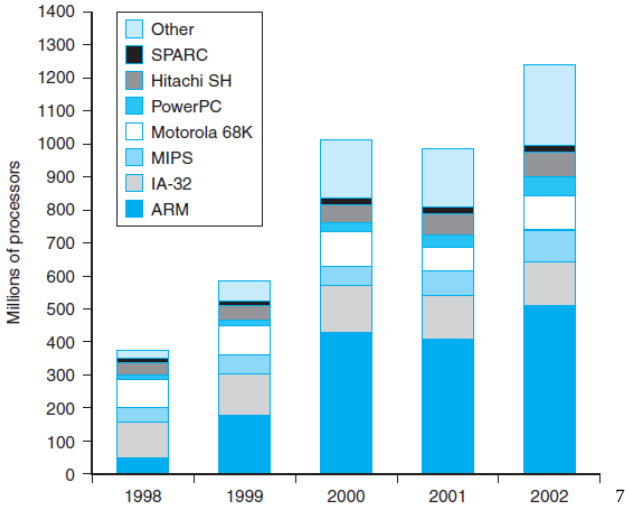
Most Popular Architectures

- MIPS is the third most popular architecture
- It's used in products like: digital camera, digital TV, DVD player, automotive, tablets, media players, network router…

- You can find more information on MIPS at this link:
- http://www.mips.com



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Architecture License

- The previous figure shows the popular computer architecture designers
- They're: ARM, Intel, MIPS, PowerPC, SPARC

- The task to produce a CPU:
- 1) Design the CPU
- 2) Build the CPU through fabrication

- Some of the companies mentioned above do both parts (design & build)
- Intel does both

- Other companies do only step (1), designing the CPU, they don't build it
- They sell the design through a license to consumer electronics companies so they can build it

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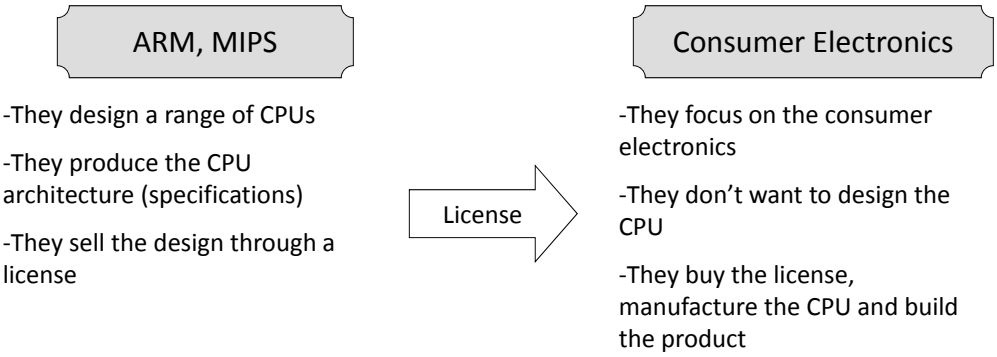
Architecture License

- The consumer electronics company have expertise on appliances (TV, DVD player, fridge, oven, …)
- They don't have expertise in designing CPUs, but they need a lot of CPUs for their products
- They buy the CPU design through a license from ARM or MIPS and fabricate the CPU for use in their appliances



Architecture License

- *Question:* why doesn't ARM and MIPS fabricate the CPU?
- MIPS have fabricated CPUs in the past but they don't do it now

One possible reason:

- The consumer electronics companies want to have the option of tweaking the design to fit their products
- They might want to produce so many versions of the same CPU; each optimized for an appliance
- It may not be feasible for a company like MIPS to keep track of all these varieties; therefore, the consumer electronics company take charge in producing these variants
- Secondly, the consumer electronic companies are already invest in large-scale production; so they're able to build factories to fabricate CPUs (or contract these tasks)

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CPU (Central Processing Unit)

- What does the CPU do?
- The main function of the processor is to execute **instructions**
- An **instruction** is the basic operation done by a computer
- Any program we're running is broken down into millions or billions of instructions
  - The CPU executes these instructions one by one

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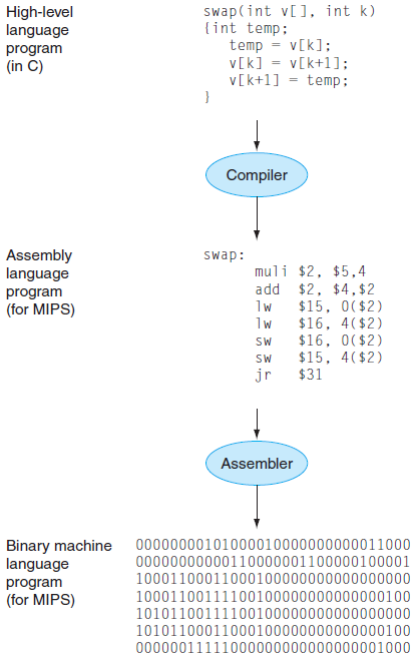
The instructions

- What are the instructions that run on the hardware (at the processor)?
- The C language statements don't run directly on the hardware
- A high-level language like C, gets compiled
- We have the **assembly language**
- The assembler transforms the assembly language into **machine language**, which is made of 1s and 0s
- The machine language is executed by the CPU! It runs directly on the hardware.



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Transistor Technology

- The CPU chips are built with transistor technology
- The improvement of transistor technologies implicate we can build faster CPUs
- Fortunately, the transistor technologies have been improving at a tremendous pace (and so the CPUs)
  - That's why, every few years, we can get a computer or a phone that's much faster than the one we had

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Transistor Technology

- Moore's law captures the improvement in transistor technology
- The number of transistors that we can put on a chip doubles every 1.5 to 2 years
  - Shown in figure on next slide
- When the chip can have more transistors, we can build a CPU with more features
- Therefore, the computer architecture designer has more to work with
  - … and should introduce new features to utilize the additional transistors

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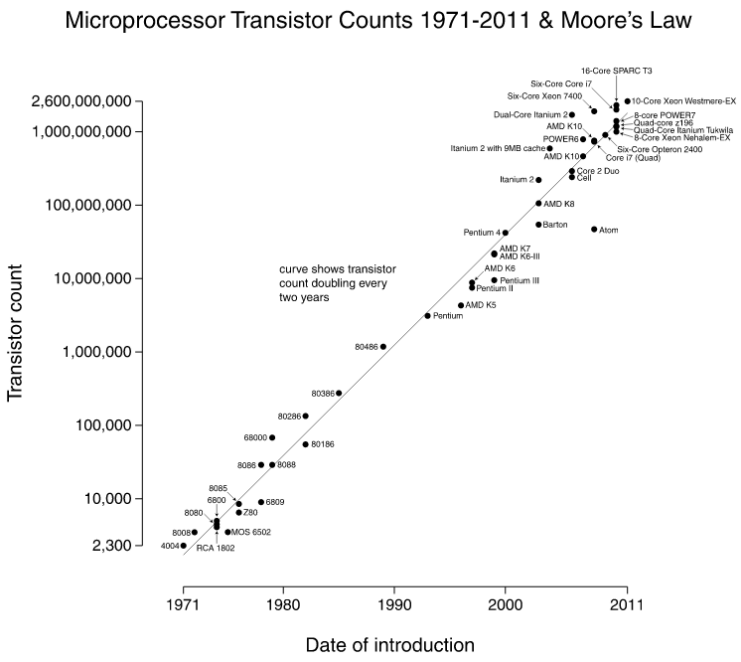
Moore's Law



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Transistor Technology

- In addition to have more transistors, the transistors were becoming faster
- It's possible to run them at a faster clock rate (eg: from 1 GHz to 2 GHz)

- However, we have hit a wall on how much we can increase the clock rate
- In most CPUs, it's not really possible to go beyond 3.6 GHz

- The higher clock rate means more power is dissipated in the chip
- When the transistors flip on/off at a high rate, they generate more heat and it's becoming difficult to cool off the chip by using the fan that's in the computer
- If the CPU chip goes beyond a certain temperature, it will start producing errors and may get damaged

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Fabrication Technology

- During the progression of Moore's law (more transistors in the chip), there were some milestones that changed the CPU design
- In early 1980s, it was possible to put between 25,000 and 50,000 transistors on a single chip
  - Then, a 32-bit microprocessor could fit on a single chip
  - Before that, a 32-bit processor was fabricated on two chips
  - Using a single chip eliminates the chip crossing connection and improves speed and power consumption
- By late 1980s, the number of transistors increased even further
- Then, it was possible to put the first-level cache memory on the CPU chip
- …

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Fabrication Technology

This trend continues to happen, integrating more parts on the CPU chip as the CPU has more and more transistors

- The second and third levels of cache can fit on the CPU chip
- Recently, the graphics card has been fit on the CPU chip
- And now, parts of the mother board (a chip called the North Bridge) has been placed on the CPU chip in some architectures

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Computer Architecture Design

- The table below shows the progression of architecture design in CPUs from 1989 through 2005

Microprocessor	Year	Clock Rate	Pipeline Stages	Issue width	Out-of-order/ Speculation	Cores	Power
i486	1989	25MHz	5	1	No	1	5W
Pentium	1993	66MHz	5	2	No	1	10W
Pentium Pro	1997	200MHz	10	3	Yes	1	29W
P4 Willamette	2001	2000MHz	22	3	Yes	1	75W
P4 Prescott	2004	3600MHz	31	3	Yes	1	103W
Core	2006	2930MHz	14	4	Yes	2	75W
UltraSparc III	2003	1950MHz	14	4	No	1	90W
UltraSparc T1	2005	1200MHz	6	1	No	8	70W

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Computer Architecture Design

- Through these years, Moore's law was providing more transistors that are faster
- In the table, the columns "Pipeline Stages", "Issue width" and "Out-of-order/Speculation" indicate sophisticated features that make the CPU faster
- Therefore, the table shows that the performance was improved by increasing the clock rate and introducing more features in the CPU
- One downside in that route was that the power consumed by the chip was increasing and the heating issue cannot be solved
- Therefore, since around 2007, we start to utilize the additional transistors in making more cores on the chip which helped in reducing the power consumed by the chip
- The multiple cores are simple cores; they don't have much features (as the table shows)

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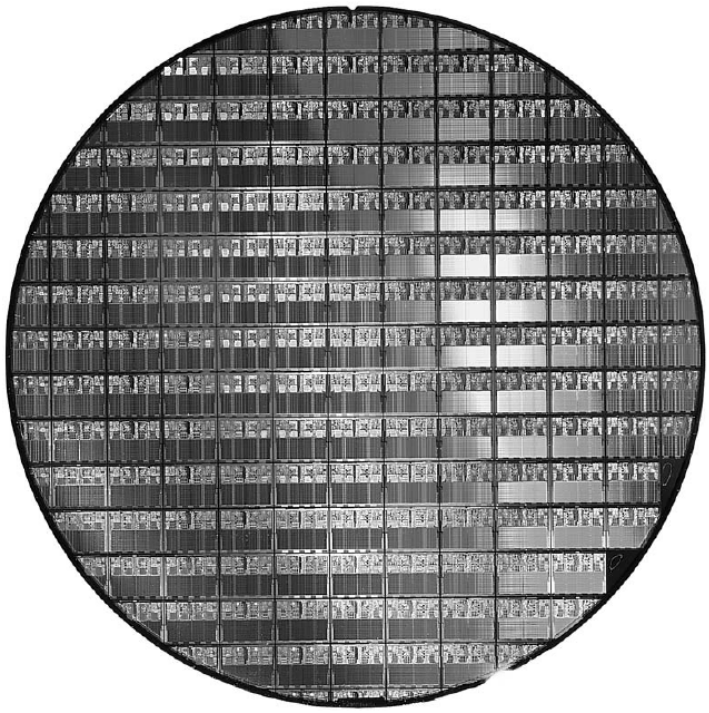
Fabrication

This silicon wafer contains 117 AMD Opteron chips

The diameter is 11.81 inches or 30 centimeters



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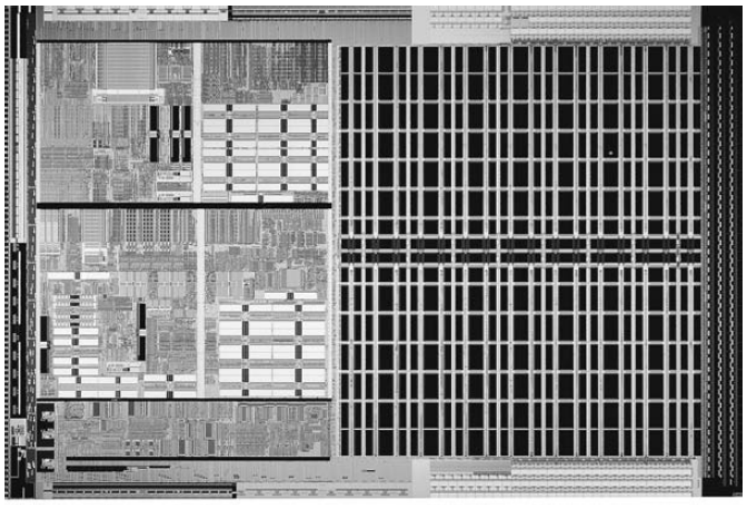
This is one of the AMD Opteron microprocessor dies



A die is a processor before testing and packaging.

We don't call it a processor yet because it needs to have the connection pins done.

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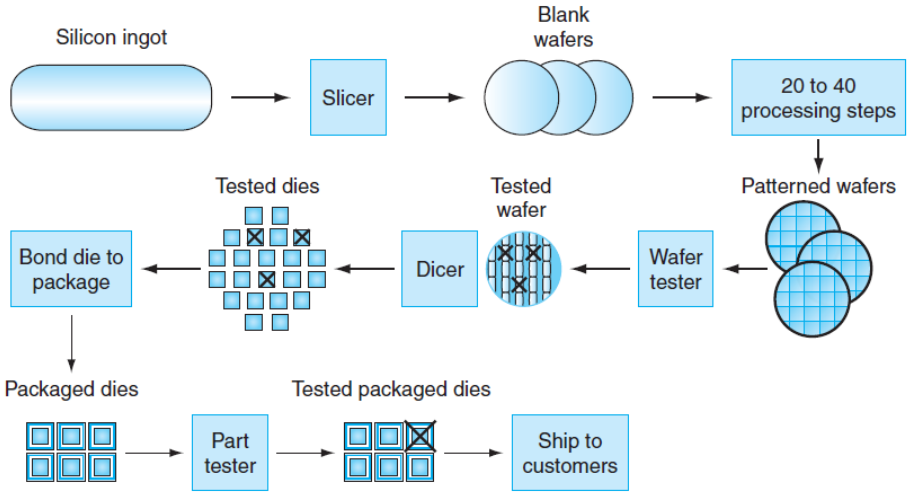
Fabrication Technology

- Who does this process?
  - Companies like Intel have fabrications plants
  - The process is very advanced manufacturing
- At UCF, there's a lab that does some of these tasks



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Silicon Ingot

The silicon ingot is a cylinder

Blank silicon wafer

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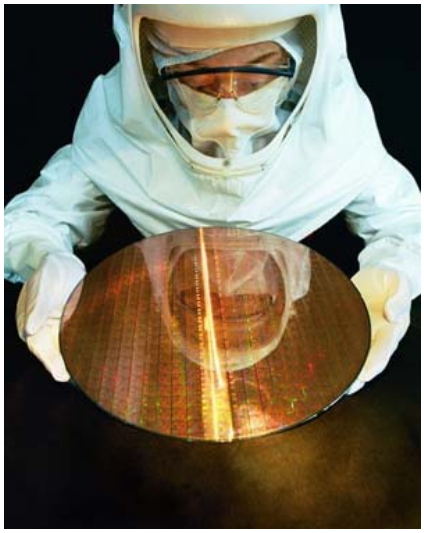
CPU Manufacturing

- Clean room environment
- Any bit of dust might ruin the processor die



A worker inspects a silicon wafer. The wafer has been processed. It contains multiple CPU dies.

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Intel Animation

- From Sand to Silicon: The Making of a Chip

http://www.youtube.com/watch?v=Q5paWn7bFg4&feature=endscreen&NR=1

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