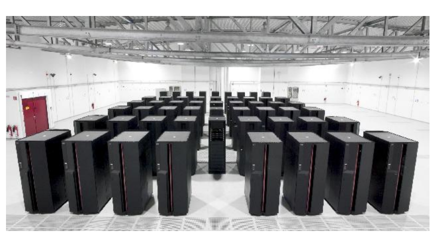
University of Massachusetts Amherst

Lecture 4–Microprocessors

ECE 197SA – Systems Appreciation

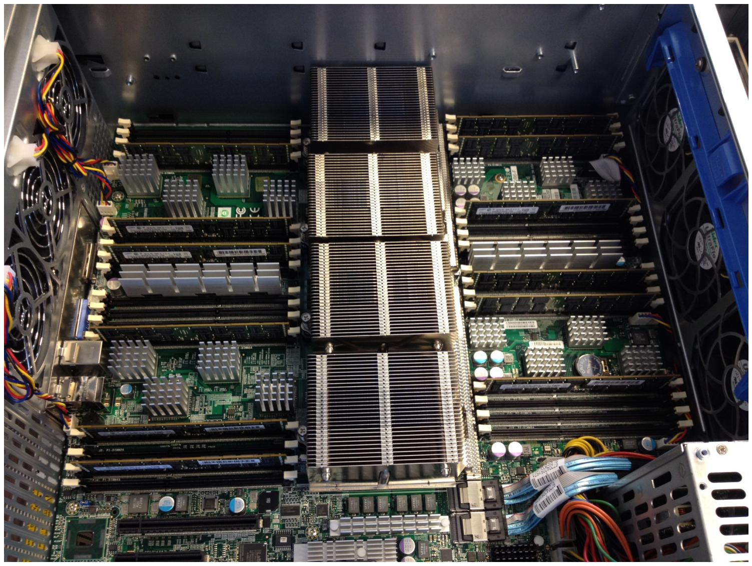
Microprocessors

- Microprocessors are at core of any computing system



Computers

- Where is the microprocessor?

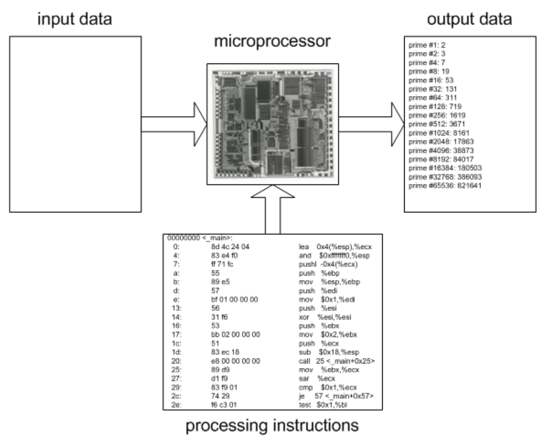


Operation

- What does a computer/microprocessor do?

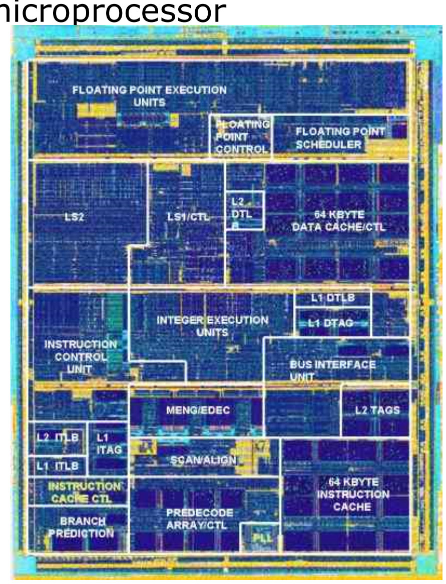
Operation

- Microprocessor performs computations
  - Input data is processed
  - Processing instructions (program) determines operations
  - Output is result of computation



Microprocessor Components

- Main components of a microprocessor
  - Computation
    - » Arithmetic operations
    - » Logic operations
    - » Moving data
    - » Conditional execution
  - Storage
    - » Registers
    - » Memory
    - » Disk
  - I/O
    - » File input/output
    - » Keyboard/mouse input
    - » Network input/output
    - » Video output
    - » Audio input/output



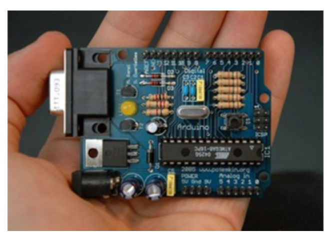
AMD Athlon (K7)

Example Microprocessors

- Microcontroller
  - Digital thermostat, key fob, remote control, digital clock, battery charger, etc.
- Embedded microprocessor
  - Cell phone, PDA, wireless router
- Microprocessor
  - Laptop, desktop, game console
- Multiple microprocessors
  - High-end laptop, desktop, game console, graphics card, supercomputer

- Many systems have multiple different processors
  - Microprocessor, hard disk controller, network interface processor, graphics processor, etc.

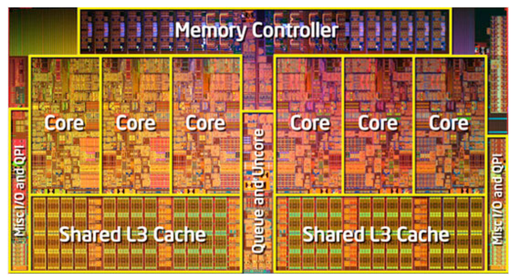
Atmel ATmega 128



- Microcontroller
  - Single processor
  - Instruction set
    - » 8-bit RISC
  - Speed
    - » Clock: 16MHz
  - Memory
    - » Data: 4kB
    - » Instruction: 128kB
  - Size
    - » A few mm^2
  - Power consumption
    - » Around 125mW

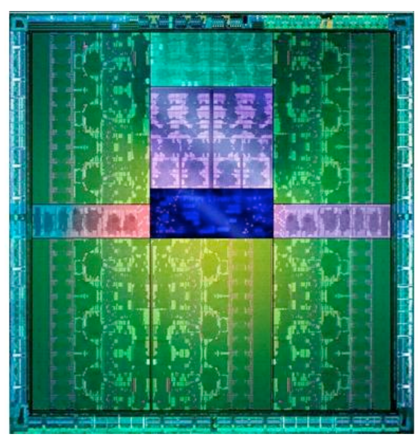
Intel Core i7

- Microprocessor
  - 6-core processor
  - Instruction set
    - » 64-bit CISC
  - Speed
    - » Clock: 3.46GHz
  - Memory
    - » On-chip cache: 12MB
  - Size
    - » 239mm^2 (32nm process)
  - Power consumption:
    - » Max 130W



NVIDIA GeForce GTX Titan Black

- Graphics processing unit
  - 2880-core processor
  - Instruction set
    - » 64-bit CUDA
  - Speed
    - » Clock: 889MHz
  - Size of chip
    - » 561mm^2 (28nm process)
    - » 7 billion transistors
  - Power consumption:
    - » Max 250W



Demo

- Microcontroller vs. laptop microprocessor
  - Same program: count number of prime numbers in interval

```
public class CountPrimes {

        public static void main(String[] args) {
                int c,i,n,p;
                final int STEP=100;

                p=0;
                c=100;
                for (n=2; n<=1000000; n++) {
                        for (i=2; i<=n/2; i++) {
                                if (n%i==0)
                            break;
                        }
                        if (i>n/2) {
                                p++;
                        }
                        if (n==c) {
        System.out.println("number of primes in [0.."+n+"] is "+p);
                                c+=STEP;
                        }
                }
        }
}
```


Demo

- Arduino Uno
  - Code:

```
long c,i,n,p;
int STEP=100;

p=0;
c=100;
for (n=2; n<=1000000; n++) {
   for (i=2; i<=n/2; i++) {
      if (n%i==0)
      break;
   }
   if (i>n/2) {
      p++;
   }
   if (n==c) {
      Serial.print("number of primes in [0..");
      Serial.print(n);
      Serial.print("] is ");
      Serial.print(p);
      Serial.print("\n");
      c+=STEP;
   }
}
```

  - Output:

```
number of primes in [0..9200] is 1140
number of primes in [0..9300] is 1151
number of primes in [0..9400] is 1162
number of primes in [0..9500] is 1177
number of primes in [0..9600] is 1184
number of primes in [0..9700] is 1197
number of primes in [0..9800] is 1208
number of primes in [0..9900] is 1220
number of primes in [0..10000] is 1229
```

- Laptop
  - Code:

```
int c,i,n,p;
final int STEP=100;

p=0;
c=100;
for (n=2; n<=1000000; n++) {
   for (i=2; i<=n/2; i++) {
      if (n%i==0)
      break;
   }
   if (i>n/2) {
      p++;
   }
   if (n==c) {
      System.out.println("number of primes in [0.."+n
+"] is "+p);
      c+=STEP;
   }
}
```

  - Output:

```
number of primes in [0..9200] is 1140
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number of primes in [0..9900] is 1220
number of primes in [0..10000] is 1229
```
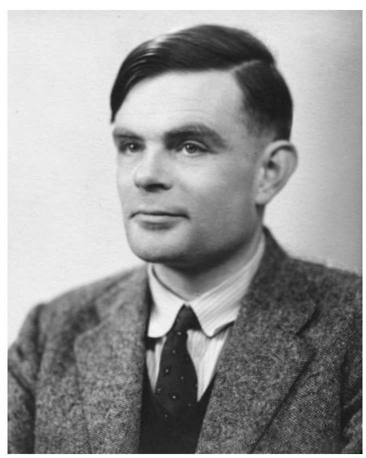

They are All the Same

- Same functionality
  - All processors can compute the same
  - "Universal computer" (Turing-complete instruction set)
- Difference in performance
  - Faster execution time of single program
  - Higher processing throughput on multiple programs
- Software can be compiled for different processors
  - Depends on software development environment

Alan Turing

- Alan Turing (1912–1954)
  - Mathematician/computer scientist
  - Famous for cryptanalysis
    - » Helped in breaking German Enigma code during World War II
  - Famous for work on computability
    - » Turing machine as "computer"
    - » Showed what class of problems can be solved by a computer
  - "Turing Award" highest recognition in the field of computer science



Increasing Performance

- How to increase processing performance?

Increasing Performance

- How to increase processing performance?
  - Faster computation
    - » Higher clock rate
  - More computation
    - » More instructions per cycle
    - » Wider words (e.g., 64-bit instead of 32-bit)
  - Data closer to processor
    - » Larger on-chip memories
  - Faster I/O
    - » Higher memory bandwidth
  - Better program
    - » Optimizing compiler
  - Parallel system
    - » Multiple processors in parallel
  - …
- Performance improvements come at cost
  - Larger chip, higher power consumption, …

Performance Considerations

- How much performance can be gained?
- Each improvement targets specific component
  - Performance gain limited to much component is used
- Amdahl's law
  - Improvement affects fraction *P* of computation time
  - Improvement provides speed up of *S* (i.e., *S* times faster)
  - Overall speedup from improvement: $\frac{1}{(1-P)+\frac{P}{S}}$
- Example
  - Speed up 30% of instructions (*P*=0.3) by factor 2 (*S*=2)
  - Overall speedup: 1/(0.7+0.3/2)=1.18 (=18% faster)
- "Make the common case fast"

Exercise

- Program execution time
  - 50% processing
  - 30% memory access
  - 20% disk access
- Improvement options (not quite realistic)
  - Processor upgrade
    - » Clock rate from 2.8 GHz to 3.1 GHz (*S*=1.1, $200)
  - Memory upgrade
    - » Bus speed from DDR3-800 to DDR3-1333 (*S*=1.67, $500)
  - Disk upgrade
    - » Disk type from hard disk to SSD (S=1.4, $300)
- Optimization
  - Which improvement provides most speedup?
  - Which improvement provides most speedup per dollar?

Exercise

- Answers

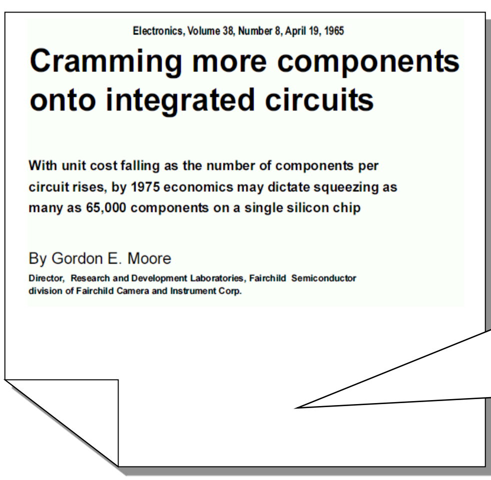
Improvement	P	S	cost	overall speedup	speedup/cost
processor	0.5	1.1	200	1.05	0.0052
memory	0.3	1.67	500	1.14	0.0023
disk	0.3	1.4	300	1.09	0.0036

  - Which improvement provides most speedup?
    - » Memory improvement (overall speedup of 1.14)
  - Which improvement provides most speedup per dollar?
    - » Processor improvement (overall speedup of 0.0052/$)

- Why do computers keep getting faster?

Moore's Law

- Milestone paper by Gordon Moore:
  - Maximum number of transistors on an integrated circuit roughly doubles every two years

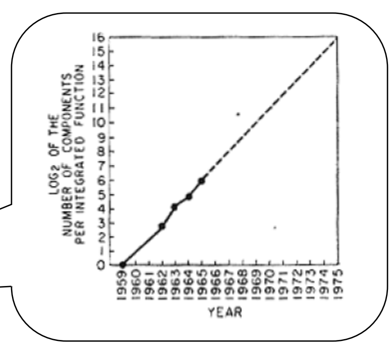

Electronics, Volume 38, Number 8, April 19, 1965

Cramming more components onto integrated circuits

With unit cost falling as the number of components per circuit rises, by 1975 economics may dictate squeezing as many as 65,000 components on a single silicon chip

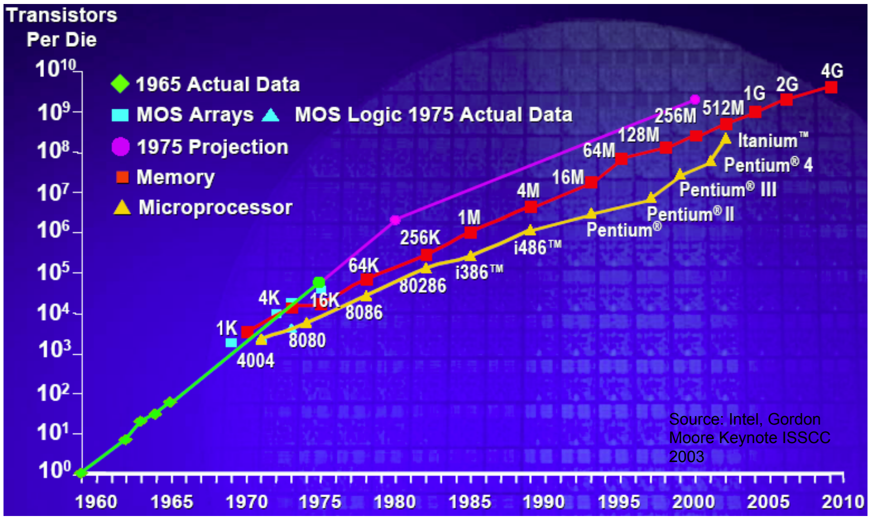
By Gordon E. Moore

Director, Research and Development Laboratories, Fairchild Semiconductor division of Fairchild Camera and Instrument Corp.



Moore’s Law

- Moore’s law over 50 years:



Side Note: Geek Jokes in the 60’s

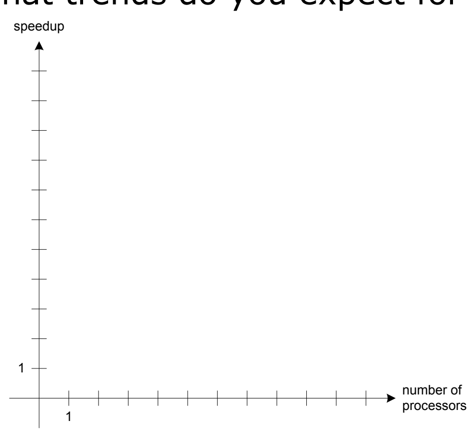
- Illustration in Moore’s paper
  - “Outrageous” prediction on what the future will look like
    - » Selling “handy home computers” in a department store…

Parallel Processing

- Most modern computers use multiple parallel cores
  - Divide processing across multiple processors
  - Overall processing can be faster
- Challenges
  - Coordination between processors necessary
  - In many cases, coordination may dominate processing time
- Workloads suitable for parallel processing
  - Scientific computing
  - Graphics processing
  - Etc.
- Most current systems are heading toward multi-core
  - Need ways to parallelizing workload (e.g., compiler)

Speedup through Parallelism

- Speedup is gain in processing time
  - Speedup for *p* processor cores is $S_p = \frac{T_1}{T_p}$
    - » T_1 is processing time on 1 core
    - » T_p is processing time on *p* cores
- What trends do you expect for speedup?



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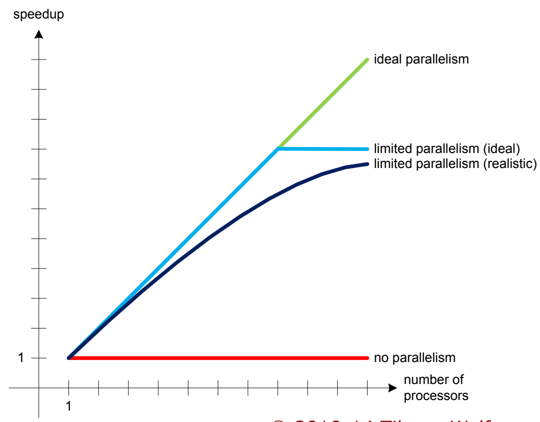
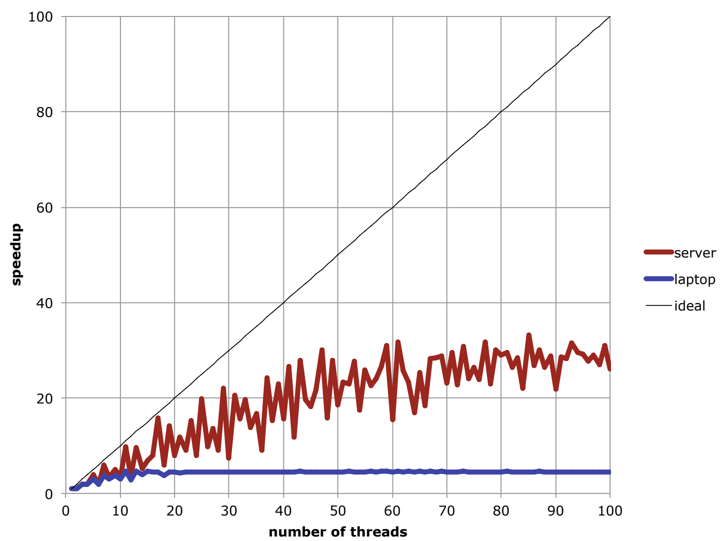


Speedup through Parallelism

- Speedup of multi-threaded (parallel) prime count



Courses in ECE Curriculum

- ECE 232 – Hardware Organization & Design
- ECE 354 – Computer Systems Lab II
- ECE 415/416 – Senior Design Project
- ECE 568 – Computer Architecture I
- ECE 668 – Computer Architecture II
- ECE 669 – Parallel Computer Architecture

Upcoming...

- Next Wednesday: solar cells
  - Power generation
- Moodle quiz