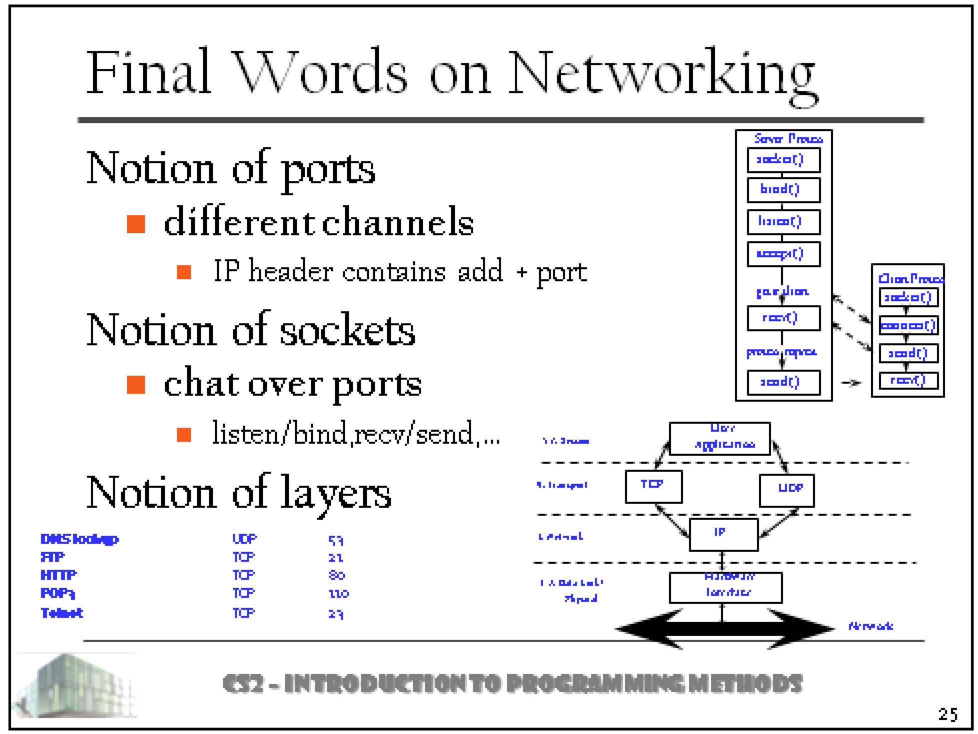
CS 2

Introduction to Programming Methods

Last Time

Networking and Graph Algorithms

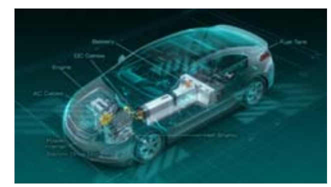
- Dijskstra and all…



Today's Topic

Concurrency

- designing and understanding systems that use parallel processing
  - virtually *all* systems in use today use parallel processing, including most safety-critical systems used in cars, airplanes, and medical devices



- touches on fundamental issues
  - predictable *performance*, functional *correctness*
    - of multicore processors, supercomputers, etc.

- just an intro
    - see G. Holzmann's class(es) and CS24 for more

What is Concurrency?

Dealt with sequential algorithms only

- can point to code & say "the program is here"
  - single "thread" of execution; Program Counter

Time

instruction 1
instruction 2
...
instruction I
instrution i+1
...
instruction n

A bit simplistic...

- many programs happen concurrently
  - Word, Photoshop, email, music, ... (called **processes**)
- even within a program, multiple "threads"
  - Word: interpreting keystrokes, formatting line and page breaks, spell checking...

Real vs. Simulated Parallelism

Computations happen at same physical time

- on different computers
- on multiple processors of a same computer
- on multiple cores of a single processor

Computations *seem* to happen at same time

- when OS/program switches rapidly between different programs/threads

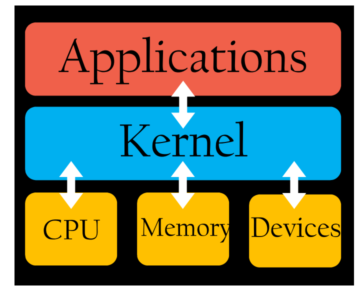
Fine and dandy if no shared resources…

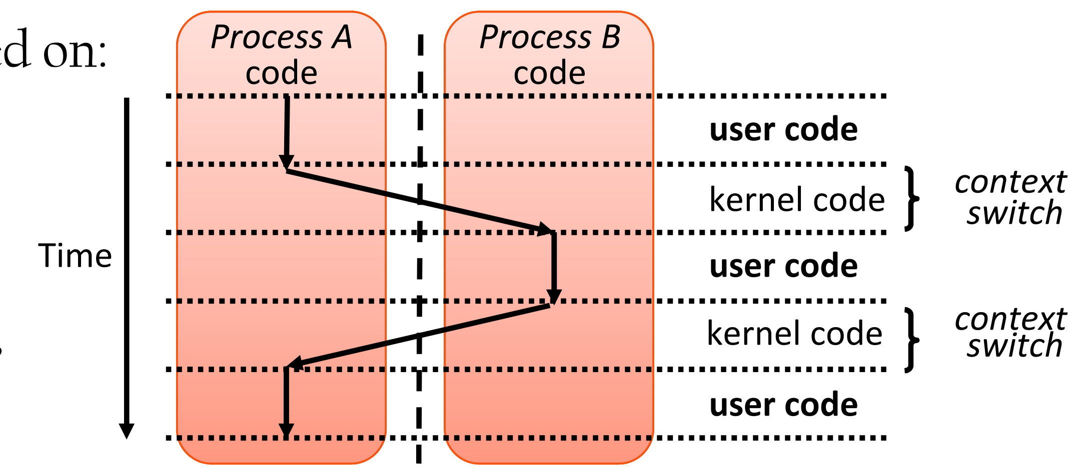
- **concurrency issues** otherwise

Switching between Processes

Processes managed by *kernel*

- piece of OS code handling access to CPU
  - goes from one process to another
    - to use CPU time most efficiently…
    - and be fair to all processes (time sharing)
  - via a *context switch*
    - decision based on:
      - fairness
      - priority
      - events (mouse, key, timer, …: interrupts)





Example of Concurrency Issues

Assume shared memory

- processes can read/write the same variable

Start f() and g() at the “same” time (and x=0)

```
f():
    global x
    for i=1 to 1000
        x = x + 1
```

```
g():
    global x
    for i=1 to 1000
        x = x + 1
```

- “x=x+1” means read memory, add 1, write to memory
- remember, execution will lead to intertwined code lines
- question: what is x when all is finished?

Execution Order

Suppose x = 42

- at a certain point

f:	g:
• get x → 42	
• increment → 43	
	• get x → 42
• write 43 → x	
	• increment → 43
	• write 43 → x

Time ↓

Net result: lost an increment

- called a **race condition** (non-deterministic results)
- hard to detect: problems are intermittent
  - all possible schedules have to be safe
  - but number of possible schedule permutations is huge!

Safe way to increment x without issues?

Synchronization

Concurrently-executing threads/processes should not execute specific portions of a program at the same time

- notion of **critical sections** (CS)
  - `x=x+1` should be done atomically
- could make special hardware instructions
  - but does not extend to database systems or web servers
- need software solutions
  - used by the coder, or/and by the kernel

Critical Section Requirements

Mutual Exclusion

- only one process is in CS at any time

Progress

- not every process waiting for CS indefinitely
  - no deadlock

Bounded Waiting

- bounded #times others get CS while one is waiting
  - no livelock

When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone.

Statute passed by Kansas Legislature

Also: fairness, simplicity/efficiciency, …

Taking Turn?

Use a variable
to determine turn

```
Process P0:
repeat
while(turn!=0){};
     CS
  turn:=1;
     <whatever>
forever
```

```
Process P1:
repeat
while(turn!=1){};
     CS
  turn:=0;
     <whatever>
forever
```

- achieves Mutual Exclusion (thru **busy wait**)
- but progress requirement is **not** satisfied
  - it requires strict alternation of CS's.
    - If a process asks for CS more often than the other, it can't get it

Checking Intent?

```
Initialization:
flag[0]:=flag[1]:=false
```

Use 2 intent flags

```
Process P0:
repeat
 flag[0]:=true;
 while(flag[1]){};
    CS
 flag[0]:=false;
    <whatever>
forever
```

```
Process P1:
repeat
 flag[1]:=true;
 while(flag[0]){};
    CS
 flag[1]:=false;
    <whatever>
forever
```

- Mutual Exclusion is satisfied
- but not the progress requirement
  - for the (interleaved) sequence:
    - » flag[0]:=true
    - » flag[1]:=true
  - both processes will wait forever (deadlock)

Peterson's Solution

Tie-breaking

- Even if both flags go up
  - and no matter how the instructions are interleaved
- … turn will always end up as either 0 or 1

```
Initialization:
flag[0]:=flag[1]:=false
turn:= 0 or 1
```

```
Process P0:
repeat
  flag[0]:=true;
  // 0 wants in
  turn:= 1;
  // 0 gives a chance to 1
  while (flag[1]&turn==1);
     CS
  flag[0]:=false;
  // 0 is done
     <whatever>
forever
```

```
Process P1:
repeat
  flag[1]:=true;
  // 1 wants in
  turn:=0;
  // 1 gives a chance to 0
  while (flag[0]&turn==0);
     CS
  flag[1]:=false;
  // 1 is done
     <whatever>
forever
```

Correctness

```
Process P0:
repeat
  flag[0]:=true;
  // 0 wants in
  turn:= 1;
  // 0 gives a chance to 1
  while (flag[1]&turn=1);
     CS
  flag[0]:=false;
  // 0 is done
     RS
forever
```

Mutual exclusion holds since:

- both P_0 and P_1 in CS means
  - both **flag[0]** and **flag[1]** must be true...
  - and **turn=0** and **turn=1** (at same time): impossible

Progress

- P_0 can be kept out of CS only if stuck in while loop
  - flag[1] = true and **turn = 1**.
- If P_1 not ready to enter CS, **flag[1] = false** → P_0 can enter CS
- If P_1 has set **flag[1]**, it is also in its while loop; then either P_0 or P_1 will go depending on value of turn
- progress condition is met

Correctness

```
Process P0:
repeat
  flag[0]:=true;
  // 0 wants in
  turn:= 1;
  // 0 gives a chance to 1
  while (flag[1]&turn=1);
     CS
  flag[0]:=false;
  // 0 is done
     RS
forever
```

Bounded Wait?

- suppose P_0 gets to go this time;

Can it go a second time indept of what P_1 does?

- if P_1 enters CS , then **turn=1**
  - but will then reset **flag[1]** to false on exit
    - » thus allowing P_0 to enter CS
- what if P_1 tries again, and has time to reset **flag[1]=true** before P_0 gets to its CS?
  - it must also set **turn=0**
    - » since P_0 is (stuck) past the point where it sets **turn** to 1:
  - P_0 will get to enter CS after at most one CS entry by P_1

Semaphores

Introduced by Dijkstra (1968)

- higher-level tool for process synchronization
  - uses an integer variable s…
    - initialized with # of available resources (think: room reservation; license counts)
  - and two operations:
    - P(s):

      atomically executes s := s-1

      delays until s>0

      until there's an opening

      V(s):

      atomically executes s:= s+1
- binary semaphore = mutex
  - P(s) before CS, V(s) after CS

No Busy Waiting!

queue is FIFO
or priority based

```
typedef struct semaphore {
    int value:
    SleepingProcessesList L;
} Semaphore;
```

OS semaphore w/ **wait queue**

- to put process to sleep

```
void P(Semaphore *S) {
    S->value = S->value - 1;
    if (S.value < 0) {
        add this process to S.L;
        block();
    }
}
```

```
void V(Semaphore *S) {
    S->value = S->value + 1;
    if (S->value >= 0) {
        remove process P from S.L;
        wakeup(P)
    }
}
```

- block(): remove process from active pool
- wakeup(): back in kernel pool and resume

Possible Use of Concurrency

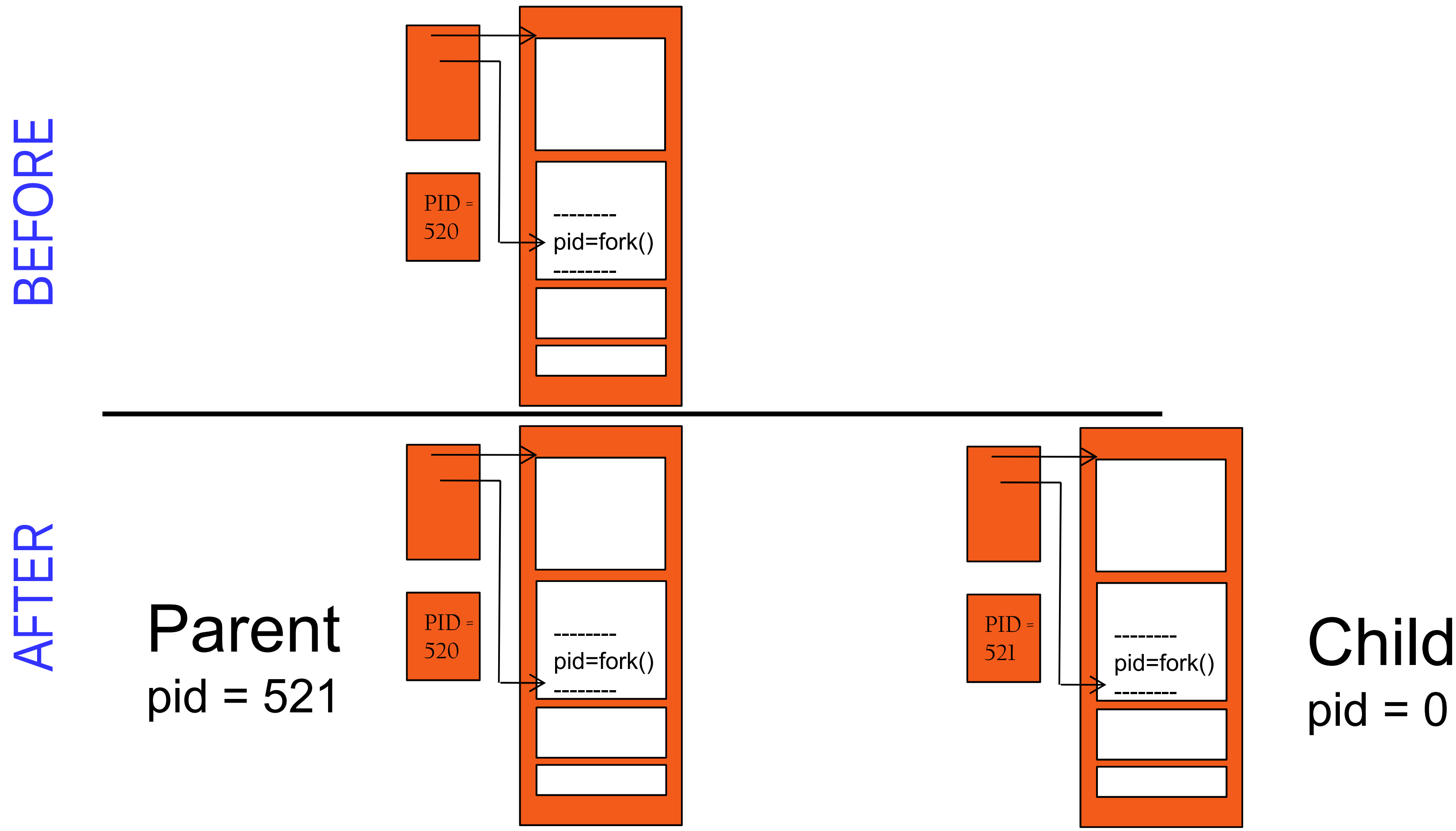
Many recursive methods involve 2 calls

- e.g., merge sort: left half and right half
- can be co-invoked!

Creation of threads by, e.g., fork/join

- fork() spawns copy

Forking



Next line of code is typically: if (pid==0) [...] else [...]

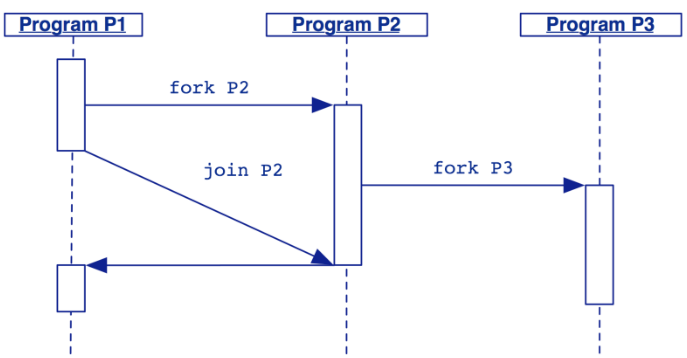
Possible Use of Concurrency

Many recursive methods involve 2 calls

- e.g., merge sort: left half and right half
- can be co-invoked!

Creation of threads by,e.g., fork/join

- fork() spawns copy
- join() waits for it to end

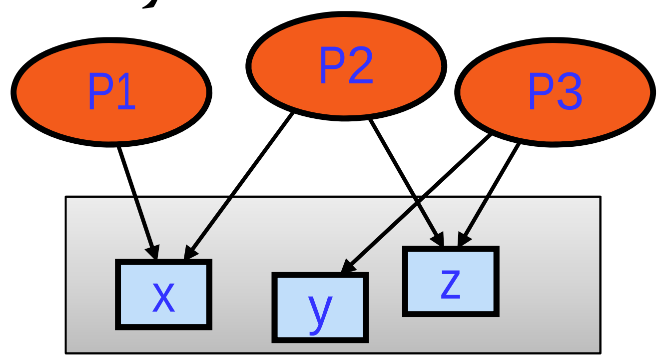


Fork and join are unstructured, so use with care…

Communication & Synchonization

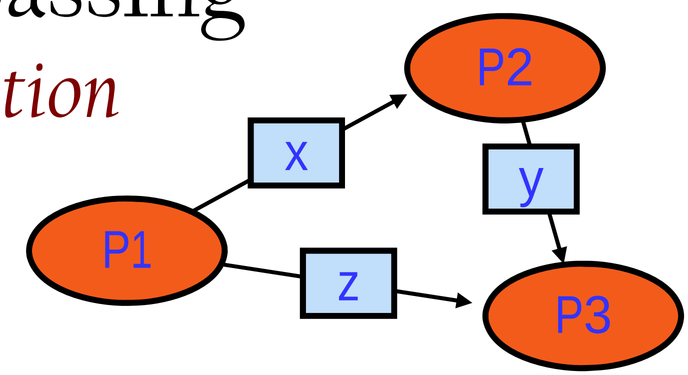
We looked at the shared memory model

- proc. “communicate” thru shared variables
- requires synchronization for memory access



Other approach: message-passing

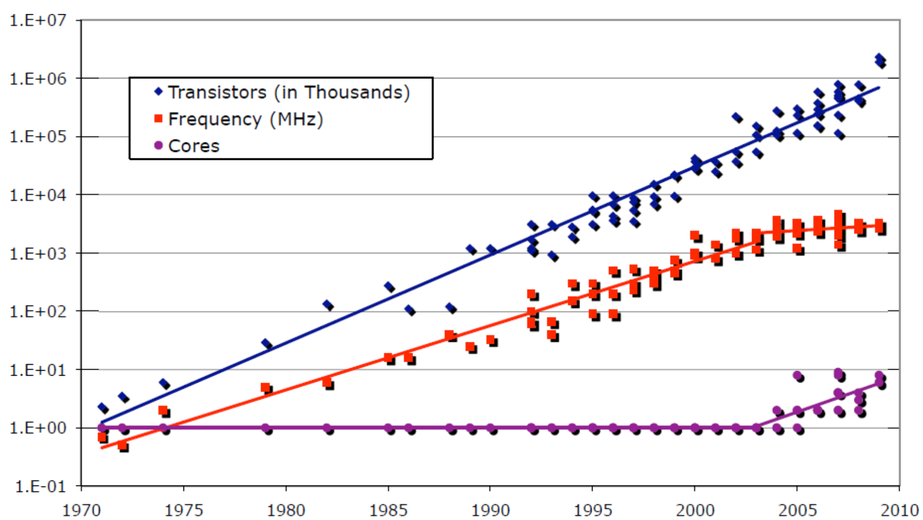
- *communication & synchronization* are combined
- (a)synchronous comm.

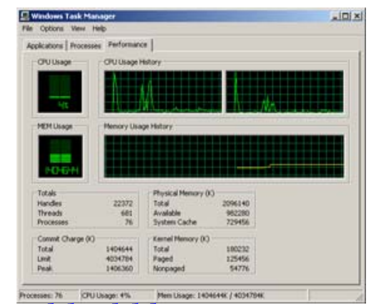


Why Should You Care?

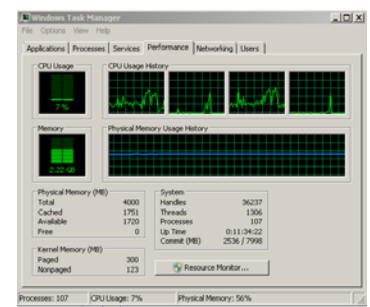
Parallel computing increasingly important

- was trendy in the 70's and 80's
- but *really* necessary now… why?
  - Moore's law, with a twist





my old, old laptop, circa 2010

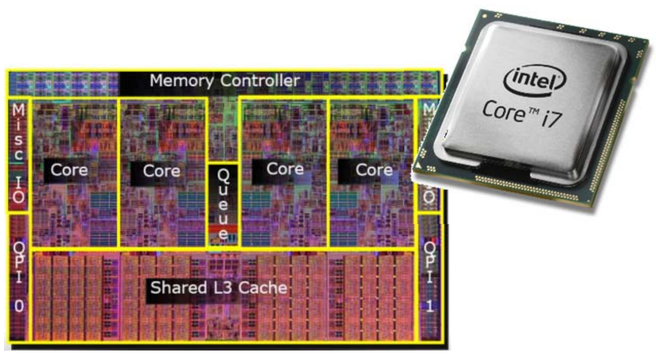


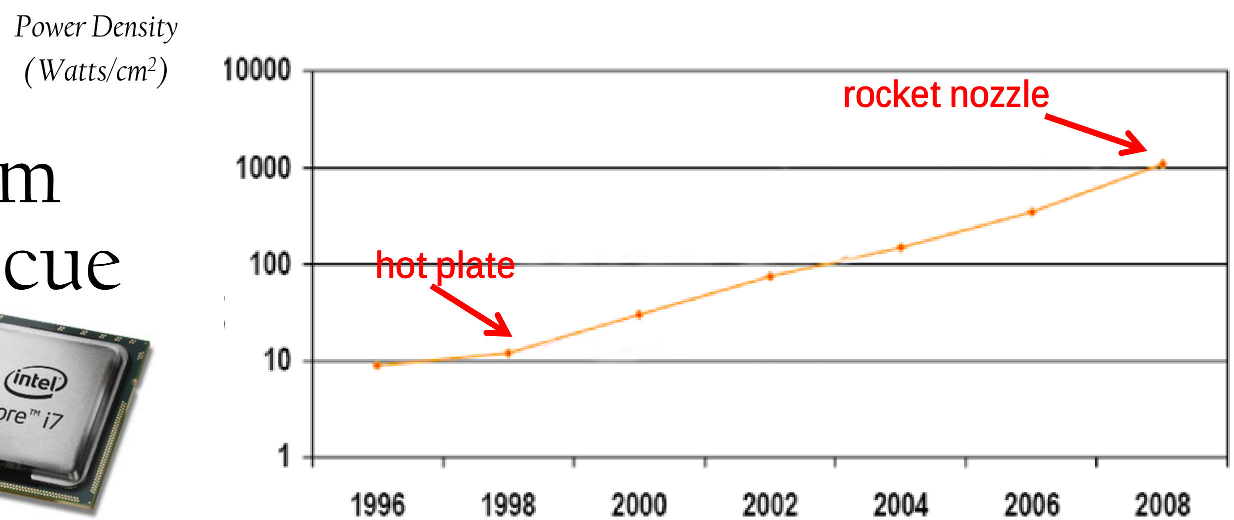
my old laptop, circa 2012

Reason: Too Hot...

Increasing transistor density...
... plus increasing clock-speed ...
means increasing *power density*

- parallelism
  to the rescue





source: Shekhar Borkar, Intel