**IBM’s Watson for the Win, Alex...**

IBM’s Watson computer (really 2,800 cores) is leading former champions $35,734 to $10,000 and $4,800. Despite a few missteps, it was correct in almost every occasion. It would clearly make a perfect backup consultant for answers like this...

ibmwatson.com

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**Concurrency & Parallelism, 10 mi up...**

- **Intra-computer**
  - Today’s lecture
  - Multiple computing “helpers” are cores within one machine
  - Aka “multi-core”
    - Although GPU parallelism is also “intra-computer”
- **Inter-computer**
  - Week 12’s lectures
  - Multiple computing “helpers” are different machines
  - Aka “distributed computing”
    - Grid & cluster computing

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**Anatomy: 5 components of any Computer**

- Processor
- Control ("brain")
- Datapath ("brawn")
- Memory
- Input
- Output

- What causes the most headaches for SW and HW designers with multi-core computing?

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**But what is INSIDE a Processor?**

- Primarily Crystalline Silicon
- 1 mm – 25 mm on a side
- 2009 “feature size” (aka process) = 45 nm = 45 x 10^-9 m
  - then 32, 22, and 16 [by yr 2013]
- 100 - 1000M transistors
- 3 - 10 conductive layers
- "CMOS" [complementary metal oxide semiconductor] - most common

- Package provides:
  - spreading of chip-level signal paths to board-level
  - heat dissipation.
  - Ceramic or plastic with gold wires.

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**John von Neumann invented this architecture**

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**UC Berkeley CS10 "The Beauty and Joy of Computing" : Concurrency (II)"**

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Moore's Law

Predicts: 2X Transistors / chip every 2 years

Year

What is this “curve”?  
a) Constant  
b) Linear  
c) Quadratic  
d) Cubic  
e) Exponential

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Moore’s Law and related curves

Power Density Prediction circa 2000

Source: S. Borkar (Intel)

Going Multi-core Helps Energy Efficiency

- Power of typical integrated circuit \( \sim C V^3 f \)
  - \( C \): Capacitance, how well it “stores” a charge
  - \( V \): Voltage
  - \( f \): Frequency, i.e., how fast clock is (e.g., 3 GHz)

Energy & Power Considerations

Courtesy: Chris Batten

Power Density (W/cm²)

Year

[Diagrams and graphs related to Moore's Law, Power Density Prediction, and Energy & Power Considerations]
Parallelism again? What's different this time?

“This shift toward increasing parallelism is not a triumphant stride forward based on breakthroughs in novel software and architectures for parallelism; instead, this plunge into parallelism is actually a retreat from even greater challenges that thwart efficient silicon implementation of traditional uniprocessor architectures.”

– Berkeley View, December 2006

- HW/SW Industry bet its future that breakthroughs will appear before it's too late

Background: Threads

- A Thread stands for “thread of execution”, is a single stream of instructions
  - A program / process can split, or fork itself into separate threads, which can (in theory) execute simultaneously
  - An easy way to describe/think about parallelism
- A single CPU can execute many threads by
  - Time Division Multiplexing
  - Multithreading is running multiple threads through the same hardware

Speedup Issues: Amdahl’s Law

- Applications can almost never be completely parallelized; some serial code remains
  - Time
    - Parallel portion
    - Serial portion
  - Number of Cores
  - s is serial fraction of program, P is # of cores (was processors)
  - Amdahl’s law:
    - Speedup = TimeS / TimeP
    - $\frac{1}{s} + (1-s) / P$, and as $P \rightarrow \infty$
    - $\frac{1}{s}$
  - Even if the parallel portion of your application speeds up perfectly, your performance may be limited by the sequential portion

Speedup Issues: Overhead

- Even assuming no sequential portion, there’s...
  - Time to think how to divide the problem up
  - Time to hand out small "work units" to workers
  - All workers may not work equally fast
  - Some workers may fail
  - There may be contention for shared resources
  - Workers could overwriting each others’ answers
  - You may have to wait until the last worker returns to proceed (the slowest / weakest link problem)
  - There’s time to put the data back together in a way that looks as if it were done by one

Life in a multi-core world...

- This “sea change” to multi-core parallelism means that the computing community has to rethink:
  - Languages
  - Architectures
  - Algorithms
  - Data Structures
  - All of the above

But parallel programming is hard!

- What if two people were calling withdraw at the same time?
  - E.g., balance=100 and two withdraw 75 each
  - Can anyone see what the problem could be?
  - This is a race condition
- In most languages, this is a problem.
  - In Scratch, the system doesn’t let two of these run at once.
Another concurrency problem … deadlock!

- Two people need to draw a graph but there is only one pencil and one ruler.
  - One grabs the pencil
  - One grabs the ruler
  - Neither release what they hold, waiting for the other to release

- Livelock also possible
  - Movement, no progress
  - Dan and Luke demo

Summary

- “Sea change” of computing because of inability to cool CPUs means we’re now in multi-core world
- This brave new world offers lots of potential for innovation by computing professionals, but challenges persist