Don’t Forget the Memory…
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Memory is Everywhere
One size DOES NOT fit all...

Innovation

- Automotive
- Computing
- Commercial & Industrial
- Mobile
- Networking
- Server
Question:

• How many different memories does your computer use?

At least 5
The Evolving Memory Hierarchy

- Level 1 Cache
- Level 2 Cache
- Main Memory
- Disk
- Boot ROM
Question:

• How many different memories does your cell phone use?

At least 4
The Cell Phone Memory Hierarchy

- Instruction Cache
- Data Cache
- LPDRAM
- NAND Flash
- uSD Card NAND
- Boot ROM
- MCP
What is the Ideal Memory?

- Fast – to keep pace with processors
- Reliable – not susceptible to corruption
- Low cost – pennies per mm$^2$
- Small – helps with low cost, but also for new platforms
- Embeddable – ability to be integrated with logic
- Low power – for dense systems and un-tethered systems
- Non-volatile – no power required to retain data
Benefit of Shrinking

• The ability to fit more bits on a wafer, thereby reducing the cost of those bits: “Shrink–o–nomic”

• The ability to add features to a product, thereby increasing performance.

• The ability to lower the power of the device.
DRAM Operation
NAND Flash Memory

• The “ideal” memory?
• Non-volatile
• Small cells – Under $6F^2$
• Low cost process
• Scaleable?
• Wear issues?
• Slow writes
• Ideal for some applications
NAND Operation

• Control Gate traps electrons injected by Fowler–Nordheim tunneling.
• Voltages of up to 20V exist during cell programming.
NAND Programming Operation

• Control Gate traps electrons injected by Fowler–Nordheim tunneling.
• Voltages of up to 20V exist during cell programming.

Cell is programmed to “0”
NAND Storage Operation

- Control Gate traps electrons injected by Fowler–Nordheim tunneling.
- Voltages of up to 20V exist during cell programming.

Cell retains its “0” state
NAND Read Operation

- Control Gate traps electrons injected by Fowler–Nordheim tunneling.
- Voltages of up to 20V exist during cell programming.

Cell read in “0” state
NAND Read Operation

- Control Gate traps electrons injected by Fowler–Nordheim tunneling.
- Voltages of up to 20V exist during cell programming.

Cell read in “1” state
3D NAND Performance Relative to Planar NAND

3D NAND cell design simultaneously improves performance and reliability

- Vertical stacking allows large number of electrons per cell independent of scaling
- No longer relying on lithography to continue scaling
- Decreased interference between cells translates into higher cycling endurance
Introducing 3D XPoint™

1000X FASTER THAN NAND

1000X ENDURANCE OF NAND

10X DENSER THAN CONVENTIONAL MEMORY

3D XPoint
3D XPoint™ Memory
Questions:

• In 1982, as the personal computer became successful, how many memory bits were there in a standard memory chip? 64K bits

• In 2015 how many memory bits are in a leading edge standard NAND Flash memory chip? 256 Billion bits
Questions:

1. How fast is the speed of light?

   About 186,200 miles/second

2. How far can light travel in the single “tick” of a 3GHz processor clock?

   About 4 inches
Question:

- How many ticks of the 3GHz processor clock does it take to access the average piece of data on a 7200RPM hard drive?

**About 40 million!**
Why SSD’s?

- Performance
- Power
- Reliability
- New form factors
SSDs do more with less power
Questions:

• How many operations per second (IOPS) can a high-end hard drive sustain?

200 IOPS

• How many operations per second (IOPS) can a high-end NAND flash-based SSD (i.e. Micron P320H) sustain?

1,400,000 IOPS*

* Limited by CPU performance. 1.7M IOPS per SSDReview.com with overclocked CPU. October 15, 2012
HDD & SSD in the Enterprise Server Market
New Form Factors
Desktop Supercomputers?

Cray 1A Supercomputer

- 80MHz CPU, 16-bit instructions, 64-bit words
- 136 Mflops
- 8MB main memory
- 640MB/sec memory BW
- 115KW operating power
Handheld Supercomputer!

**iPhone 6**

- 1GHz Dual core 32-bit CPU (~2000MHz) ~ 12X
- 450MHz GPU 25.5 GFLOP ~ 200X
- 1GB DRAM main memory ~ 128X
- 8.5GB/sec memory BW ~ 12X

- 0.45W avg. operating power: 1/250,000th!
Memory Research Areas

• DRAM:
  ‣ New materials: High–K gates, Low–K dielectrics
  ‣ New structures: 3D transistors, lattices, TSV’s
  ‣ New features: Low power, DDR4
  ‣ New architectures: HMC, HBM
  ‣ New packaging: 3D integration

• NAND:
  ‣ New materials
  ‣ New dimensions: 3D NAND cells
  ‣ New “Systems”: SSD’s

• 3DX:
  ‣ New dimensions: 3D

• New Types:
  ‣ MRAM, STT–RAM, Programmable conductor
Dean's Top 10
Top 10 Reasons You Want to Be an Engineer

1. For the great memories!
2. It rationalizes why you always took things apart as a kid
3. You always were fascinated by trains
4. It sure beats flippin’ burgers!
5. You love calculus, differential equations, numerical analysis…
6. At least your computer/phone/tablet listens to you
7. You would have been a doctor or a lawyer, but where’s the challenge?
8. You believe anything is possible
9. You’re going to get rich off that cold fusion project you have going in your bathtub
10. It’s logical
Final Advice:

Be a “T” person!
Questions?