FIBER OPTIC INTERCONNECTS

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Fiber Optic Utilization

- Local Area Networks (LAN)
- Wide Area Networks (WAN)
- Communication Networks
- Data Centers
- Desktop / Laptop Computers
Section 1

PHYSICS OF FIBER OPTICS
• Total Internal Reflection

• Wave Division Multiplexing (WDM)
Section 2

LARGE SCALE INTERCONNECTS
• High Performance Systems (Facebook.com)
• Storage Area Networks (SAN)
• Programming Models
  – Message Passing Interface (MPI)
  – InfiniBand Protocol
• Shared Resources
• USB, Firewire, Ethernet, SATA, PCI Express, Fibre Channel
Facebook Datacenter Spec.

- 500,000 New Users / Day (2009)
- 9.5% of all Internet Traffic
- 100,000,000 Picture Uploads / Day
- Prineville
  - OpenCompute.org
  - 147,000 sqft.
  - 38% More Efficient and 24% Less Expensive
  - Comparable to Google.com or Microsoft for much cheaper
Section 3

SMALL SCALE SYSTEMS
• On-Chip Interconnects
• CMOS Integration
  – 3D Die Stacking
  – Crystalline Waveguides
  – Polymer Waveguides
  – Propagation Delay and Latency Concerns
    • 30 to 40 vs. 3 to 4 clock cycles
• Thermal Issues
  – Local Temperature
  – Water Cooling? (expensive)
• More Issues
  – Slow Encoding
  – Currently no CMOS on-chip lasers

• Successful Simulations at University of Arizona
  – 256 Cores, 3D Stacked (64 Tiles)
  – Crystalline Waveguides
  – 81.92 TFLOPS

• Current Technology
  – Intel Core i7 = 107.55 GFLOPS (double precision)
  – Nvidia Tesla GPU = 515 GFLOPS (double precision)
    • 1.03 TFLOPS (single precision)
  – AMD FireStream = 1.2 TFLOPS (single precision)
• Waveguides vs. Electrical
• Production Costs
  – Business Pressure
  – Lack of CAD Tooling
• Bandwidth Density
  – WDM vs. Non-WDM vs. Electrical
• Costs: Hollow, Polymer, Crystal
• Overcoming the “fundamental limits of electrical signaling”
**Figure 7:** Comparison of bandwidth density of electrical and optical interconnects.

<table>
<thead>
<tr>
<th>Expected Year</th>
<th>Technology Size</th>
<th>Electrical</th>
<th>Optical</th>
<th>Optical with WDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>90nm</td>
<td>3.16 Gbps/µm</td>
<td>1 Gbps/µm</td>
<td>1.99 Gbps/µm</td>
</tr>
<tr>
<td>2007</td>
<td>65nm</td>
<td>7.94 Gbps/µm</td>
<td>1.99 Gbps/µm</td>
<td>12.59 Gbps/µm</td>
</tr>
<tr>
<td>2010</td>
<td>45nm</td>
<td>15.84 Gbps/µm</td>
<td>2.51 Gbps/µm</td>
<td>31.62 Gbps/µm</td>
</tr>
<tr>
<td>2013</td>
<td>32nm</td>
<td>31.62 Gbps/µm</td>
<td>3.98 Gbps/µm</td>
<td>63.10 Gbps/µm</td>
</tr>
<tr>
<td>2016</td>
<td>22nm</td>
<td>79.43 Gbps/µm</td>
<td>7.94 Gbps/µm</td>
<td>158.49 Gbps/µm</td>
</tr>
</tbody>
</table>
Section 5

OTHER MODERN FIBER OPTICS
• Google Fiber Internet
  – Kansas City, Kansas
  – Population 145k
  – Arms Race?
    • Facebook vs. Google
• Intel Thunderbolt
  – Codename Light Peak
  – Apple Mac Book Pro

<table>
<thead>
<tr>
<th></th>
<th>Maximum Speed</th>
<th>Compatibility</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>USB 2.0</td>
<td>480 Megabits per second, half-duplex</td>
<td>USB 2.0, USB 1.1</td>
<td>Up to 2.5 watts</td>
</tr>
<tr>
<td>USB 3.0</td>
<td>5 Gigabits per second, full-duplex</td>
<td>USB 3.0, USB 2.0, USB 1.1</td>
<td>Up to 9.0 watts</td>
</tr>
<tr>
<td>FireWire 800</td>
<td>800 Megabits per second, full-duplex</td>
<td>FireWire 800, FireWire 400</td>
<td>Up to 45 watts</td>
</tr>
<tr>
<td>eSATA</td>
<td>3 Gigabits per second, full-duplex</td>
<td>eSATA only (though combination USB-eSATA ports are common)</td>
<td>None</td>
</tr>
<tr>
<td>Thunderbolt</td>
<td>10 Gigabits per second, per channel, bidirectional. Two channels per port.</td>
<td>DisplayPort 1.1, Thunderbolt (PCIe protocol)</td>
<td>Up to 10 watts</td>
</tr>
</tbody>
</table>
Average broadband speeds — worldwide

Megabits per second

- Japan: 61.0
- Korea: 45.6
- Netherlands: 21.7
- Sweden: 18.2
- France: 17.6
- Canada: 7.6
- Poland: 7.5
- Germany: 6.0
- United States: 4.8
- UK: 2.6
- Greece: 1.0

Credit: Organization for Economic Co-Operation and Development (OECD)
Section 6

CONCLUSION
• Fully Connected Homes
  – Fiber Internet, 100x Faster
  – Fast Gateway, Faster Internal Network
• Device Communication
  – Thunderbolt
    • Home Media Server
    • Data Transfer
• Fiber is slow to move into PC Boxes
  – CMOS, VLSI, etc.
REFERENCES


Questions?