Cloud Computing Driving Datacenter Innovation

Global Semiconductor Alliance Board of Directors Meeting

James Hamilton, 2011/9/14

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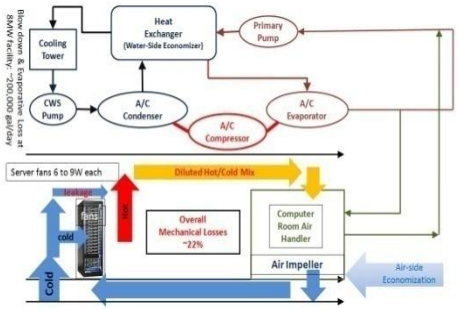
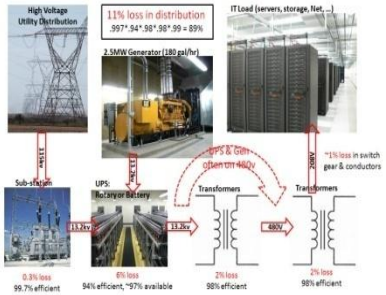
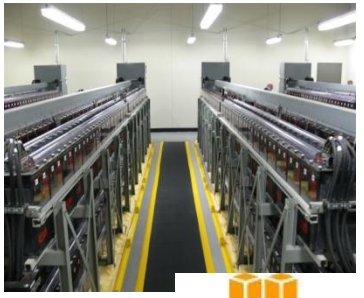
Agenda

- Cloud & Accelerating Pace of Innovation
- Technology Changes
  - Memory wall & Storage Chasm
  - Disk is Tape
  - Sea Change in Networking
- Cloud Computing Economics







Talk does not necessarily represent positions of current or past employers

Cloud Computing Driving Wave of Innovation & Growth

- Datacenter pace of innovation increasing
  - More innovation in last 5 years than previous 15
  - Driven by cloud service providers & very high-scale internet applications like search
- Not just a cost center
  - At scale, infrastructure costs dominate
  - Makes it cost effective to hire mechanical, power, server, & net specialists
- Infrastructure **is** the business rather than merely overhead

Perspective on Scaling

Plunging Cost of Computing

- Rapidly declining cost of computing
  - Technology & cloud computing economies of scale
- Warehouse & analytical use scales inversely with cost
  - Lower costs supports more data & deeper analysis
- Traditional transactional systems scale with business
  - Purchases, ad impressions, pages served, etc.
  - Computational trading & machine-to-machine transactions scale faster limited only by value of transaction & cost

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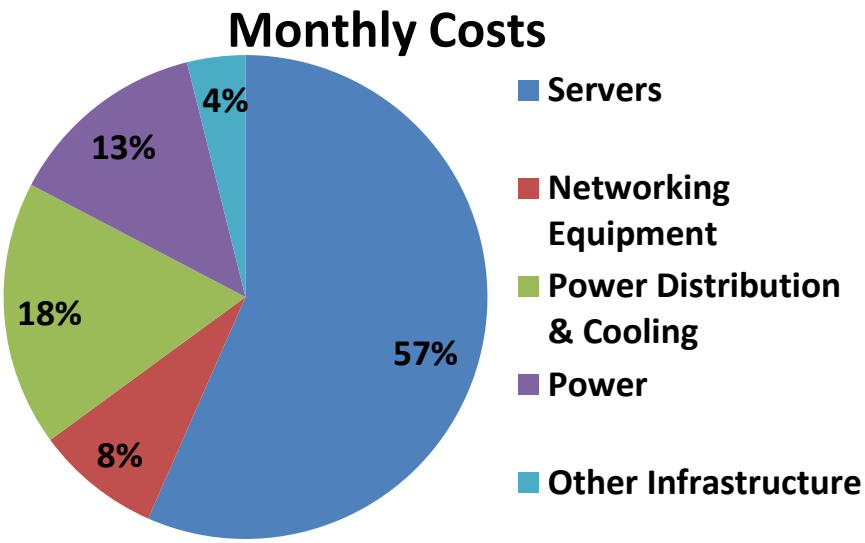
Where Does the Money Go at Scale?

- **Assumptions:**
  - Facility: ~$88M for 8MW critical power
  - Servers: 46,000 @ $1.45k each
  - Commercial Power: ~$0.07/kWhr
  - Power Usage Effectiveness: 1.45



3yr server & 10 yr infrastructure amortization

- **Observations:**
  - 31% costs functionally related to power (trending up while server costs down)
  - Networking high at 8% of overall costs & 19% of total server cost (many pay more)

From: http://perspectives.mvdirona.com/2010/09/18/OverallDataCenterCosts.aspx

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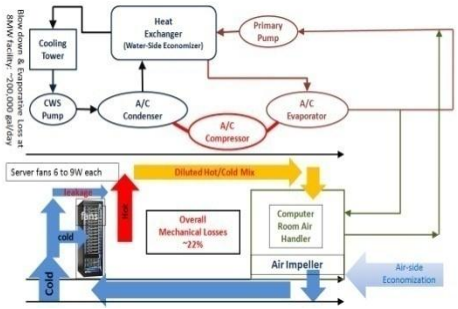

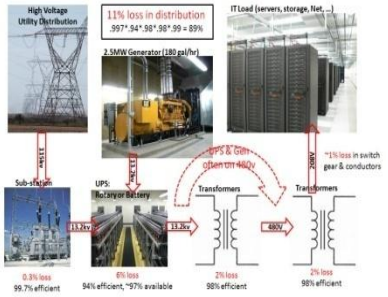

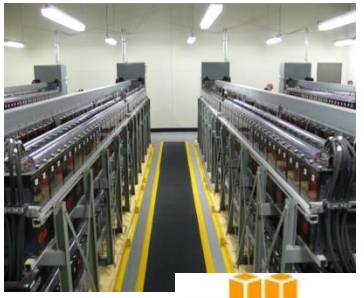

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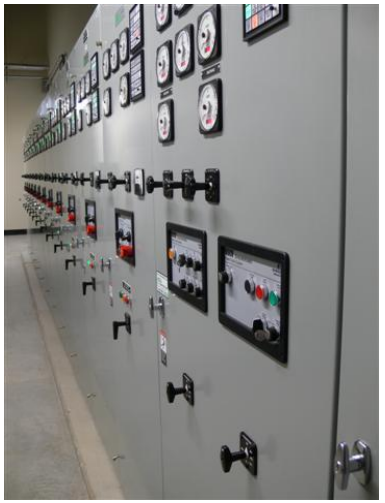
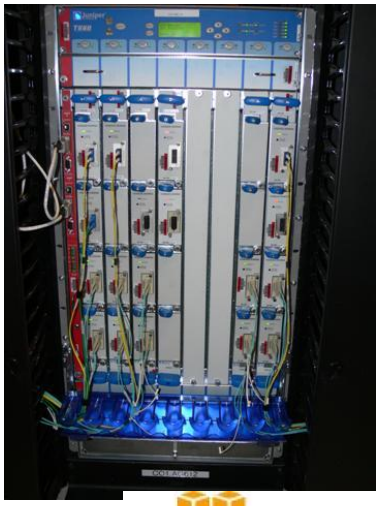
Limits to Computation



- Processor cycles are cheap and getting cheaper
- What limits application of infinite cores?
  1. **Power**: cost rising and will dominate
  2. **Data**: inability to get data to processor when needed
- Most sub-Moore attributes need most innovation
  - Infinite processors require infinite power
  - Getting data to processors in time to use next cycle:
    - Caches, multi-threading, ILP,…
    - All techniques consume power
    - All off chip techniques consume a lot of power
- Power & data movement key constraints
  - Requires more complex programming model with different optimization points



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Storage & Memory B/W lagging CPU

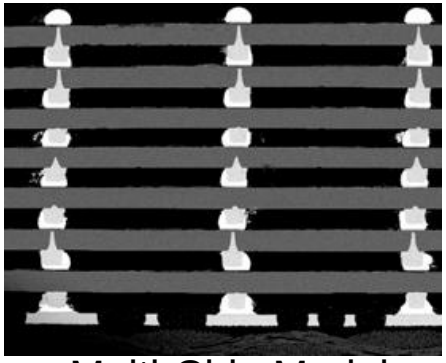
	CPU	DRAM	LAN	Disk
Annual bandwidth improvement (all milestones)	1.5	1.27	1.39	1.28
Annual latency Improvement (all milestones)	1.17	1.07	1.12	1.11

- CPU B/W requirements out-pacing memory and storage
- Disk & memory getting "further" away from CPU
  - Core limiting factor: power consumption & data availability
  - Powered CPU cores have no value without data
- Large sequential transfers better for both memory & disk

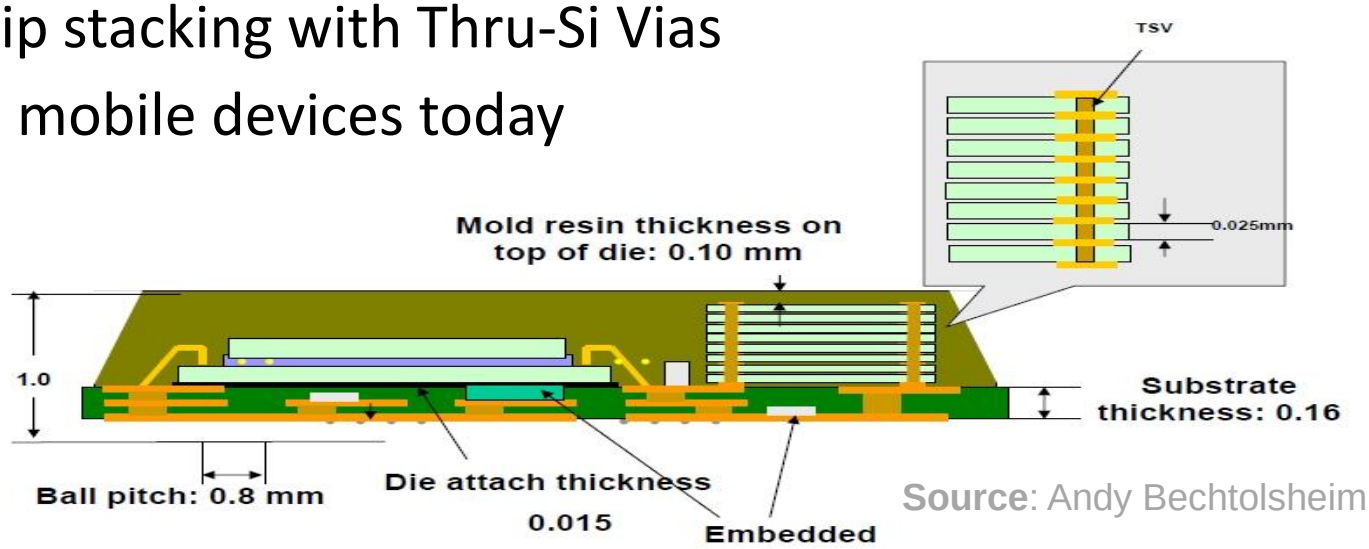
Source: Dave Patterson: Why Latency Lags Bandwidth and What It Means to Computing

Memory Wall

- Adding processor I/O pins has a positive impact but at significant power cost
  - Positive but bounded impact
- Taming the memory wall:
  - 3D chip stacking with Thru-Si Vias
  - Lab & mobile devices today



Multi-Chip Module

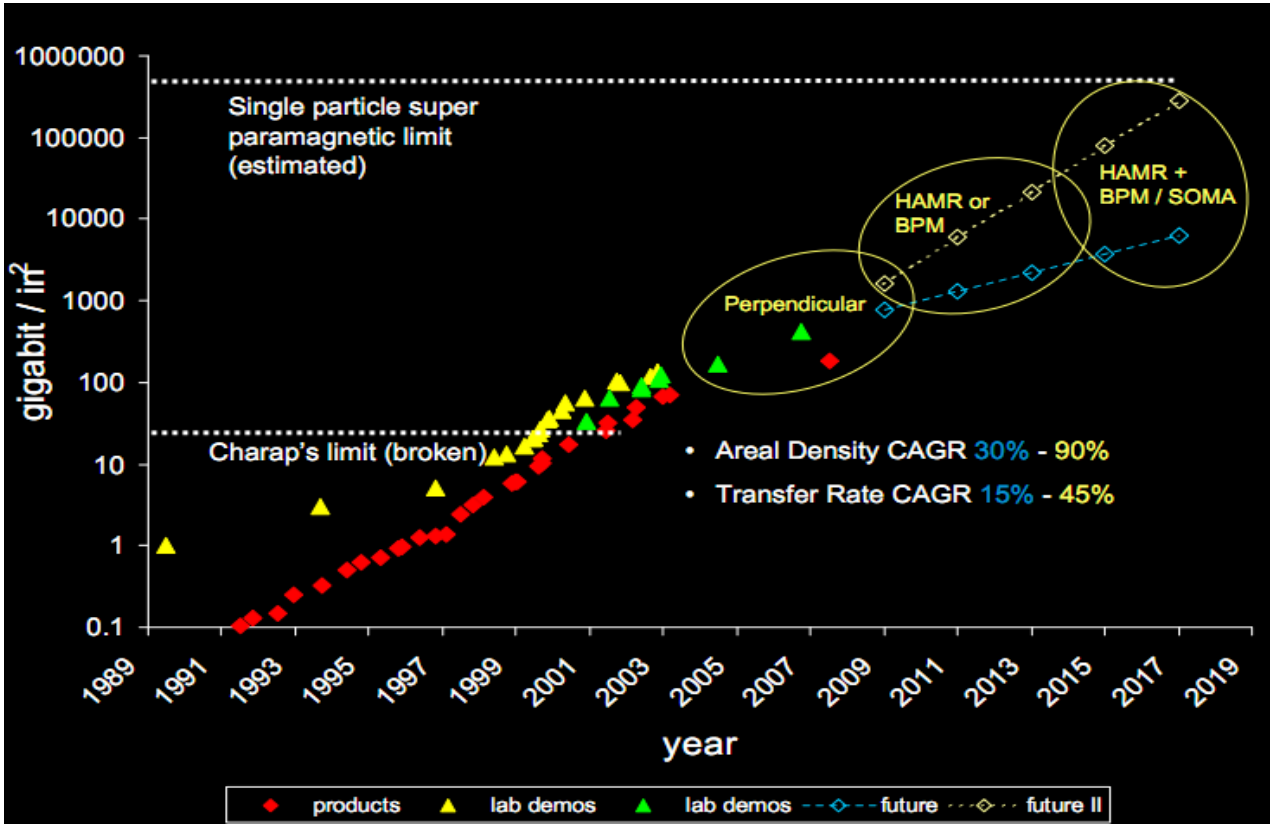


Source: Andy Bechtolsheim

- But what about HDD & storage chasm?

HDD: Capacity

- Capacity growth continues unabated

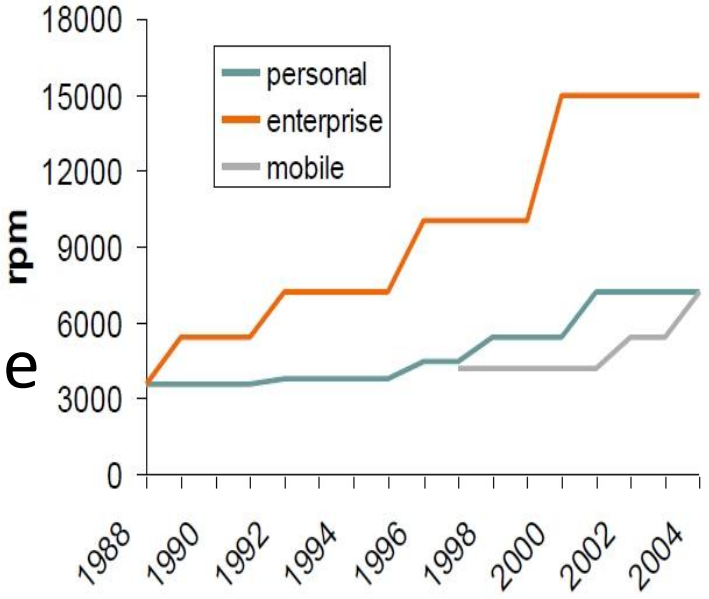


- Capacity isn't the problem
  - What about bandwidth and IOPS?

Source: Dave Anderson

HDD: Rotational Speed

- RPM contributes negatively to:
  - rotational vibration
  - Non-Repeating Run Out (NRRO)
  - Power cubically related to RPM
- >15k RPM not economically viable
  - no improvement in sight
- RPM not improving & seek times only improving very slowly
- IOPS improvements looking forward remain slow



product information for Seagate and Control Data disc drives since 1988, mobile includes Toshiba drives since 1997

Source: Dave Anderson

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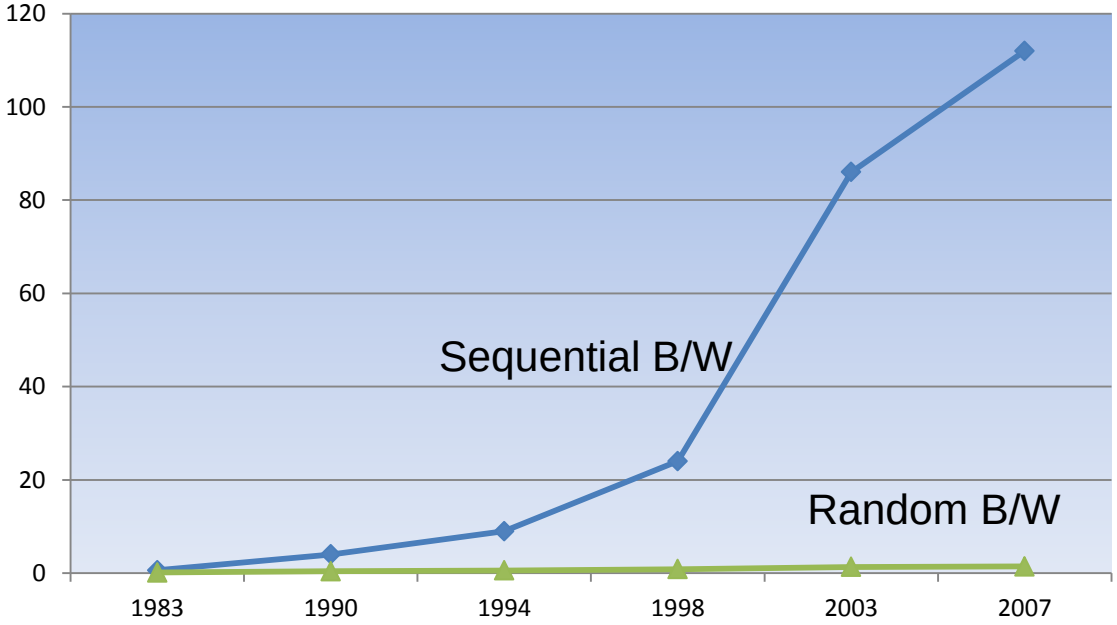
Disk Becomes Tape



Tape is Dead
Disk is Tape
Flash is Disk
RAM Locality is King

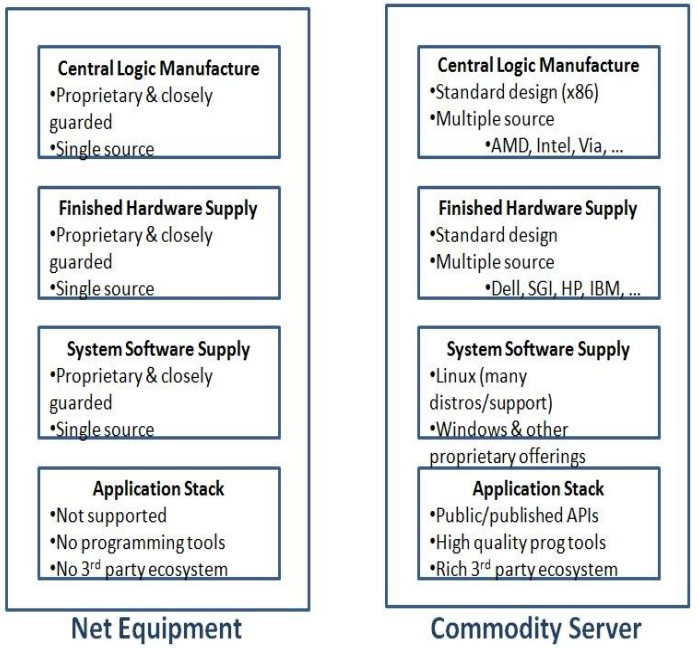
Jim Gray
Microsoft
December 2006

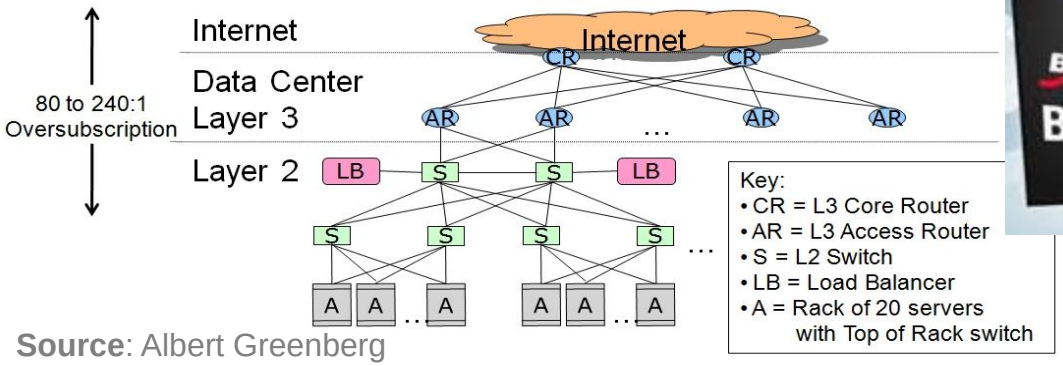
- Disk random access B/W growth ~10% of sequential B/W
- Random read 3TB disk: 31 days @ 140 IOPS (8kb)
  - 8.3 hours sequentially
- Storage Chasm widening
  - Disk becomes tape

Source: Dave Patterson with James Hamilton updates

Sea Change in Networking

- Current networks over-subscribed
  - Forces workload placement restrictions
  - Goal: all points in datacenter equidistant
- Mainframe model goes commodity
  - Competition at each layer over vertical integ.
- Get onto networking on Moores Law path
  - ASIC port count growth at near constant cost
  - Competition: Broadcom, Marvell, Fulcrum,…





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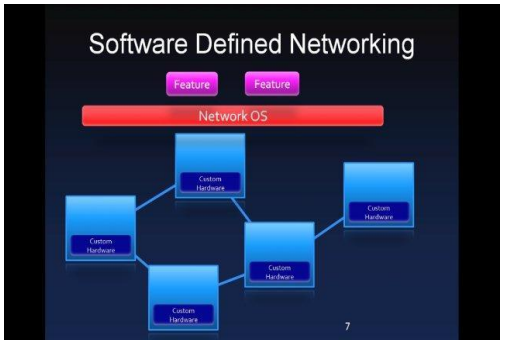
Source: Albert Greenberg

Networking Roadmap

- Move to commodity routing:
  - Much less expensive & lower power
  - More redundancy & bandwidth
  - Get on Moore's law Path (ASIC port count growth)
- Centralized control plane
  - OpenFlow/Software Defined Networking
- Client side:
  - Virtualized NIC: Avoid hypervisor tax
  - ROCEE & iWarp: Avoid O/S transition
  - Cut-through routing: Avoid store and forward delay
  - B/W increases continue: 10GigE commodity
    - 40G and 100G coming



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Client Storage Migration to Cloud

- Client disk rapidly replaced by local semiconductor caches
  - Flash becoming primary client storage media
  - Higher performance, Lower power, smaller form factor, greater shock resistance, scale down below HDD cost floor, greater humidity range, wider temp range, lower service costs, …
- Same trend in embedded devices
  - Well connected with cloud-hosted storage
- Clients storage drives cloud storage
  - Value added services, many data copies, shared access, indexed, classified, analyzed, monetized, reported, …

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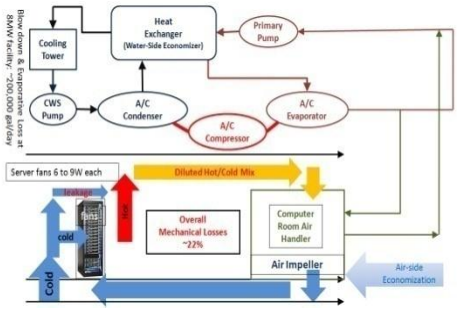

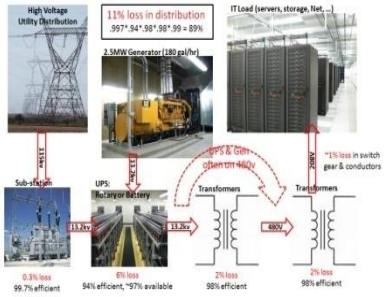

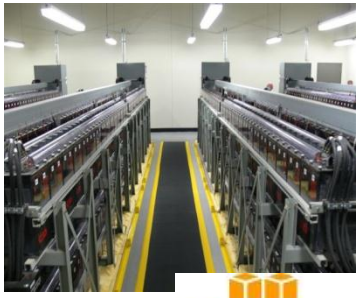

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Infrastructure at Scale

- Datacenter design efficiency
  - Average datacenter efficiency low with PUE over 2.0 (Source: EPA)
    - Many with PUE well over 3.0
  - High scale cloud services in the 1.2 to 1.5 range
  - Lowers computing cost & better for environment
- Multiple datacenters
  - At scale multiple datacenters can be used
    - Close to customer
    - Inter-datacenter data redundancy
    - Address international markets efficiently
- Avoid massive upfront data cost & years to fully utilize
  - Scale supports pervasive automation investment

Utilization & Economics

- Server utilization problem
  - 30% utilization VERY good &10% to 20% common
    - Expensive & not good for environment
  - Solution: pool number of heterogeneous services
    - Single reserve capacity pool far more efficient
    - Non-correlated peaks & law of large numbers
- Pay as you go & pay as you grow model
  - Don’t block the business
  - Don’t over buy
  - Transfers capital expense to variable expense
  - Leverage capital for core business rather than infrastructure
- Charge back models drive good application owner behavior
  - Cost encourages prioritization of work by application developers
  - Spot Market: High scale needed to make an efficient market

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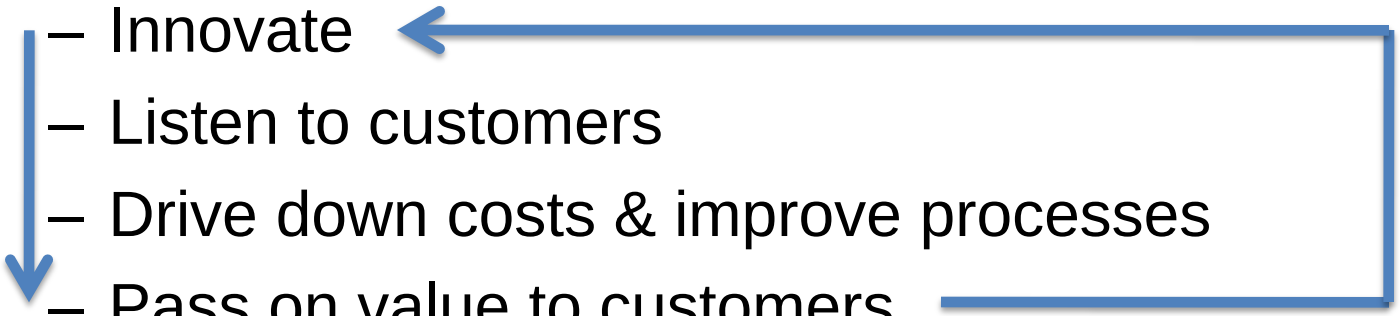
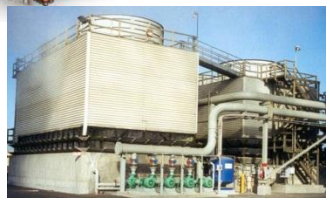
Amazon Cycle of Innovation

- 15+ years of operational excellence
  - Managing secure, highly available, multi-datacenter infrastructure
- Experienced at low margin cycle of innovation:
  - Innovate
  - Listen to customers
  - Drive down costs & improve processes
  - Pass on value to customers
- AWS price reductions expected to continue
  - 11 price reductions in 4 years



Summary



- Cloud scale driving quickening pace of innovation
- Plunging costs driving bigger data sets and more complex analysis
  - Data moving up memory hierarchy
  - Data moving up the storage hierarchy
- Networking costs & capabilities changing fundamentally
- Cloud computing fundamentally changing server-side infrastructure

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Questions?

- **Slides will be posted to:**
  - http://mvdirona.com/jrh/work
- **Perspectives Blog:**
  - http://perspectives.mvdirona.com/
- **Email:**
  - James@amazon.com