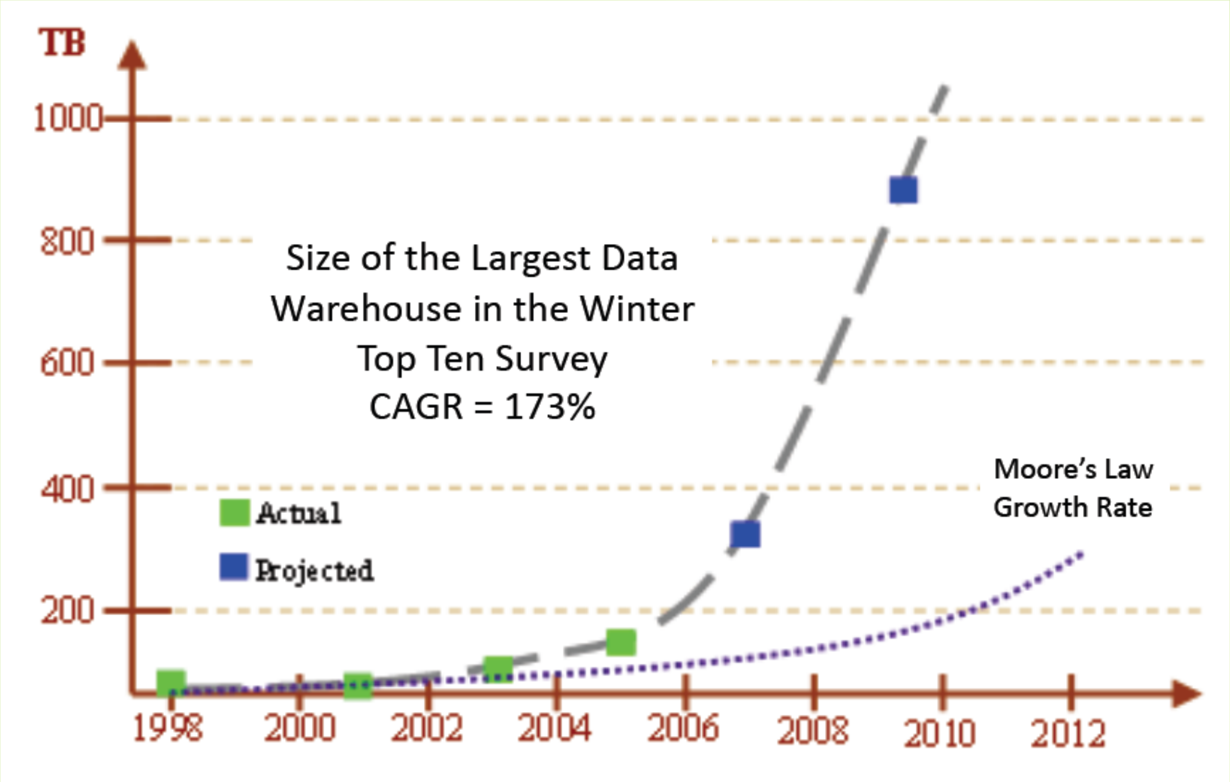
Bridging the Computation Gap in a Future of Massive Data

Fred Chong

Director, Greenscale Center
for Energy-Efficient Computing
Director, Computer Engineering
UC Santa Barbara

GREENSCALE

Computation Gap



- Optimistic technology scaling assumptions
- "Internet of Things"
- Greg Papadopoulos, keynote IGCC June 2012:

"$1 trillion market for ubiquitous sensors."

GREENSCALE

Outline

- Bridging the gap

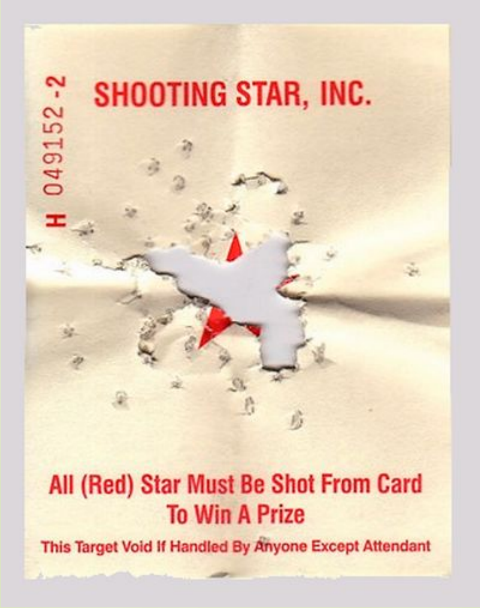
- Environmental Costs

- Cultural change

GREENSCALE

Efficiency Gap

- IEE/Kavli Roundtable
- 40X efficiency gap in 13 years
- No single solution
  - Gains needed at many levels of the system



[IEEE Design and Test 2014]

Solutions

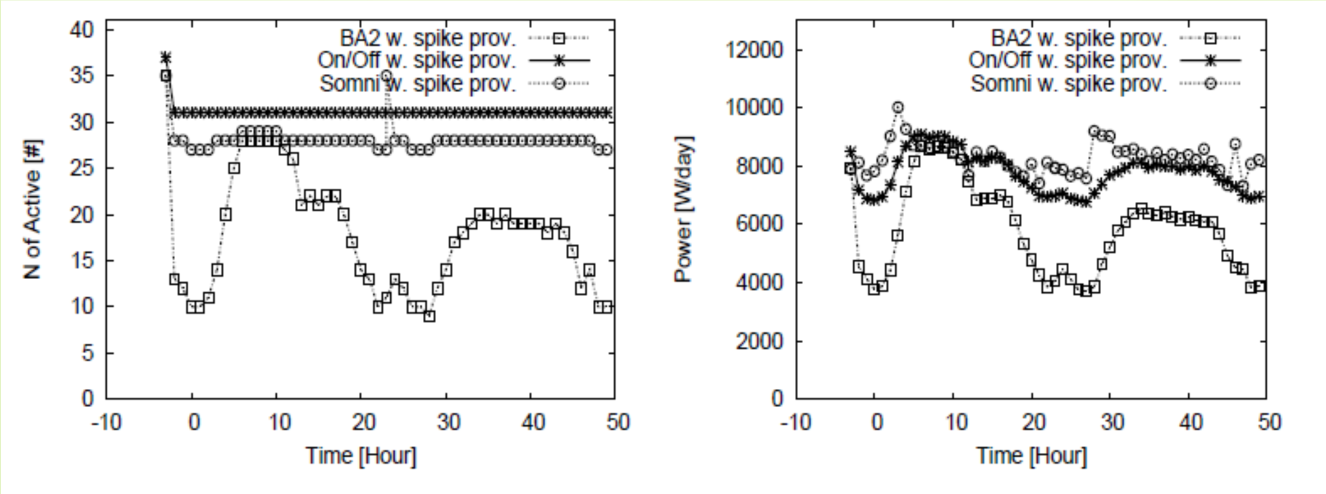
- Eliminate Waste
  - Turn stuff off
  - Avoid overprovisioning

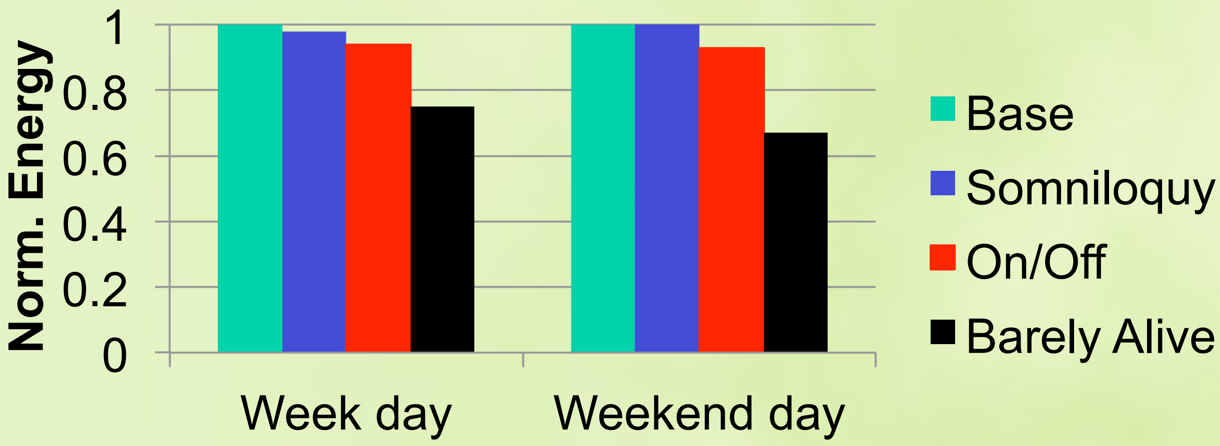
- Change the Rules
  - New Technologies
  - Approximate Computing

- Will give several examples
  - About 20% savings each

GREENSCALE

Barely-Alive Servers

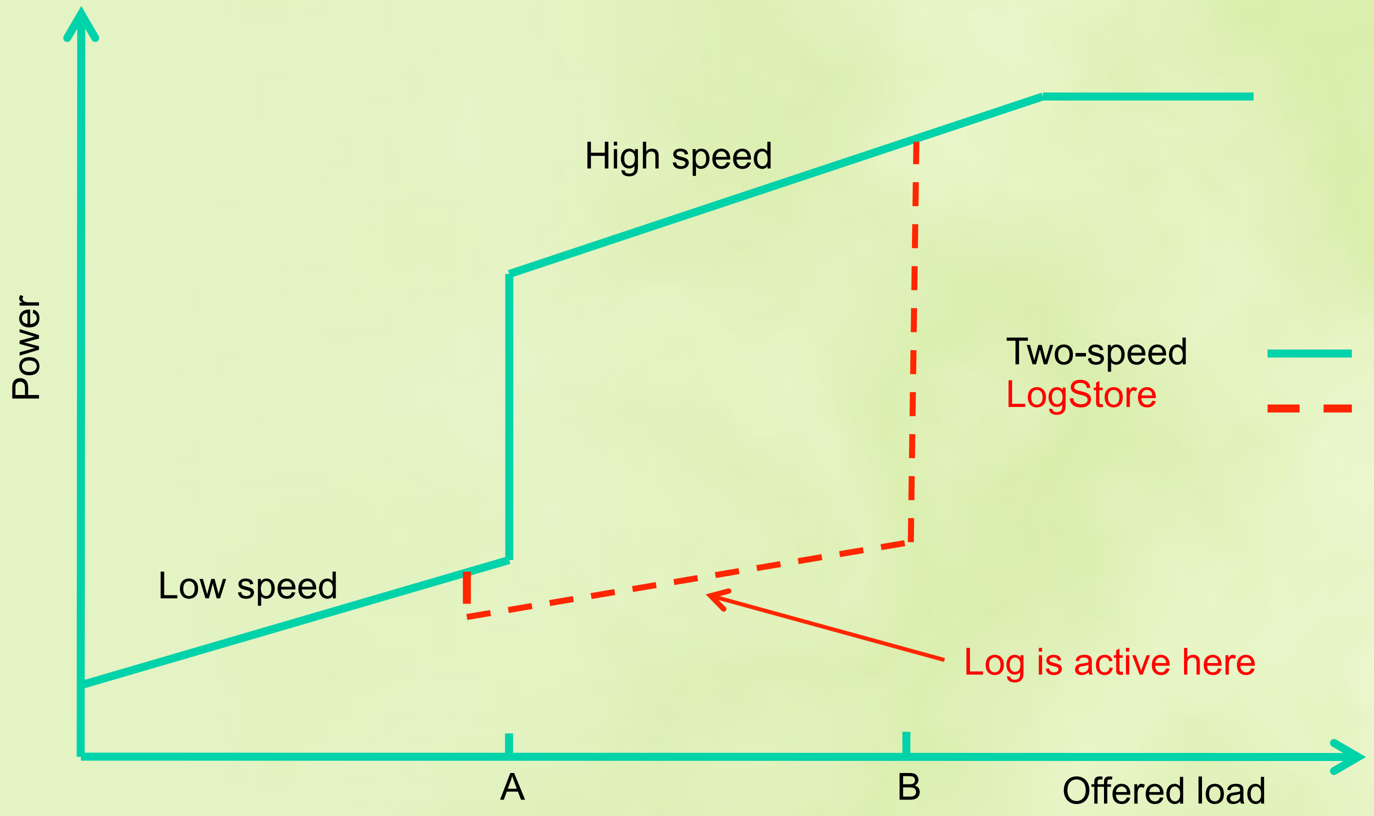




- Turn off microprocessors but allow other servers to use memory
- *Decouple load variation from data variation*

[JETC'12]

LogStore: Extending Low-Power Disk Modes

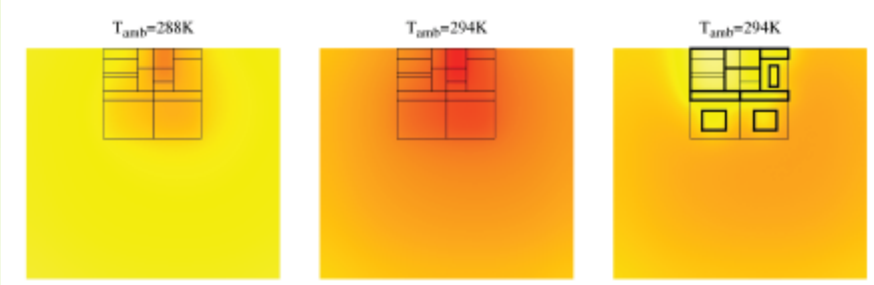


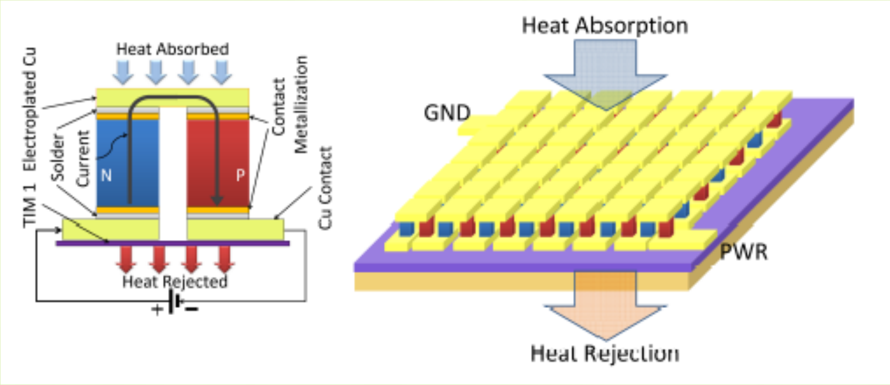
- Random disk writes are energy intensive (require higher speed to meet performance needs)
- *Sequentially logging writes can defer high-speed operation*

[FAST'12]

Targeted Thermoelectric Cooling

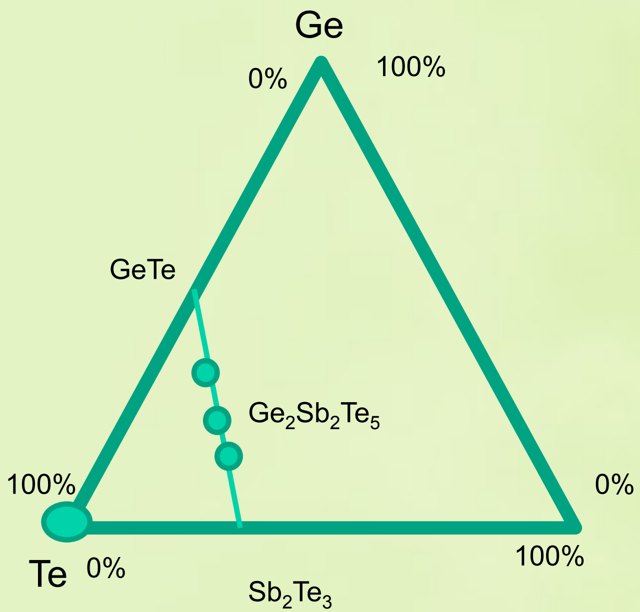
- Superlattice layer on microprocessor
- Acts as a Peltier heat spreader targeted at hot spots
- *Avoids worst-case provisioning in datacenter-level cooling*

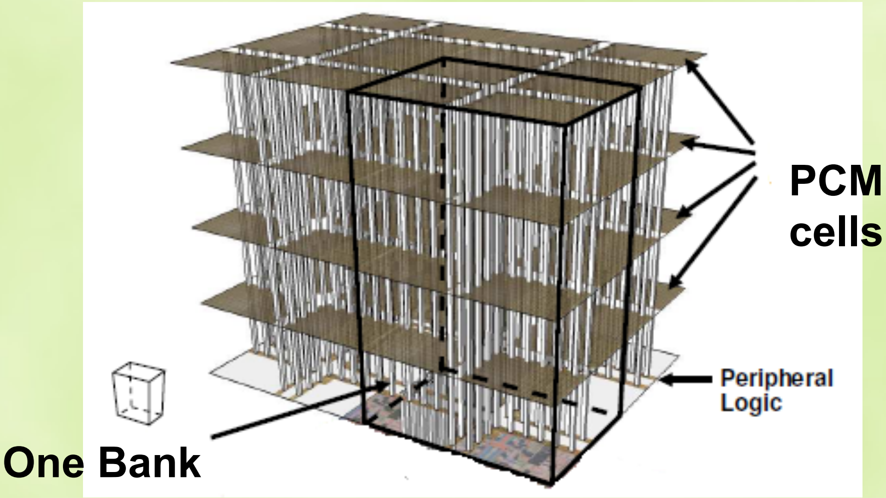




[ISCA'11]

Heterogeneous 3D Phase-Change Memory

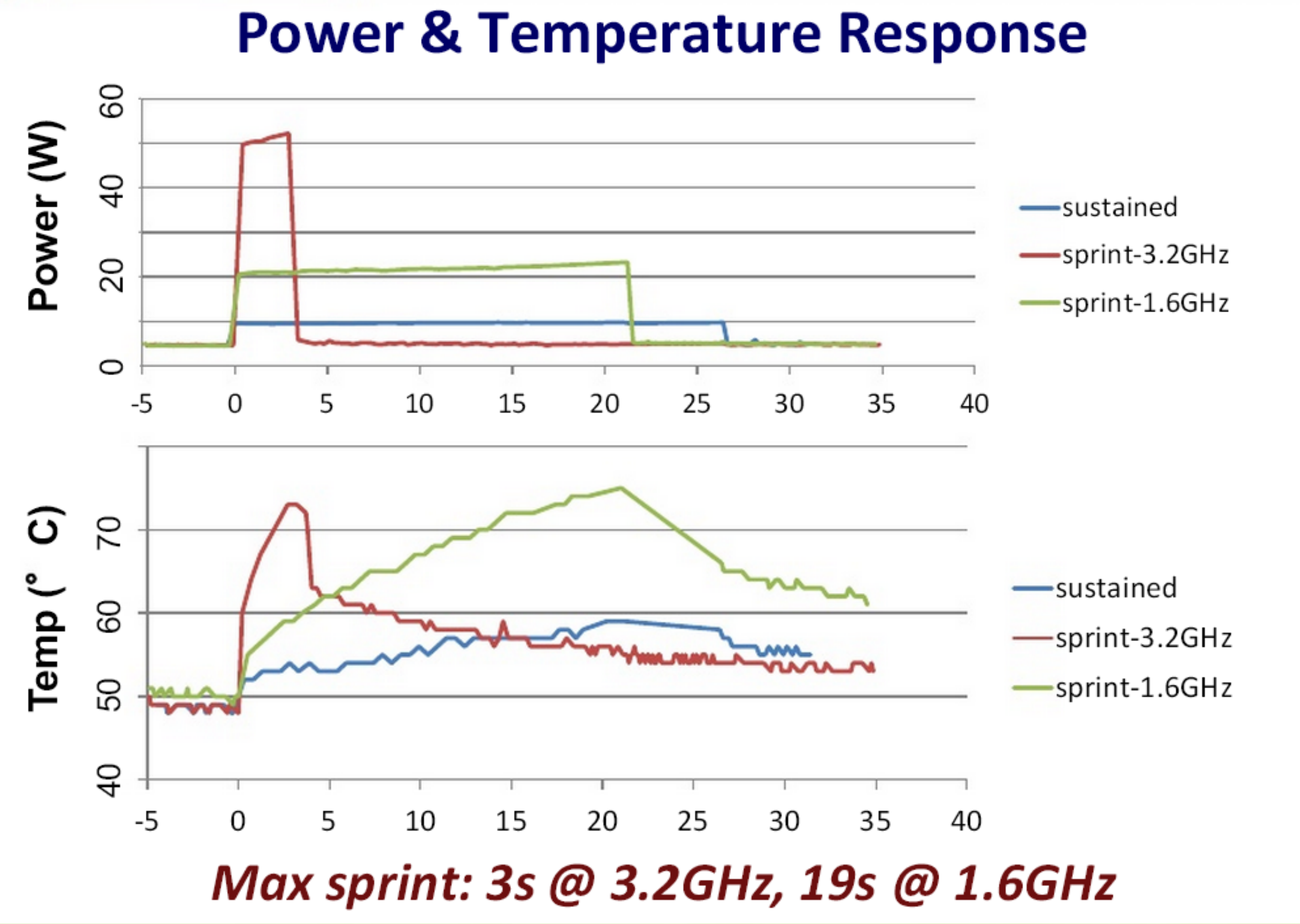




- Different operating temperatures in 3D stack
- Tailor GST mixture to operating temperature
- 10% memory energy savings

GREENSCALE

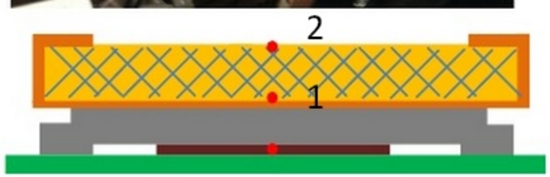
Computational Sprinting

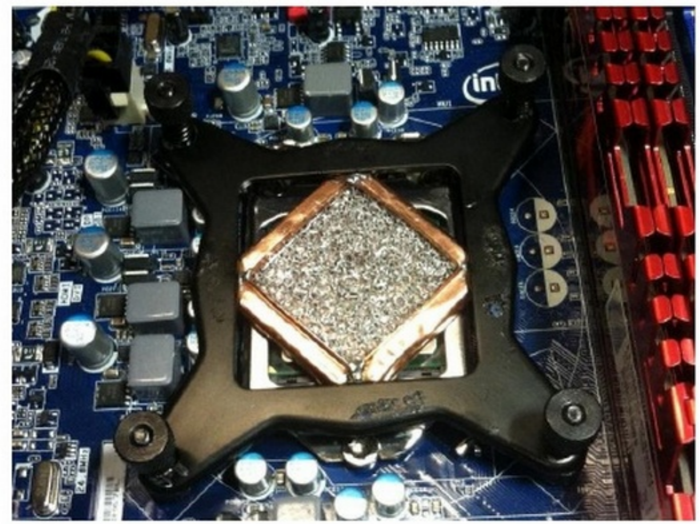


Wenisch, U Mich

Phase-Change Heat Sink

PCM Heat Sink Prototype



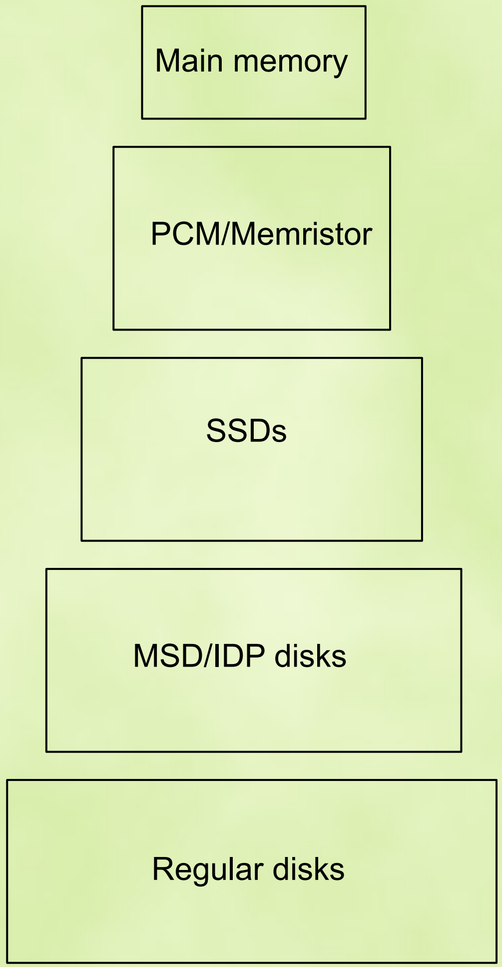


- Aluminum foam mesh **filled with Paraffin wax**
  - Relatively form-stable; melting point near 55 °C
  - **Working on a fully-sealed prototype w/ thermocouples**

GREENSCALE

Deep Memory Hierarchies

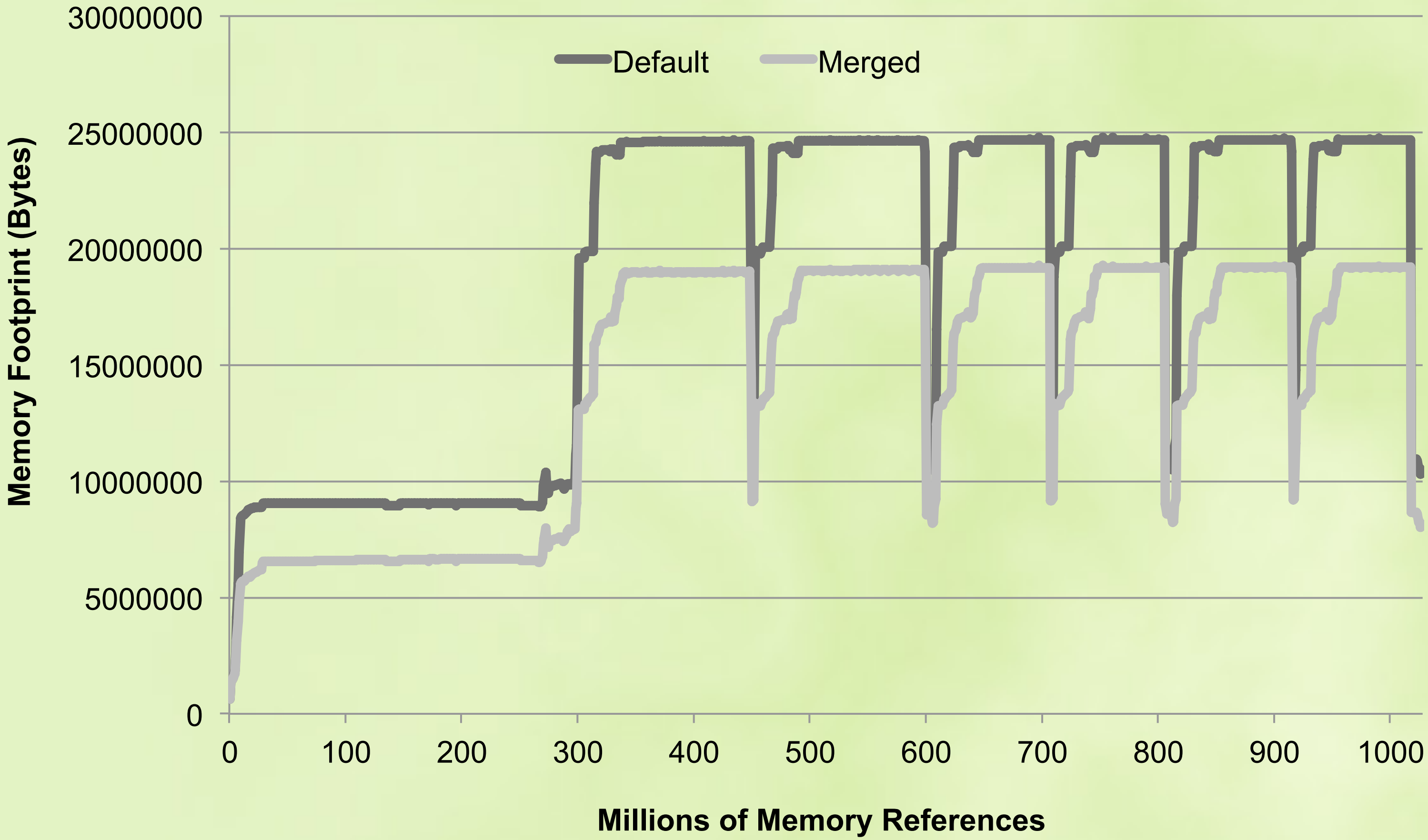
- Motivation: Hierarchy is very non-energy-proportional
  - Existing technologies: faster flash, multi-speed & IDP disks
  - New byte-addressable technologies: PCM & STT-RAM
  - Deep hierarchy can improve energy-proportionality
- Recent Progress:
  - Predict data location instead of search
  - *Simpler design allows compact table to be recalibrated periodically (22% energy savings)*



[IPDPS'14 (Best Paper)]

GREENSCALE

Memory De-duplication



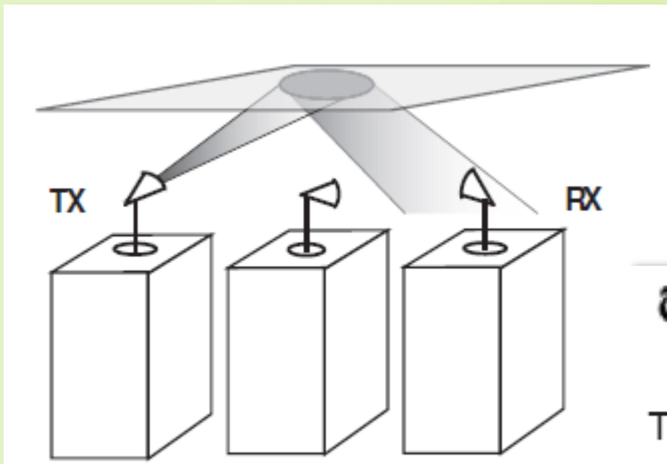
- 32% avg memory savings on MPI apps
  - 60% max

[IPDPS'11]

Approximation

- Approximate de-duplication
- Approximate computation
  - NPU 3.0X energy savings [Esmailzadeh 13]
- Guided approximation with information flow techniques

3D Beamforming in Datacenters



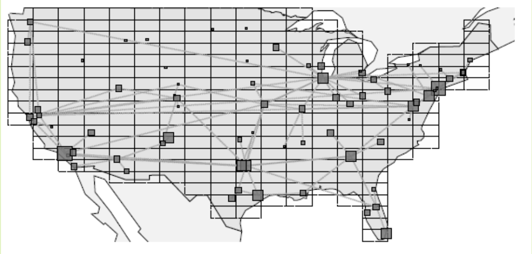
A Wireless Way Around Data Center Traffic Jams »

To battle information overload at data centers, researchers are testing a new option: high-frequency wireless links that can help move the data along during crunch times.

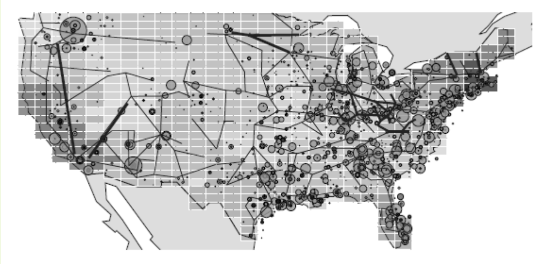
- Zheng and Zhao with Vahdat at Google
- 60 Ghz links with 2-6 Gbps
- *Flexible BW for burst loads*

[Sigcomm'12]

Datacenter Placement

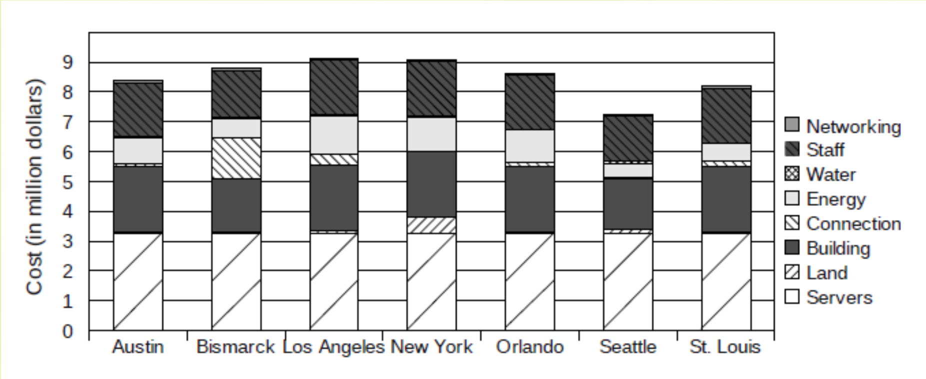


Datacenter Placement Example

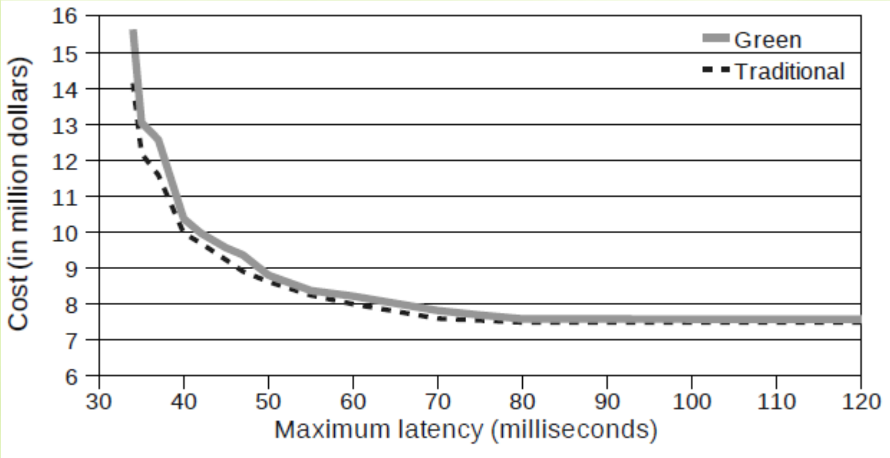


Electricity Rates

Temperature



Cost Breakdowns



Cost of Green Datacenters

[Goiri et al, ICDCS'11]

Bridging the Gap

- 40X in 13 years
- Assuming 20% improvements can be compounded:
  - Need a new idea deployed every 7-8 months!
  - Probably much worse!

GREENSCALE

Part II: Environmental Costs to Bridging the Gap

GREENSCALE

Server = SUV

=

- More precisely:
  - 80 billion terawatt-hr / yr = 6 million SUVs in carbon production (10 mpg, 11K miles/yr)

GREENSCALE

Warehouse Computing

=

- Google at Columbia River Gorge => hydroelectric power
- $30B annual energy bill worldwide
- Energy starting to cost more than capital expenditures

Resource Use in Silicon Fabrication

- 1.6 kilowatt-hrs / cm^2
- 20 liters water / cm^2
- 3.3 billion active cell phone subscriptions
- (212 Billion wireless devices by 2020)

[IDC 13]

- ~20 cm^2 / phone
- 106 billion kilowatt-hrs (recall that datacenters use 80 billion kwh annually)

GREENSCALE

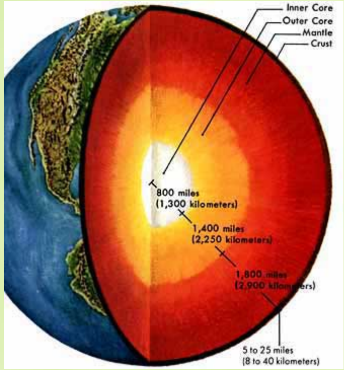
Throughput

- 280 Million phones sold / quarter
- Average lifetime of a phone: 1.5-2 yrs
- Old phones sitting in drawers, but throughput of over 1 billion phones / yr
- 32 billion kilowatt-hrs / yr just for uproc

GREENSCALE

Other Impacts

- 400 billion liters of water
  - 160,000 olympic swimming pools
  - More than double annual global bottled water consumption
- 400 million kg of soil to remediate just the copper (more copper on surface than inside the earth!)



Biodegradable Materials

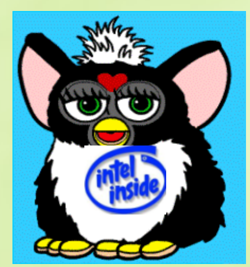
- Biodegradable plastics
  - Fire retardants are bad
- Organic LEDs / transistors

Microprocessor Reuse?

- Problem: obsolescence resulting from rapid improvements

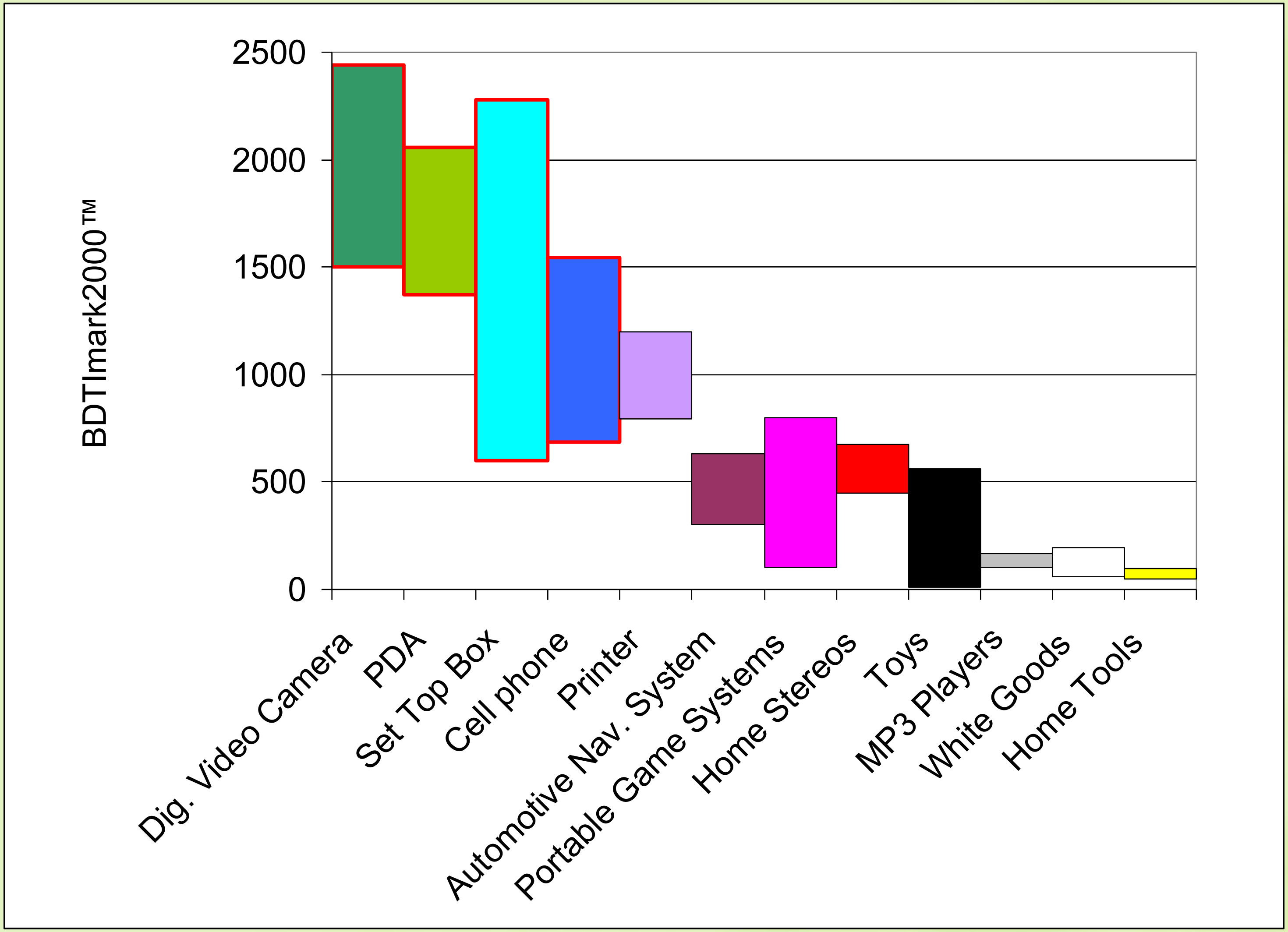
- Solution: microprocessor food chain

[IEEE Computer ’07]



GREENSCALE

Example Applications

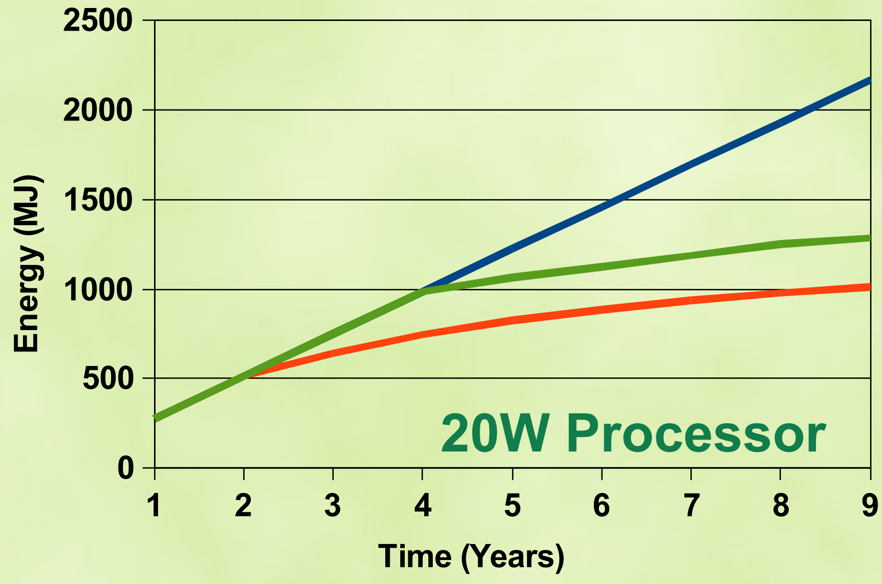


The BDTImark2000(tm) is a summary measure of signal processing speed.
For more info and scores see www.BDTI.com

Lifetime Energy Savings

- Depends on die-size
  - Die sizes are getting smaller
- Depends on in-use energy consumption
  - Assume 3 hours of use per day
    - .5 W processors probably should be re-used
    - 20 W processor, upgrade!

Re-Use
New Processor Every 2 Years
New Processor Every 4 Years



Technical Challenges of Re-Use

- Form Factor
  - Can’t put a Pentium in the space of an 8051
- Battery Life
  - Is adequate power consumption good enough?
  - Voltage scaling
- ISA compatibility
  - Some ISA are more efficient on specific workloads
  - May require extra cycles
    - Erode the efficiency of our re-use strategy

GREENSCALE

Design for Reuse

- Design for several applications and lifetimes, not just one
- More severe wearout
- Added overhead to support different applications
- Design for easier reprogramming
- Design for easier reclamation and re-tasking
  - form factor, wireless or serial communication

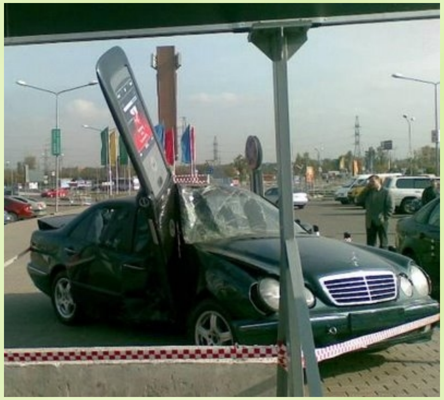
Standard building blocks

GREENSCALE

Reclamation Costs

- < $7 cell phone
- Recycling surcharge + deposit

Cost (US $)	Cell Phone**	Computer***
Collection*	6.00	23.50
Transportation	0.35	0.43
Sorting	-	3.50
Dismantling	0.03	2.75
Refining	0.32	7.87
Dispose of non-hazardous waste	0.01	0.83
Dispose of hazardous waste	0.03	5.00



*Average (cell phone:$4 to $8; computer:$13 to $34)

**Results from survey conducted with fifteen private US electronic recycling firms [Bhuie et al, 2004]

***[Boon et al., 2000]

GREENSCALE

Handset Reuse

- Refurbished phones
  - Only millions captured
  - Political issues
- PDAs
  - Learning tool / diary in elementary schools
  - Parking permit / navigator
- Location beacon
- Shipping container tracking
- *Just park benches?*

GREENSCALE

Reuse Summary

- Silicon fabrication and disposal are serious environmental concerns
- Reuse is a challenging goal, but we have to face the impact of our exponentionally-growing computing demands

Part III: Cultural Change

Cultural Change

- Some sustainable technologies and practices exist, but managers and designers unaccustomed to the tradeoffs
- Need to develop frameworks and educate the next generation of technical leaders

GREENSCALE

Measuring Energy

- Coal-fired electric plants – 35% efficient
- Electrical transmission lines – 90% efficient
- Datacenter power distribution – also optimized for peak
- Other inefficiencies
  - Server power supplies
  - Battery charger / battery efficiency

www.epa.gov/cleanenergy/energy-resources/calculator.html

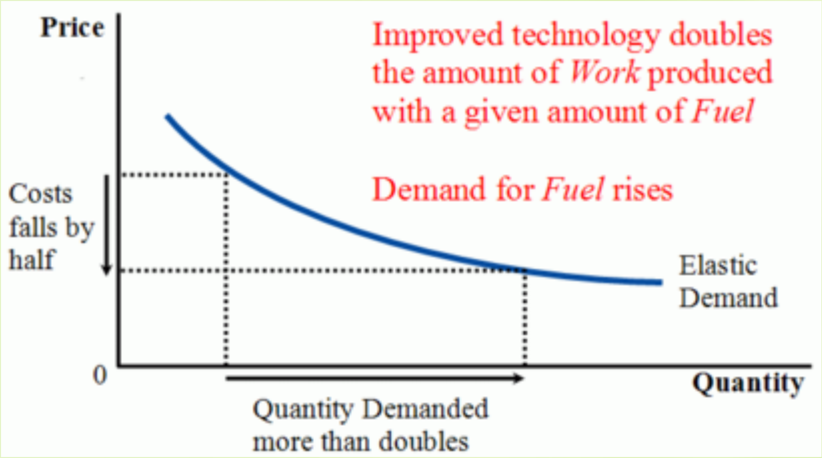
Life-Cycle Analysis

- Sustainable systems require a higher-level analysis
    - Energy and carbon metrics
    - Supply chains, end-of-life
- Challenge: proprietary data
    - Study academic fabrication facilities
- Make friends with your local industrial ecologist!

Reacting to Policy

- Standards and policies
  - Energy-star, SPEC power
  - Standards need knowledgeable participants
- Companies need to know how to respond to legislation and standards
  - WEEE, RoHS, Energy-star

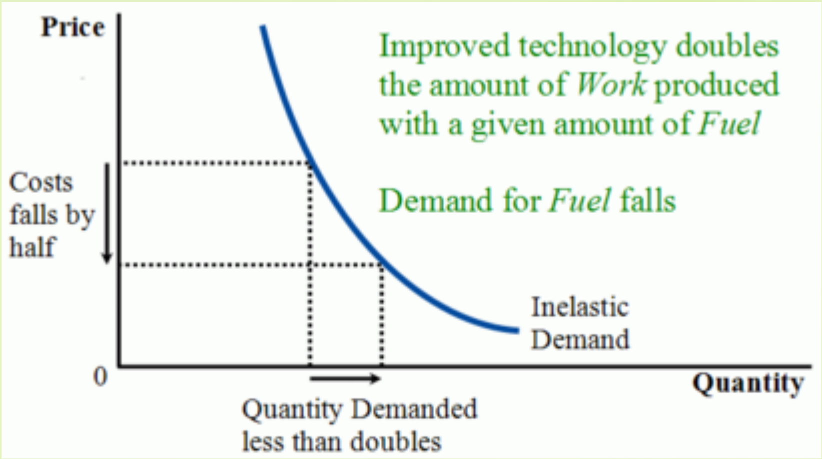
Caveat: Jevons Paradox



- Efficiency in coal-fired machines led to greater demand for coal

GREENSCALE

Jevons Paradox



- Demand for computing could be elastic
- Need to measure productivity

Closing Remarks

- Computing for massive data poses significant sustainability challenges
- Good technical problems, but many are multidisciplinary
- We need to train the next generation of multidisciplinary engineers

energy.cs.ucsb.edu

GREENSCALE

Acknowledgements

- Luiz Barroso, Urs Hoezle, Bill Weihl (Google)
- Partha Raganathan (Google)
- Ricardo Bianchini (Rutgers)
- Roland Geyer (UCSB)
- Raj Amirtharajah, Venkatesh Akella (UC Davis)
- John Oliver (Calpoly)

GREENSCALE