Resource Efficient Computing for Warehouse-scale Datacenters

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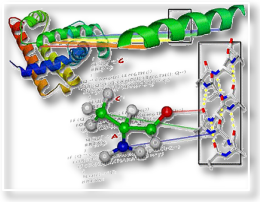
Computing is the Innovation Catalyst



Science

Government

Commerce

Healthcare

Education

Entertainment

Faster, cheaper, greener

The Datacenter as a Computer

[K. Vaid, Microsoft Global Foundation Services, 2010]

Advantages of Large-scale Datacenters

- Scalable capabilities for demanding services
  - Websearch, social nets, machine translation, cloud computing
  - Compute, storage, networking
- Cost effective
  - Low capital & operational expenses
  - Low total cost of ownership (TCO)

Datacenter Scaling

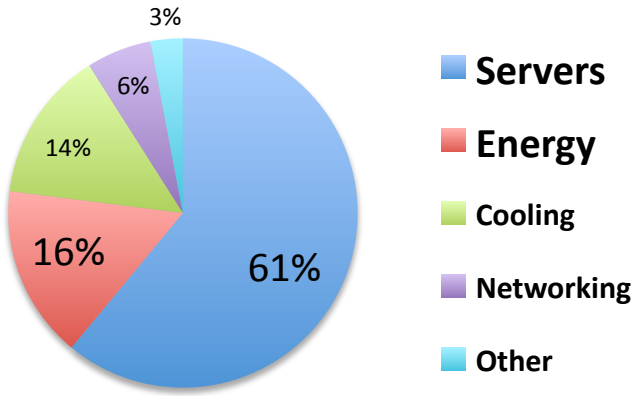
- Cost reduction
  - ~~Switch to commodity servers~~ — *one time trick*
  - ~~Improved power delivery & cooling~~ — *PUE < 1.15*
- Capability scaling
  - ~~More datacenters~~ — *>$300M per DC*
  - ~~More servers per datacenter~~ — *@60MW per DC*
  - ~~Multicore servers~~ — *End of voltage scaling*
  - Scalable network fabrics

Datacenter Scaling through Resource Efficiency

- Are we using our current resources efficiently?
- Are we building the right systems to begin with?

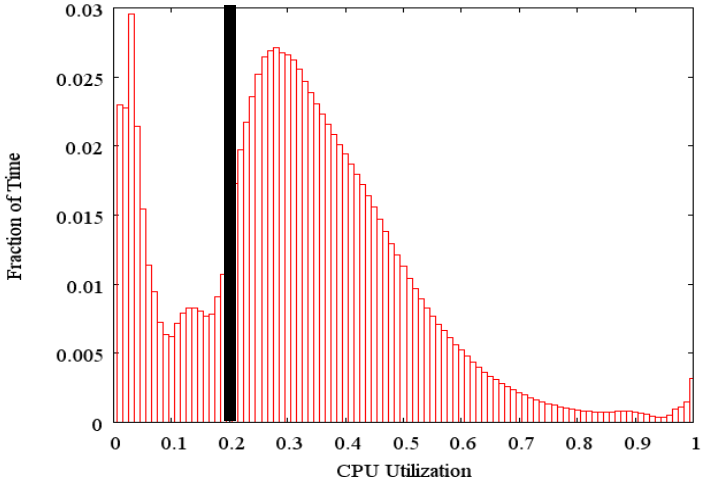
Our Focus: Server Utilization

Total Cost of Ownership



[J. Hamilton, http://mvdirona.com]

Server utilization



[U. Hoelzle and L. Barosso, 2009]

- Servers dominate datacenter cost
  - CapEx and OpEx
- Server resources are poorly utilized
  - CPUs cores, memory, storage

Low Utilization

- Primary reasons
  - Diurnal user traffic & unexpected spikes
  - Planning for future traffic growth
  - Difficulty of designing balanced servers
- Higher utilization through workload co-scheduling
  - Analytics run on front-end servers when traffic is low
  - Spiking services overflow on servers for other services
  - Servers with unused resources export them to other servers
    - E.g., storage, Flash, memory
- *So, why hasn't co-scheduling solved the problem yet?*

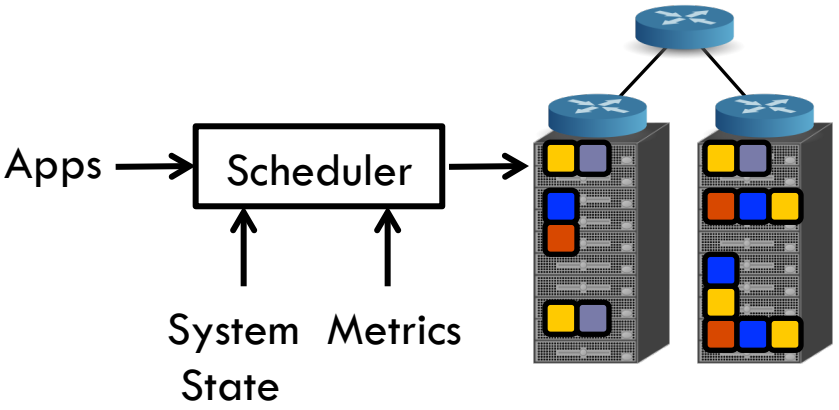
Interference→ Poor Performance & QoS

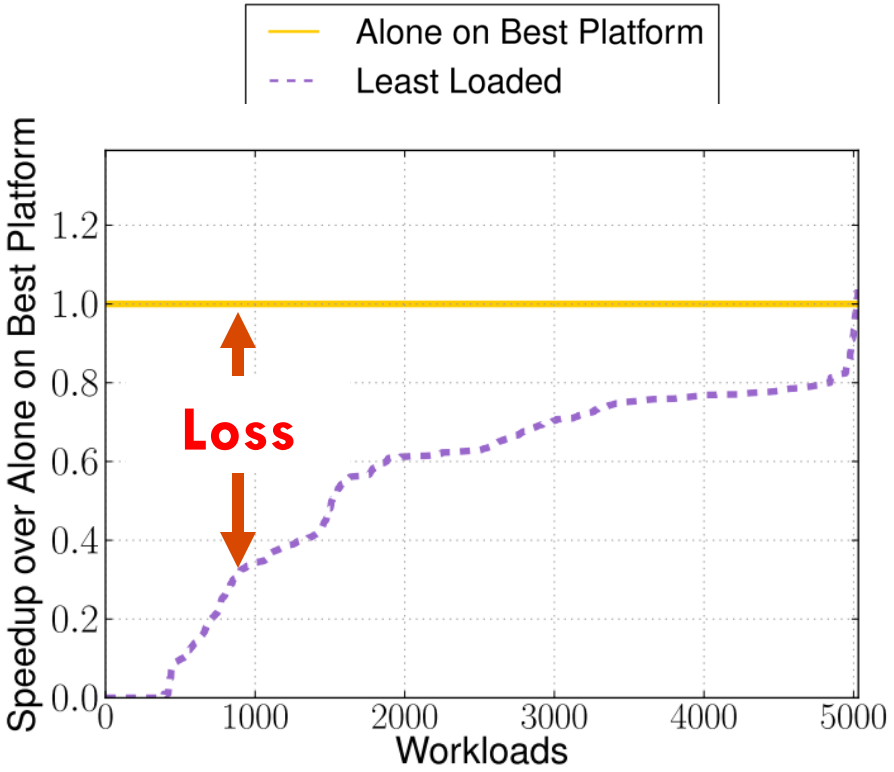
- Interference on shared resources
  - Cores, caches, memory, storage, network
  - Large performance losses
    - E.g. 40% for Google apps [Tang'11]
- QoS issue for latency-critical applications
  - Optimized for for low 99th percentile latency in addition to throughput
  - Assume 1% chance of >1sec server latency, 100 servers used per request
  - Then 63% chance of user request latency >1sec
- Common cures lead to poor utilization
  - Limited resource sharing
  - Exaggerated reservations

Higher Resource Efficiency wo/ QoS Loss

- Research agenda
  - Workload analysis
    - Understand resource needs, impact of interference
  - Mechanisms for interference reduction
    - HW & SW isolation mechanisms (e.g., cache partitioning)
  - Interference-aware datacenter management
    - Scheduling for min interference and max resource use
  - Resource efficient hardware design
    - Energy efficient, optimized for sharing
- Potential for >5x improvement in TCO

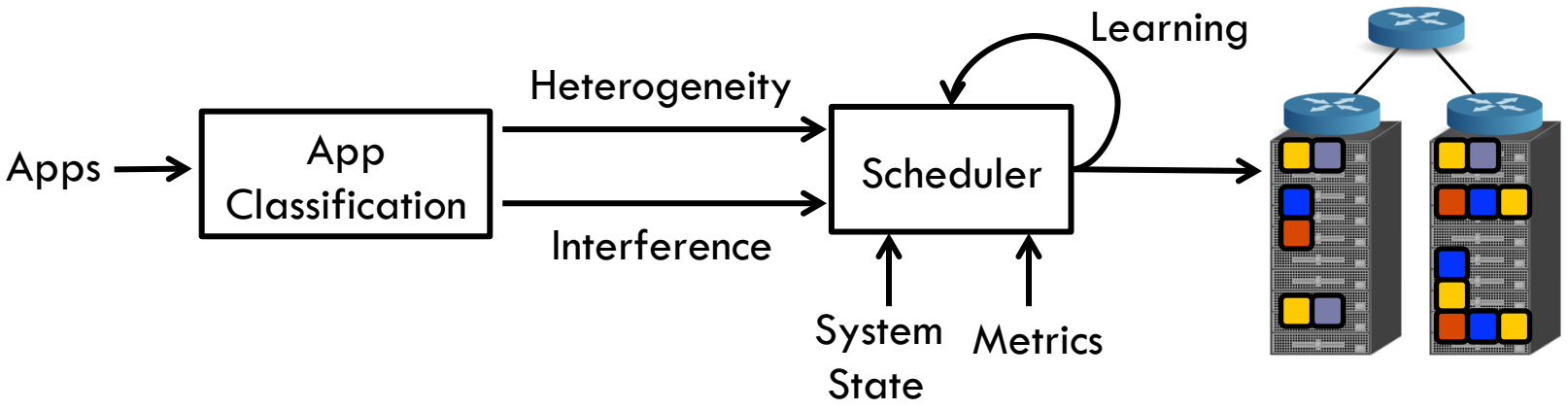
Datacenter Scheduling





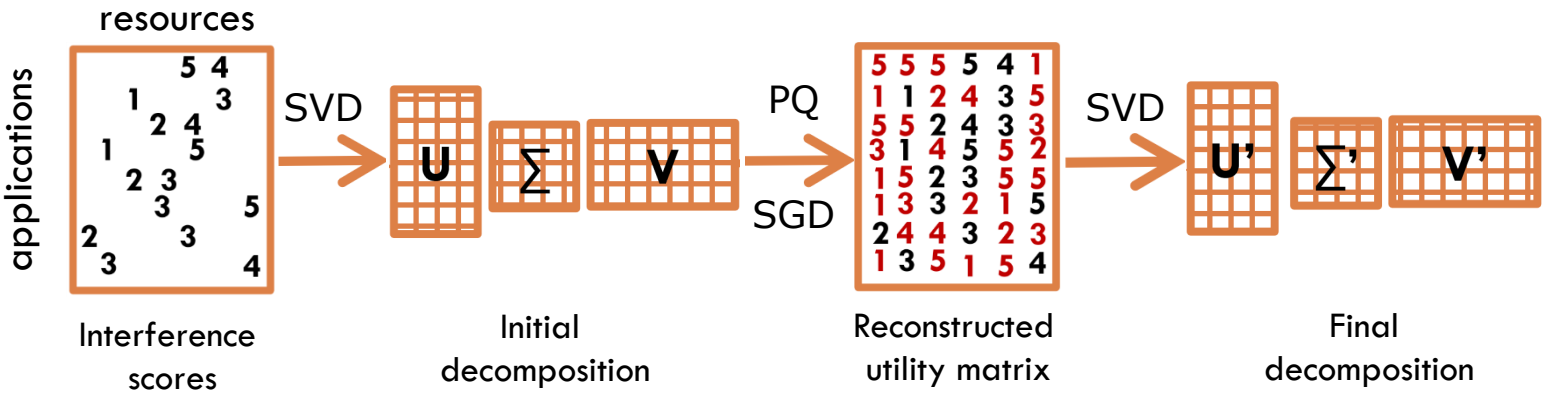
- Two obstacles to good performance
  - Interference: sharing resources with other apps
  - Heterogeneity: running on suboptimal server configuration

Paragon: interference-aware Scheduling [ASPLOS'13]



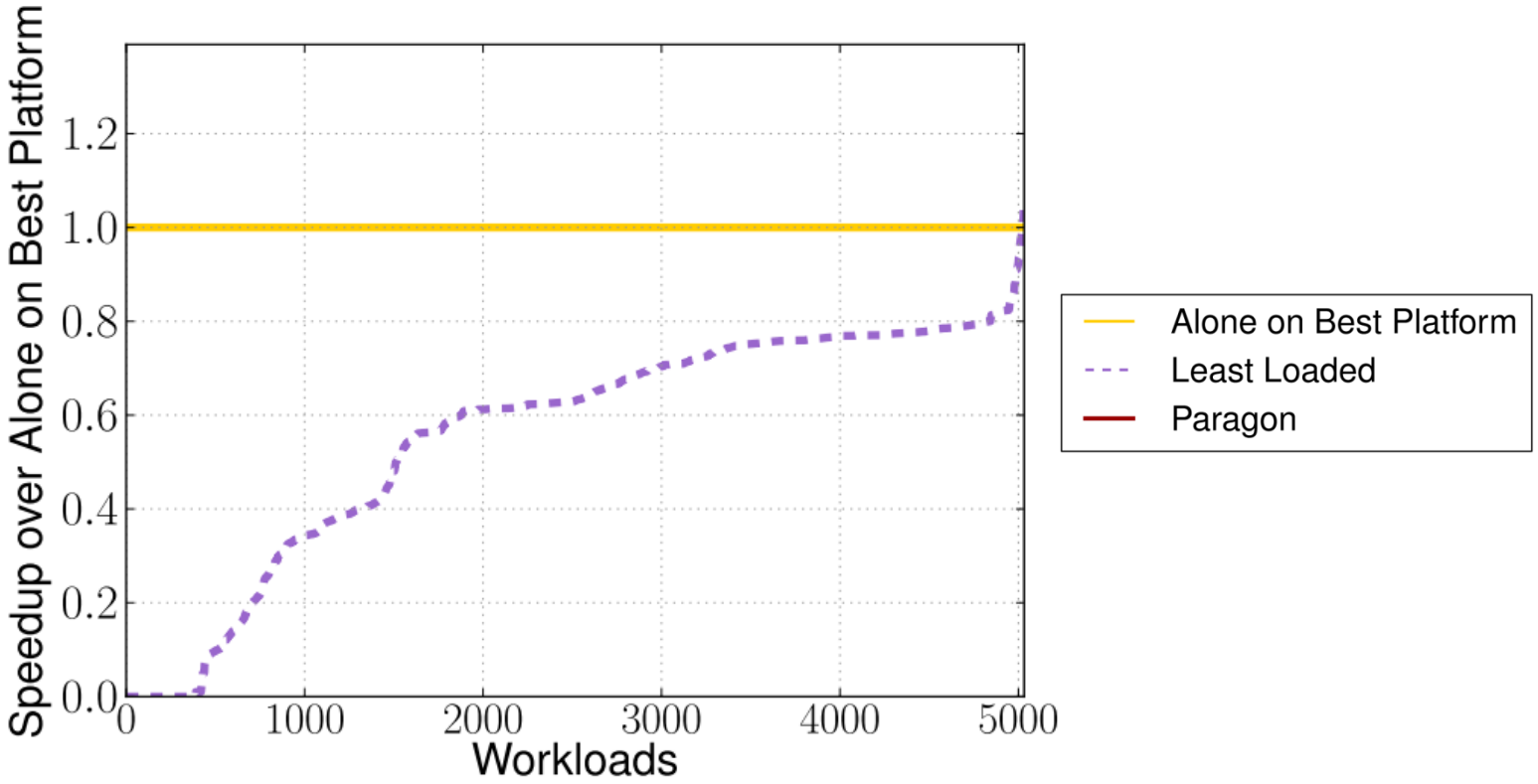
- Quickly classify incoming apps
  - For heterogeneity and interference caused/tolerated
- Heterogeneity & interference aware scheduling
  - Send apps to best possible server configuration
  - Co-schedule apps that don't interfere much
- Monitor & adapt
  - Deviation from expected behavior signals error or phase change

Fast & Accurate Classification



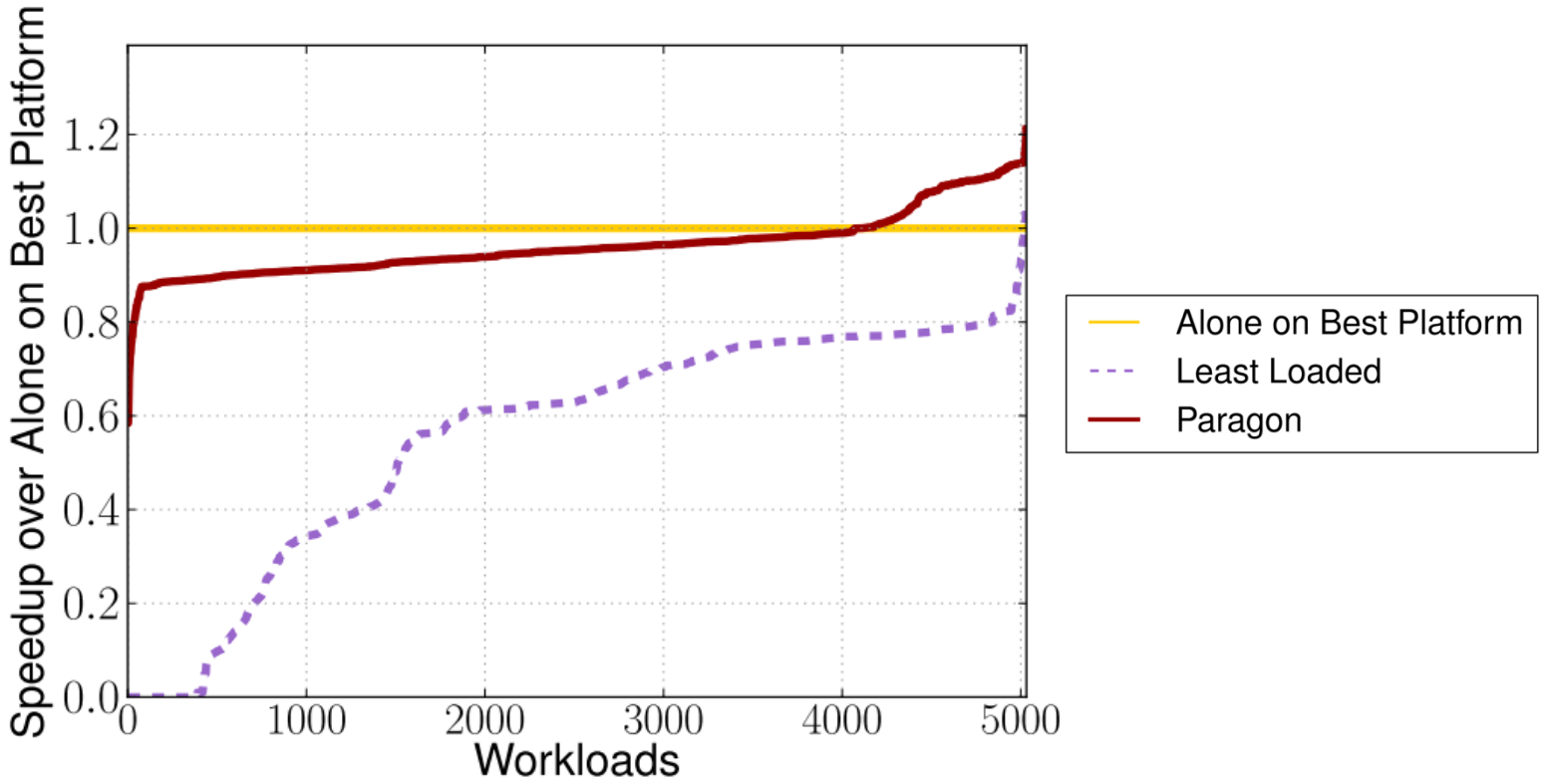
- Cannot afford to exhaustively analyze workloads
  - High churn rates of evolving and/or unknown apps
- Classification using collaborative filtering
  - Similar to recommendations for movies and other products
  - Leverage knowledge from previously scheduled apps
  - Within 1min of sparse profiling we can estimate
    - How much interference an app causes/tolerates on each resource
    - How well it will perform on each server type

Paragon Evaluation



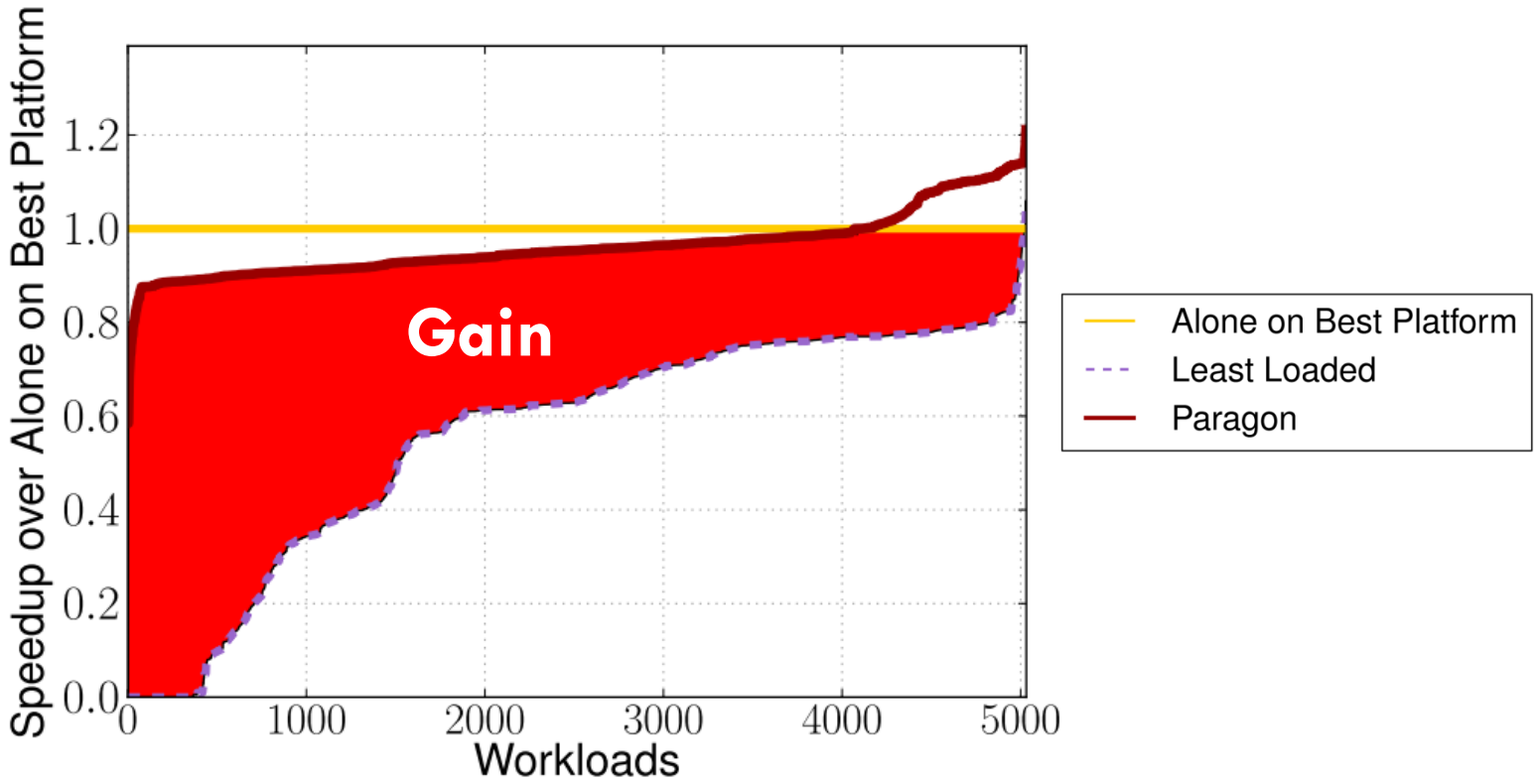
- 5K apps on 1K EC2 instances (14 server types)

Paragon Evaluation



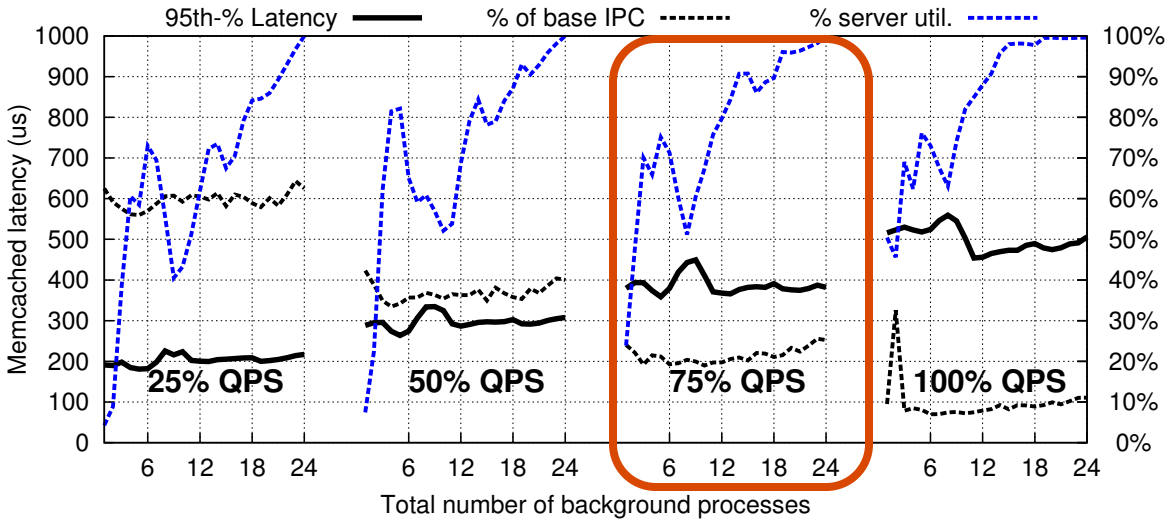
- Better performance with same resources
  - Most workloads within 10% of ideal performance

Paragon Evaluation



- Better performance with same resources
  - Most workloads within 10% of ideal performance
  - Can serve additional apps without the need for more HW

High Utilization & Latency-critical Apps



- Example: scheduling work on underutilized memcached servers
  - Reporting QPS at cutoff of 500usec for 95th % latency
- High potential for utilization improvement
  - All the way to 100% CPU utilization impact QoS impact
- Several open issues
  - System configuration, OS scheduling, management of hardware resources

Datacenter Scaling through Resource Efficiency

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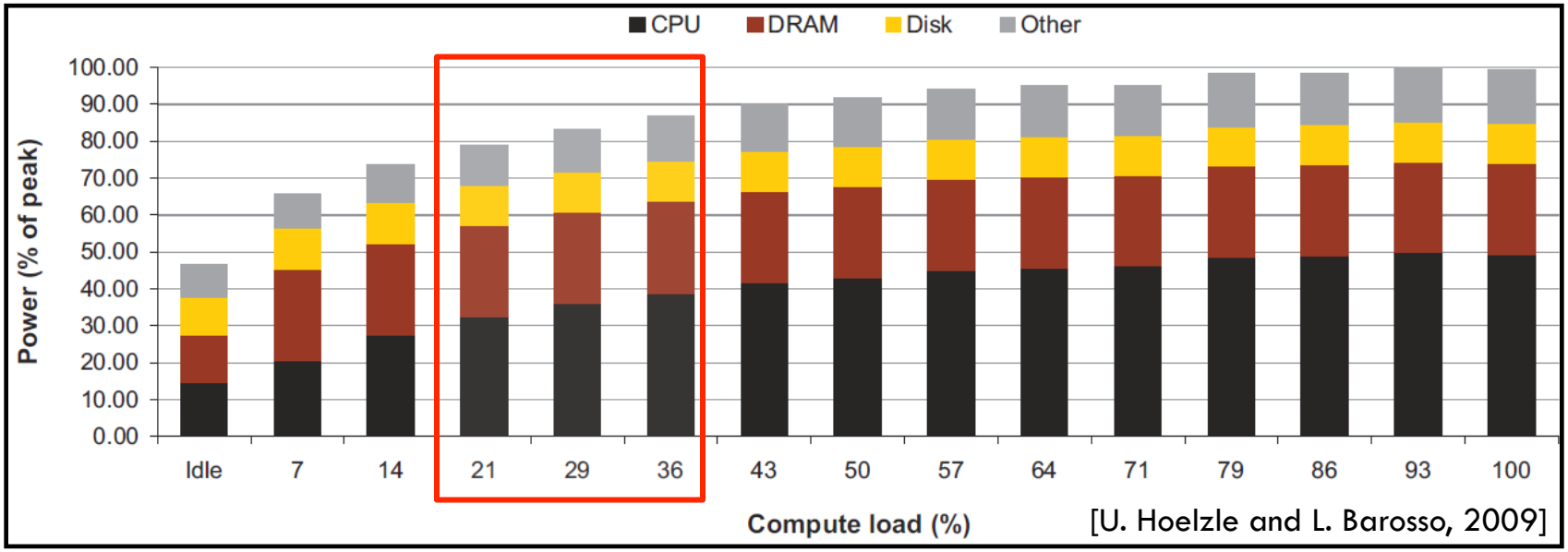
- Are we building the right systems to begin with? ⬅

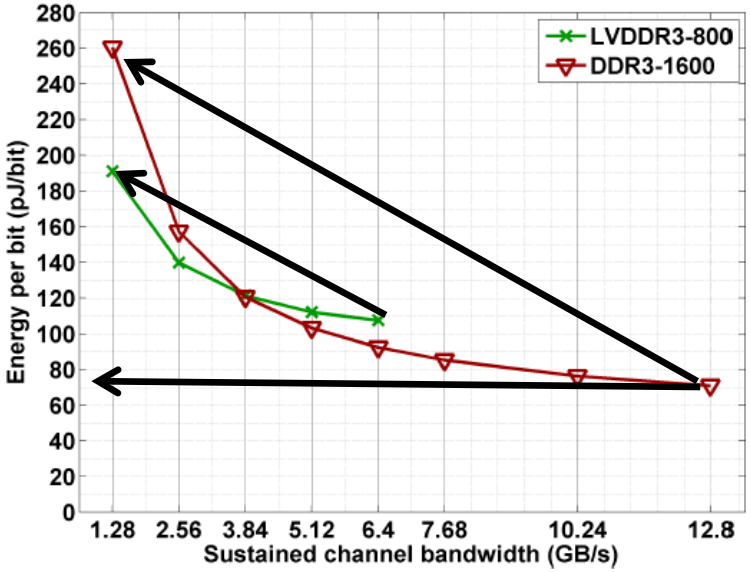
Main Memory in Datacenters



- Server power main energy bottleneck in datacenters
  - PUE of ~1.1 → the rest of the system is energy efficient
- Significant main memory (DRAM) power
  - 25-40% of server power across all utilization points
  - Low dynamic range → no energy proportionality

DDR3 Energy Characteristics

- DDR3 optimized for high bandwidth (1.5V, 800MHz)
  - On chip DLLs & on-die-termination lead to high static power
  - 70pJ/bit @ 100% utilization, 260pJ/bit at low data rates
- LVDDR3 alternative (1.35V, 400MHz)
  - Lower Vdd → higher on-die-termination
  - Still disproportional at 190pJ/bit
- Need memory systems that consume lower energy and are proportional
  - What metric can we trade for efficiency?



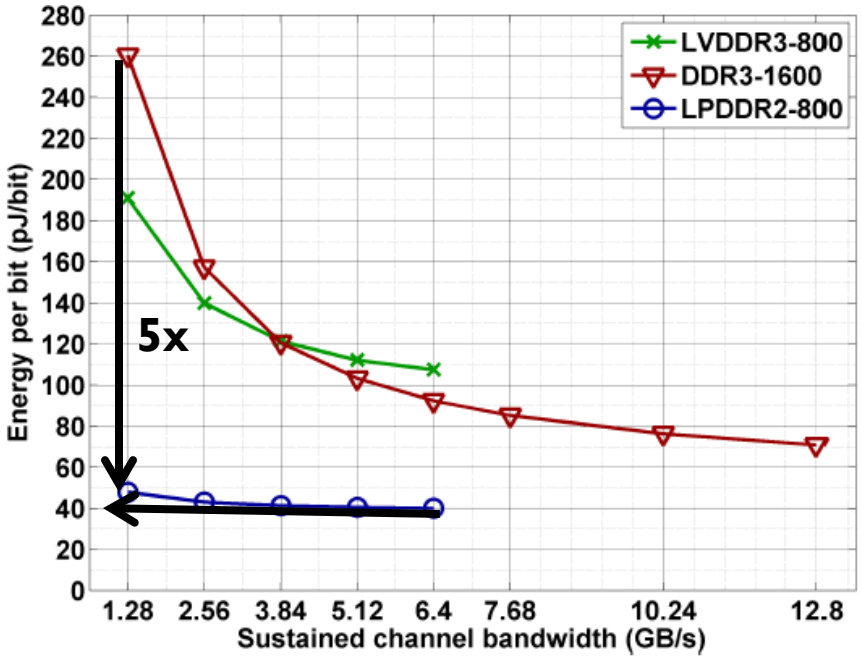
Memory Use in Datacenters

Resource Utilization for Microsoft Services under Stress Testing [Micro'11]

	CPU Utilization	**Memory BW Utilization**	Disk BW Utilization
Large-scale analytics	88%	**1.6%**	8%
Search	97%	**5.8%**	36%

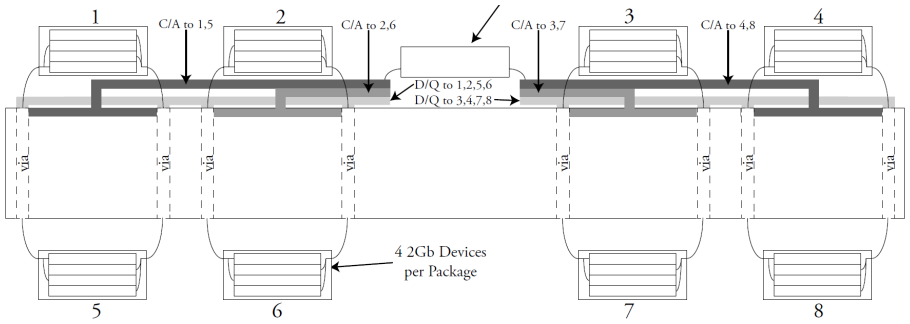
- Online apps rely on memory capacity, density, reliability
  - But not on memory bandwidth
  - Web-search and map-reduce
    - CPU or DRAM latency bound, <6% peak DRAM bandwidth used
  - Memory caching, DRAM-based storage, social media
    - Overall bandwidth by network (<10% of DRAM bandwidth)
- We can trade off bandwidth for energy efficiency

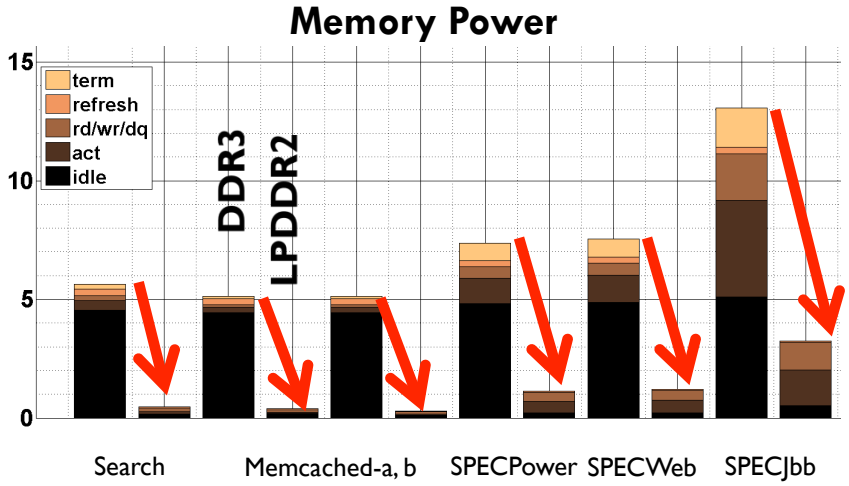
Mobile DRAMs for Datacenter Servers [ISCA'12]



- Same core, capacity, and latency as DDR3
- Interface optimized for lower power & lower bandwidth ($^1/_2$)
  - No termination, lower frequency, faster powerdown modes
- Energy proportional & energy efficient

Mobile DRAMs for Datacenter Servers [ISCA'12]





- LPDDR2 module: die stacking + buffered module design
  - High capacity + good signal integrity
- 5x reduction in memory power, no performance loss
  - Save power or increase capability in TCO neutral manner
- Unintended consequences
  - Energy efficient DRAM → L3 cache power now dominates

Summary

- Resource efficiency
  - A promising approach for scalability & cost efficiency
  - Potential for large benefits in TCO
- Key questions
  - Are we using our current resources efficiently?
    - Research on understanding, reducing, and managing interference
    - Hardware & software
  - Are we building the right systems to begin with?
    - Research on new compute, memory, and storage structures