Performance Scalability of a Multi-core Web Server

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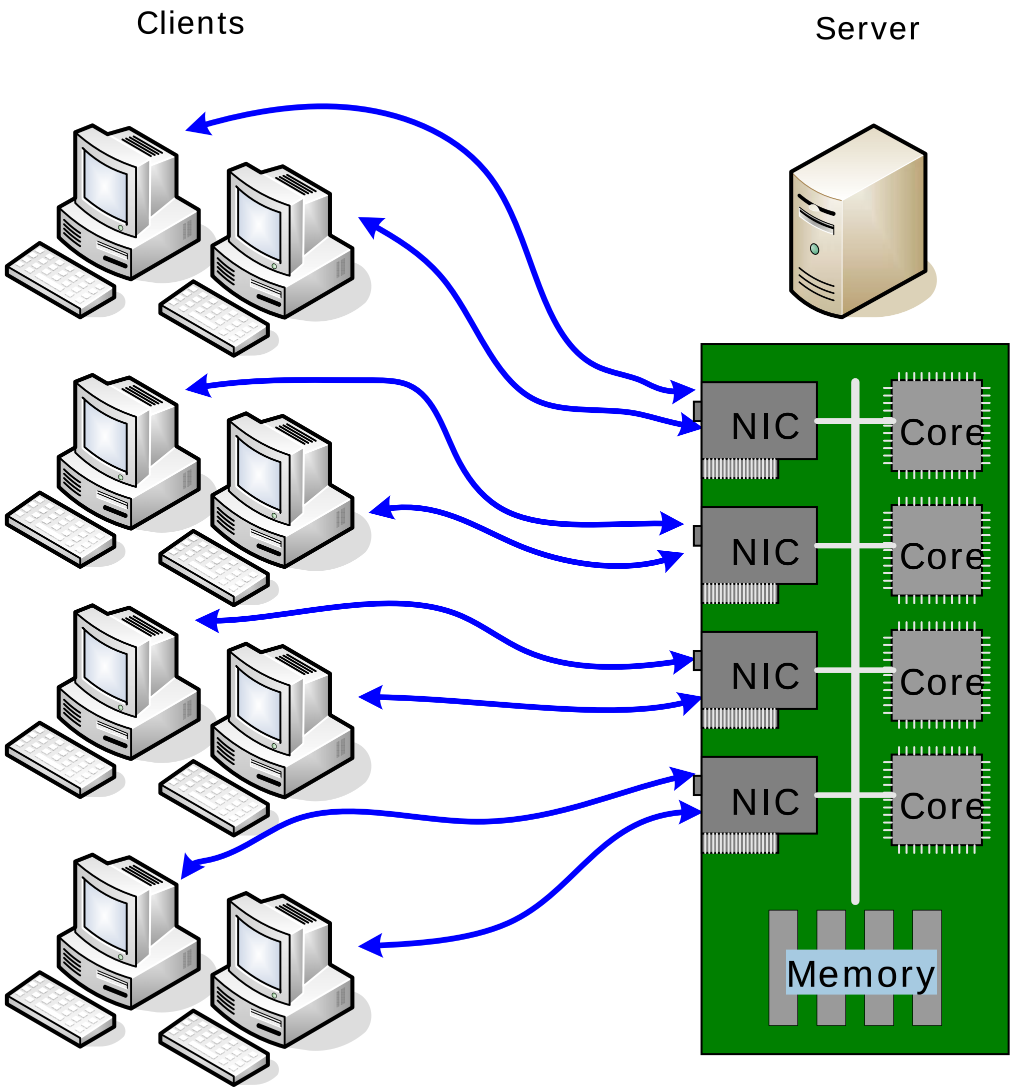
Overview

- The number of CPU cores on modern servers is increasing rapidly
- Premise: for highly parallel workloads **performance should scale with the number of cores**
- We tested this premise for **web servers**
- Our results show that **web servers do not scale**
- We tested for common problems with poor parallel programming
- We found **few parallelism problems** in the TCP/IP stack and the web software
- Instead, we found **problems inherent to server hardware design**

Why Performance Should Scale

- Typical networked servers
  - Have multiple cores
  - Have NICs mapped onto cores
  - Supports many clients
  - Each client has its own flow
- Independence between flows
  - Parallelism in the TCP/IP stack
  - Parallelism the application
- **Because of flow-level parallelism, performance should scale**

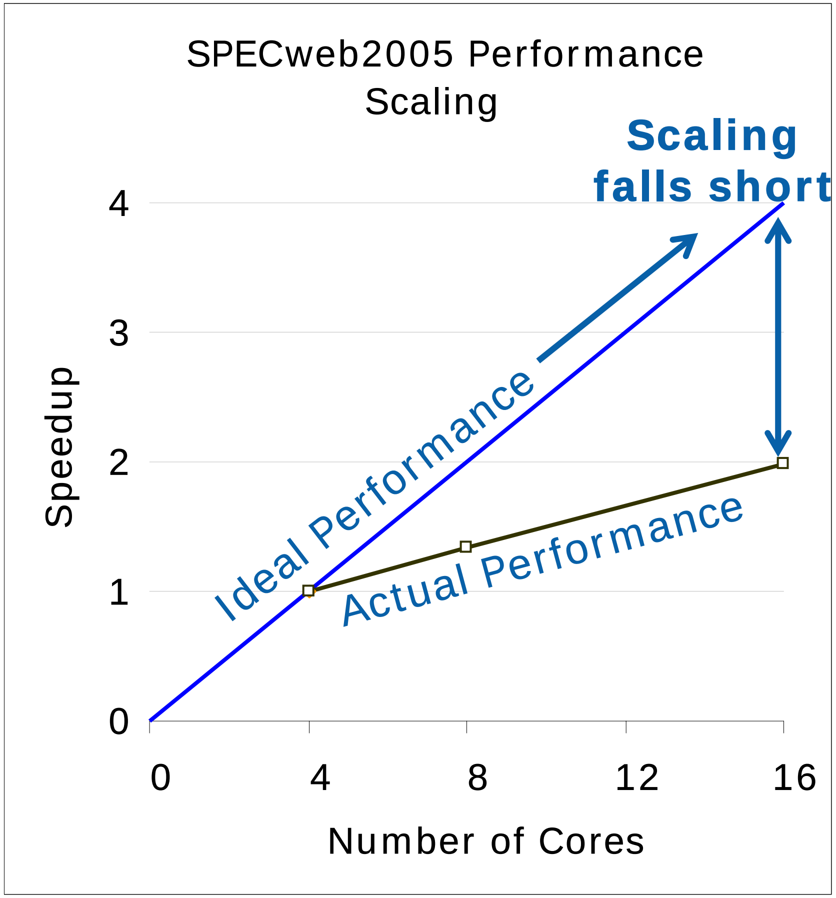


How Performance Scales on Web Servers

Example web server benchmark: SPECweb2005
- Official results from HP
- Similar scaling for Intel and AMD CPUs
- Performance metric is throughput

- Ideal performance scales linearly
- Actual Performance scales poorly
  - 2x the cores
  - 1.5x the performance

Performance does not scale with the number of cores!

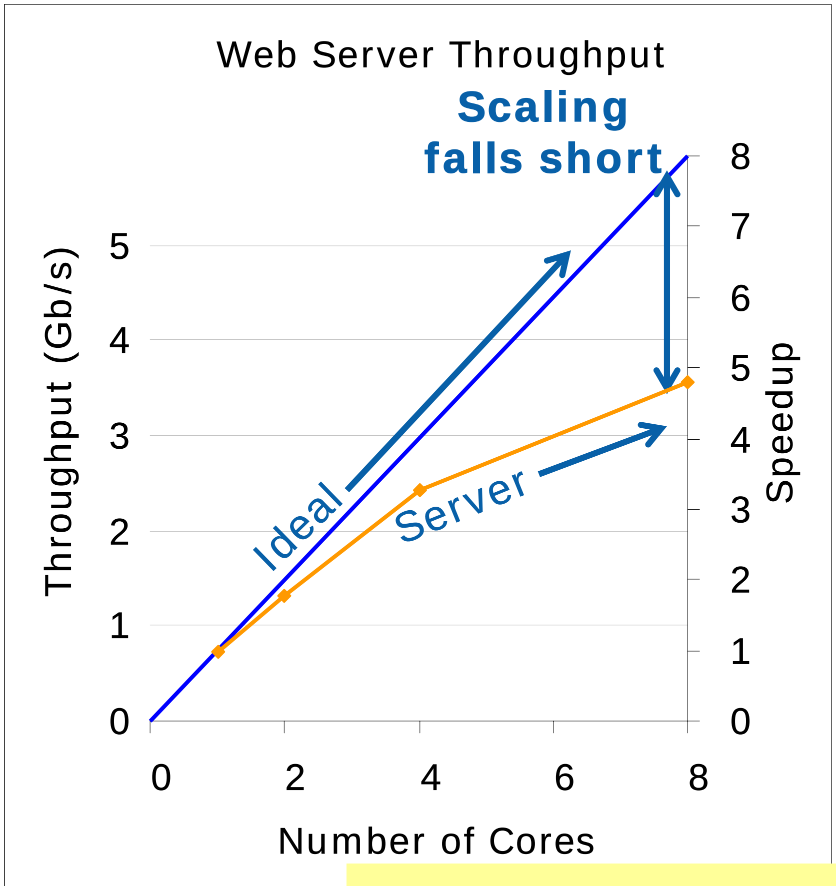


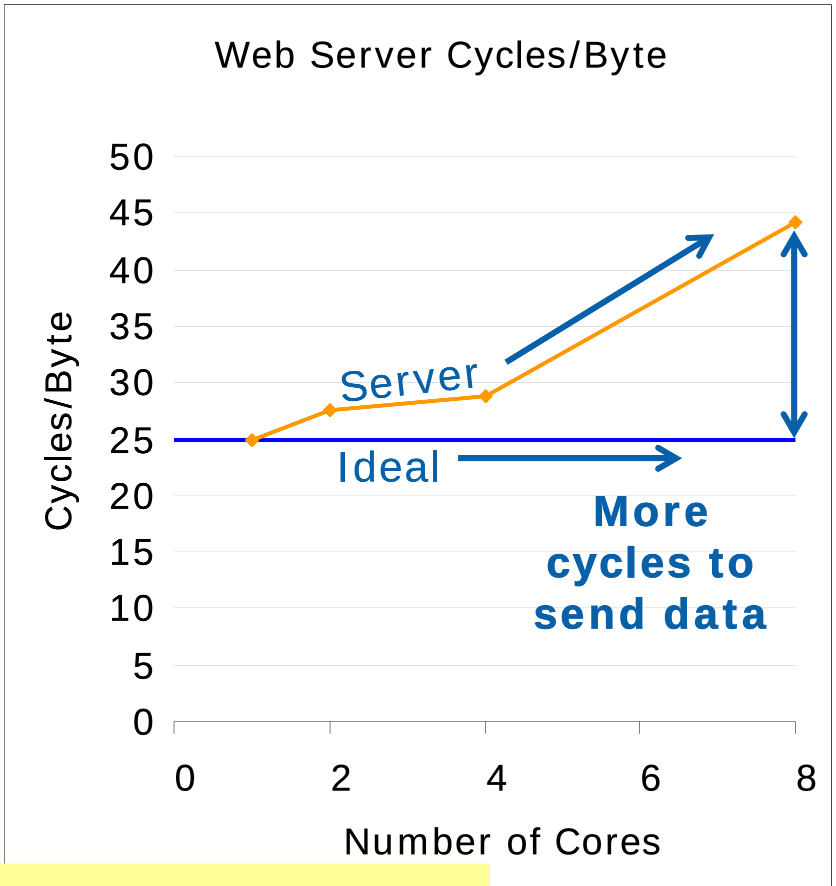
Determining Why Performance Scales Poorly

- Reproduced the published results on our own server
- Tested common causes of poor scaling

- System
  - 8-core Intel Xeon server
  - 4 1GbE NICs
- Software
  - Apache 2, Linux 2.6, PHP 5 Web Server
  - SPECweb2005 Support Workload
    - Highest throughput of 3 SPECweb2005 workloads
- Performance Metrics
  - Compare **throughput** when increasing from 1 to 8 cores
  - Compare **cycles executed per byte transmitted** when increasing from 1 to 8 cores

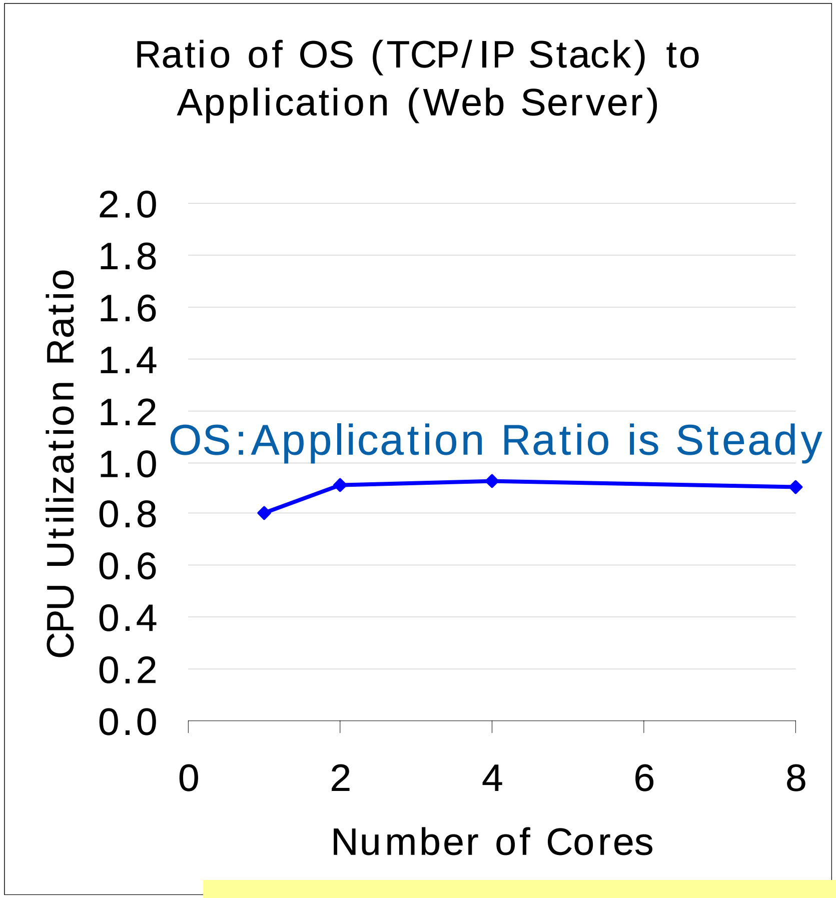
Our Performance Scaling Results

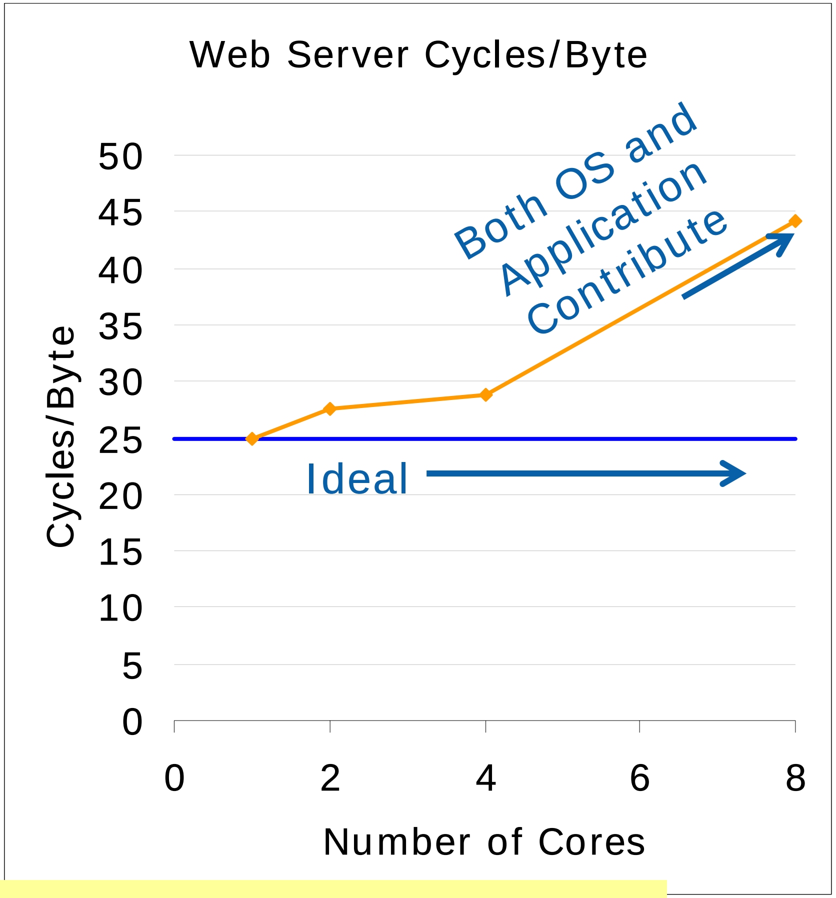




Like the published results, our server scales poorly.

Where Does Cycles per Byte Increase?



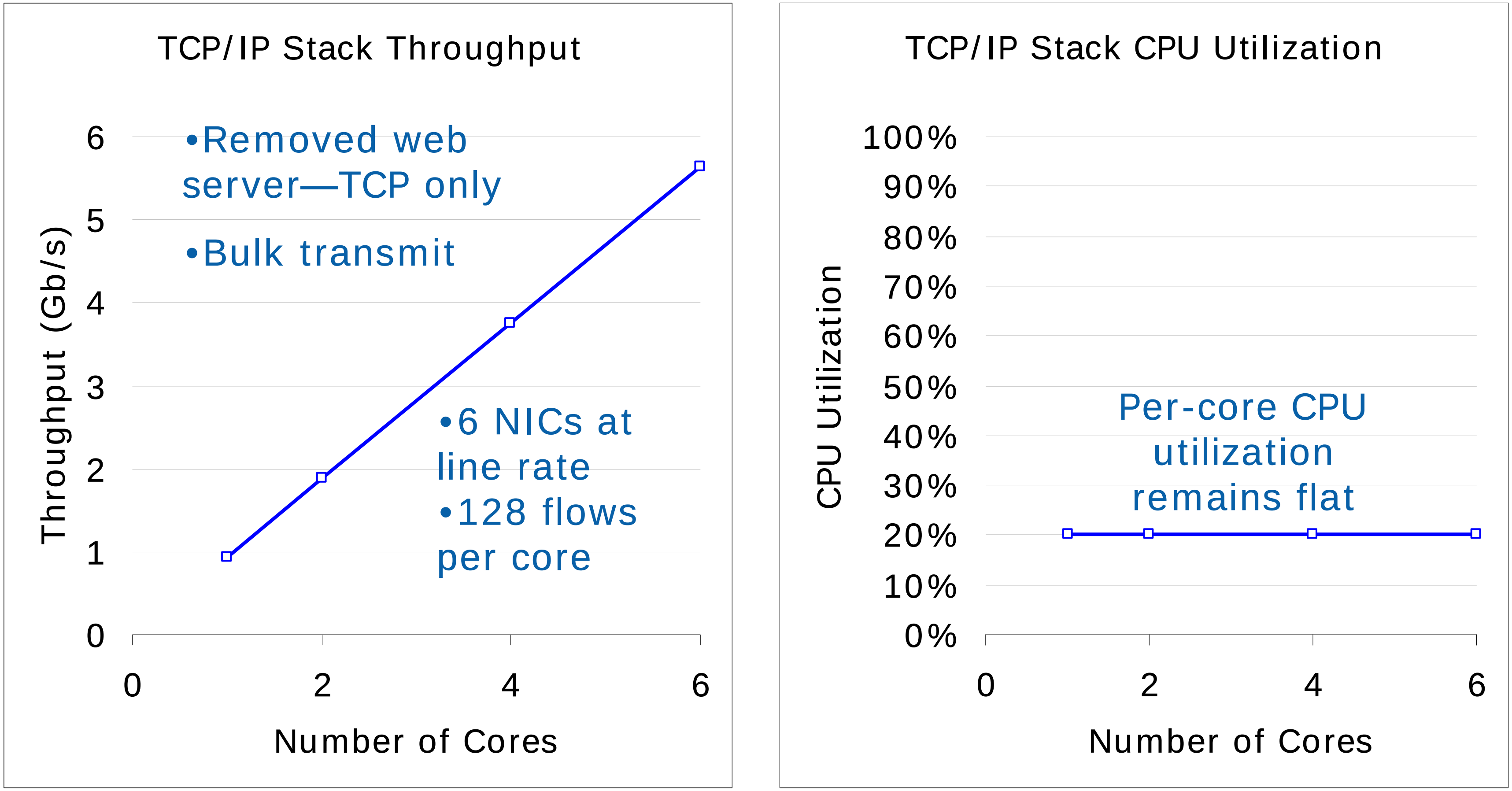


Either both OS and application are poorly parallelized or something else is affecting them both.

Possible Causes of Poor Scaling

- We investigated many other causes—details in paper
- Potential parallelism problems in software
  - Bad parallelism in the TCP/IP stack
  - Longer code path per flow
  - Stalls due to cache and TLB misses
- Potential scaling problems in hardware
  - Stalls due to system bus saturation

Scaling in the TCP/IP Stack



The TCP/IP stack is parallelized well.

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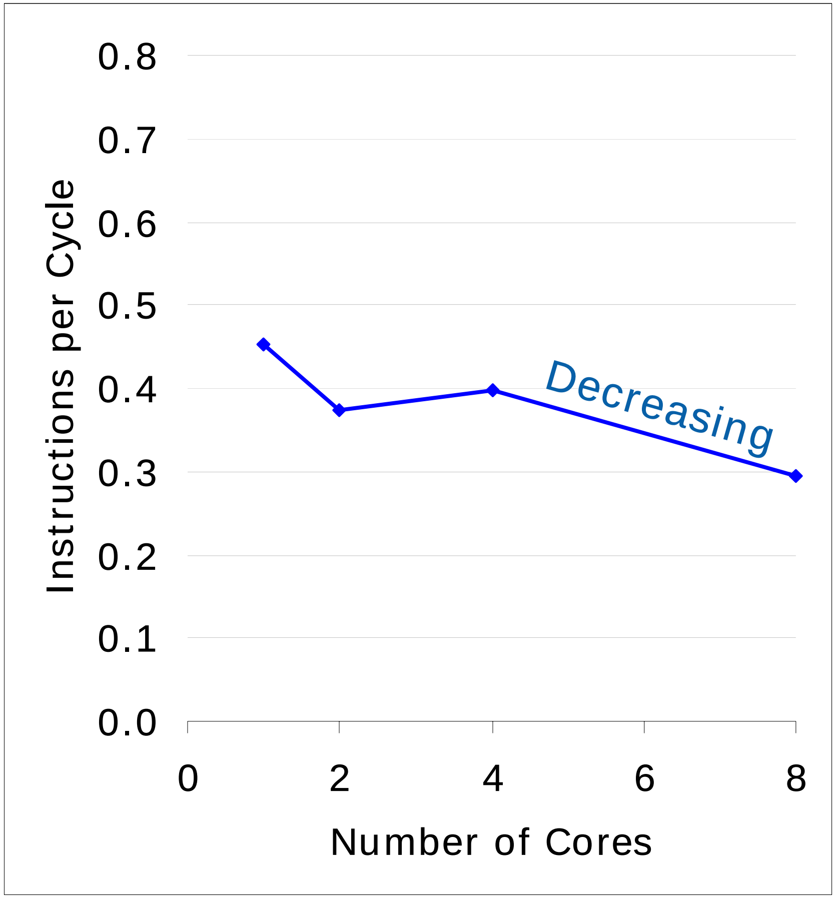
Code Path Scaling

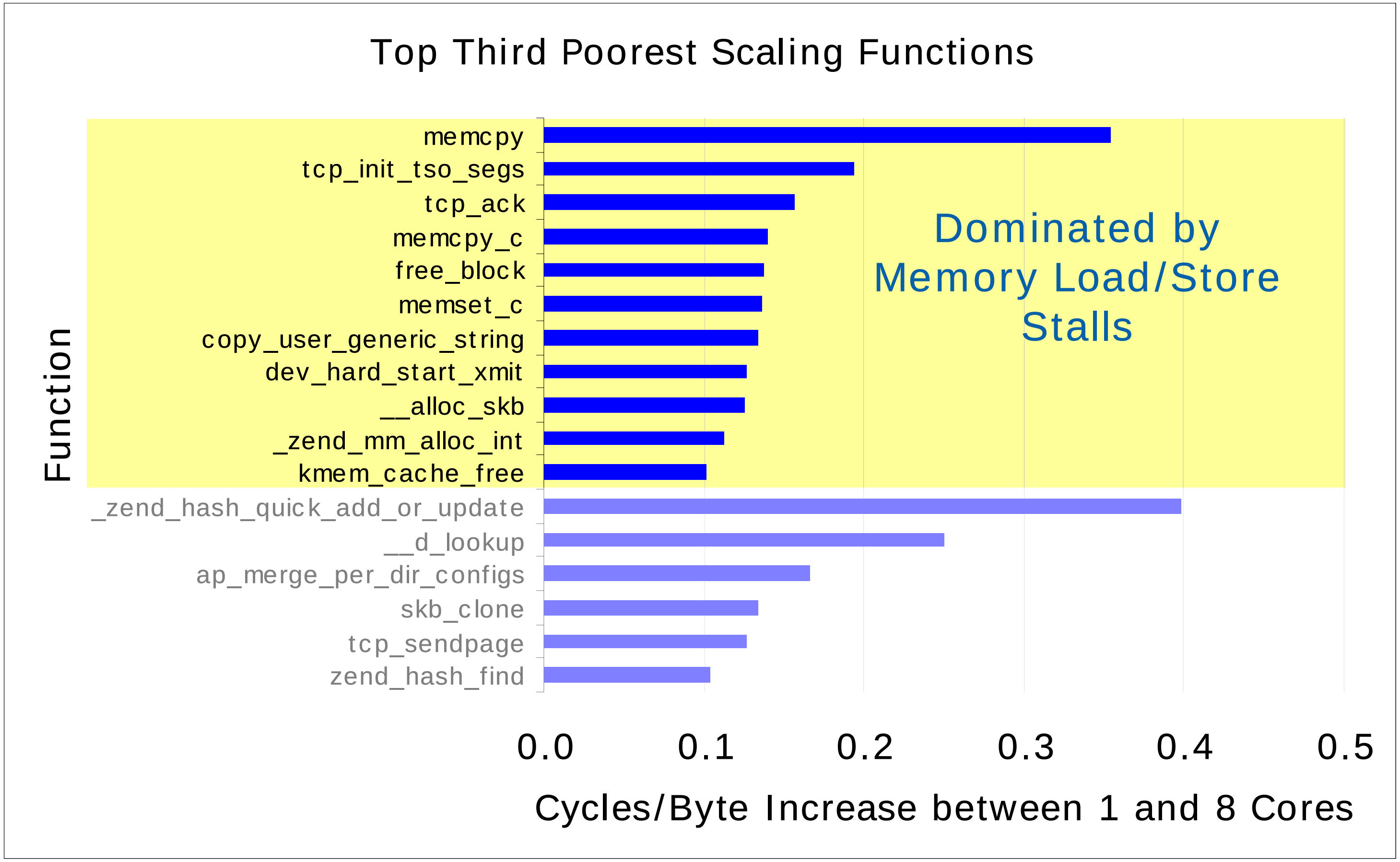
- Length of code path may increase with number of cores
- Examples
  - Waiting longer for spin locks
  - Traversing larger data structures
- Increases instructions per cycle (IPC)
- In fact, IPC is **decreasing**

Code path does not increase significantly.

Decreasing IPC suggests instruction pipeline stalls.



Finding Pipeline Stalls



Scaling is harmed the most by stalls for memory loads and stores.

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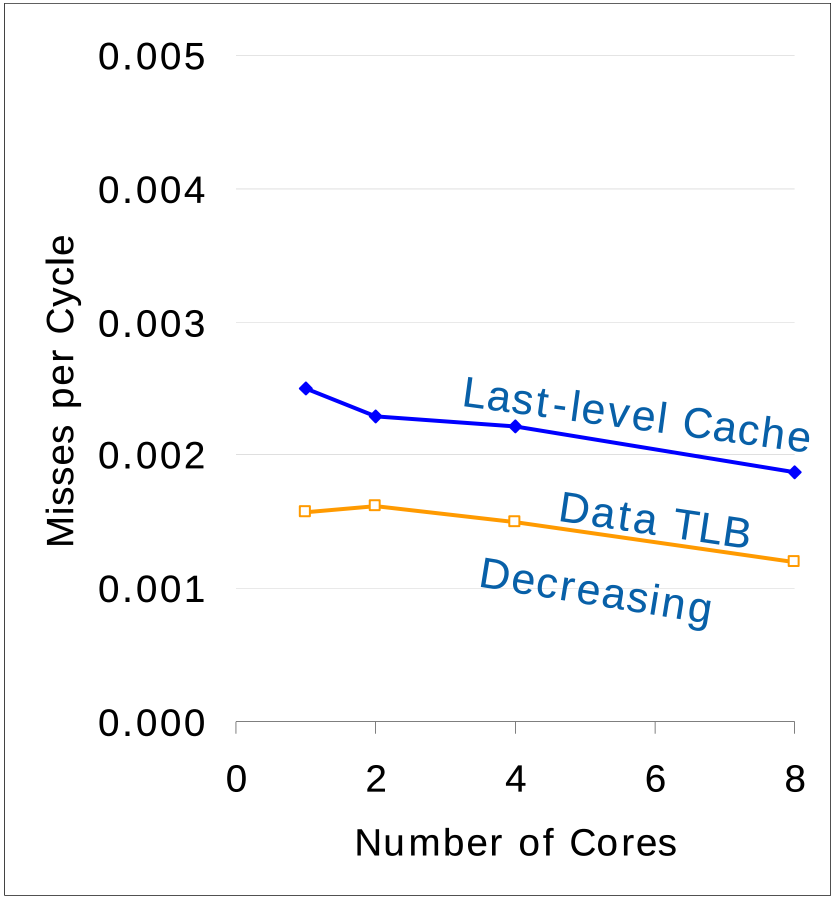
Stalls Caused by Cache and TLB Misses

- More cache and TLB misses can increase memory accesses
- Can be caused by increased data sharing between cores
- In fact, cache and TLB misses are **decreasing** per cycle

Cache and TLB misses do not cause memory load/store stalls.
Something else does.



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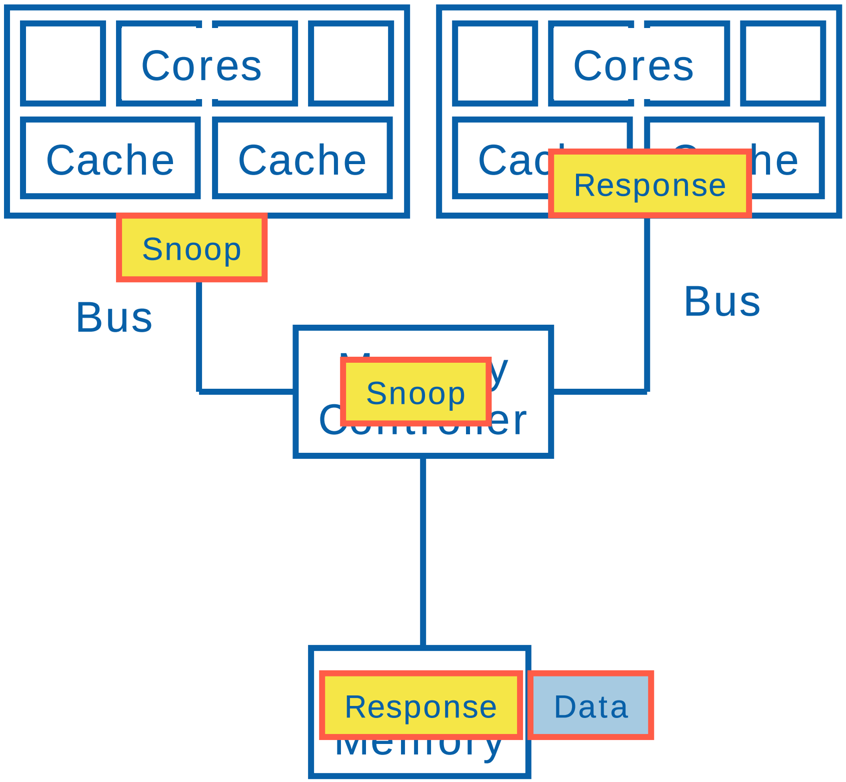
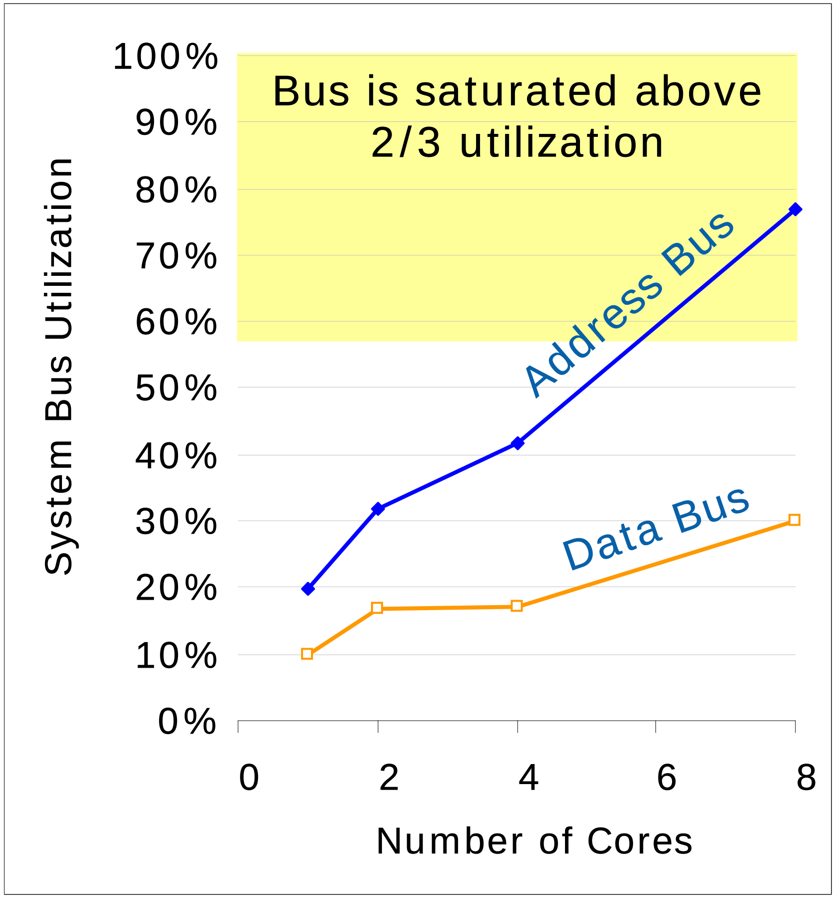
Possible Cause of Bus Saturation

- The system bus (front-side bus) has two main components
  - **Address Bus** carries requests and responses for data, called **snoops**
  - **Data Bus** carries the data itself
- Bus Transaction Example
  - A cache miss generates a snoop on the address bus
  - Snoop is **broadcast** to memory and **all remote caches** to find the most current data
  - Current copy of data is in memory
  - **All remote caches** and memory respond
- More caches mean **more sources and more destinations** for snoops
- **Snoops grow $O(n^2)$ with the number of caches!**



The Effect of Snoops on Scaling

- Snoops may increase bus utilization
- Bus utilization above 2/3 is considered **saturated**
- Data bus utilization increases, but is not saturated
- Confirms data sharing between cores is minimal
- **Address bus utilization increases faster**
- **Becomes saturated on 8 cores**
- **Address bus saturation causes of poor scaling!**



Insights

- Although web servers are highly parallelized and share little data…
- Systems are designed for shared memory applications
- **Snoops are broadcast regardless of good parallelism**

Conclusions

- Our web server scales poorly with the number of cores
- The OS and application exploit flow-level parallelism and scale well
- **Address bus saturation due to broadcast snoops causes poor scaling**

Reducing The Effect Broadcast Snoops

- More or faster links between processors (e.g. Intel QuickPath Interconnect, HyperTransport)
  - Because of $O(n^2)$ growth in broadcast snoops
  - Need $O(n^2)$ growth in number or speed of links to keep up
  - Not a scalable solution
- Introduce directories and directory caches
  - Replaces broadcast snooping entirely
  - But comes with more latency and cost
- There is no ideal solution yet—this is a current area of our research.

Thanks!

Questions?