Capriccio: Scalable Threads for Internet Services (by Behren, Condit, Zhou, Necula, Brewer)

Presented by

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Main Contribution

- Capriccio implements a scalable user-level thread package as an alternative to event-based and kernel-thread models.
- The authors demonstrate scalability to 100,000 threads and argue the model should be a more efficient alternative for Internet Server implementation

Key Features

- Scalability with user-level threads
  - Cooperative scheduling
  - Asynchronous disk I/O
  - Efficient thread operations - O(1)
- Linked stack management
- Resource-aware scheduling

Outline

- Related Work and “Debate”
- Capriccio Scalability
- Linked Stack Management
- Resource-Aware Scheduling
- Conclusion

Related Work

- Events vs. Threads (Ouserhout, Laura and Needham, Adya, SEDA)
- User-level thread packages (Filaments, NT Fibers, State Threads, Scheduler Activations)
- Kernel Threads (NTPL, Pthreads)
- Stack Management (Lazy Threads)

Debate – event-based side

- Event-based arguments by Ousterhout (Why threads are bad?, 1996)
  - Events are more efficient (context switching, locking overheads with threads)
  - Threads - hard to program (deadlocks, synchronization)
  - Poor thread support (portability, debugging)
- Many event-based implementation (Harvest, Flash, SEDA)

Debate – other arguments

- Neutral argument by Lauer and Needham (On the duality of OS system structures, 1978)
- Pro-thread arguments by Behren, Condit, Brewer (Why events are bad?, 2003)
  - Greater code readability
  - No “stack-ripping”
  - Slow thread performance - implementation artifact
  - High performance servers more sensitive to scheduling

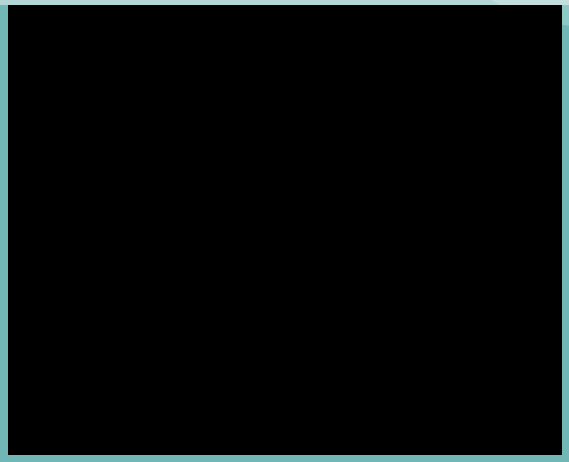
Why user-level threads?

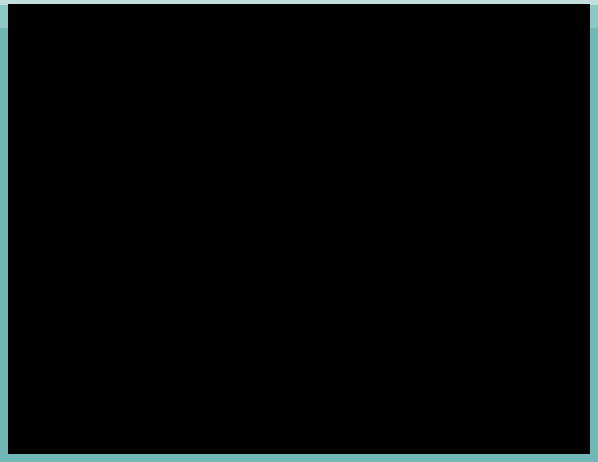
- Decoupling from the OS/kernel
  - OS independence
  - Kernel variation
  - Address application-specific needs
- Cooperative threading – more efficient synchronization
- Less “kernel crossing”
- Better memory management

Implementation

- Non-blocking wrappers for blocking I/O
- Asynchronous disk I/O where possible
- Cheap synchronization
- Efficient O(1) thread operations

Benchmarks





- (left) Capriccio scales to 100,000 threads
- (right) Network I/O throughput with Capriccio only has 10% overhead over epoll
- With asynchronous I/O disk performance is comparable in Capriccio vs. other thread packages

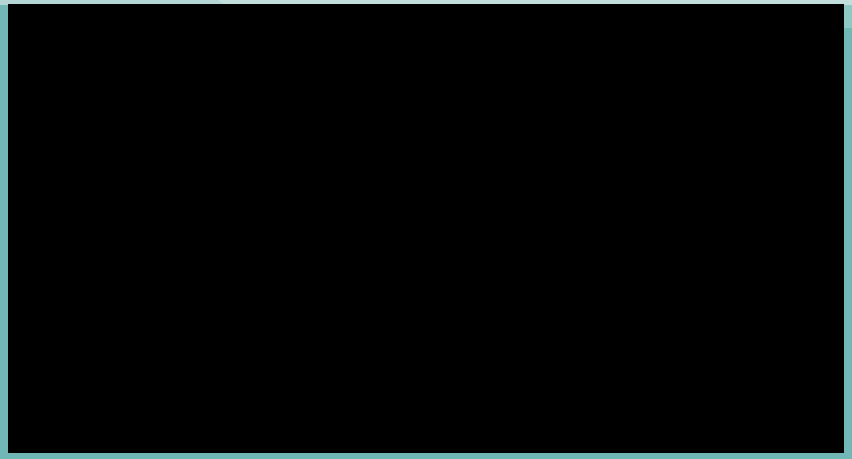
Disadvantages of user-level threads

- Non-blocking wrappers of blocking I/O increase kernel crossings
- Difficult to integrate with multiple processor scheduling

Dynamic Linked Stacks

- Problem: Conservative stack allocations per thread are unsuitable for programs with many threads.
- Solution: Dynamic stack allocation with linked chunks alleviates VM pressure and improves paging behavior.
- Method: Compile-time analysis and checkpoint injection into the code.

Weighted Call Graph



- Each node is a call site annotated with the maximum stack space for that call.
- Checkpoints must be inserted at each recursive frame and well-spaced call sites.
- Checkpoints determine whether to allocate a new stack chunk.

Challenging cases

- Function pointers are only determined at run-time.
- External function calls require conservative stack allocation.

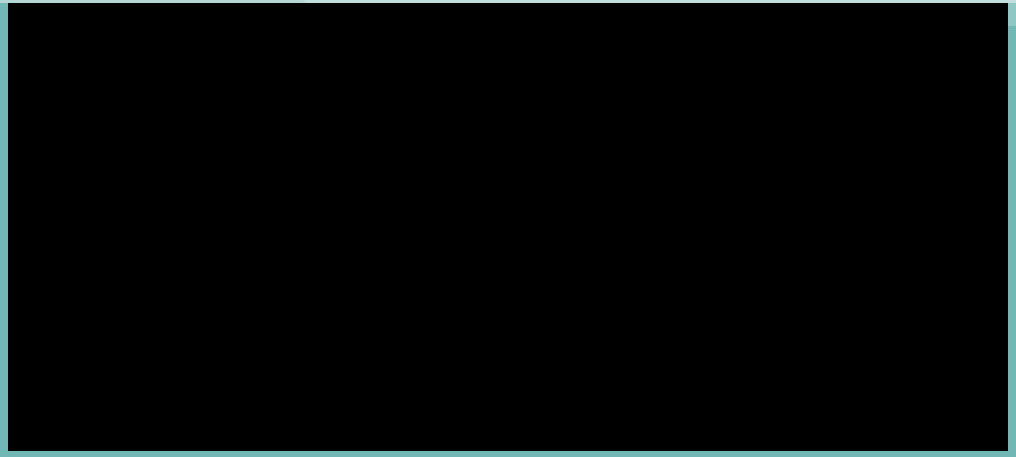
Apache 2.0.44 Benchmark

- Given 2 KB “max-path” only 10.6% call sites required check-pointing code.
- Overhead in the number of instructions was 3-4%.

Resource-Aware Scheduling

- Key idea: View an application as a sequence of stages separated by blocking points.
- Method: Track resources (CPU, memory, file descriptors) used at each stage and schedule threads according to resources.

Blocking Graph

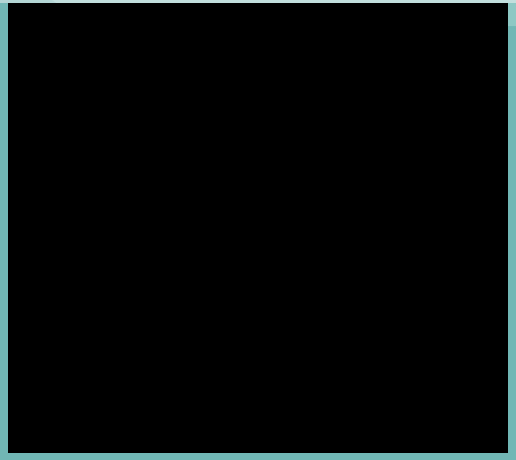


- Tracking CPU cycles and other resource usage at each edge and node.
- Threads are scheduled so that for each resource, utilization is increased until maximum throughput and then throttled back.

Pitfalls

- Maximum capacity of a particular resource is difficult to determine (e.g: internal memory pools)
- Thrashing is not easily detectable.
- Non-yielding threads lead to unfairness and starvation in cooperative scheduling.
- Blocking graphs are expensive to maintain (for Apache 2.0.44 stack trace overhead is 8% of execution time).

Web Server Performance



- Apache 2.0.44 on a 4x500 MHz Pentium server has 15%higher throughput with Capriccio.

Conclusion

- Capriccio demonstrates a user-level thread package that achieves
  - High scalability
  - Efficient stack management
  - Scheduling based on resource usage
- Drawbacks
  - Performance not comparable to event-based systems
  - High overhead in stack tracing
  - Lack of sufficient multi-processor support

Future Work

- Extending Capriccio to work with multiple processors
- Reducing the kernel crossings with batching asynchronous network I/O
- Disambiguate function pointers in stack allocation
- Improving resource-aware scheduling
  - Tracking variance in resource usage
  - Better detection of thrashing