Parallel & Concurrent Programming:

Server Architectures

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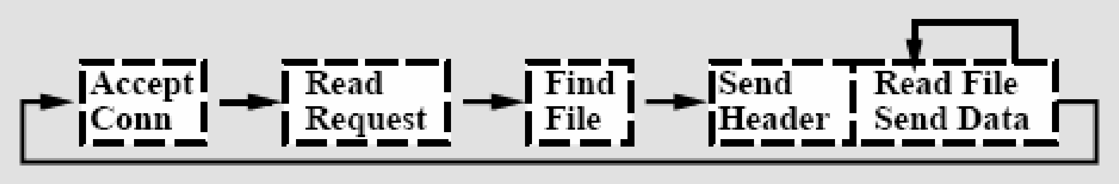
Outline

- Last time:
  - Lock "improvements"
  - **Non-blocking** operations
  - **`java.nio`** library
- Today:
  - Server **architectures**
    - Focus: web servers
    - Performance & ease of programming

Web Servers

- Client (IE, Mozilla) requests **`http://foo.com/bar.html`**
- In response, web server
  - **Accepts** network connection
    - Persistent in http/1.1
  - **Reads** request (**`bar.html`**)
  - **Reads** requested file or execute CGI
  - **Sends** header and file / output

Example: Single-Thread



- **Single-threaded server:**
  - One process handles all web connections, step by step
- **Advantages:**
  - Easy! 1 thread = no race conditions, etc.
- **Disadvantages:**
  - *Only one client at a time*
  - Unacceptably simple

Figures from *Flash* [Pai et al., USENIX 99]

Web Server Goals

- Performance goals:
  - Support as many simultaneous clients as possible
    - High concurrency
    - Low memory consumption per client
  - Provide **high throughput, low response time (*latency*)**
- Software engineering goals:
  - Simple to *understand*, *extend*, *employ desired optimizations & features*, and *debug*

Optimizations & Features

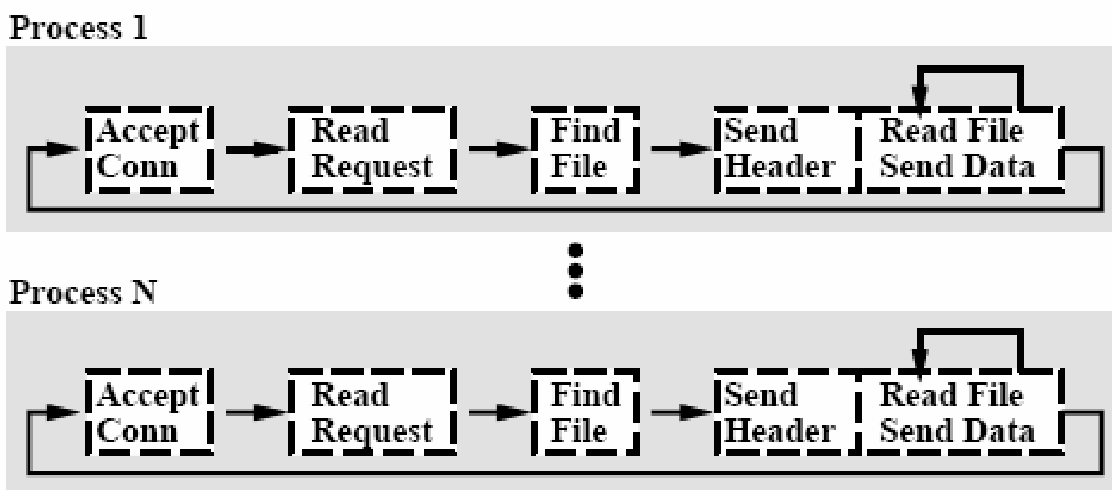
- Optimizations: **caching**
  - Pathname translations
  - Results of script executions
    - Turns dynamic pages into static pages
  - File reads
    - Avoids disk I/O, expensive systems calls: **`stat()`**
- Features: **logging**, **statistics gathering, access control**…

- *Lots of centralized data structures*

Server Architectures

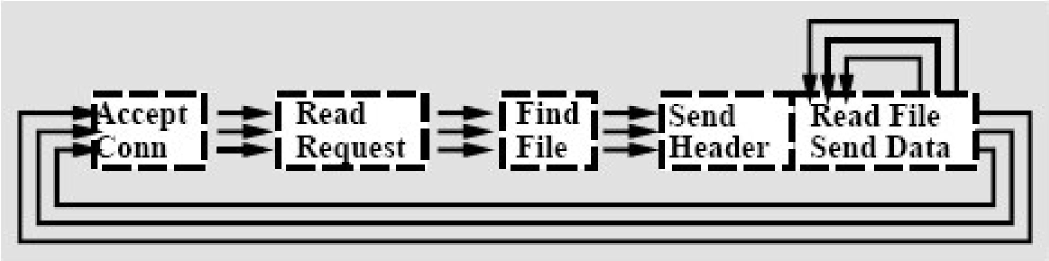
- **MP/MT**
  - Multiprocess/multithreaded (Apache)
- **SPED**
  - Single-process event-driven (thttpd, Zeus)
- **AMPED**
  - asymmetric multiprocess event-driven (Flash)

Multiprocess Architecture



- **Advantages:**
  - Takes advantage of multiple processors
  - Debugging, etc.?
- **Disadvantages:**
  - IPC (maintain caches, logs)
  - Memory cost, limited # clients, context switches

Multithreaded



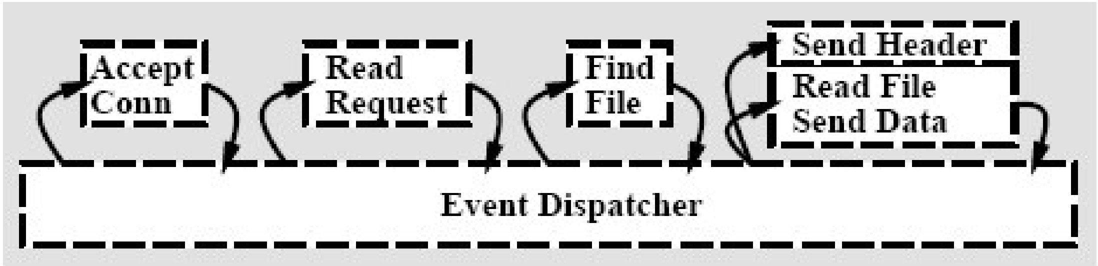
- **Advantages**
  - Takes advantage of multiple processors
  - Extensibility
- **Disadvantages**
  - Synch, races
  - Memory cost (kernel vs. user-level)
  - Startup cost? Context switches?
  - **Blocking I/O**

Blocking I/O

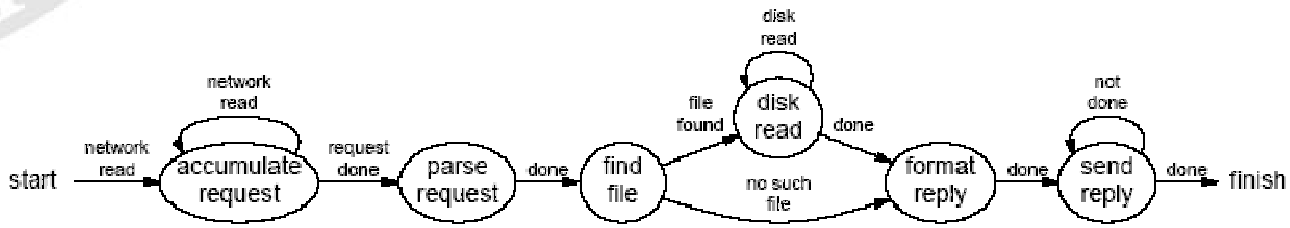
- Can specify "non-blocking" for some I/O calls, but:
  - Non-blocking supported for network I/O, but generally not disk operations
- POSIX standard **AIO**: **A**synchronous **I/O**
  - Supports only reads & writes, not **`open()`** or **`stat()`**

⇨ **Must work around blocking I/O**

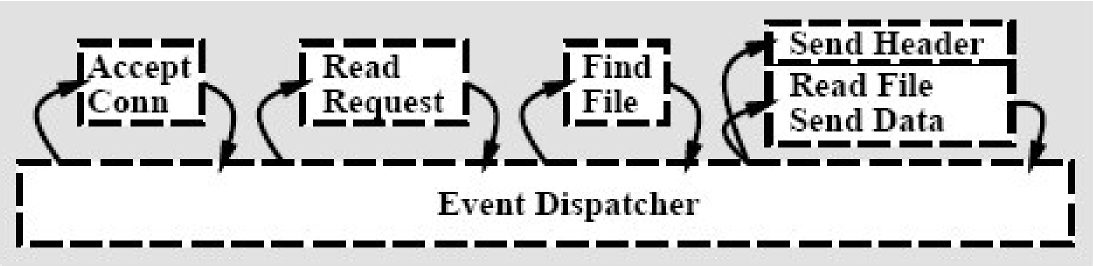
SPED



- Single-process event-driven
  - Uses **`select()`** to check for ready file descriptors
  - Processes ready items, moves to next “stage”
    - One **finite state machine** per client

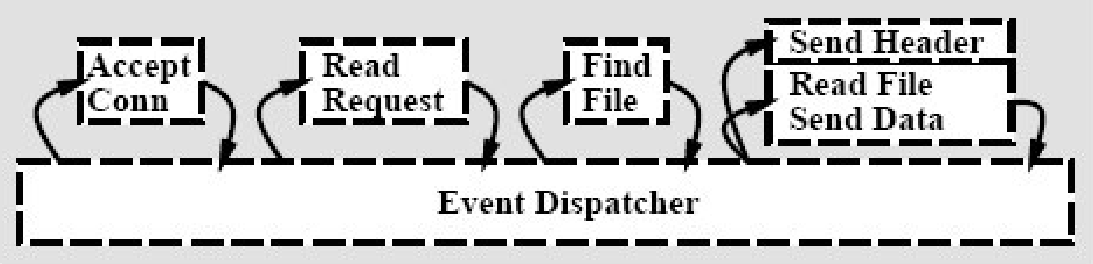


SPED Example (thttpd)



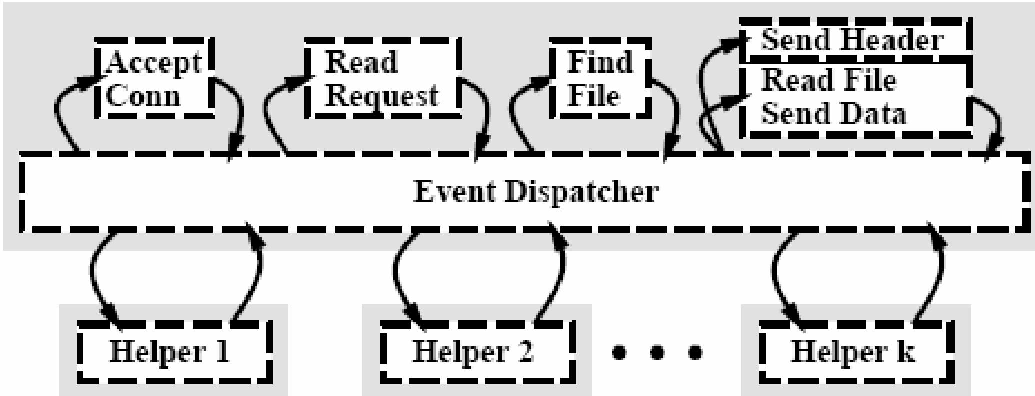
- Loop until shut down:
  - Accept new connections
  - For each ready file descriptor, switch (status):
    - READ_MODE - handle read
    - SEND_MODE - handle send
    - WRITE_MODE - handle write

SPED Pros & Cons



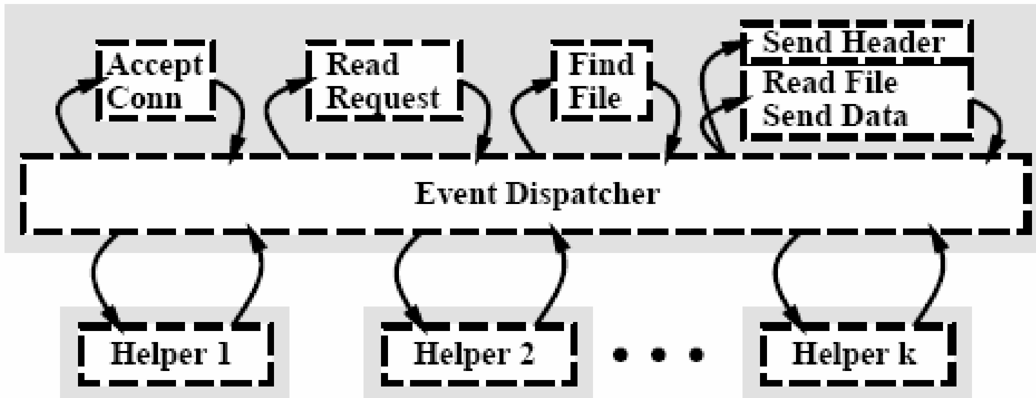
- **Advantages:**
  - No context switches, synchronization, IPC, etc.
  - Low memory overhead
- **Disadvantages:**
  - Multiple processors?
  - Blocking I/O?
  - Programming complexity…

AMPED



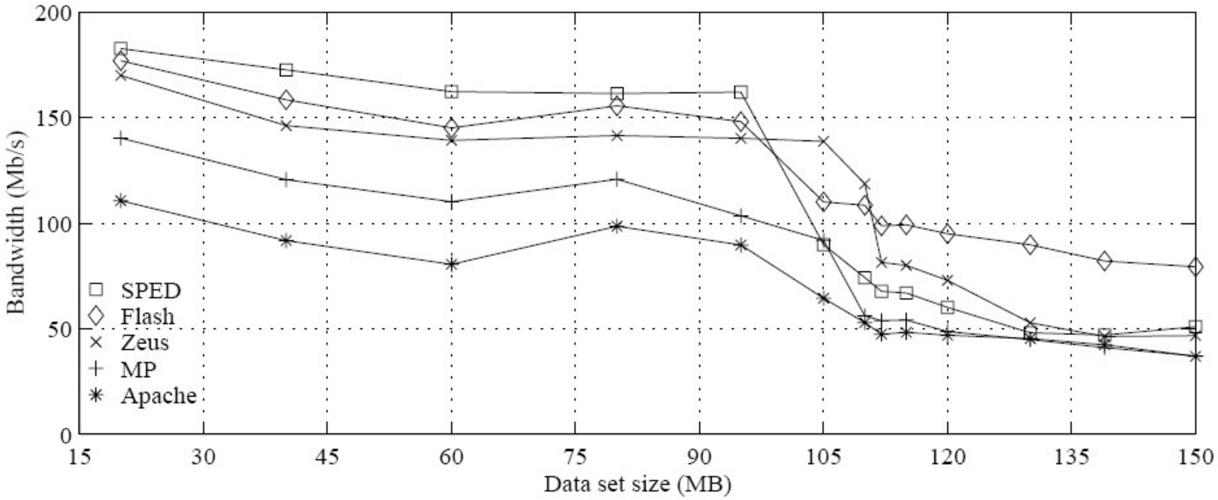
- **A**symmetric **M**ulti**P**rocess **E**vent-**D**riven
  - Like SPED, but with **helper processes** for blocking I/O
    - e.g., one or two per disk, more for multi-arm disks

AMPED Pros & Cons



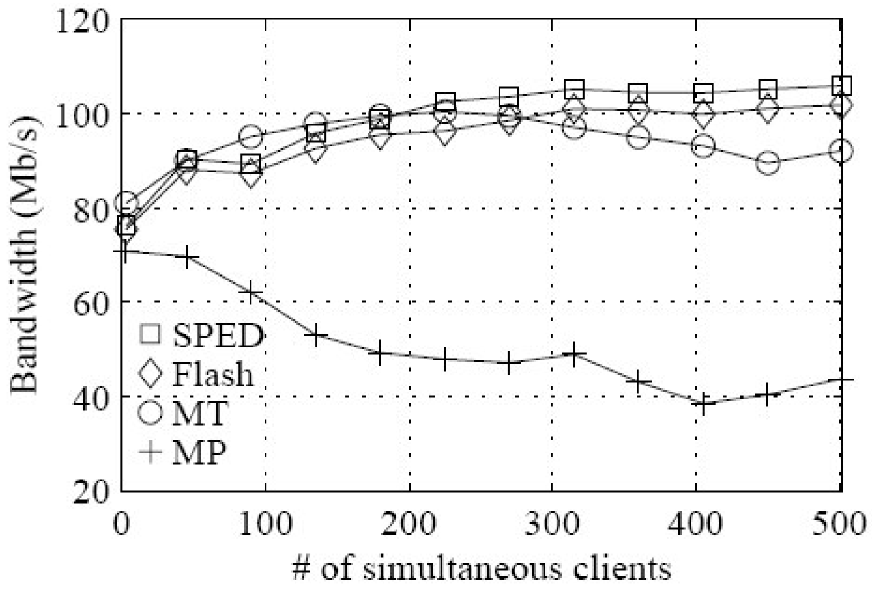
- **Advantages:**
  - Same as event-driven, but no blocking
    - No context switches, synchronization, IPC, etc.
    - Low memory overhead
- **Disadvantages:**
  - Multiple processors?

Throughput versus "Size"



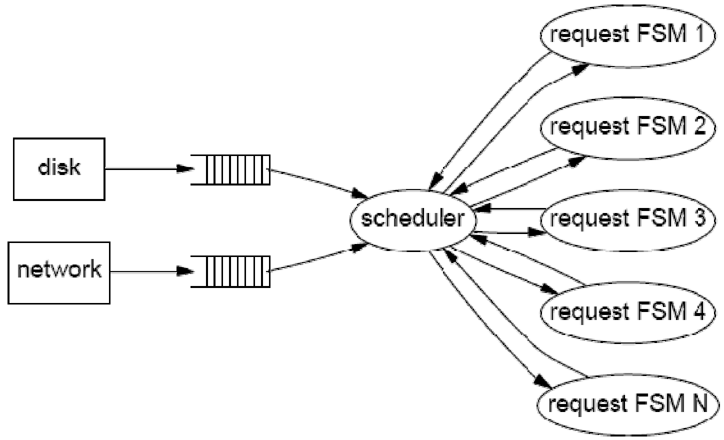
- 96MB = available RAM for *buffer cache*
  - In RAM: SPED wins
  - On disk: blocking I/O dominates

Throughput vs. # Clients



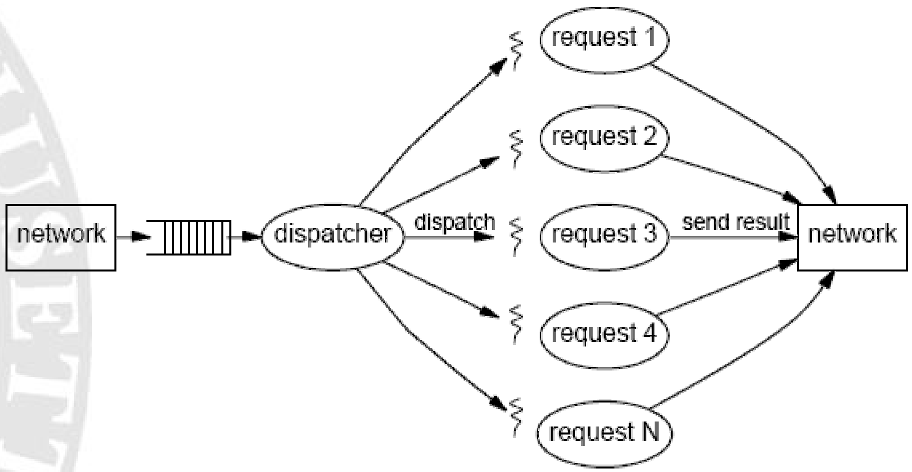
- WAN conditions
  - Why does MP do so badly?
- **Note: all experiments on uniprocessor**

Problems with Events



- Do not take advantage of multiple processors
- Long-running handler = high latency
- *Events obscure control flow*
  - No state across request handlers
  - Break code into "call" event and "return" event
    - *continuation-passing style*
  - **Hard to write, understand & debug**

Problems with Threads

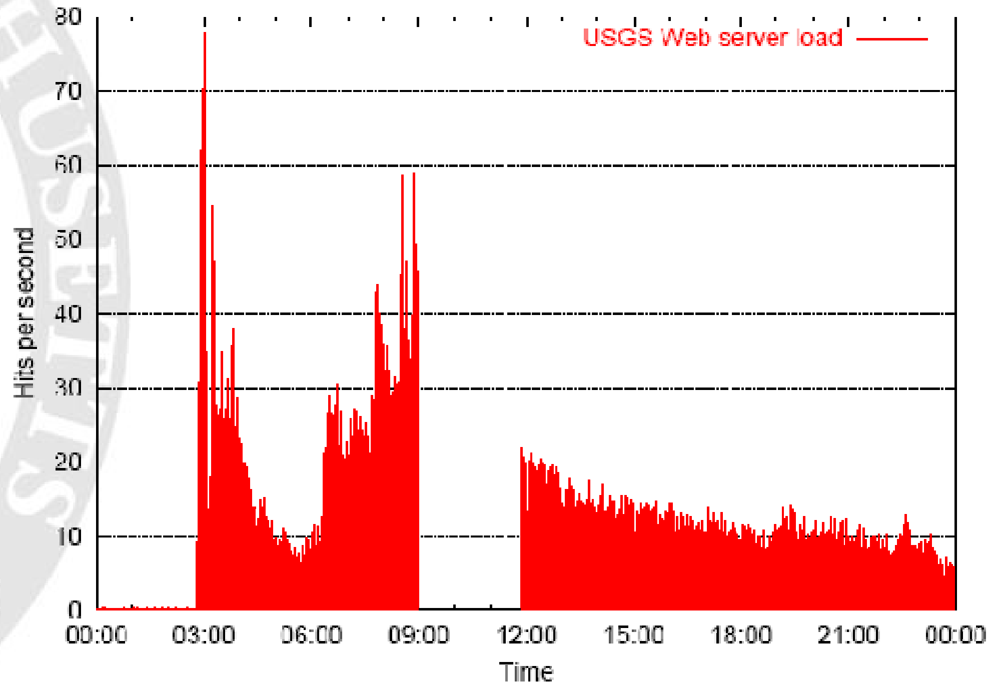


- Synchronization overhead & complexity, deadlock
- Race conditions difficult to debug
  - Timing dependencies result in **Heisenbugs**
- Priority inversion

SEDA

- Hybrid approach: mixes thread pools with events
- **S**taged **E**vent-**D**riven **A**rchitecture
  - Event-driven stages separated by queues
  - Thread pools per stage
  - Provides **load conditioning:** degrades service gracefully
    - **Admission control**
    - **Load shedding**

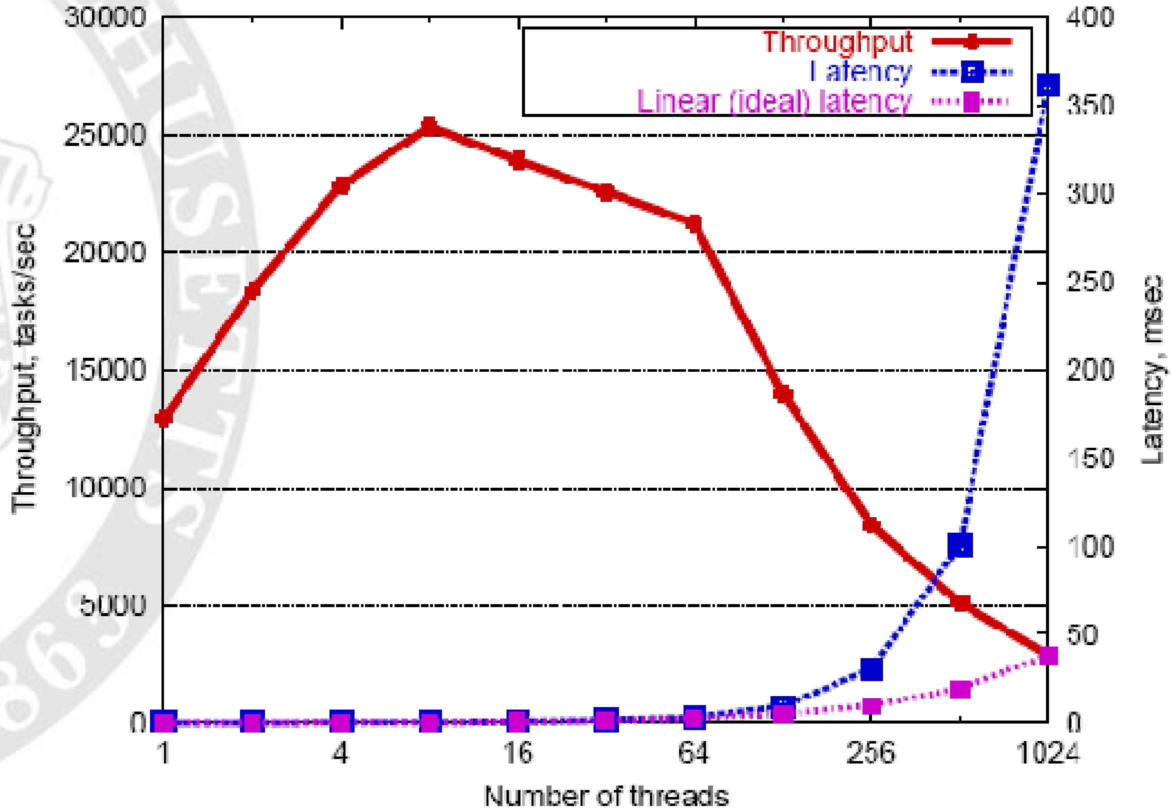
Bursty Load



- Web server logs for USGS site after 1999 earthquake
- 3 orders of magnitude increase
  - a.k.a. “Slashdotting”

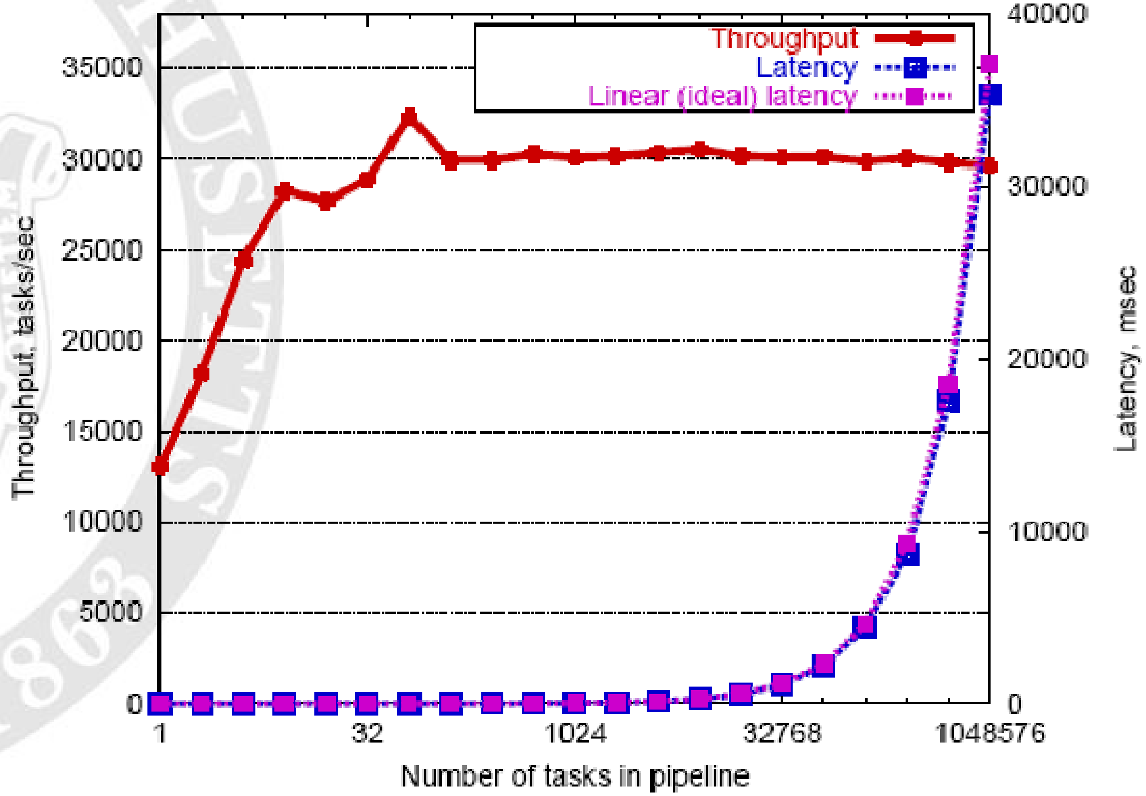
Figures from *SEDA* [Welsh et al.,SOSP 01]

Effect of Load



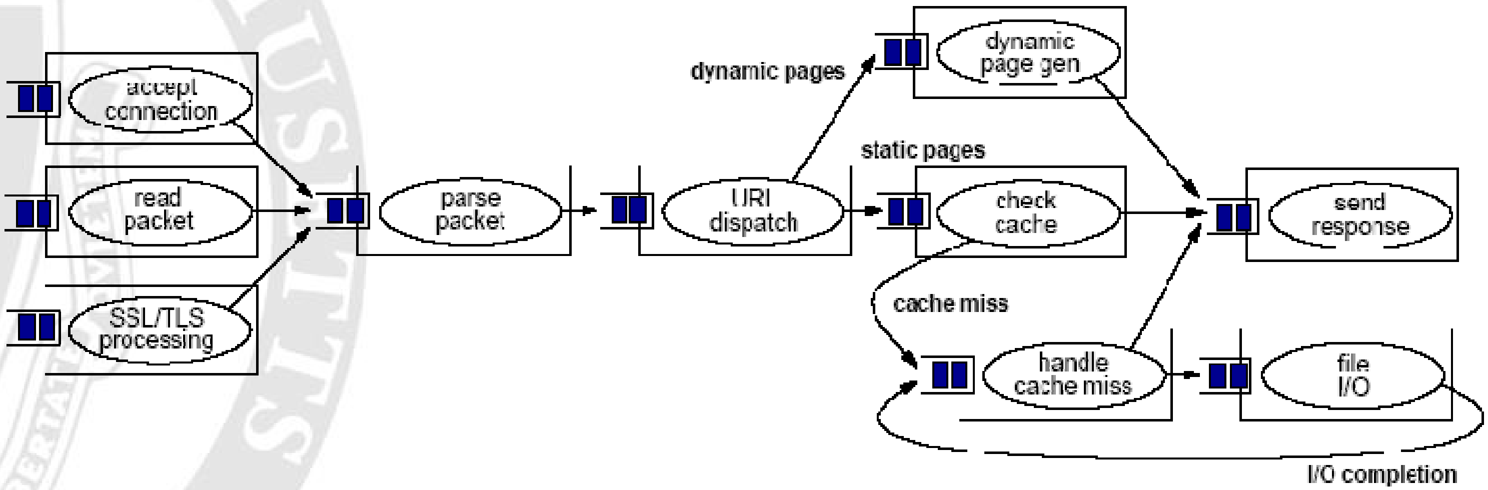
- Simulated on thread-pool server
  - What happened?

Effect of Load



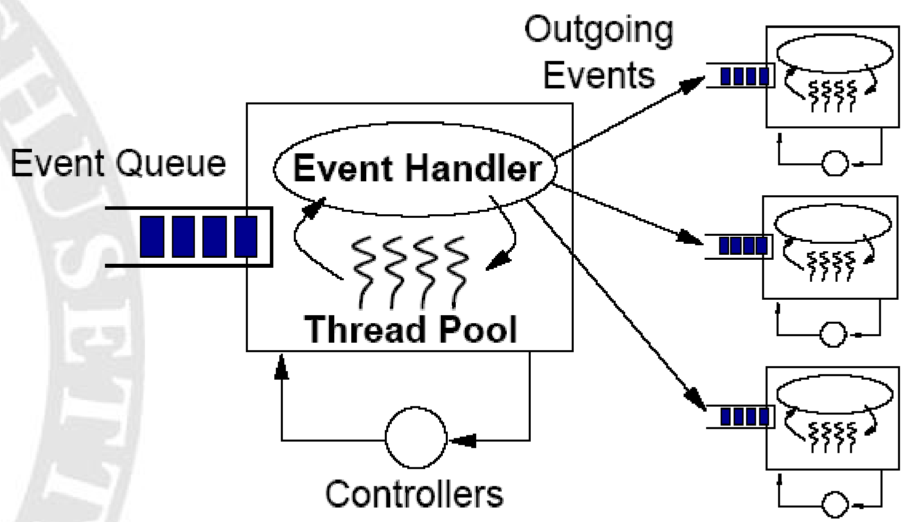
- Event-driven server (all in RAM)

SEDA approach



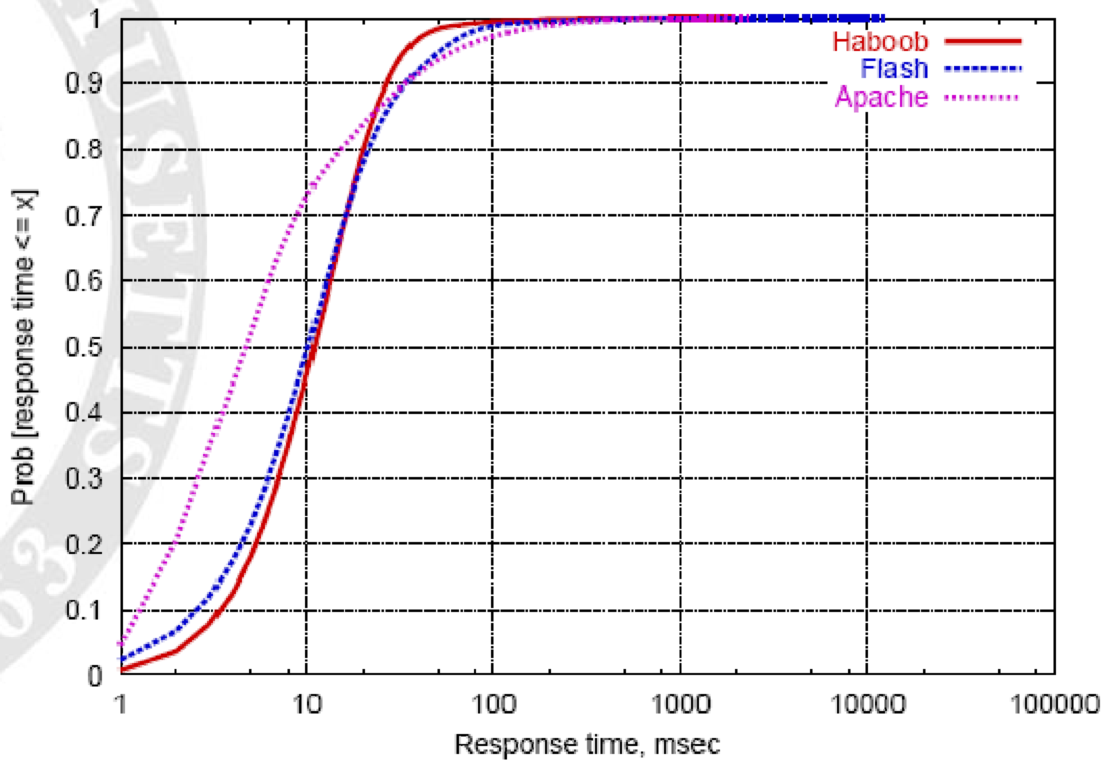
- Events organized into **stages**
  - Connect output of one stage to input of next

SEDA stages



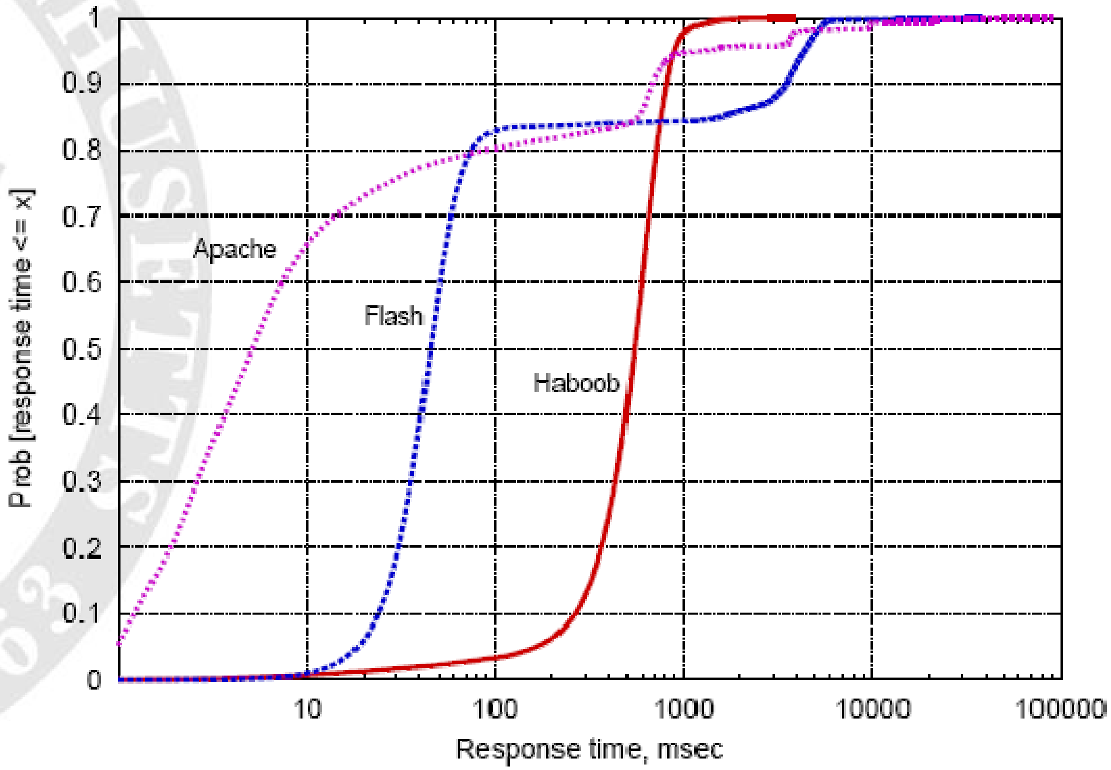
- Each stage: **thread pool** processes **batches** of events
  - Amortizes ops, locality
- Can perform admissions control on own queue
  - Shed load, etc.
- **Controller:**
  - Adjusts resource allocations & scheduling
  - E.g., reduces # threads in pool when thruput degrades

Load & Response Time



- 64 clients
- Nearly identical response time curve

Load & Response Time



- 1024 clients
- Note the **heavy tail** (minutes!)

The End

- But isn't it still painful to write event-driven code?
- Next time: alternatives
  - Capriccio, Flux