CSC2231: Making clusters faster

http://www.cs.toronto.edu/~stefan/courses/csc2231/05au

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Administrivia

- **Next lecture: failures**
  - There are two papers assigned for reading
    - Oppenheimer's study on causes of failures for Internet clusters
    - Intel Pittsburgh's paper on failures on the wide-area
    - Read both!!!
    - Submit review for first paper only (Oppenheimer)

How to optimize performance

How to optimize performance

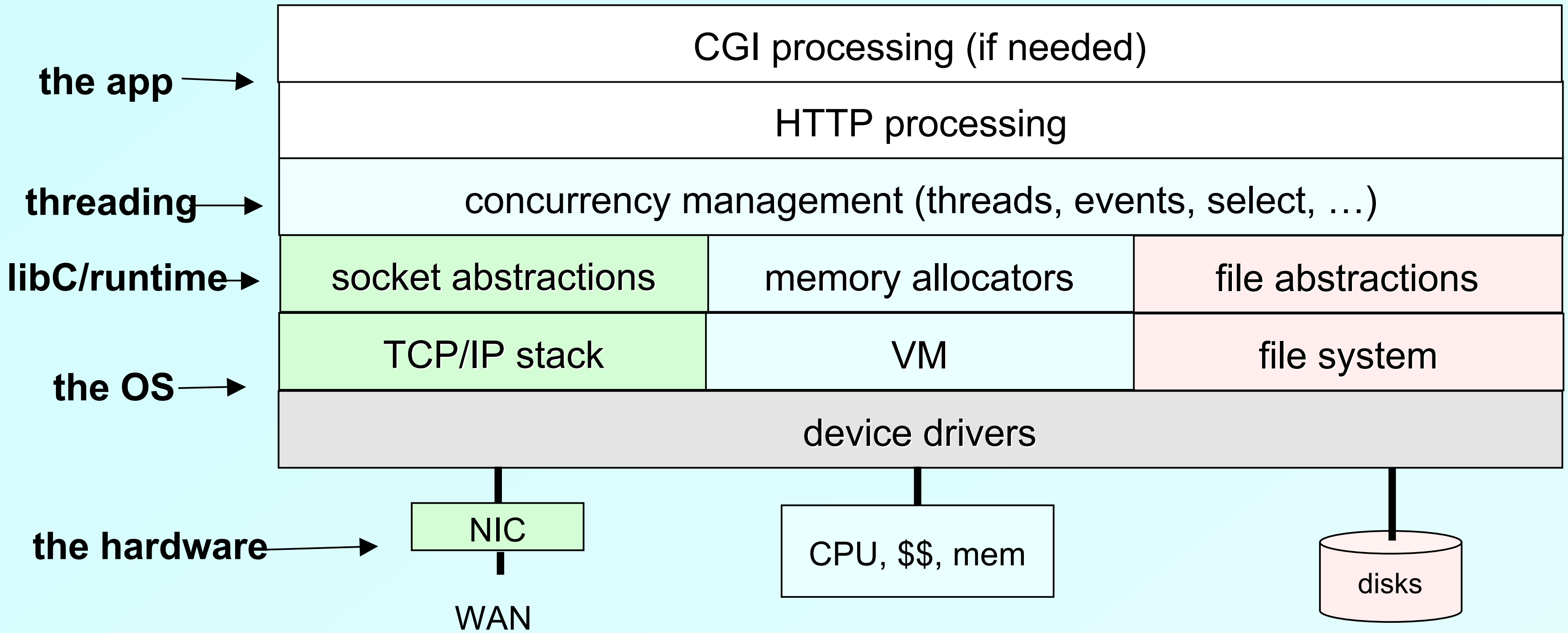
- **Step 1: Find bottleneck in the system**

- **Step 2: Widen the bottleneck**

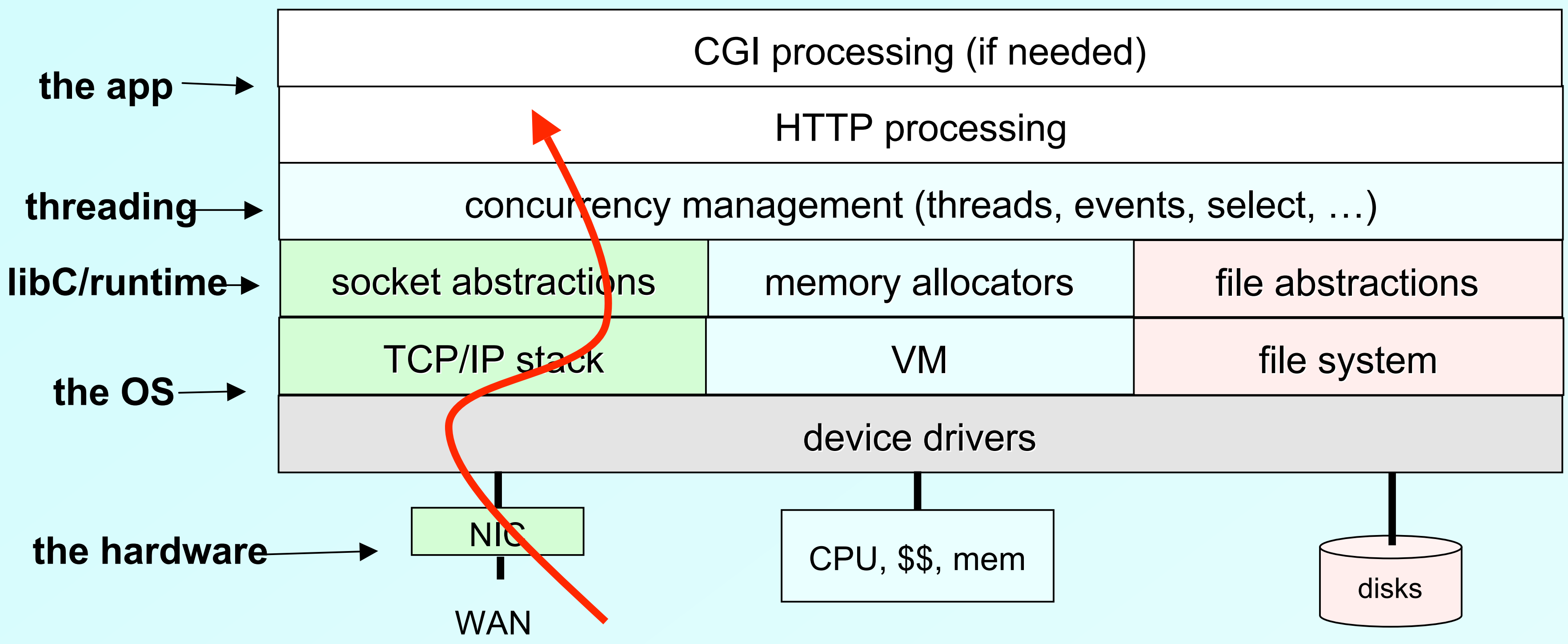
How to optimize performance

- **Step 1: Find bottleneck in the system**
  - May be tough to find in complex/parallel systems
  - May depend on the workload
    - Scale, concurrency, popularity distribution
  - May change over time
    - Hardware trends, workload trends
- **Step 2: Widen the bottleneck**
  - Add more resources
  - Optimize current resource consumption

Single machine Web server



Single machine Web server



Packet processing path

- **1400 byte packet arrival costs on 1.7 GHz P4/Linux**
  - Device driver: 12us
  - TCP stack: 10us
  - User/kernel crossing: 1us
  - Extra copies: 0.3us
- **Max throughput:**
  - 550Mbps or roughly 10K web requests/sec
  - Upper bound (CPU is 100% utilized, nothing left for apps)
- **Probably not the bottleneck for Web servers**

Packet processing

- **Per-byte overhead:**
  - Cost scales with packet size
    - DMA between NIC/host
    - Memory copies (kernel/user space)
    - Data manipulation (checksums)
  - Solutions? Zero-copy networking, user-level networking, smart NICs
- **Per-packet overhead:**
  - Cost scaled with number of packets
    - Buffer allocation
    - Interrupt processing overhead
    - Data structure manipulation
  - Solutions? Optimize network stacks, OS architecture

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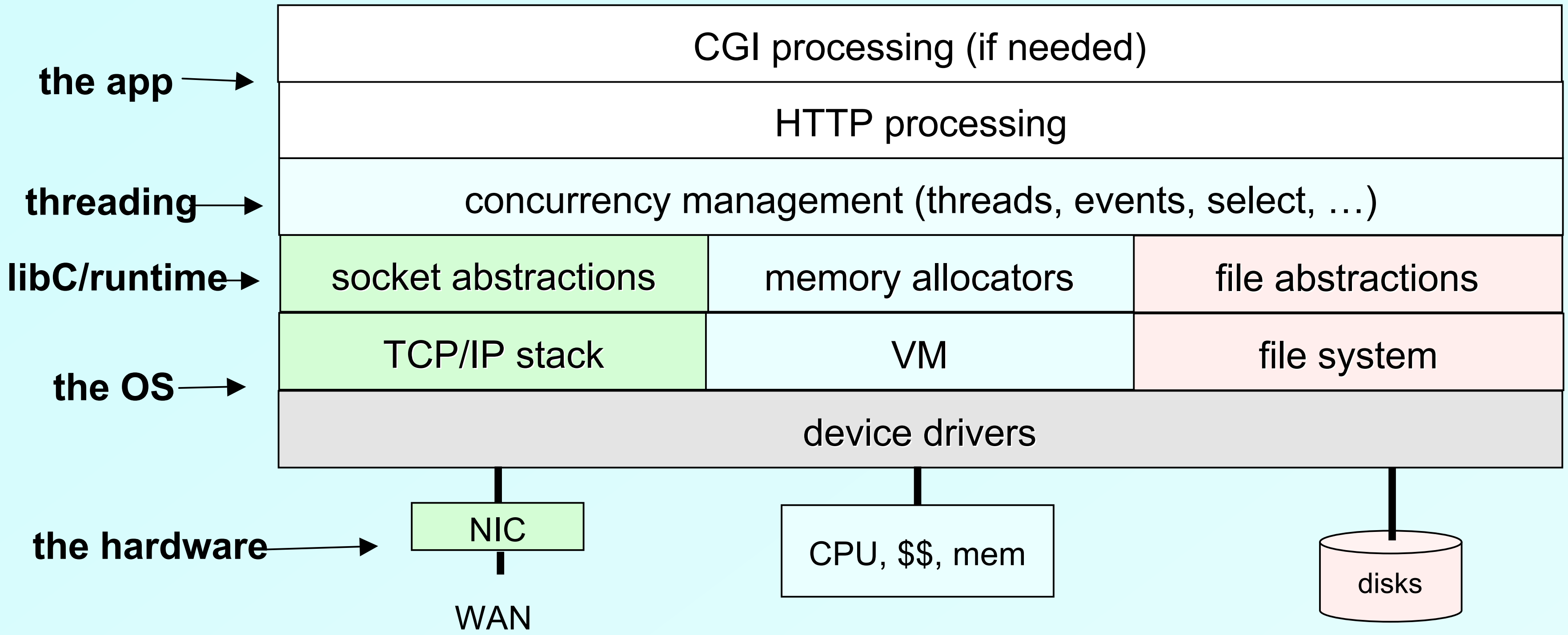

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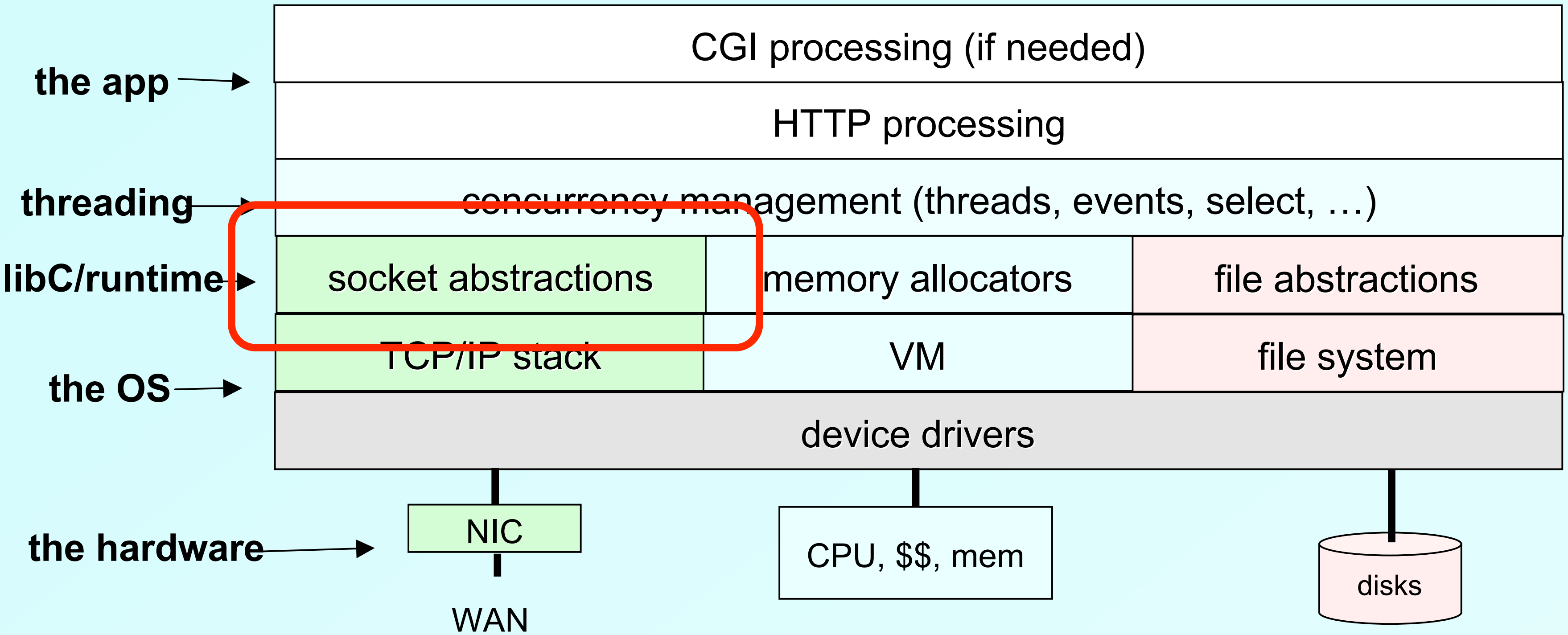

Socket abstractions

- **Pitfall: benchmarking on a LAN rather than WAN**
  - # of concurrent connections = f(latency, Xput)
  - State size is proportional to # of concurrent connections
- **Scaling to large number of concurrent connections**
  - initial select() was broken for long-lived connections
- **Handling long-lived, large transfers**
  - Provision socket buffers correctly
    - Only matters for high throughput connections
  - Any issues related to exceeding the 32bit TCP number space?

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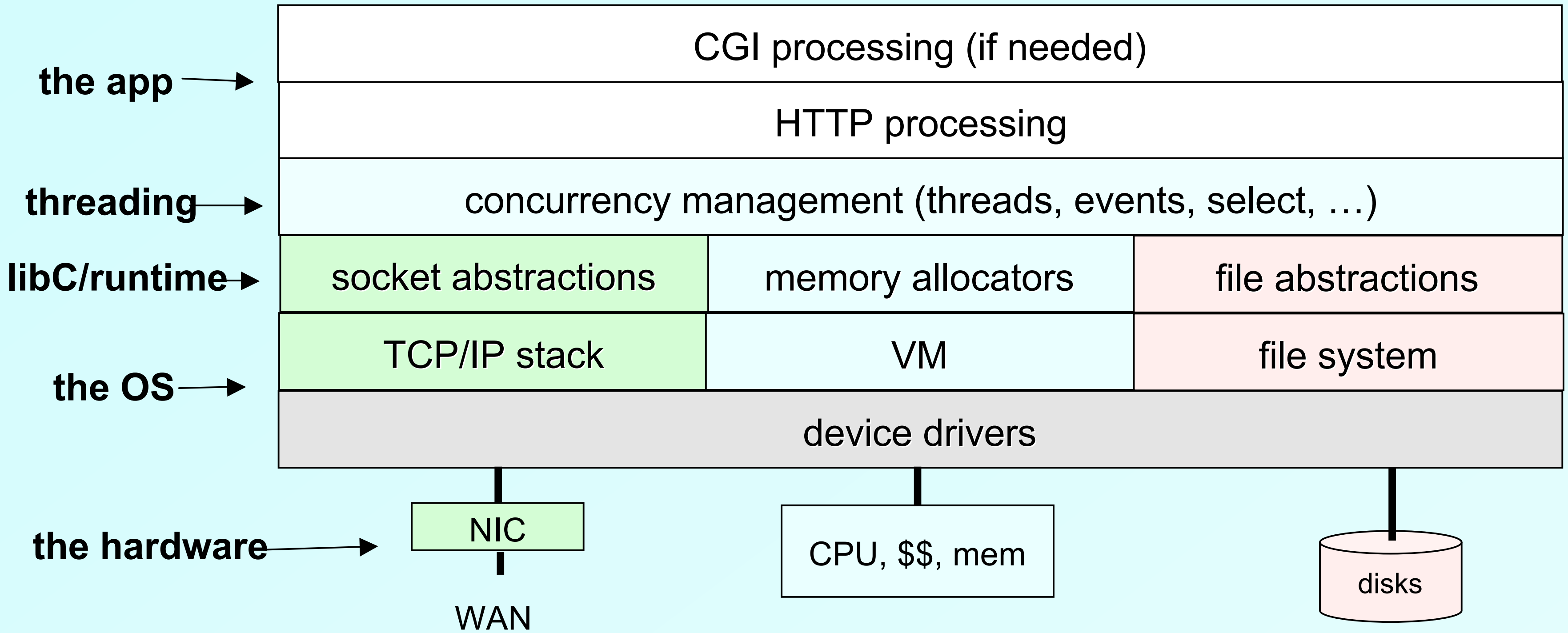

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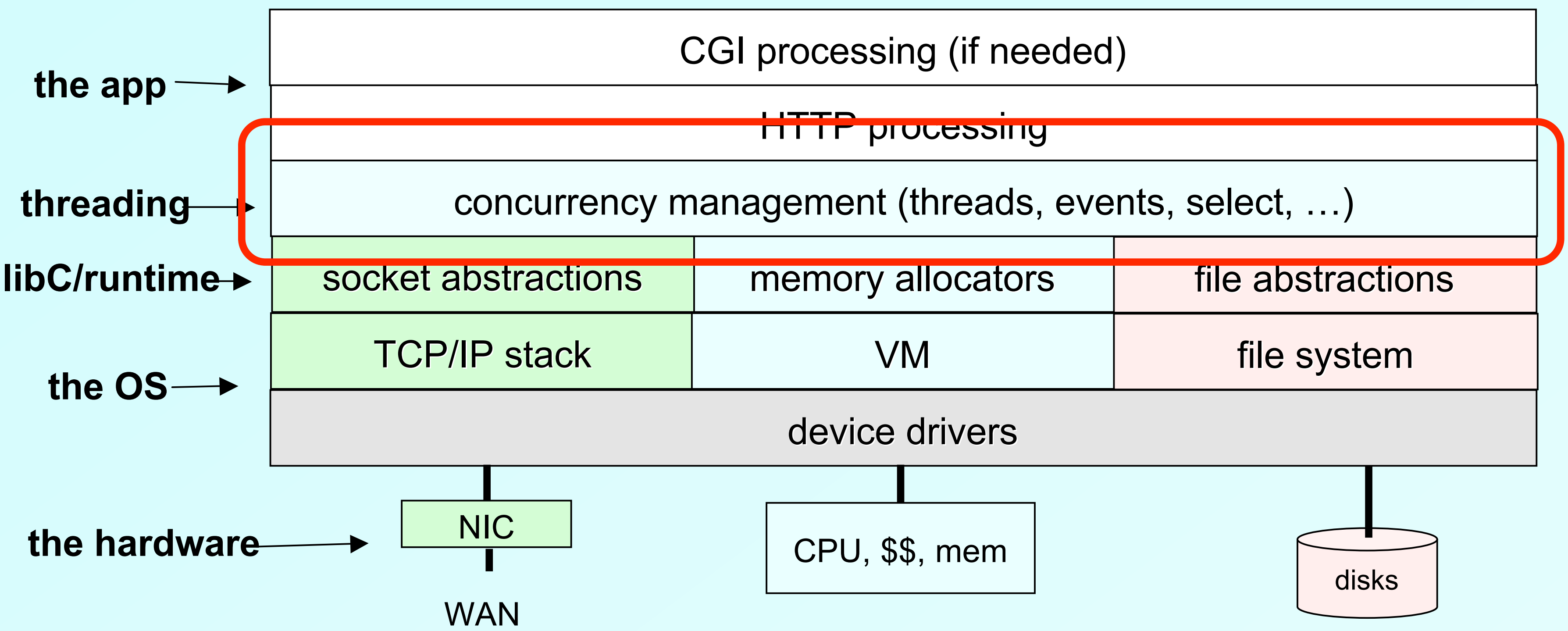


Concurrency management

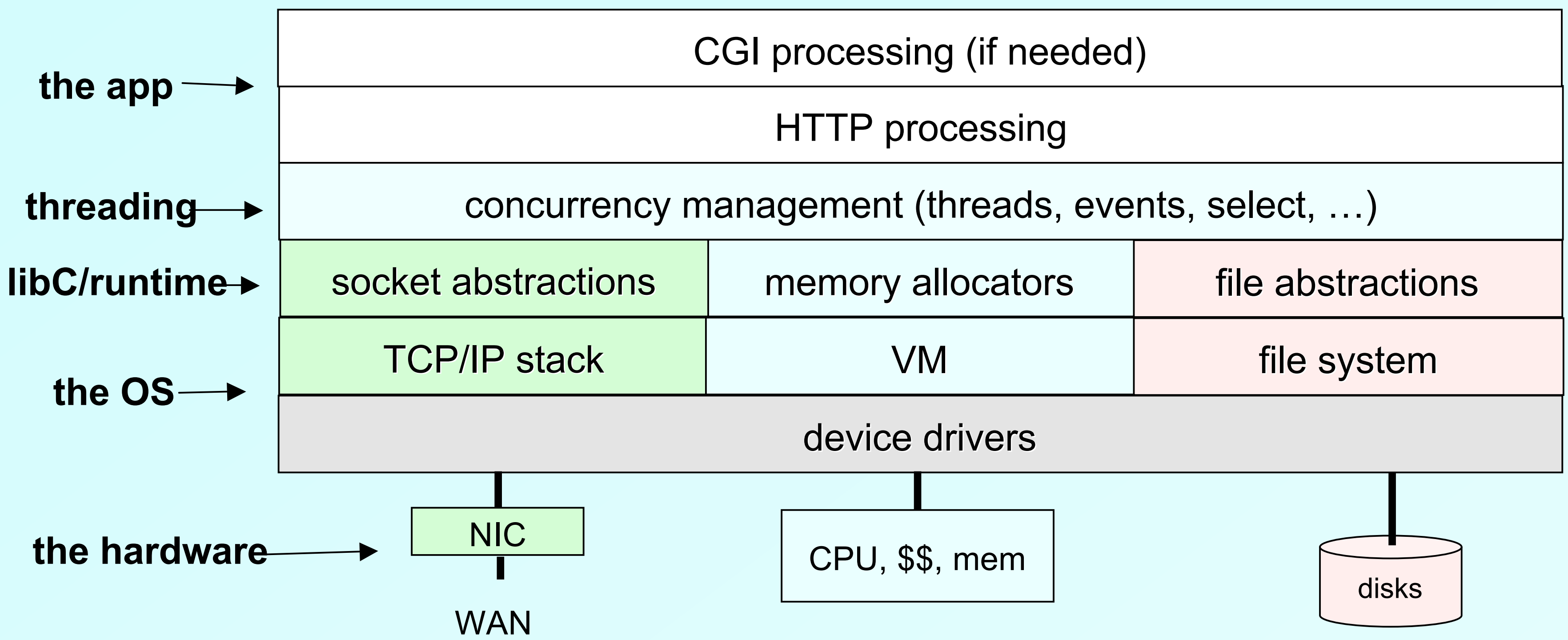
- **A religious topic: threads vs. events**
  - Threads
    - Easier to program
    - Easy to understand and exploit parallelism (multi-proc)
  - Events
    - Easier to program
    - Scheduling can be controlled and exploited
      - Not hidden in the thread scheduler or lock
    - Performance, scaling
- **All this makes sense only…**
  - If the bottleneck is due to threads/events (unlikely)

Pipeline servers: L1/L2 cache

- **Claim: instructions-per-cycle is low on servers**
  - Threads hurt I-cache performance
  - Idea: re-architect software into computational stages
    - Execute each task repetitively in a stage

- **Problems:**
  - Quite a drastic change in architecture
  - Working set size of stage must align well with I-cache size
  - Performance pay-off is minimal
    - 5-10% improvement (1 month of Moore's law)

Single machine Web server



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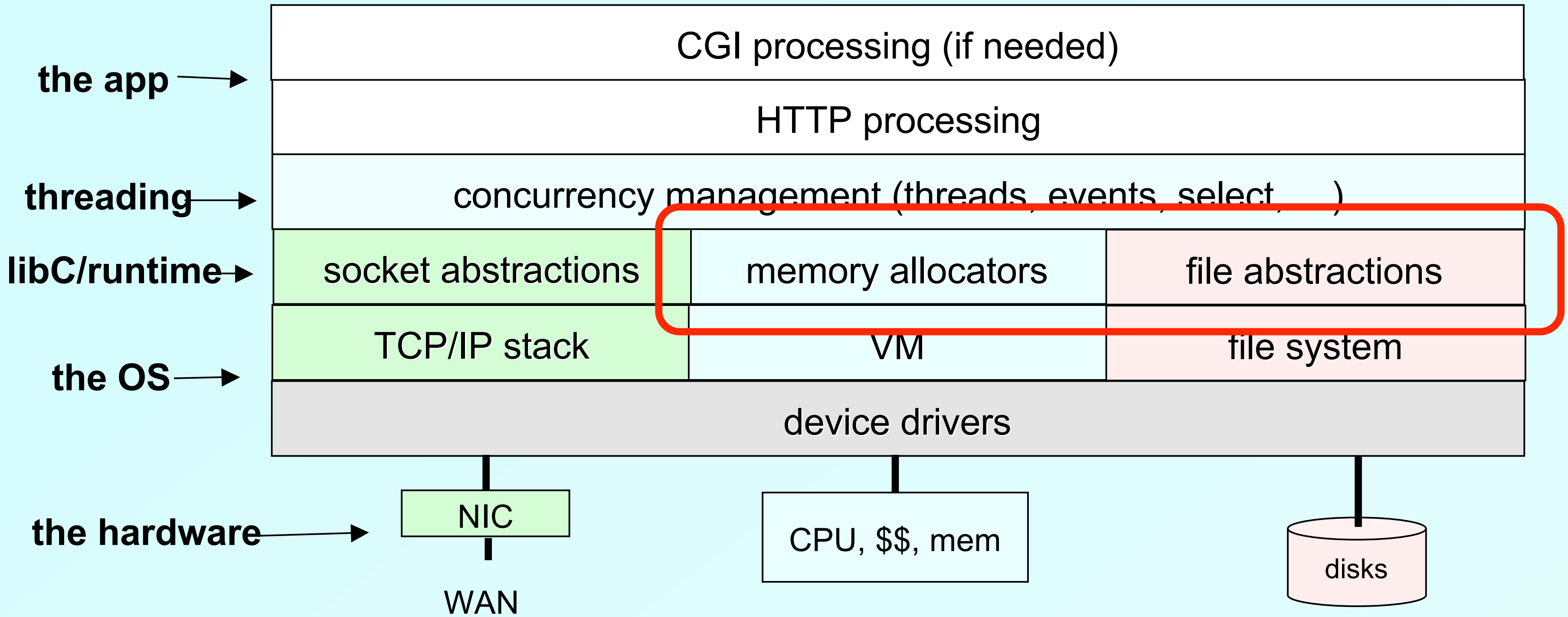

Memory management

- **Cache and VM performance:**
  - Memory allocation research:
    - Efficient layout to avoid VM pressure
    - Parallelize to avoid becoming bottleneck on SMPs
    - Stack layout matters also

- **Issues:**
  - This machinery is very well-hidden
    - Hard to expose or take advantage of it

Disks

- **If you move the disk arm, it will be your bottleneck**
  - Seek: 5ms
    - 16 millions cycles on a 3GHz machine
    - 500 Kilo-bytes of throughput over a Gb link
- **Ideas?**

Disks

- **If you move the disk arm, it will be your bottleneck**
  - Seek: 5ms
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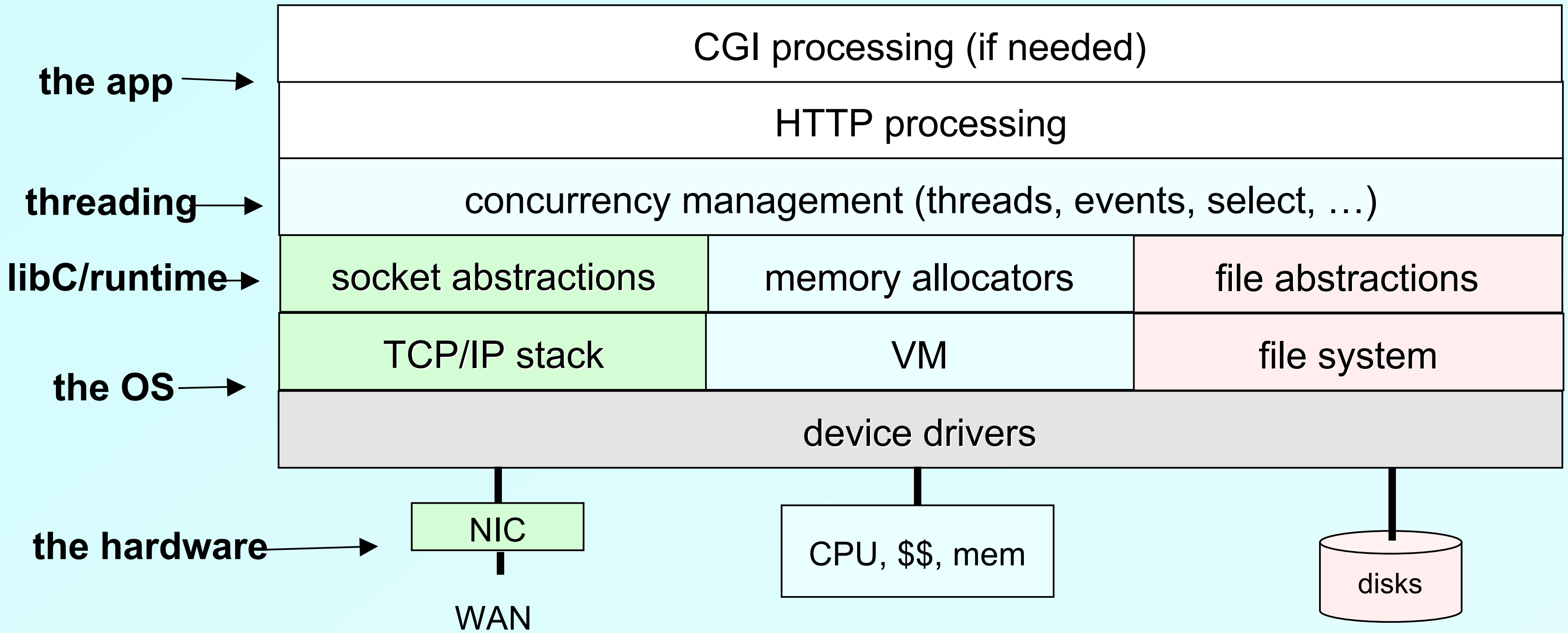
- **Ideas?**
  - Buy lots of memory to cache disk
  - Avoid writes, or use logging to write sequentially
  - Avoid reads, or read more data and cache (just in case)
    - Clever layout
  - Batch reads and writes
  - Buy lots of disks

Single machine Web server



Higher-level Issues

- **Overload management**
  - If offered load exceeds your capacity, what happens?
  - Need to reject load early, otherwise you'll livelock
    - Admission control outside server (L4 switch)
    - Switch to polling (instead of interrupts) on high load
    - Reject early in the TCP stack
- **Differential quality of service**
  - Service only high-priority requests

Latency vs. Throughput

- **Harchol-Balter: optimizing order of request handling**
  - Network stacks and servers are "fair"
    - Each connection is processed at an equal rate
  - Not optimal if we want to minimize average latency
    - Or minimize amount of state in a server
  - Instead: process connections with SRJF
    - Doesn't matter under light load
    - Matters as approach capacity (10x latency at 90% load)
- **Issues:**
  - How do you estimate the "length" of a connection
  - Starvation of long jobs

HTTP Mambo-Jambo

- **HTTP is broken in many ways**
  - Many small connections (HTTP 1.0)
    - Overhead of establishing TCP connection is bad
    - Persistent connections helped
  - Chatty, untokenized wireline protocol
    - Headers account for 5-700 bytes / object
    - Irrelevant for wired servers/clients
    - Matters more for wireless

Clusters

- **Increase performance:**
  - Replicate:
    - Load-balancing: avoid any replica from becoming bottleneck
    - Mitzenmacher:
      - State information is good enough
      - Goal: avoid worst-case (and not achieve optimal)
      - Sample two or three, pick best
  - Partitioning:
    - LARD

Discussion

- **Low-bandwidth last-hop:**
  - We know how to make server faster, but …
  - The real bottleneck is low bandwidth on the last mile
  - Solutions?

Discussion

- **Low-bandwidth last-hop:**
  - We know how to make server faster, but …
  - The real bottleneck is low bandwidth on the last mile
  - Solutions?
    - Better compression
      - Content adaptation
      - Content hashcaches
    - Latency-hiding with pipelined rendering/streaming
      - Works well for the Web
    - Latency-hiding with aggressive prefetching
      - Every bit of unused bandwidth is a missed opportunity
      - ISPs hate this

Discussion

- **Content is getting bigger**
  - Web: 4-6KB
  - P2P: audio 4MB, video 1GB
  - Other forms of distribution?

Discussion

- **Content is getting bigger**
  - Web: 4-6KB
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  - Other forms of distribution?
    - Sneaker-net
    - Satellites/TV cable/HDTV
  - Any new server issues?