Designing for Performance: Concurrency and Parallelism

COS 518: Computer Systems
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Adapted from slides by Mike Freedman

Definitions

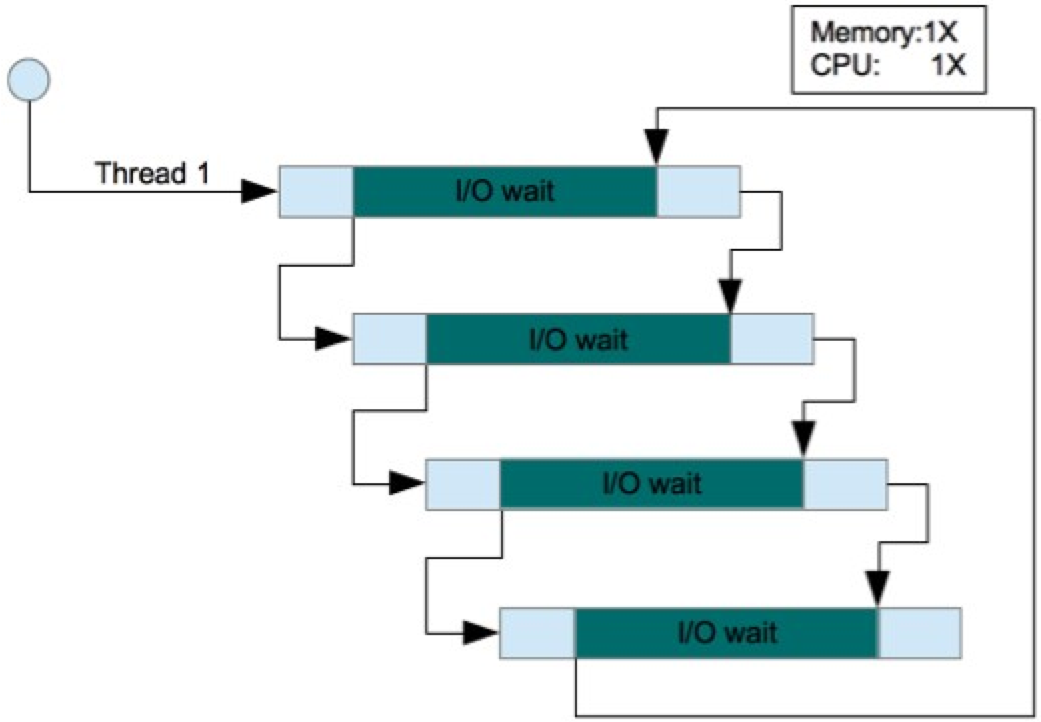
- Concurrency:
  - Execution of two or more tasks overlap in time.
- Parallelism:
  - Execution of two or more tasks occurs simultaneous.

Concurrency without parallelism?

- Parts of tasks interact with other subsystem
  - Network I/O, Disk I/O, GPU, ...

- Other task can be scheduled while first waits on subsystem's response

Concurrency without parrallelism?

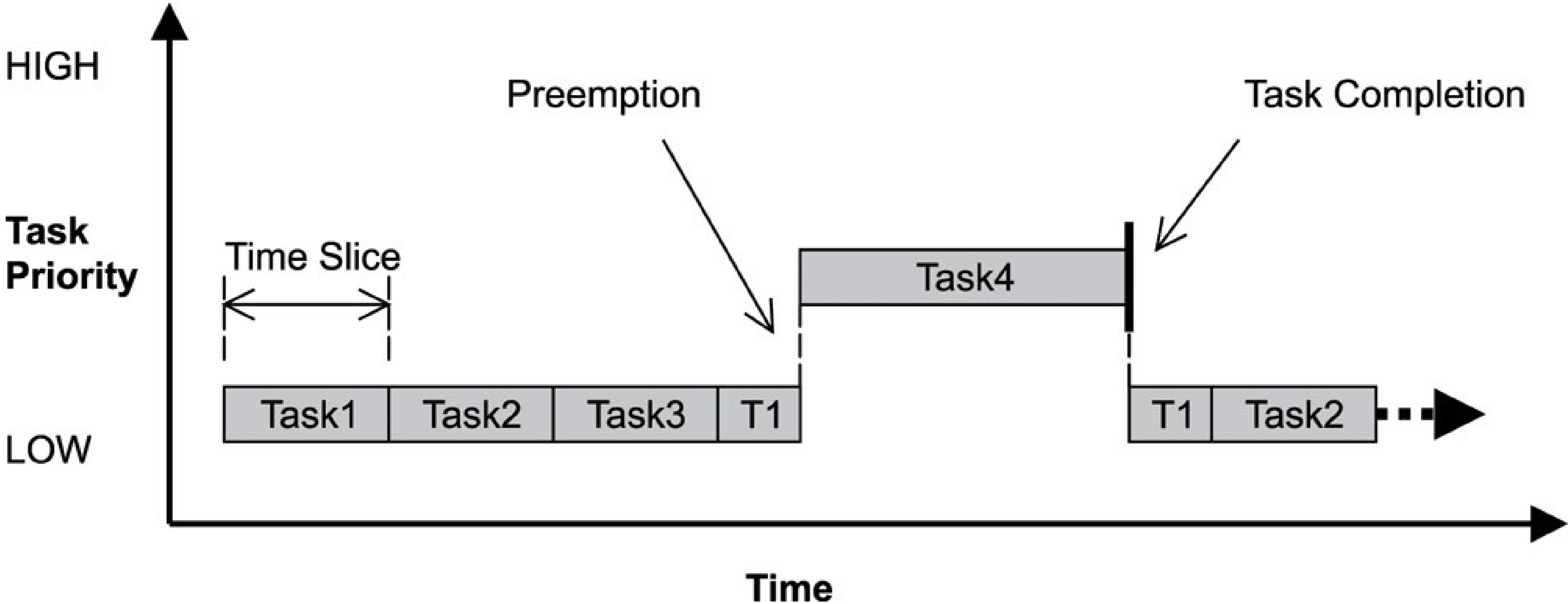


Source:
bjoor.me

Scheduling for fairness

- On time-sharing system also want to schedule between tasks, even if one not blocking
  - Otherwise, certain tasks can keep processing
  - Leads to starvation of other tasks
- Preemptive scheduling
  - Interrupt processing of tasks to process another task (why with tasks and not network packets?)
- Many scheduling disciplines
  - FIFO, Shortest Remaining Time, Strict Priority, Round-Robin

Preemptive Scheduling

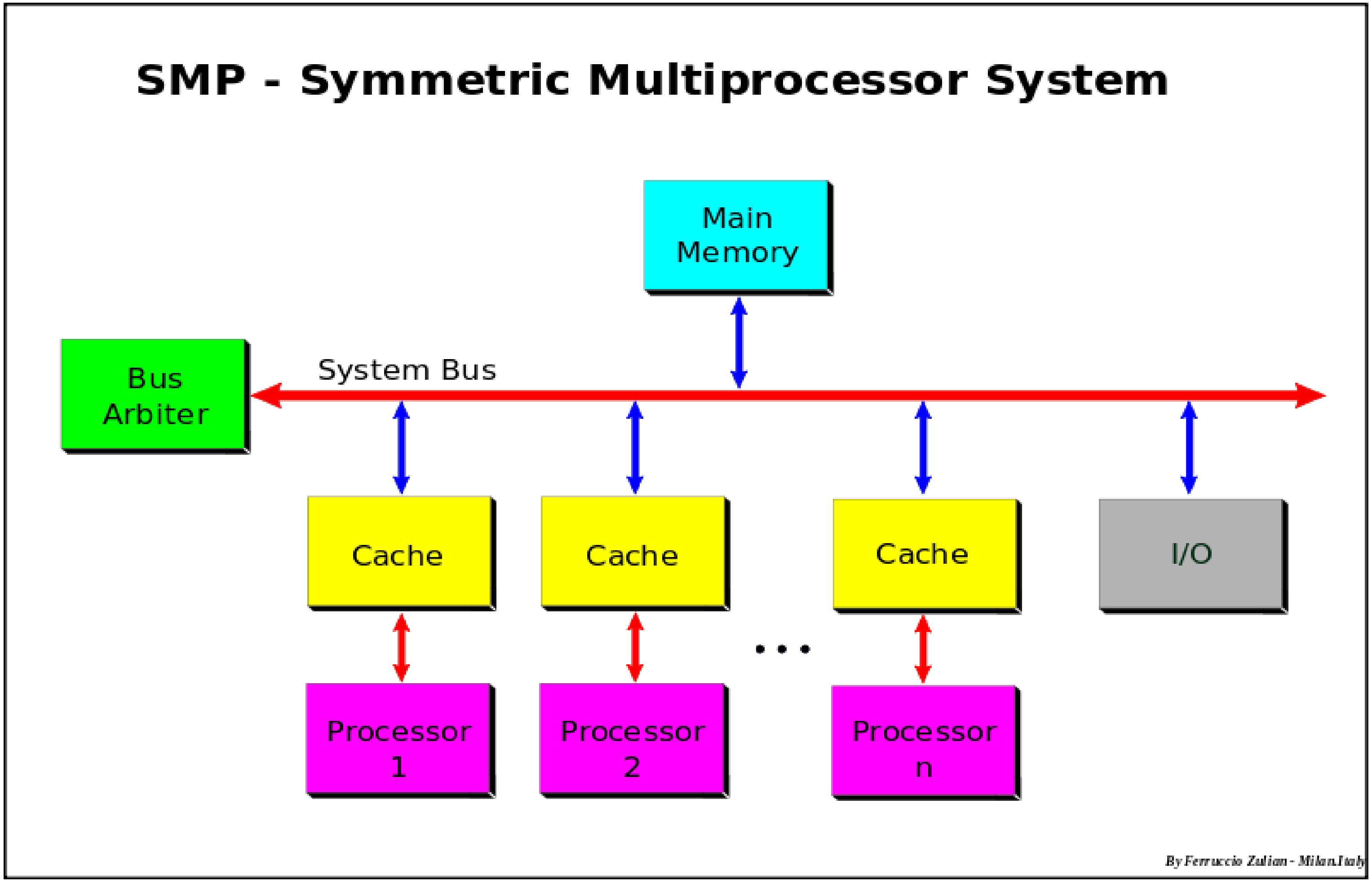


Source: embeddedlinux.org.cn

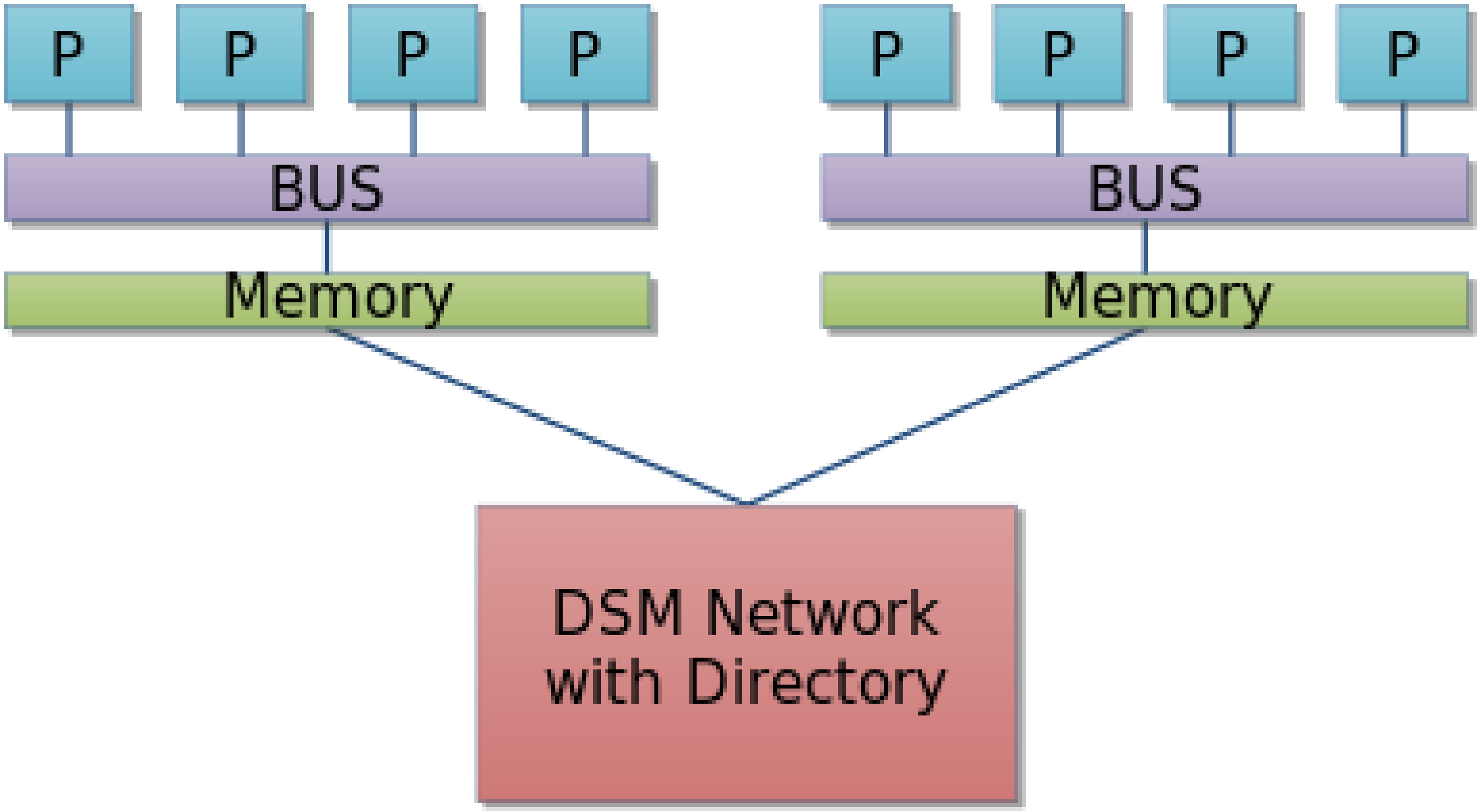
Concurrency with parallelism

- Execute code concurrently across CPUs
  - Clusters
  - Cores
- CPU parallelism different from distributed systems as ready availability to shared memory
  - Yet to avoid difference between parallelism b/w local and remote cores, many apps just use message passing between both (like HPC's use of MPI)

Symmetric Multiprocessors (SMPs)



Non-Uniform Memory Architectures (NUMA)



Pros/Cons of NUMA

- Pros
  - Applications split between different processors can share memory close to hardware
  - Reduced bus bandwidth usage
- Cons
  - Must ensure applications sharing memory are run on processors sharing memory

Forms of task parallelism

- Processes
  - Isolated process address space
  - Higher overhead between switching processes
- Threads
  - Concurrency within process
  - Shared address space
  - Three forms
    - Kernel threads (1:1) : Kernel support, can leverage hardware parallelism
    - User threads (N:1): Thread library in system runtime, fastest context switching, but cannot benefit from multi-threaded/proc hardware
    - Hybrid (M:N): Schedule M user threads on N kernel threads. Complex.

Programming with threads

- Multithreaded version:

```
webserverLoop() {
     newconn = accept();
     ThreadCreate(processReq(), newconn);
}
```

- Advantages of threaded version:
  – Can share file caches kept in memory, results of CGI scripts, ...
  – What if too many requests come in at once?

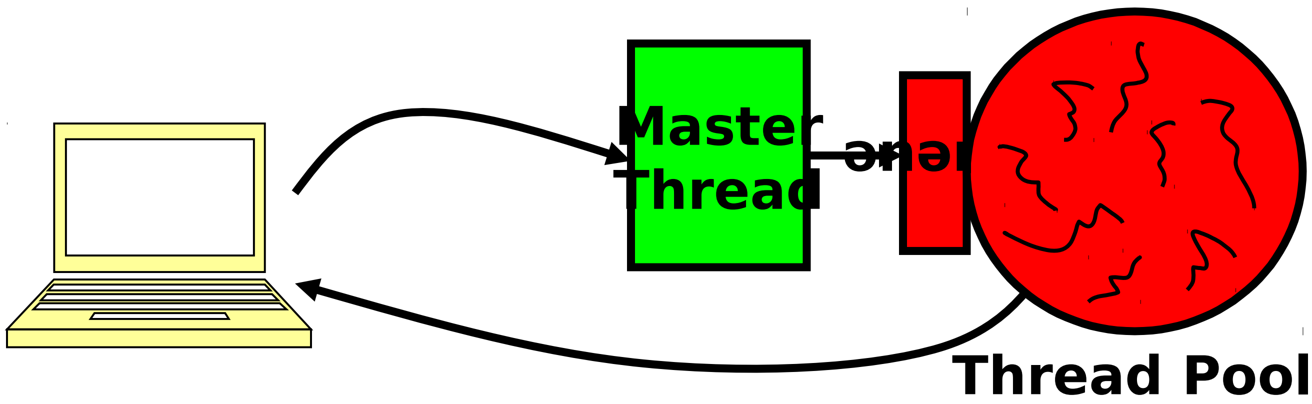
Dispatching packets to processes

- Network interrupts run at higher kernel priority than user-level tasks
  - Can lead to Receiver Livelock: All effort on receiving packets, no real work done
- Types of dispatch
  - Interrupts: One per network packet
  - Interrupt Coalescing: Wait for several pkts or timeout
  - poll: Make the user space / OS ask you

Livelock with threadCreate

- Cost of new threads < new proc, but still not free
- How much useful concurrency can you support?
  - If hardware support, # cores * # hyperthreads
  - Also, depends on I/O patterns of computation (e.g. how much threads pause on externel I/O)
- So if you keep getting new connections
  - ...and keep creating new threads per connection
  - ...much faster than you can complete threads...
  - ...driven to livelock

Thread Pools




```
master() {
  allocThreads(slave,queue);
  while(TRUE) {
      conn=accept();
      enqueue(queue,conn);
      wakeUp(queue);
  }
}
```

```
slave(queue) {
   while(TRUE) {
      conn=Dequeue(queue);
      if (conn==null)
         sleepOn(queue);
      else
         processReq(conn);
   }
}
```

Thread Pools

- How to choose how many threads are appropriate in your thread pool?

Parallelizing the NIC

- Where does master thread (recv) run?
- How is state transferred in multi-core machine?
- Higher performance if state doesn't need to be xferred between cores/CPUs
- Multi-queue NIC
  - ~O(100) queues in the NIC
  - Flow-hashing to map flows to NIC queues
  - One thread per (v)core to receive
  - Multiple threads per core to process

Writing Threads vs. Events

```
conn = accept()
read(conn, inbuf, inlen)
webobj = parse_http(inbuf)
filefd = open(webobj.getLocalFilename())
if (filefd < 0)
  send(conn, 404Object())
else {
  send(conn, HttpHeaders())
  read(filefd, filebuf, len)
  while (len != EOF) {
        send(conn, filebuf, len)
        read(fd, filebuf, len)
}}
close(filefd)
close(conn)
```

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Async IO and event-based programming

- Events and async IO
  - `select`
  - Callbacks and stack ripping
  - State across callbacks (function currying)
  - `libasync`

- Async IO and multithreads
  - Boost's `asio strand` model