Announcements

- Room change ELA1
- Parallelism and Concurrent final exam overlap
- Students without pre-requisite courses

Recap of Week 1

Pamela Delgado

February 20, 2019

(slides Willy Zwaenepoel)

What does the OS do?

- Abstraction: makes hardware easier to use
- Resource management: allocate hardware resources between users

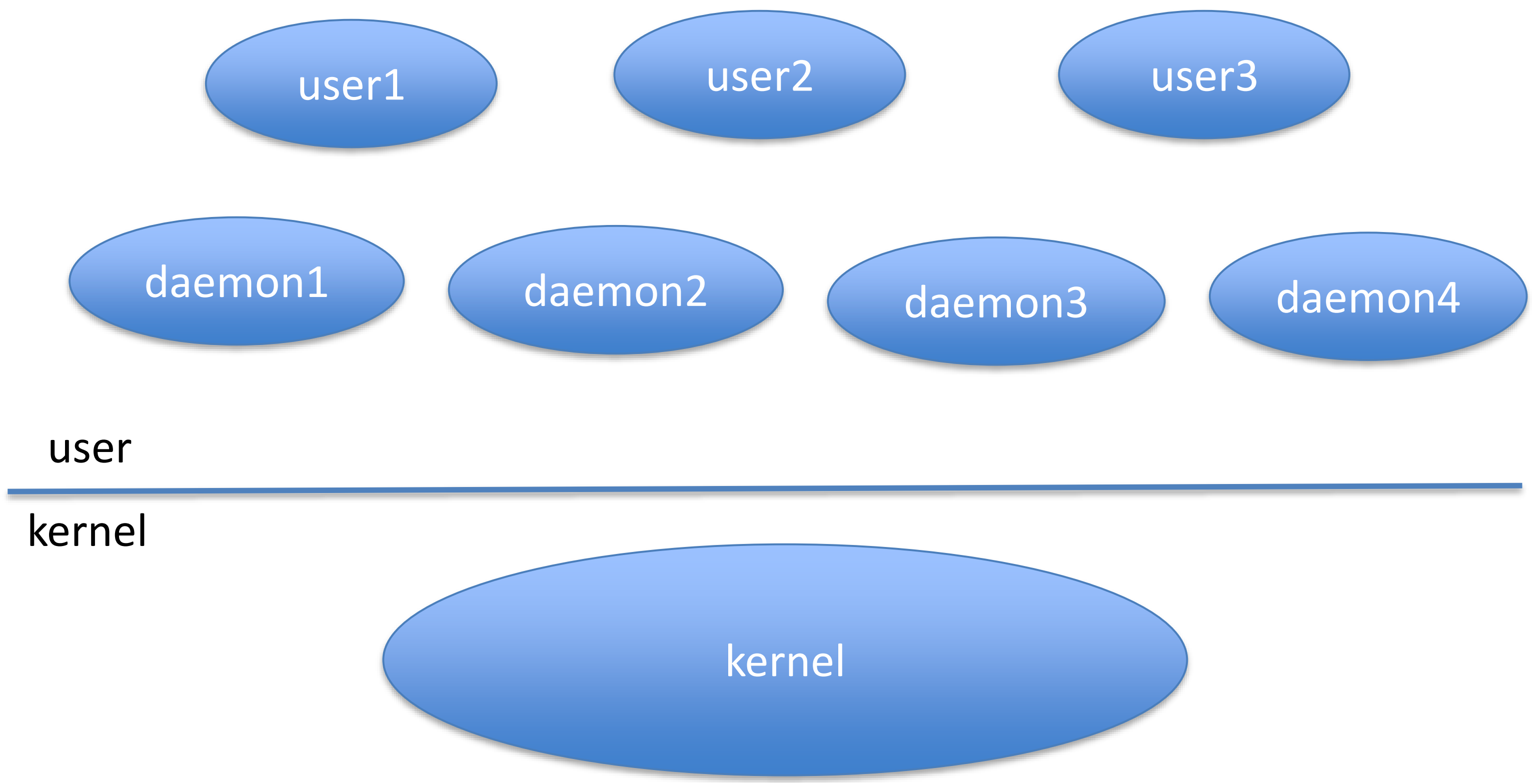
Key Components

- Process management
  - CPU ➔ processes
- Memory management
  - Memory ➔ address spaces
- File systems
  - Disk, SSD ➔ files

User/Kernel Mode

- User mode:
  - Applications
  - System programs
- Kernel mode:
  - OS kernel

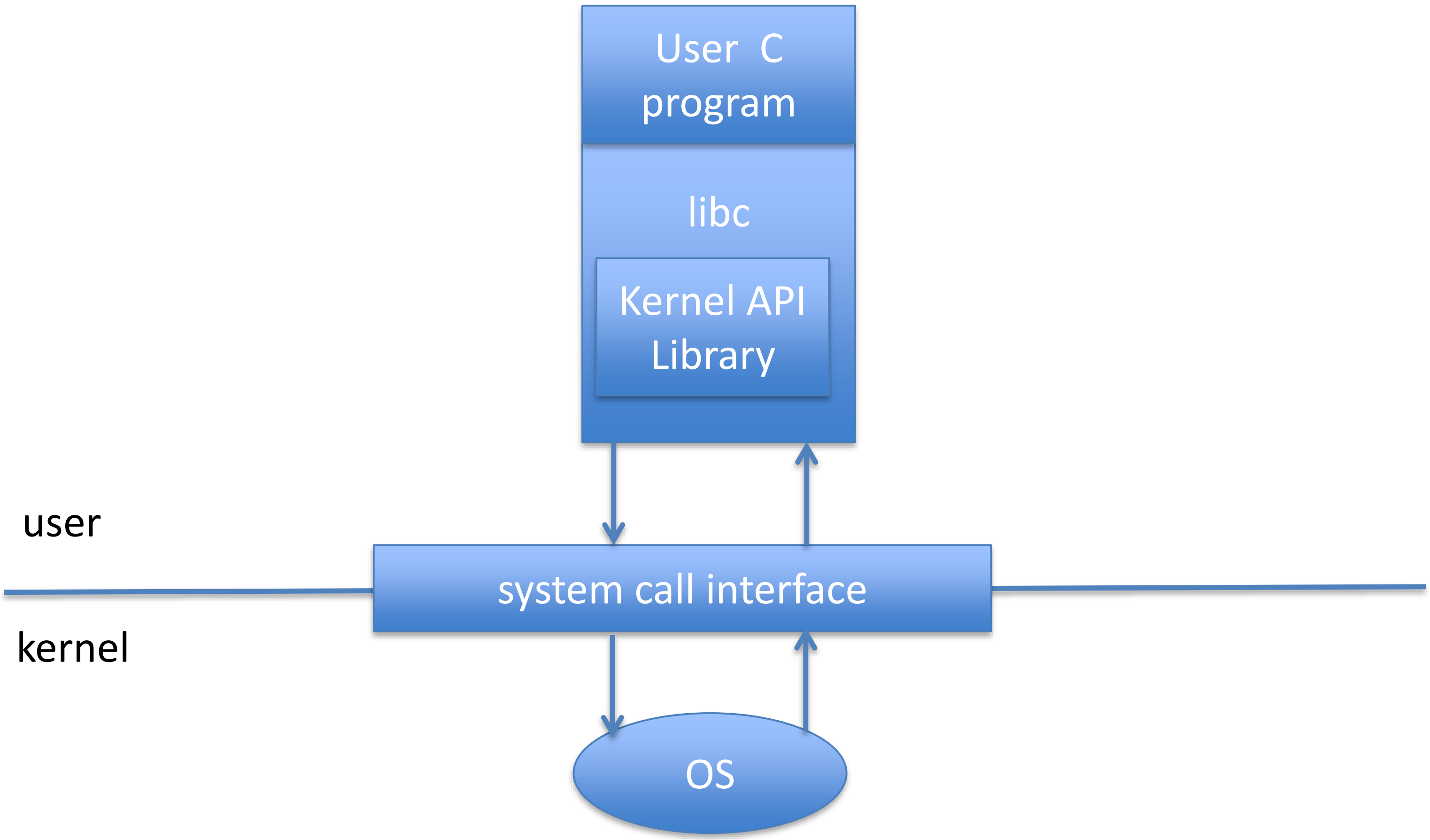
User/Kernel Mode



System Calls

- Only way for application to call kernel
- Special instruction
- Often wrapped by kernel API, libc

Interaction Application/Kernel



Kernel is Event-Driven Program

- Nothing to do

} Do nothing

Kernel is Event-Driven Program

- Nothing to do

} Do nothing

- Interrupt (from device)
- Trap (from process)
- System call (from process}

} Start running

Lecture 2
Process Management

Pamela Delgado

February 27, 2019

(slides Willy Zwaenepoel)

Key Concepts

- Process
- Linux process tree
- Process switch
- Process scheduler

What is a Process?

- Process = program in execution
- Program
  - Executable code
  - Usually represented by a file on disk
- Process
  - Executing code
  - Usually represented in memory

What does a Process do?
(as far as a user is concerned)

- It can do anything

- Shell
- Compiler
- Editor
- Browser
- …

- These are all processes

Process Identification

- Each process has a unique process identifier
- Always referred to as “pid”

Basic Operations on Processes

- Create a process
- Terminate a process
  - Normal exit
  - Error
  - Terminated by another process

Linux Process Primitives

- pid = fork()
- exec(filename)
- exit()
- wait()

pid = fork()

- Creates an *identical* copy of parent
- In parent, returns pid of child
- In child, returns 0

exec(filename)

- Loads executable from file with filename

wait()

- Wait for one of its children to terminate

exit()

- Terminate the process

Typical fork()-ing Code Segment

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

Before fork()

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

After fork()

parent

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

child

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

After fork()

parent

```
if ( pid_child ) {
    wait()
}
else {
    exec( filename )
}
```

child

```
if ( 0 ) {
    wait()
}
else {
    exec( filename )
}
```

After fork()

parent

```
if ( pid_child ) {
    wait()
}
else {
    exec( filename )
}
```

child

```
if ( 0 ) {
    wait()
}
else {
    exec( filename )
}
```

After exec()

parent

```
if ( pid_child ) {
    wait()
}
else {
    exec( filename )
}
```

child

```
main() {
    ...


    exit()
}
```

After exit()

parent

```
if ( pid_child ) {
    wait() returns
}
else {
    exec( filename )
}
```

Question about fork-exec

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

does it make sense
to write code here?

Outline of Linux Shell

```
forever {
    read from input
    if( logout) exit()
    if ( pid = fork() ) {
        wait()
    }
    else {
        exec( filename )
    }
}
```

Operation

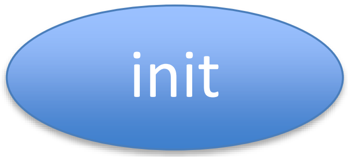
- New command line (!= logout)
  - Shell forks a new process and waits
  - Child executes program on command line

The Linux Process Tree

Boot

- First process after boot is the init process
- Happens by black magic

User logs in



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- Init forks and waits
- Child execs shell

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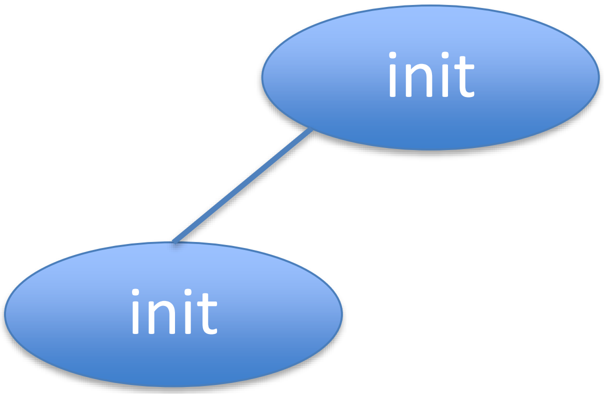

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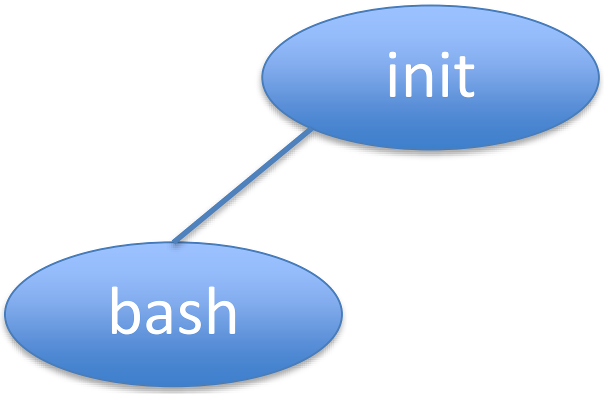
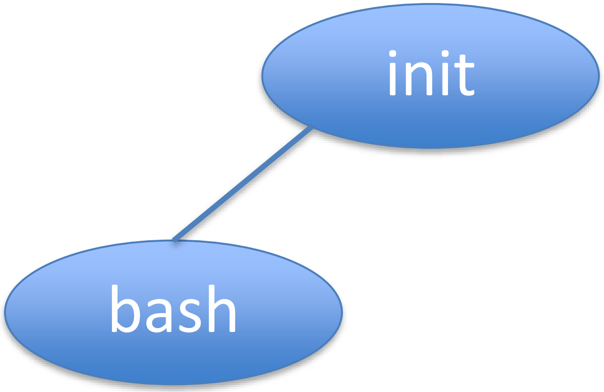


User runs make



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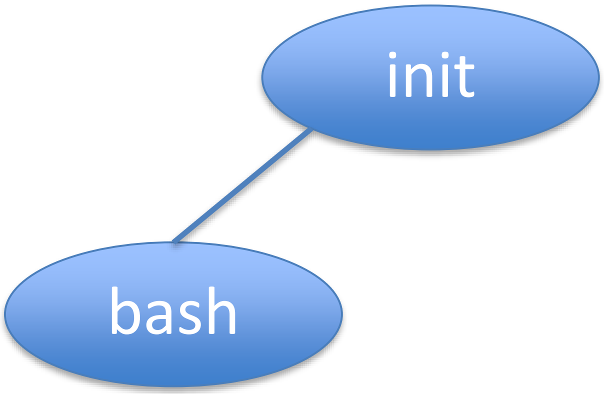

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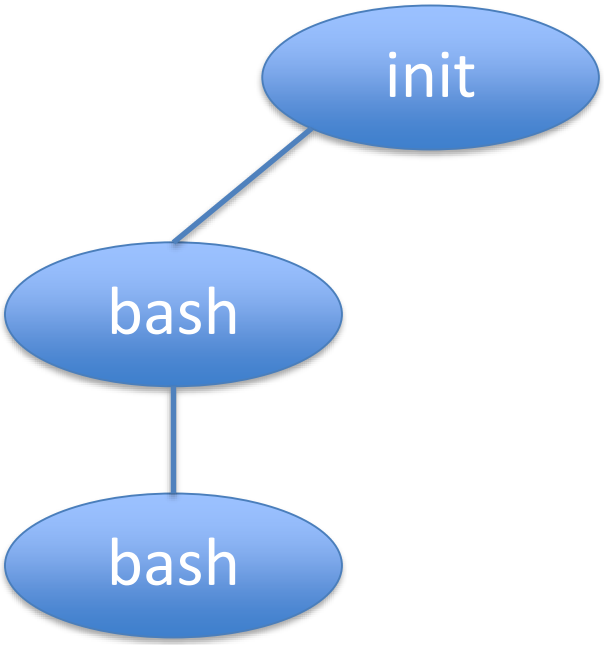

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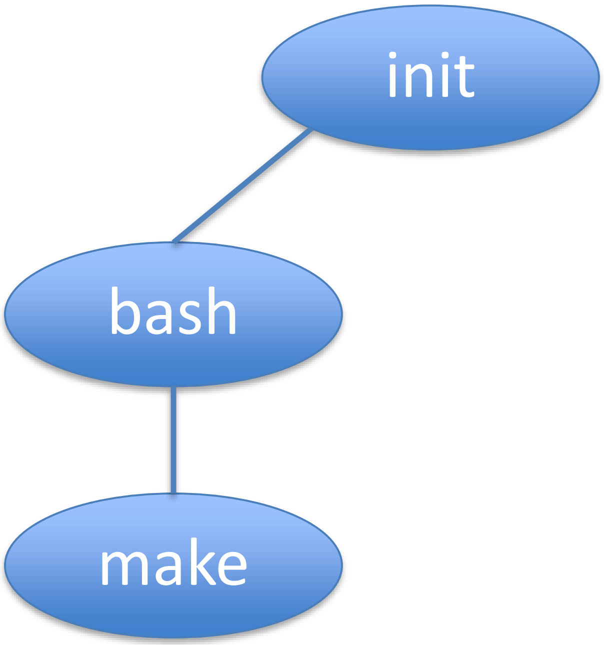
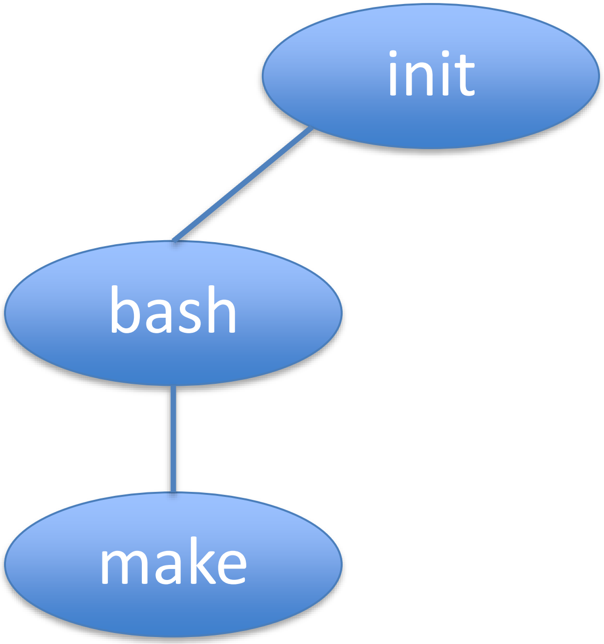


Another user logs in



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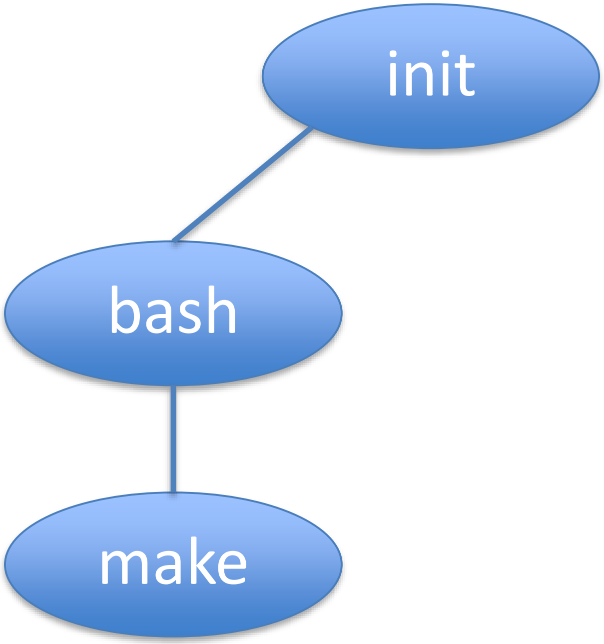

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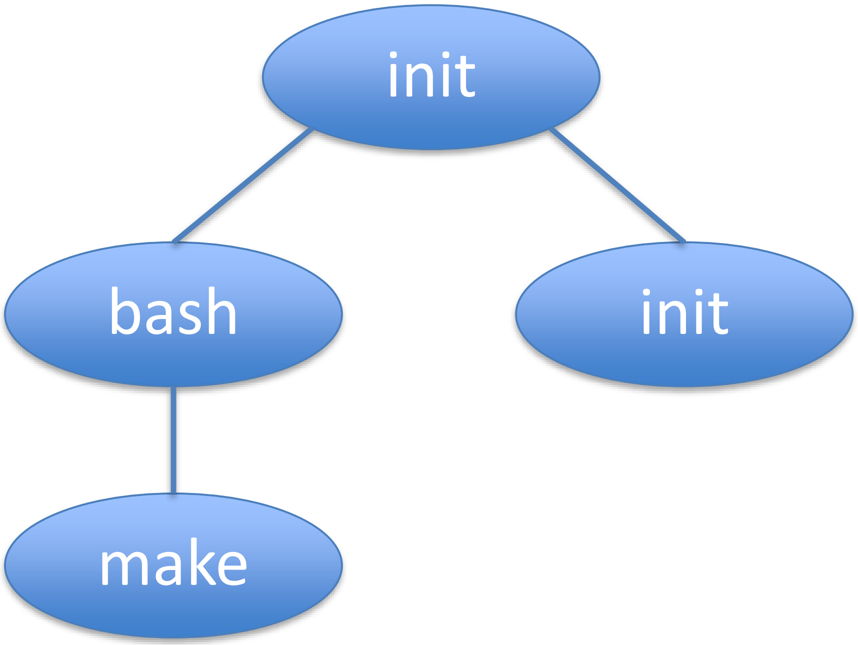

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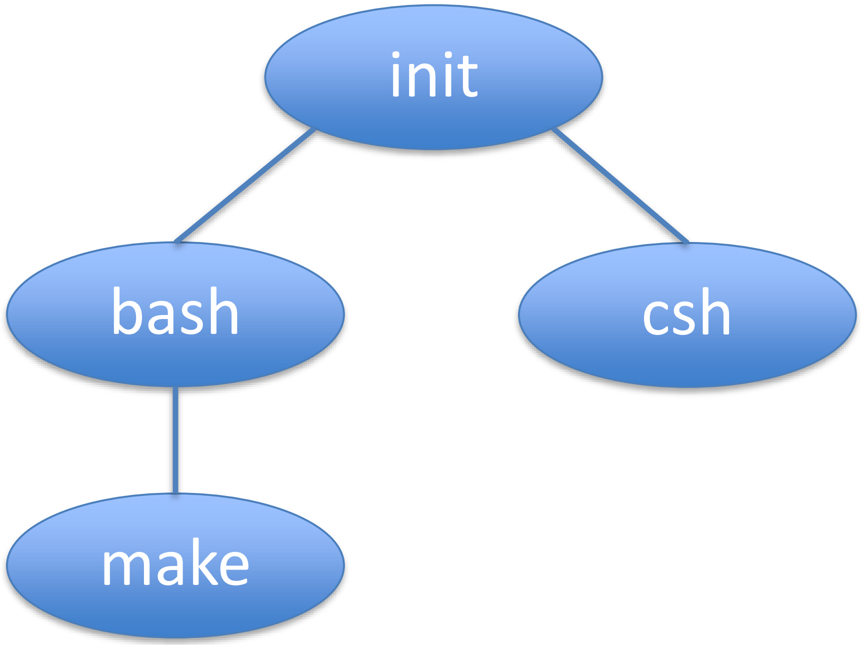
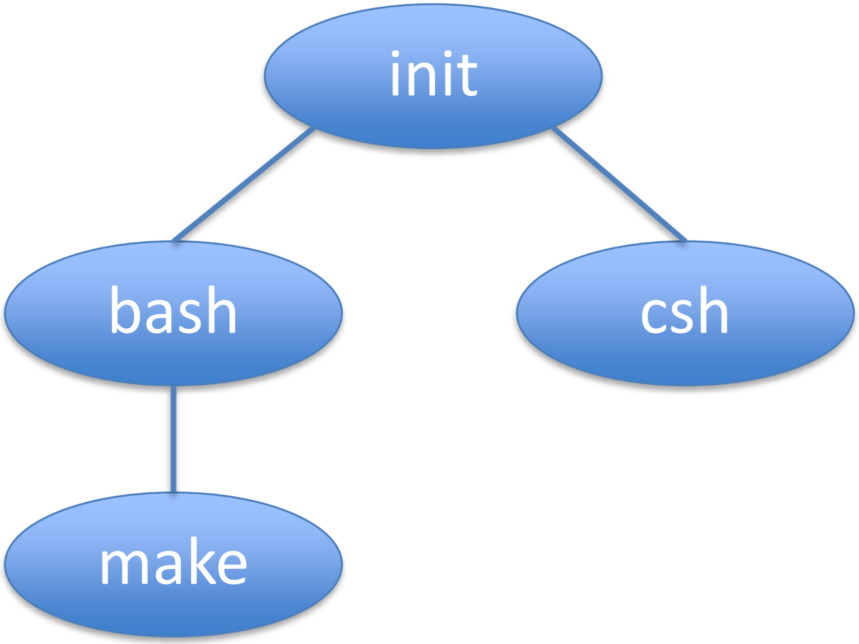


Make runs gcc



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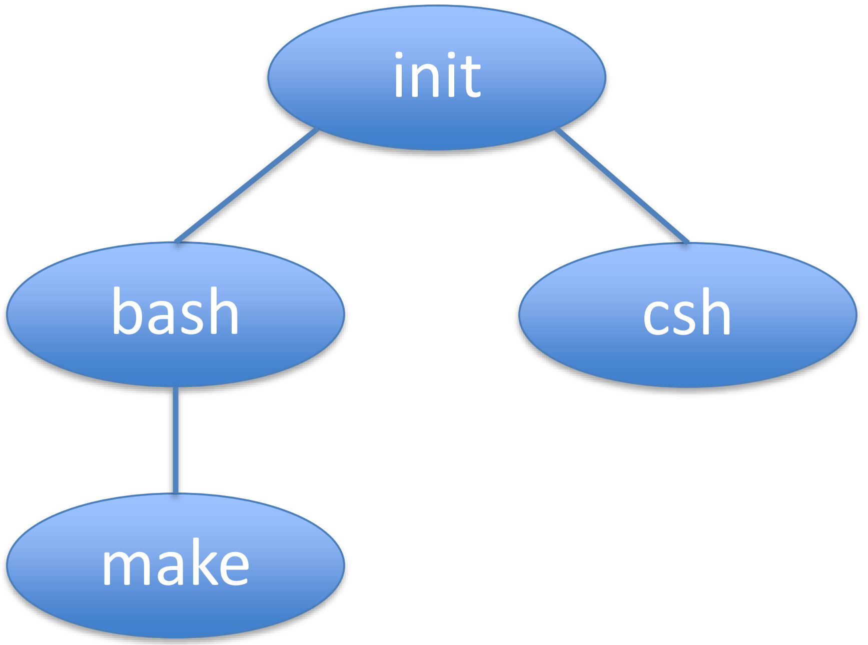

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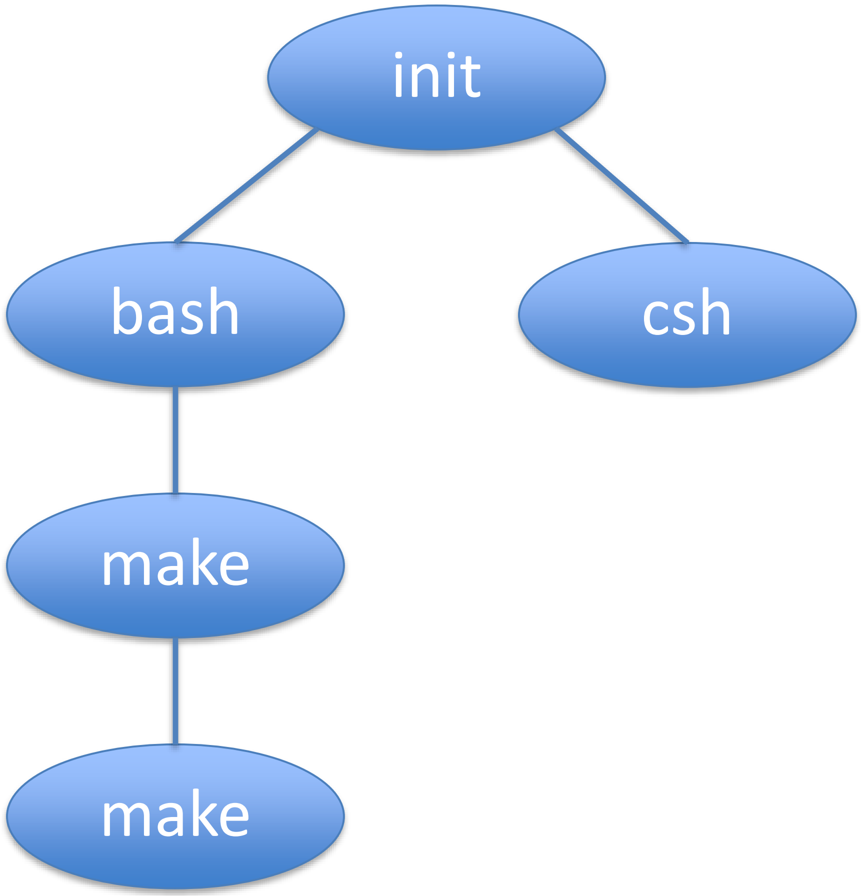

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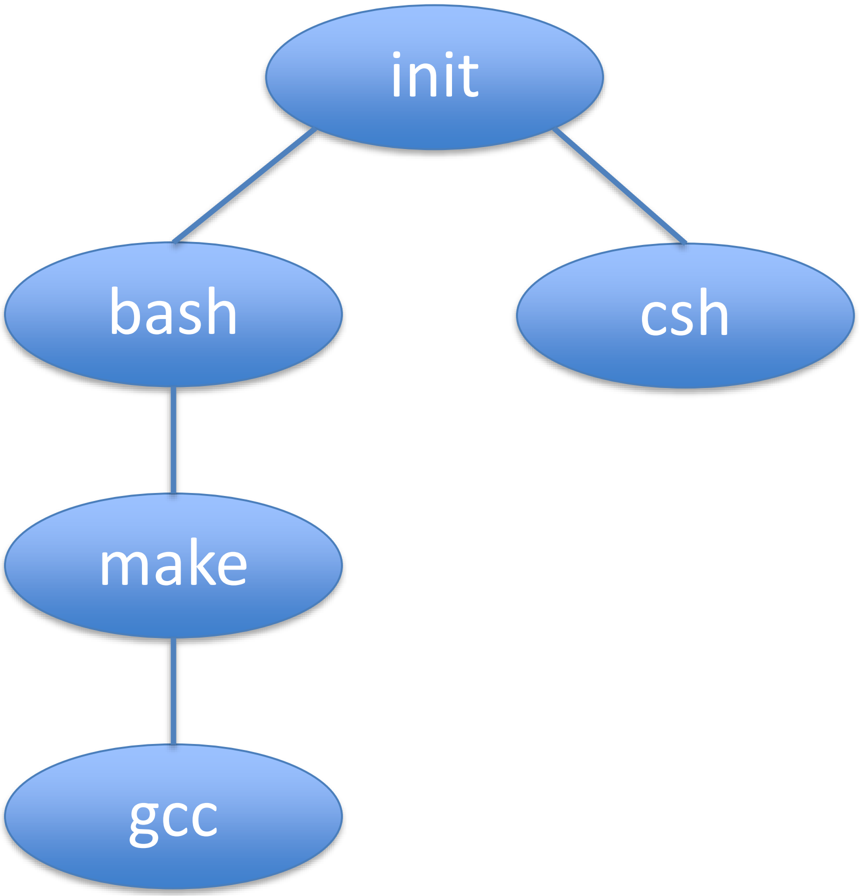
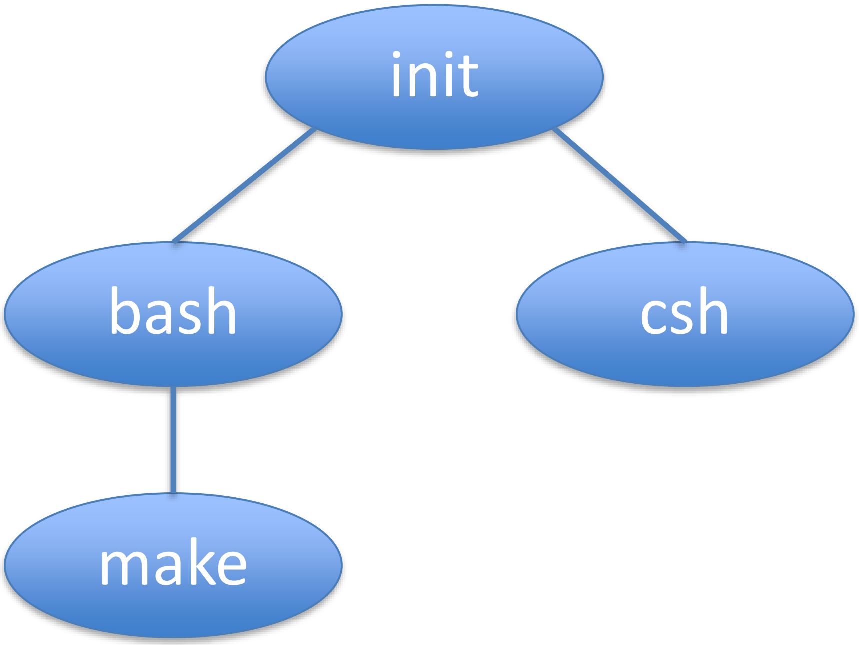


Gcc finishes

- Gcc exits
- Make returns from wait



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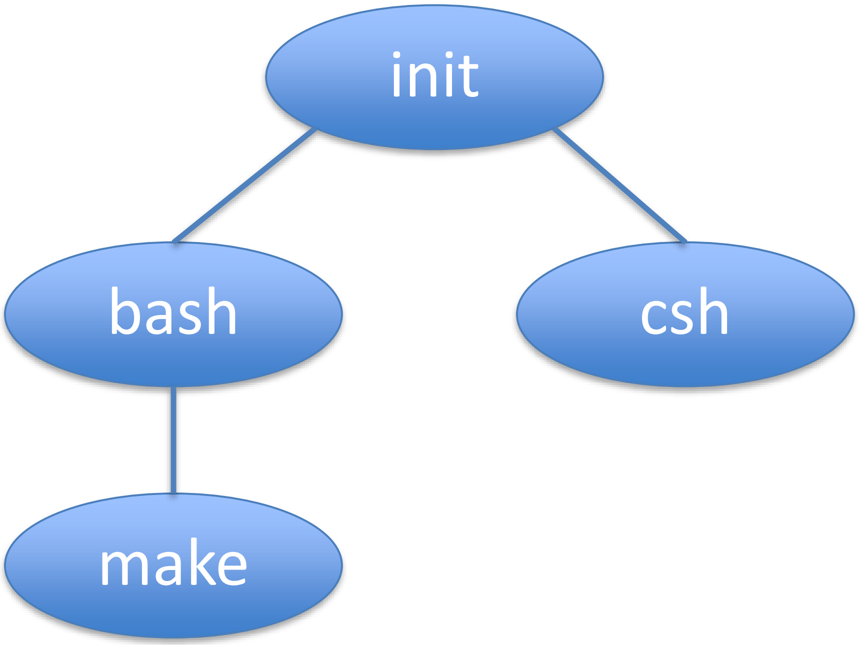

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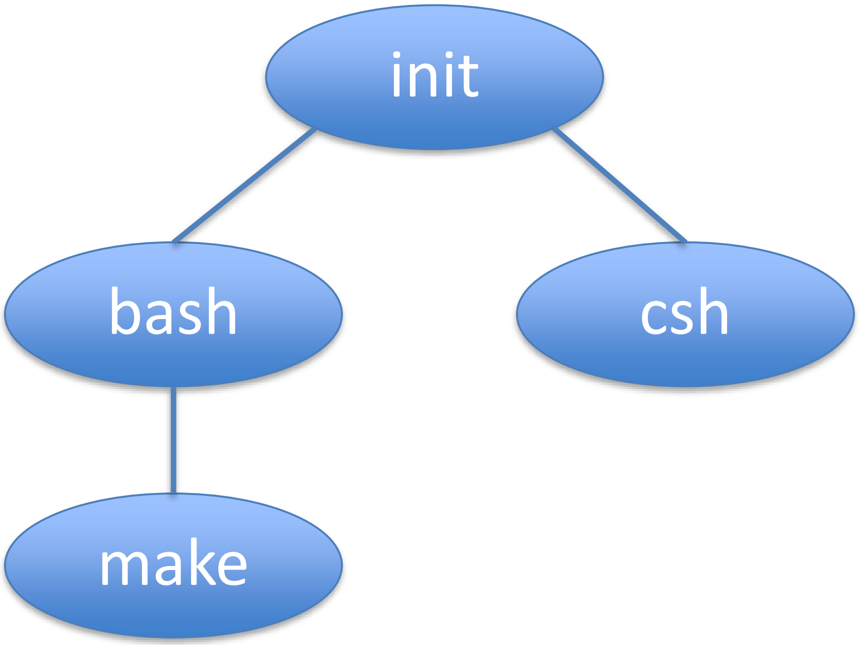
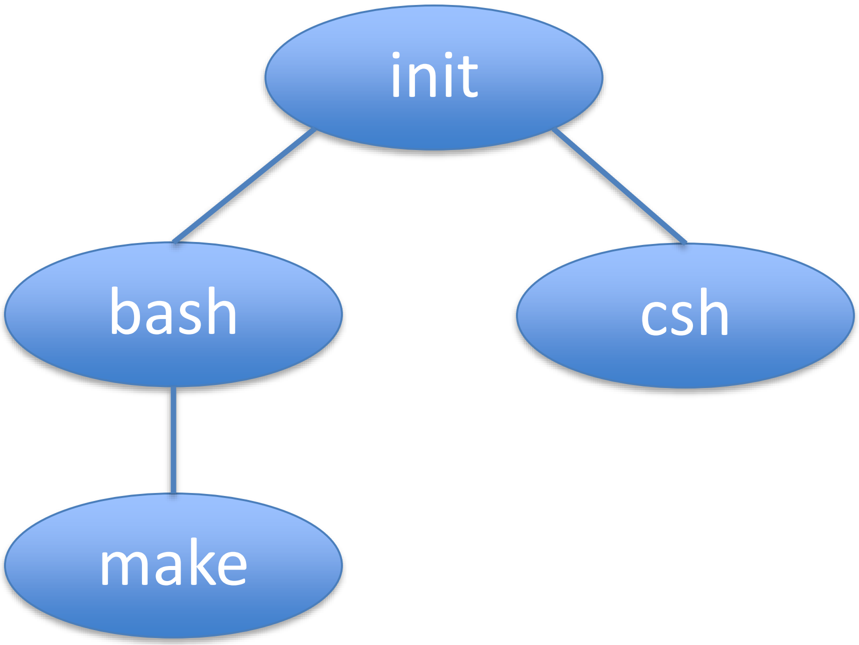
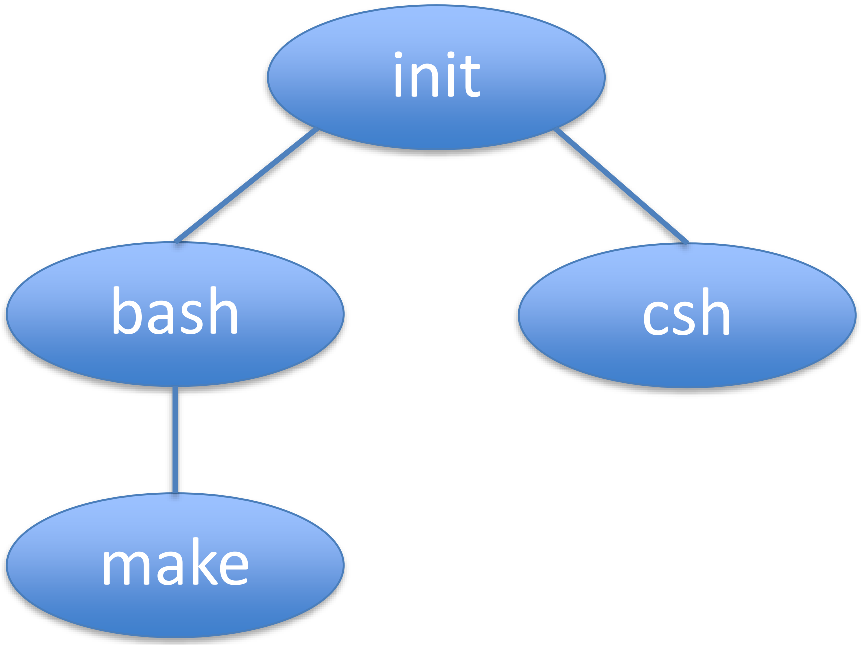


Second user logs out



Second user logs out

- Csh exits
- Init returns from wait



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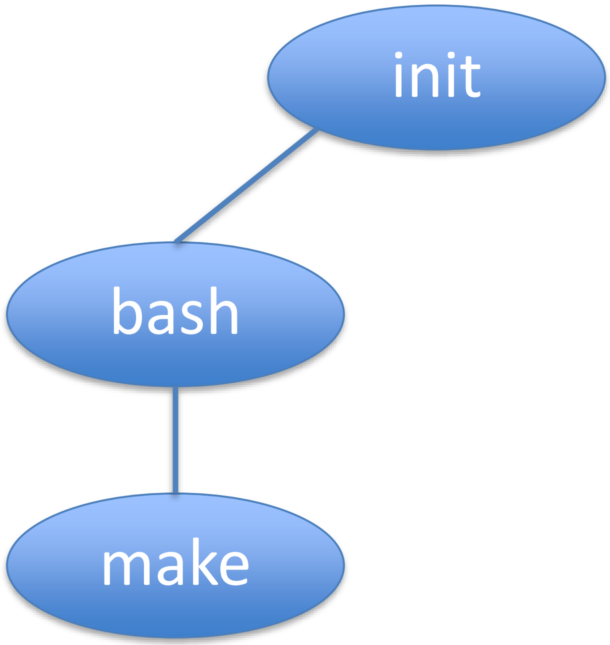

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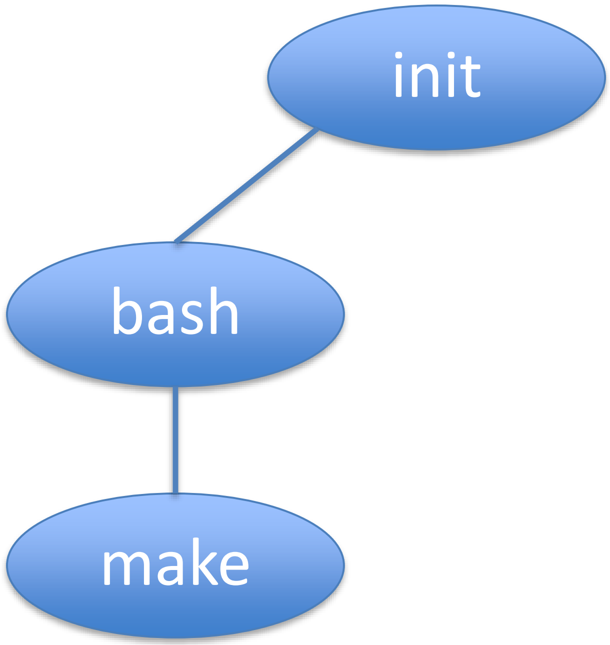
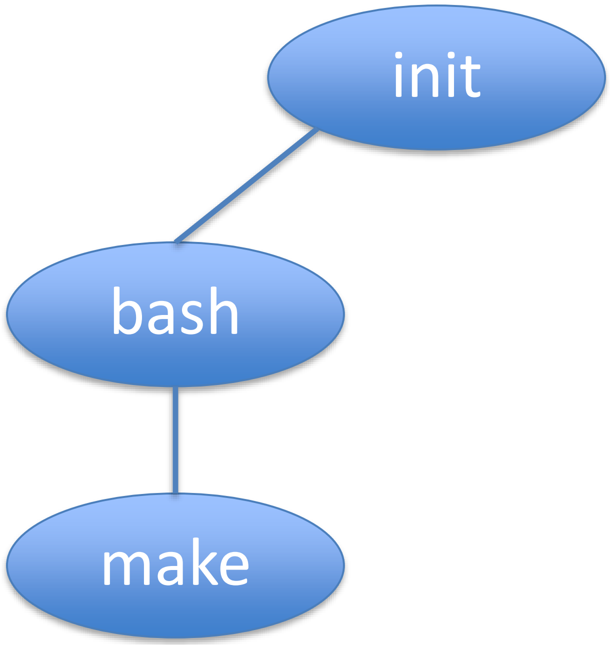


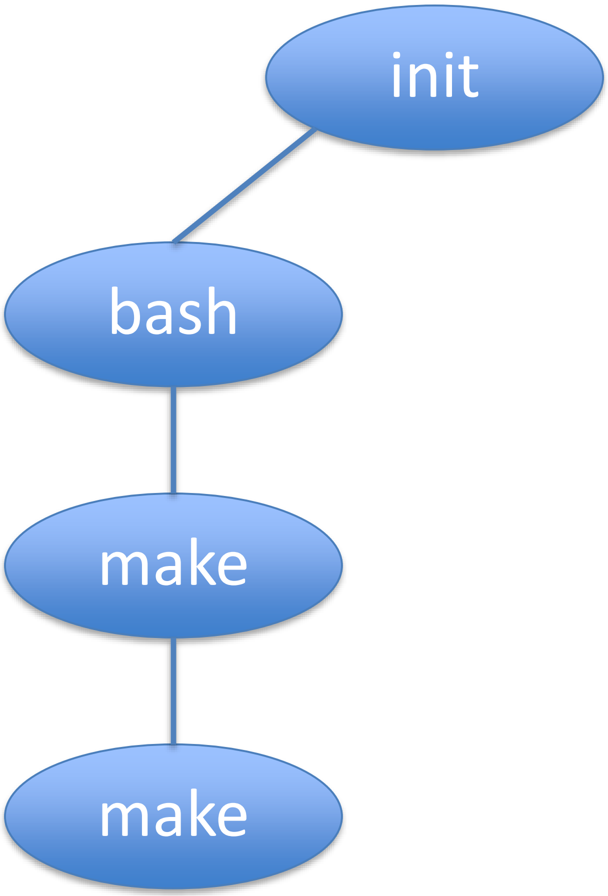
Make runs cp

- Make forks and waits
- Child execs cp



Make runs cp

- Make works and waits
- Child execs cp



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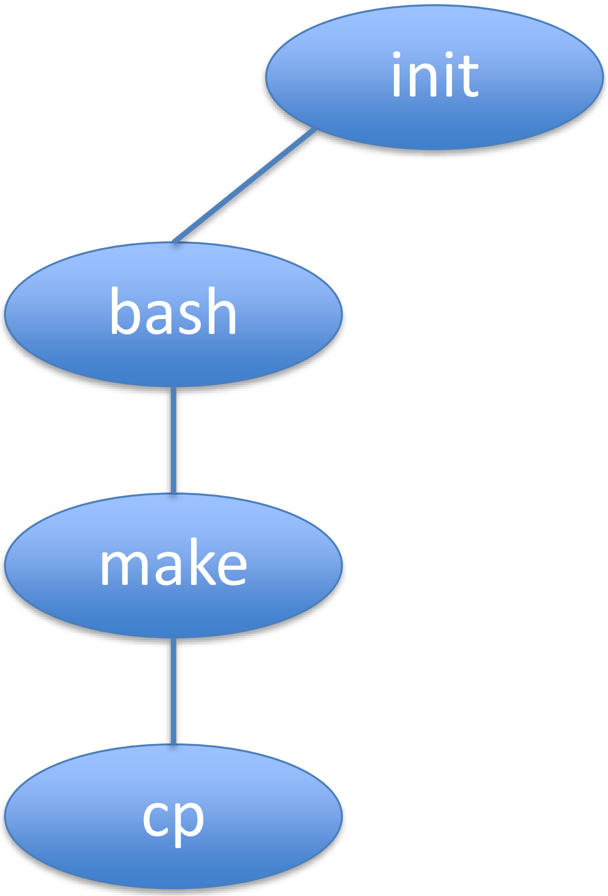


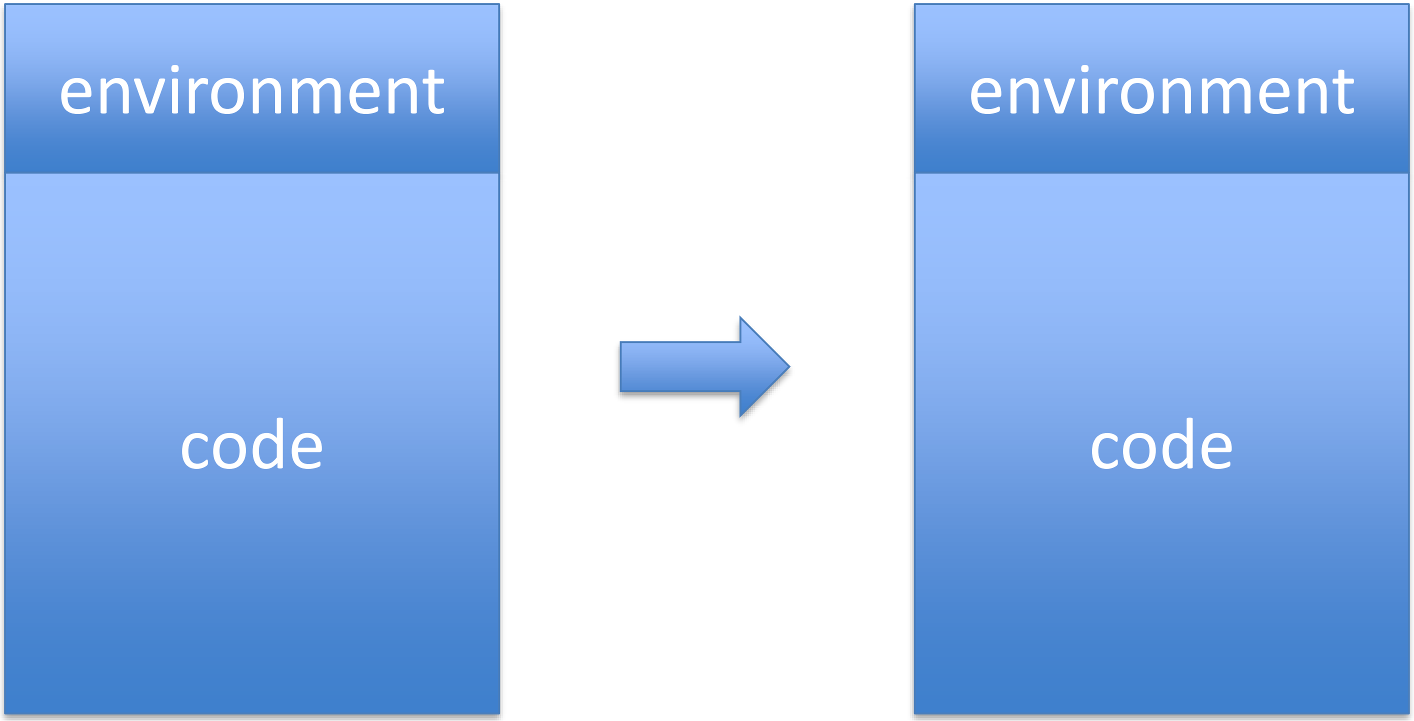
Why fork+exec vs. create?

Process = Environment + Code

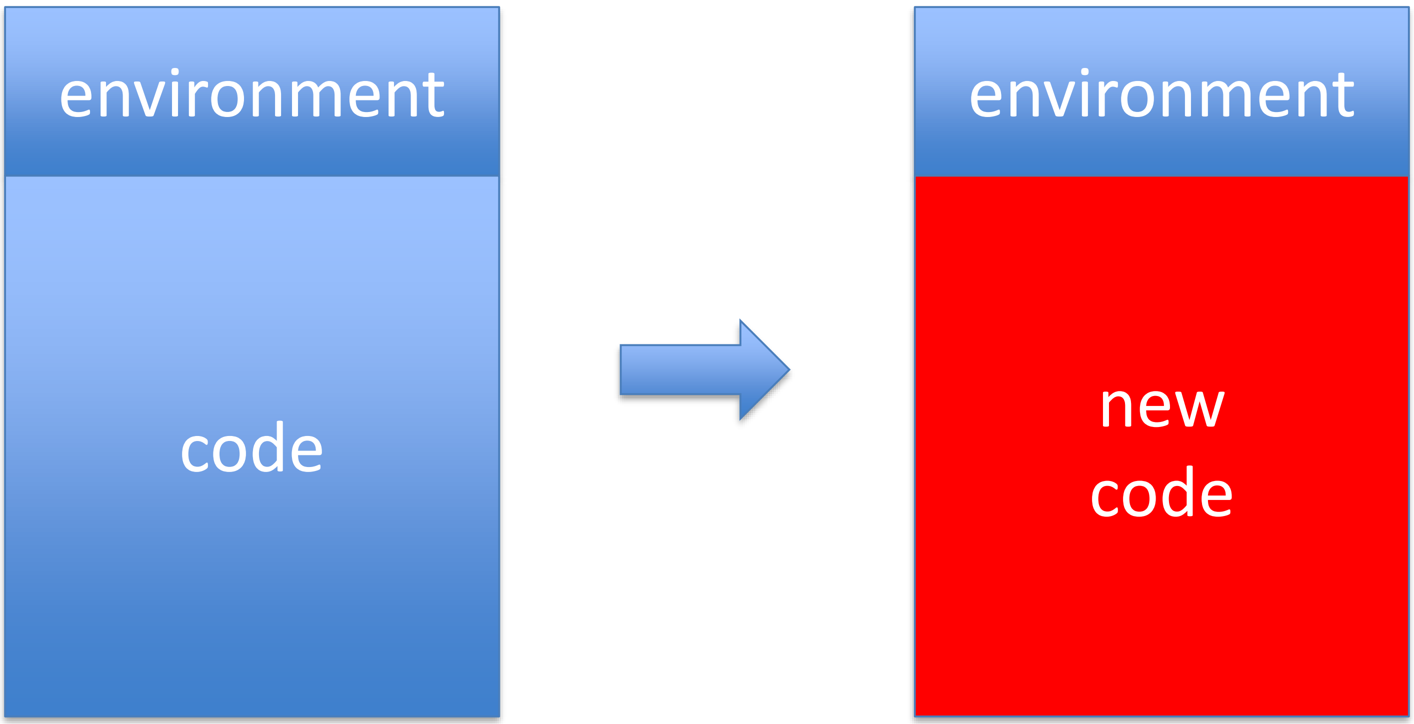
- Environment includes:
  - Ownership
  - Open files
  - Values of environment variables

Process = Environment + Code

After a fork()



After an exec() in the Child



Advantage

- Child automatically inherits environment

Question about fork-exec

```
if ( pid = fork() ) {
    wait()
}
else {
    exec( filename )
}
```

does it make sense
to write code here?

Given New Definition of exec

```
forever {
    read from input
    if( logout) exit()
    if ( pid = fork() ) {
        wait()
    }
    else {
        exec( filename )
    }
}
```

does it make sense to write code here?

Answer

- Yes
- Shell can manipulate environment of child
- For instance, can manipulate stdin and stdout
- See exercises for details

What does a process do?
(as far as a user is concerned)

- It can do anything

- Shell
- Compiler
- Editor
- Browser
- …

- These are all processes

What does a process do?
(as far as the OS is concerned)

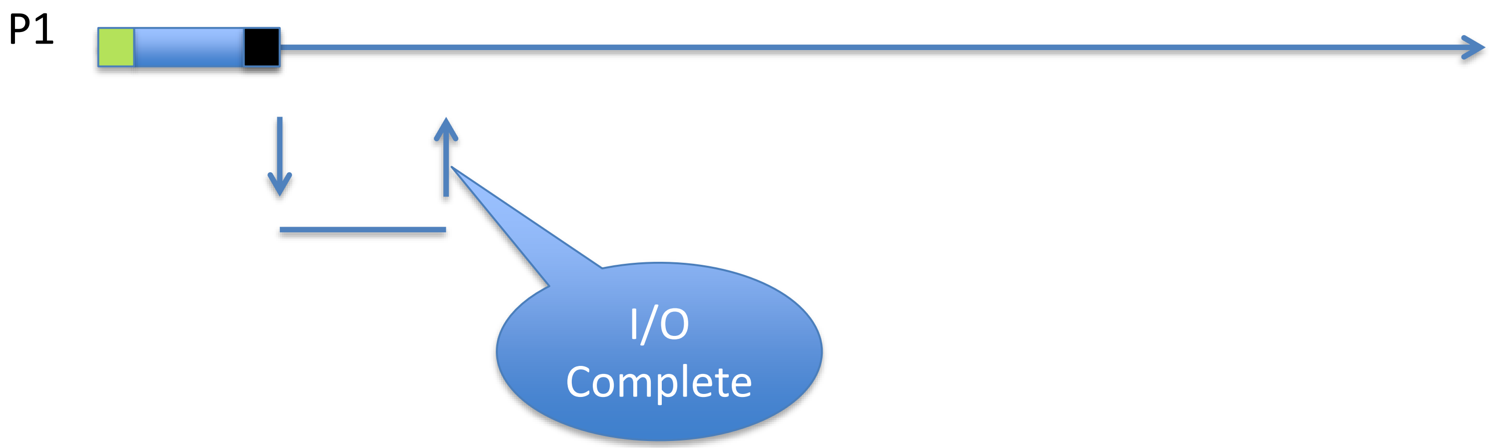
- Either it computes (uses the CPU)
- Or it does I/O (uses a device)

Single Process System

Single Process System

Single Process System

Single Process System



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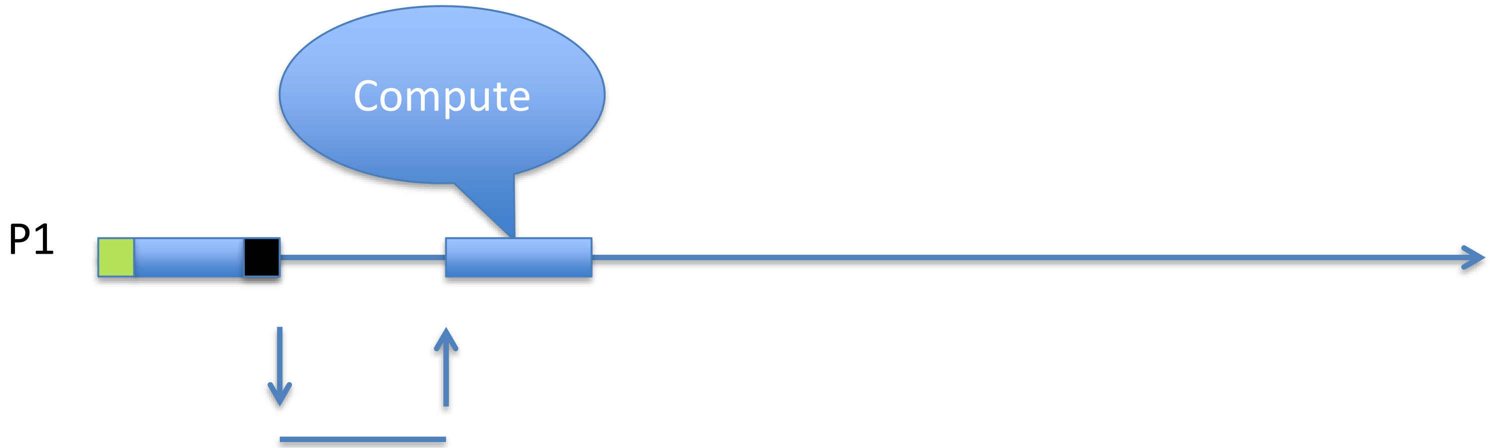

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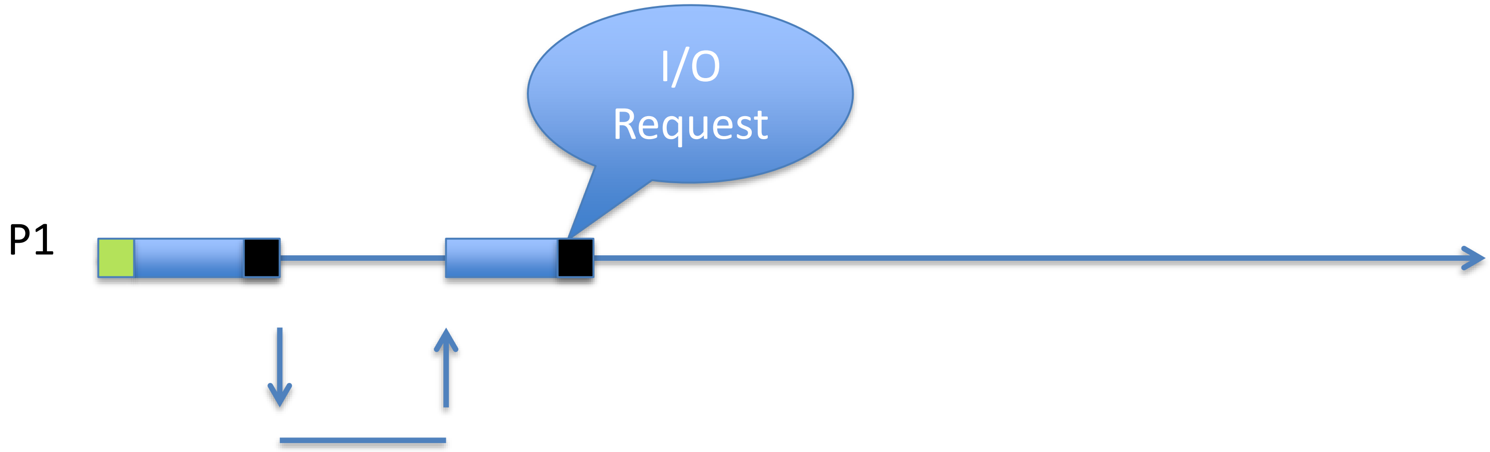

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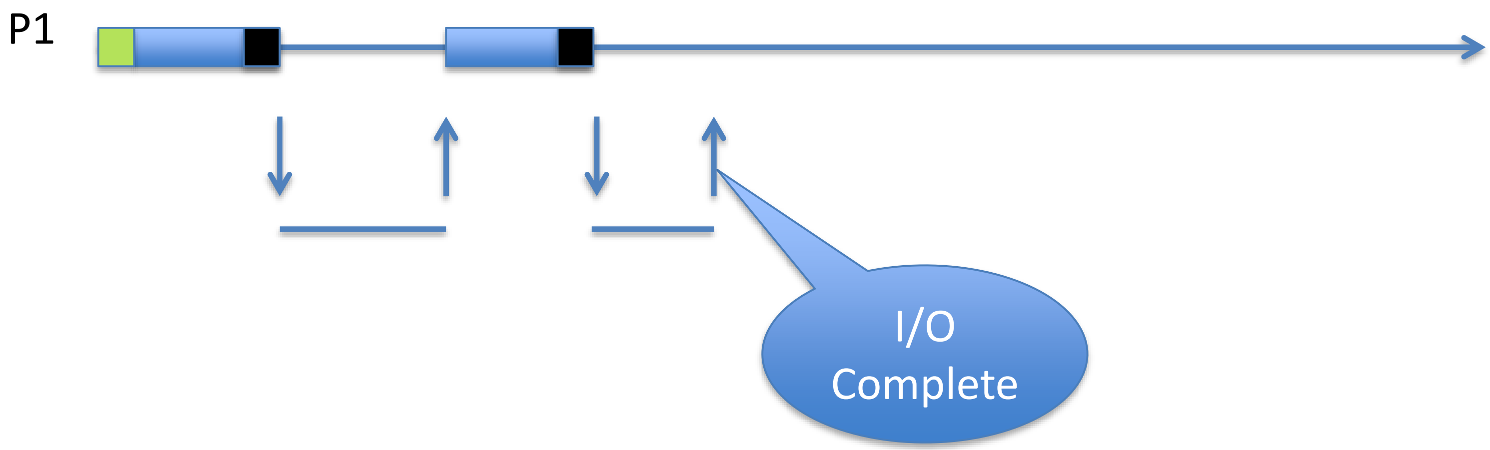

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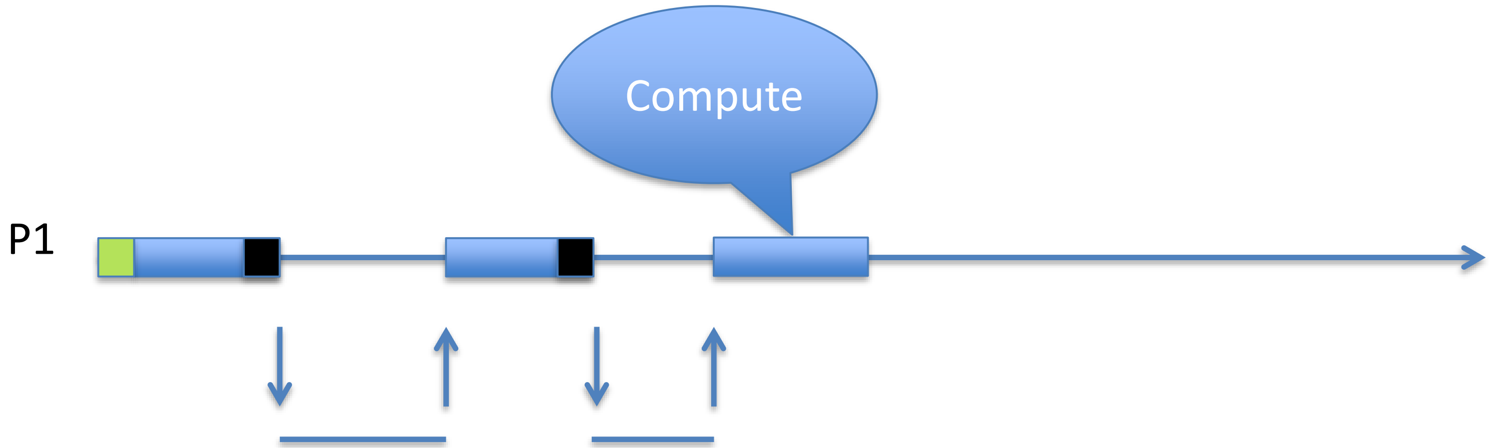

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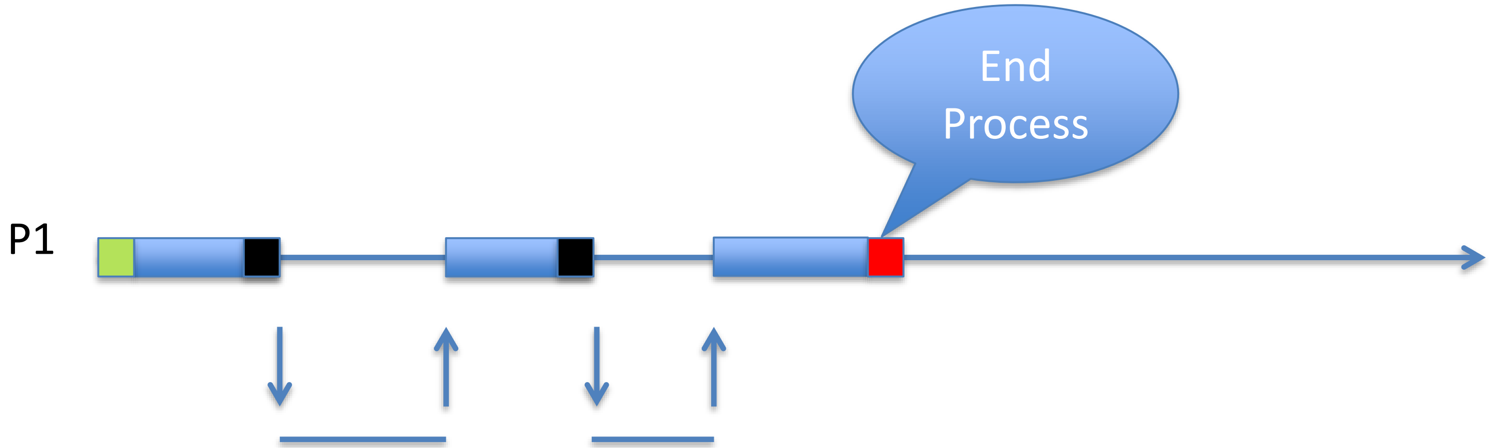
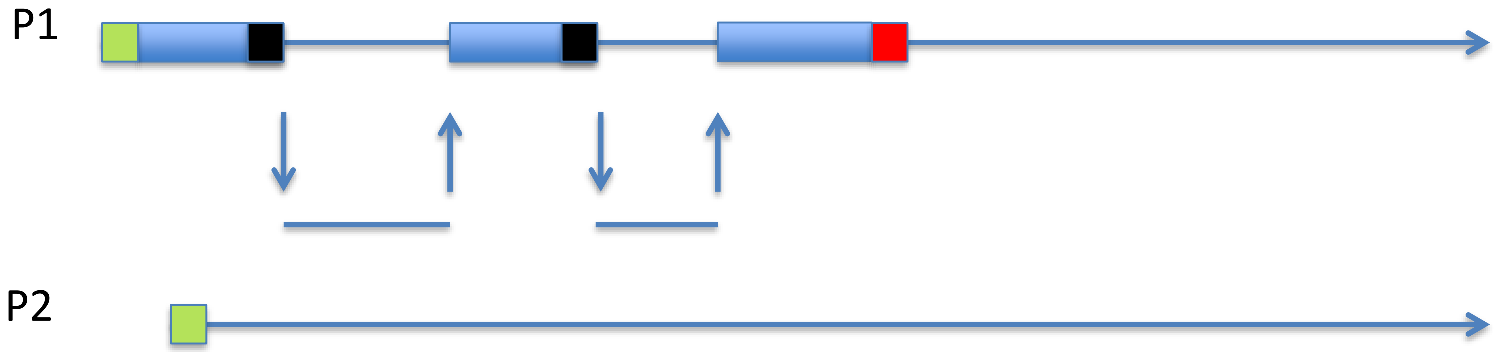


A Second Process



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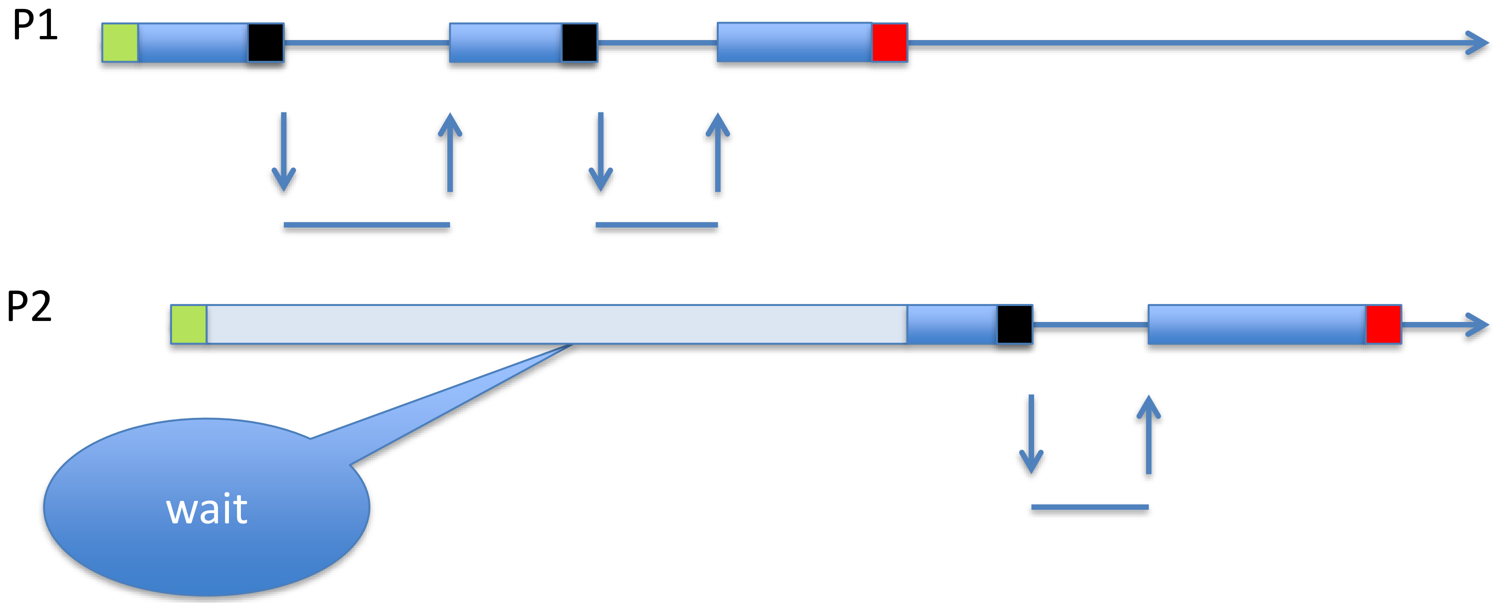
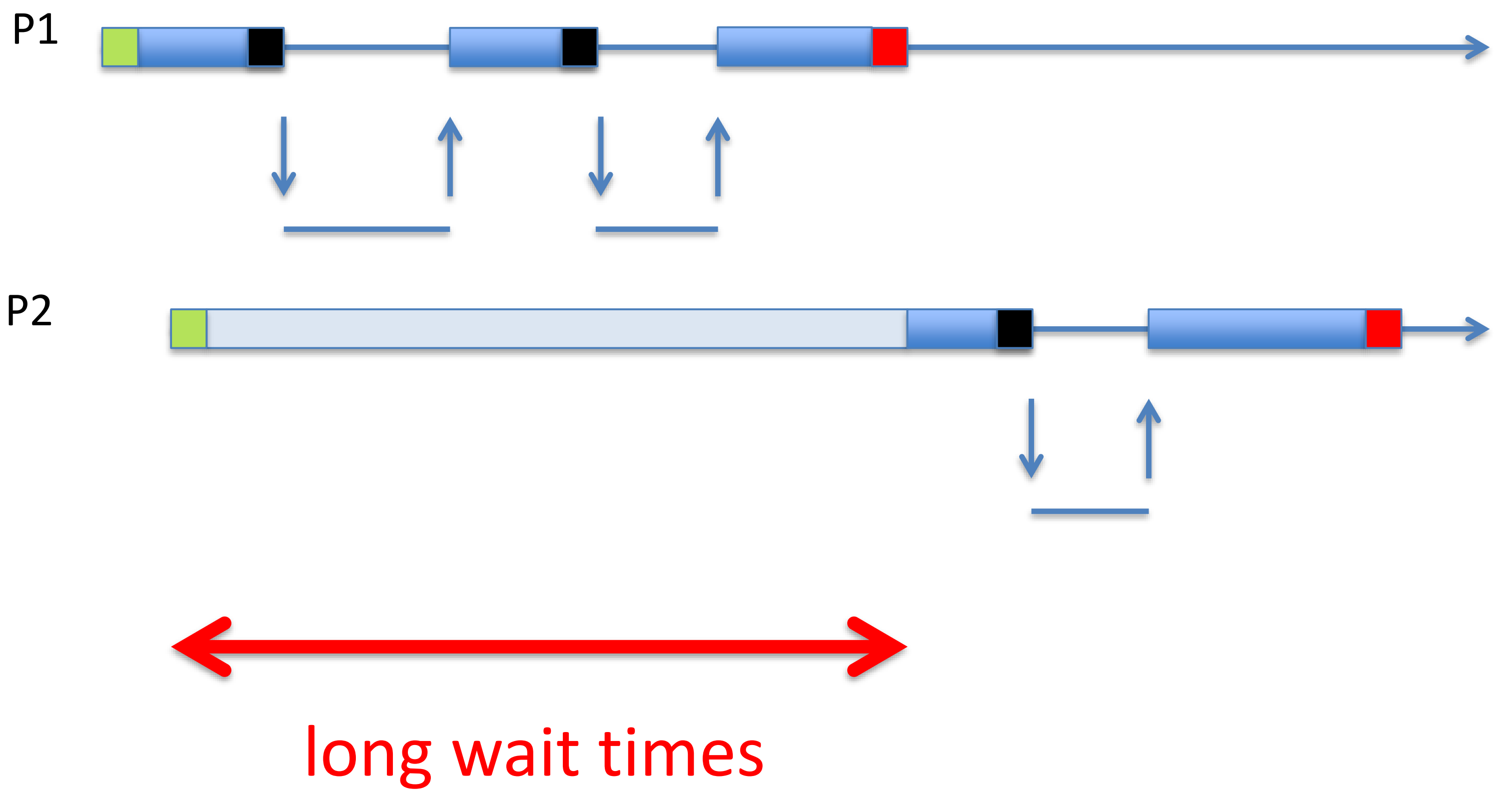


Two Issues



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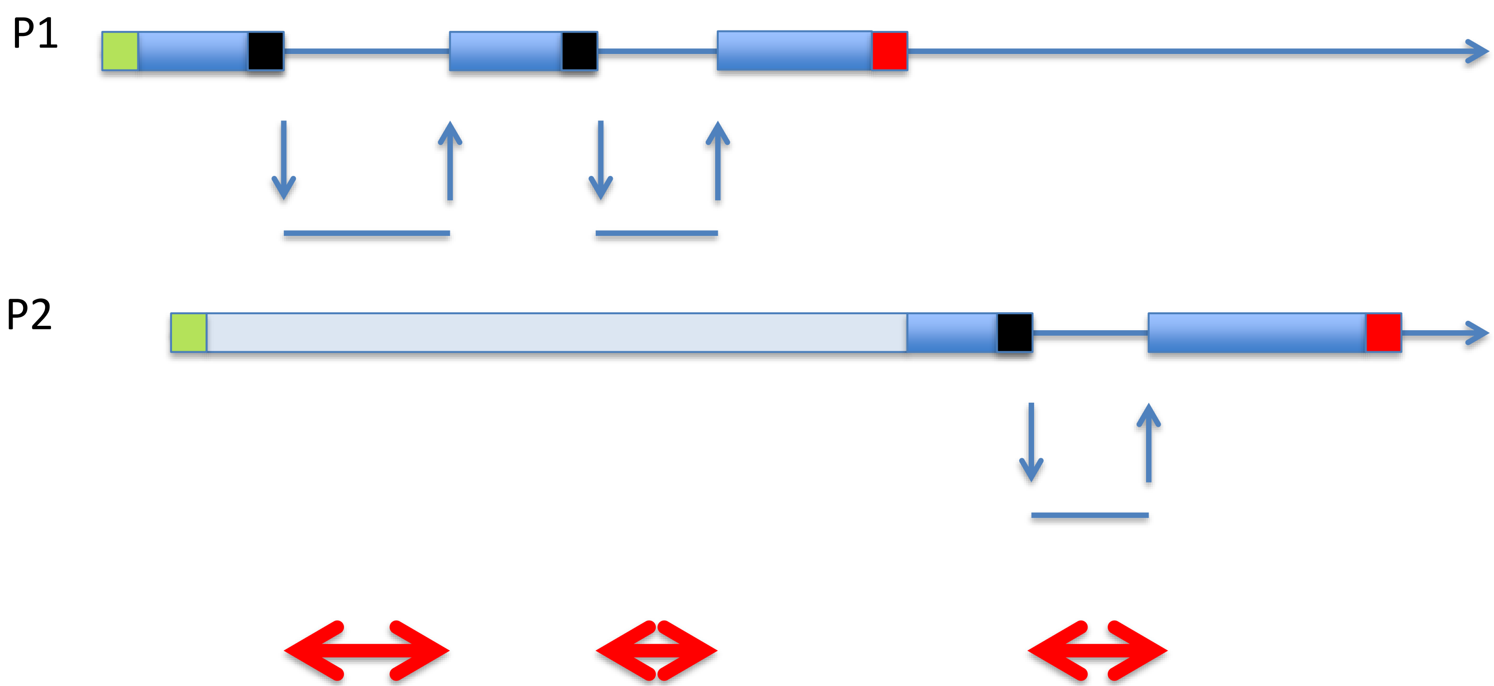

low utilization (long CPU idle times)

Single Process System

- Is very inefficient
  - Very poor CPU utilization
- Is very annoying
  - You can’t do anything else

Multiprocess System

- Many processes in the system
- One uses the CPU
- When it does an I/O
  - It waits for the I/O to complete
  - It leaves the CPU idle
- *Another process gets the CPU*

Multiprocess System

Multiprocess System

Multiprocess System

Multiprocess System

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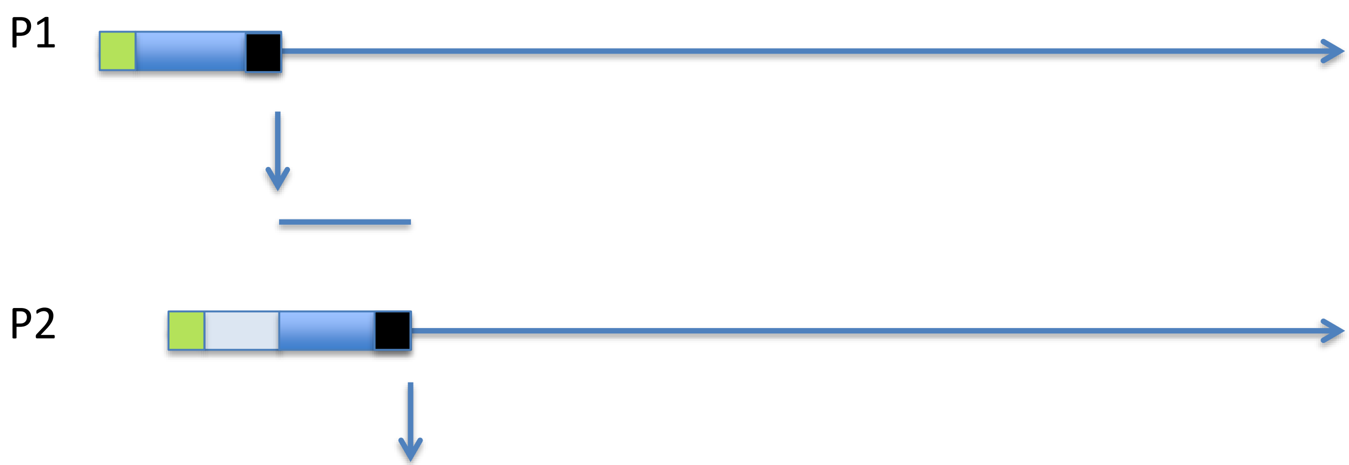
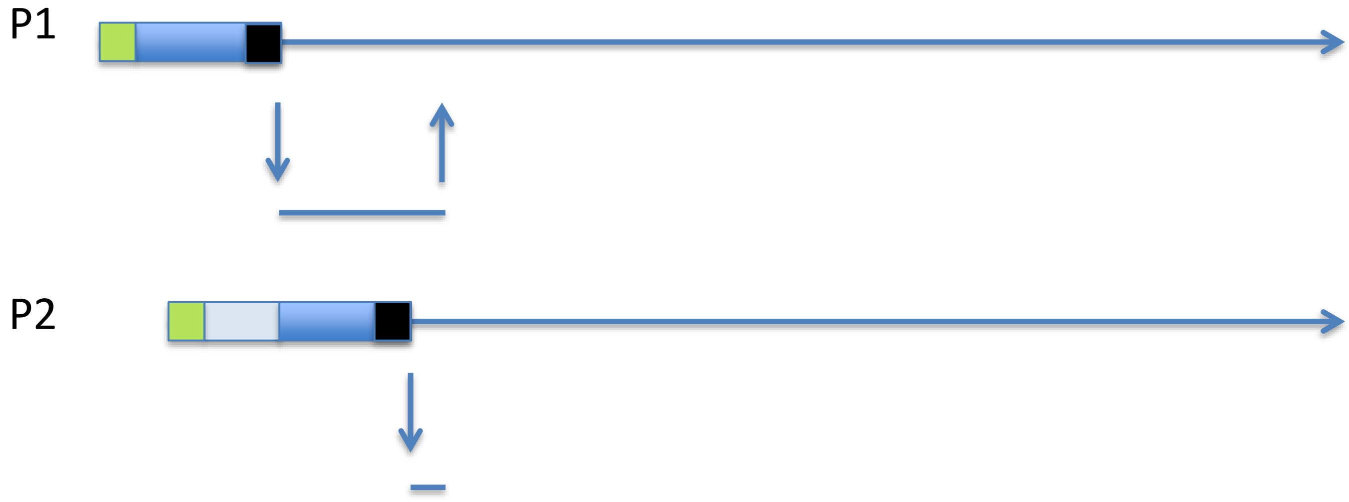
Multiprocess System



Multiprocess System



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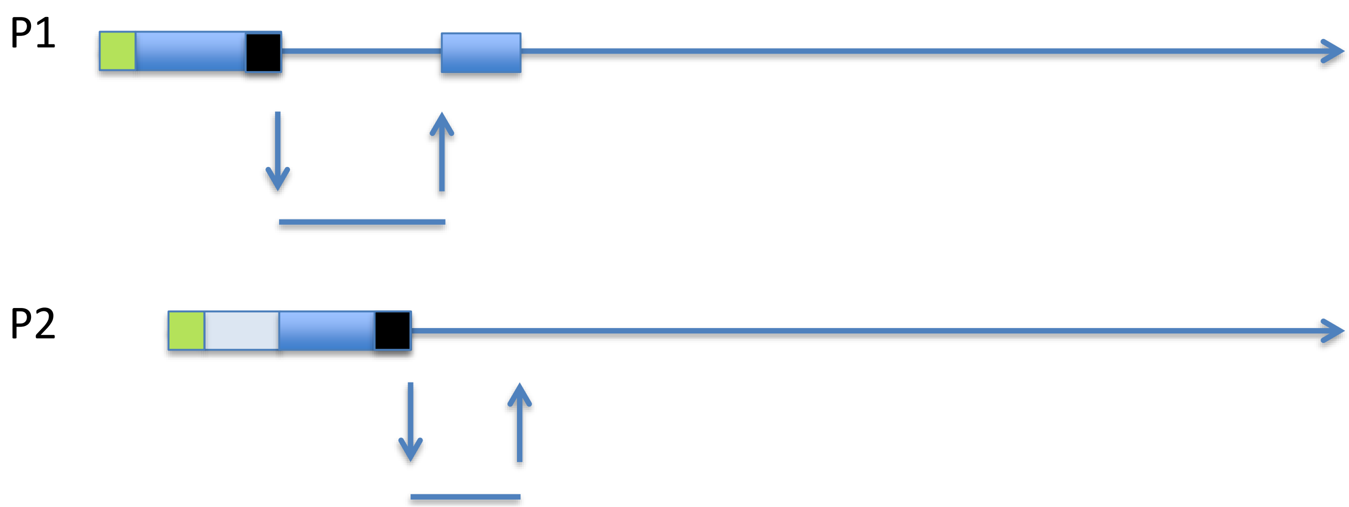

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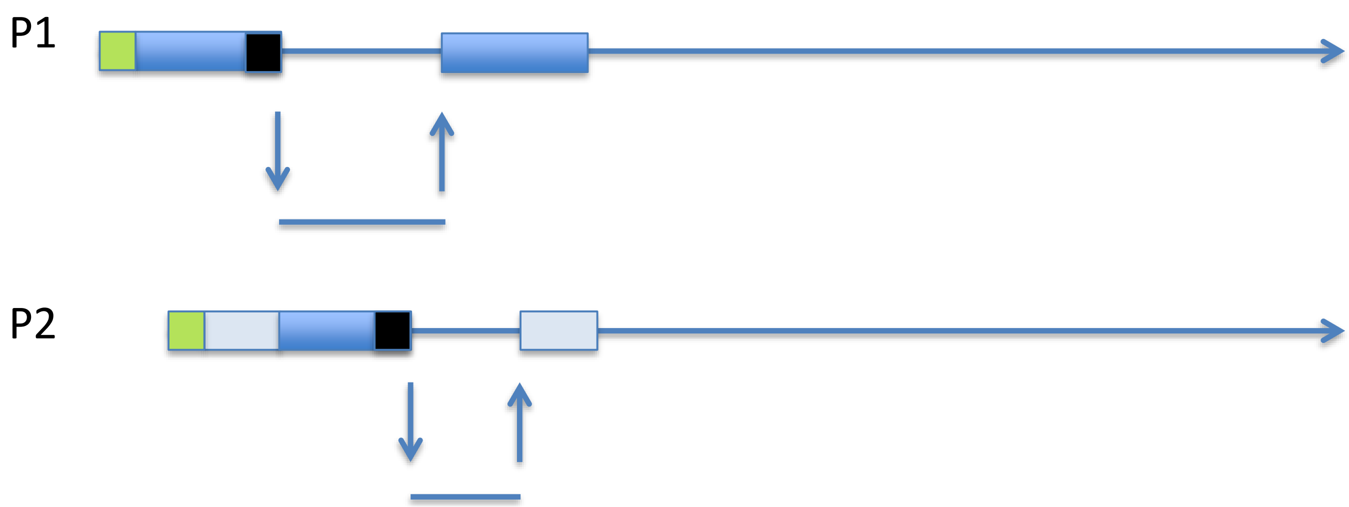

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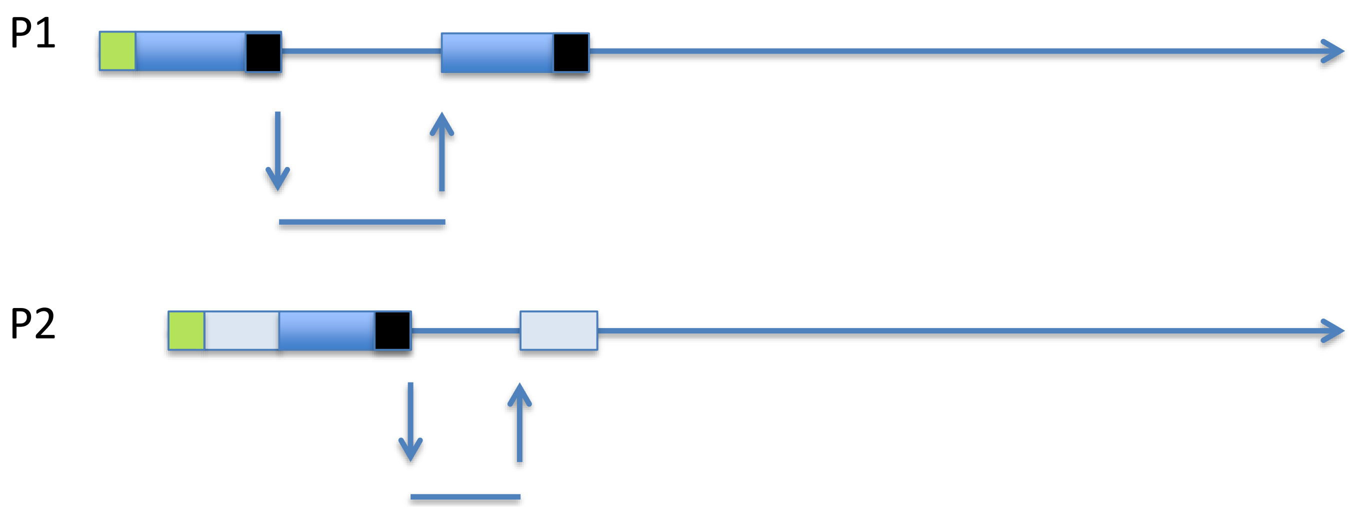

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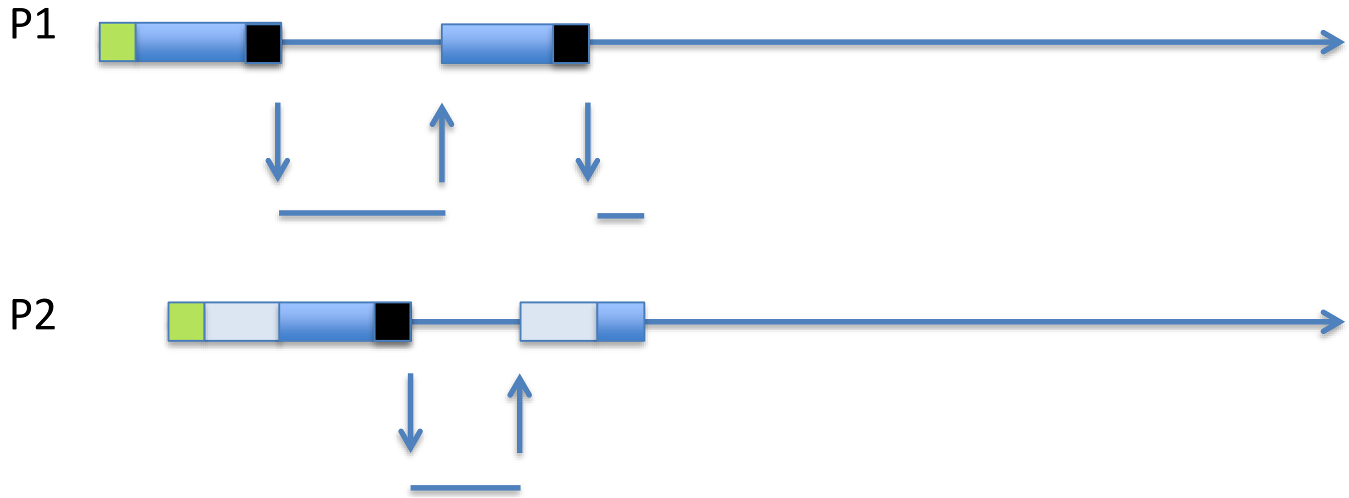

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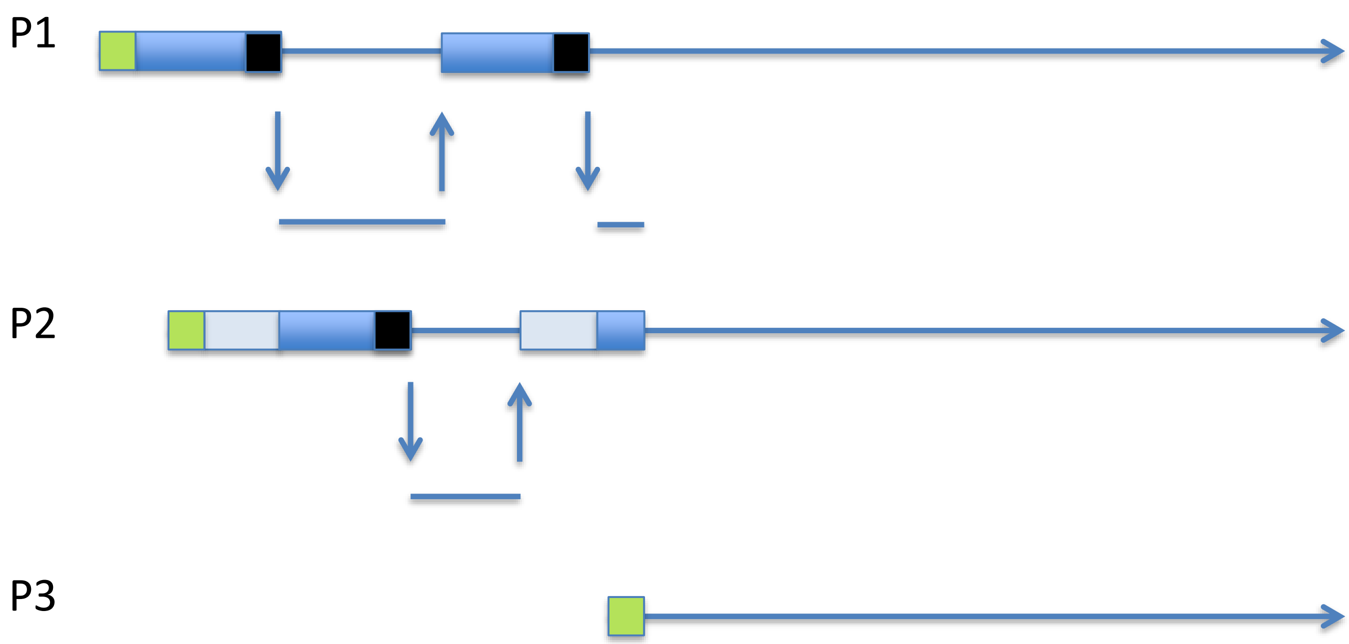

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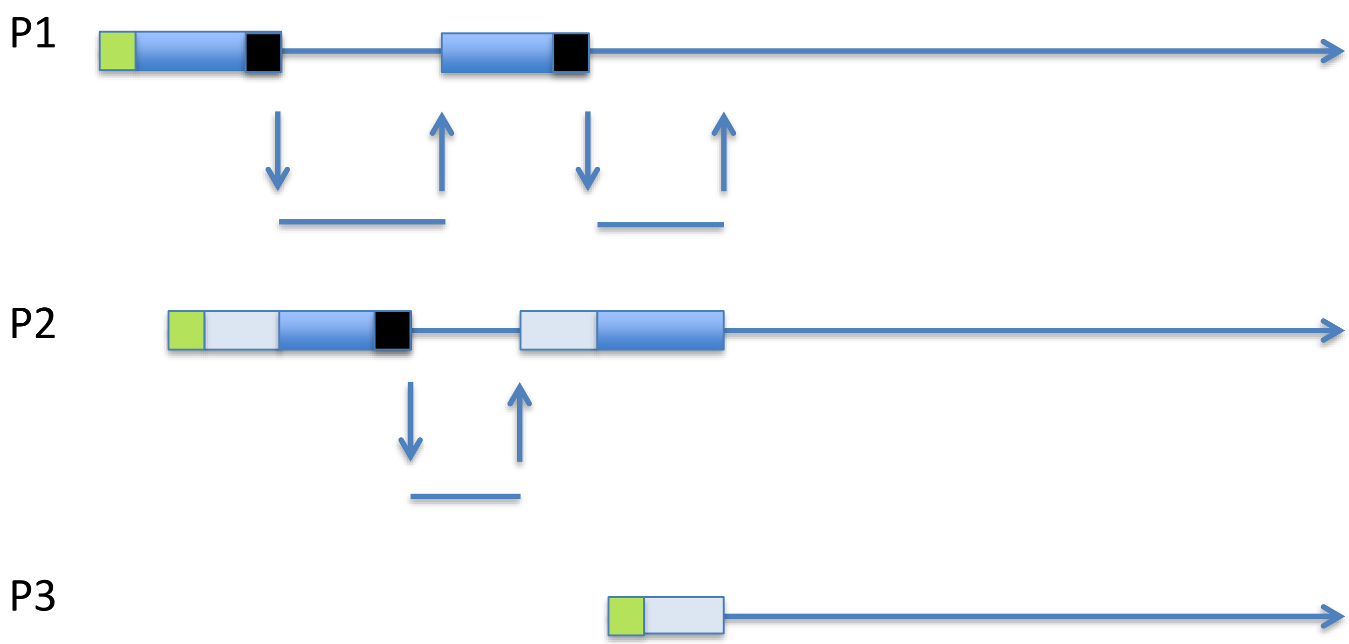

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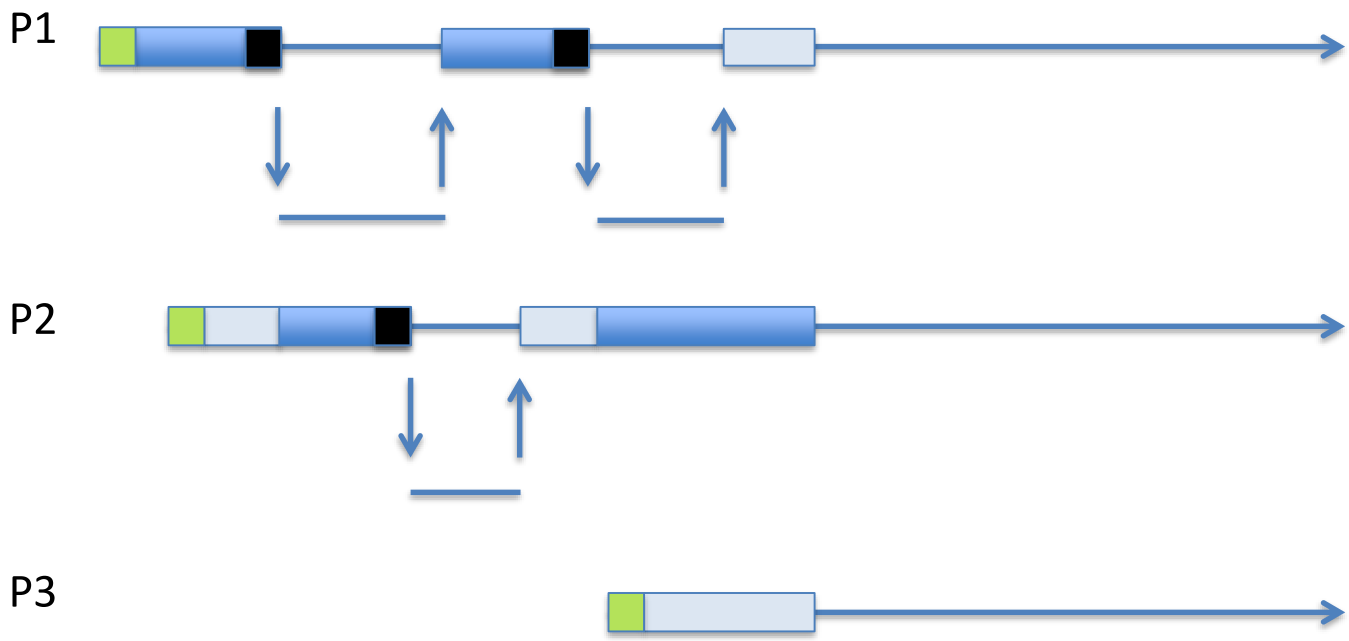

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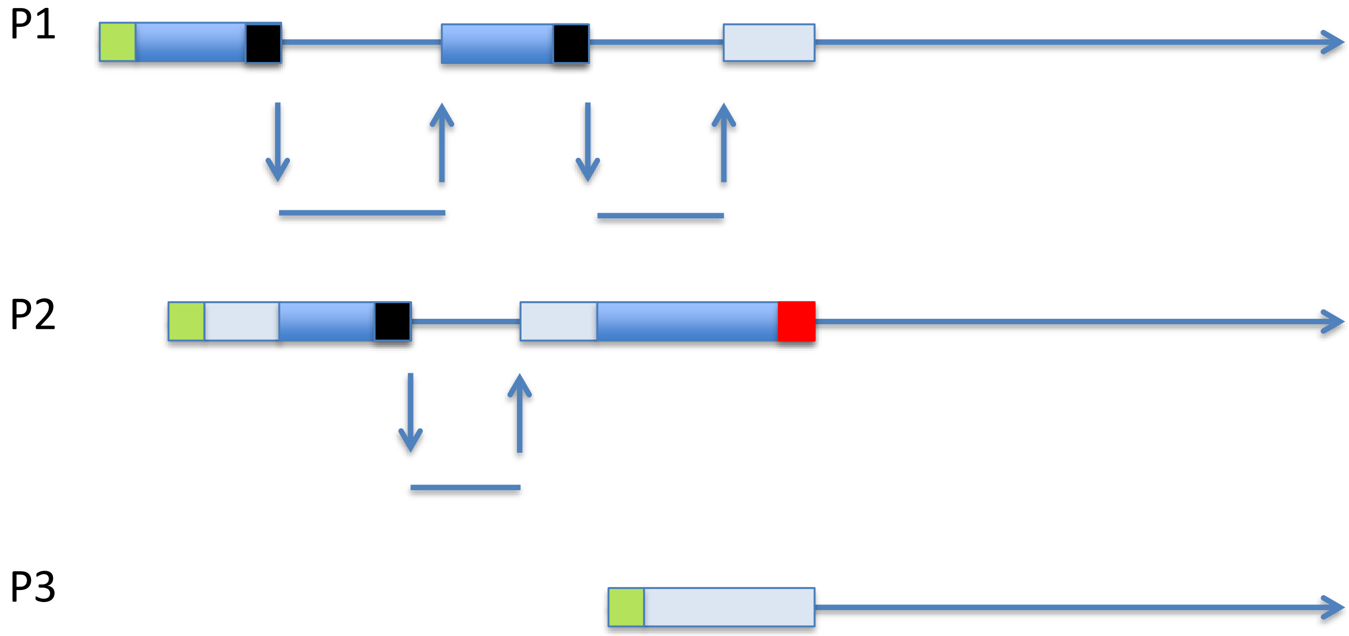

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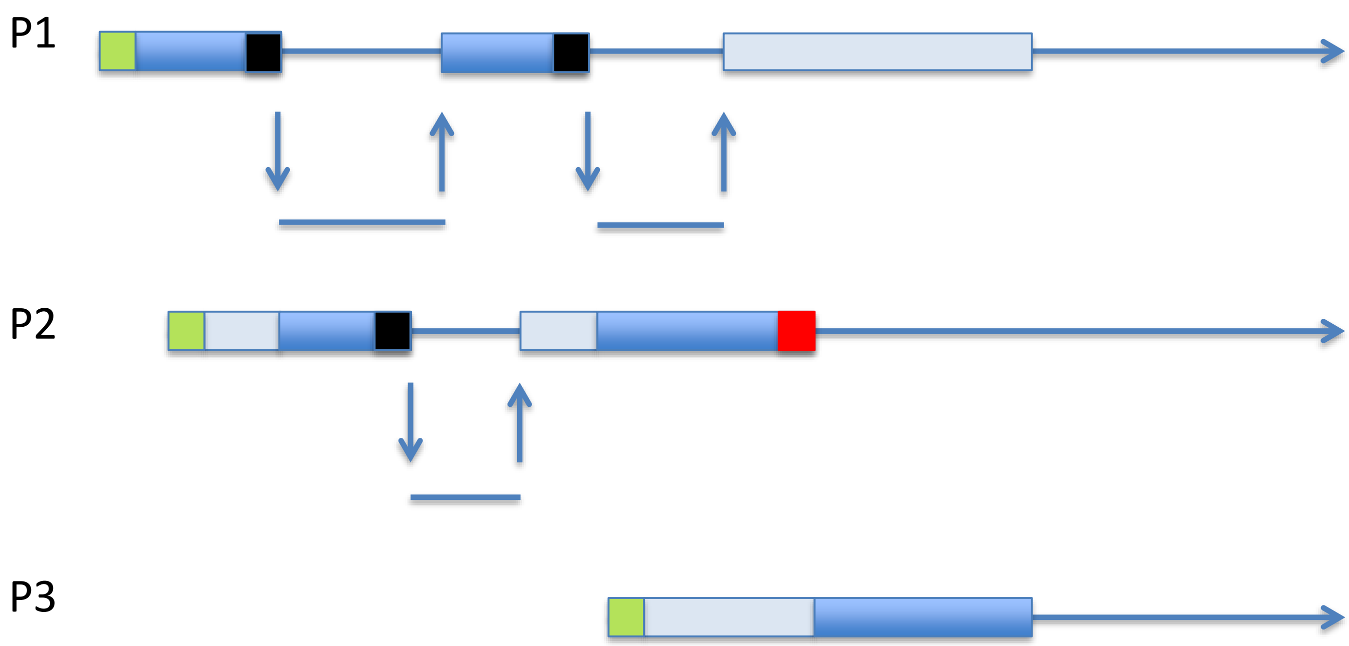

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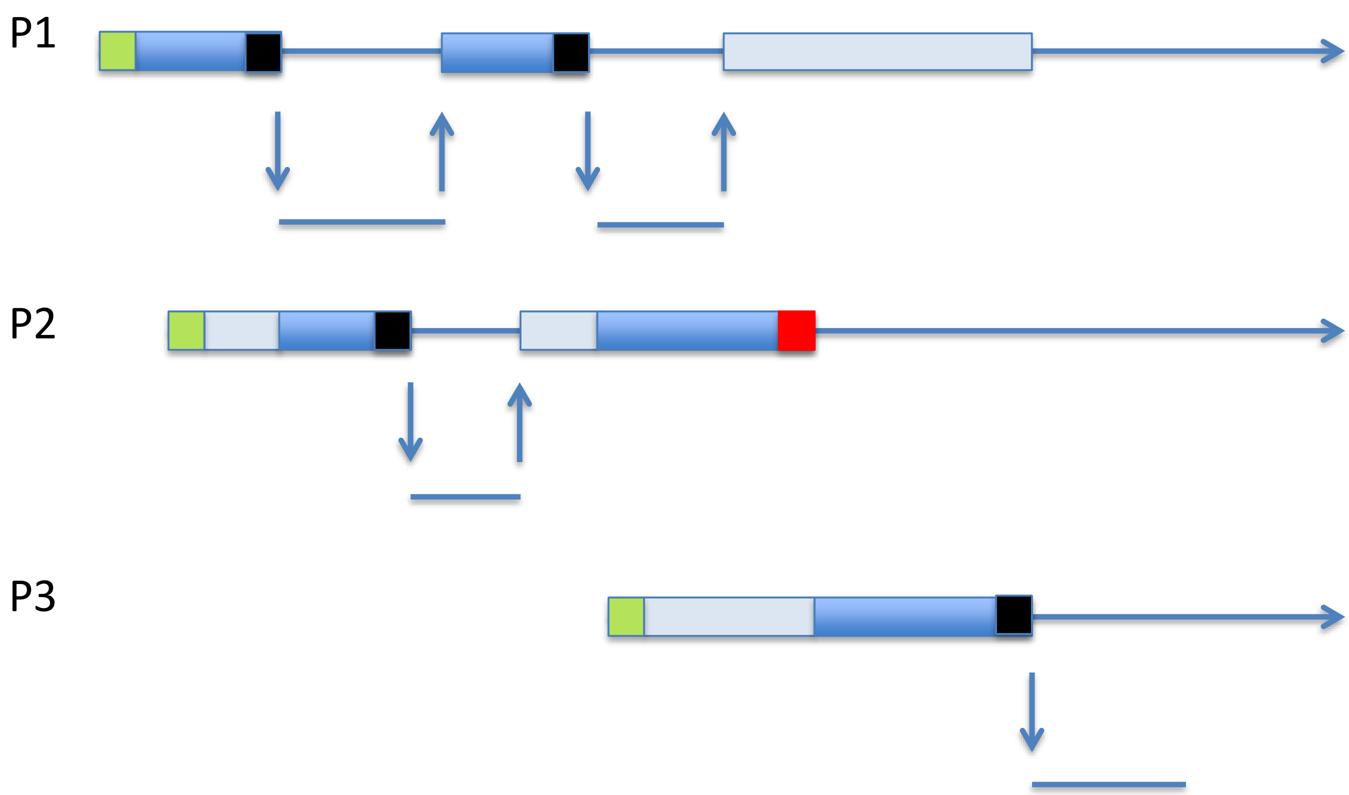

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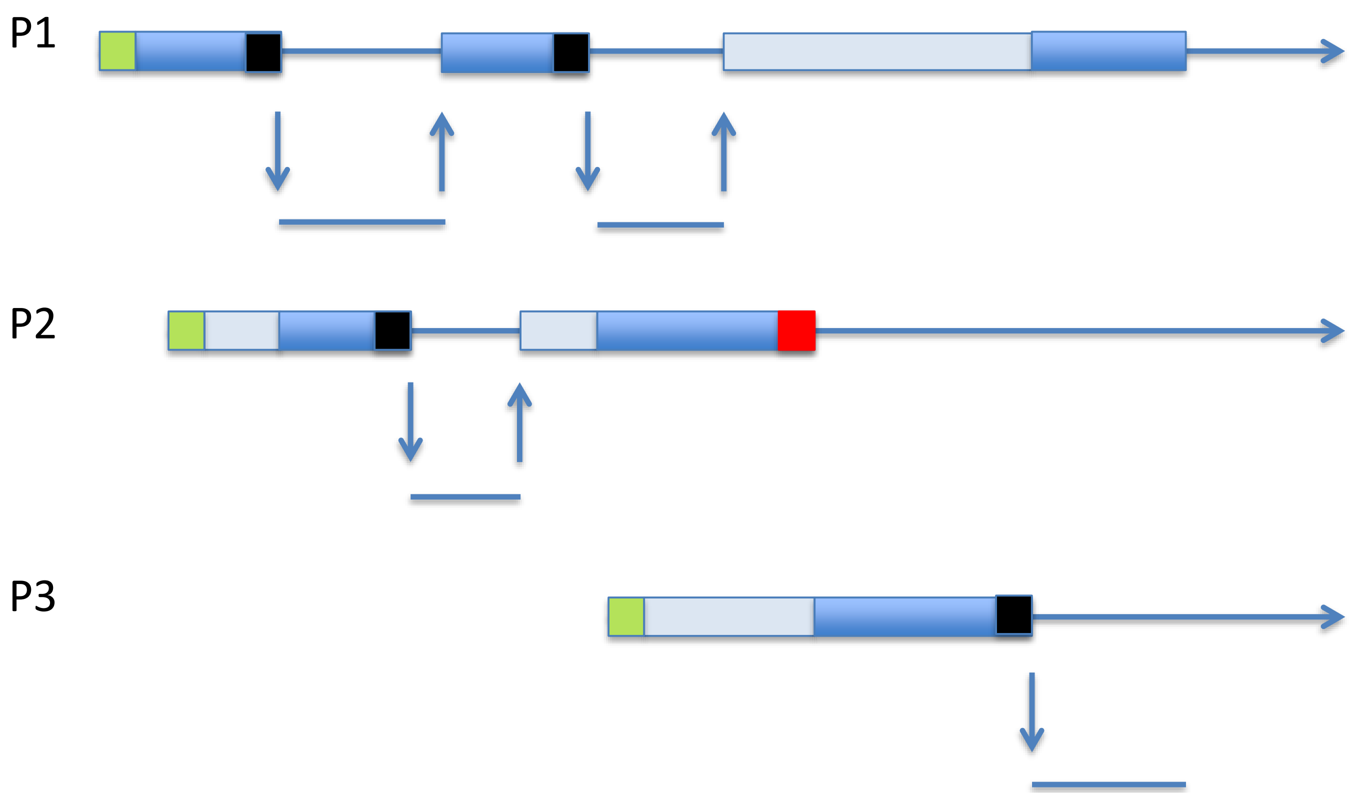

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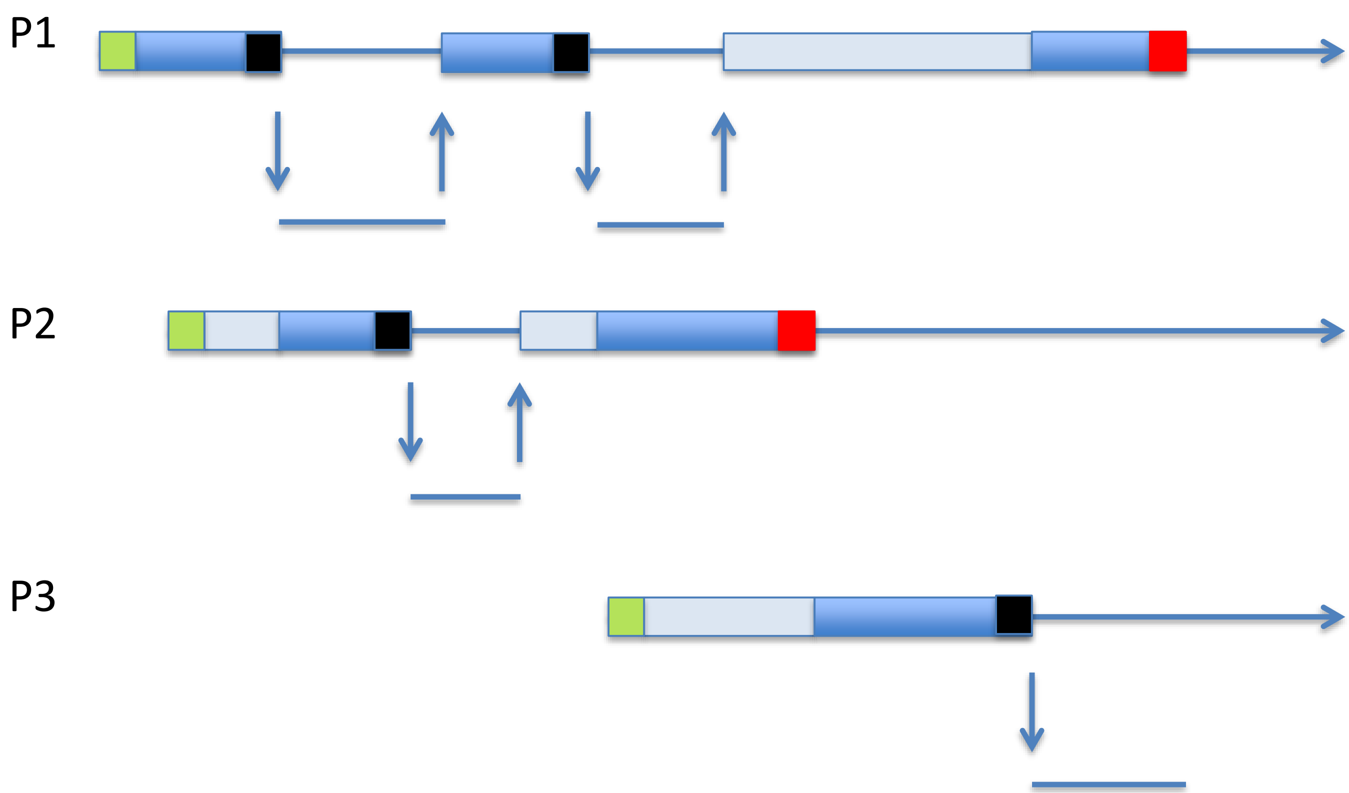

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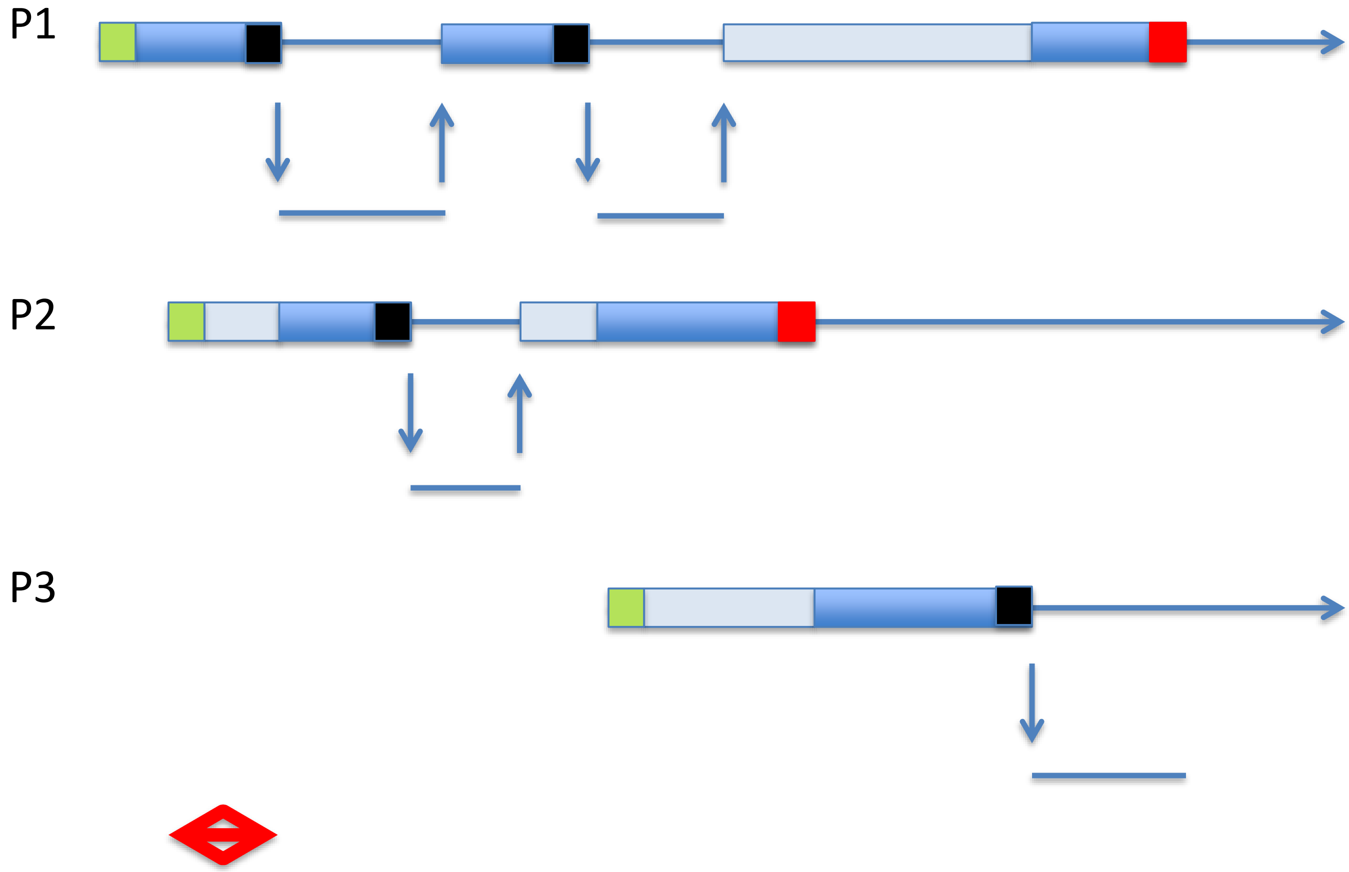
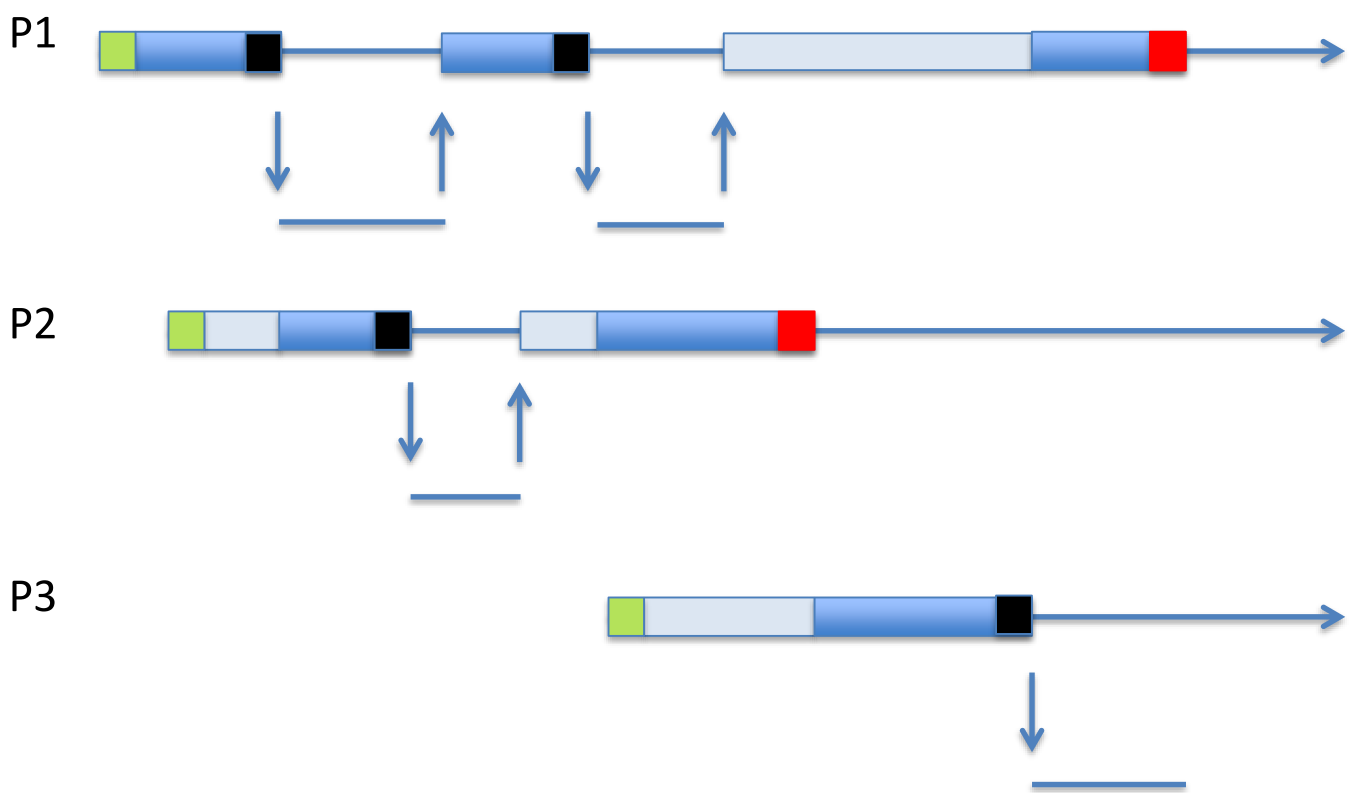


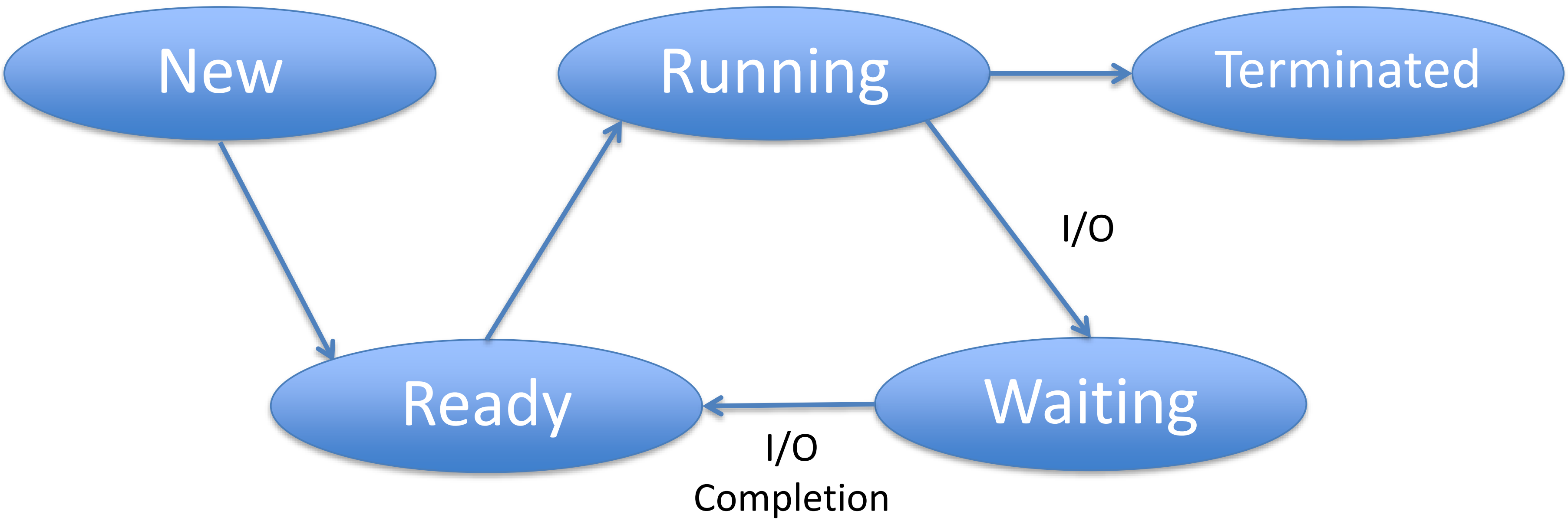
short wait time

Multiprocess System



high utilization (short CPU idle times)

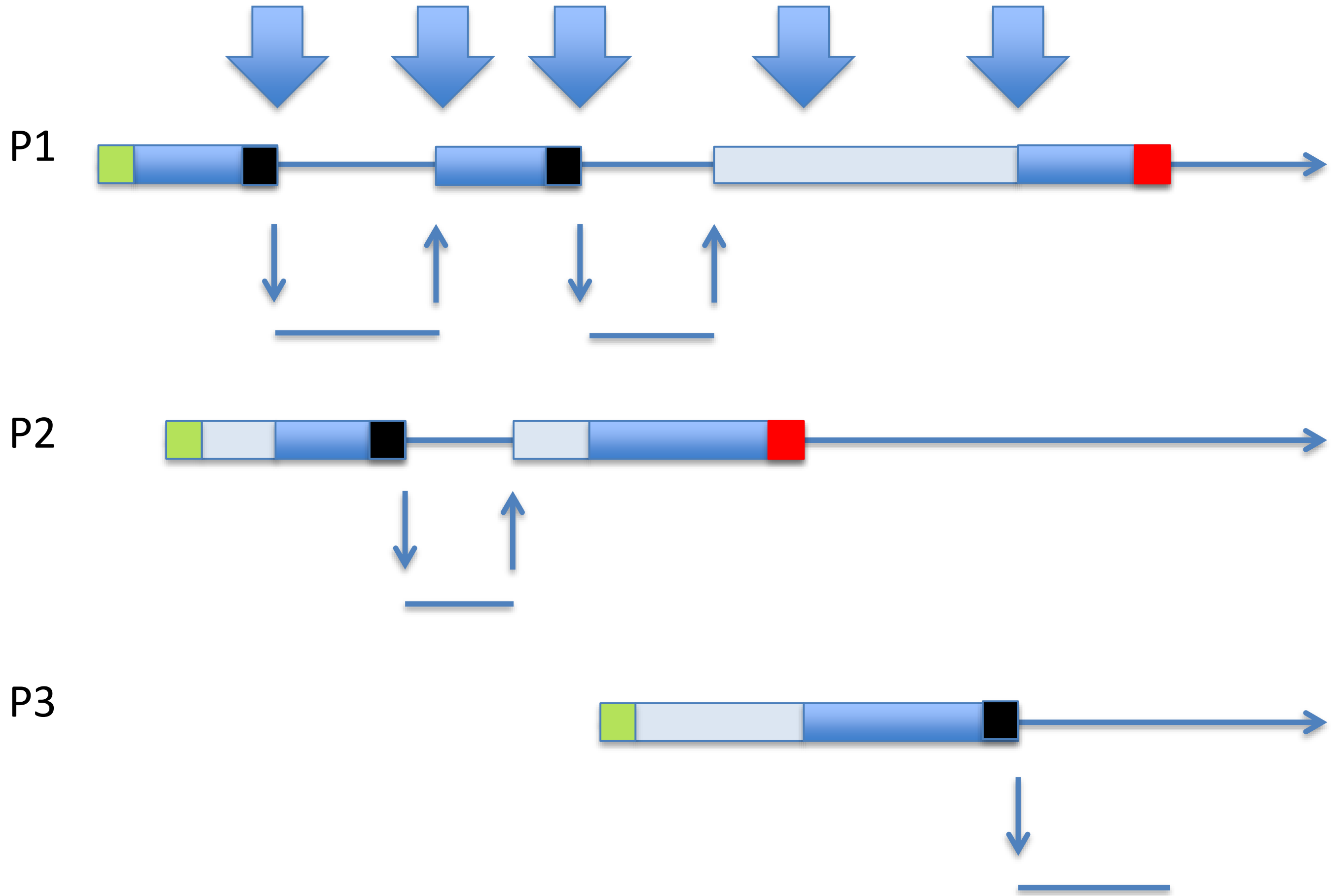
Process State Diagram for Multiprocessing System



Two Important Concepts

- Process switch
- Process scheduling

Process Switch



Process Switch

- Switch from one process running on the CPU to another process
- Such that you can later switch back to the process currently holding the CPU

Process Switch Implementation

- Process consists of:
  - Code (including libraries)
  - Stack
  - Heap
  - Registers (including PC)
  - MMU info (ignore for now)

Process

Process Switch Implementation

- Process:
  - Code
  - Stack
  - Heap
  - Registers
  - MMU info

Code, Stack, Heap: Resides in process-private locations

Registers, MMU info: Resides in shared locations

Process Switch P1 → P2

- Save registers(P1) to somewhere
- Restore registers(P2) from somewhere

- Where to save to and restore from?

Process Control Block

- Kernel must remember processes
- Each process has a process control block (PCB)
- Process control block contains
  - Process identifier (unique id)
  - Process state
  - *Space to support process switch (save area)*
- Process Control Block Array
  - Indexed by hash(pid)

Process Switch P1 → P2

- Save registers → PCB[P1].SaveArea
- Restore PCB[P2].SaveArea → registers

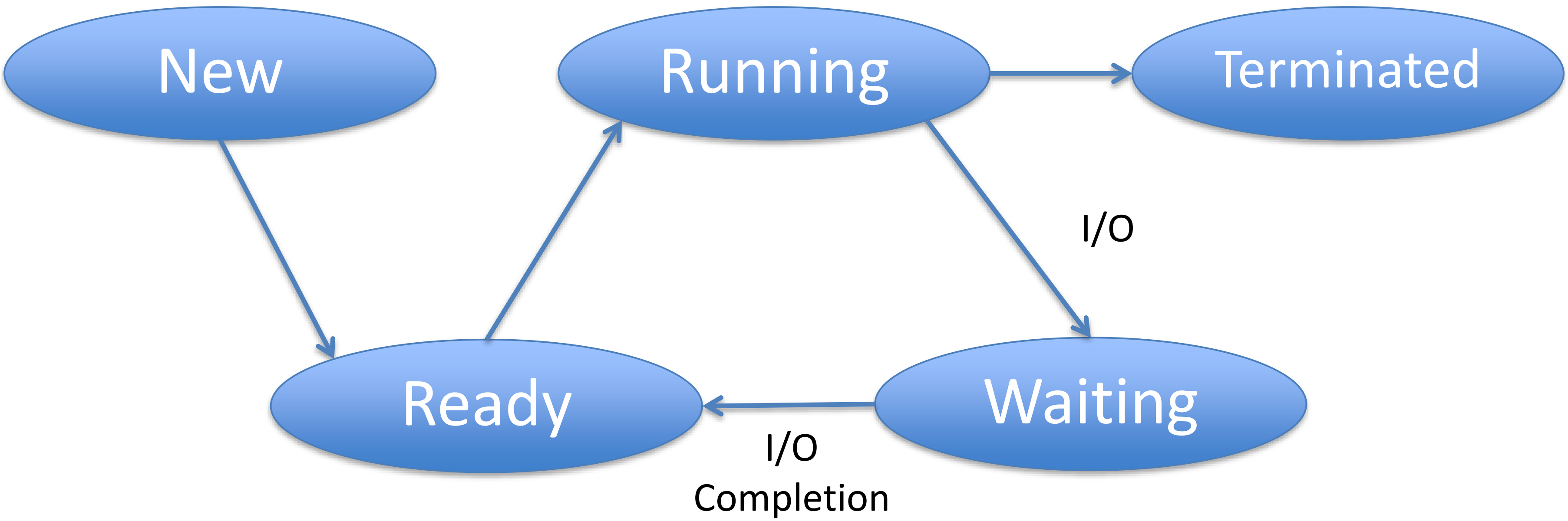
Process Switch - Caveat

- A process switch is an expensive operation!
- Requires saving and restoring lots of stuff
  - Not just registers
  - Also MMU information
- Has to be implemented very efficiently
- Has to be used with care

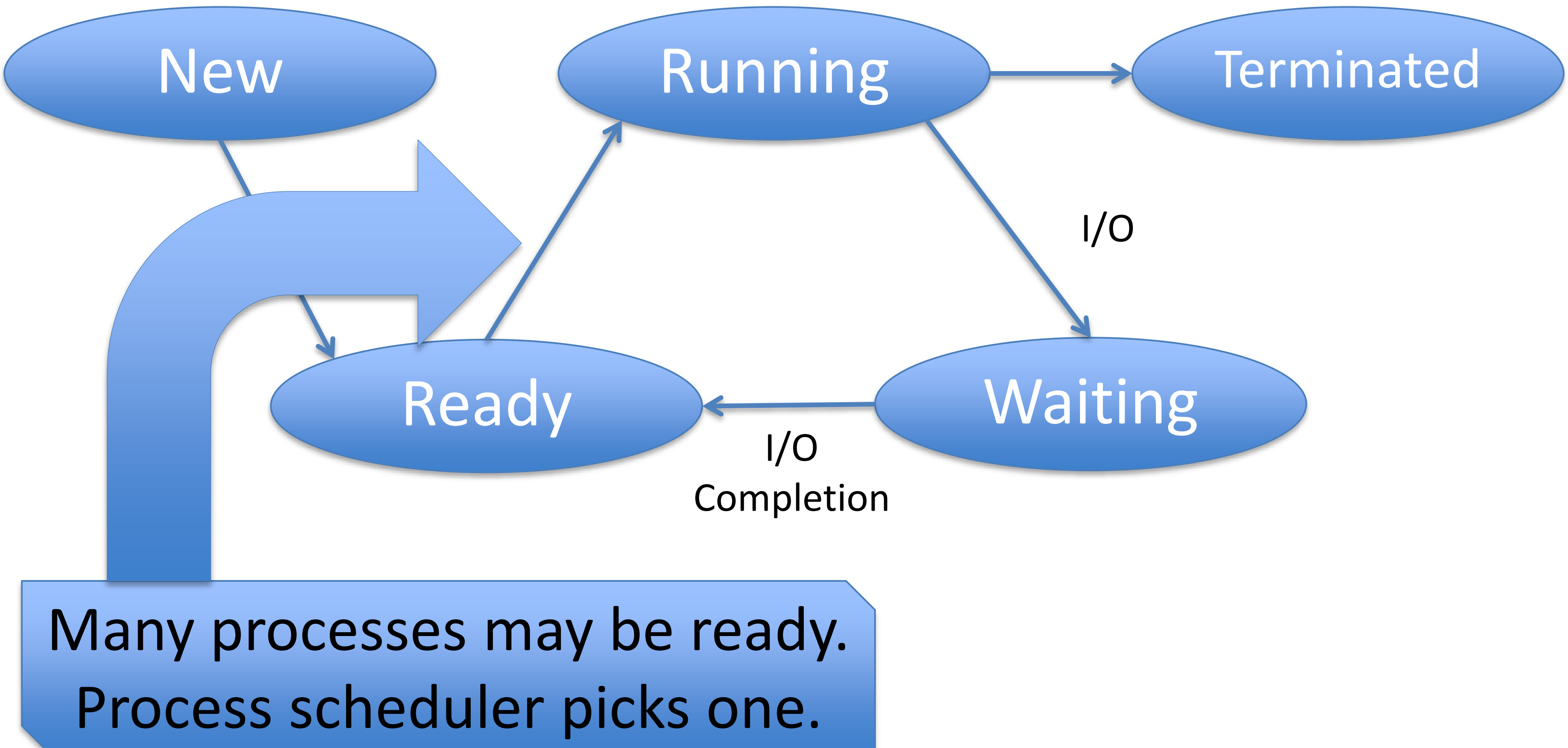
Two Important Concepts

- Process switch
- *Process scheduling*

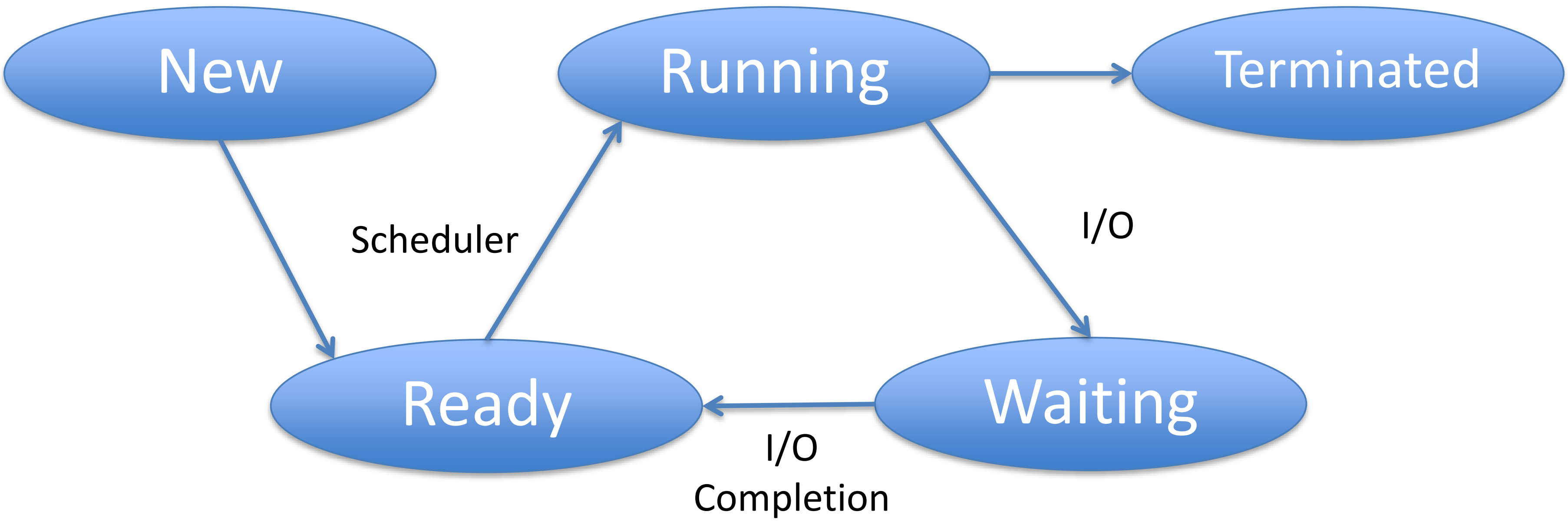
Process Scheduling



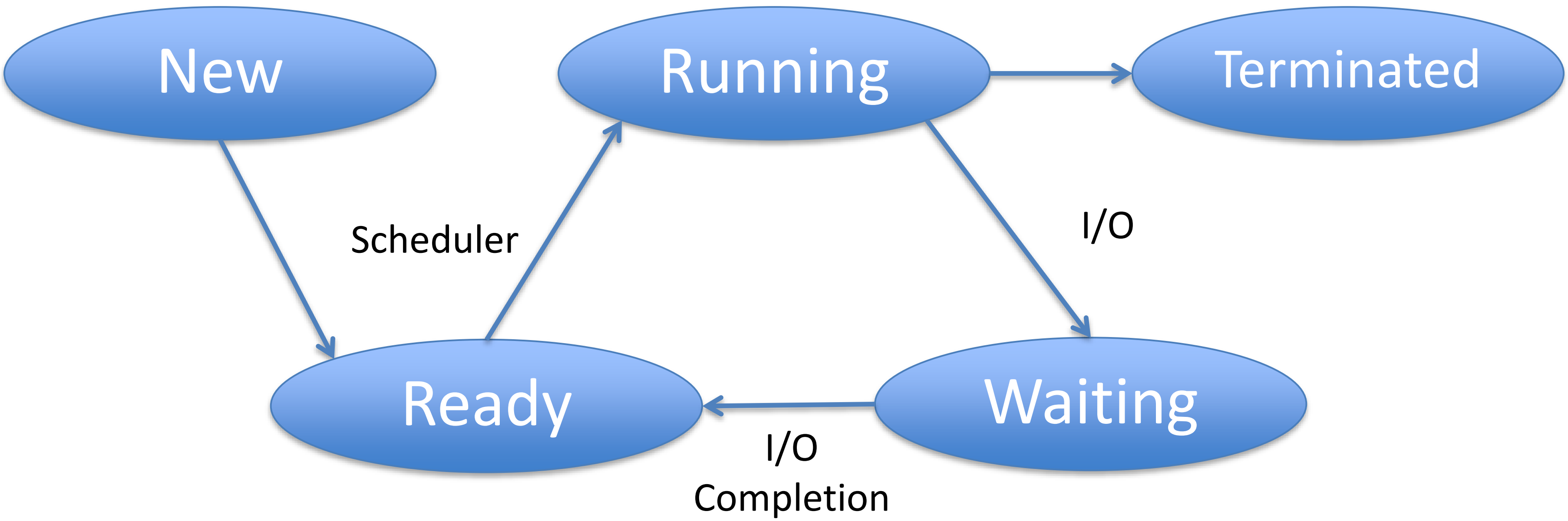
Process Scheduling



Process Scheduling

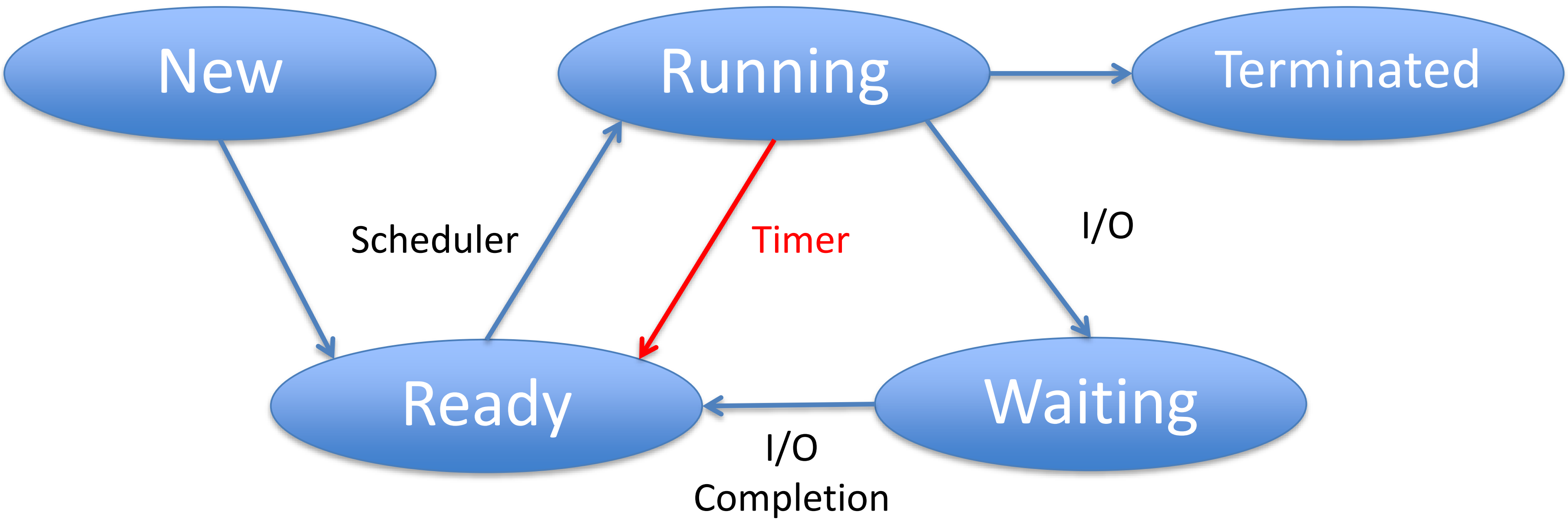


Problem



A process could run forever, locking all other processes out

Solution


New
Running
Terminated
Scheduler
Timer
I/O
Ready
Waiting
I/O
Completion

Preemptive vs Non-preemptive Scheduler

- Non-preemptive:
  - Process only voluntarily relinquishes CPU
- Preemptive
  - Process may be forced off CPU

Advantages - Disadvantages

- Non-preemptive
  - Process can monopolize CPU
  - Only useful in special circumstances
- Preemptive
  - Process can be thrown out at any time
  - Usually not a problem, but sometimes it is
- Intermediate solutions are possible

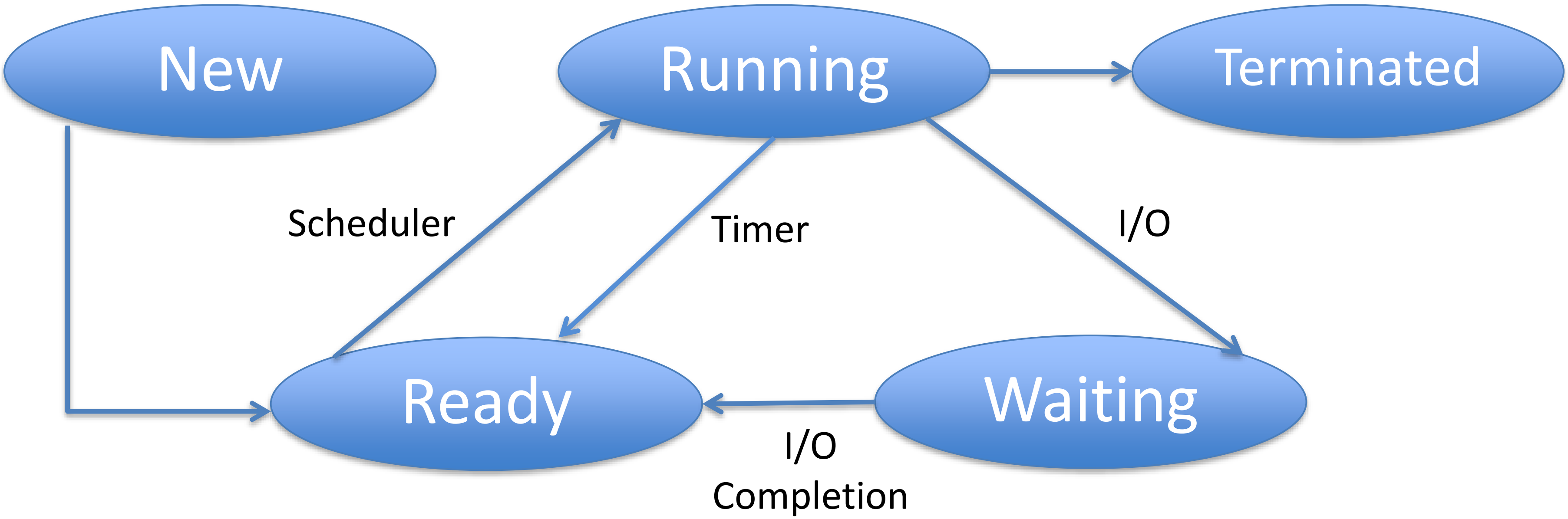
Process Scheduling Implementation

- Remember running process
- Maintain sets of queues
  - (CPU) ready queue
  - I/O device queue (one per device)
- PCBs sit in queues

How does the Scheduler run?

- Scheduler is part of the kernel
- How does kernel run?

How does Scheduler run?



The scheduler runs when

1) process starts or terminates (system call)
2) running process performs an I/O (system call)
3) I/O completes (I/O interrupt)
4) timer expires (timer interrupt)

How does the Scheduler Run?

- At end of handlers for
  - System calls
  - Interrupts
  - Traps
- Scheduler runs: decides on process to run
- Switches to a new process
- Sets another timer

Scheduling Algorithm

- Decides which ready process gets to run

What makes a good scheduling algorithm?

- It depends …

Interactive vs. Batch

- Interactive = you are waiting for the result
  - E.g., browser, editor, …
  - Tend to be short
- Batch = you will look at result later
  - E.g., supercomputing center, offline analysis, …
  - Tend to be long

What makes a good scheduler for interactive?

- Short response time
- Response time = wait from ready to running

What makes a good scheduler for batch?

- High throughput
- Throughput = number of jobs completed

Response Time vs. Throughput

- Conflicting goals
- From throughput perspective
  - Scheduler is overhead
  - Run scheduler as little as possible
- From response time perspective
  - Want to go quickly from ready to running
  - Run scheduler often

Trouble is …

- Often, scheduler does not know a priori if a process is interactive or batch

What makes a good scheduler?

- It depends …
- Possibilities:
  - Fast response time for interactive processes
  - High throughput for batch process

What makes a good scheduler?

- It depends …
- Possibilities:
  - Fast response time for interactive processes
  - High throughput for compute-bound process
  - “Important” jobs get done quickly
  - “Fairness”
  - …

Example Scheduling Algorithms

- First come, first served (FCFS)
- Shortest job first (SJF)
- Round robin (RR)
- Priority (PR)
- Combination schedulers

A Note about Terminology

- Think of scheduler as managing a queue
- Process ready: insert it into queue
  - According to scheduling policy
- Scheduling decision: run head of queue

- Not always implemented this way!!

First come, first served (FCFS)

- Process ready: insert at tail of queue
- Head of queue: “oldest” ready process
- By definition, non-preemptive

First come, first served (FCFS)

- Process ready: insert at tail of queue
- Head of queue: “oldest” ready process
- By definition, non-preemptive

- Low overhead – few scheduling events
- Good throughput
- Uneven response time – stuck behind long job
- Extreme case – process monopolizes CPU

Shortest Job First (SJF)

- Process ready
  - Insert in queue according to length
- Head of queue: “shortest” process
- Can be preemptive or non-preemptive
- From now on, only consider preemptive

Shortest Job First (SJF)

- Process ready
  - Insert in queue according to length
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- From now on, only consider preemptive

- Good response time for short jobs
- Can lead to starvation of long jobs
- Difficult to predict job length

Round Robin (RR)

- Define time quantum Δ
- Process ready: put at tail of queue
- Head of queue: run for Δ time
- After Δ
  - Put running process at the tail of the queue
  - Re-schedule

RR: Compromise for Long and Short Jobs

- Short jobs finish quickly (a few rounds)
- Long jobs are not postponed forever

- No need to know job length
- Discover length by how many Δ's it needs

Round Robin (RR)

- How to pick Δ?
- Too small
  - Many scheduling events
  - Good response time
  - Low throughput
- Too large
  - Few scheduling events
  - Good throughput
  - Poor response time
- Typical value: ~ 10 milliseconds

Priority (PR)

- Assign each process a priority Pr(P)
- Process ready:
  - Insert in queue according to Pr(P)
- Head of queue: highest-priority process

Priority (PR)

- Assign each process a priority Pr(P)
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- Differentiation according to job importance
- Prone to starvation of low-priority jobs

A Variation: Priority + Aging (PR + A)

- Assign each process a priority Pr(P)
- Process ready:
  - Insert in q according to Pr(P)
- Reduce priority over time

A Variation: Priority + Aging (PR + A)

- Assign each process a priority Pr(P)
- Process ready:
  - Insert in q according to Pr(P)
- Reduce priority over time

- Lessens problem of starving low-priority jobs

Combination Approaches

- Almost all real schedulers are combinations
- Examples:
  - PR + RR
  - RR + FCFS
- Typical implementation:
  - Multiple queues

PR + RR

- As with priority
- But RR between processes with equal priority
- Typical implementation:
  - Multiple queues, one for each priority
  - Process ready:
    - Insert at tail of queue with its priority
  - Schedule:
    - Head of non-empty queue with highest priority for Δ

RR + FCFS

- Two queues: one for RR, one for FCFS
- Initially, process goes in RR queue
- After n Δ's, it goes in FCFS queue

Scheduler Implementation

- Must be very efficient
- Runs (at least) every Δ
- If Δ = 100 msec, scheduler run takes 10 msec

  10% of your machine is gone!
- Be careful with large number of processes

Summary

- Process
- Linux process tree
- Process switch
- Process scheduler

Summary

- Process
  - Program in execution
- Linux process tree
- Process switch
- Process scheduler

Summary

- Process
- Linux process tree
  - Created by fork() / exec() / wait() / exit()
- Process switch
- Process scheduler

Summary

- Process
- Linux process tree
- Process switch
  - Change of process using the CPU
  - Save and restore registers and other info
- Process scheduler

Summary

- Process
- Linux process tree
- Process switch
- Process scheduler
  - Decides which process to run next