COMP 346

Review

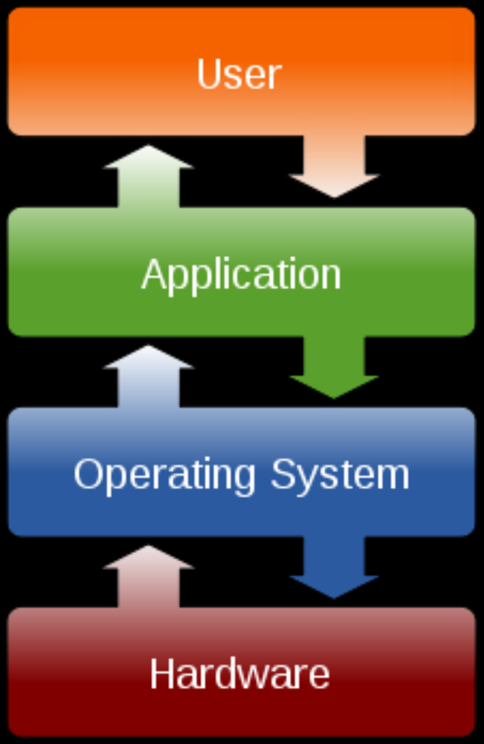
https://github.com/comp346/W15

Agenda

1. Functionality of Operating System
2. Concurrent Programming
3. Liveness
4. Synchronization
5. CPU Scheduling
6. Virtual Memory

Operating System

- Interacts with hardware
- Manages resources (CPU Cycles & Memory)
- Provide services for applications



OS Features

- Process management
- Memory management
- File system
- Peripheral devices
- Networking
- Security

Concurrent Programming

Advantages
- Better utilize CPU
- Increase responsiveness

Disadvantages
- Nondeterministic
- Safety
- Liveness
- Context Switch (can downgrade performance)

Utilize CPU

Amdahl's Law

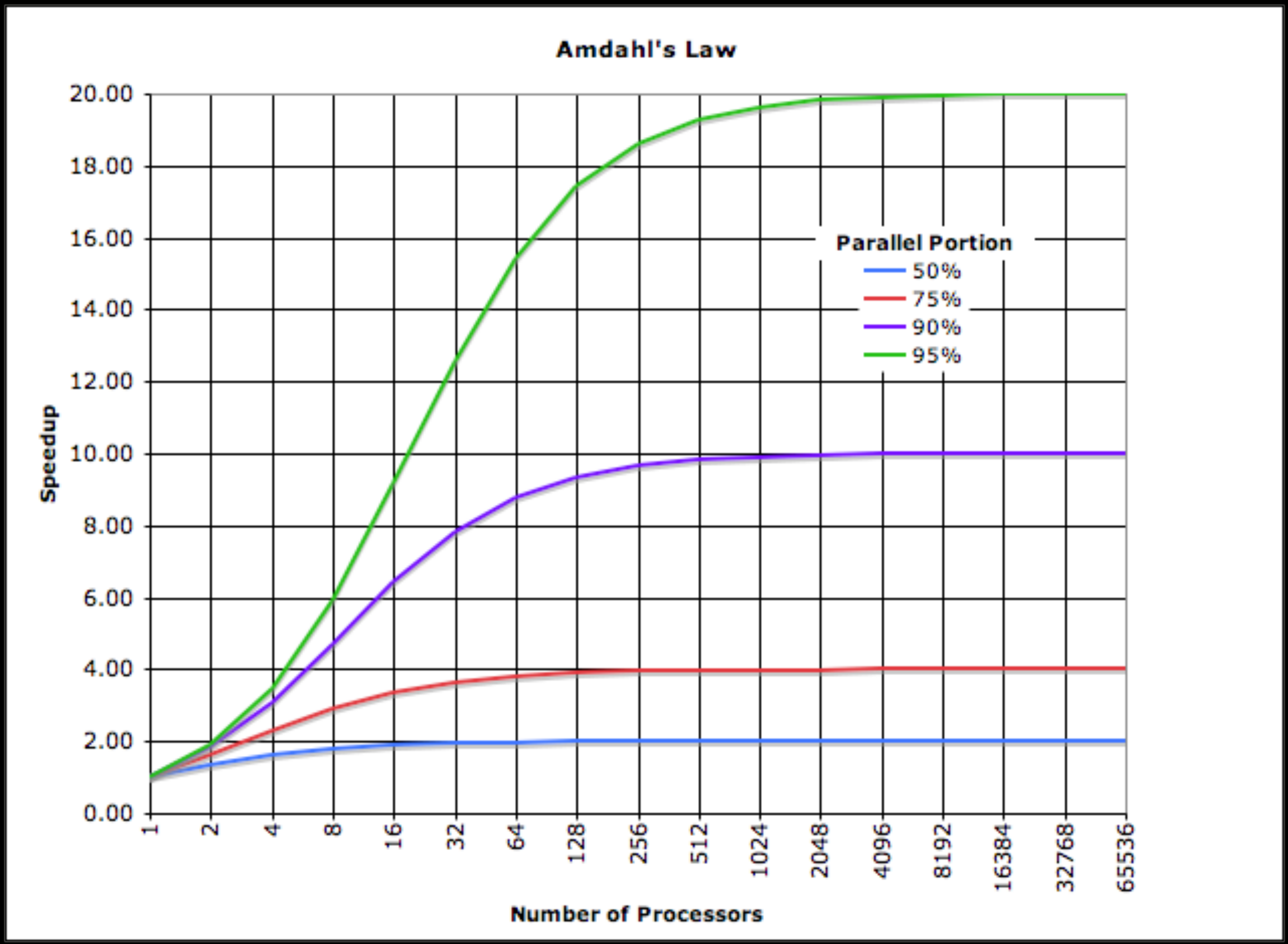
$$Speedup \leq \frac{1}{F + \frac{(1-F)}{N}}$$

N is number of cores

F is fraction of serial code

Serial code must be execute sequentially

Amdahl's Law



Amdahl's Law
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Speedup
1
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
32768
65536
Number of Processors
Parallel Portion
50%
75%
90%
95%

Nondeterministic

- Hard to reproduce the problem
- In the assignments, results are intermittent

SAFETY

Something bad never happens

LIVENESS

Something good eventually happens

Safety vs Liveness

Using synchronization

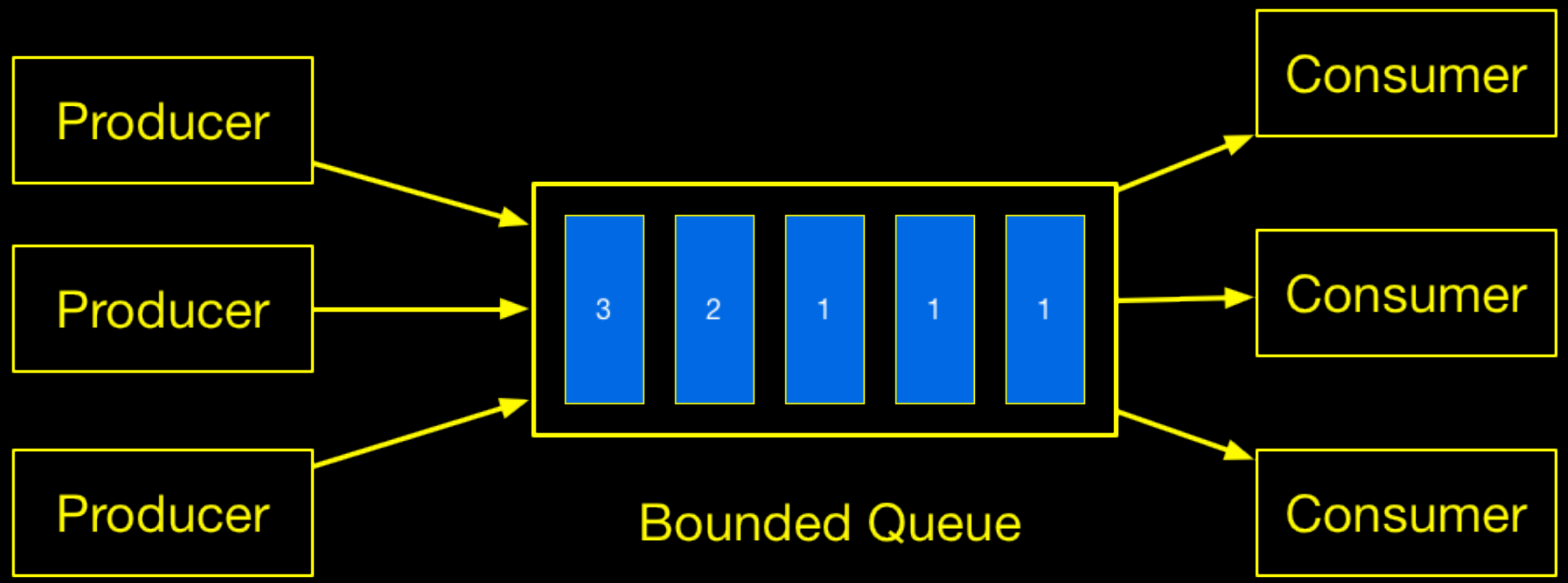
- To achieve **safety**
- But can prevent **liveness**

Liveness Issues

1. Starvation
2. Livelock
3. Poor responsiveness
4. **Deadlock**

Starvation

Starvation describes a situation where a thread is unable to gain regular access to shared resources and is unable to make progress.

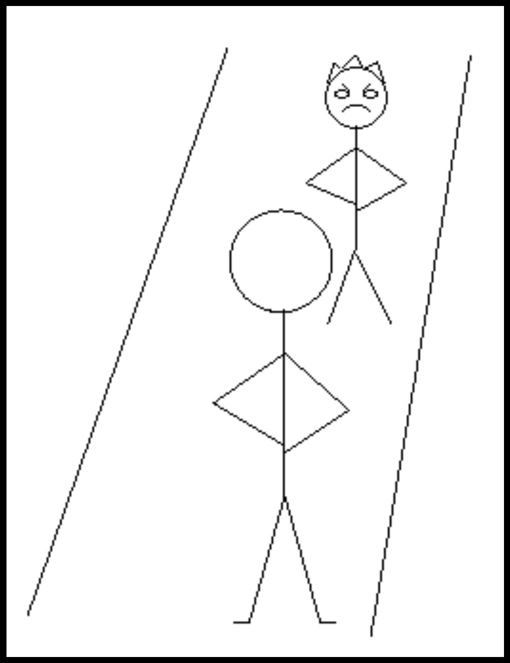


Livelock

Participants continuously change their state in response to the action of another thread

1. A move to his left to let B pass

2. B move to his right to let A pass



Poor Responsiveness

- Common in GUI applications
- Occurs when user interface freeze

Solution

Heavy tasks should be executed in background

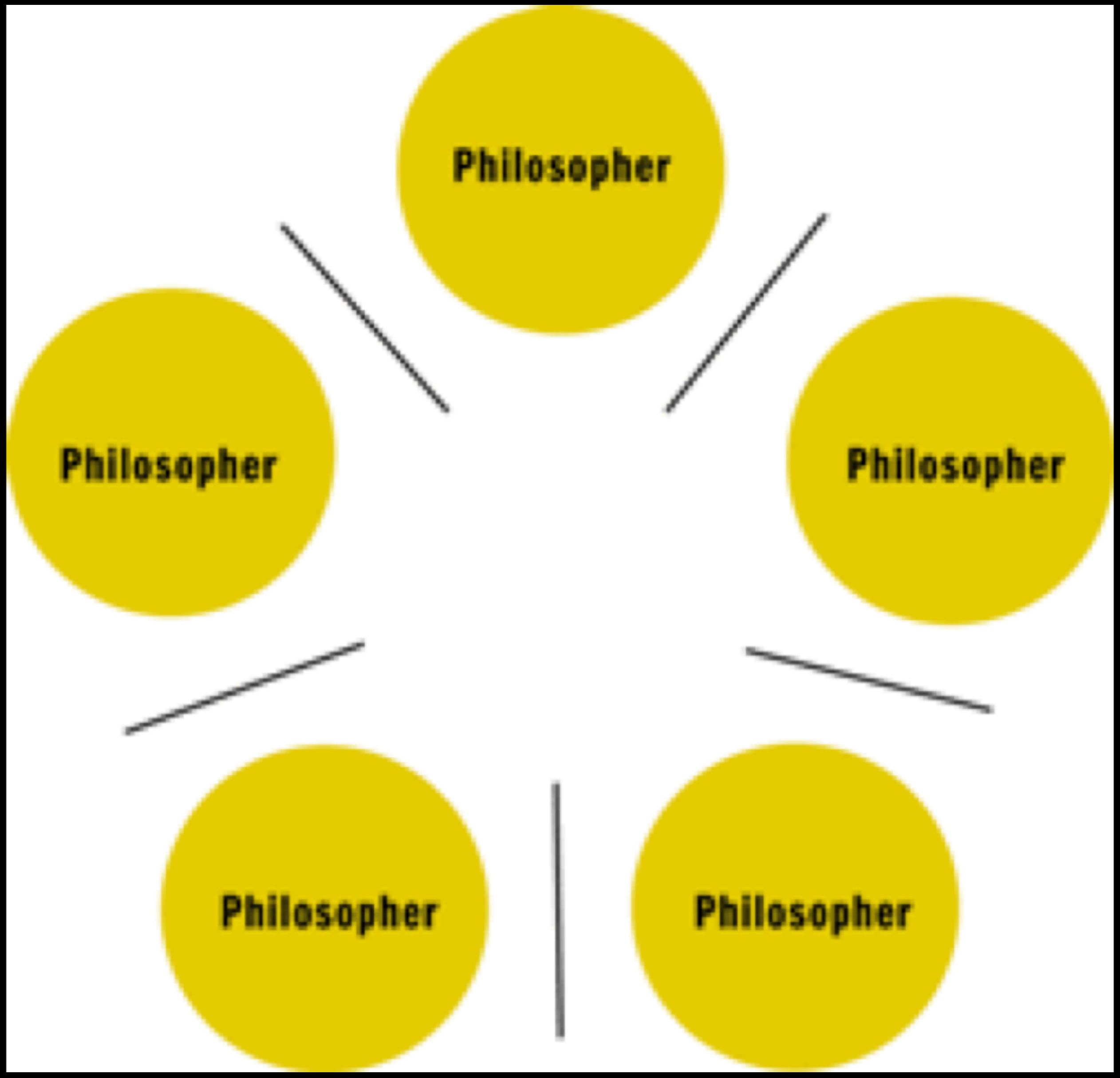
Deadlock

Deadlock arises when several participants are waiting on each other to reach a specific state to be able to progress.

As none of them can progress without some other participant to reach a certain state.

Dining Philosophers

Eating requires 2 chopsticks

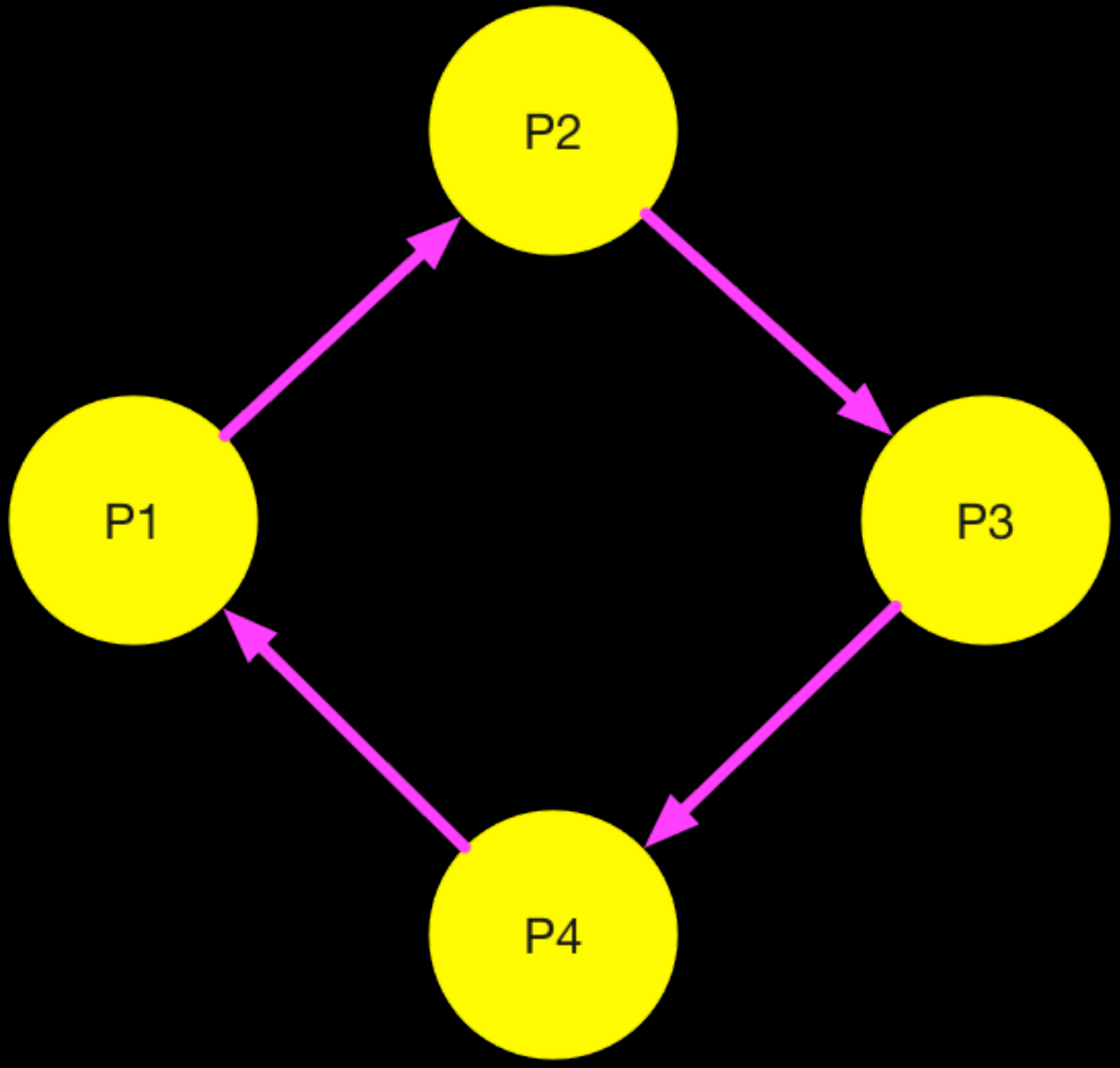


Deadlock occurs if all hold

1. **Mutual Exclusion:** at least one process exclusively uses a resource
2. **Hold and wait:** a process holds at least one resources and needs more, which are held by others
3. **No preemption:** resources are released only in voluntary manner
4. **Circular wait:** P1 → P2 → … → PN → P1

Deadlock Analysis

- Processes are nodes
- Edges are resource relations
- Cyclic => Deadlock



Locking order

```
public void transferMoney(Account fromAcc,
                          Account toAcc, amount) {
  synchronized (fromAcc) {
    synchronized (toAcc) {
      fromAccount.debit(amount);
      toAccount.credit(amount);
    }
  }
}
```

Can deadlock occur ?

Deadlock happens if

A transfer to B and B transfer to A at the same time.

- transferMoney(A, B, _);
- transferMoney(B, A, _);

Deadlock Summary

1. Deadlock is one of the biggest issues of concurrency
2. Deadlock is not obvious
3. Four conditions of deadlock

Synchronization

1. Semaphore
2. Mutex == Binary Semaphore
3. SpinLock
4. ReentrantLock
5. Barrier
6. Monitor

SpinLock vs Mutex

- SpinLock keeps polling resource until acquired
- Mutex is a more polite, wait until notified

Modern Lock: Hybrid implementation

ReentrantLock

- A lock with ownership
- Once owned, can call "lock" multiple times

No deadlock with Ownership

```
class Stack {
  ReentrantLock lock = new ReentrantLock();
  public E peek(){
    try{
      lock.lock();
      if(isEmpty())throws EmptyStackException
      return topElement;
    }finally{
      lock.unlock();
    }
  }

  bool isEmpty(){
    try{
      lock.lock();
      return length == 0;
    }finally{
      lock.unlock();
    }
  }
}
```

Deadlock without Ownership

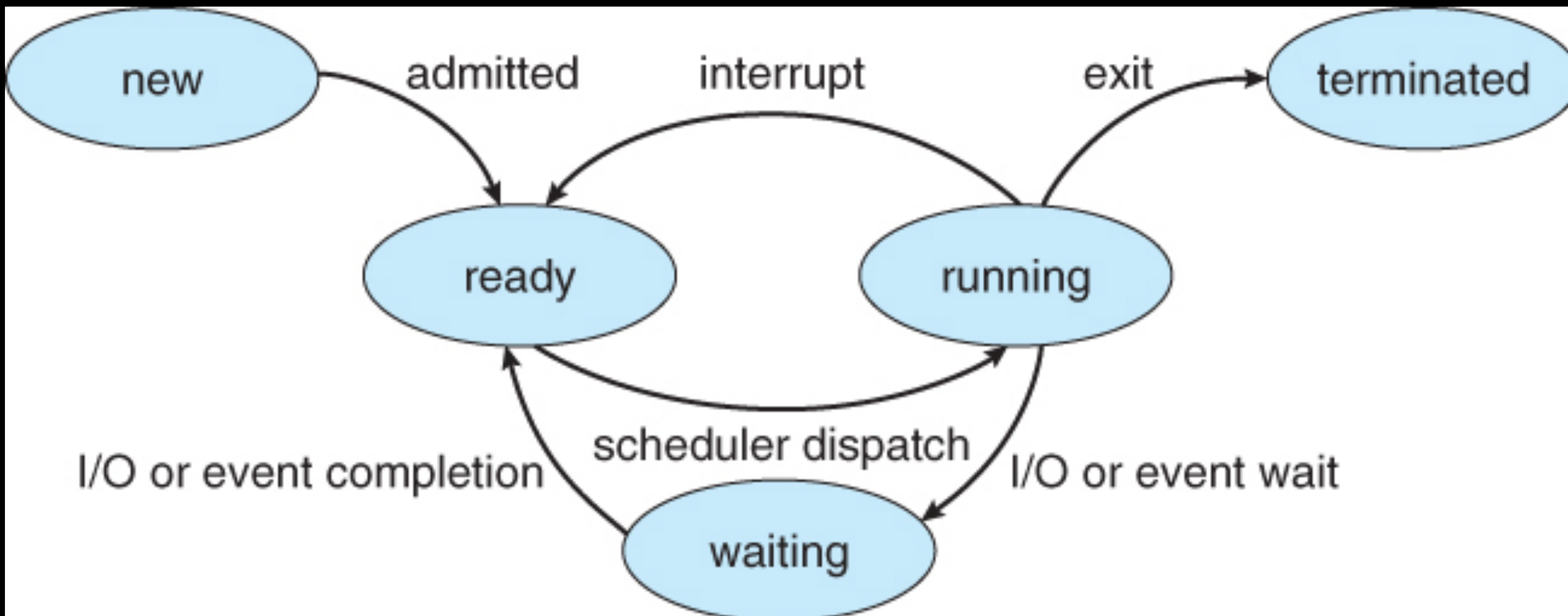
```
class Stack {
  Semaphore lock = new Semaphore(1);
  public E peek(){
    try{
      lock.lock();
      if(isEmpty())throws EmptyStackException
      return topElement;
    }finally{
      lock.unlock();
    }
  }

  bool isEmpty(){
    try{
      lock.lock(); //Deadlock here when called inside peek()
      return length == 0;
    }finally{
      lock.unlock();
    }
  }
}
```

Locking pattern

```
try{
  lock.lock();
  //do something
  //Even return here
}finally{
  lock.unlock();
}
```

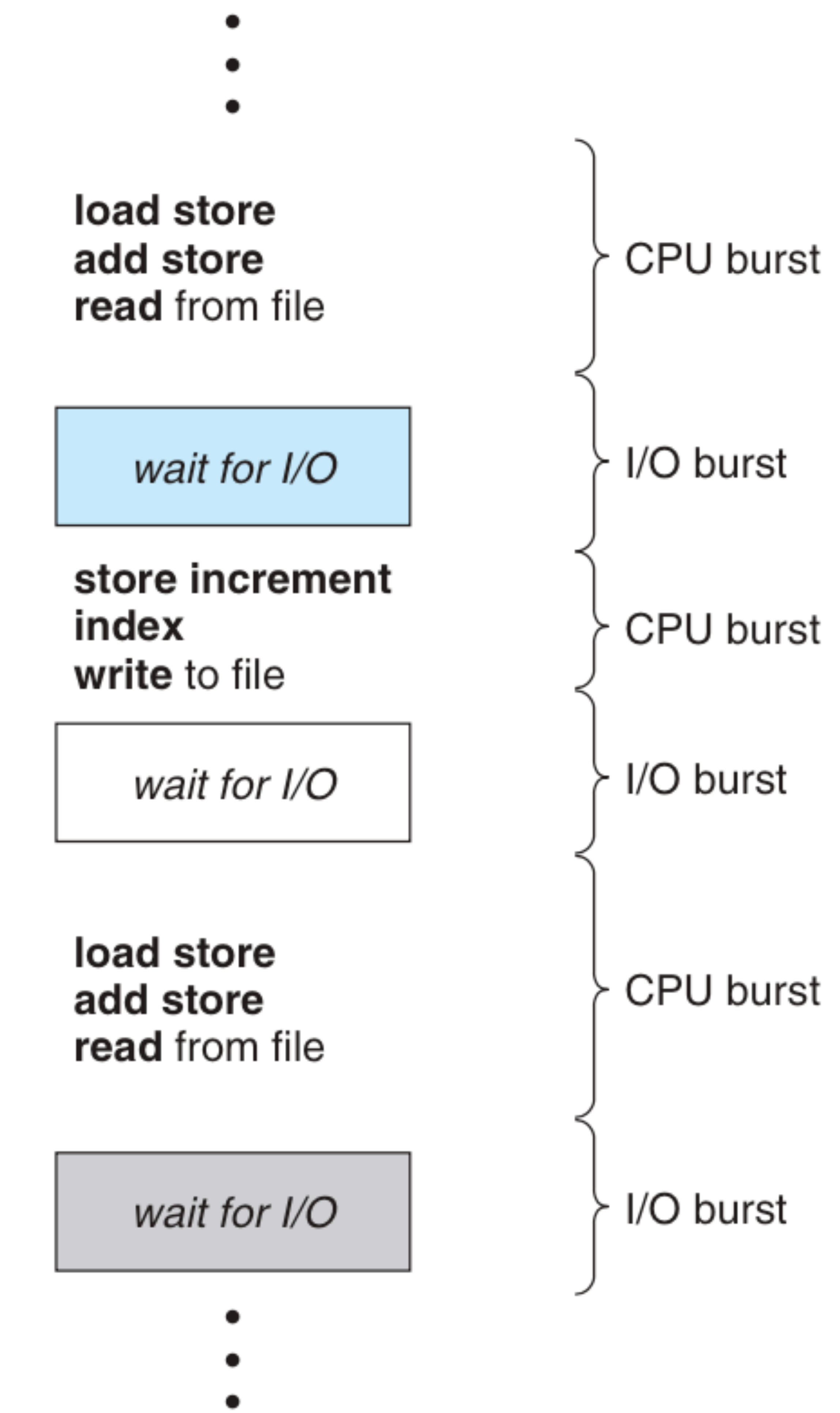
`synchronized` is `ReentrantLock`

Process states



Process Execution

- Computation uses CPU
- I/O does not use CPU



CPU Scheduling

Having **N** programs & **K** processors

Wants:

1. Maximize "throughput"
2. Minimize "turnaround time"
3. Minimize "response time"

Which jobs to assign to which CPU, and how long?

Criterion

- **Throughput**
  Number of jobs complete per unit of time
  Higher is better

- **Turnaround time**
  Time for each job to complete after submit
  Lower is better

- **Response time**
  Time from request to the first response
  Lower is better

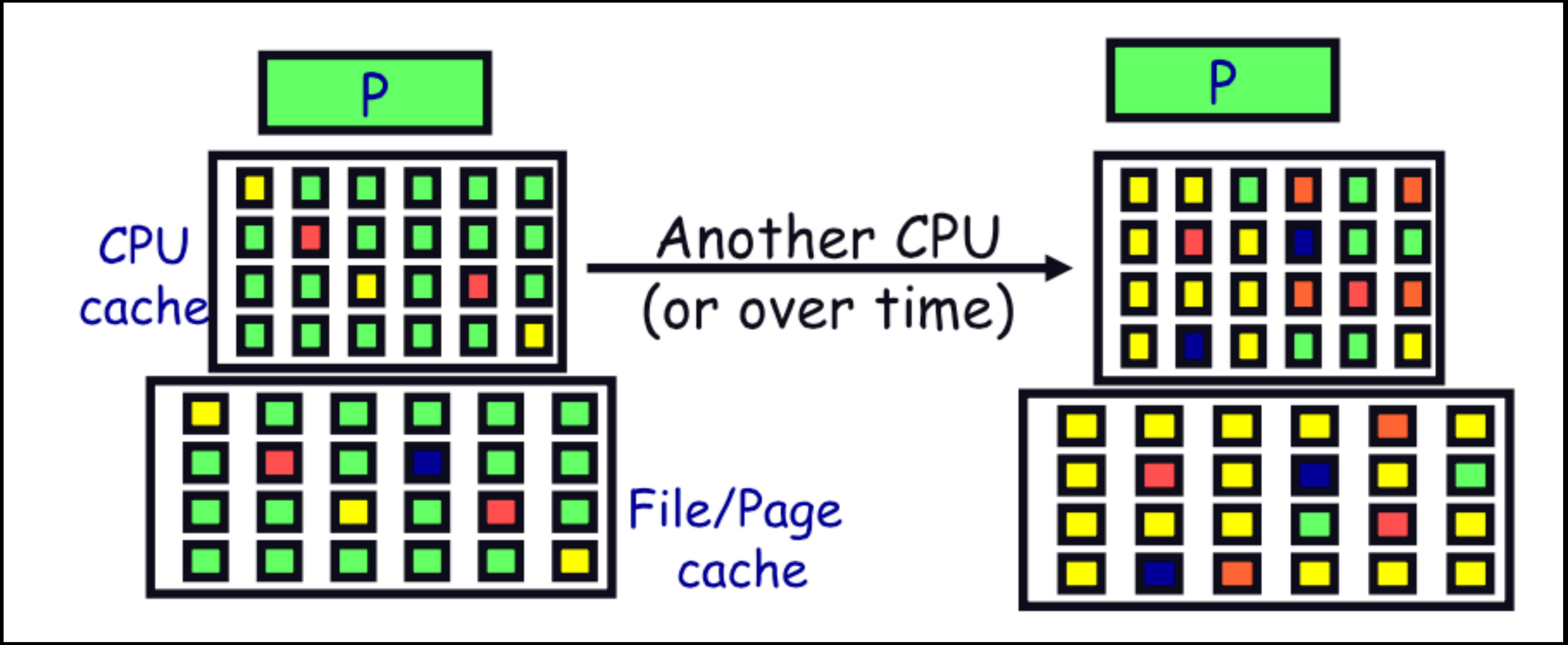
Context Switching

Happens when save current execution, restore previous execution

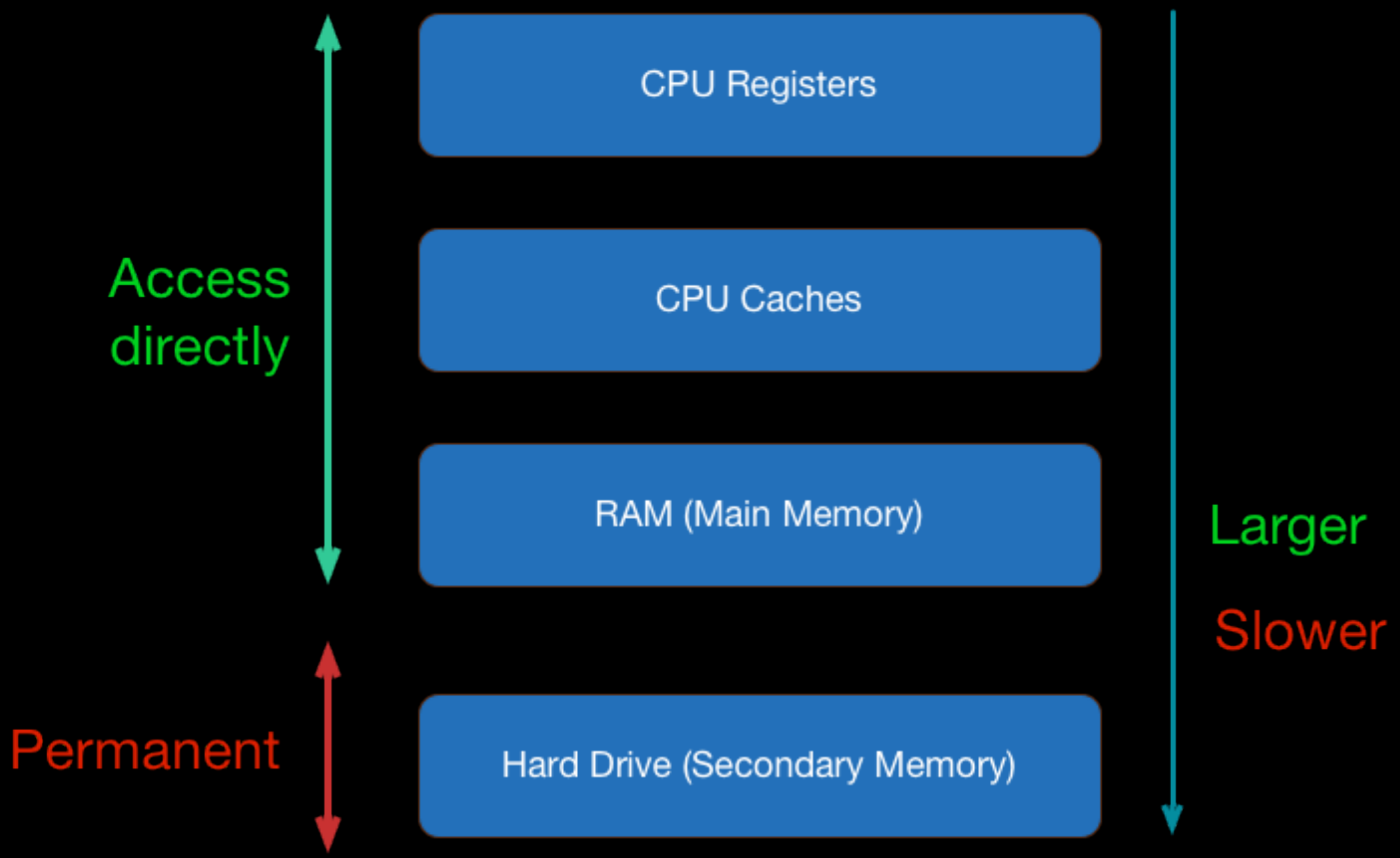
- Save & restore registers
- Switch address spaces (expensive)

Hidden cost

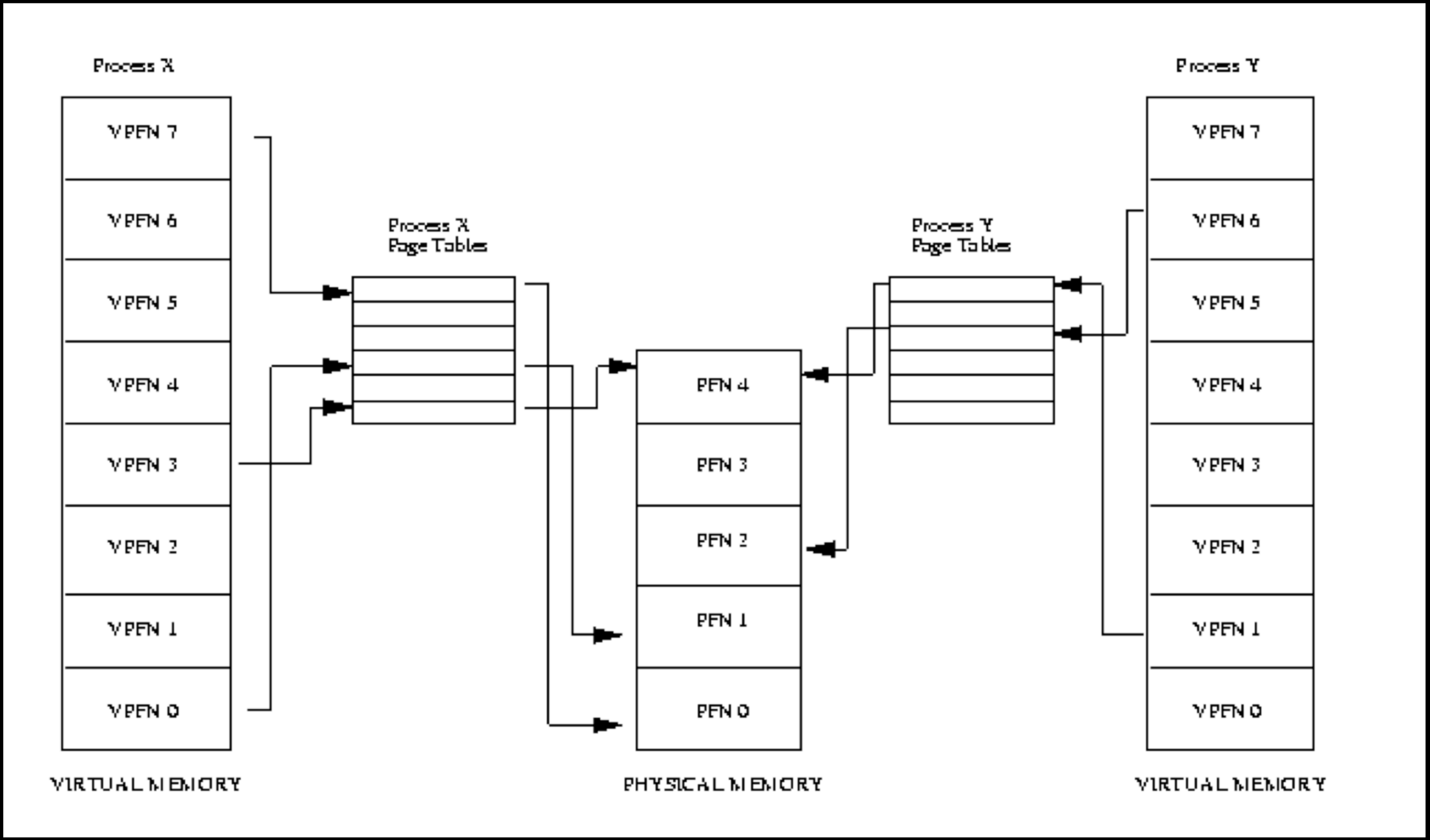
- Cache outdated
- Page fault



Memory Hierarchy



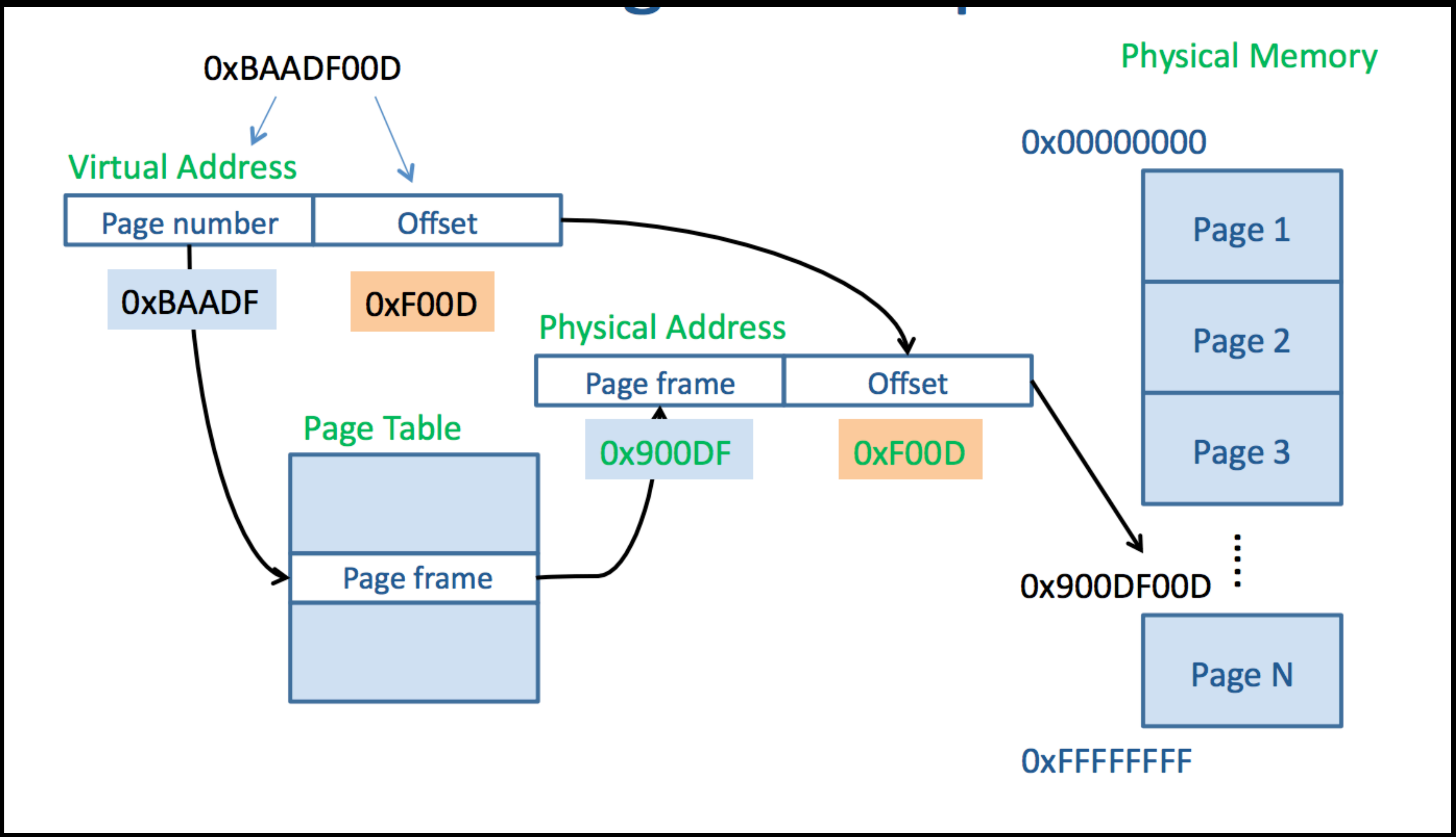
Virtual Memory



How Virtual Memory works

- Application accesses its virtual memory
- Memory is divided up into pages (fixed size)
- CPU & OS handle mapping

Address Translation

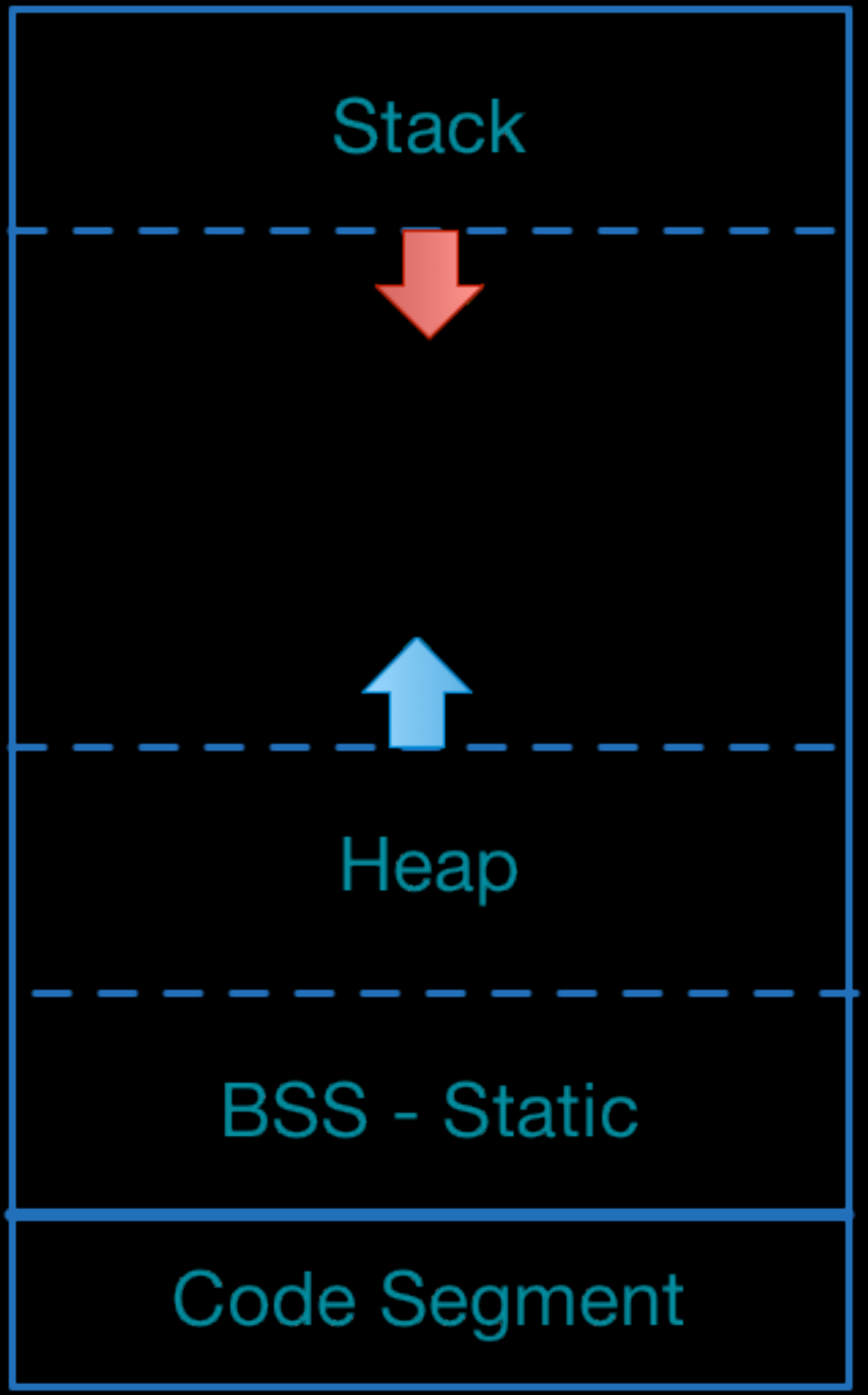


Translation is done by MMU (Memory Management Unit)

InProcess Memory Structure

Data Segment
- BSS
- Heap
- Stack

Data Segment is dynamic
Code Segment is readonly



Stack

Behaves like `Regular Stack` (LIFO)

Push when

- Enter scope (function or loop)
- Declare primitive variables

Pop when

- Exit scope (function or loop)

StackOverflow

- Overflow when calling many functions nestly
- Common issue of non-tail recursive functions

```java
class Overflow {
  static int count = 0;
  static void repeat(){
    count += 1;
    repeat();
  }

  public static void main(String[] args){
    try{
      repeat();
    }catch(Throwable e){
      System.err.println("Completed times: " + count);
      System.err.println("Reason: " + e);
    }
  }
}
```

Completed times: 22127

Reason: java.lang.StackOverflowError

Manage Stack Segment

- No, it is handled automatically by process
- Avoid "very long recursive calls"

Heap

- Dynamic allocation memory
- Allocated memory when creating objects
- Deallocated memory when release objects

Manage Heap

1. **Manual Heap**
    - C: malloc/free
    - C++: new/delete
2. **Garbage Collection(GC)**
   Java, C#, Javascript
3. **Reference Counting**
   Swift, Objective-C, Rust, C++

OutOfMemory

```
class OutOfMemory {
  public static void main(String[] args){
    int GB = 1024 * 1024 * 1024;
    Object[]os = new Object[GB];
  }
}
```

Exception in thread "main"
java.lang.OutOfMemoryError: Java heap space
 at OutOfMemory.main(OutOfMemory.java:4)

Cyclic Reference

- `Object A` has **STRONG** reference to `B`
- `Object B` also has **STRONG** reference to `A`
- GC or ARC can not break **CYCLIC REFERENCE**
- GC languages still have `Memory Leaks` issues

Thank you very much