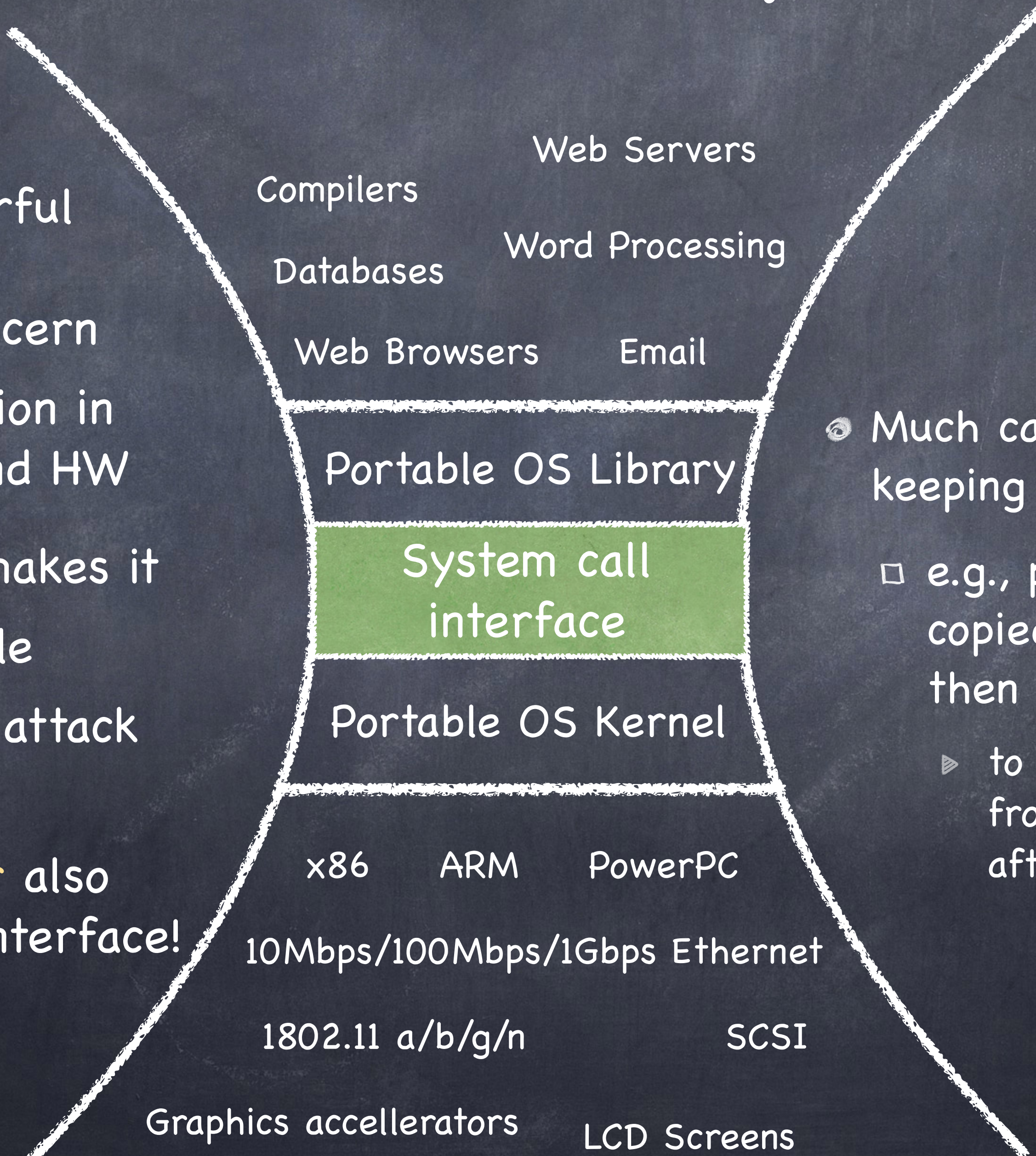
System calls

- Programming interface to the services the OS provides:
  - read input/write to screen
  - create/read/write/delete files
  - create new processes
  - send/receive network packets
  - get the time / set alarms
  - terminate current process
  - …

The Skinny

- Simple and powerful interface allows separation of concern
  - Eases innovation in user space and HW
- "Narrow waist" makes it
  - highly portable
  - robust (small attack surface)
- Internet IP layer also offers a skinny interface!

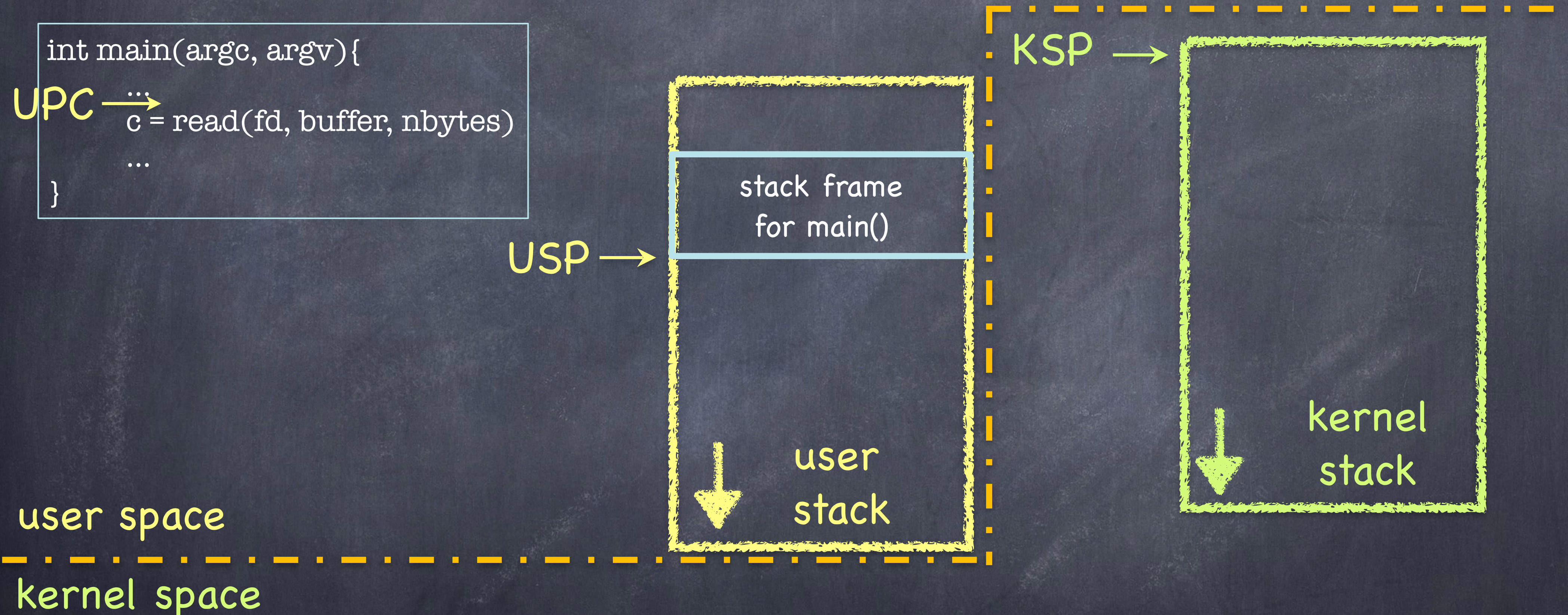


- Much care spent in keeping interface secure
  - e.g., parameters first copied to kernel space, then checked
    - to prevent user program from changing them after they are checked!

Executing a System Call

- Process:
  - Calls system call function in library
  - Places arguments in registers and/or pushes them onto user stack
  - Places syscall type in a dedicated register
  - Executes syscall machine instruction
- Kernel
  - Executes syscall interrupt handler
  - Places result in dedicated register
  - Executes RETURN_FROM_INTERRUPT
- Process:
  - Executes RETURN_FROM_FUNCTION

Executing read System Call



UPC: user program counter

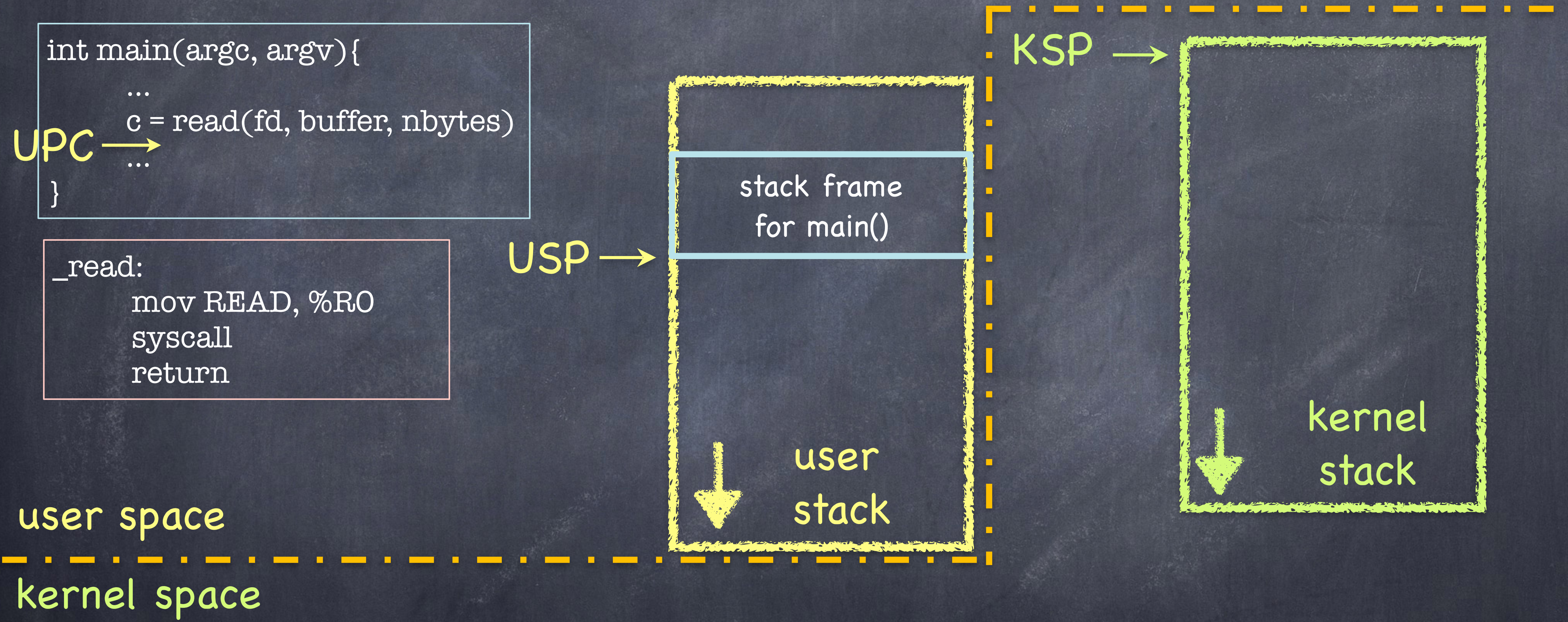
USP: user stack pointer

KSP: kernel stack pointer

KPC: kernel program counter

note: kernel stack is empty while user process running

Executing read System Call



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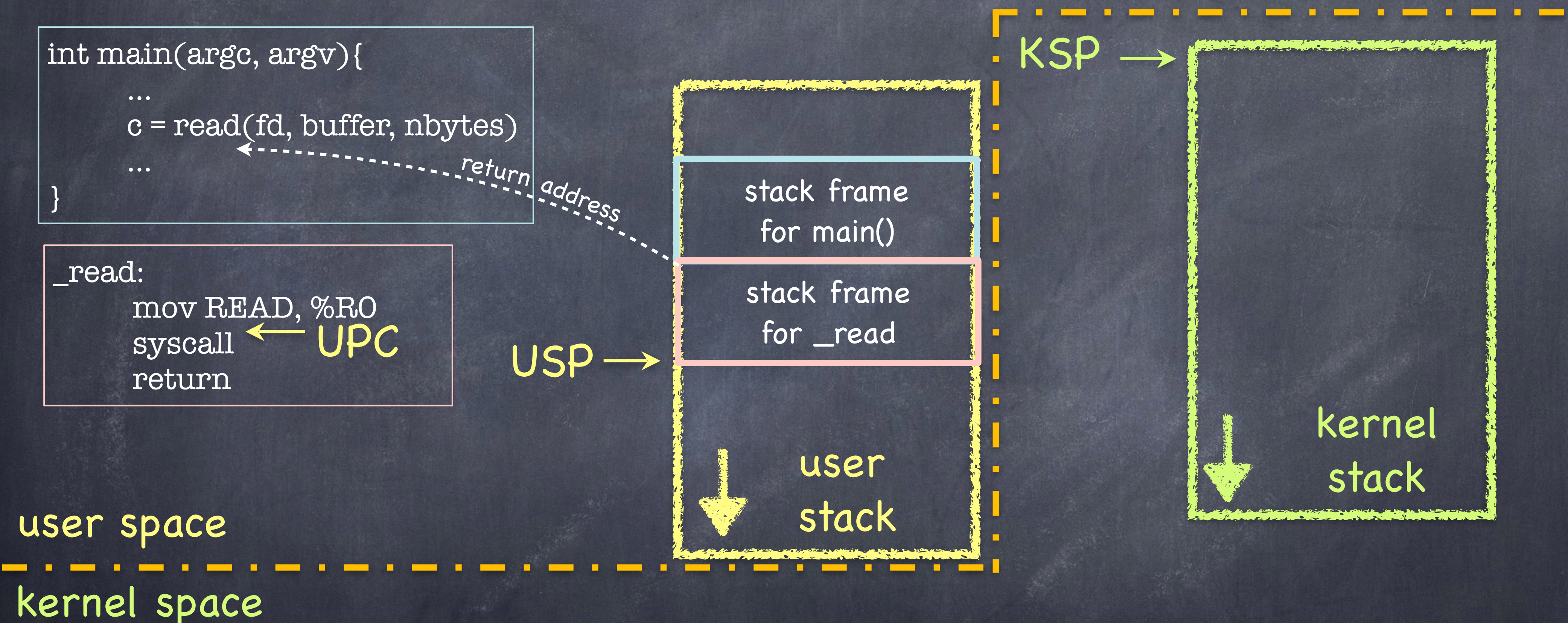

UPC: user program counter

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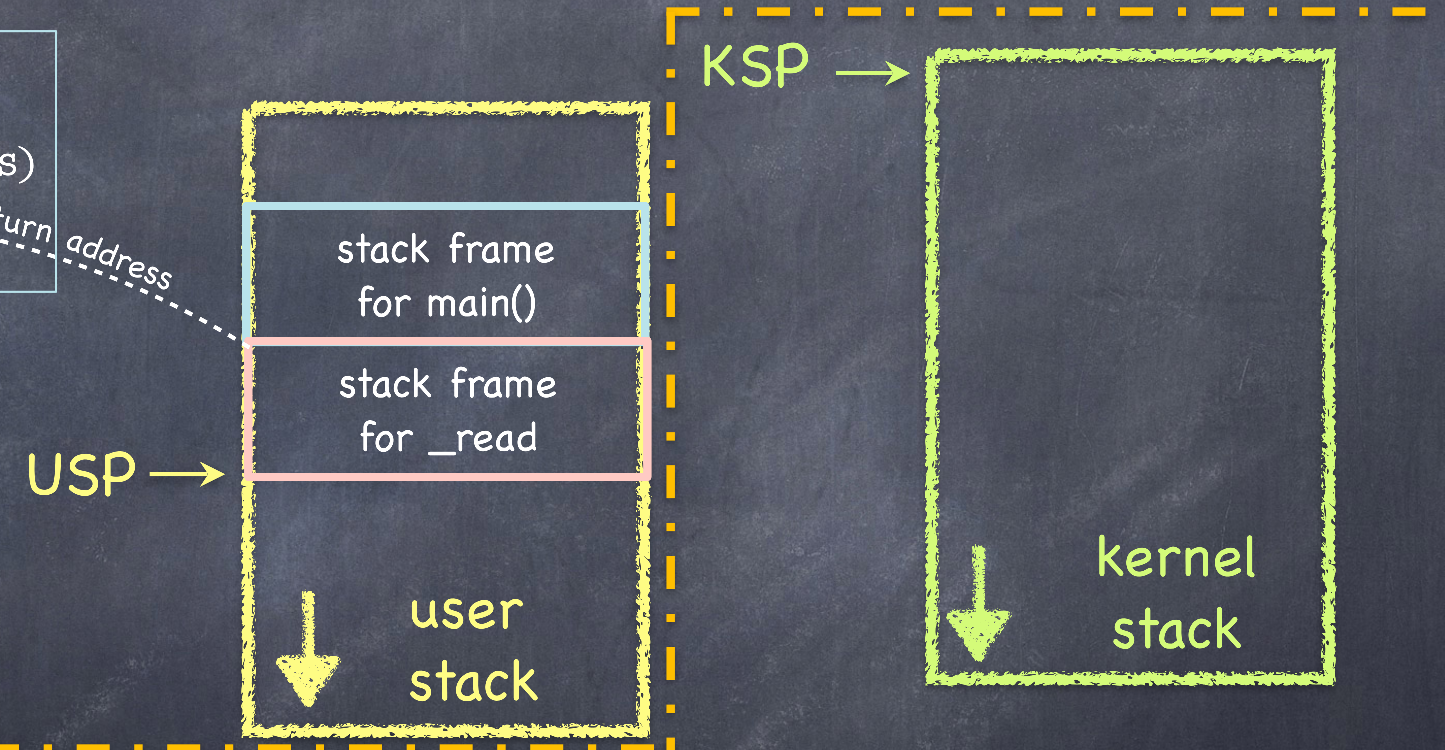
note: kernel stack is empty while user process running

Executing read System Call

```
int main(argc, argv){
        ...
        c = read(fd, buffer, nbytes)
        ...
}
```

```
_read:
        mov READ, %R0
        syscall
        return          ← UPC
```



user space

kernel space

```
HandleIntrSyscall:      ← KPC
push %Rn
...
push %R1
call __handleSyscall
pop %R1
...
pop %Rn
return_from_interrupt
```

Executing read System Call

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int main(argc, argv){
        ...
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}
```

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_read:
        mov READ, %R0
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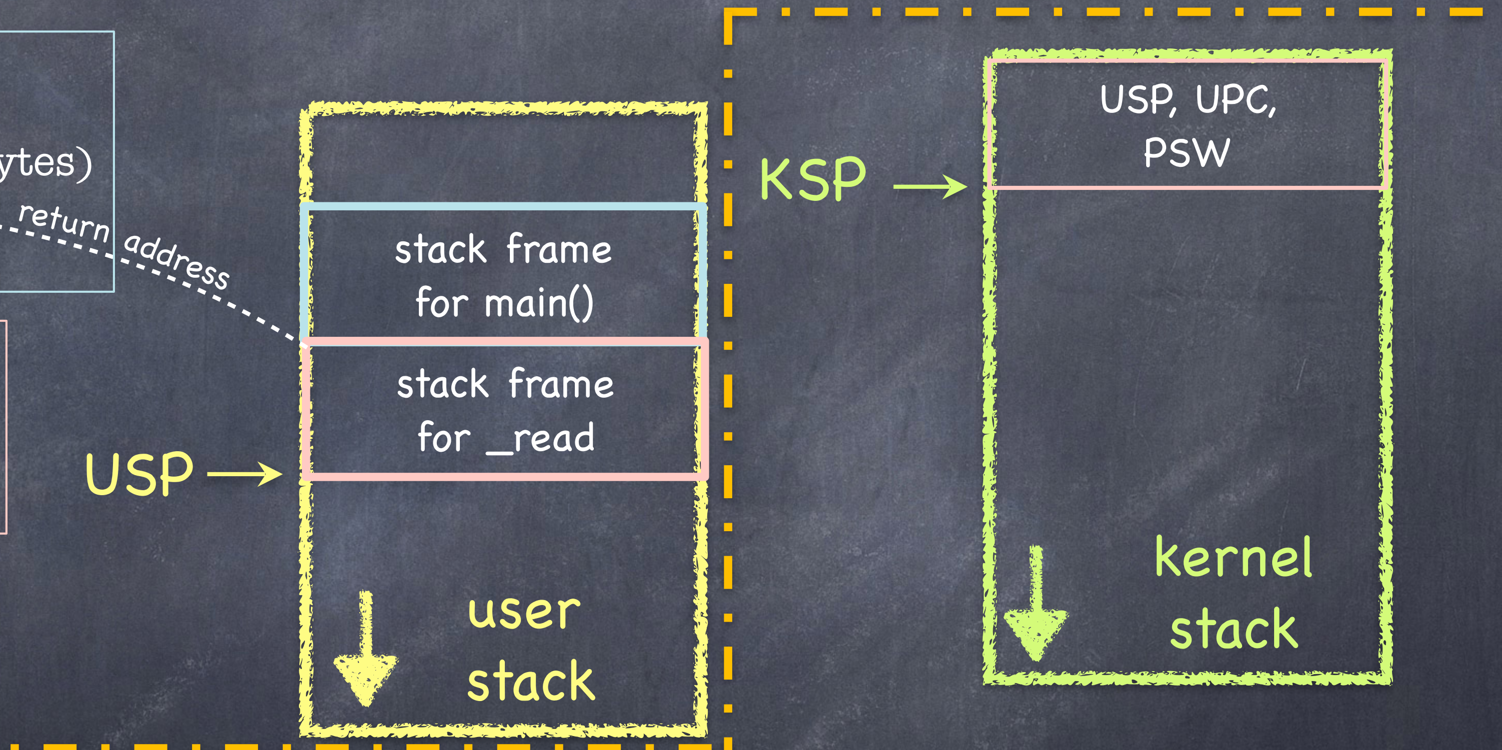

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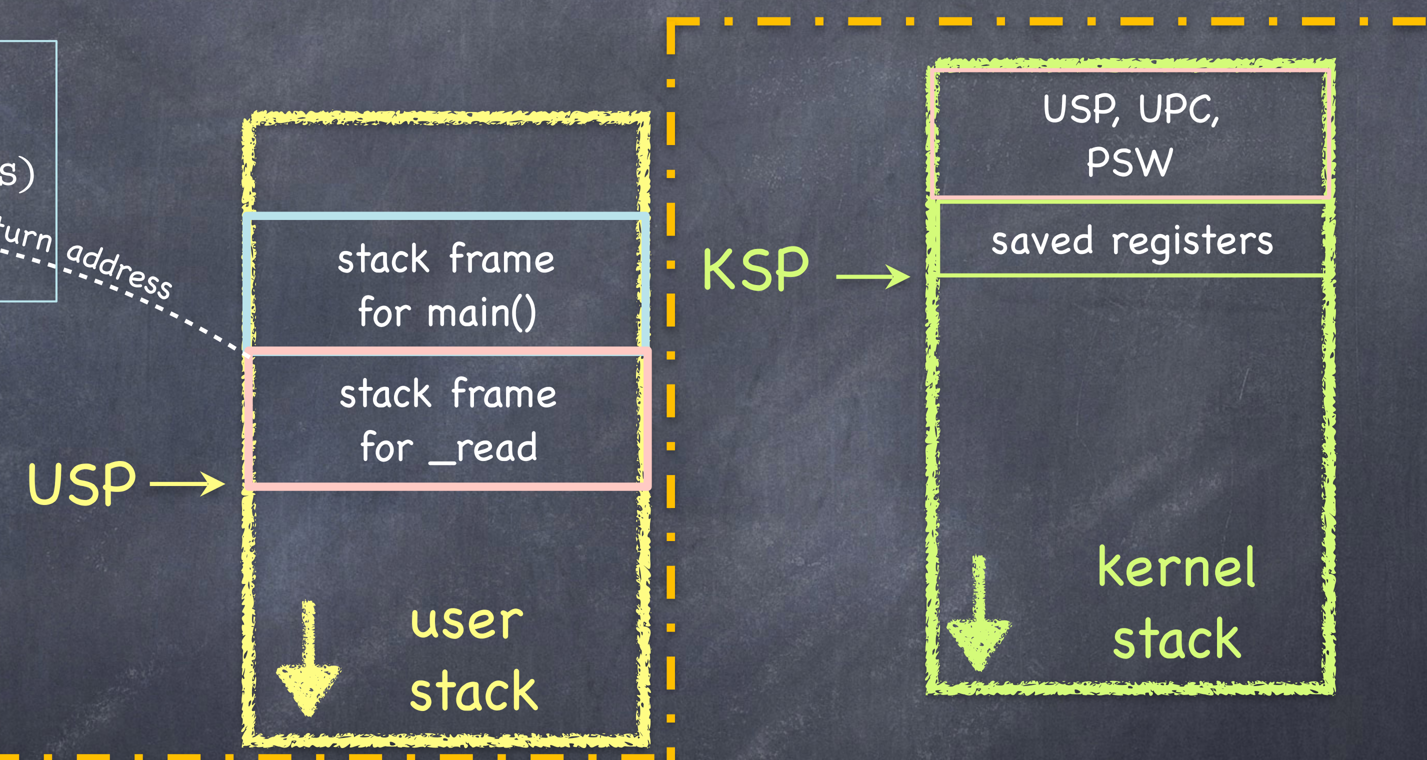

user space

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Executing read System Call

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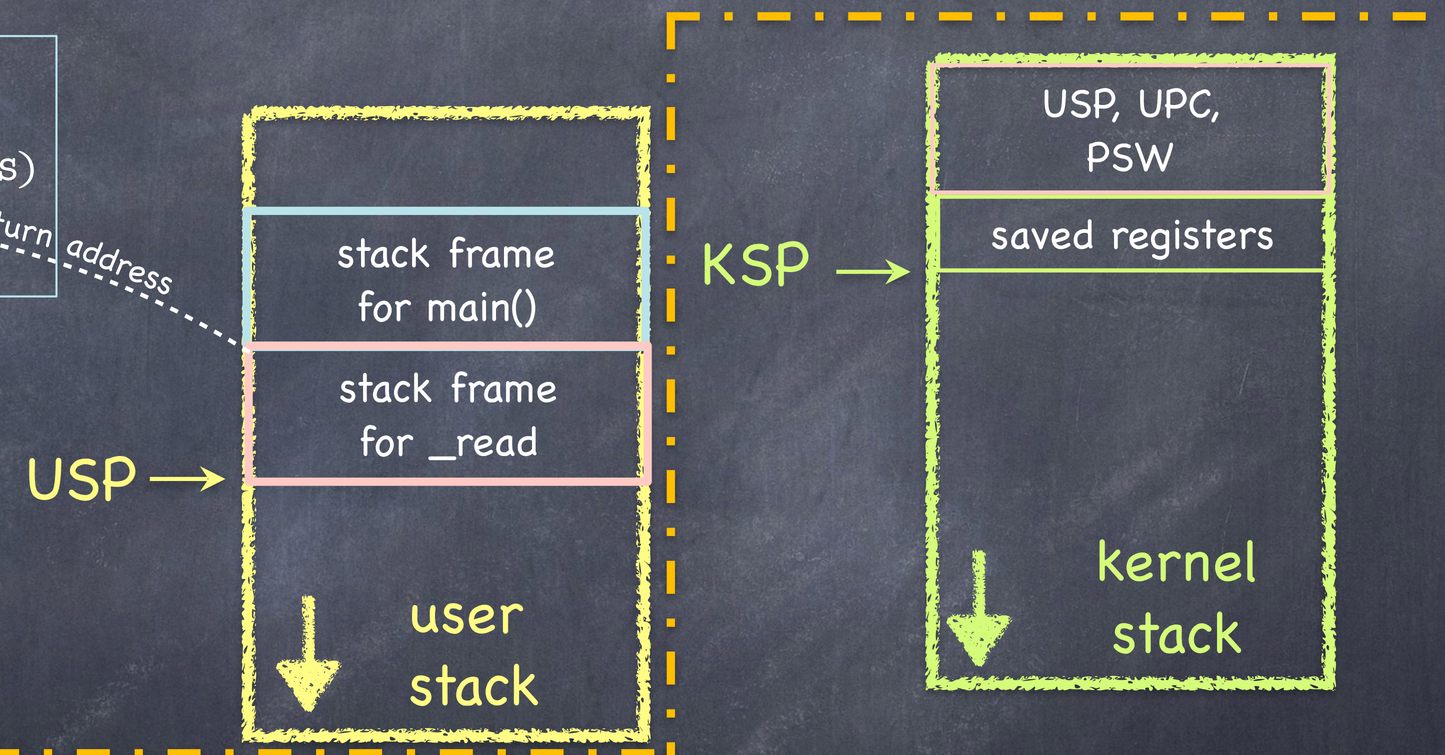


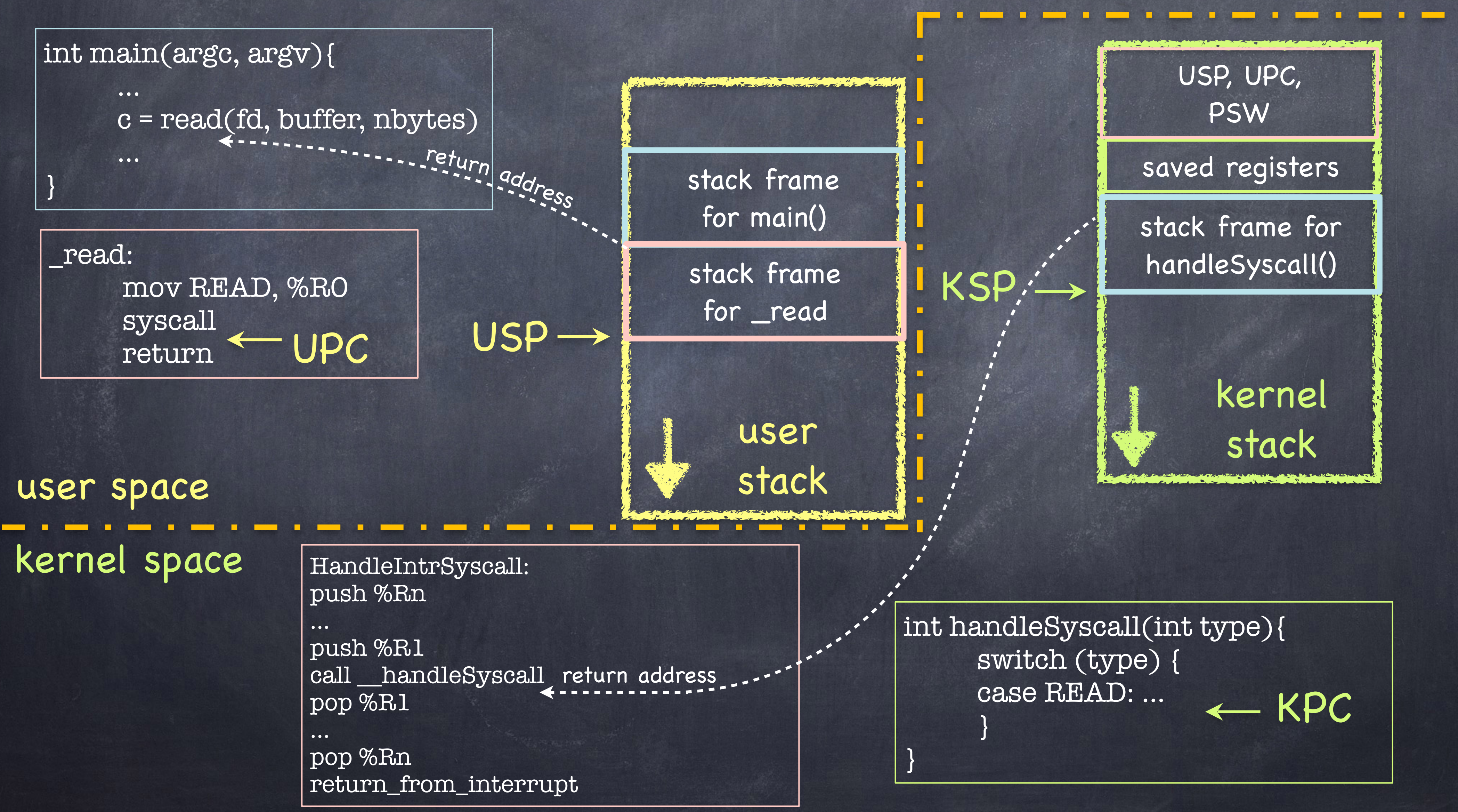
user space

kernel space

```
HandleIntrSyscall:
push %Rn
...
push %R1
call __handleSyscall    ← KPC
pop %R1
...
pop %Rn
return_from_interrupt
```

```
int handleSyscall(int type){
        switch (type) {
        case READ: ...
        }
}
```

Executing read System Call



What if read needs to block?

- read may need to block if
  - It reads from a terminal
  - It reads from disk, and block is not in cache
  - It reads from a remote file server

We should run another process!

How to run multiple processes

The Problem

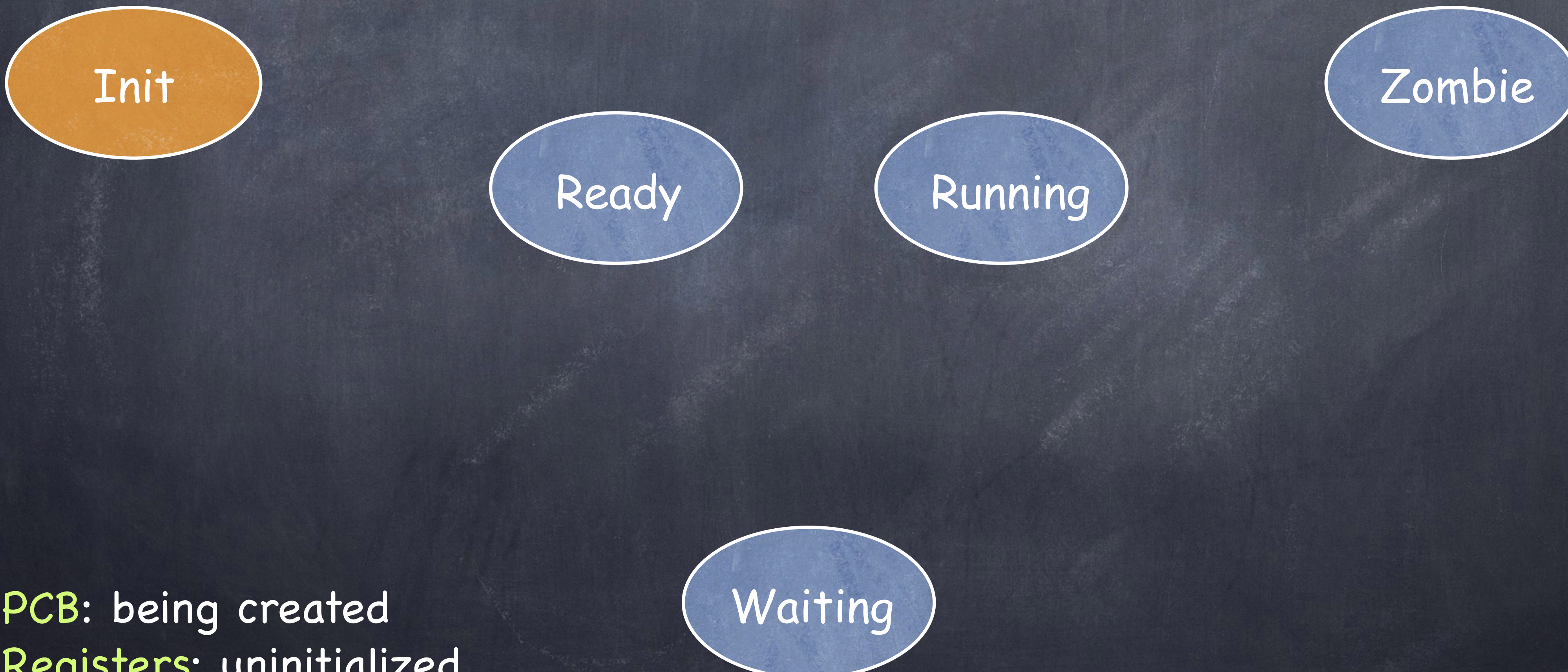
- Say (for simplicity) we have a single core CPU
- A process physically runs on the CPU
- Yet each process somehow has its own
  - Registers
  - Memory
  - I/O Resources
- Need to multiplex/schedule to create virtual CPUs for each process

Our friend, the Process Control Block

- A per-process data structure held by OS, with
  - location in memory (page table)
  - location of executable on disk
  - id of user executing this process (uid)
  - process identifier (pid)
  - process status (running, waiting, etc.)
  - scheduling info
  - kernel stack
  - saved kernel SP (when process is not running)
    - points into kernel stack
    - kernel stack contains saved registers (from user mode) and kernel call stack for this process
  - ...and more

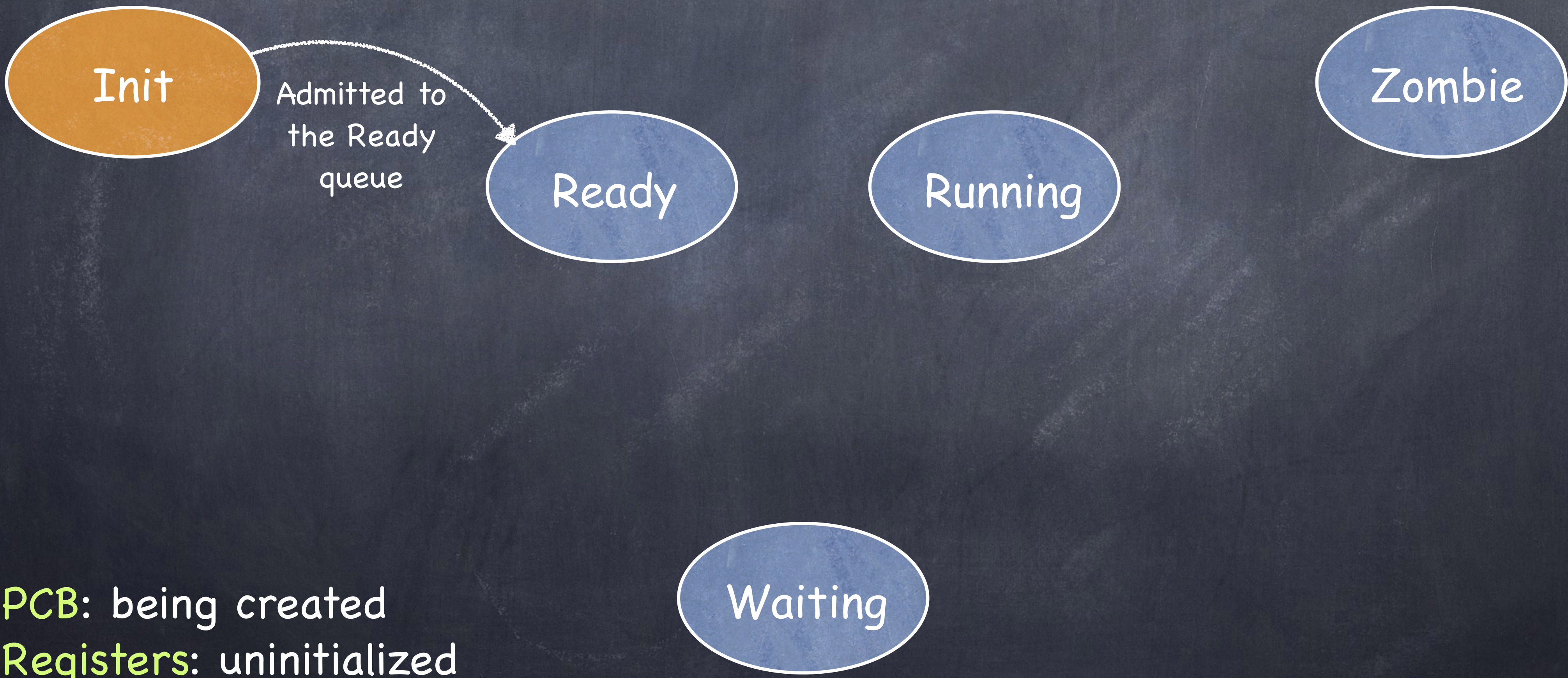
Process Life Cycle

Process Life Cycle



PCB: being created
Registers: uninitialized

Process Life Cycle



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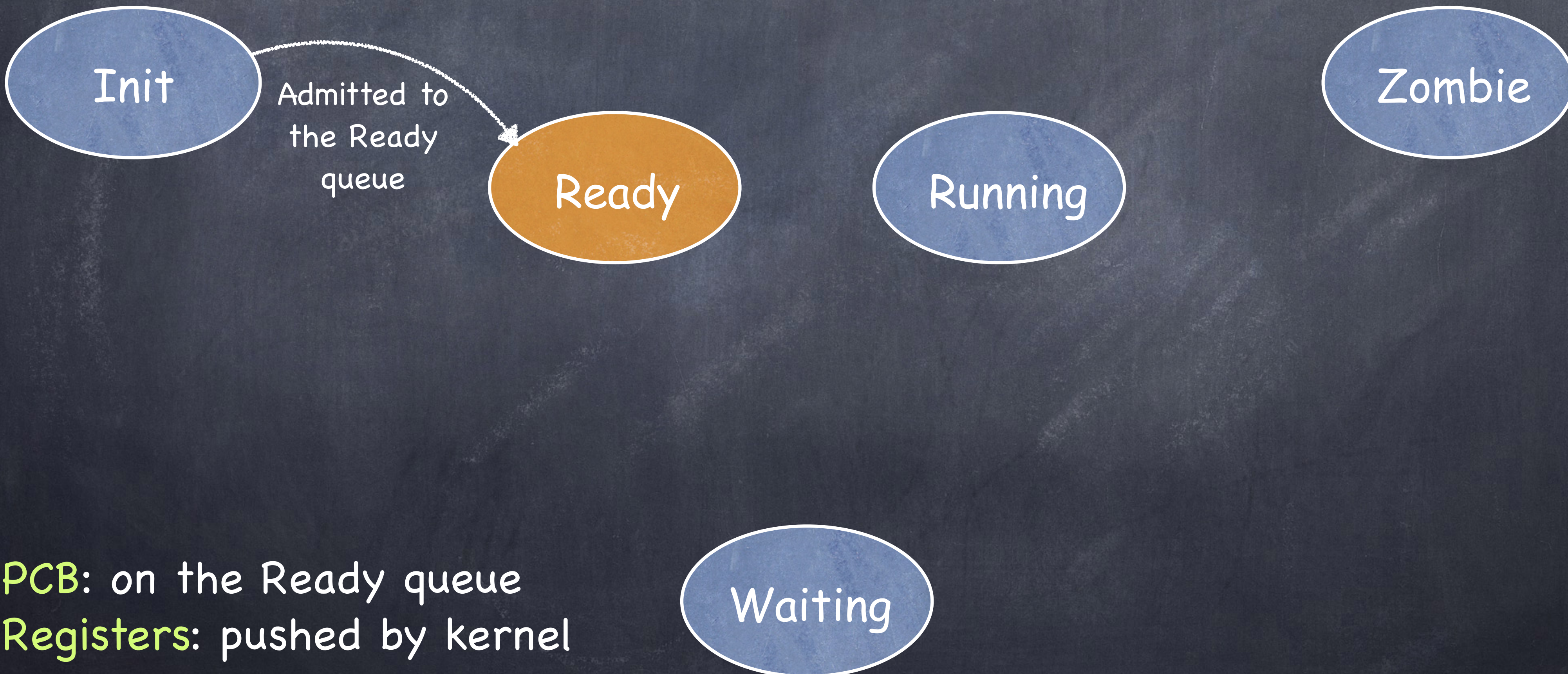
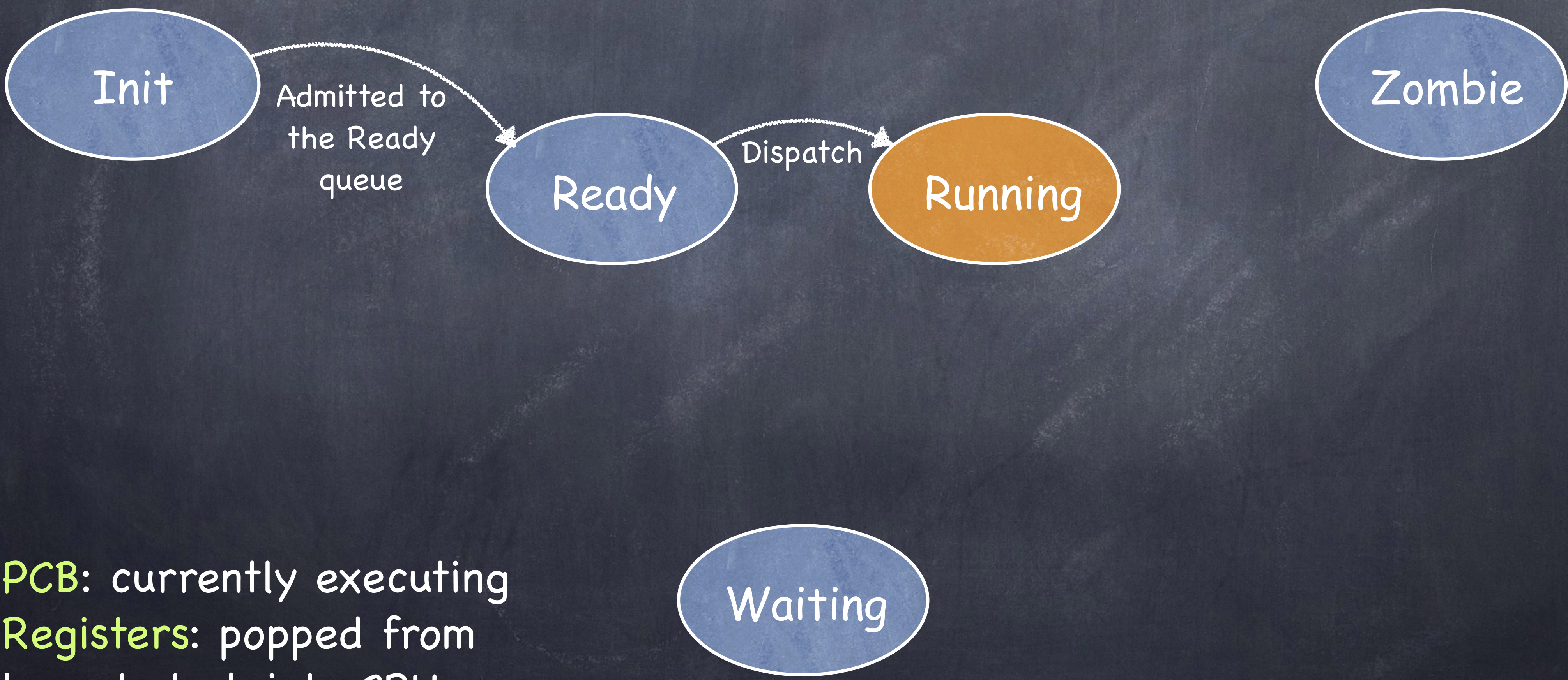
Process Life Cycle



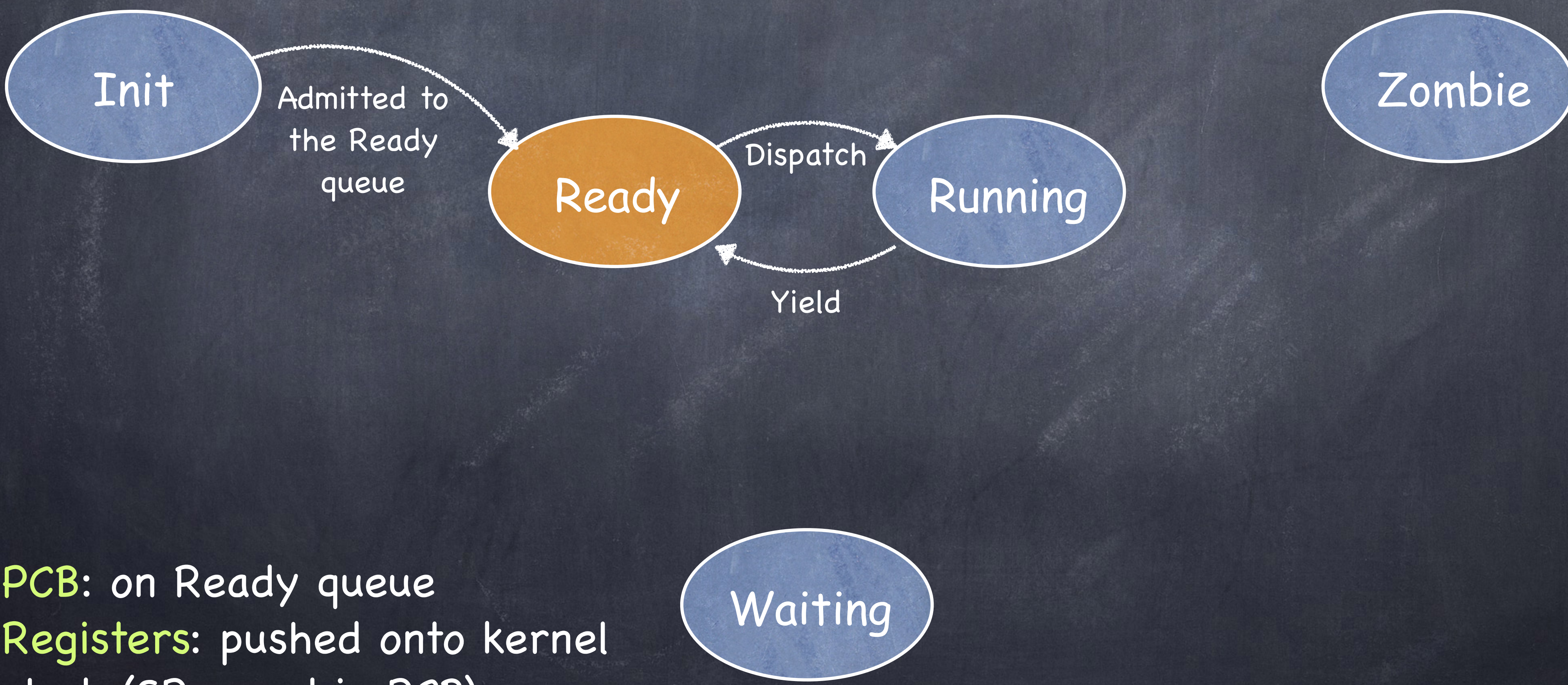
PCB: on the Ready queue
Registers: pushed by kernel code onto kernel stack

Process Life Cycle



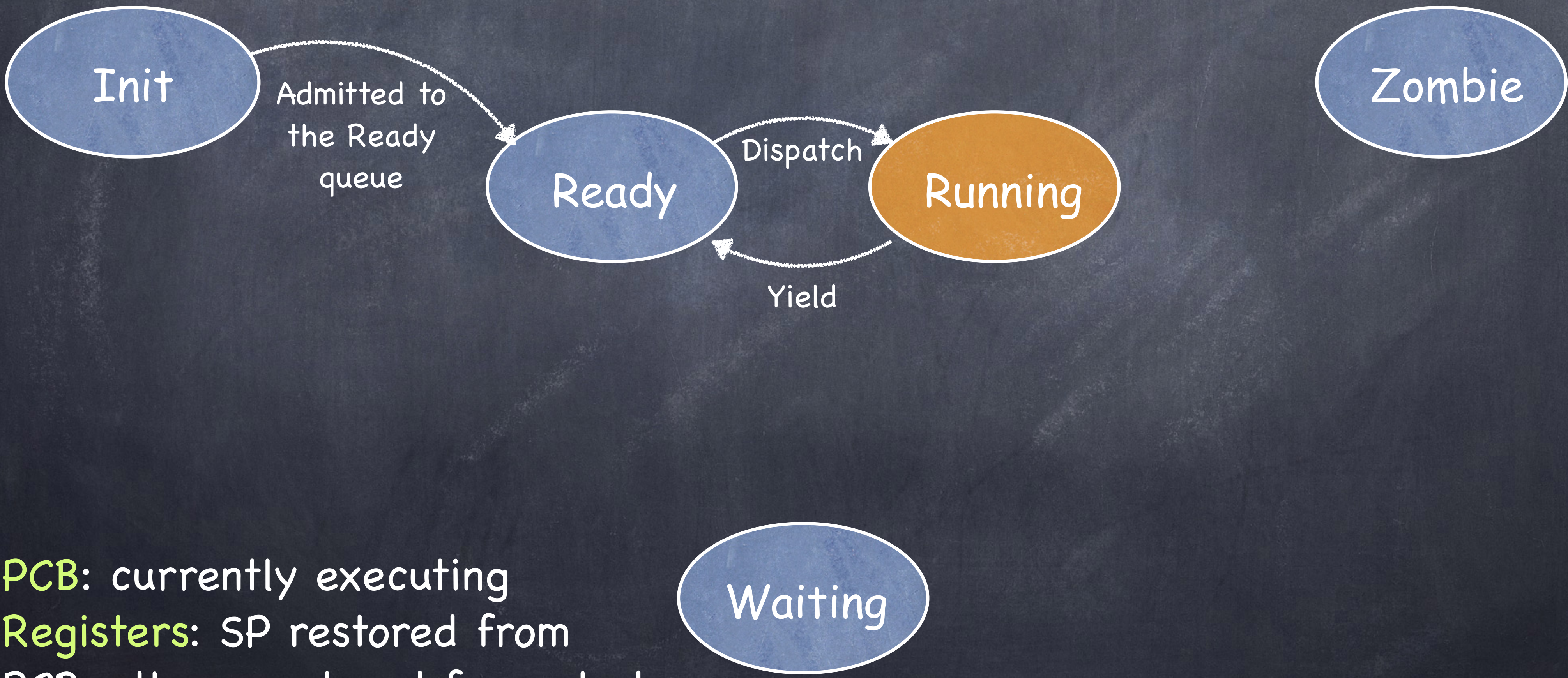
PCB: currently executing
Registers: popped from
kernel stack into CPU

Process Life Cycle



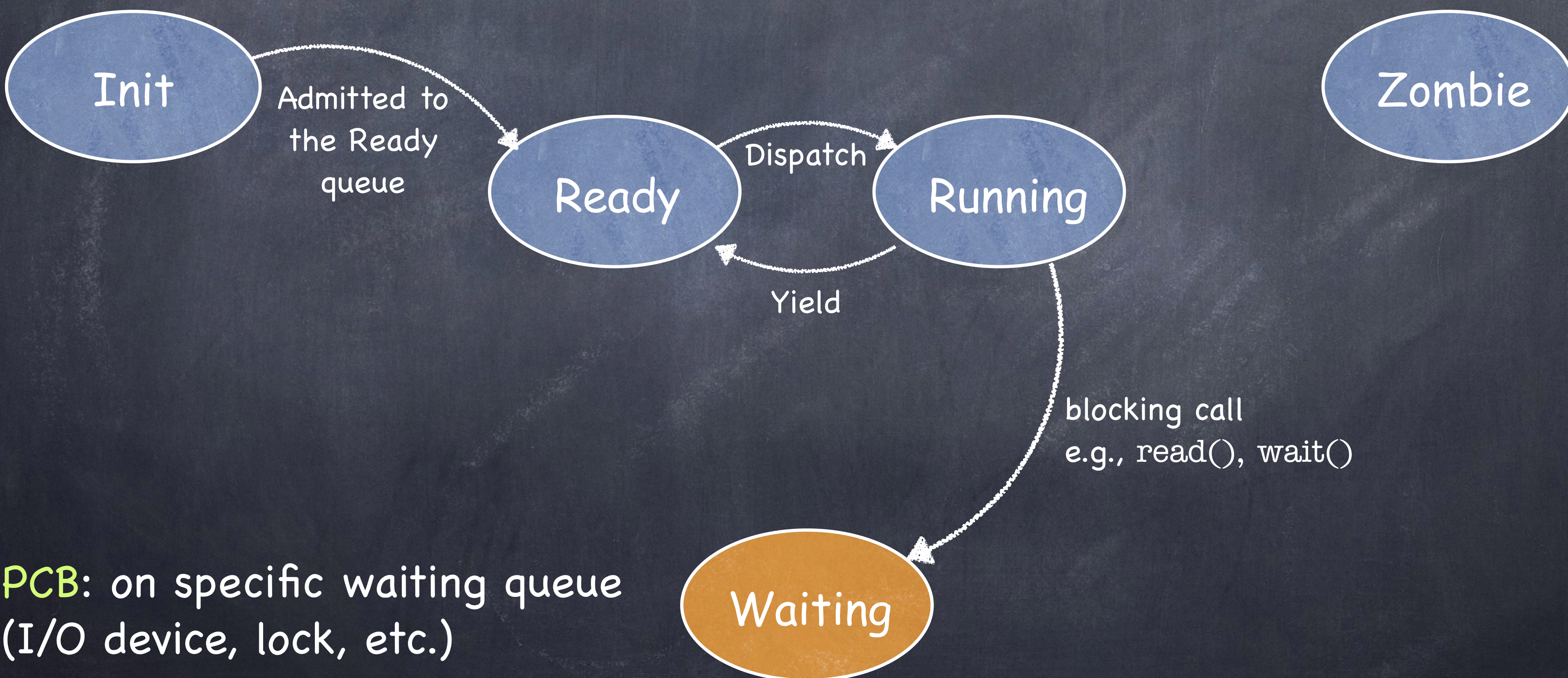
PCB: on Ready queue
Registers: pushed onto kernel stack (SP saved in PCB)

Process Life Cycle



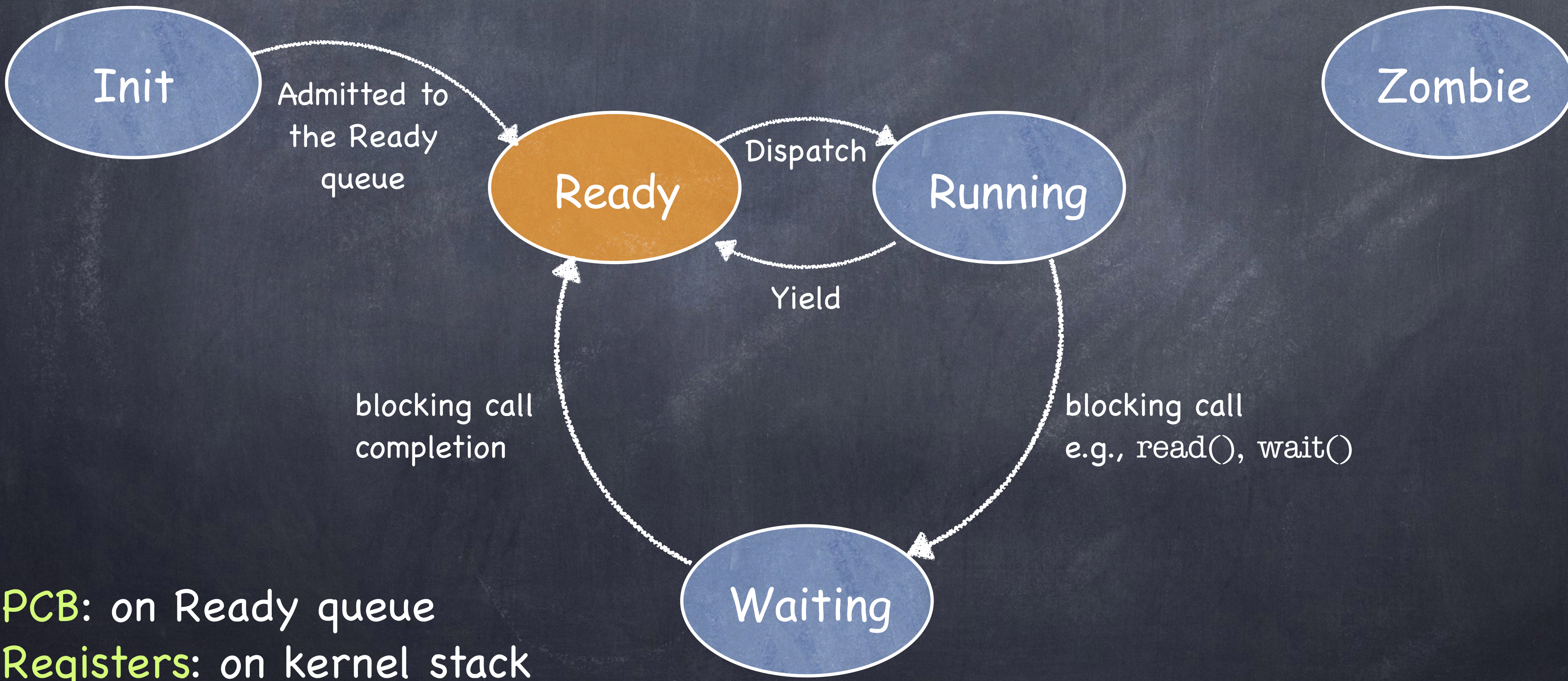
PCB: currently executing
Registers: SP restored from PCB; others restored from stack

Process Life Cycle



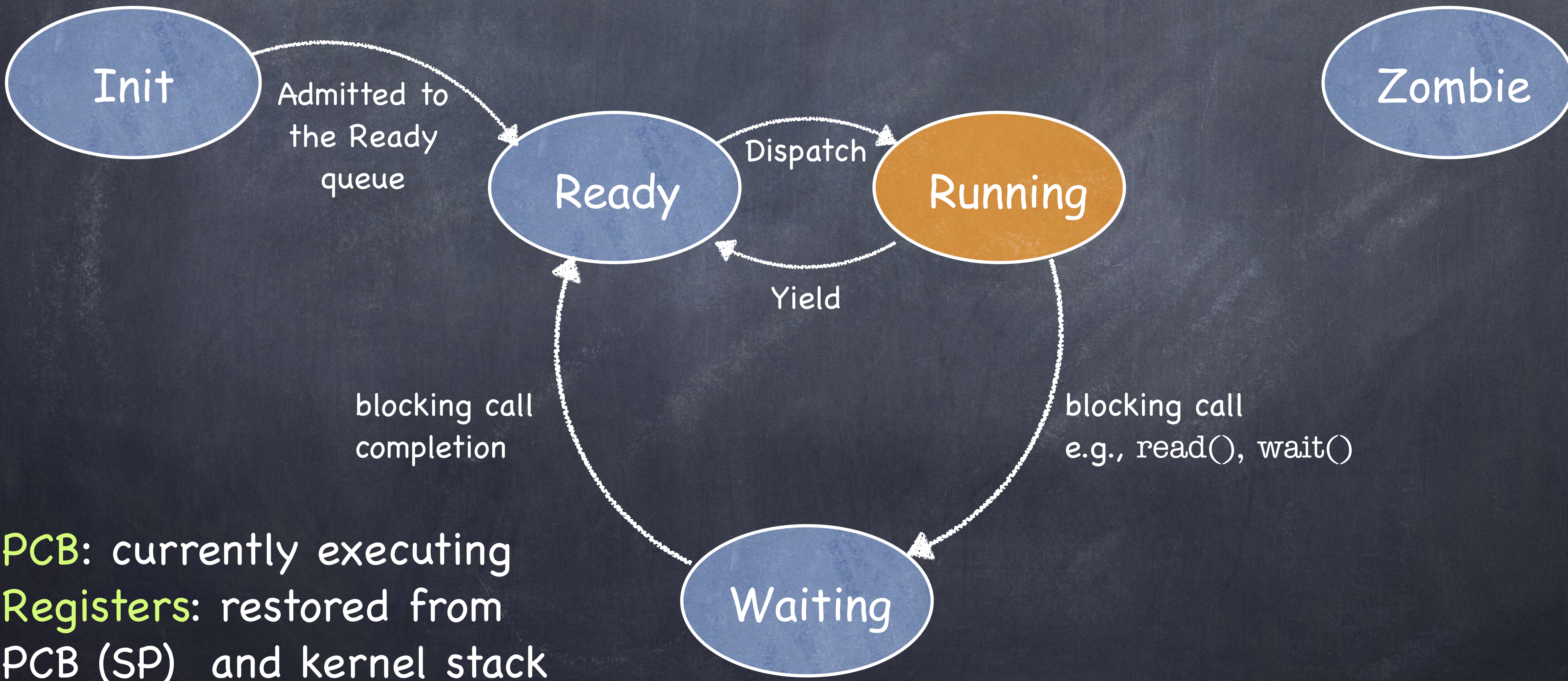
PCB: on specific waiting queue (I/O device, lock, etc.)
Registers: on kernel stack

Process Life Cycle



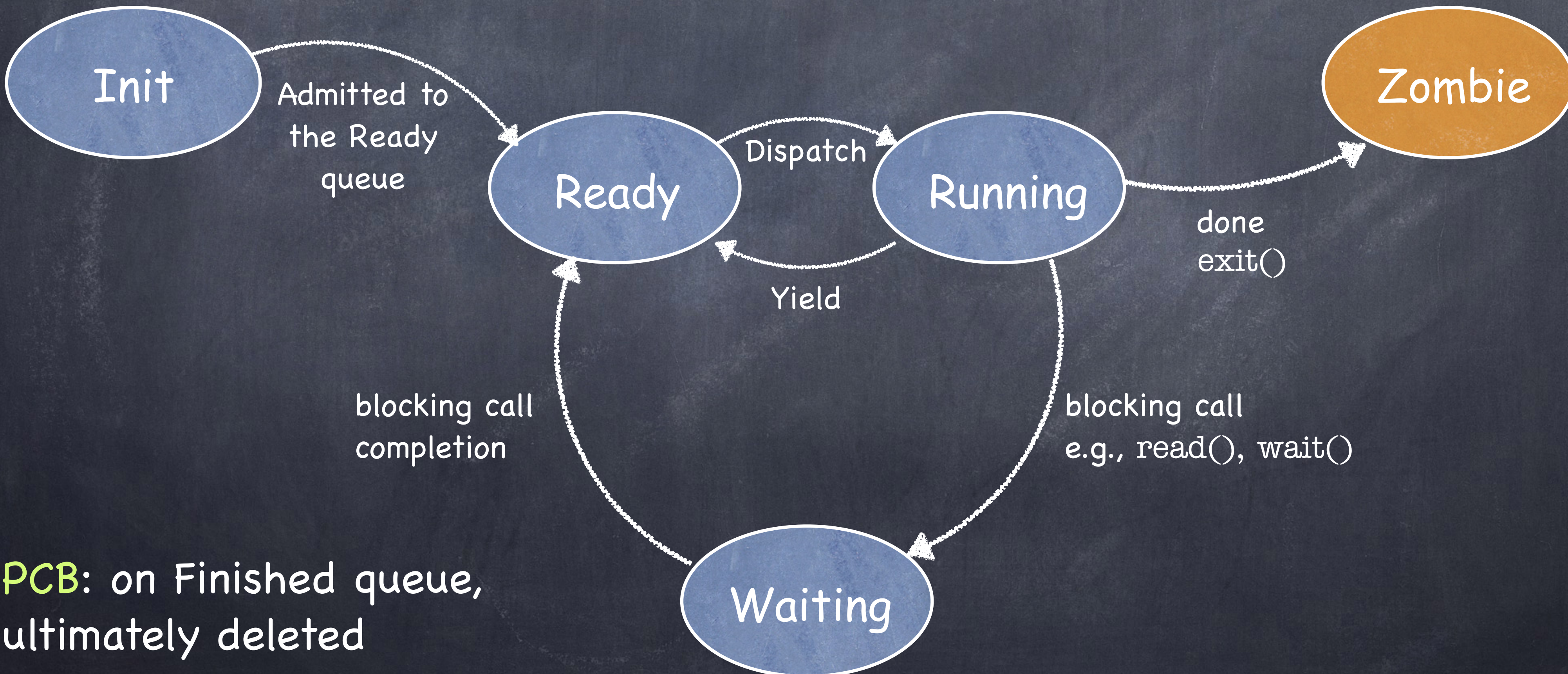
PCB: on Ready queue
Registers: on kernel stack

Process Life Cycle



PCB: currently executing
Registers: restored from PCB (SP) and kernel stack into CPU

Process Life Cycle



PCB: on Finished queue, ultimately deleted
Registers: no longer needed

Invariants to keep in mind

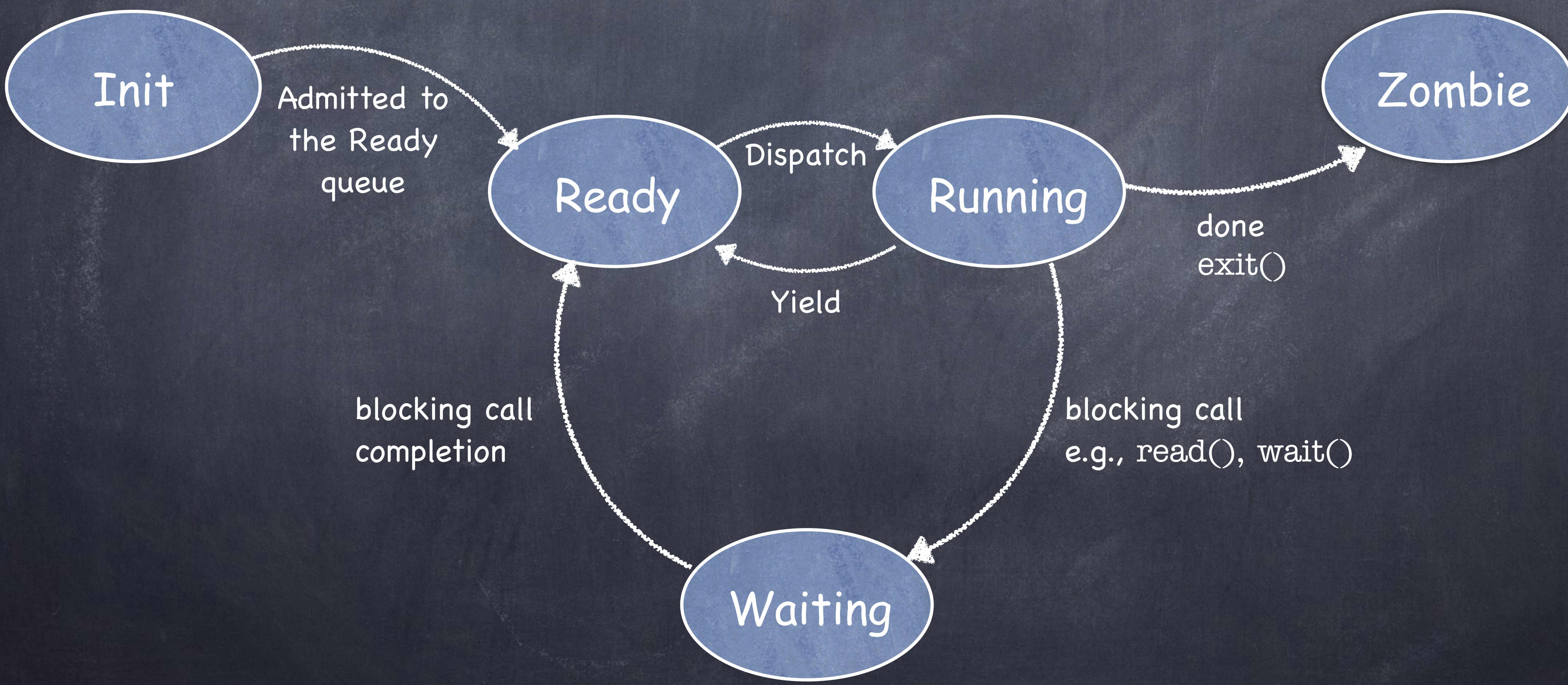
- At most one process/core running at any time
- When CPU in user mode, current process is RUNNING and its kernel stack is empty
- If process is RUNNING
  - its PCB not on any queue
  - it is not necessarily in USER mode
- If process is READY or WAITING
  - its registers are saved at the top of its kernel/interrupt stack
  - its PCB is either
    - on the READY queue (if READY)
    - on some WAIT queue (if WAITING)
- If process is a ZOMBIE
  - its PCB is on FINISHED queue

Cleaning up Zombies

- Process cannot clean up itself
  - hard to clean up and switch without a stack!
- Process can be cleaned up
  - by some other process, checking for zombies before returning to RUNNING state
  - or by parent which waits for it
    - but what if parent turns into a zombie first?
  - or by a dedicated "reaper" process

- Linux uses a combination
  - if alive, parent cleans up child that it is waiting for
  - if parent is dead, child process is inherited by the initial process, which is continually waiting

Process Life Cycle



How to Yield/Wait?

- Must switch the "CPU state" (the context) captured in its registers and PSW
- Must switch from executing the current process to executing some other READY process
  - Current process: RUNNING → READY
  - Next process: READY → RUNNING

1. Save kernel registers of Current on its kernel stack
2. Save kernel SP of Current in its PCB
3. Restore kernel SP of Next from its PCB
4. Restore kernel registers of Next from its kernel stack