Processes

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Outline

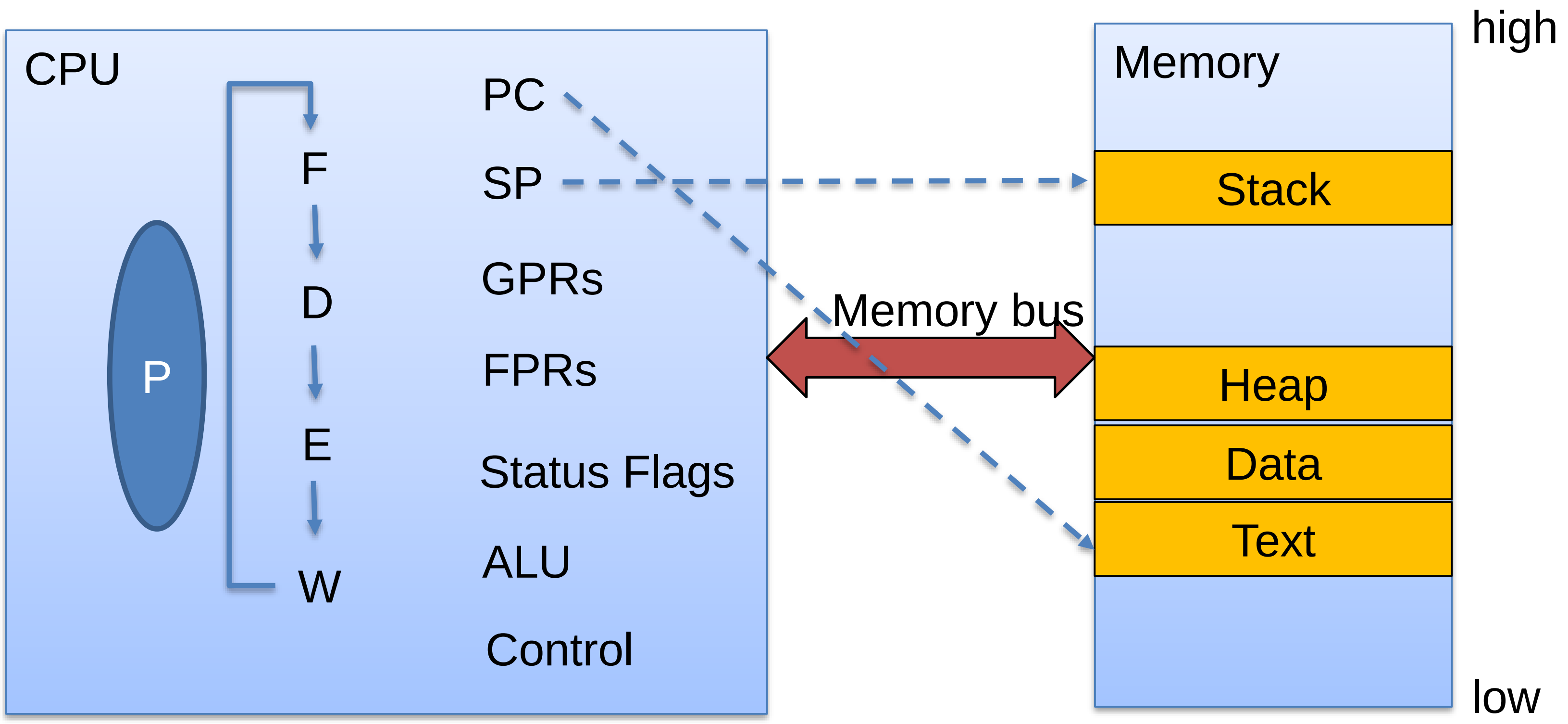
- “running programs”
- What is in a Process?
    - A snapshot view
    - Context saving and restoring
- Process States and PCB
- Operations on process
    - Process Scheduling
    - Process Creation
    - Process Termination

Snapshot view - I

- Assume a process using the CPU at a point in time.
  - What are the “resources” that the running program would be using?

Snapshot view - II

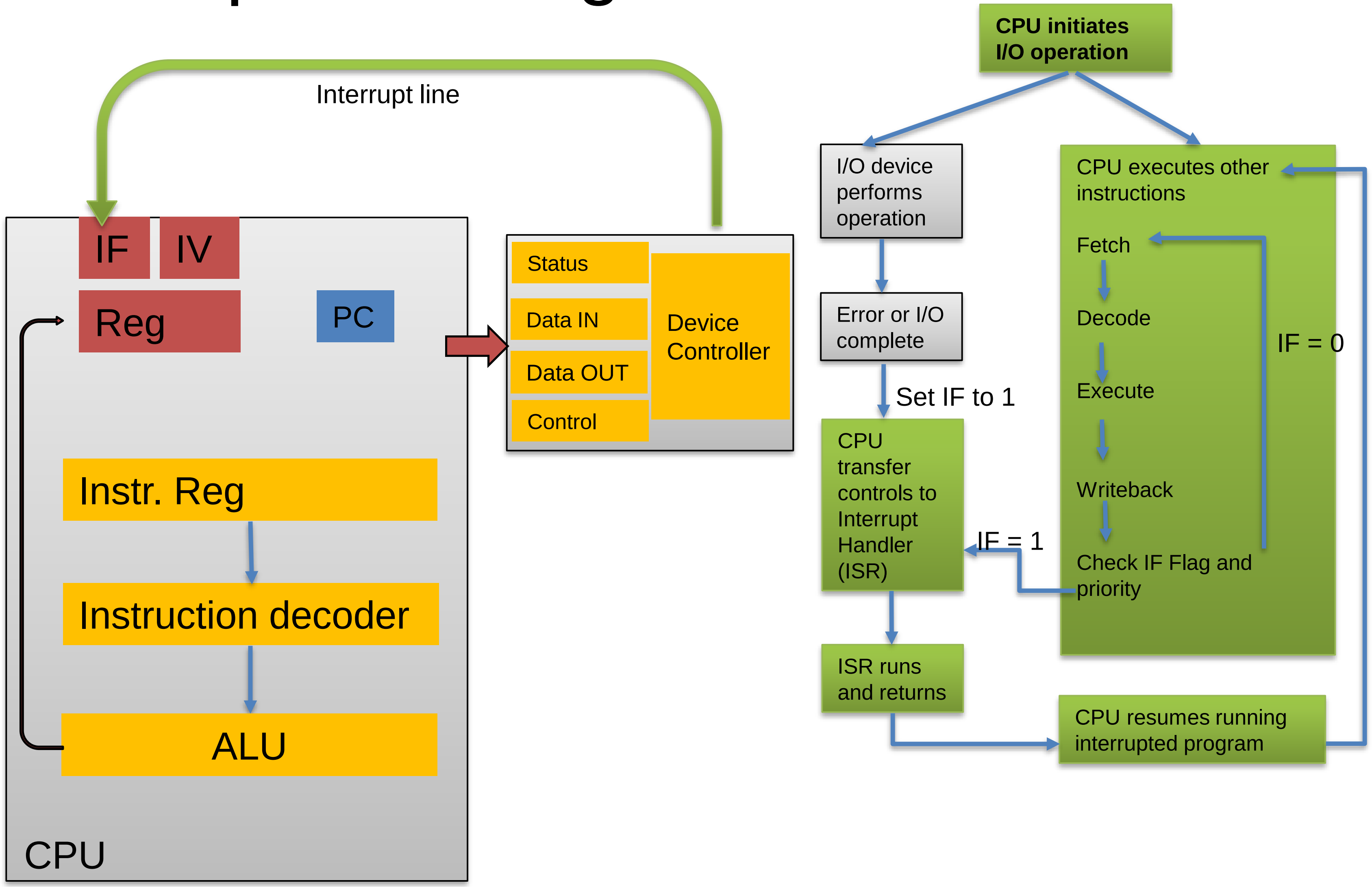
- Process is running. So at least using Memory and CPU.
- What is it using in ?



Context of a process

- User registers (including FPs, PC, SP).
- Status flags and other special registers (more later)
- Why registers only?
  - How about ALU, Control Unit and all the stuff in Memory?
    - Treat ALU and Control Unit like a black box
    - Registers are the input into ALU and Control Unit
    - Save the registers values and restore them later.
    - Same register values ensure the same behaviour from ALU and Control Unit.
    - Memory taken care of by OS memory management.

Interrupt Handling - revisited


CPU initiates I/O operation
Interrupt line
IF
IV
Reg
PC
Instr. Reg
Instruction decoder
ALU
CPU
Status
Data IN
Data OUT
Control
Device Controller
I/O device performs operation
Error or I/O complete
Set IF to 1
CPU transfer controls to Interrupt Handler (ISR)
IF = 1
ISR runs and returns
CPU executes other instructions
Fetch
Decode
Execute
Writeback
Check IF Flag and priority
IF = 0
CPU resumes running interrupted program

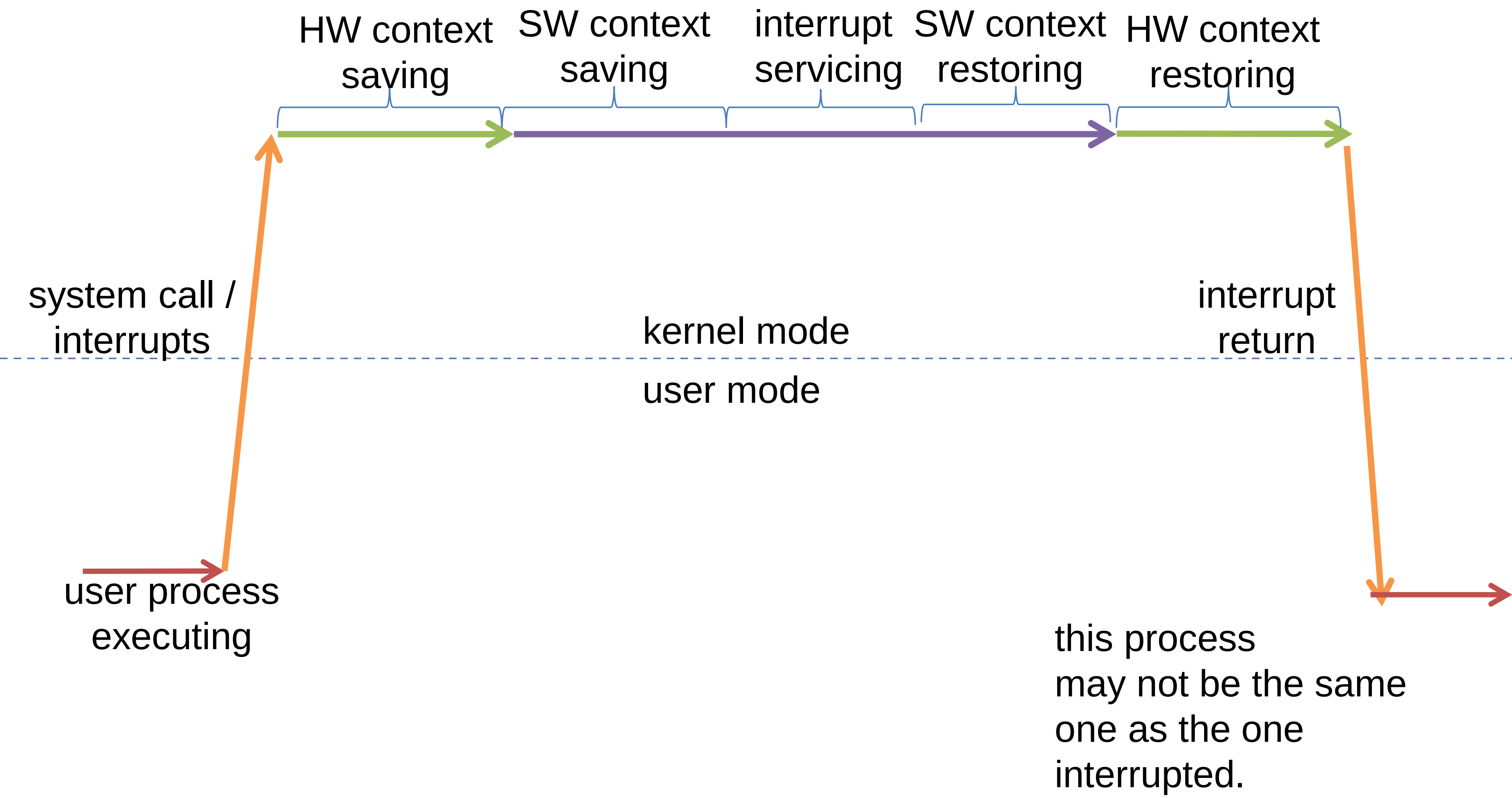
HW context saving / restoring

- Automatic (no instructions involved)
- What if the CPU don’t support HW saving?
  - HW MUST support some kind of saving.
  - At least HW must save the PC and SP.
  - Too late for ISR to save PC and SP by the time ISR is running.
- Where does it save to?
  - HW reads the SP
  - Save the registers to the stack.
- Restoring is the reverse of saving.

SW context saving/restoring

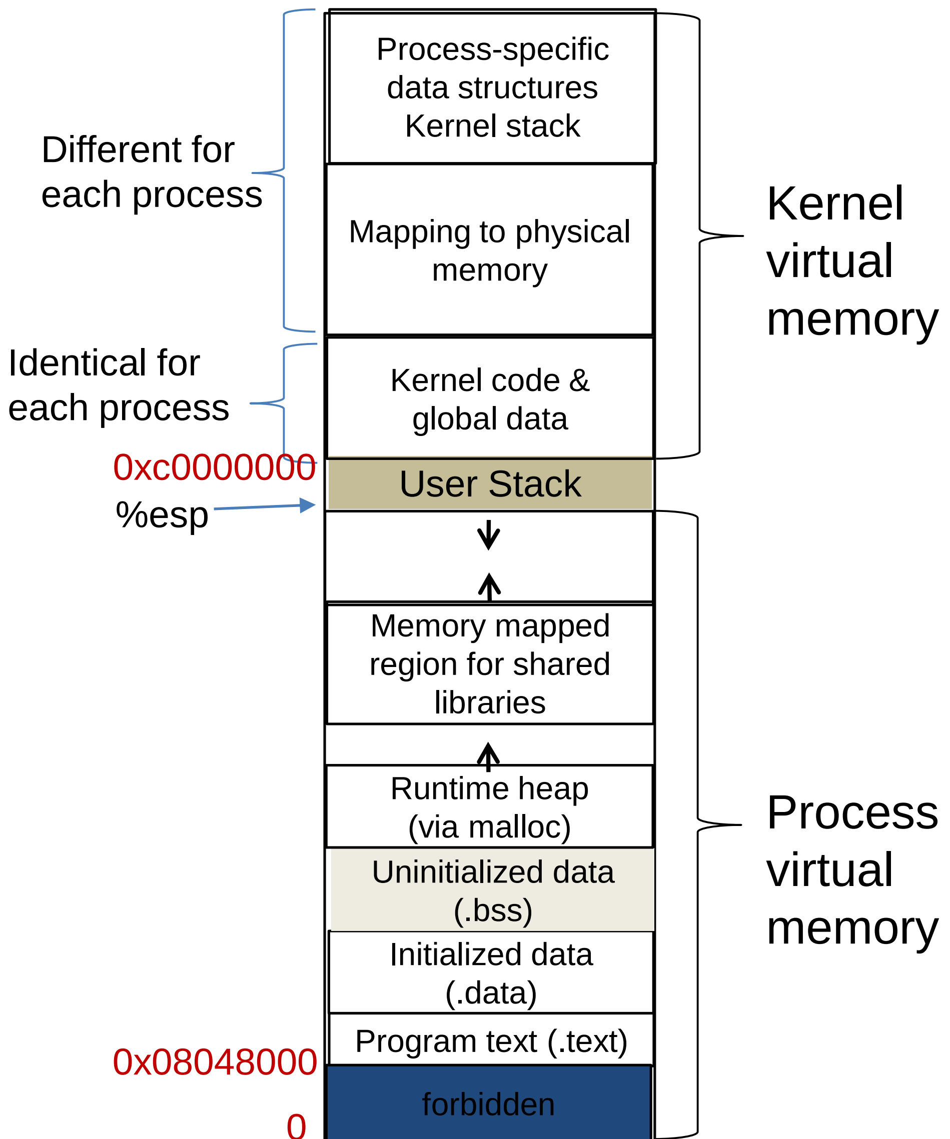
- Usually the 1st thing done in ISR
- Sometimes HW context saving doesn’t save all the registers!
    - e.g., x86 only saves the GPRs but not the FPRs.
    - FPRs not saved unless used
- SW context saving : selective vs HW saves the registers regardless whether required or not!

System call/Interrupts Revisited



Example of Virtual Memory Layout

- Interrupt context
  - User mode➔kernel mode
  - Kernel mode
  - Save on kernel mode stack for intrpt (intrpt stack)
- Process context
  - Syscall
  - Save state on its kernel stack



Different for each process
Identical for each process
Process-specific data structures Kernel stack
Mapping to physical memory
Kernel code & global data
Kernel virtual memory
0xc0000000
%esp
User Stack
Memory mapped region for shared libraries
Runtime heap (via malloc)
Uninitialized data (.bss)
Initialized data (.data)
Program text (.text)
0x08048000
forbidden
0
Process virtual memory

x86 Interrupt

before ISR code execution

- Save current stack pointer
- Save current program counter
- Save current processor status word (condition codes)
- Switch to kernel stack; put SP, PC, PSW on stack
- Switch to kernel mode

Vector through interrupt table

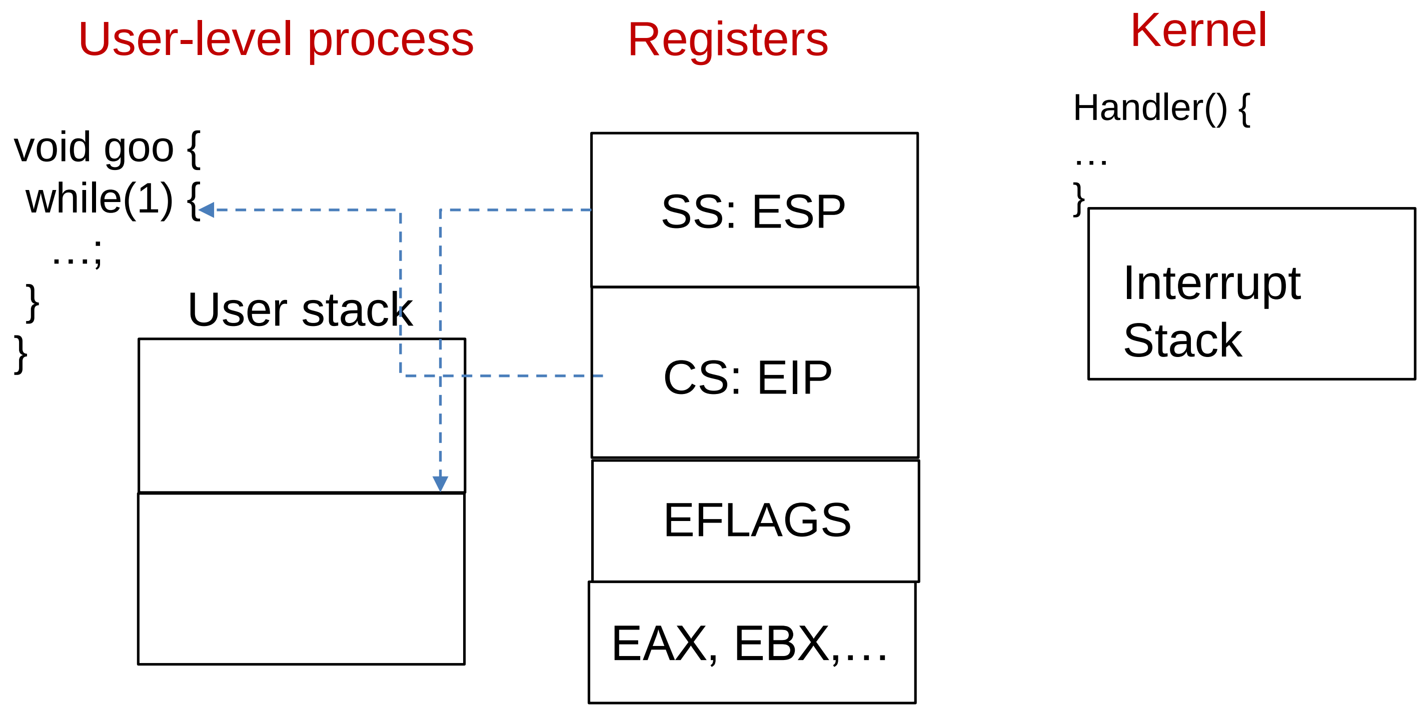
ISR saves registers it might clobber

Execution of handler code

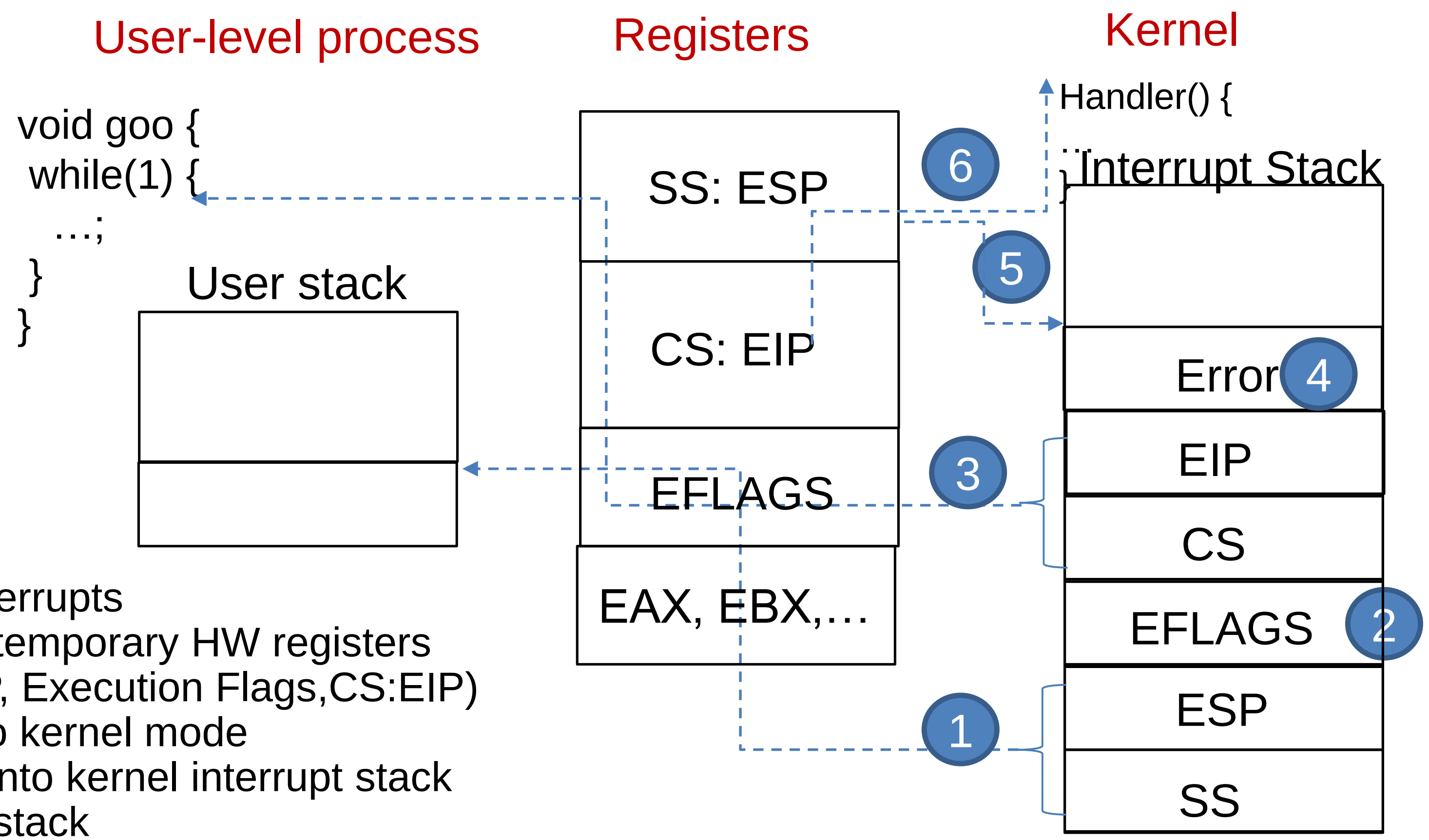
Return / Restoring of process state (IRET instruction)

Before Interrupt

- pointers: segment base+offset
- Current instructions: CS+EIP
- Current privilege: low-order bit of the ESP

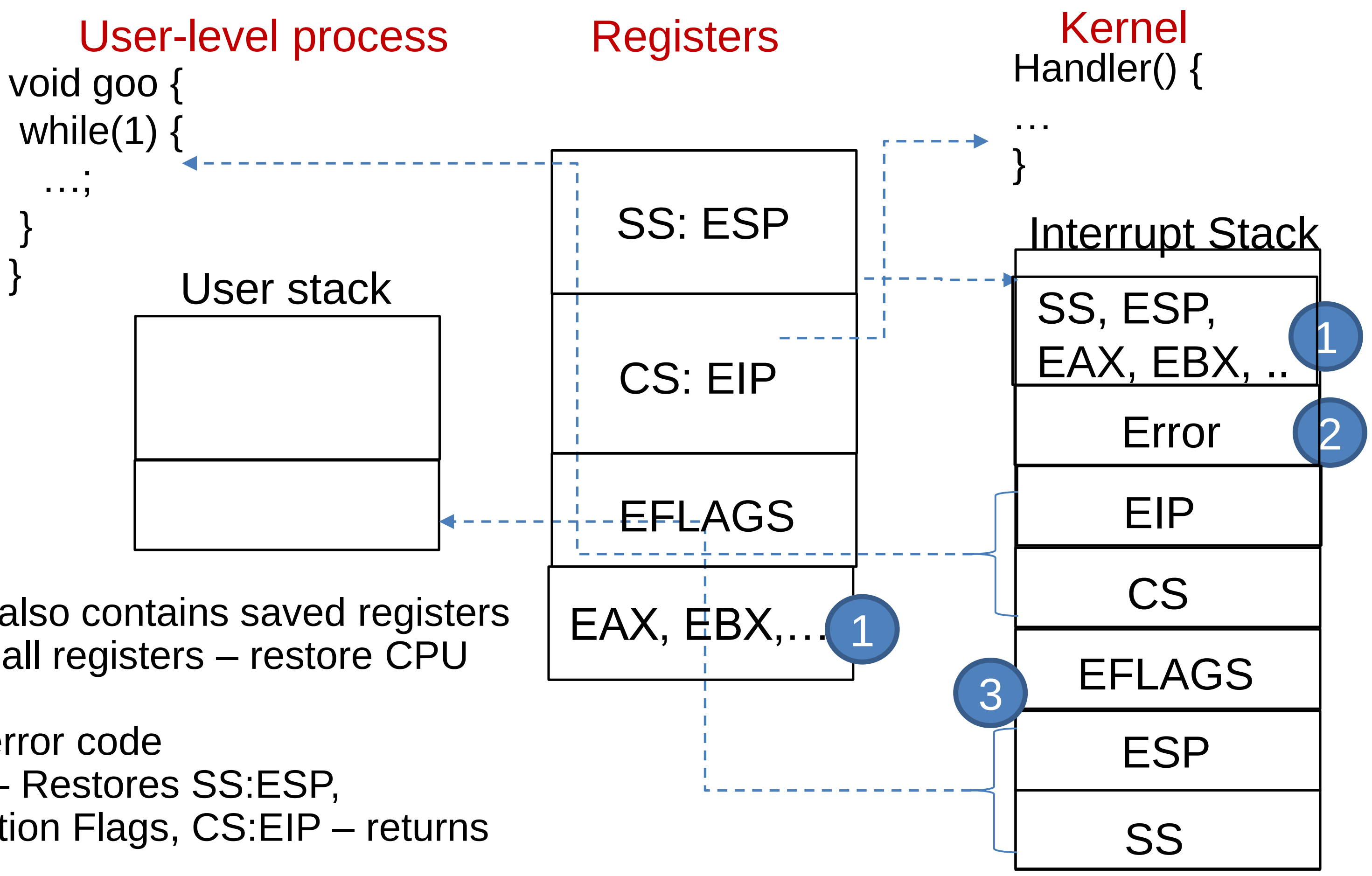


During Interrupt



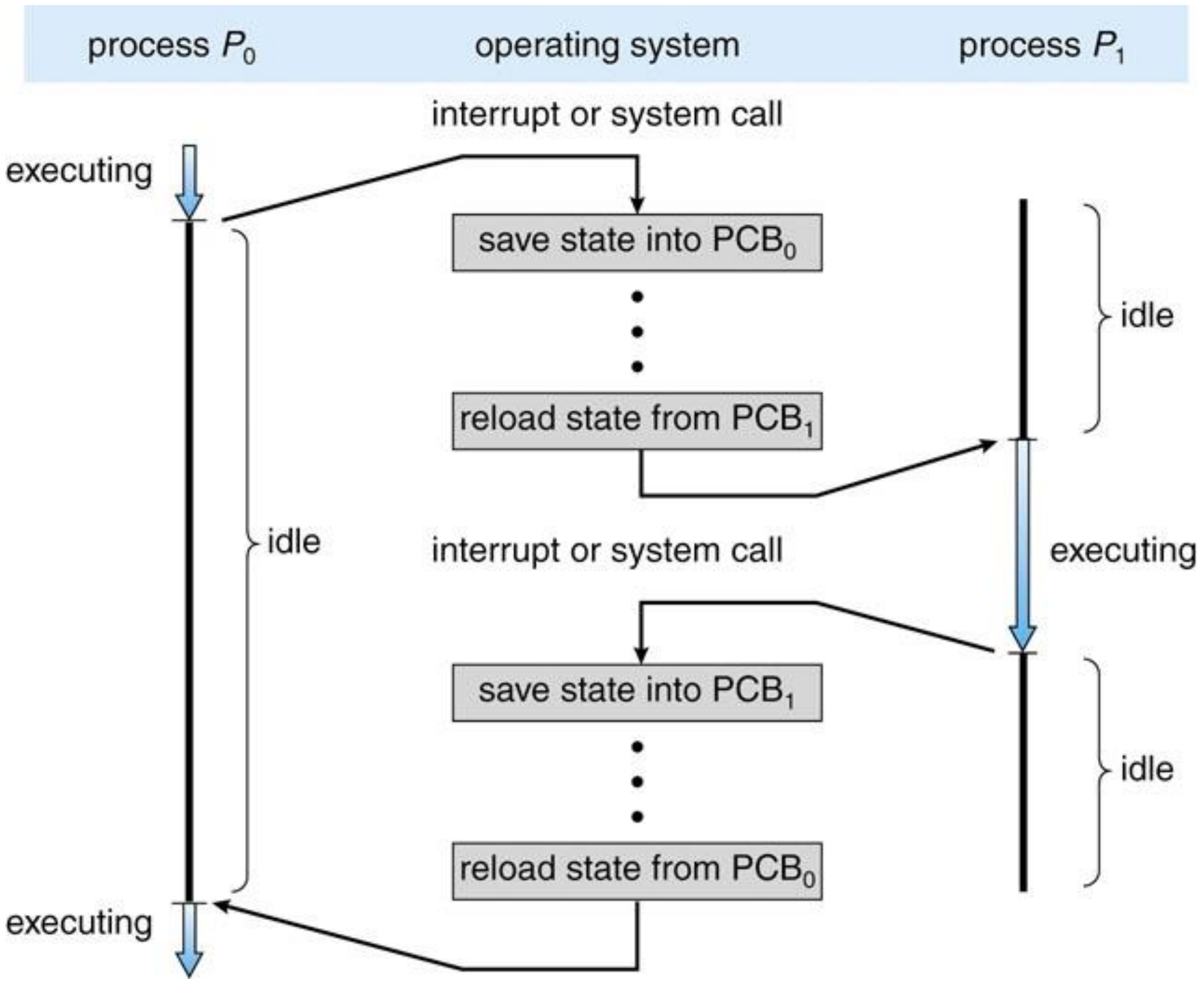
- Mask interrupts
- Save to temporary HW registers (SS:ESP, Execution Flags,CS:EIP)
- Switch to kernel mode
- Switch onto kernel interrupt stack
- Push to stack
- Save error code
- Invoke interrupt hander

After Interrupt

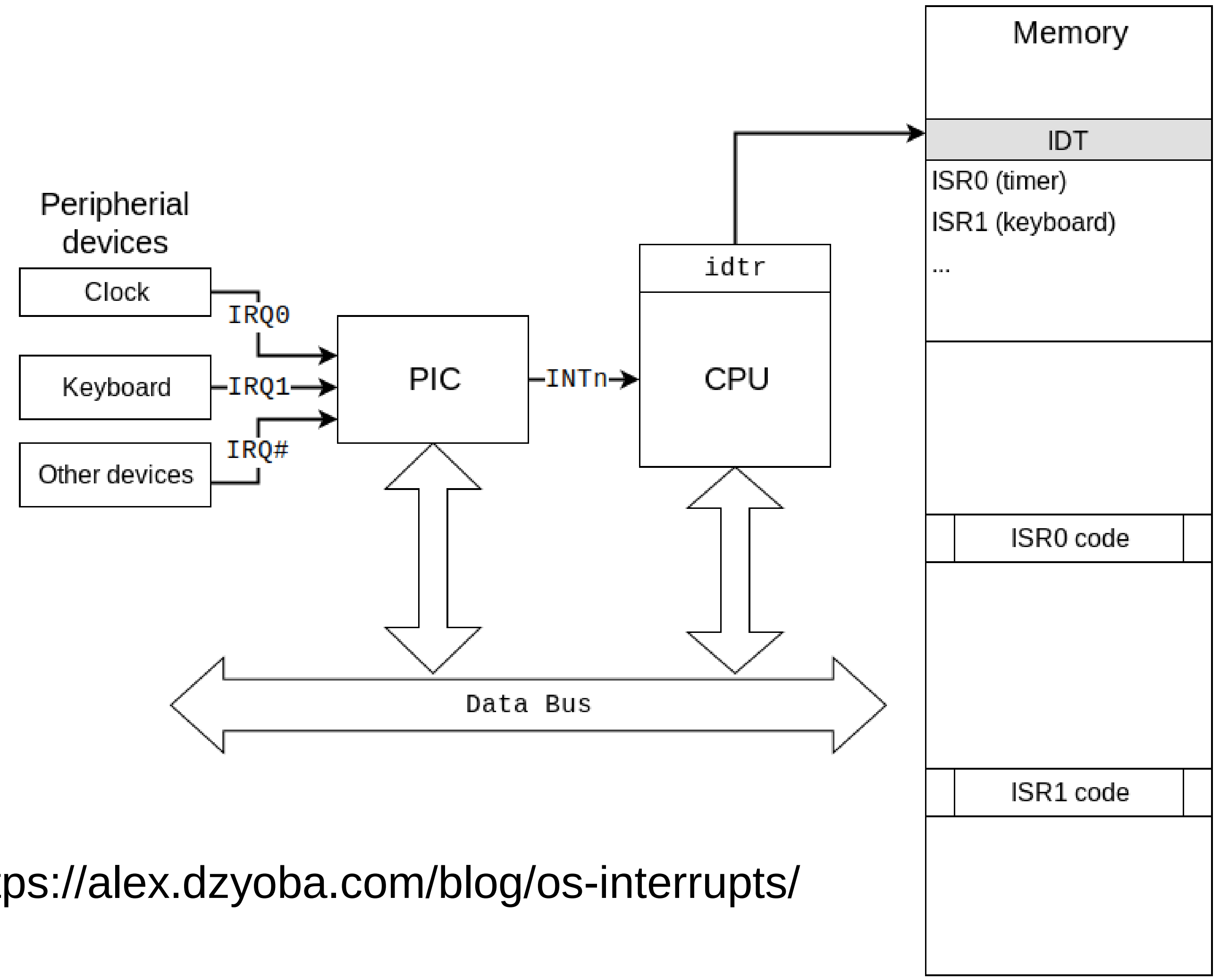


- Stack also contains saved registers
- POPs all registers – restore CPU state
- POP error code
- IRET – Restores SS:ESP, Execution Flags, CS:EIP – returns

Context Switch



Example of Interrupt



https://alex.dzyoba.com/blog/os-interrupts/

ISR occurred in user mode

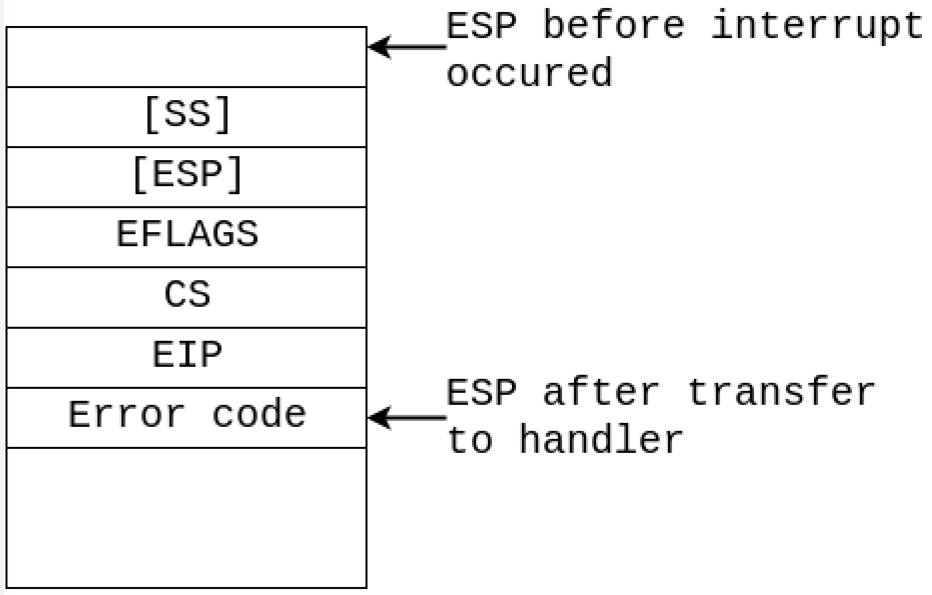
1. Temporarily saves (internally) the current contents of the SS, ESP, EFLAGS, CS and EIP registers.
2. Loads the segment selector and the stack pointer for the new stack (that is, the stack for the privilege level being called) from the TSS into the SS and ESP registers and switches to the new stack.
3. Pushes the temporarily saved SS, ESP, EFLAGS, CS, and EIP values for the interrupted procedure’s stack onto the new stack.
4. Pushes an error code on the new stack (if appropriate).
5. Loads the segment selector for the new code segment and the new instruction pointer (from the interrupt gate or trap gate) into the CS and EIP registers, respectively.
6. If the call is through an interrupt gate, clears the IF flag in the EFLAGS register.
7. Begins execution of the handler procedure at the new privilege level.

ISR occurred in kernel mode

1. Push the current contents of the EFLAGS, CS, and EIP registers (in that order) on the stack.
2. Push an error code (if appropriate) on the stack.
3. Load the segment selector for the new code segment and the new instruction pointer (from the interrupt gate or trap gate) into the CS and EIP registers, respectively.
4. Clear the IF flag in the EFLAGS, if the call is through an interrupt gate.
5. Begin execution of the handler procedure.

ISR Procedure

1.Save the state of interrupted procedure
2.Save previous data segment
3.Reload data segment registers with kernel data descriptors
4.Acknowledge interrupt by sending EOI to PIC
5.Do the work
6.Restore data segment
7.Restore the state of interrupted procedure
8.Enable interrupts
9.Exit interrupt handler with `iret`



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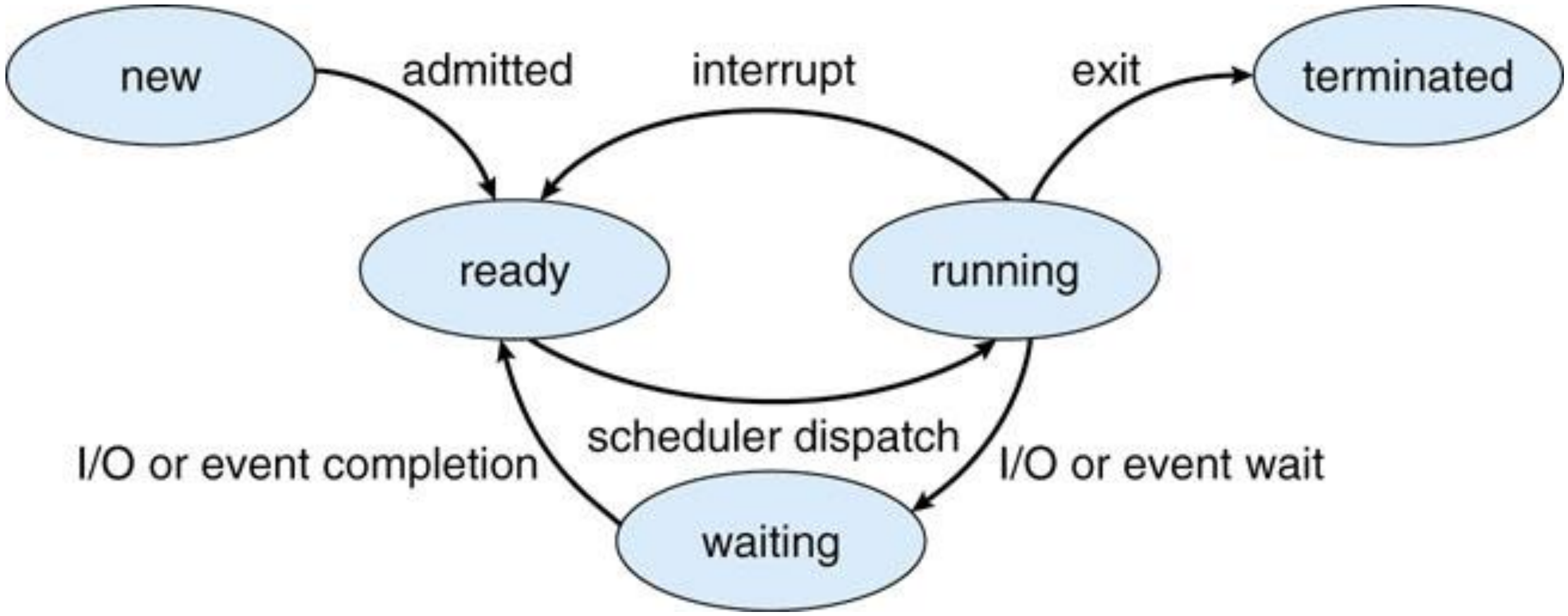
Process state transitions



Process state

- New – Process being prepared for loading and execution.
- Running – Process using the CPU.
- Waiting – Process waiting for some I/O event or signal.
- Ready – Process ready to run.
- Terminated – Process has finished execution.

Process Control Block (PCB)

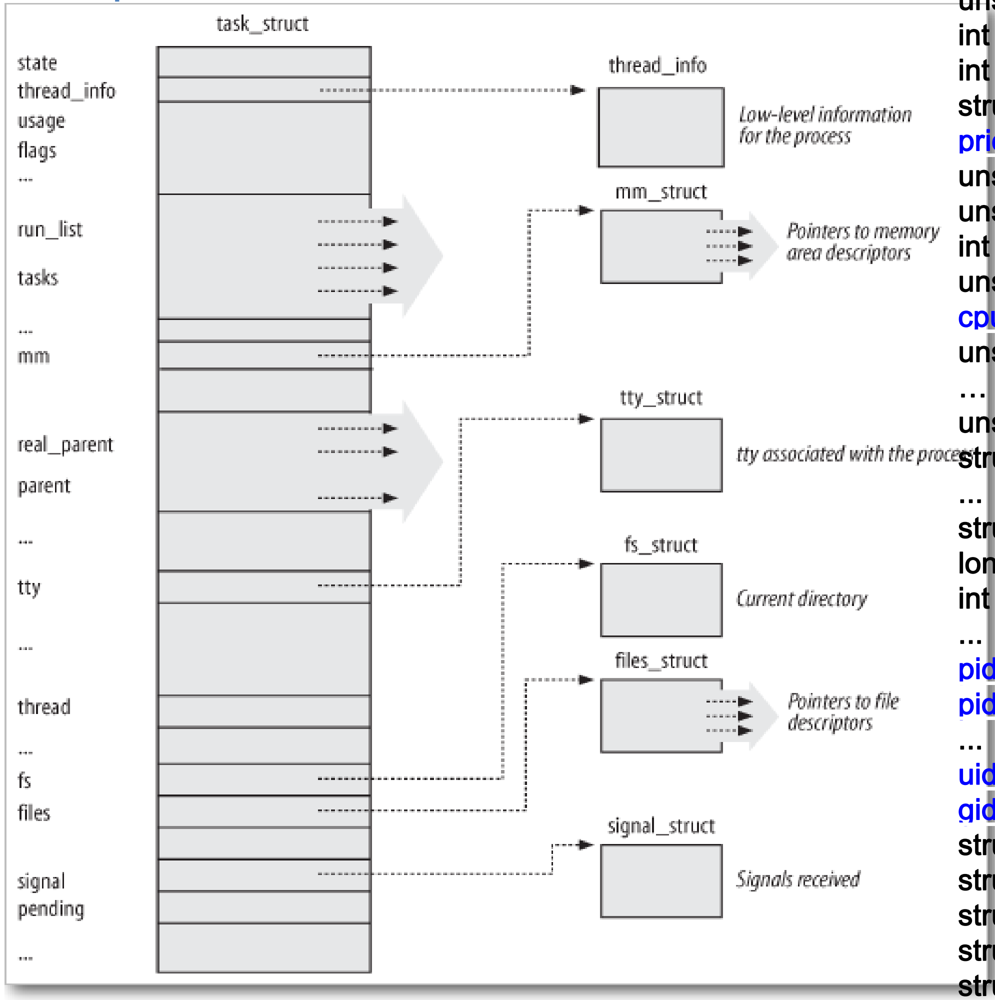
- Data struct **per** process.
- Maintained by OS.
- Not directly accessible.
- Usually a linked list.

What is stored in PCB?

- Process ID (identifier uniquely identifying the process)
- Process state (New, Running , Waiting etc)
- Context (or pointer to context)
  - Saved here during SW context saving.
  - PC, SP, GPRs etc.
- CPU scheduling info
  - Scheduling Policy / Priority
- Memory management Info (learn later)
- Accounting Info
- I/O Status
  - Files opened to the process, I/O devices used in the process etc

http://lxr.free-electrons.com/source/include/linux/sched.h#L1474

Struct task_struct



```
struct task_struct {
    volatile long state; /* -1 unrunnable, 0 runnable, >0 stopped */
    struct thread_info *thread_info;
    atomic_t usage;
    unsigned long flags; /* per process flags, defined below */
    unsigned long ptrace;
    int lock_depth; /* Lock depth */
    int prio, static_prio;
    struct list_head run_list;
    prio_array_t *array;
    unsigned long sleep_avg;
    unsigned long long timestamp, last_ran;
    int activated; tate
    unsigned long policy;
    cpumask_t cpus_allowed;
    unsigned int time_slice, first_time_slice;
    …
    unsigned long rt_priority;
    struct list_head tasks;
    …
    struct mm_struct *mm, *active_mm;
    long exit_state;
    int exit_code, exit_signal;
    …
    pid_t pid;
    pid_t tgid;
    …
    uid_t uid,euid,suid,fsuid;
    gid_t gid,egid,sgid,fsgid;
    struct task_struct *real_parent; /*real parent process (w. debug)*/
    struct task_struct *parent; /* parent process */
    struct list_head children; /* list of my children */
    struct list_head sibling; /* linkage in my parent's children list */
    struct task_struct *group_leader; /* threadgroup leader */
```

Process State Transitions

- New to Ready
  - PCB Initialized
  - Memory Allocated
- Ready to Running
  - Scheduler picked this process to run from the ready processes
  - You have another linked list of ready processes (ready queue)
- Running to Ready
  - Interrupt happens. (HW Interrupt Or Fault/Exception)
- Running to Waiting
  - During ***some*** system calls. (Especially I/O and process synchronization)
- Waiting to Ready
  - I/O event or Signal Process is waiting for has arrived.
- Running to Terminated
  - When program has finished, maintain info about this process for a while. (Why?)

Lecture Outline

- “running programs” (Why inverted commas?)
- What is in a Process?
    - A snapshot view
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- Operations on process
    - Process Scheduling
    - Process Creation
    - Process Termination

Process Scheduling

- Selecting *n* process from ready queue to run in *n* CPUs.
- Which processes to choose?
  - Depends on scheduling algorithm and process attributes…

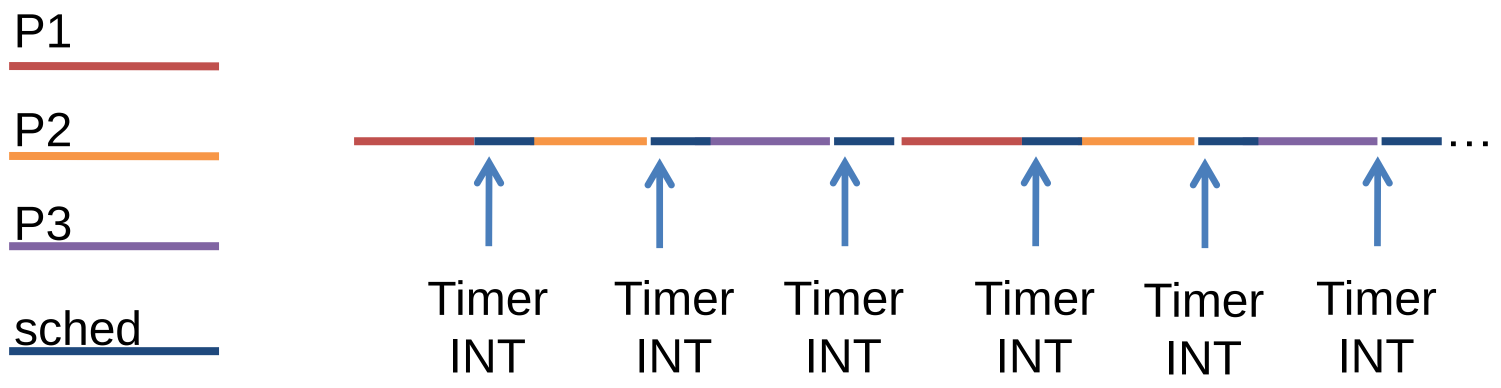
When is an opportunity for scheduling?

- A process goes from
  - running to waiting
  - running to ready
  - waiting to ready*
  - New to ready*
  - running to terminated

Process scheduling

- Non-preemptive
  - Sequential execution
- Preemptive (time-shared)
  - Time slices/Timer Interrupt

Round-Robin scheduling



Process creation

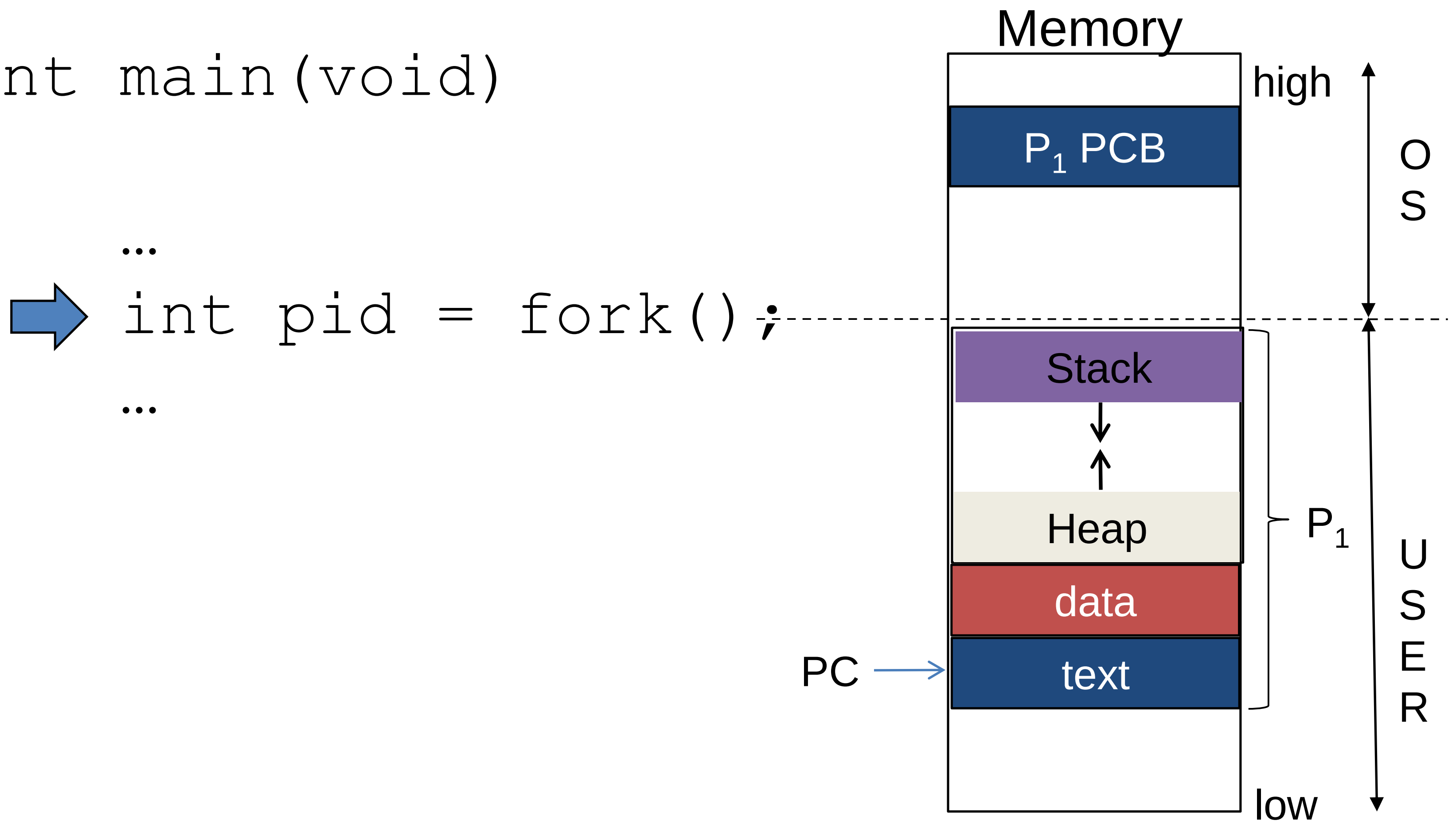
- 2 things
  - Create a process
  - Loading and running a program
- Linux
  - 2 separate APIs
  - fork() – create process
  - exec() – run a new program
- Windows
  - 1 API
  - CreateProcess (both create process and run a new program)

Linux Process Creation: `fork()` - I

- parent `fork` child
- exact replica of parent (same memory contents, files, etc)
  - Different pid
  - Different return value for `fork()`
  - `Other diff see https://linux.die.net/man/2/fork`
- `wait()` call and `exit()` call

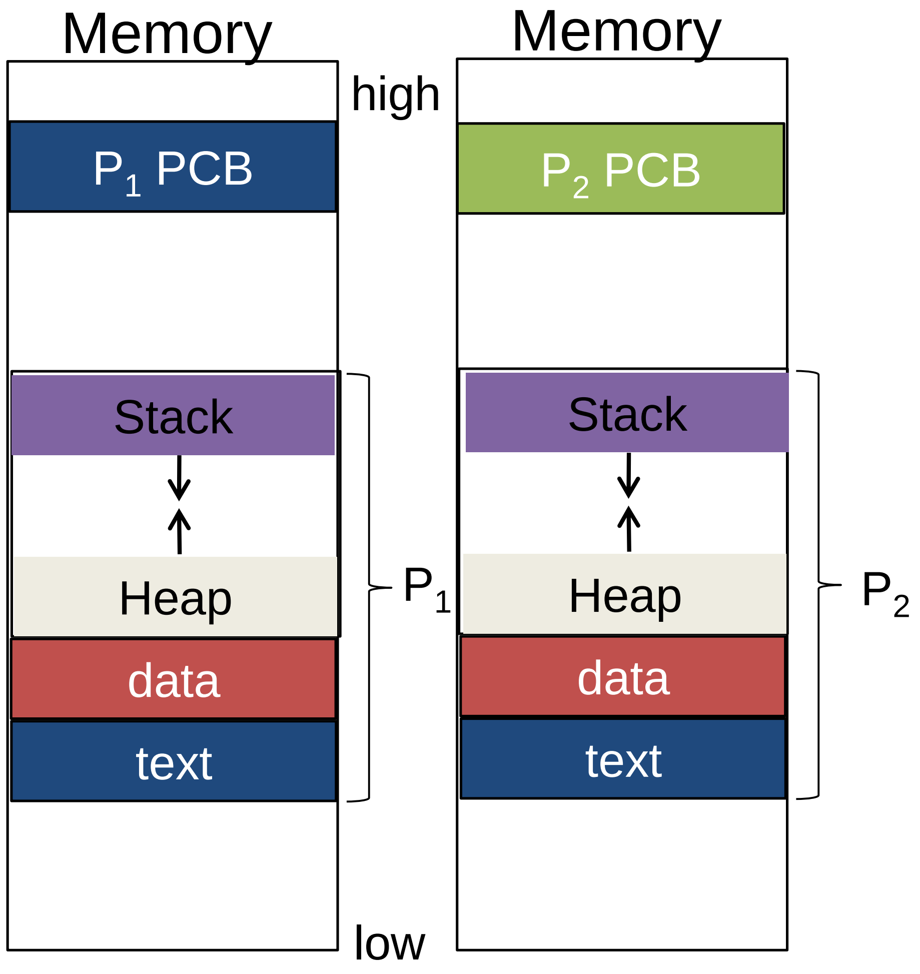
How fork works (1)

```
int main(void)
{
    …
    int pid = fork();
    …
}
```



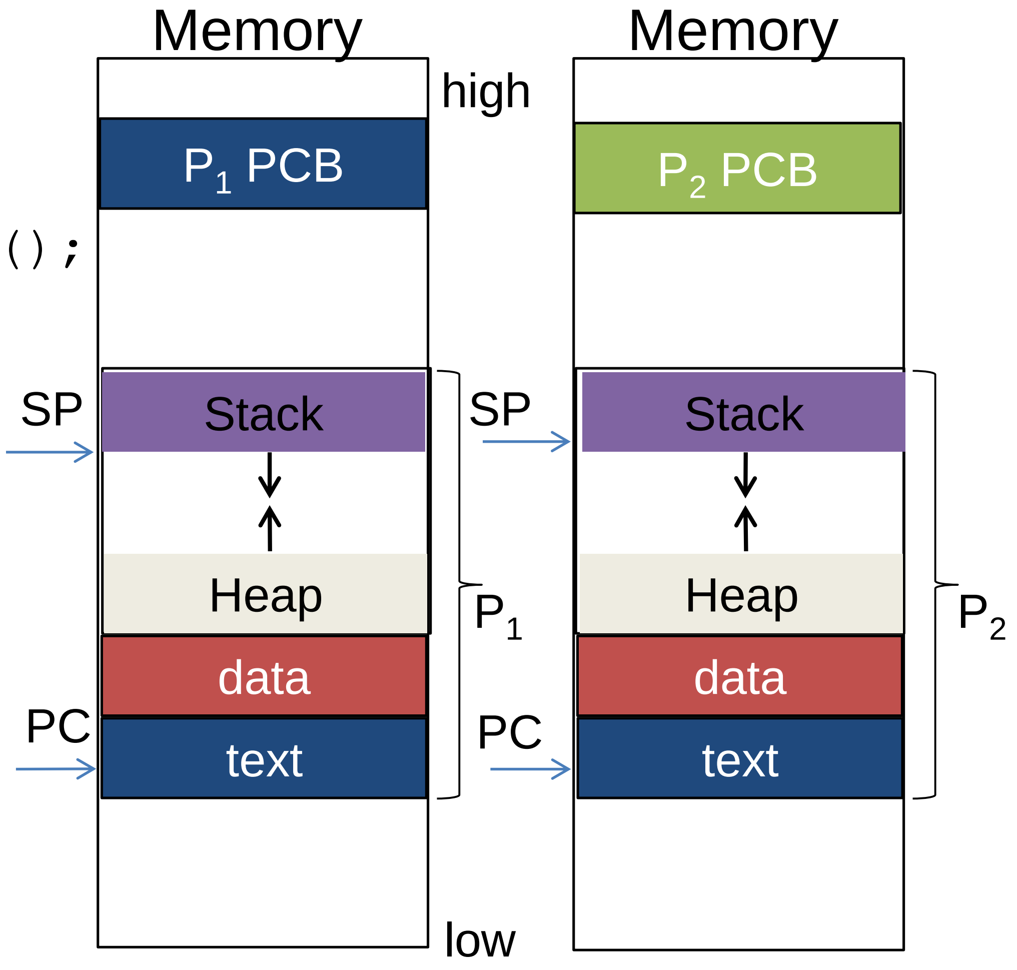
How fork works (2)

```
int main(void)
{
     …
     int pid = fork();
     …
}
```

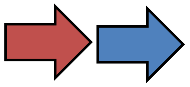


How fork works (3)

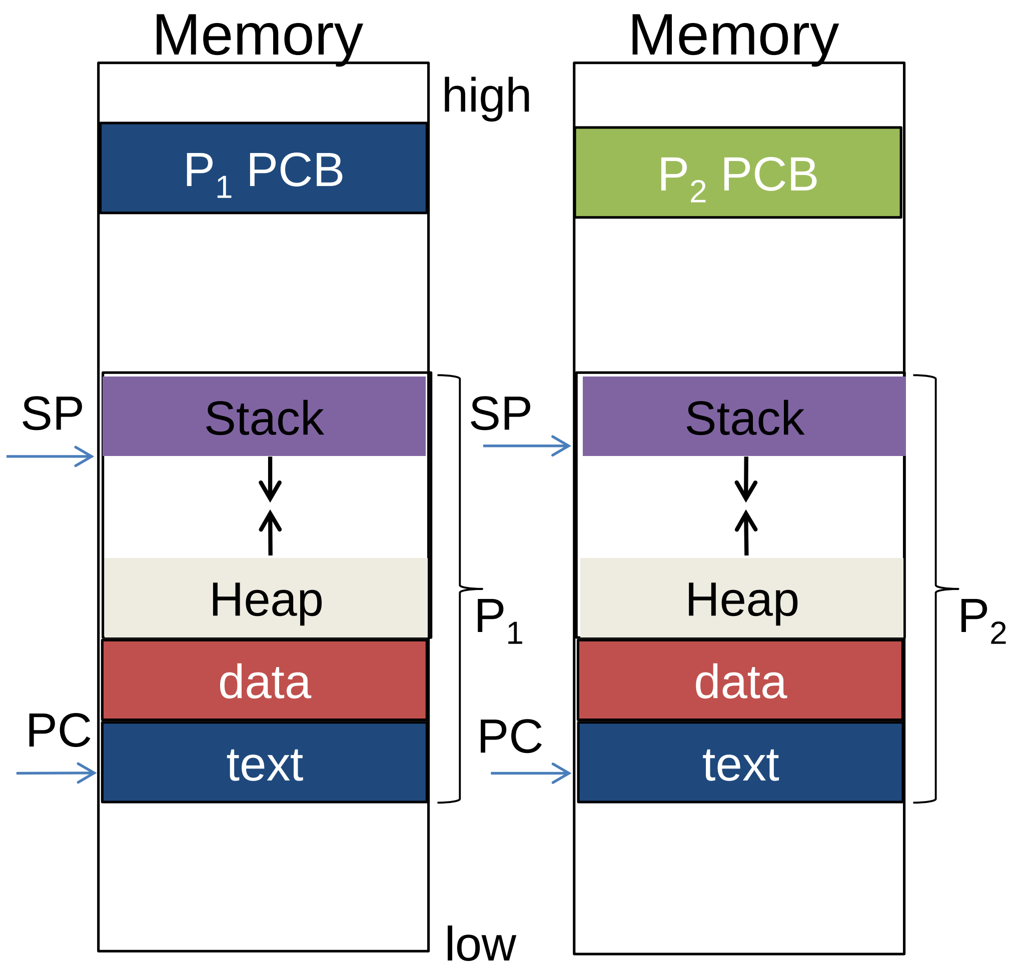
```
int main(void)
{
    …
    int pid = fork();
    …
}
```



How fork works (4)



```
int main(void)
{
    …
    int pid = fork();
    …
}
```

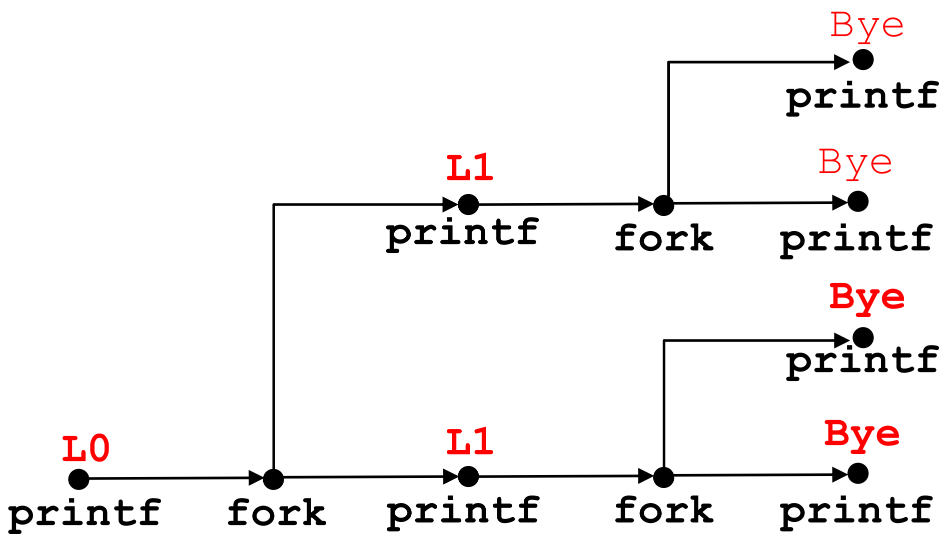


Linux Process Creation: `fork()` - II

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>   // standard POSIX header file
#include <sys/wait.h> // POSIX header file for 'wait' function

int main(void) {
  int i = -1;
  int pid;
  pid = getpid();
  fprintf(stdout,"parent pid = %d\n",pid);

  pid = fork();

  if (pid == 0) {
    for (i=0; i < 10; ++i) {
      fprintf(stdout,"child process: %d\n",i);
      sleep(1);  }
    exit(0);
  } else {
    fprintf(stdout,"child pid = %d\n",pid);
    fprintf(stdout,"waiting for child\n");
    wait(NULL);
    fprintf(stdout,"child terminated\n");
  }

  fprintf(stdout,"parent terminating\n");
  return 0;
}
```

fork Example: Two consecutive forks

```
void fork2()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
}                                forks.c
```

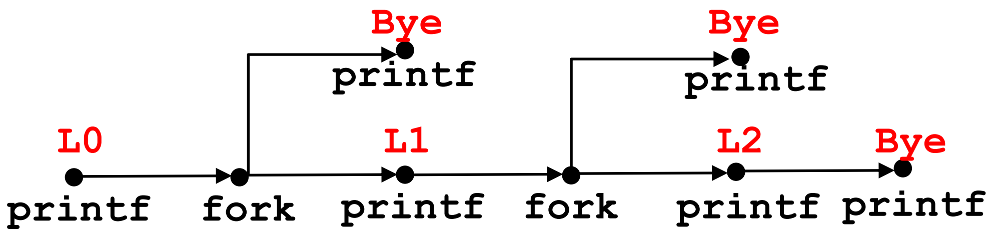


Feasible output:	Infeasible output:
L0	L0
L1	Bye
Bye	L1
Bye	Bye
L1	L1
Bye	Bye
Bye	Bye

fork Example: Nested forks in parent

```
void fork4()
{
    printf("L0\n");
    if (fork() != 0) {
        printf("L1\n");
        if (fork() != 0) {
            printf("L2\n");
        }
    }
    printf("Bye\n");
}
```

forks.c

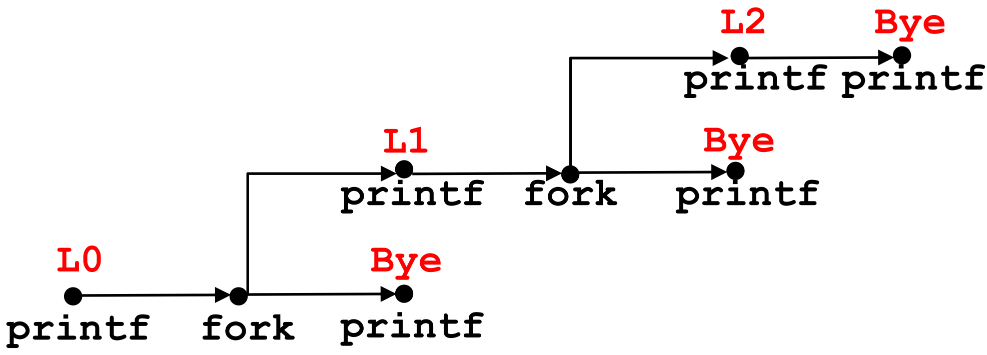


Feasible output:	Infeasible output:
L0	L0
L1	Bye
Bye	L1
Bye	Bye
L2	Bye
Bye	L2

fork Example: Nested forks in children

```
void fork5()
{
    printf("L0\n");
    if (fork() == 0) {
        printf("L1\n");
        if (fork() == 0) {
            printf("L2\n");
        }
    }
    printf("Bye\n");
}
```

forks.c



Feasible output:	Infeasible output:
L0	L0
Bye	Bye
L1	L1
L2	Bye
Bye	Bye
Bye	L2

Homework – What does the following code print?

```
int main()
{
   …
   fork();
   fork();
   printf(“Hello World\n”);
   …
}
```

- How many processes are created by this?

Linux Process Creation: `exec()`

- `exec()` family of functions
- A function that executes a new program in the *same* process.
    - Or replace the image of a process with a new one.
- Basic arguments into exec()
    - File that contains the new program you want to execute.
    - Arguments for the new program.
    - Optional: Environment variables for the new program.

Different ways to pass the arguments

- Filename of new program
  - Either using PATH environment variable
  - Or Full Path Name
- Arguments for the new program
  - Either in a comma list. (NULL terminated)
  - Or a string array (NULL terminated)
- Environment Variables
  - Passed in a string array.

Linux Process Creation: `exec()`

- `fork` creates a process
- How to run a new program?
  - `exec()` family of functions
- Different front ends for `execve()`

```
int execve(const char *filename, char *const argv[],
                  char *const envp[]);
```

```
int execl(const char *path, const char *arg, ...);
int execlp(const char *file, const char *arg, ...);
int execle(const char *path, const char *arg,
          ..., char * const envp[]);
int execv(const char *path, char *const argv[]);
int execvp(const char *file, char *const argv[]);
```

Suffixes l, v, p and e

l	specifies that the argument pointers (arg0, arg1, ..., argn) are passed as separate arguments. Typically, the l suffix is used when you know in advance the number of arguments to be passed.
v	specifies that the argument pointers (argv[0] ..., arg[n]) are passed as an array of pointers. Typically, the v suffix is used when a variable number of arguments is to be passed.
p	specifies that the function searches for the file in those directories specified by the PATH environment variable (without the p suffix, the function searches only the current working directory). If the path parameter does not contain an explicit directory, the function searches first the current directory, then the directories set with the PATH environment variable.
e	specifies that the argument env can be passed to the child process, letting you alter the environment for the child process. Without the e suffix, child processes inherit the environment of the parent process.

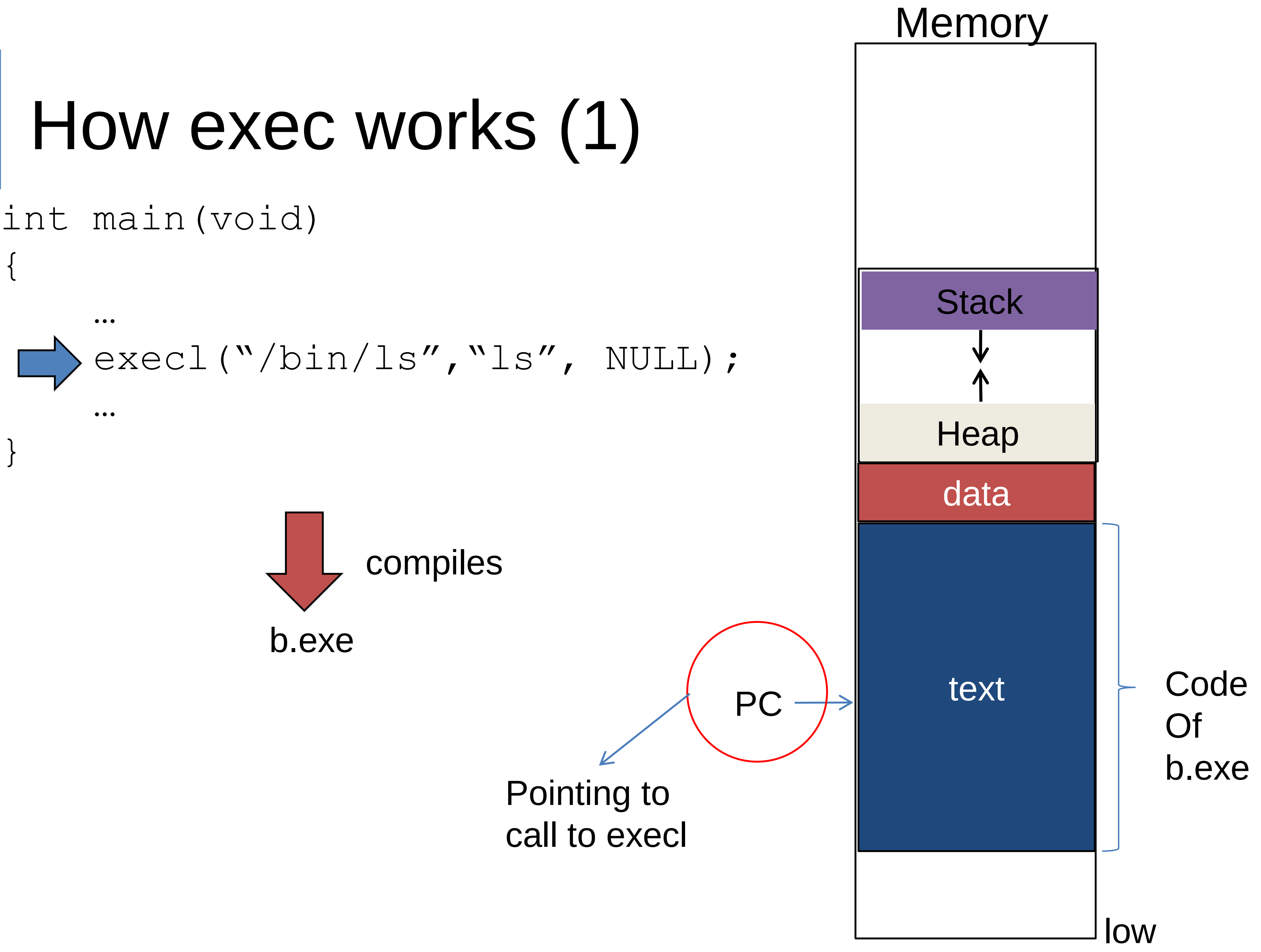
Linux Process Creation: `exec()`

```
#include <stdio.h>
#include <unistd.h>
#include <sys/wait.h>
int main(void) {
  int pid;
  fprintf(stdout,"creating child process\n");
  pid = fork();
  if (pid == 0)
    execl("/usr/games/gnome-sudoku","sudoku",NULL);
  else {
    fprintf(stdout,"waiting for child to terminate\n");
    wait(NULL);
    fprintf(stdout,"parent terminating\n");
  }
  return 0;
}
```

The first argument, by convention, should point to the filename associated with the file being executed

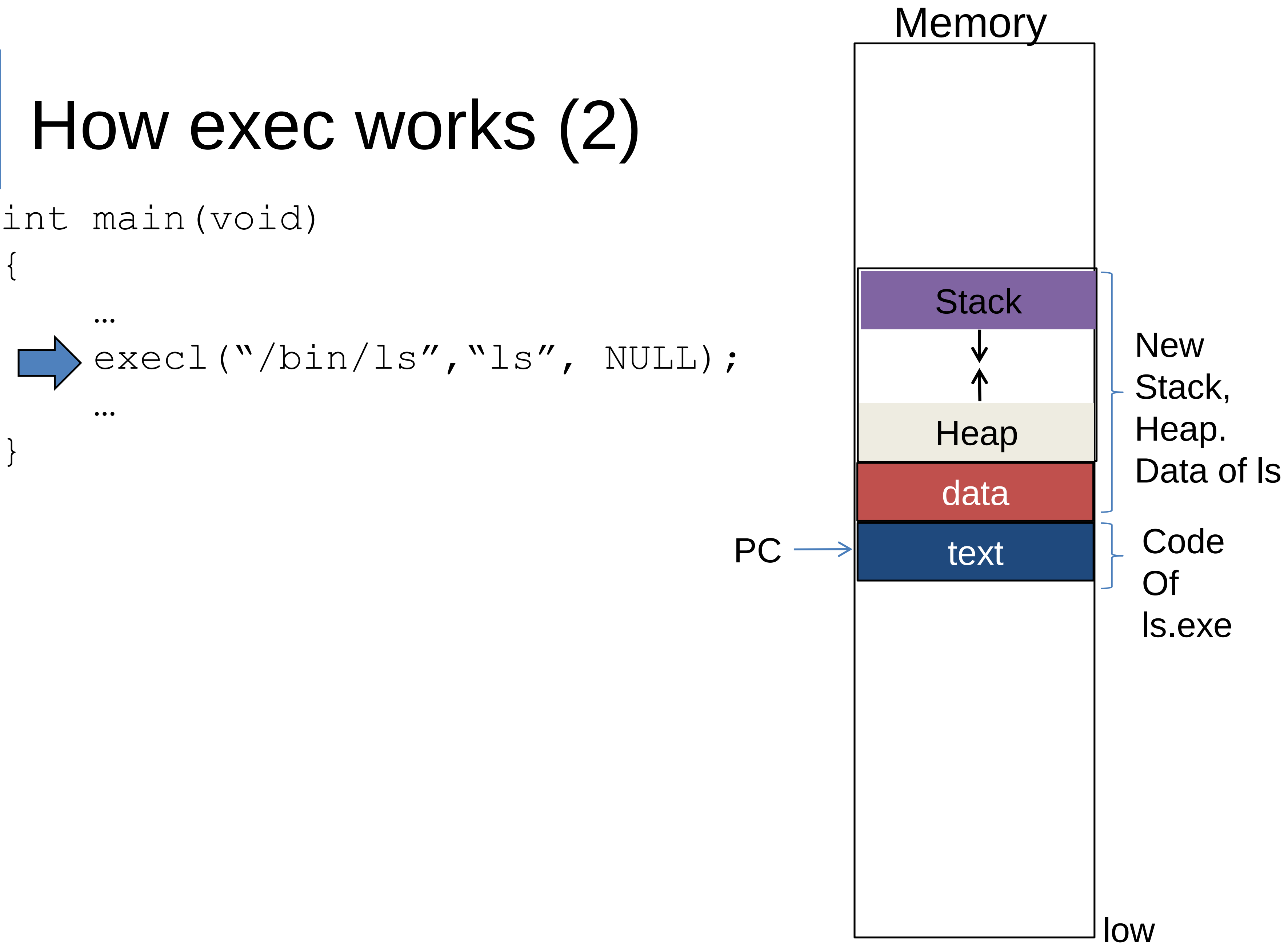
How exec works (1)

```
int main(void)
{
    …
    execl("/bin/ls","ls", NULL);
    …
}
```



How exec works (2)

```
int main(void)
{
    …
    execl("/bin/ls","ls", NULL);
    …
}
```



Windows Process Creation

- `CreateProcess()`
- Takes in 10 arguments!
- `WaitForSingleObject()`
- `WaitForMultipleObjects()`

Example: CreateProcess

```
#include <iostream>
#include <windows.h>
using namespace std;
int main(void) {
  STARTUPINFO start_info;
  PROCESS_INFORMATION proc_info;
  ZeroMemory(&start_info,sizeof(STARTUPINFO));
  ZeroMemory(&proc_info,sizeof(PROCESS_INFORMATION));
  cout << "creating child process" << endl;
  CreateProcess("c:\\windows\\system32\\mspaint.exe",0,0,0,FALSE,
       0,0,0, &start_info,&proc_info);
  cout << "waiting for child to terminate" << endl;
  WaitForSingleObject(proc_info.hProcess,INFINITE);
  cout << "parent terminating" << endl;
  CloseHandle(proc_info.hProcess);
  CloseHandle(proc_info.hThread);
  return 0;
}
```

Multiple child processes

```
#include <iostream>
#include <windows.h>
using namespace std;
int main(void) {
  const int COUNT = 2;
  HANDLE proc[COUNT], thread[COUNT];
  for (int i=0; i < COUNT; ++i) {
    STARTUPINFO start_info;
    PROCESS_INFORMATION proc_info;
    ZeroMemory(&start_info,sizeof(STARTUPINFO));
    ZeroMemory(&proc_info,sizeof(PROCESS_INFORMATION));

  CreateProcess("c:\\windows\\system32\\mspaint.exe",0,0,0,FALSE,0,0,0,&start_in
  fo,&proc_info);
    proc[i] = proc_info.hProcess;
    thread[i] = proc_info.hThread;
  }
  WaitForMultipleObjects(COUNT,proc,TRUE,INFINITE);
  for (int i=0; i < COUNT; ++i) {
    CloseHandle(proc[i]);
    CloseHandle(thread[i]);
  }
  return 0;
}
```