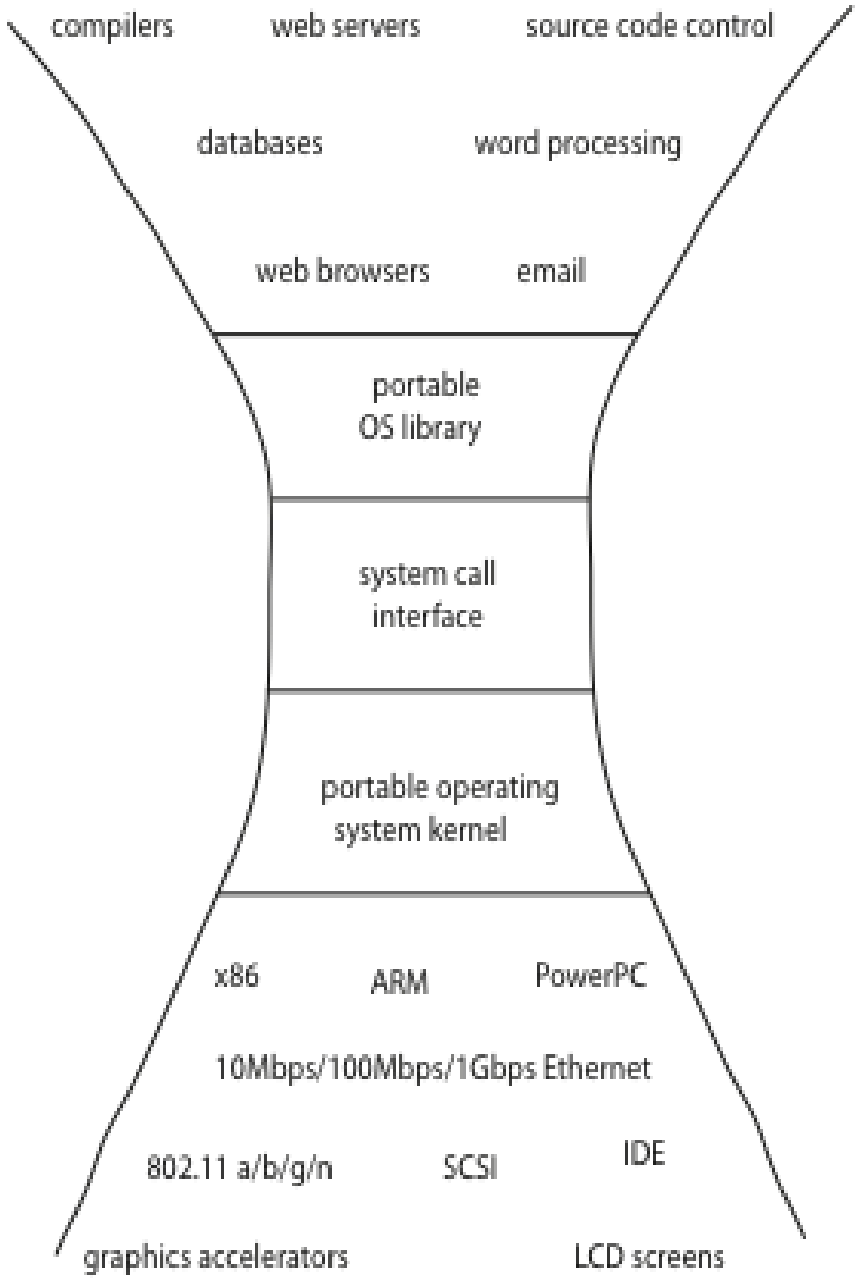
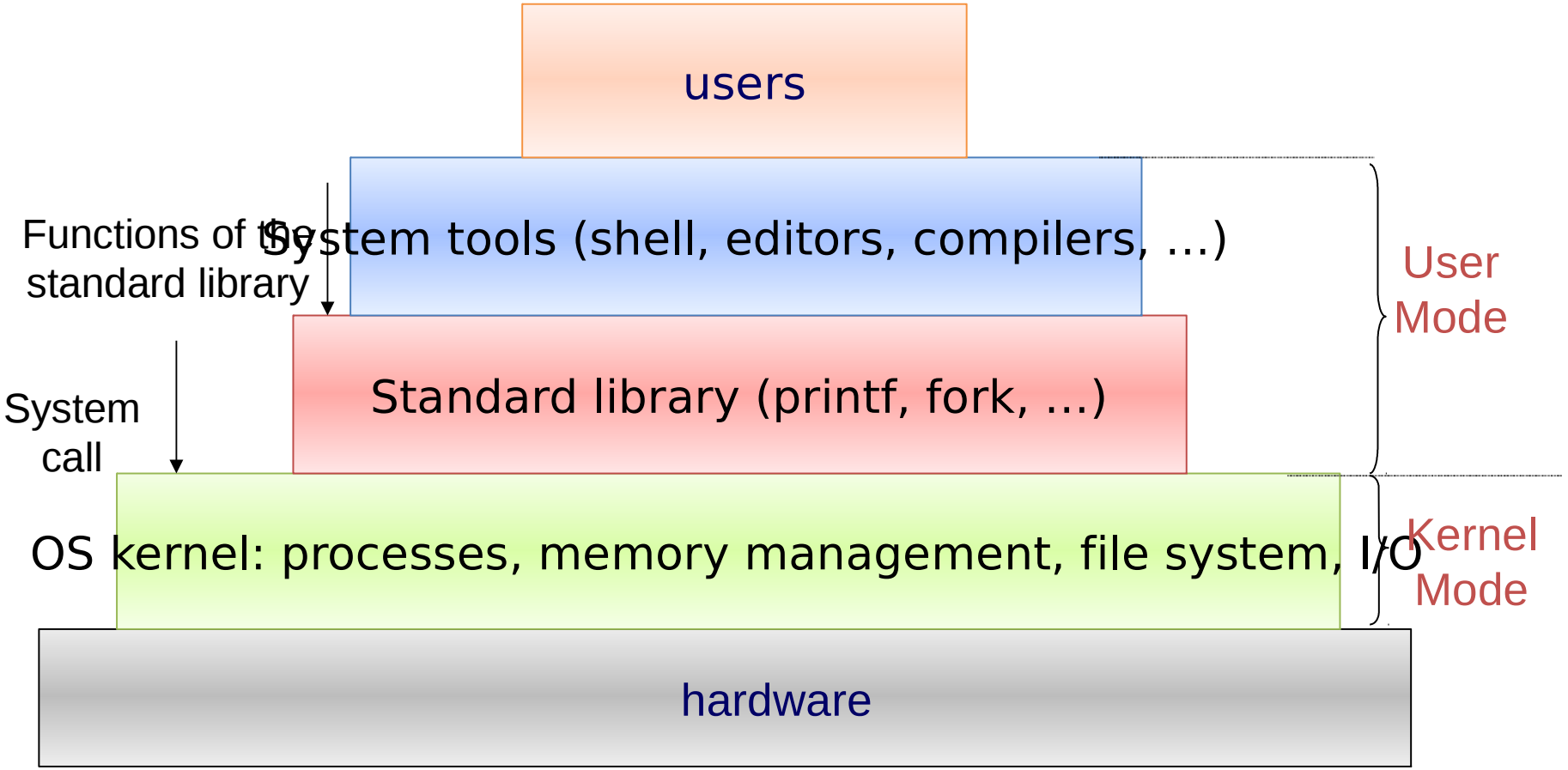
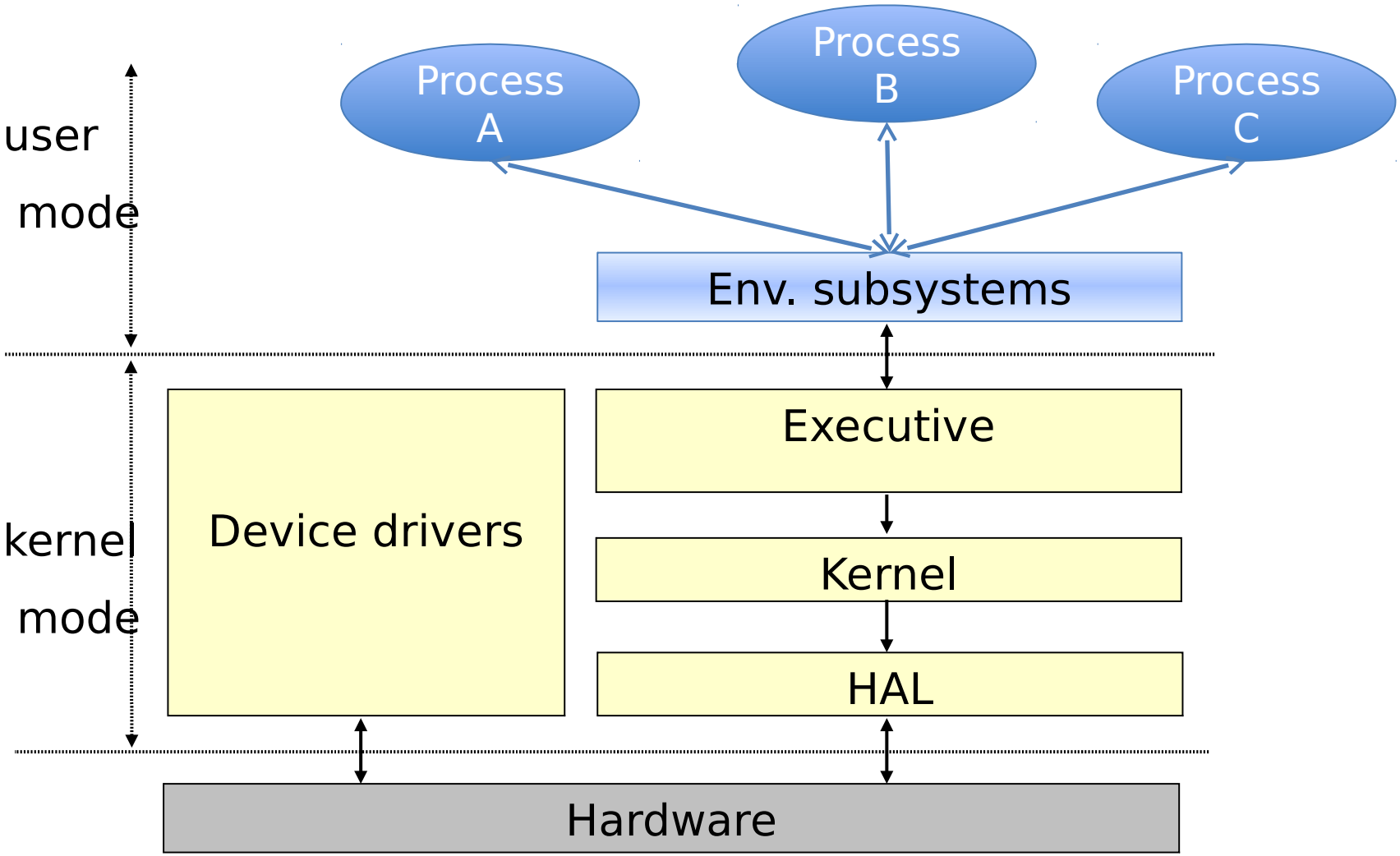
Structure


compilers
web servers
source code control
databases
word processing
web browsers
email
portable
OS library
system call
interface
portable operating
system kernel
x86
ARM
PowerPC
10Mbps/100Mbps/1Gbps Ethernet
802.11 a/b/g/n
SCSI
IDE
graphics accelerators
LCD screens

Unix architecture



Windows architecture



Programming Interface

Main Points

- Creating and managing processes
  - fork, exec, wait
- Performing I/O
  - open, read, write, close
- Communicating between processes
  - pipe, dup, select, connect
- Example: implementing a shell

Shell

- A shell is a job control system
  - Allows programmer to create and manage a set of programs to do some task
  - Windows, MacOS, Linux all have shells

- Example: to compile a C program

```
cc –c sourcefile1.c

cc –c sourcefile2.c

ln –o program sourcefile1.o sourcefile2.o
```

Question

- If the shell runs at user-level, what system calls does it make to run each of the programs?
  - Ex: cc, ln

Windows CreateProcess

- System call to create a new process to run a program
  - Create and initialize the process control block (PCB) in the kernel
  - Create and initialize a new address space
  - Load the program into the address space
  - Copy arguments into memory in the address space
  - Initialize the hardware context to start execution at ``start''
  - Inform the scheduler that the new process is ready to run

Windows CreateProcess API (simplified)

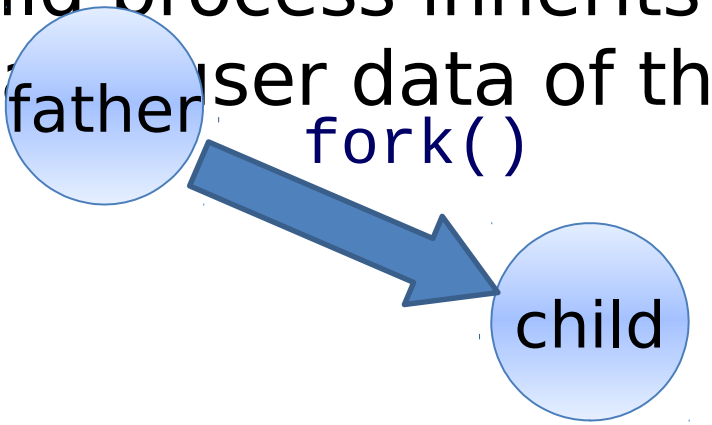
```
if (!CreateProcess(
    NULL,           // No module name (use command line)
    argv[1],        // Command line
    NULL,           // Process handle not inheritable
    NULL,           // Thread handle not inheritable
    FALSE,          // Set handle inheritance to FALSE
    0,               // No creation flags
    NULL,           // Use parent's environment block
    NULL,           // Use parent's starting directory
    &si,            // Pointer to STARTUPINFO structure
    &pi )           // Pointer to PROCESS_INFORMATION structure
)
```

UNIX Process Management

- UNIX fork – system call to create a copy of the current process, and start it running
  - No arguments!
- UNIX exec – system call to change the program being run by the current process
- UNIX wait – system call to wait for a process to finish
- UNIX signal – system call to send a notification to another process

UNIX fork()

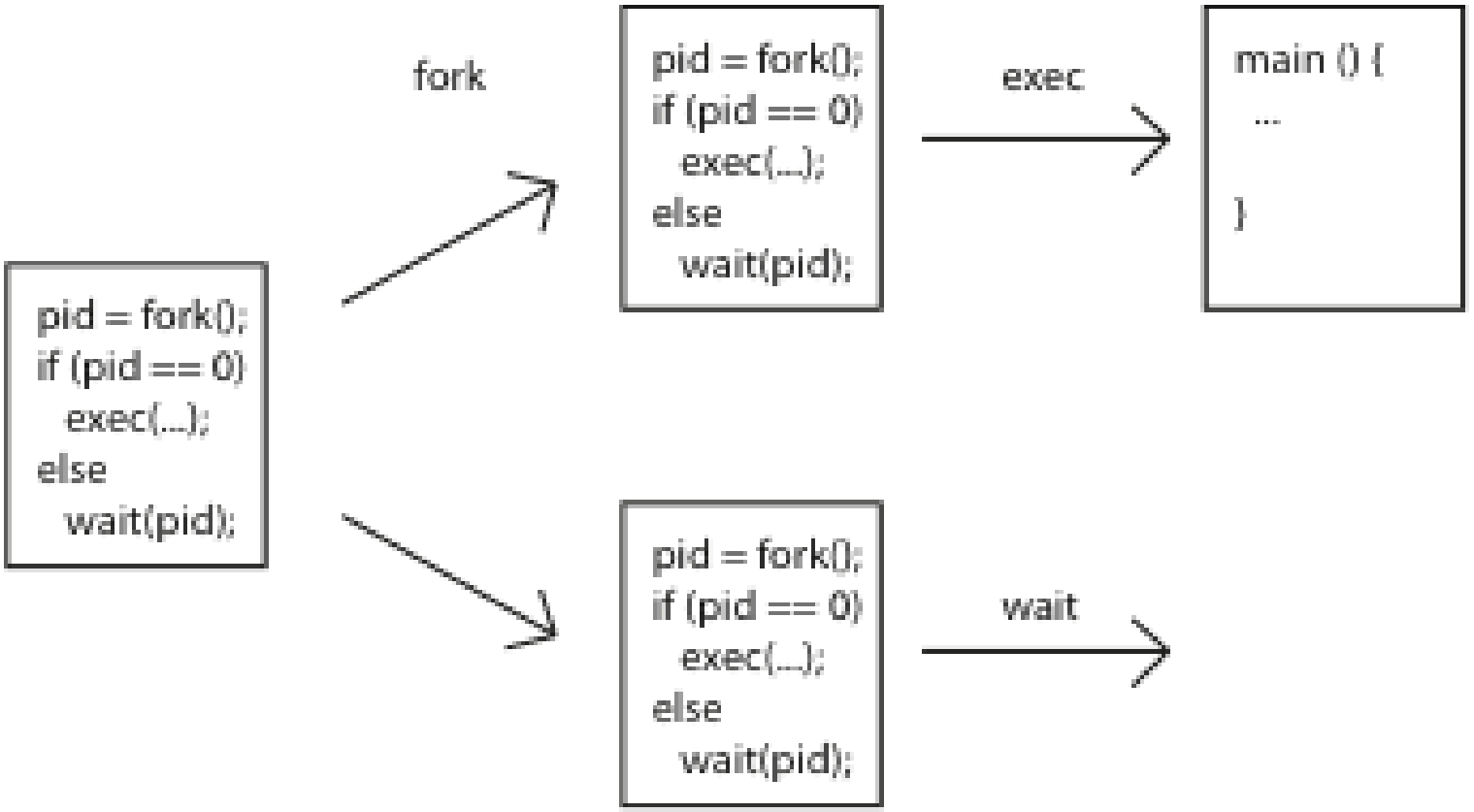
- `fork()` is used to generate a child process:
  - The father and its child share the same code
  - The child process inherits a copy of the kernel and user data of the father



UNIX fork()

- `fork()` does not take input params
- Returns an integer:
  - For the child it is 0
  - For the father is:
  - A positive value that represents the PID of the child
  - A negative value that represents an error code

UNIX Process Management



Question: What does this code print?

```
int child_pid = fork();
if (child_pid == 0) {          // I'm the child process
    printf("I am process #%d\n", getpid());
    return 0;
} else {                       // I'm the parent process
    printf("I am parent of process #%d\n", child_pid);
    return 0;
}
```

Questions

- Can UNIX fork() return an error? Why?
- Can UNIX exec() return an error? Why?
- Can UNIX wait() ever return immediately? Why?

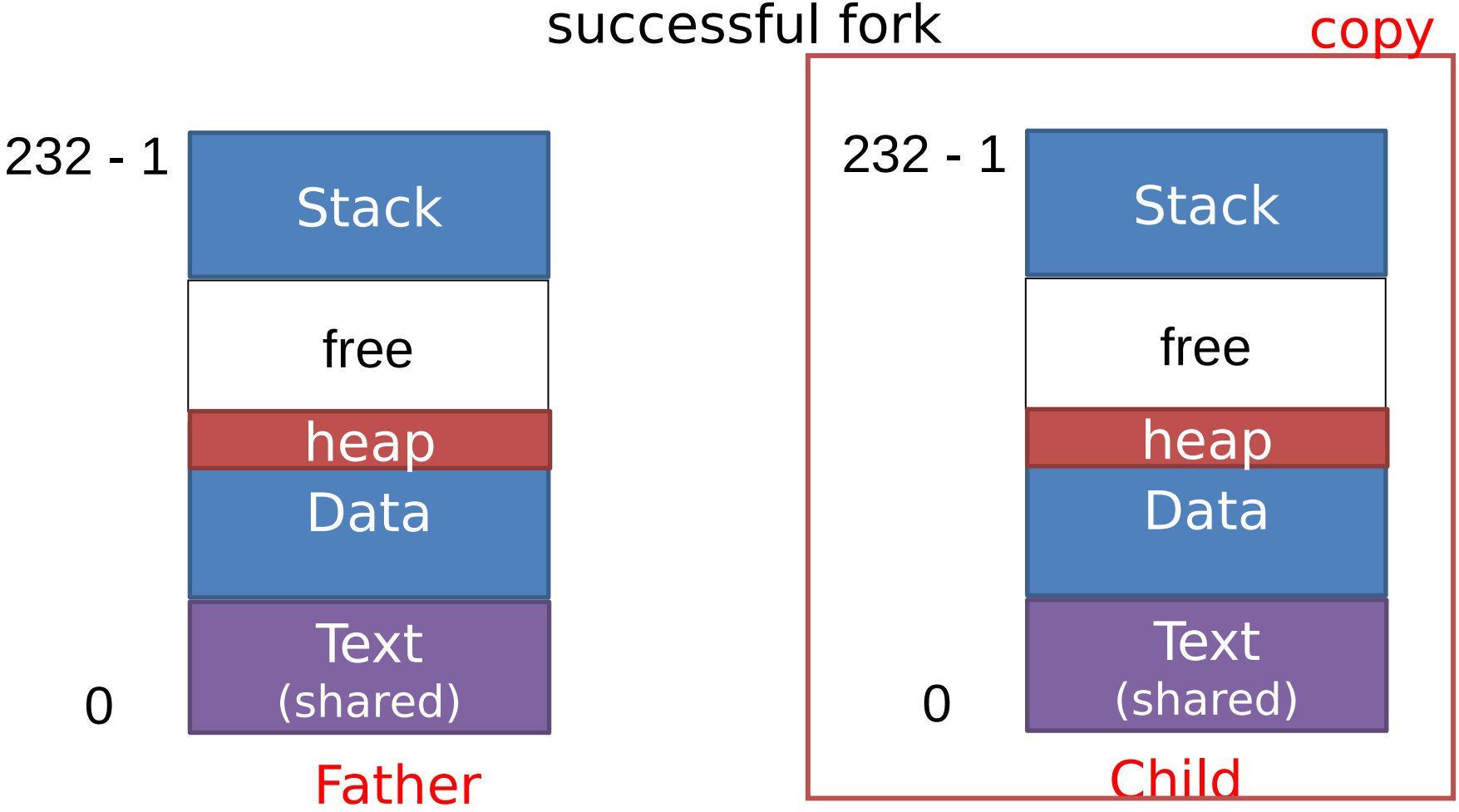
Implementing UNIX fork

Steps to implement UNIX fork

- Create and initialize the process control block (PCB) in the kernel
- Namely, a process structure and a user structure
- Create a new address space
- Initialize the address space with a copy of the entire contents of the address space of the parent
- Inherit the execution context of the parent (e.g., any open files)
- Inform the scheduler that the new process is ready to run

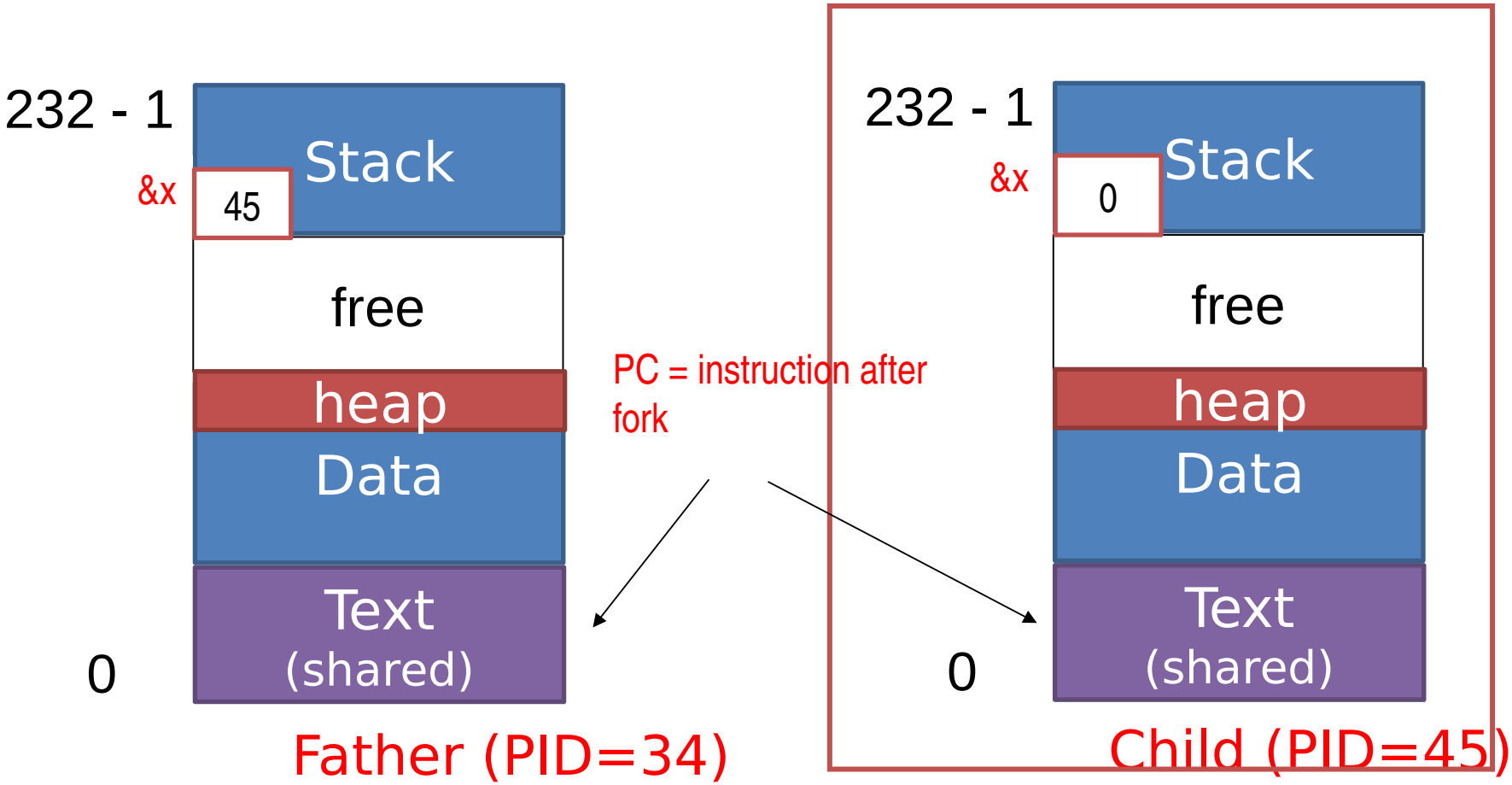
Implementing UNIX fork

Addressing spaces of the father and the child after a successful fork



Implementing UNIX fork

Addressing spaces of the father and the child after a successful fork



Implementing UNIX fork

- Steps to implement UNIX fork
  - Load the program into the current address space
  - Copy arguments into memory in the address space
  - Initialize the hardware context to start execution at ``start''

UNIX exec

- Replaces the code executed by a process
  - Does not create a new process, inherits PBC and changes address space
- Replaces the data
- Example:
  - `int execl(char *pathname, char *arg0, .. char *argN, (char*)0)`
  - `Pathname` is the name of an executable file
  - `argN[1]`,..`argN[…]` are the arguments passed to the program
  - list terminated with `(char *)0`

UNIX exec

- If it’s successful it does not return
  - The process executes another program
- If it fails it returns an error code
- After exec the process:
  - Keeps the PID
  - Keeps the PCB (process and user structures)
  - But it changes references to code and data memory
  - Resets the pending signals
  - Keeps the kernel stack
  - Keeps the assigned resources (open files)

Process termination in UNIX

- A process can terminate:
  - Because of an exception due to illegal actions
  - By invoking the system call `exit`
- The terminated process returns an exit value to its father
  - The father receives the value by the system call `wait`
  - If the father didn’t already call the `wait`, the terminated process switches to zombie state
  - If the father is already terminated, the init process adopts its children

exit() and wait()

- `void exit(int status);`
  - Status is the termination code
  - exit never returns
  - Frees memory, releases resources
  - If it switches to zombie, keeps the PBC until the father invokes `wait`
- `int wait(int *status);`
  - Status if the PID of the terminated process or an error code

UNIX I/O

- Uniformity
  - All operations on all files, devices use the same set of system calls: open, close, read, write
- Open before use
  - Open returns a handle (file descriptor) for use in later calls on the file
- Byte-oriented
- Kernel-buffered read/write
- Explicit close
  - To garbage collect the open file descriptor

UNIX File System Interface

- UNIX file open is a Swiss Army knife:
  - Open the file, return file descriptor
  - Options:
  - if file doesn’t exist, return an error
  - If file doesn’t exist, create file and open it
  - If file does exist, return an error
  - If file does exist, open file
  - If file exists but isn’t empty, nix it then open
  - If file exists but isn’t empty, return an error
  - …

Interface Design Question

- Why not separate syscalls for open/create/exists?

```
if (!exists(name))
    create(name);   // can create fail?
fd = open(name);   // does the file exist?
```

Implementing a Shell

```
char *prog, **args;
int child_pid;

// Read and parse the input a line at a time
while (readAndParseCmdLine(&prog, &args)) {
   child_pid = fork();      // create a child process
    if (child_pid == 0) {
       exec(prog, args);       // I'm the child process.  Run program
      // NOT REACHED
    } else {
       wait(child_pid);       // I'm the parent, wait for child
       return 0;
    }
}
```