143A: Principles of Operating Systems

Lecture 3: OS Interfaces

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20 Socks

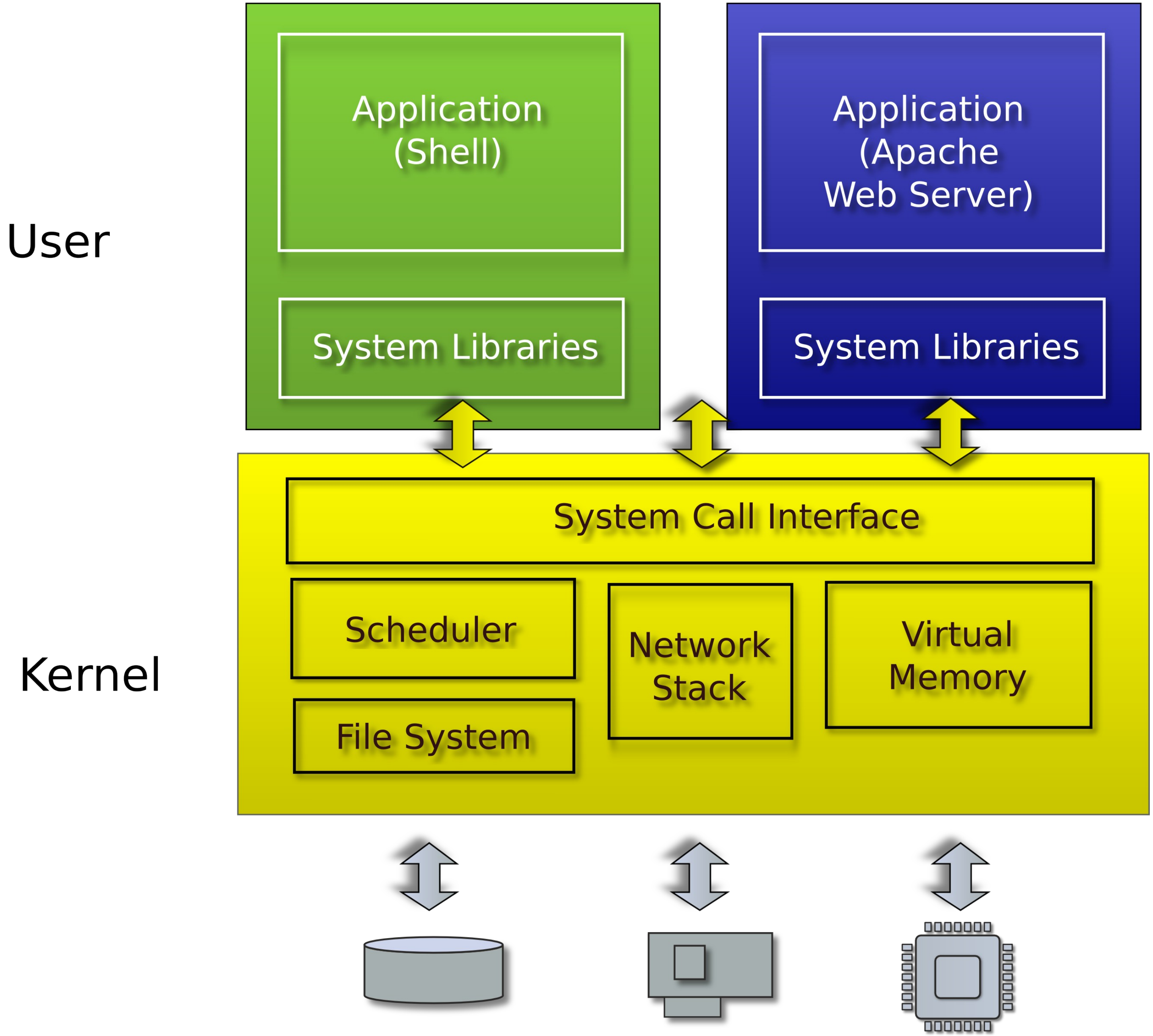
Ten red socks and ten blue socks are all mixed up in a dresser drawer. The 20 socks are exactly alike except for their color. The room is in pitch darkness and you want two matching socks.

What is the smallest number of socks you must take out of the drawer in order to be certain that you have a pair that match?

Operating system interfaces

- Share hardware across multiple processes
  - Illusion of private CPU, private memory
- Abstract hardware
  - Hide details of specific hardware devices
- Provide services
  - Serve as a library for applications
- Security
  - Isolation of processes, users, namesapces
  - Controlled ways to communicate (in a secure manner)

Typical UNIX OS

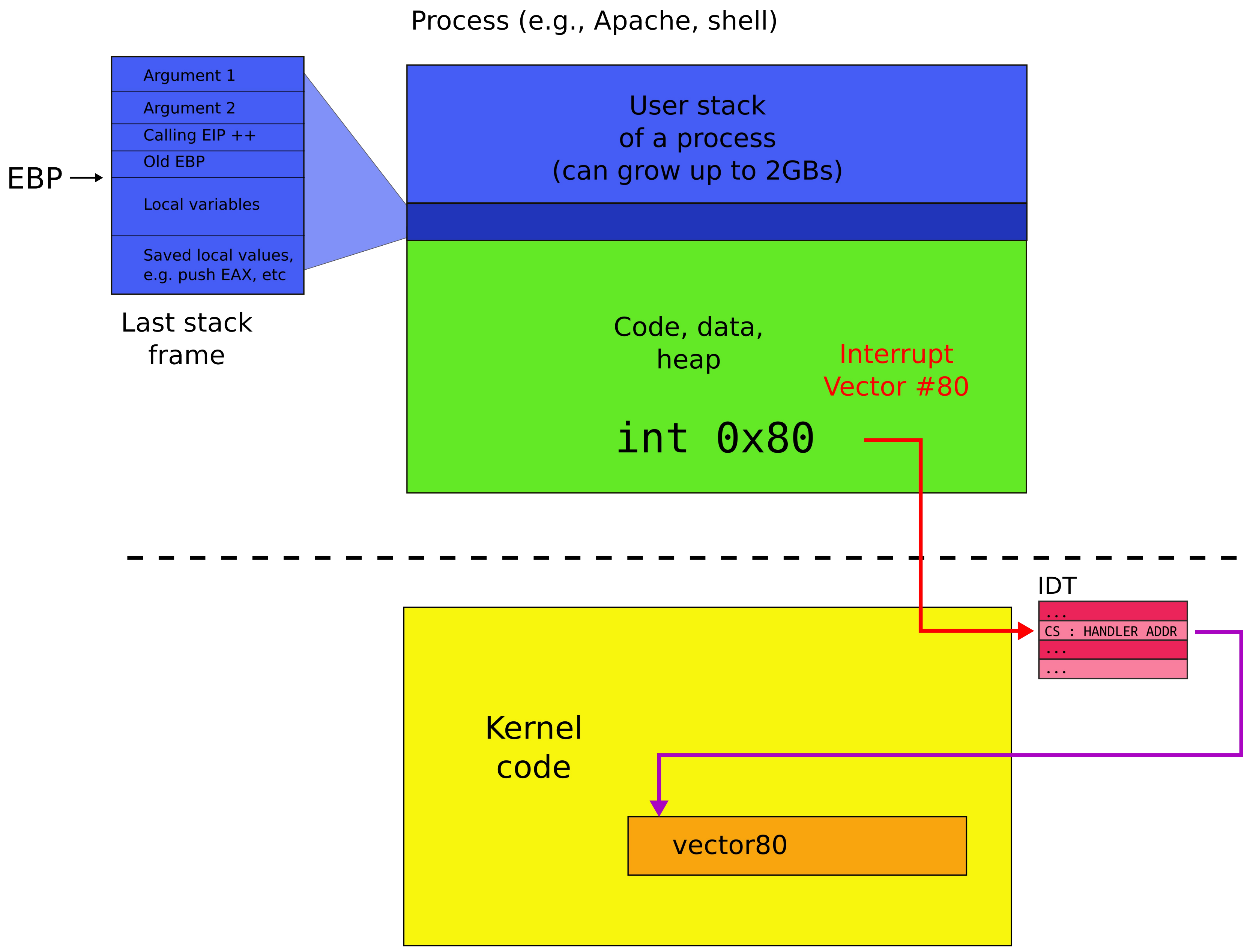


System calls

- Provide user to kernel communication
  - Effectively an invocation of a kernel function

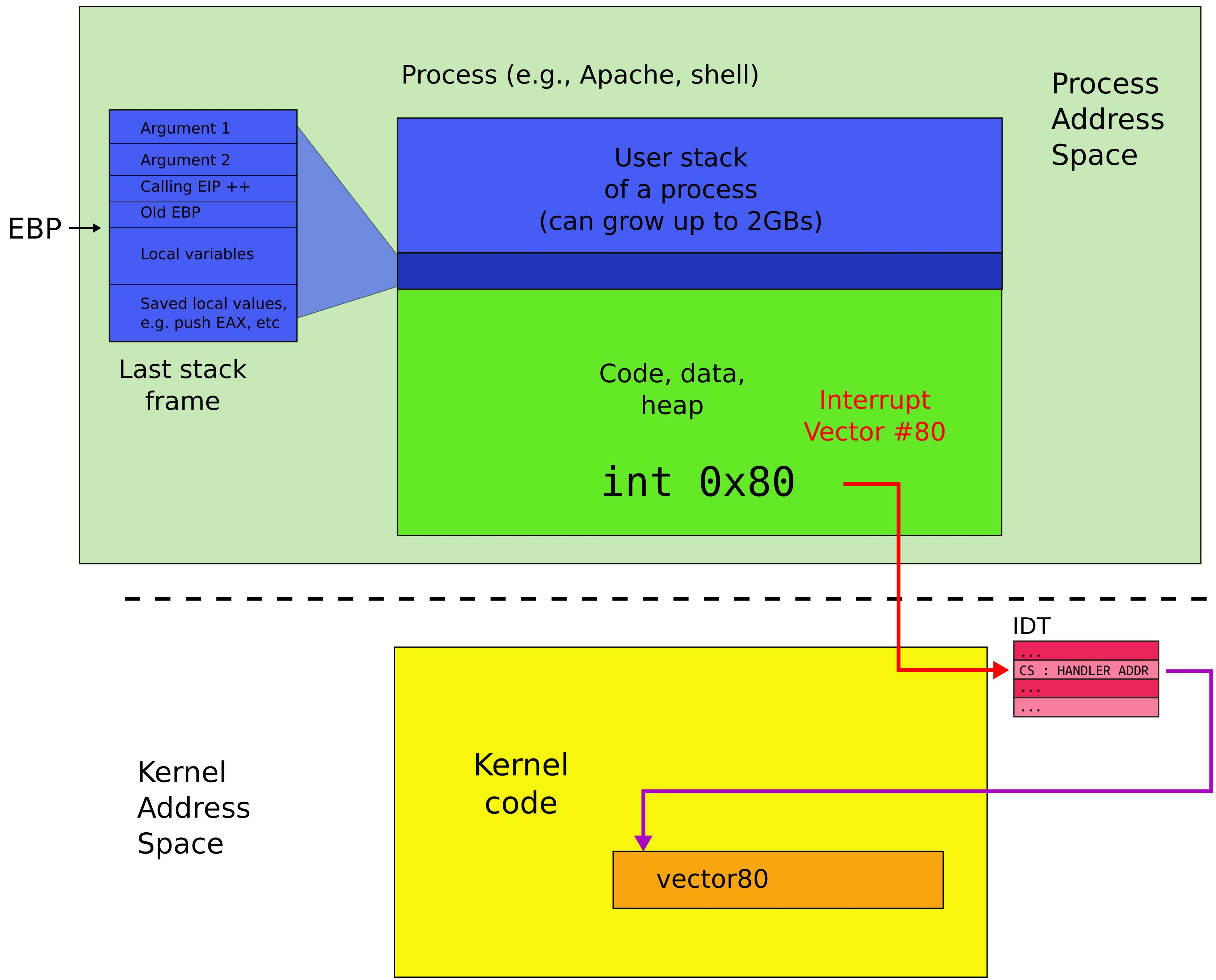
- *System calls are the interface of the OS*

System call

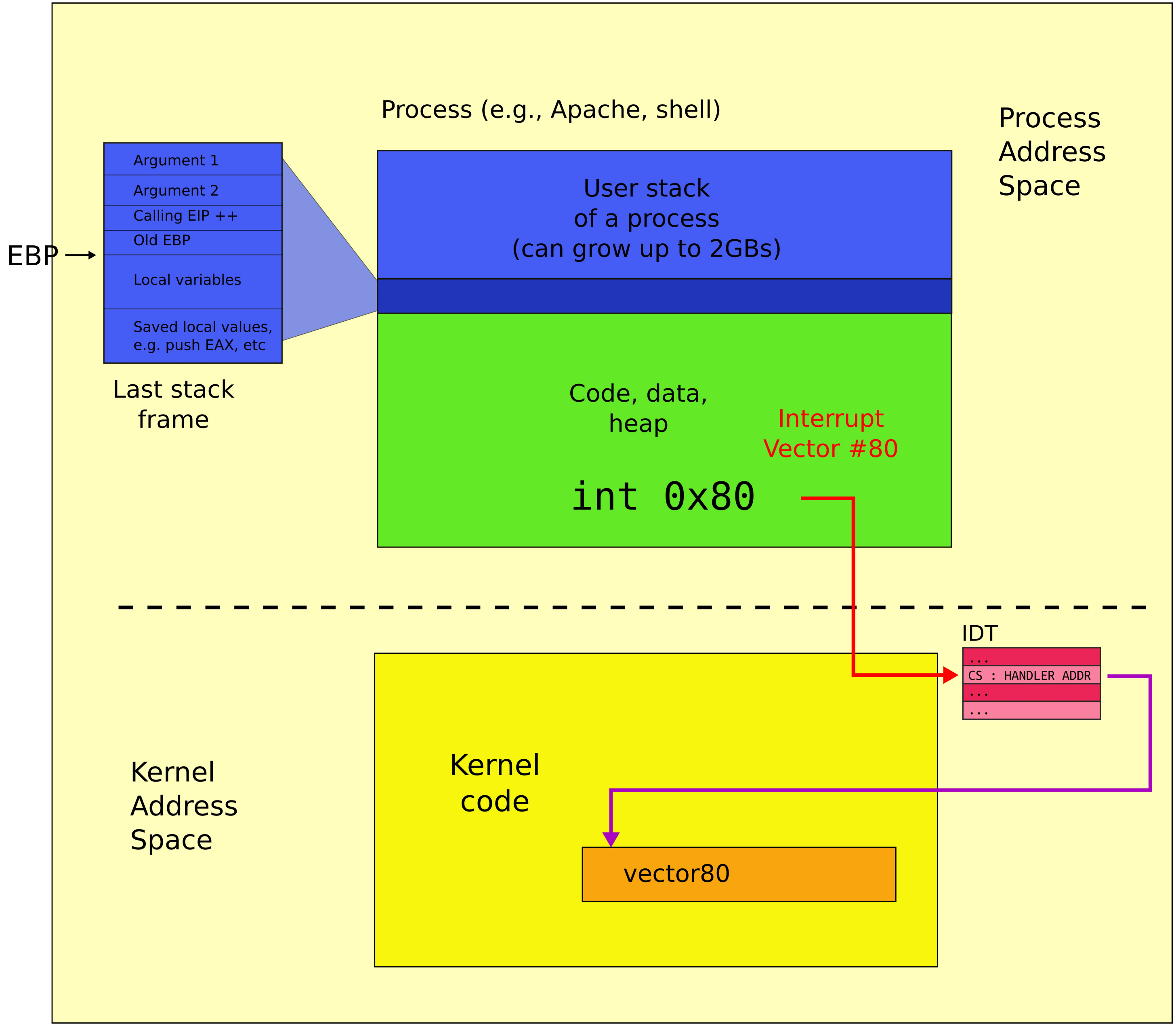


Process (e.g., Apache, shell)
Argument 1
Argument 2
Calling EIP ++
Old EBP
Local variables
Saved local values,
e.g. push EAX, etc
EBP
Last stack
frame
User stack
of a process
(can grow up to 2GBs)
Code, data,
heap
Interrupt
Vector #80
int 0x80
IDT
...
CS : HANDLER ADDR
...
...
Kernel
code
vector80

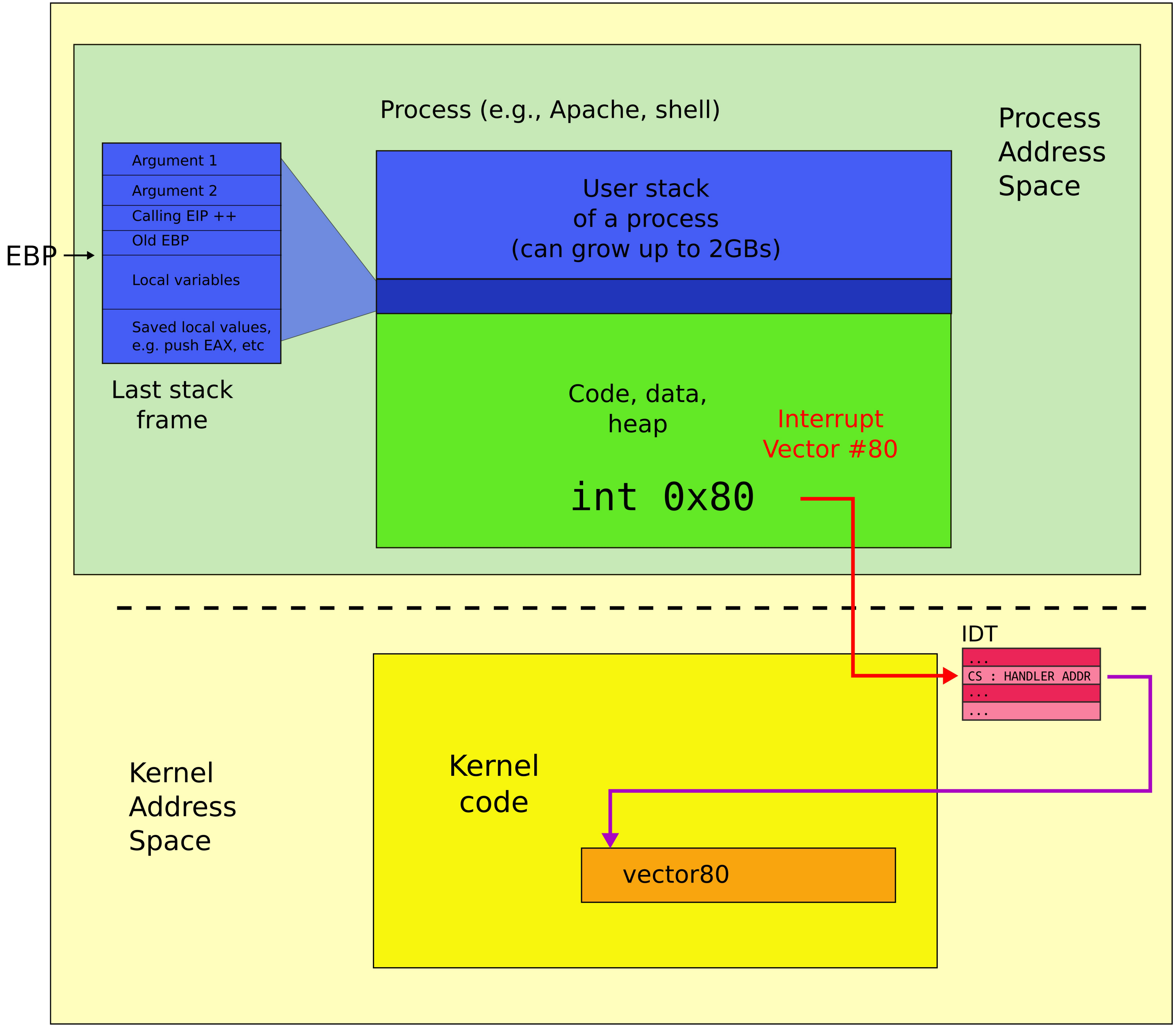
User address space



Kernel address space



Kernel and user address spaces

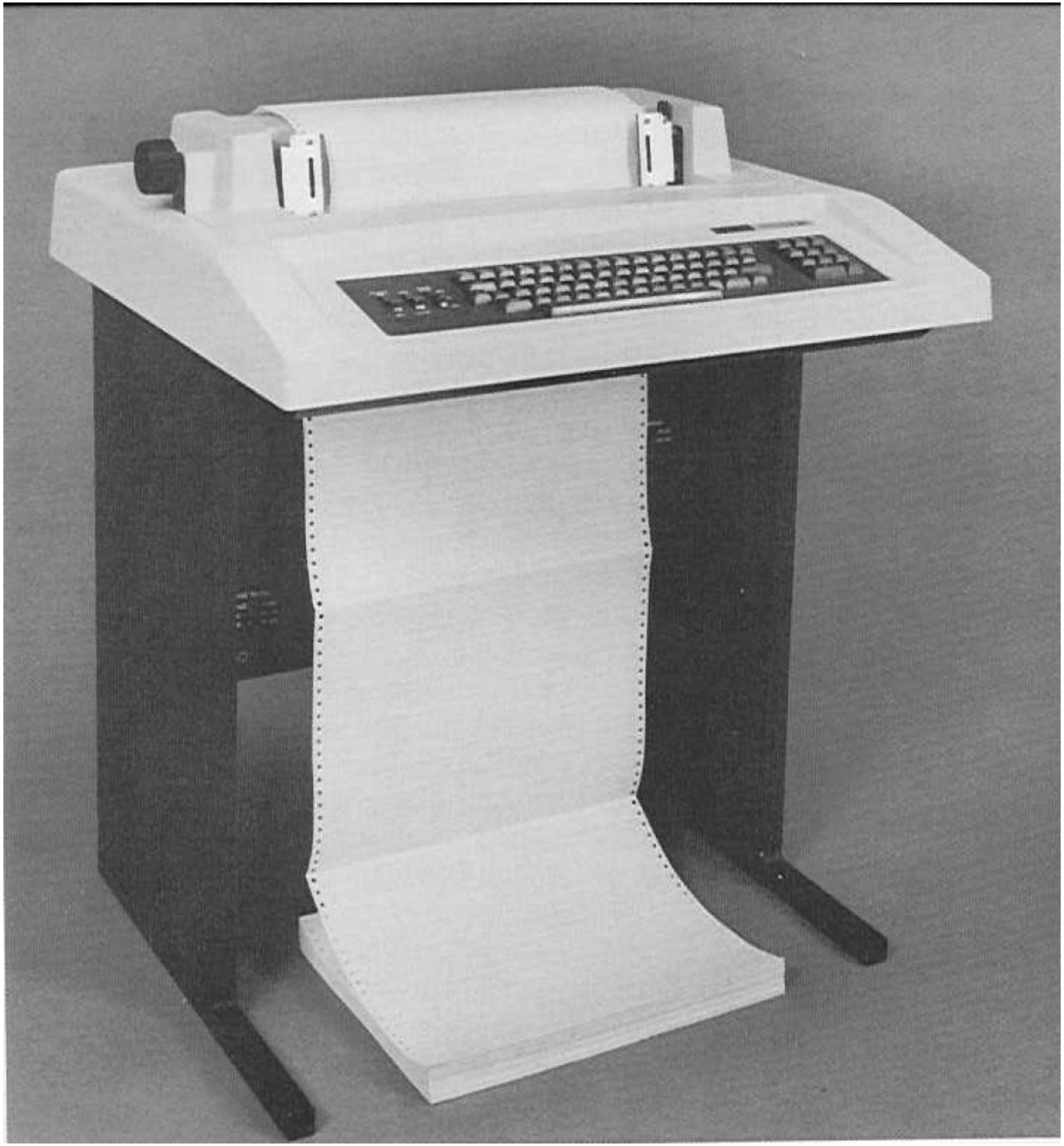


System calls, interface for...

- Processes
  - Creating, exiting, waiting, terminating
- Memory
  - Allocation
- Files and folders
  - Opening, reading, writing, closing
- Inter-process communication
  - Pipe

UNIX (xv6) system calls are designed around the shell

Ken Thompson (sitting) and Dennis Ritchie working together at a PDP-11



DEC LA36 DECwriter II Terminal

DEC VT100 terminal, 1980

Shell

- Normal process
- Interacts with the kernel through system calls
  - Creates new processes

`fork()` -- create new process

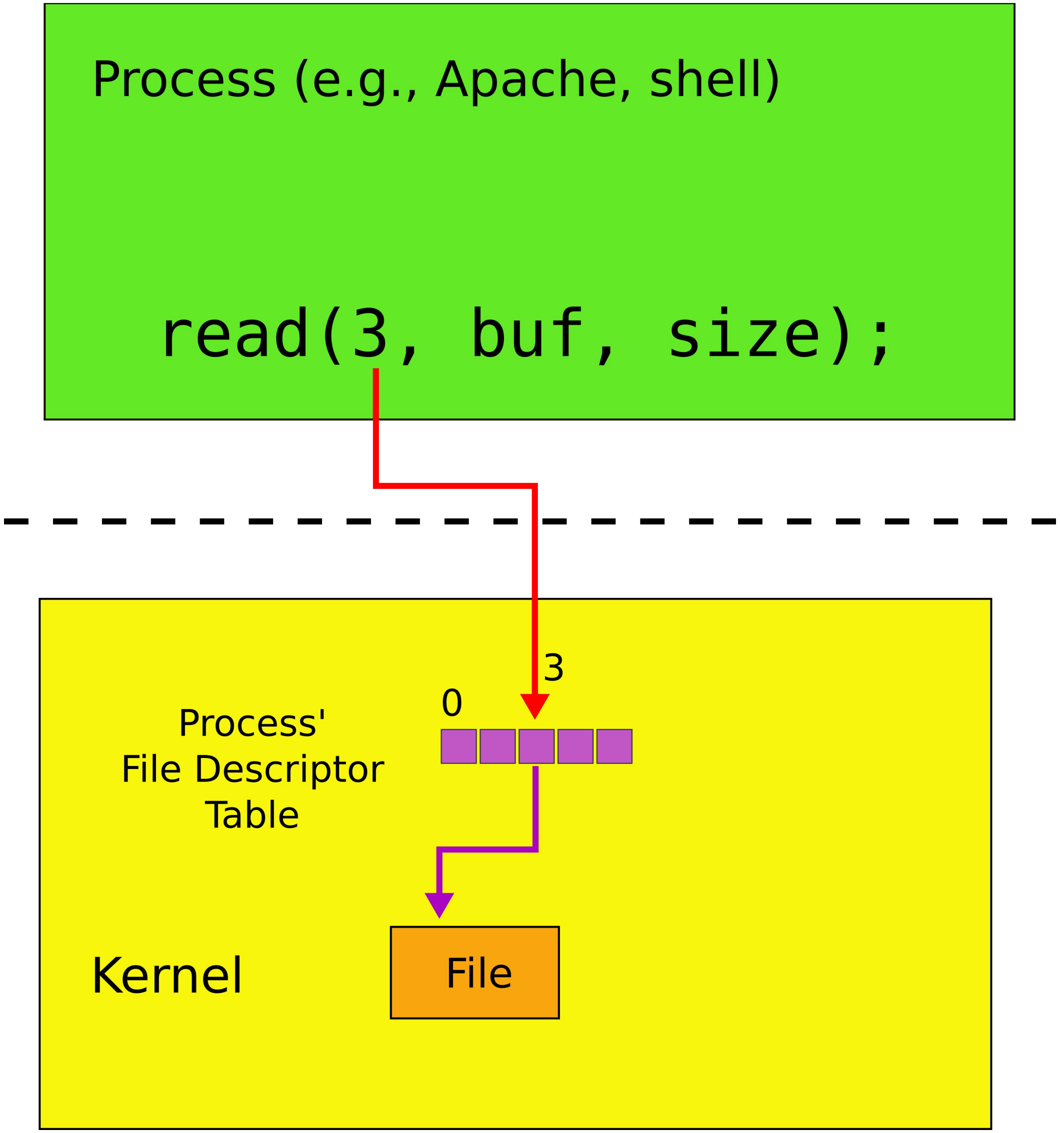
```
int pid;

pid = fork();
if(pid > 0){
    printf("parent: child=%d\n", pid);
    pid = wait();
    printf("child %d is done\n", pid);
} else if(pid == 0){
    printf("child: exiting\n");
    exit();
} else {
    printf("fork error\n");
}
```

More process management

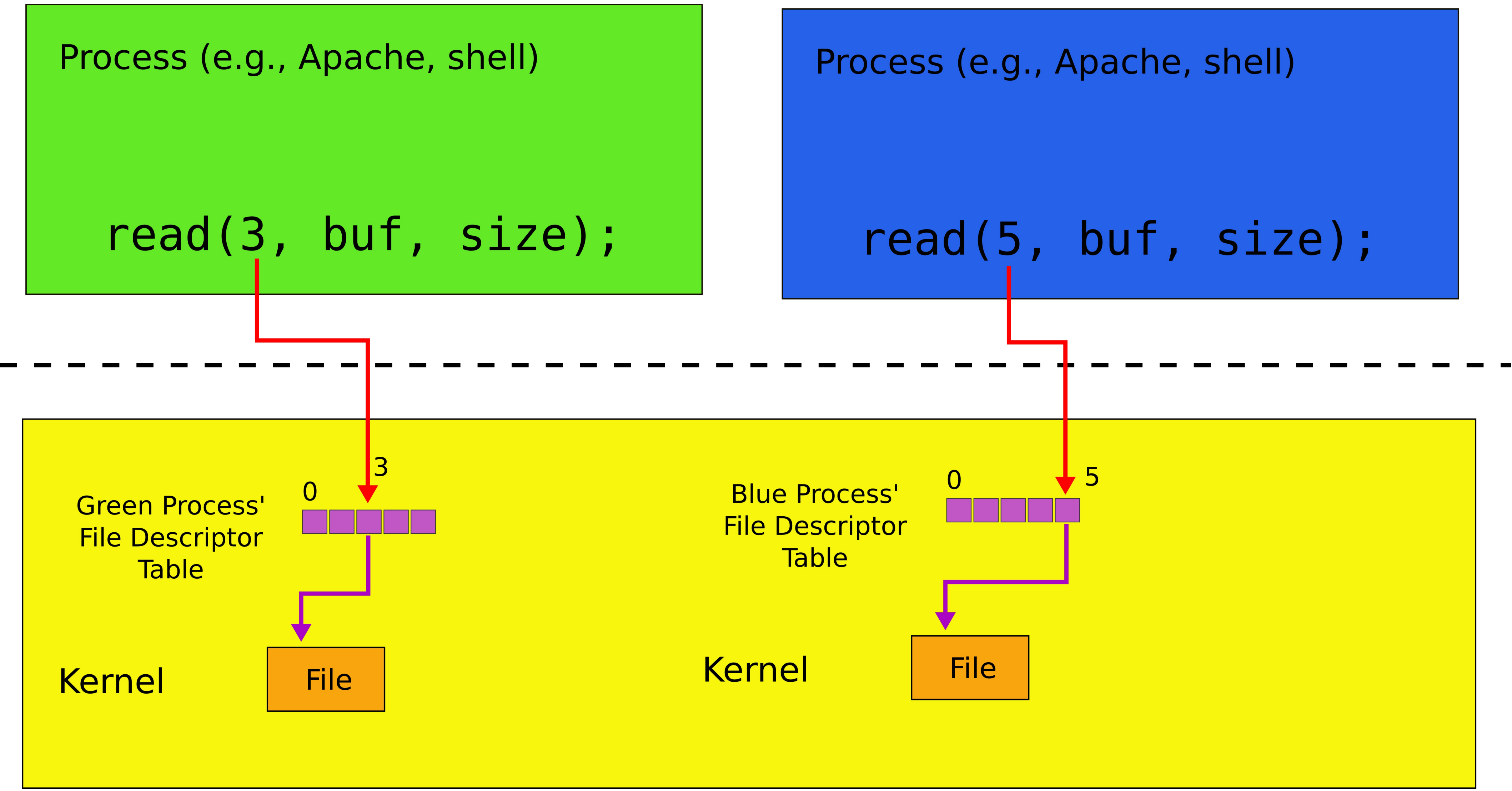
- `exit()` -- terminate current processsss
- `wait()` -- wait for the child to exit
- `exec()` -- replace memory of a current process with a memory image (of a program) loaded from a file

```
char *argv[3];
argv[0] = "echo";
argv[1] = "hello";
argv[2] = 0;
exec("/bin/echo", argv);
printf("exec error\n");
```

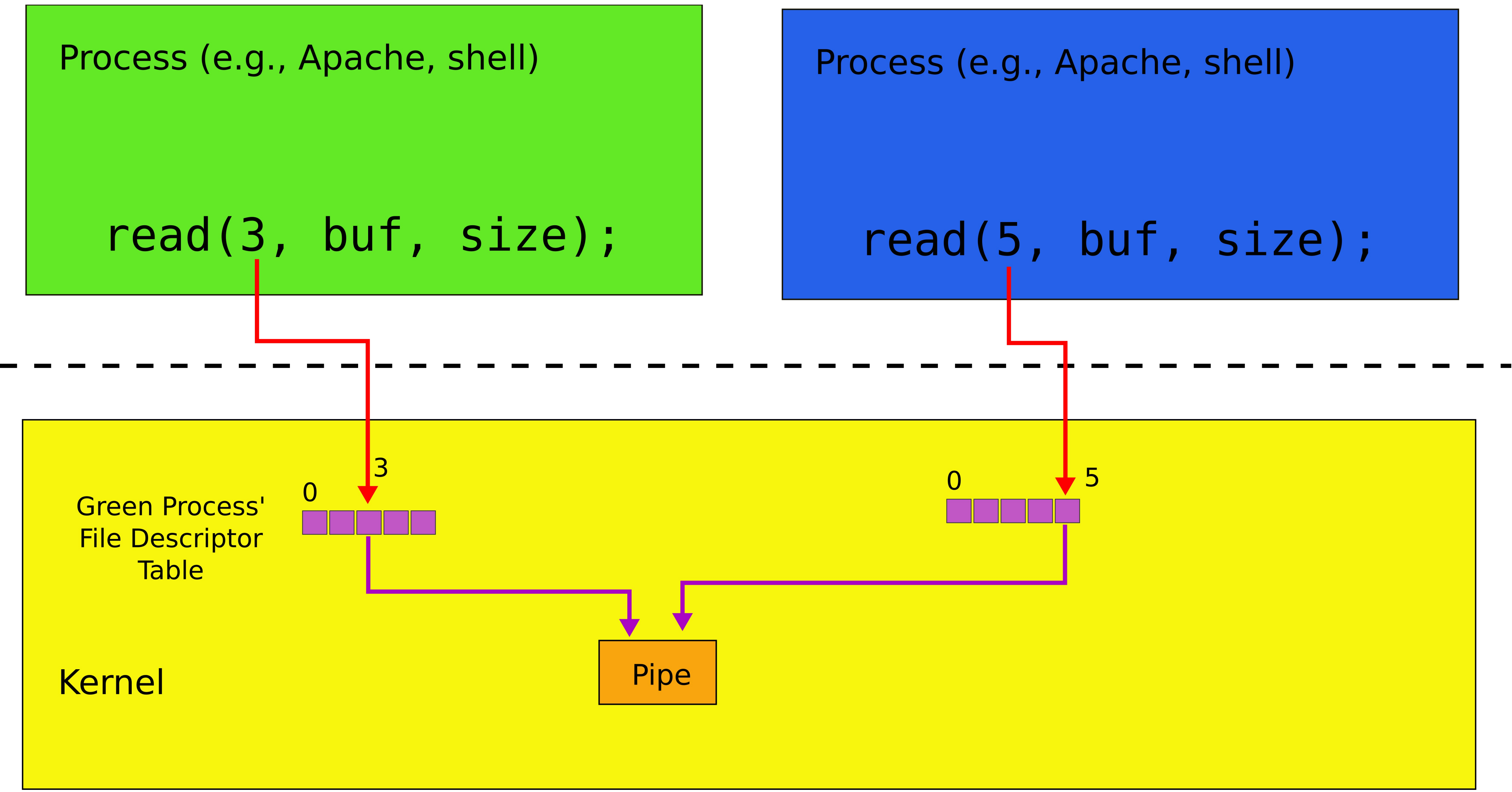
File descriptors



File descriptors: two processes



Two file descriptors pointing to a pipe



File descriptors

- An index into a table, i.e., just an integer
- The table maintains pointers to “file” objects
  - Abstracts files, devices, pipes
  - In UNIX everything is a pipe – all objects provide file interface
- Process may obtain file descriptors through
  - Opening a file, directory, device
  - By creating a pipe
  - Duplicating an existing descriptor

Standard file descriptors

- Just a convention
  - 0 – standard input
  - 1 – standard output
  - 2 – standard error
- This convention is used by the shell to implement I/O redirection and pipes

File I/O

- `read(fd, buf, n)` – read `n` bytes from `fd` into `buf`
- `write(fd, buf, n)` – write `n` bytes from `buf` into `fd`

Example: cat

```
char buf[512]; int n;
for(;;) {
    n = read(0, buf, sizeof buf);
    if(n == 0)
        break;
    if(n < 0) {
        fprintf(2, "read error\n");
        exit(); }
    if(write(1, buf, n) != n) {
        fprintf(2, "write error\n");
        exit();
    }
}
```

File I/O redirection

- `close(fd)` – closes file descriptor
  - **The next opened file descriptor will have the lowest number**
- `fork` replaces process memory, but
  - leaves its file table (table of the file descriptors untouched)

Example: cat < input.txt

```
char *argv[2];
argv[0] = "cat";
argv[1] = 0;
if(fork() == 0) {
    close(0);
    open("input.txt", O_RDONLY);
    exec("cat", argv);
}
```

`pipe` - interprocess communication

- Pipe is a kernel buffer exposed as a pair of file descriptors
    - One for reading, one for writing
- Pipes allow processes to communicate
    - Send messages to each other

```
int p[2];
char *argv[2]; argv[0] = "wc"; argv[1] = 0;
pipe(p);
if(fork() == 0) {
    close(0);
    dup(p[0]);
    close(p[0]);
    close(p[1]);
    exec("/bin/wc", argv);
} else {
    write(p[1], "hello world\n", 12);
    close(p[0]);
    close(p[1]);
}
```

wc on the read end of the pipe

Pipes

- Shell composes simple utilities into more complex actions with pipes, e.g.

```
grep FORK sh.c | wc -l
```

- Create a pipe and connect ends

Xv6 demo

Files

- Files
  - Uninterpreted arrays of bytes
- Directories
  - Named references to other files and directories

Creating files

- `mkdir()` – creates a directory
- `open(O_CREATE)` – creates a file
- `mknod()` – creates an empty files marked as device
  - Major and minor numbers uniquely identify the device in the kernel
- `fstat()` – retrieve information about a file

  - Named references to other files and directories

Fstat

- `fstat()` – retrieve information about a file

```
#define T_DIR 1 // Directory
#define T_FILE 2 // File
#define T_DEV 3 // Device
struct stat {
      short type; // Type of file
      int dev; // File system's disk device
      uint ino; // Inode number
      short nlink; // Number of links to file
      uint size; // Size of file in bytes
};
```

Links, inodes

- Same file can have multiple names – links
  - But unique inode number
- `link()` – create a link
- `unlink()` – delete file
- Example, create a temporary file

```
fd = open("/tmp/xyz", O_CREATE|O_RDWR);
unlink("/tmp/xyz");
```

Xv6 system calls

fork() Create a process
exit() Terminate the current process
wait() Wait for a child process to exit
kill(pid) Terminate process pid
getpid() Return the current process's pid
sleep(n) Sleep for n clock ticks
exec(filename, *argv) Load a file and execute it
sbrk(n) Grow process's memory by n bytes
open(filename, flags) Open a file; the flags indicate read/write
read(fd, buf, n) Read n bytes from an open file into buf
write(fd, buf, n) Write n bytes to an open file
close(fd) Release open file fd
dup(fd) Duplicate fd
pipe(p) Create a pipe and return fd's in p
chdir(dirname) Change the current directory
mkdir(dirname) Create a new directory
mknod(name, major, minor) Create a device file
fstat(fd) Return info about an open file
link(f1, f2) Create another name (f2) for the file f1
unlink(filename) Remove a file

Xv6 demo

In many ways xv6 is an OS you run today

Speakers from the 1984 Summer Usenix Conference (Salt Lake City, UT)