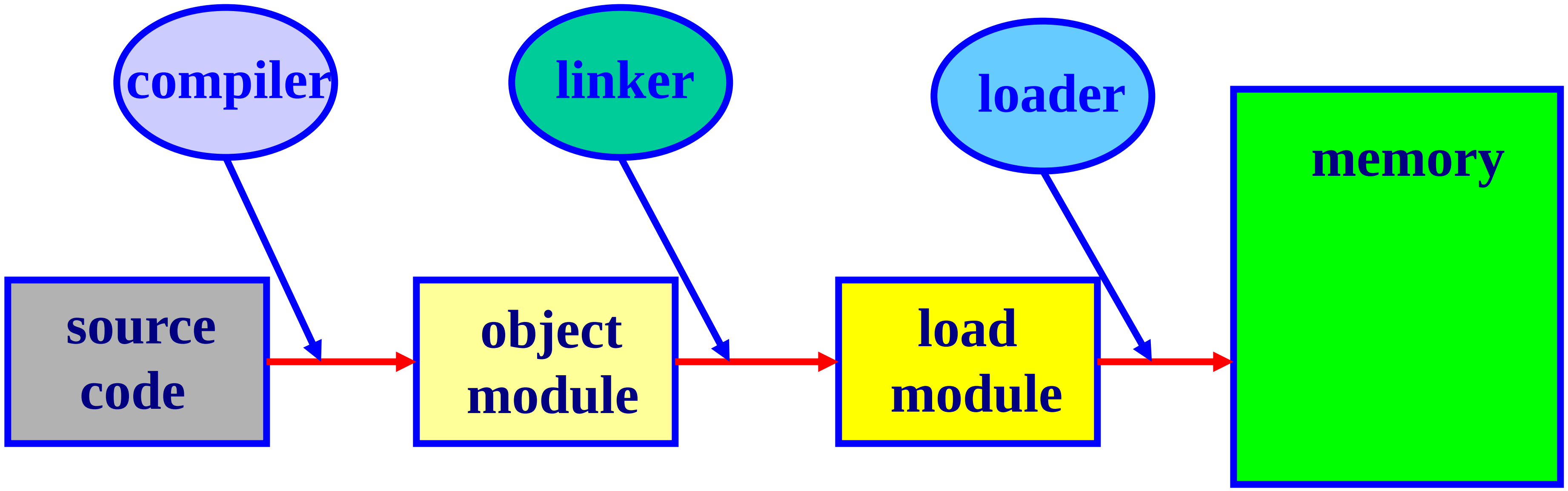
Part II
Processes and Threads
Process Basics

Program testing can be used to show the presence of bugs,
but never to show their absence

Edsger W. Dijkstra

From Compilation to Execution

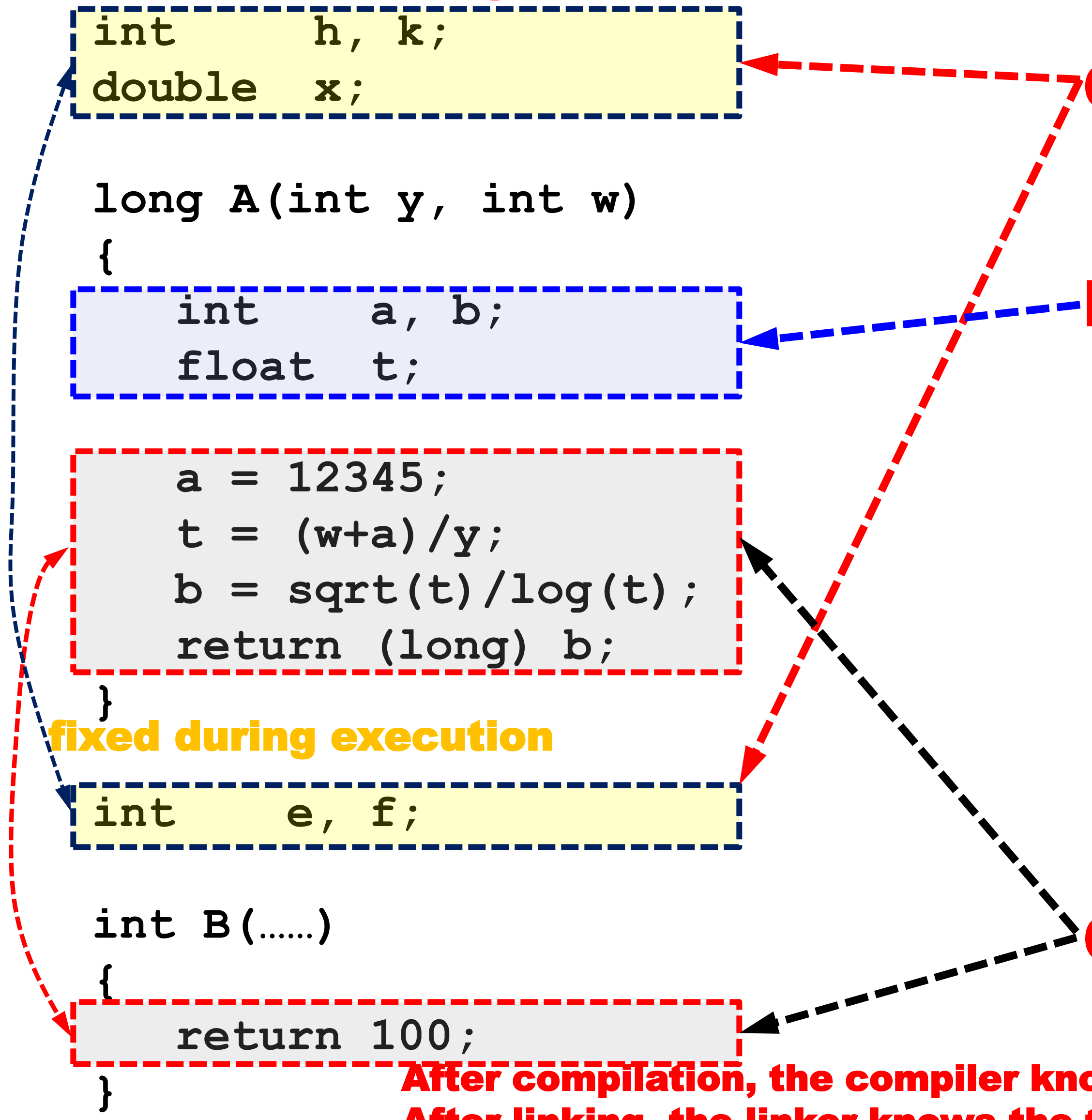
- A compiler compiles source files to `.o` files.
- A linker links `.o` files and other libraries together, producing a binary executable (e.g., `a.out`).
- A loader loads a binary executable into memory for execution.



What Is a Process?

- When the OS runs a program (i.e., a binary executable), this program is loaded into memory and the control is transferred to this program's first instruction. Then, the program runs.
- **A process is a program in execution**.
- A process is more than a program, because a process has a program counter, stack, data section, code section, etc. (i.e., the runtime stuffs)
- Moreover, multiple processes may be associated with one program (e.g., running the same program, say `a.out`, multiple times at the same time).

Memory Use of a Program: 1/10



```
int     h, k;
double  x;

long A(int y, int w)
{
   int    a, b;
   float  t;

   a = 12345;
   t = (w+a)/y;
   b = sqrt(t)/log(t);
   return (long) b;
}
```

fixed during execution

```
int    e, f;

int B(......)
{
   return 100;
}
```

Global Variables

They are declared outside of any function

Local Variables

These variables are declared in a function and can only be used in that function.

Outside of that function these variables cannot be seen and cannot be used

Code

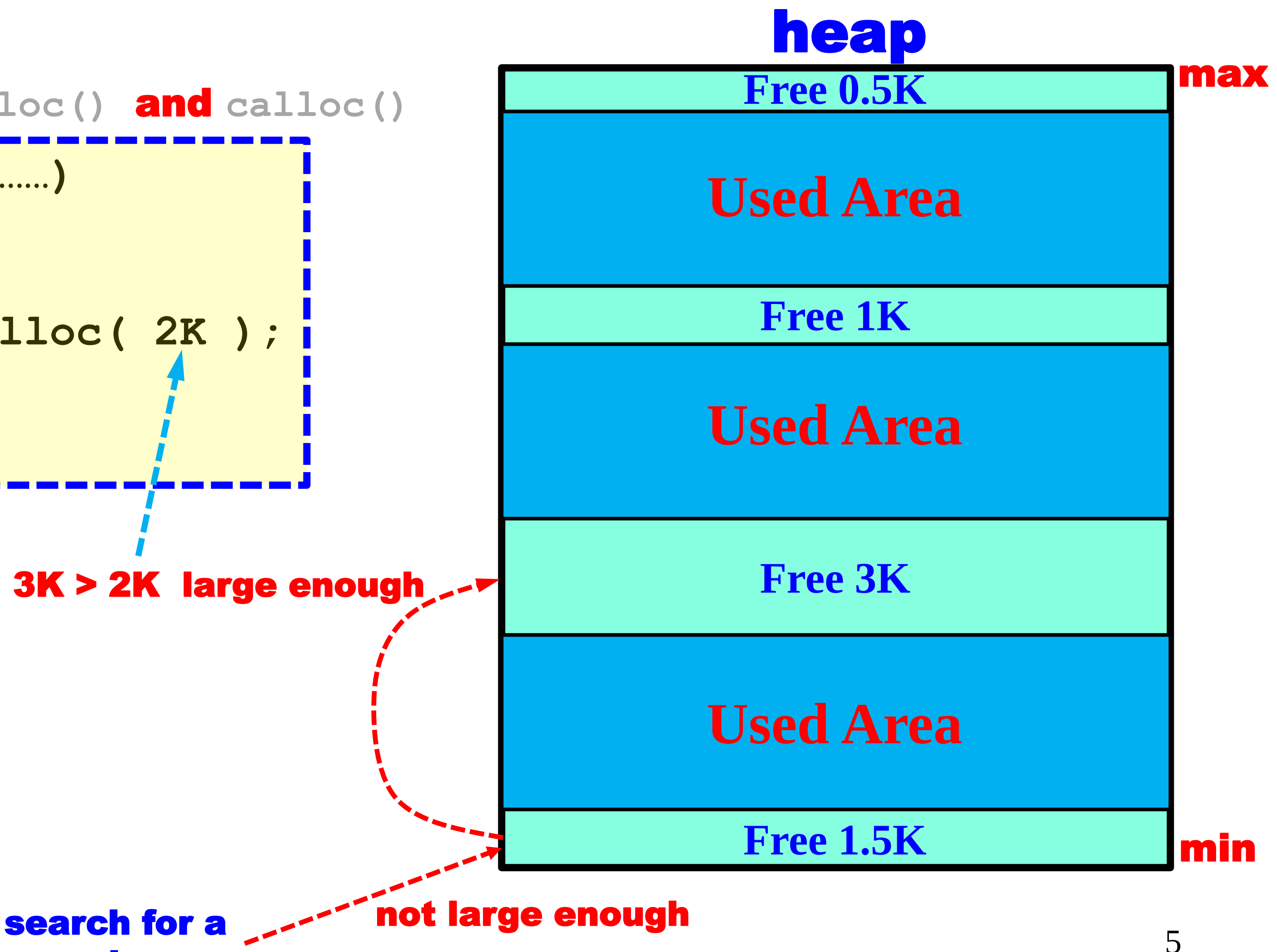
Executable instructions

After compilation, the compiler knows the total size of global variables
After linking, the linker knows the total size of the code

Memory Use of a Program: 2/10

memory for malloc() and calloc()

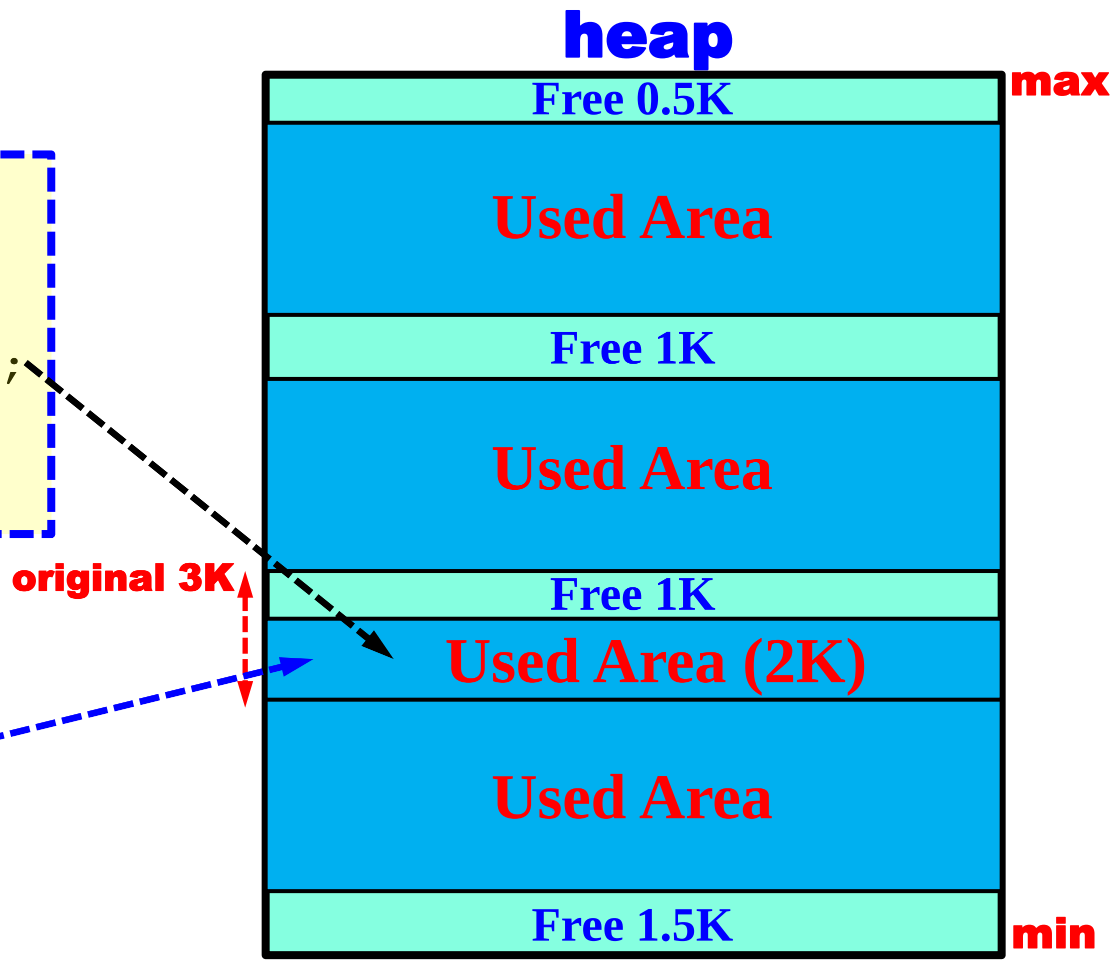
```
double K(......)
{
    ..;
    p = malloc( 2K );
    ..;
}
```



search for a large enough area

Memory Use of a Program: 3/10

```
double K(......)
{
    ..;
    p = malloc( 2K );
    ..;
}
```



allocate 2K out of this 3K for this request

The memory area for `malloc()` and `calloc()` is called the **heap**

Memory Use of a Program: 4/10

```
int D(.. ..)
{
    int u,v;
    …
}

double C(.. ..)
{
    double w;
    long   t;
    …
}

long  B(.. ..)
{
    char b[20];
    .. ..
    C(.. ..);
}

void A(.. ..)
{
    short m, n;
    B(.. ..);
}
```

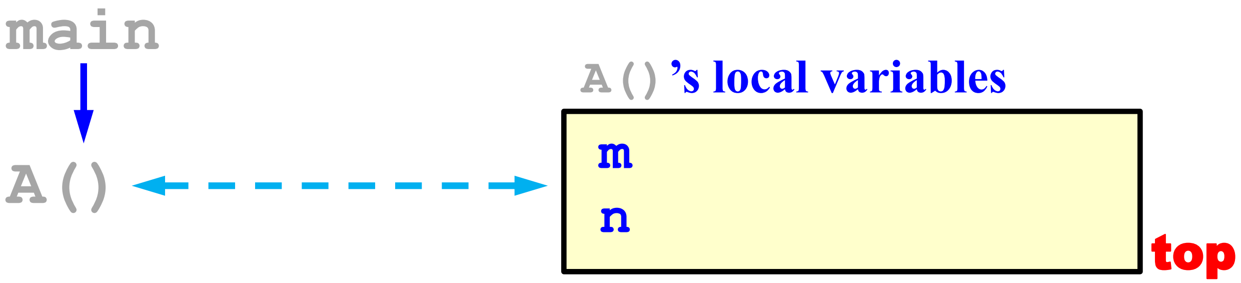
NOTE: When a function is called, all variables declared in this function must be available for this function to execute properly. After this function returns these local variables are no more needed.

- When `main()` calls `A()`, `m` and `n` must be available
- When `A()` calls `B()`, `b[20]` must be available
- When `B()` calls `C()`, `w` and `t` must be available
- When `C()` returns, `w` and `t` are not needed
- When `B()` returns, `b[20]` is not needed
- When `A()` returns, `m` and `n` are not needed

Call-Return order follows a first-in-last-out (FILO) order
The allocation order of local variable is also FILO.

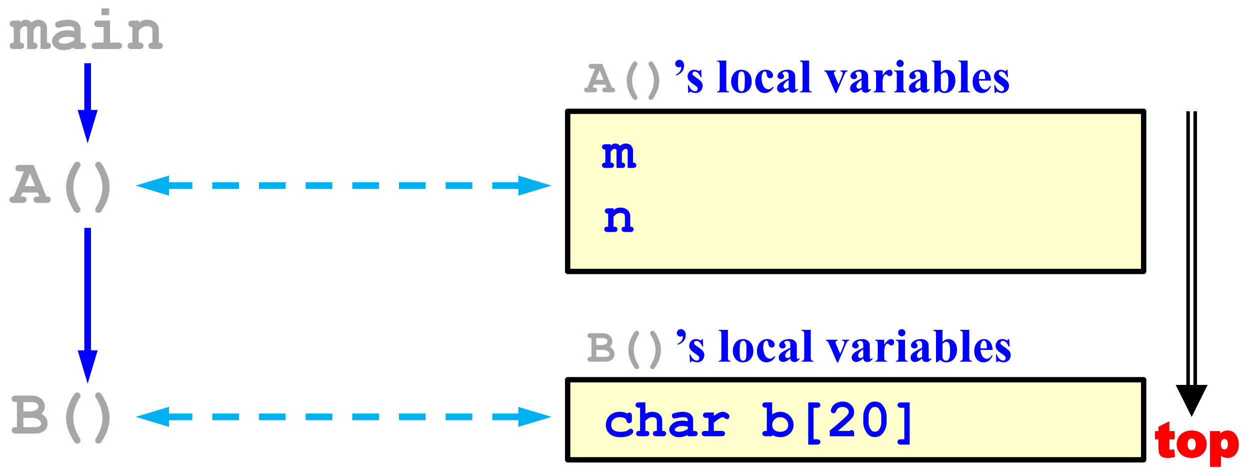
Memory Use of a Program: 5/10

```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```



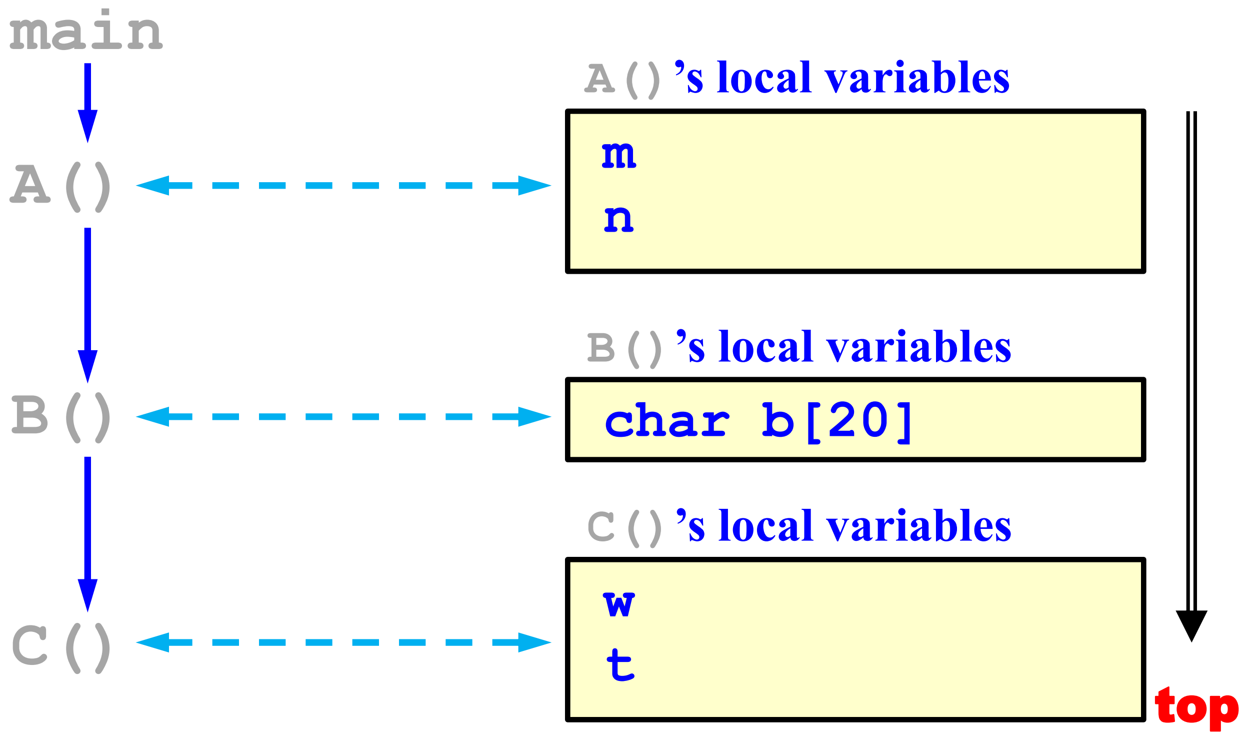
Memory Use of a Program: 6/10

```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```



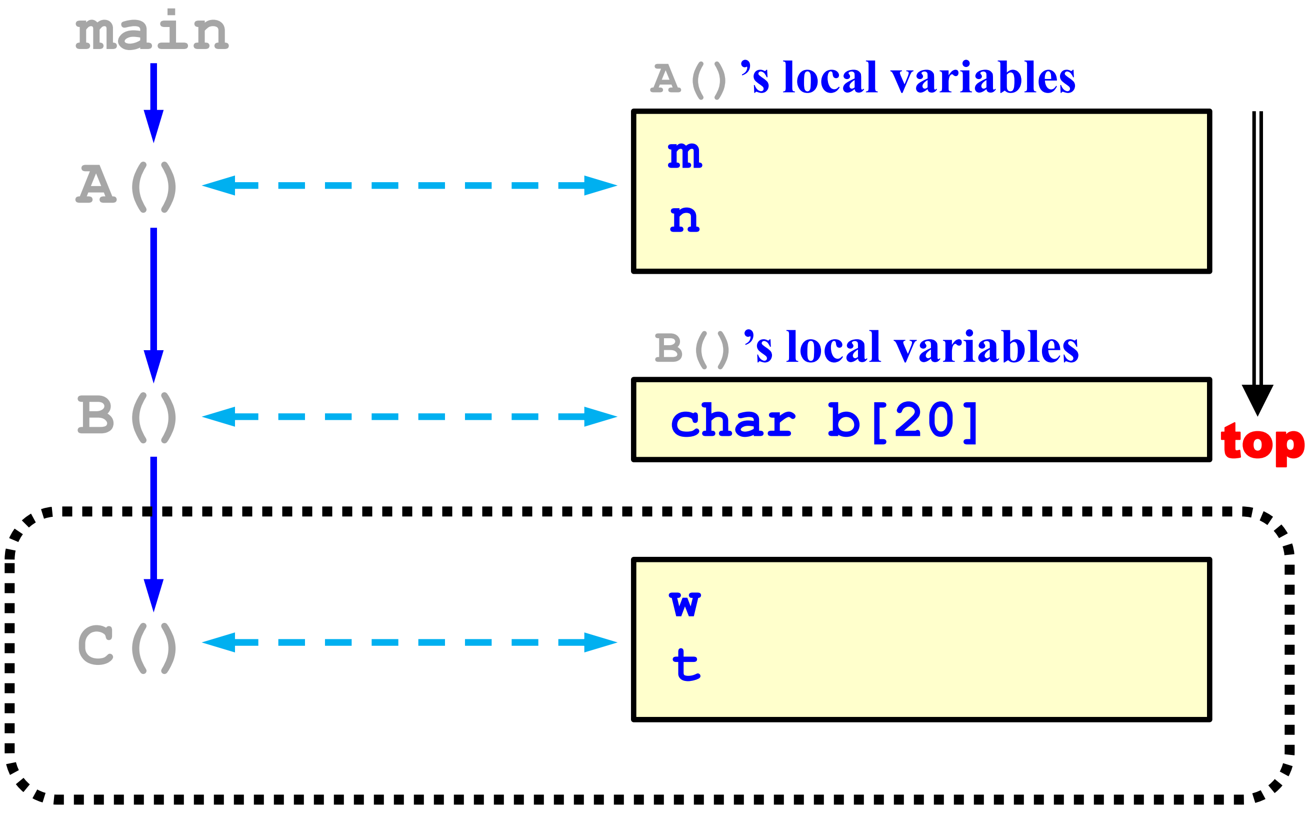
Memory Use of a Program: 7/10

```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```



Memory Use of a Program: 8/10

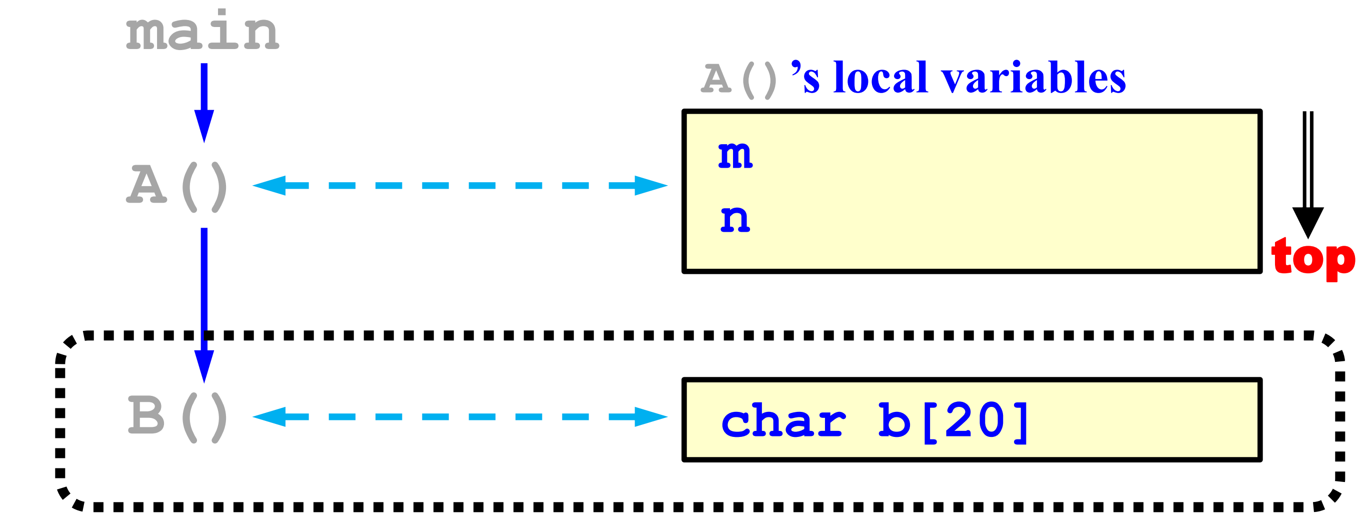
```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```



C() **returns, its local variables are not needed.**

Memory Use of a Program: 9/10

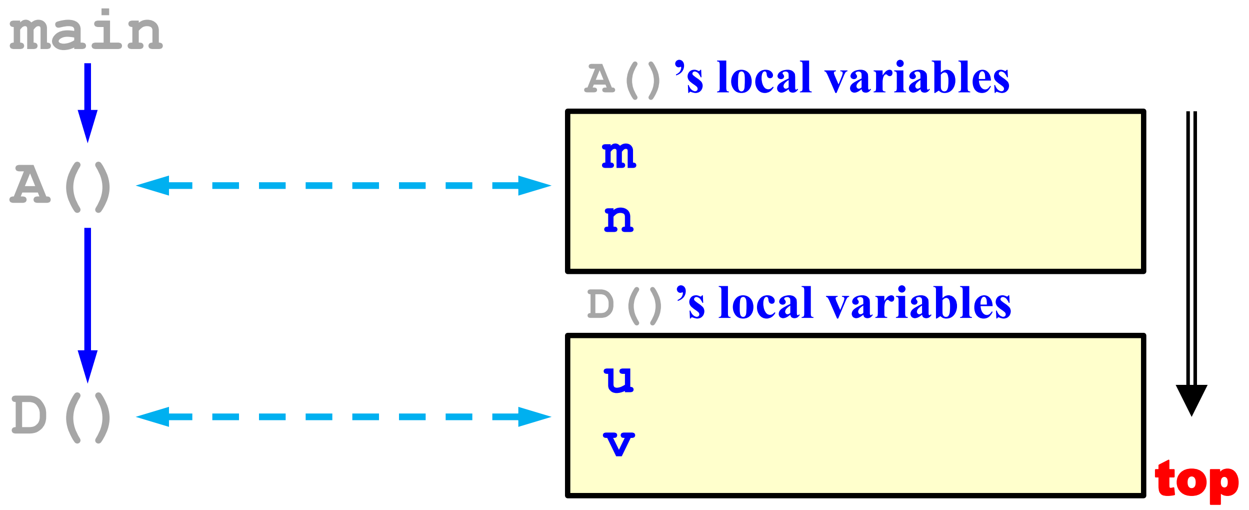
```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```



B() returns, its local variables are not needed.

Memory Use of a Program: 10/10

```
int D(.. ..)
{
   int u,v;
   …
}

double C(.. ..)
{
   double w;
   long   t;
   …
}

long  B(.. ..)
{
   char b[20];
   .. ..
   C(.. ..);
}

void A(.. ..)
{
   short m, n;
   B(.. ..);
}
```

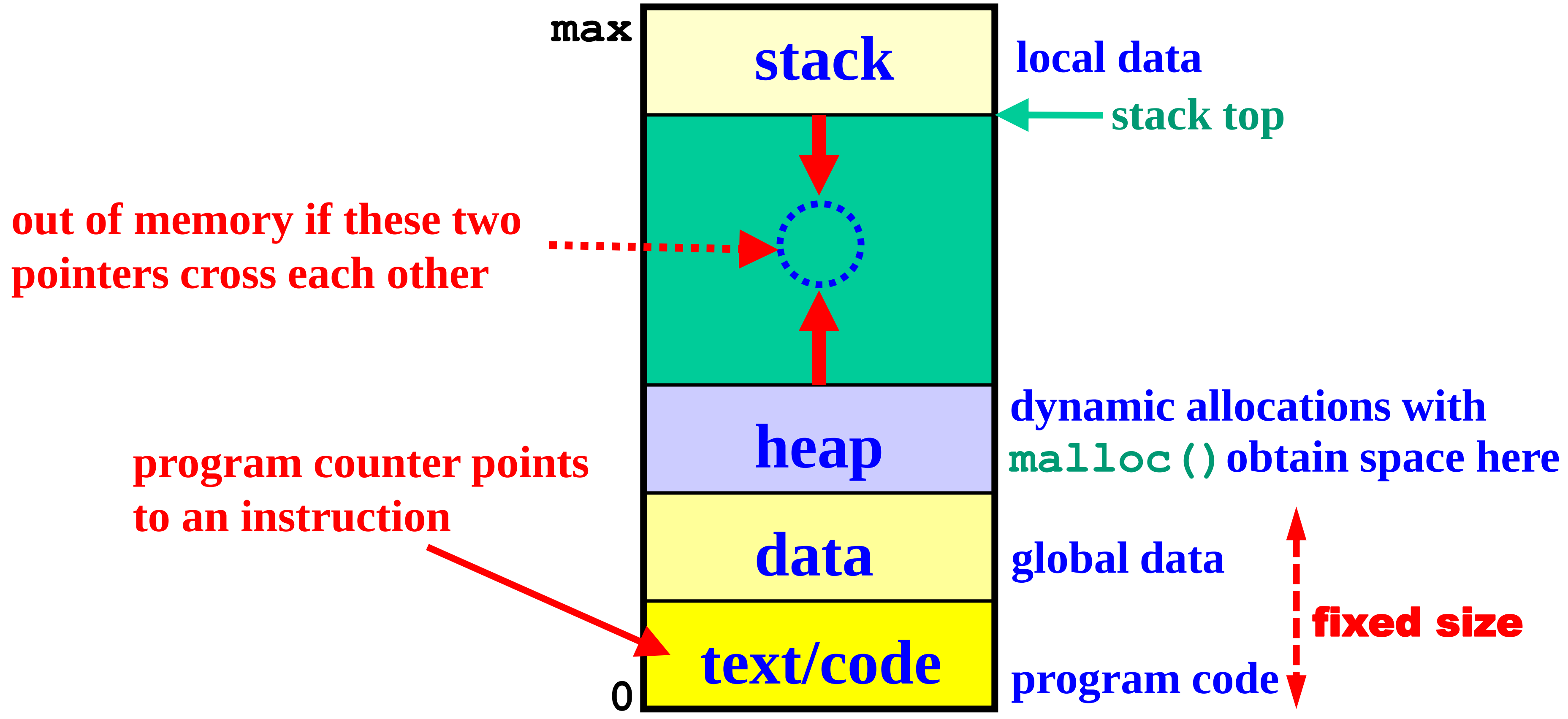


What if `A()` calls `D()`, `D()`'s local variables must be allocated, perhaps overwriting the area previous used by `B()`.

What Have We Learned?

- The call-return sequence is first-in-last-out or last-in-first-out!
- **This is a stack**!
- To allocate memory for the local variables of functions, we need a **STACK**.
- In summary, a **heap** is needed for `malloc()`, `calloc()`, etc. (**dynamic allocation**), and a **stack** to be used for local variables declared in functions (**first-in-last-out**).

Process Space

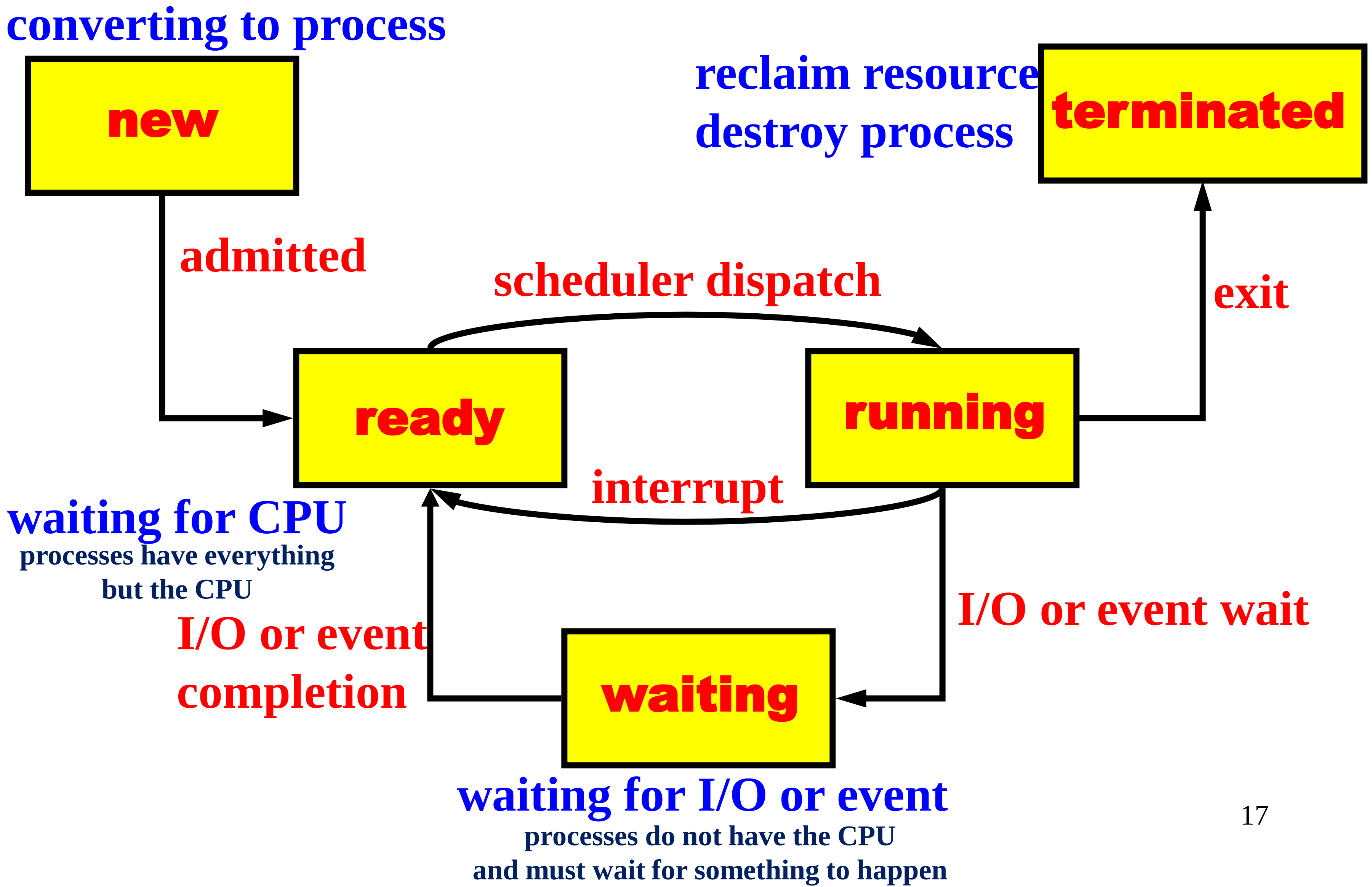

max
stack
local data
stack top
out of memory if these two pointers cross each other
heap
dynamic allocations with malloc() obtain space here
program counter points to an instruction
data
global data
fixed size
text/code
program code
0

Process States

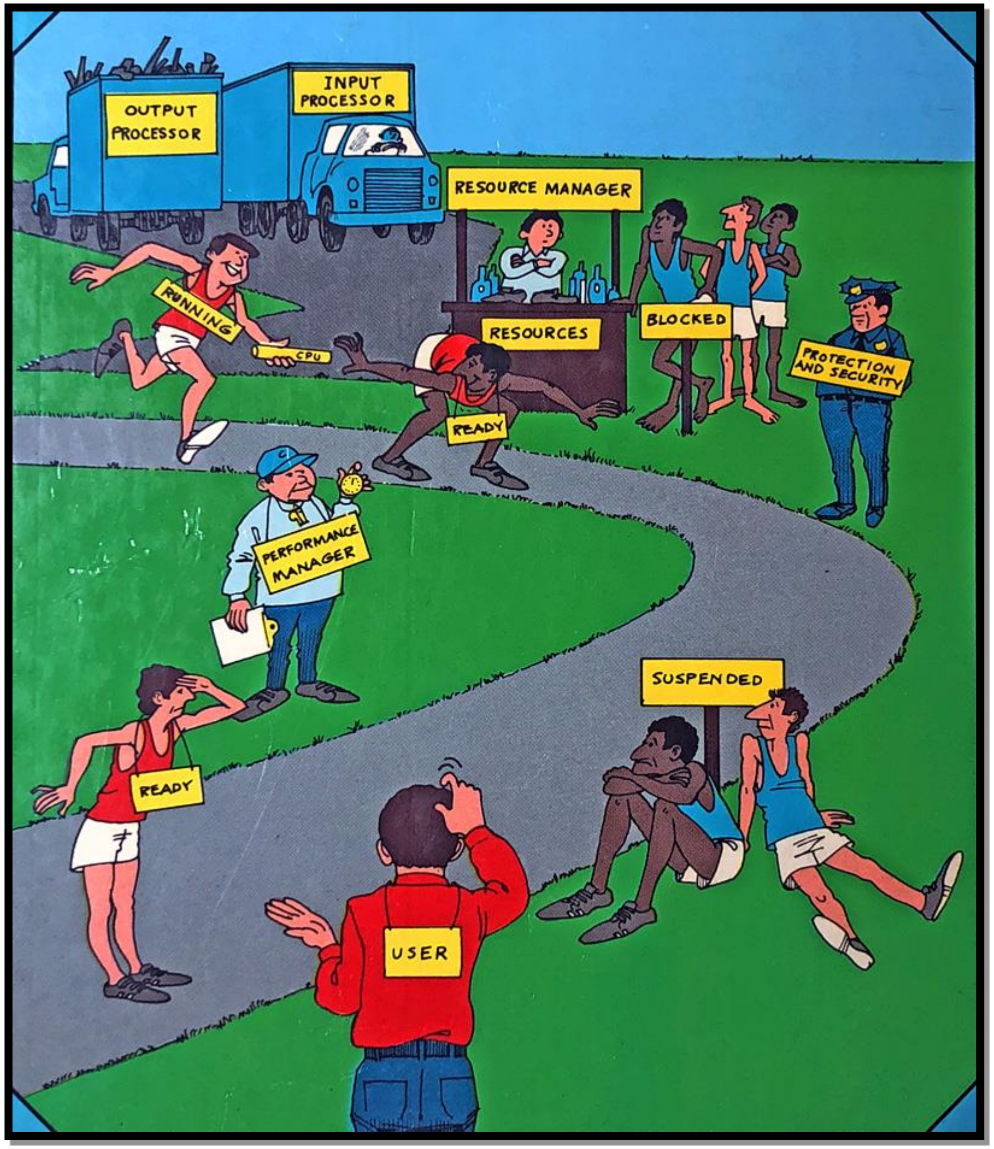
At any moment, a process can be in one of the five states: new, running, waiting, ready and terminated.

- **New**: The process is being created
- **Running**: The process is executing on a CPU
- **Waiting**: The process is waiting for some event to occur (e.g., waiting for I/O completion)
- **Ready**: The process has everything but the CPU. It is waiting to be assigned to a processor.
- **Terminated**: The process has finished execution.

Process State Diagram

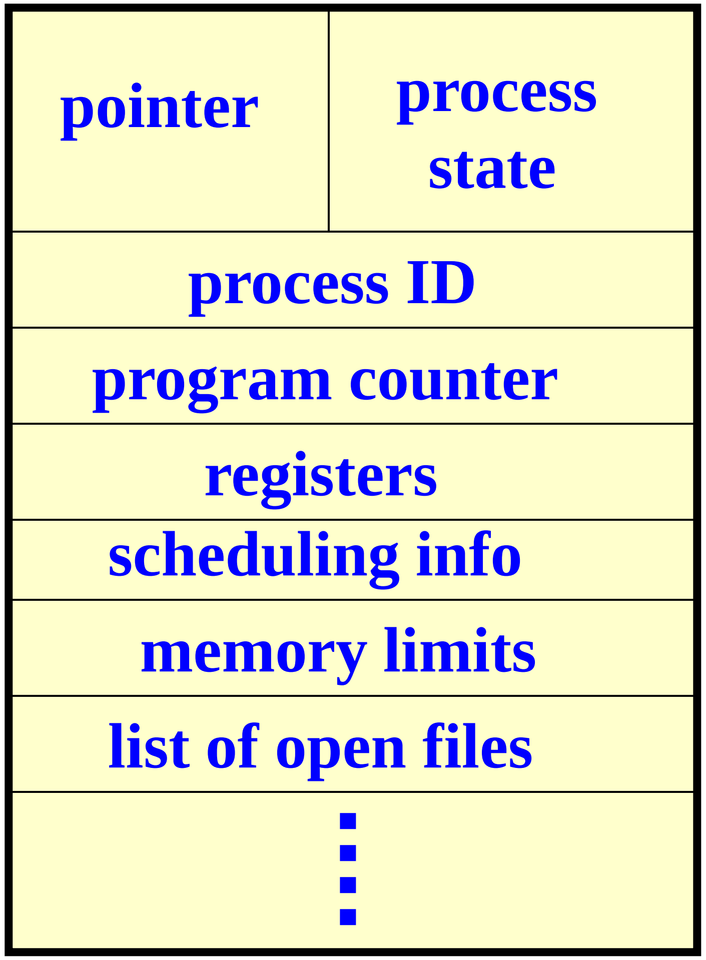


Process State Diagram



Lubomir Bic and Alan C. Shaw,
***The Logical Design of Operating Systems*,**
Second Edition,
Prentice Hall, 1988

Process Representation in OS



- Each process is assigned a unique number, the **process ID**.
- Process info are stored in a table, the **process control block** (**PCB**).
- These PCBs are chained into several data structures. For example, all processes in the ready state are in the **ready queue**.

Process Scheduling: 1/2

- Since the number of processes may be larger than the number of available CPUs, the OS must maintain maximum CPU utilization (i.e., all CPU's being as busy as possible).
- To determine which process can do what, processes are chained into a number of scheduling queues.
- For example, in addition to the ready queue, each event may have its own scheduling queue (*i.e.*, waiting queue).

Process Scheduling: 2/2

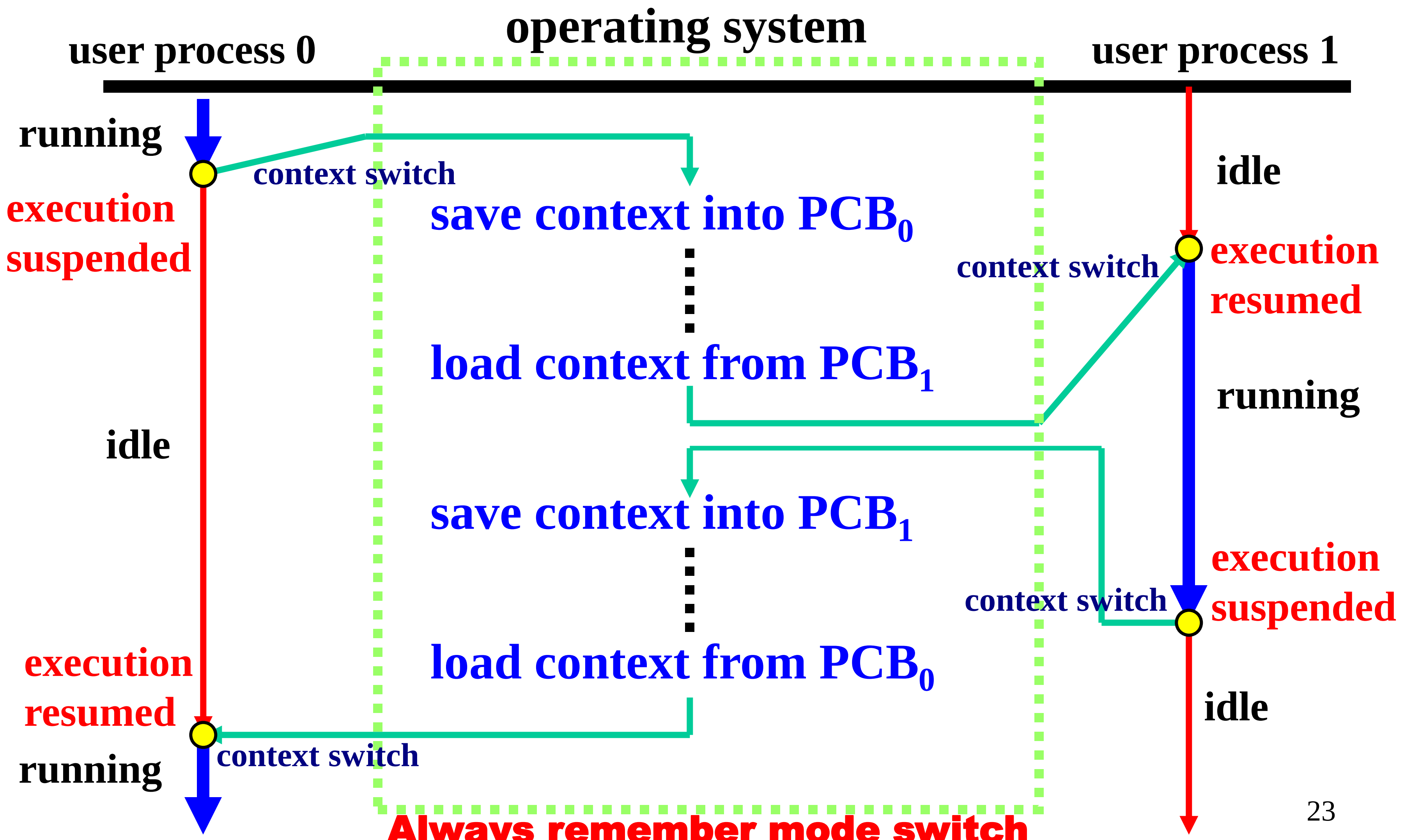
- The ready queue, which may be organized into several sub-queues, has all processes ready to run.
- The OS has a **CPU scheduler**.
- When a CPU is free, the CPU scheduler looks at the ready queue, picks a process, and resumes its execution.
- The way of picking a process from the ready queue is referred to as **scheduling policy**.
- Scheduling policy is unimportant to this course because we **cannot make any assumption** about it.

Context Switch: 1/2

- **What is a process context?** **The context of a process includes process ID, process state, the values of CPU registers, the program counter, and other memory/file management information (i.e., execution environment).**
- **What is a context switch?** **After the CPU scheduler selects a process and before allocates a CPU to it, the CPU scheduler must**
  - **save the context of the currently running process,**
  - **put it back to the ready queue or waiting state,**
  - **load the context of the selected process, and**
  - **go to the saved program counter.**

mode switching may be needed

Context Switch: 2/2



Always remember mode switch

Operations on Processes

- There are three commonly seen operations:
  - **Process Creation**: Create a new process. The newly created is the child of the original. Unix uses `fork()` to create new processes.
  - **Process Termination**: Terminate the execution of a process. Unix uses `exit()`.
  - **Process Join**: Wait for the completion of a child process. Unix uses `wait()`.
- `fork()`, `exit()` and `wait()` are system calls.

Some Required Header Files

- **Before you use processes, include header files `sys/types.h` and `unistd.h`.**
- **`sys/types.h` has all system data types, and `unistd.h` declares standard symbolic constants and types.**

```
#include  <sys/types.h>
#include  <unistd.h>
```

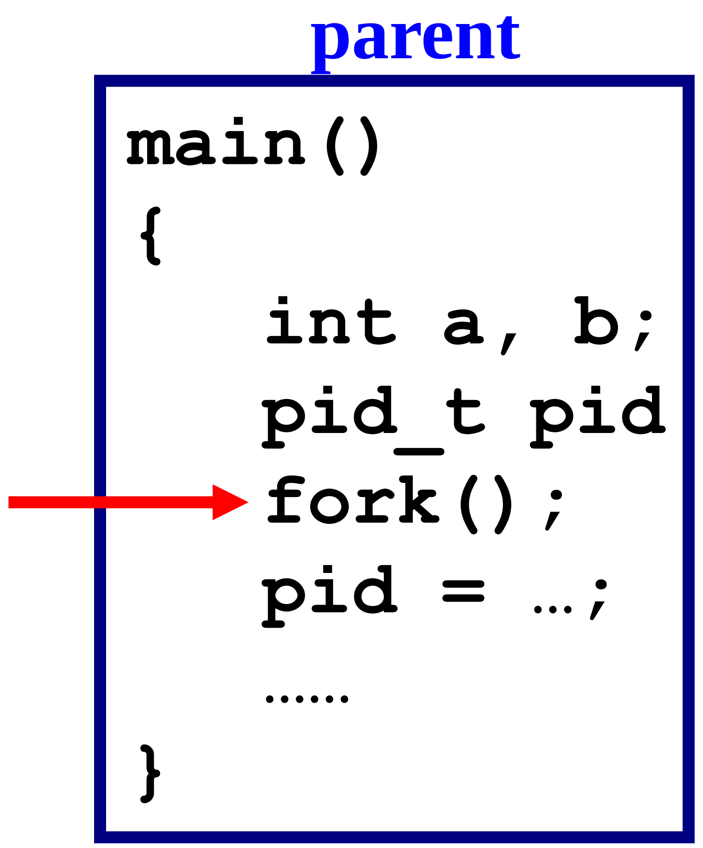
The fork() System Call

- The purpose of `fork()` is to create a child process. The creating and created processes are the parent and child, respectively.
- `fork()` does not require any argument!
- If the call to `fork()` is successful, Unix creates an identical but separate address space for the child process to run.
- Both processes start running with the instruction following the `fork()` system call.

fork() Return Values

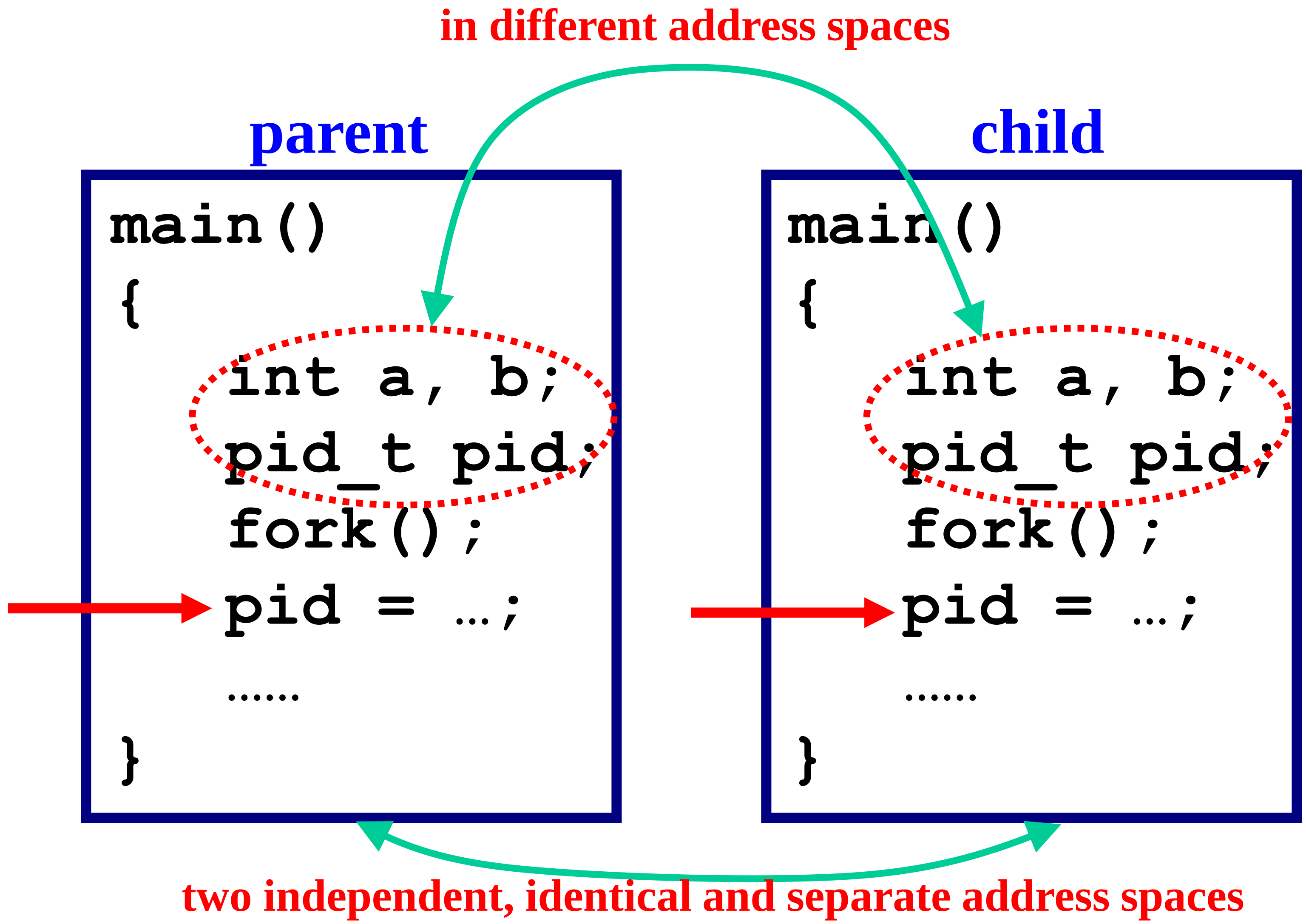
- A negative value means the creation of a child process was unsuccessful.
- A zero means the process is a child.
- Otherwise, `fork()` returns the process ID of the child process. The ID is of type `pid_t`.
- Function `getpid()` returns the process ID of the caller.
- Function `getppid()` returns the parent's process ID. If the calling process has no parent, `getppid()` returns `1`.

Before the Execution of fork()



```
main()
{
    int a, b;
    pid_t pid
    fork();
    pid = …;
    ……
}
```

After the Execution of fork()


in different address spaces
parent
child
two independent, identical and separate address spaces

```
main()
{
   int a, b;
   pid_t pid;
   fork();
   pid = …;
   ……
}
```

```
main()
{
   int a, b;
   pid_t pid;
   fork();
   pid = …;
   ……
}
```

Be Aware of `printf()`: 1/3

- **Processes running from the same terminal window share the same `stdout`.**
- **This can cause problems when using `printf()` due to *interleaved* execution.**
- **When printing multiple items using `printf()` from different processes execution may be switched in the middle.**

Be Aware of `printf()`: 2/3

- Process 1 and Process 2 are shown below.
- After printing `A` by Process 1, Process 2 may print something and vice versa.
- Both processes print to the same `stdout`!
- The output could be a mixed one from Process 1 and Process 2.

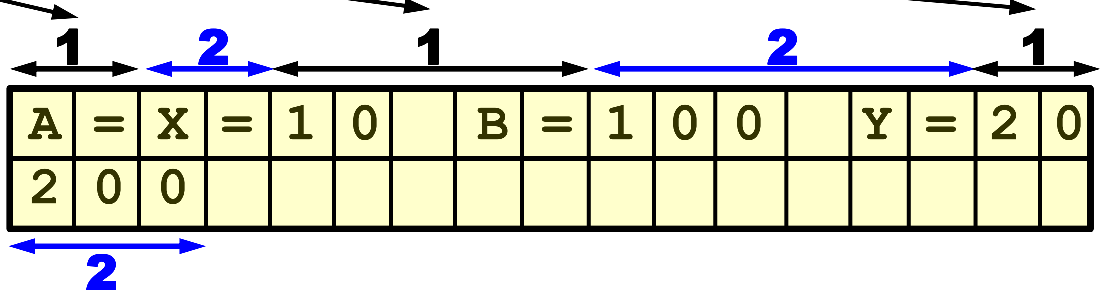
Process 1	Process 2
`A = 10; B = 20;`	`X = 100; Y = 200;`
`printf("A=%d B=%d\n",A,B);`	`printf("X=%d Y=%d\n",X,Y);`

Be Aware of `printf()`: 3/3

- Process 1 and Process 2 are shown below.
- Remember interleaved execution.

Process 1	Process 2
`A = 10; B = 20;`	`X = 100; Y = 200;`
`printf("A=%d B=%d\n",A,B);`	`printf("X=%d Y=%d\n",X,Y);`

Process 1	Process 2
`print A`	
	`print X`
`print B`	
	`print Y`



we assume that the process is switched out when doing conversions from `int` to ASCII (`%d`)

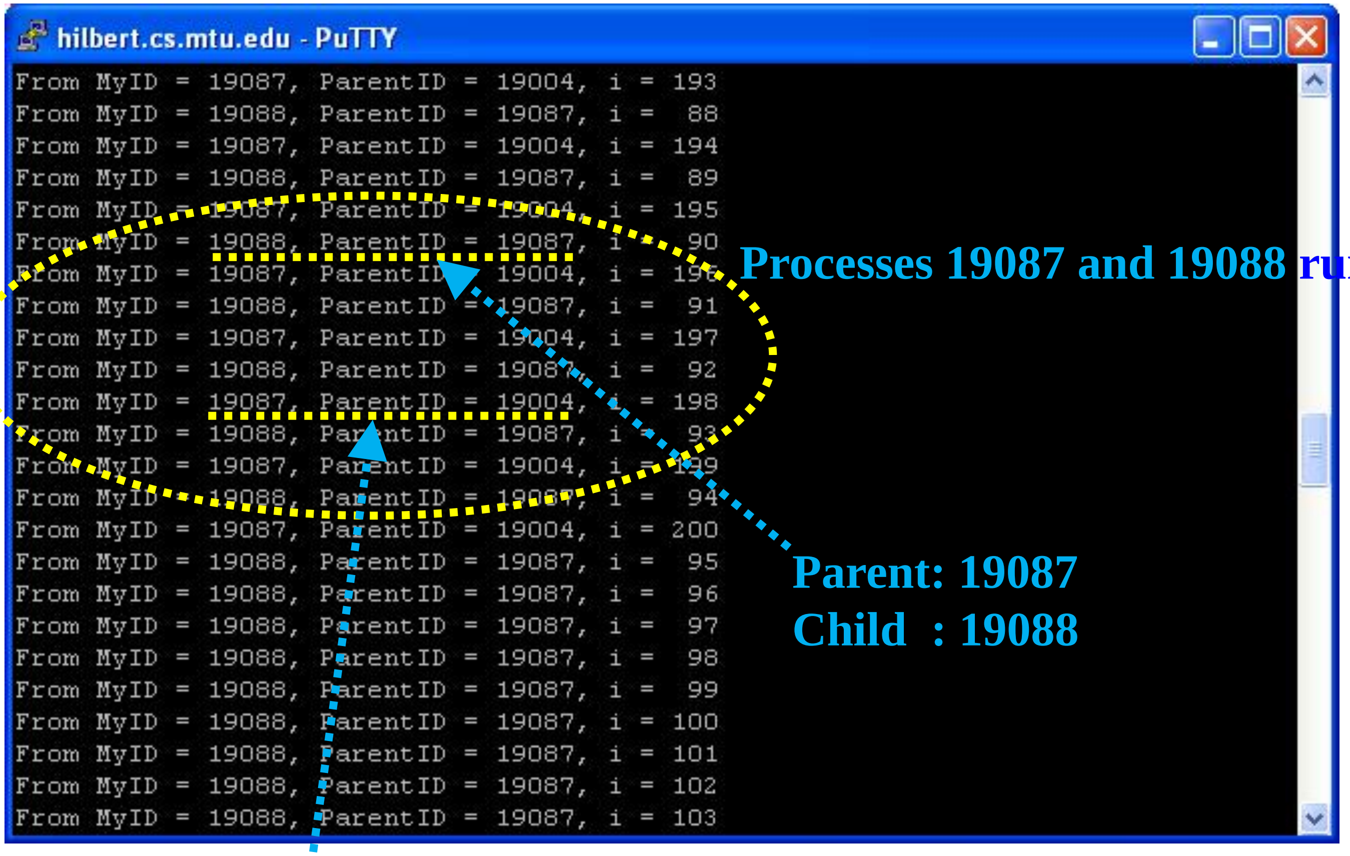
Example 1: 1/2

fork-1.c

```
#include  <stdio.h>
#include  <string.h>
#include  <sys/types.h>
#include  <unistd.h>

void main(void)
{
   pid_t  MyID, ParentID;
   int    i;
   char   buf[100];

   fork();                     // create a child process
   MyID     = getpid();   // get my process ID
   ParentID = getppid(); // get my parent's process ID
   for (i = 1; i <= 200; i++) {
      sprintf(buf, "From MyID=%ld, ParentID=%ld, i=%3d\n",
                   MyID, ParentID, i);
      write(1, buf, strlen(buf));   // REMEMBER: why we
   }                                //    don't use printf?
}
```

this is stdout

Example 1: 2/2



```
From MyID = 19087, ParentID = 19004, i = 193
From MyID = 19088, ParentID = 19087, i =  88
From MyID = 19087, ParentID = 19004, i = 194
From MyID = 19088, ParentID = 19087, i =  89
From MyID = 19087, ParentID = 19004, i = 195
From MyID = 19088, ParentID = 19087, i =  90
From MyID = 19087, ParentID = 19004, i = 196
From MyID = 19088, ParentID = 19087, i =  91
From MyID = 19087, ParentID = 19004, i = 197
From MyID = 19088, ParentID = 19087, i =  92
From MyID = 19087, ParentID = 19004, i = 198
From MyID = 19088, ParentID = 19087, i =  93
From MyID = 19087, ParentID = 19004, i = 199
From MyID = 19088, ParentID = 19087, i =  94
From MyID = 19087, ParentID = 19004, i = 200
From MyID = 19088, ParentID = 19087, i =  95
From MyID = 19088, ParentID = 19087, i =  96
From MyID = 19088, ParentID = 19087, i =  97
From MyID = 19088, ParentID = 19087, i =  98
From MyID = 19088, ParentID = 19087, i =  99
From MyID = 19088, ParentID = 19087, i = 100
From MyID = 19088, ParentID = 19087, i = 101
From MyID = 19088, ParentID = 19087, i = 102
From MyID = 19088, ParentID = 19087, i = 103
```

Processes 19087 and 19088 run concurrently

Parent: 19087
Child : 19088

$$\begin{tikzcd} 19004 \arrow[d] \\ 19087 \arrow[d] \\ 19088 \end{tikzcd}$$

Parent 19087's parent is 19004, the shell that executes `fork-1`

fork(): A Typical Use

```
main(void)
{
  pid_t pid;

  pid = fork();
  if (pid < 0)
    printf("Oops!");
  else if (pid == 0)
    child();
  else // pid > 0
    parent();
}
```

```
void child(void)
{
  int i;
  for (i=1; i<=10; i++)
    printf(" Child:%d\n", i);
  printf("Child done\n");
}

void parent(void)
{
  int i;
  for (i=1; i<=10; i++)
    printf("Parent:%d\n", i);
  printf("Parent done\n");
}
```

we use `printfs` here to save space.

Before the Execution of fork()

parent

pid = ?

```
main(void)
{
  → pid = fork();
    if (pid == 0)
       child();
    else
       parent();
}

void child(void)
{  ......  }

void parent(void)
{  ......  }
```

After the Execution of fork() 1/2

parent

pid=123

```
main(void)
{
   pid = fork();
   if (pid == 0)
      child();
   else
      parent();
}

void child(void)
{ ...... }

void parent(void)
{ ...... }
```

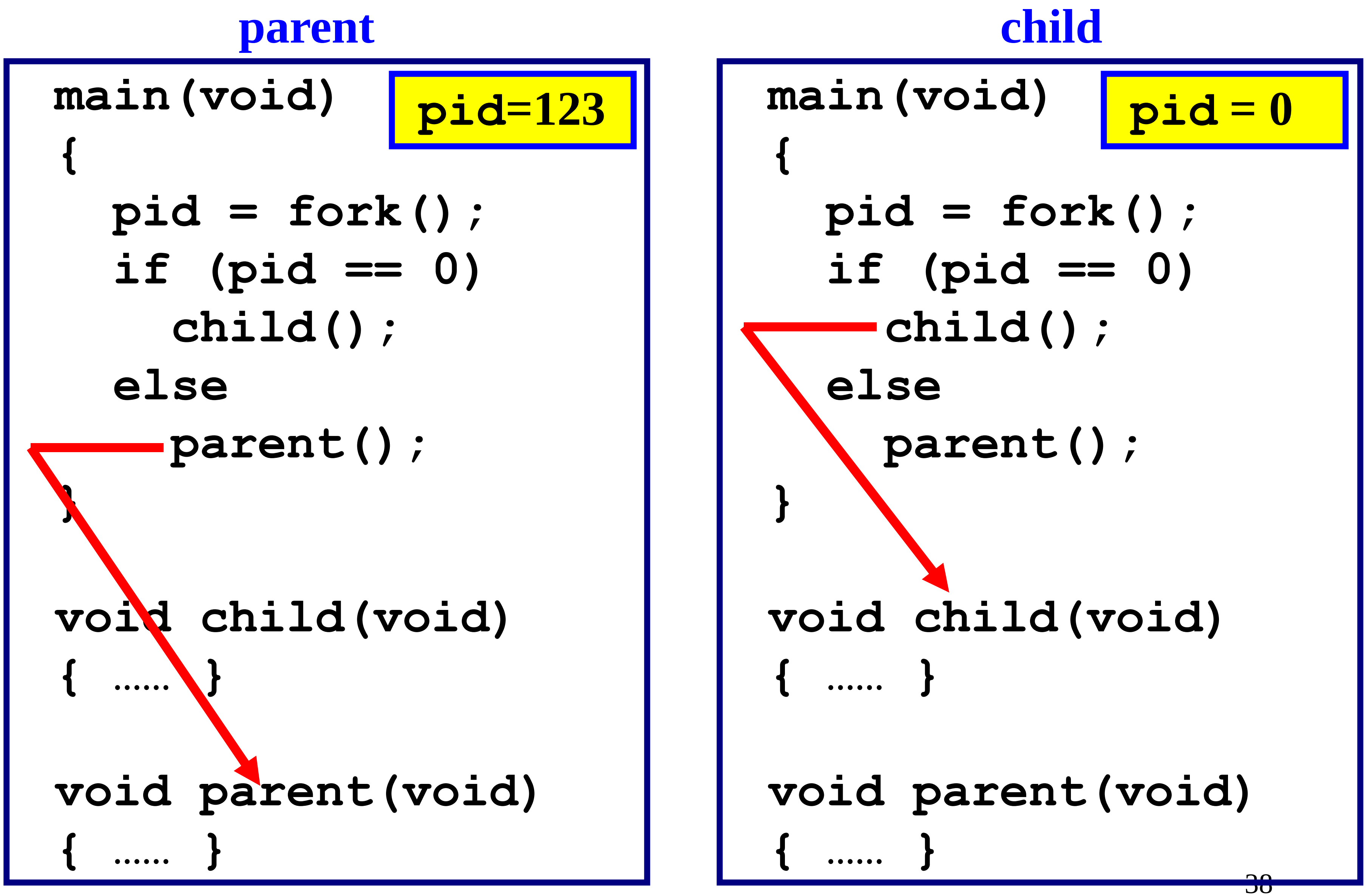
child

pid = 0

```
main(void)
{
   pid = fork();
   if (pid == 0)
      child();
   else
      parent();
}

void child(void)
{ ...... }

void parent(void)
{ ...... }
```

in two different address spaces

After the Execution of fork() 2/2



parent

```
main(void)                pid=123
{
   pid = fork();
   if (pid == 0)
      child();
   else
      parent();
}


void child(void)
{  ......  }

void parent(void)
{  ......  }
```

child

```
main(void)                pid = 0
{
   pid = fork();
   if (pid == 0)
      child();
   else
      parent();
}


void child(void)
{  ......  }

void parent(void)
{  ......  }
```

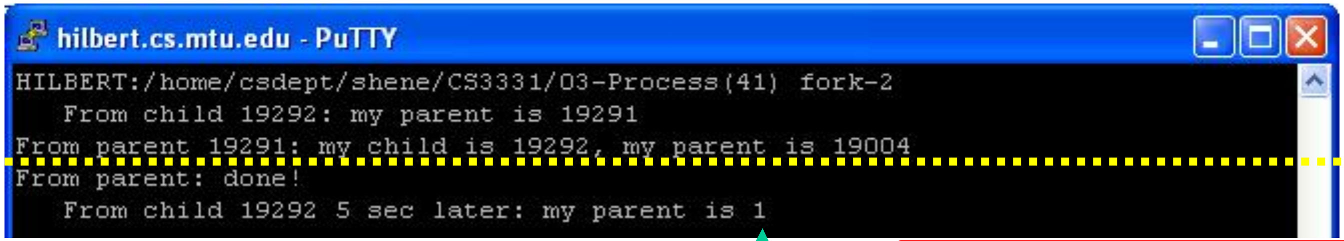
Example 2: 1/2

fork-2.c

force the child to print after the parent terminates

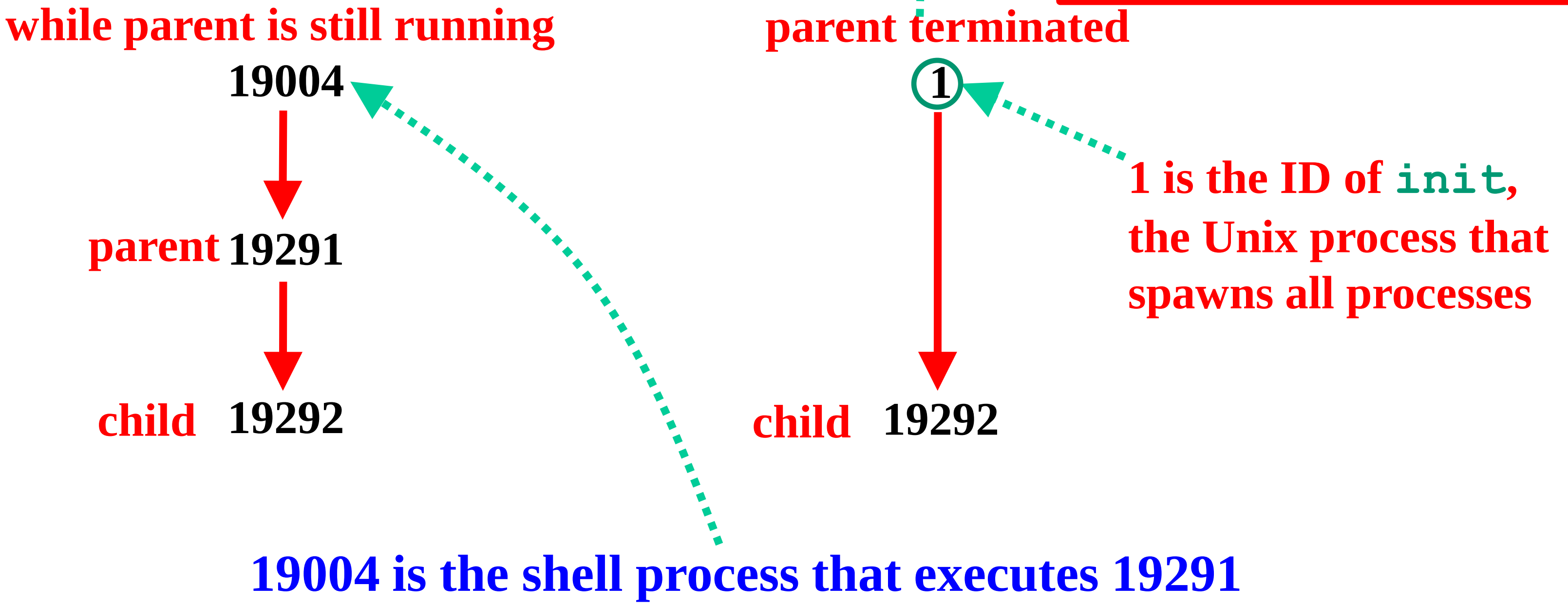
```
#include .........            // child exits first
void main(void)
{
   pid_t  pid;

   pid = fork();
   if (pid == 0) {            // child here
      printf("   From child %ld: my parent is %ld\n",
                        getpid(), getppid());
      sleep(5);
      printf("   From child %ld 5 sec later: parent %ld\n",
                        getpid(), getppid());
   }
   else {                     // parent here
      sleep(2);
      printf("From parent %ld: child %ld, parent %ld\n",
                 getpid(), pid, getppid());
      printf("From parent: done!\n");
   }
}
```

Example 2: 2/2



```
HILBERT:/home/csdept/shene/CS3331/03-Process(41) fork-2
    From child 19292: my parent is 19291
From parent 19291: my child is 19292, my parent is 19004
From parent: done!
    From child 19292 5 sec later: my parent is 1
```

Orphan children have a new parent `init`, the Unix process that spawns all processes



1 is the ID of `init`, the Unix process that spawns all processes

19004 is the shell process that executes 19291

Example 3: 1/2

fork-3.c

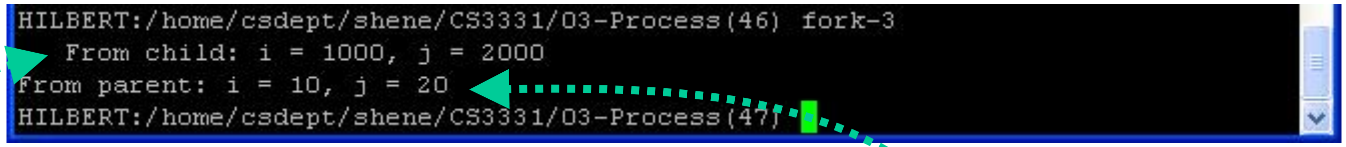
```
#include  ......   // separate address spaces

void  main(void)
{
   pid_t  pid;
   char   out[100];
   int    i = 10, j = 20;

   if ((pid = fork()) == 0) {    // child here
      i = 1000; j = 2000;        // child changes values
      sprintf(out, "   From child: i=%d, j=%d\n", i, j);
      write(1, out, strlen(out));
   }
   else {                        // parent here
      sleep(3);
      sprintf(out, "From parent: i=%d, j=%d\n", i, j);
      write(1, out, strlen(out));
   }
}
```

this is equivalent to

```
pid = fork();
if (pid == 0)  ...
```

force the parent to print after the child terminated

Example 3: 2/2



```
HILBERT:/home/csdept/shene/CS3331/03-Process(46) fork-3
   From child: i = 1000, j = 2000
From parent: i = 10, j = 20
HILBERT:/home/csdept/shene/CS3331/03-Process(47)
```

child changes `i` and `j` to 1000 and 2000 from 10 and 20, respectively

parent's `i` and `j` are not affected because parent and child have independent and separate address space

The wait() System Call

- The `wait()` system call blocks the caller until **one of its child processes** exits or a signal is received.
- `wait()` takes a pointer to an integer variable and returns the process ID of the completed process. If no child process is running, `wait()` returns `-1`.
- Some flags that indicate the completion status of the child process are passed back with the integer pointer.

How to Use wait()?

- **Wait for an unspecified child process:**

```
wait(&status);
```

- **Wait for a number, say `n`, of unspecified child processes:**

```
for (i = 0; i < n; i++)
    wait(&status);
```

- **Wait for a specific child process whose ID is known:**

```
while (pid != wait(&status))
    ;
```

wait() System Call Example

```
void main(void)
{
   pid_t pid, pid_child;
   int   status;

   if ((pid = fork()) == 0)  // child here
      child();
   else {                    // parent here
      parent();
      pid_child = wait(&status);
   }
}
```

Zombie Processes: 1/4

- A **zombie** or **defunct** process is a process that terminates its execution before its parent executes the `wait()` system call.
- A zombie process only has an entry in the system process table and does not consume much system resource.
- A zombie process will be removed completely when its parent terminates or when its parent executes the `wait()` system call waiting for this child.

Zombie Processes: 2/4

- **Between the termination of the child and the termination of its parent (or the parent executes the `wait()` system call), the child is a zombie or defunct process.**
- **A zombie process is in the terminated state.**
- **The `kill` command cannot kill zombie processes because they had died (terminated)!**
- **To find out whether you have zombie processes, use `ps -af`.**

Zombie Processes: 3/4

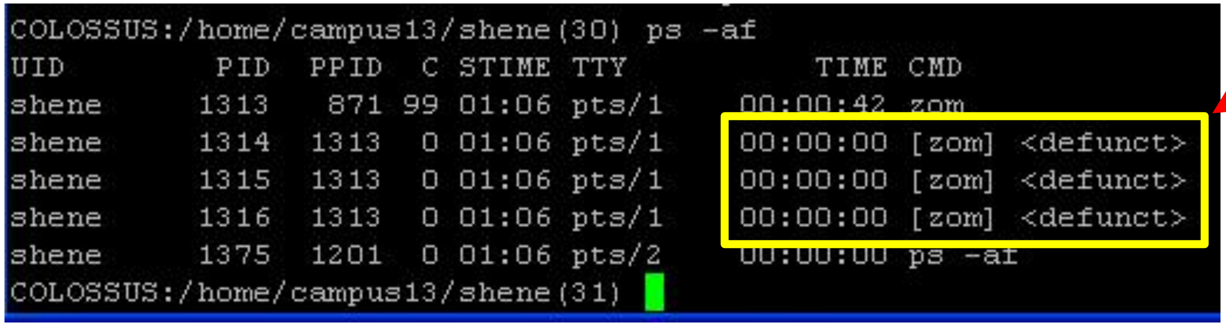
- Suppose we have the following code:

```
if (fork() > 0)
     if (fork() > 0)
          for (fork() > 0)
               while (1 == 1) ;
```

- The parent creates three child processes and loops forever (i.e., never dies). Each child process does nothing and terminates immediately.
- Therefore, we have three zombie processes!

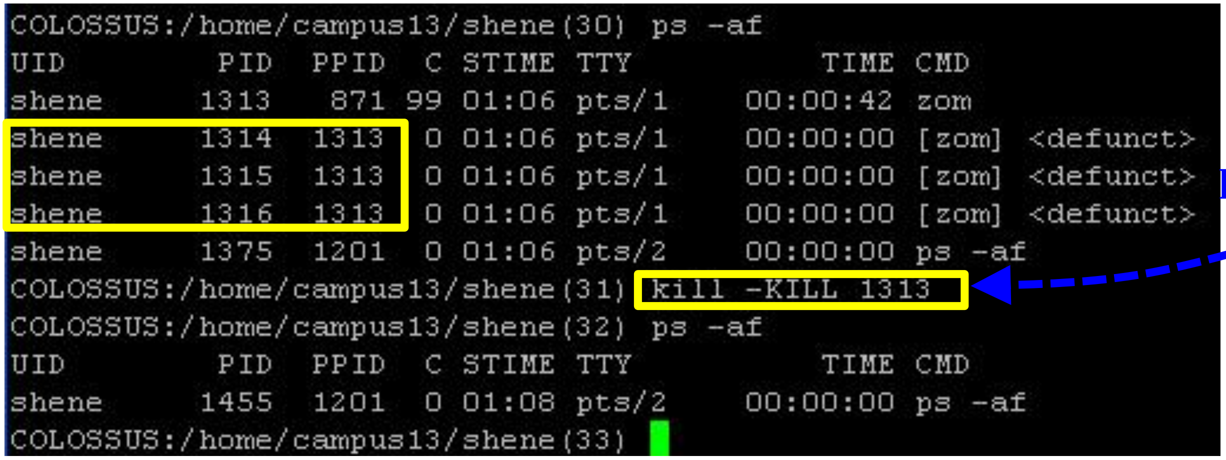
Zombie Processes: 4/4

- We have three zombie processes, marked as defunct.



```
COLOSSUS:/home/campus13/shene(30) ps -af
UID        PID  PPID  C STIME TTY          TIME CMD
shene     1313   871 99 01:06 pts/1    00:00:42 zom
shene     1314  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1315  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1316  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1375  1201  0 01:06 pts/2    00:00:00 ps -af
COLOSSUS:/home/campus13/shene(31)
```

- You need to kill the parent to kill its child zombies.



```
COLOSSUS:/home/campus13/shene(30) ps -af
UID        PID  PPID  C STIME TTY          TIME CMD
shene     1313   871 99 01:06 pts/1    00:00:42 zom
shene     1314  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1315  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1316  1313  0 01:06 pts/1    00:00:00 [zom] <defunct>
shene     1375  1201  0 01:06 pts/2    00:00:00 ps -af
COLOSSUS:/home/campus13/shene(31) kill -KILL 1313
COLOSSUS:/home/campus13/shene(32) ps -af
UID        PID  PPID  C STIME TTY          TIME CMD
shene     1455  1201  0 01:08 pts/2    00:00:00 ps -af
COLOSSUS:/home/campus13/shene(33)
```

process 1313 created 1314, 1315 and 1316, the three zombie processes

kill the parent 1313

no more zombie processes

Daemon Processes: 1/2

- A **daemon** (*DEE-mun* or *DAY-mun*) process is a background process that is detached from a terminal.
- They are used to answer requests and/or to provide services. Commonly seen ones are `inetd`, `httpd`, `nfsd`, `sshd`, `lpd`, `syslogd` …
- Daemon processes are usually created when the system started by the `init` process, the mother of all processes with PID 1.
- It could also be created by a process that immediately exits after creation, making the created process adapted by `init`.

Daemon Processes: 2/2

- Daemon processes usually have PPID 1 (the `init` process) and have names like `*d`.
- Not all process names end with `d` are daemons.
- You may use `ps -ef | awk '$3 == 1'` to list all processes whose parent is `init`:

this is the PPID column

```
root    PID 2124   1 0  2018 ?       00:00:00 /usr/sbin/lvmetad -f
root        2159   1 0  2018 ?       00:00:03 /usr/lib/systemd/systemd-udevd
root        4158   1 0  2018 ?       00:00:26 /sbin/auditd
root        4185   1 0  2018 ?       00:03:18 /usr/sbin/irqbalance --foreground
rpc         4187   1 0  2018 ?       00:00:04 /sbin/rpcbind -w
rtkit       4188   1 0  2018 ?       00:00:24 /usr/libexec/rtkit-daemon
            ................................
root        4221   1 0  2018 ?       00:00:00 /usr/sbin/smartd -n -q never
..................................
root        4951   1 0  2018 ?       00:00:01 rhnsd
root        4961   1 0  2018 ?       00:00:22 /usr/sbin/ypbind -n
            ................................
```

PPID

`*d` program name

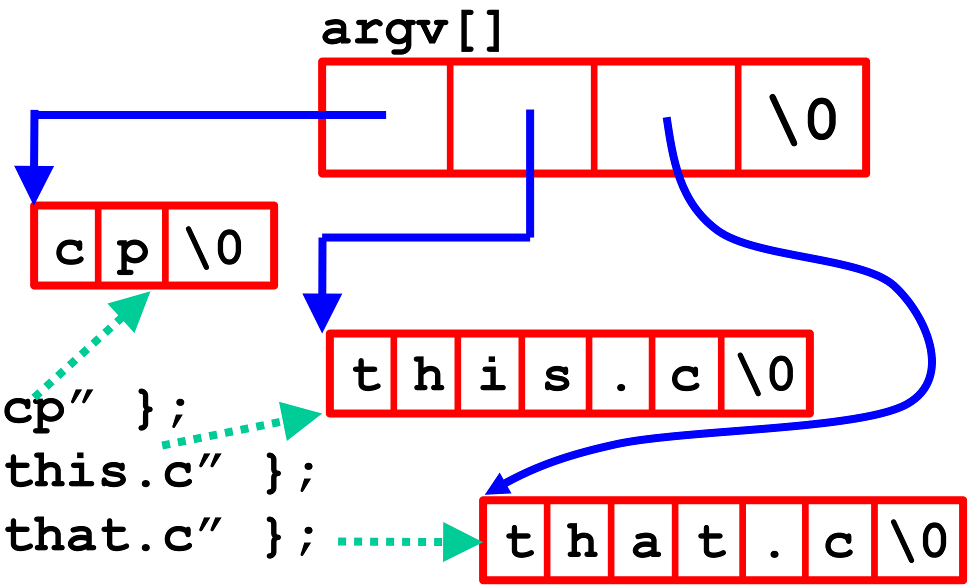
The exec() System Calls

- **A newly created process may run a different program rather than that of the parent.**
- **This is done using the `exec` system calls. We will only discuss `execvp()`:**

```
int execvp(char *file, char *argv[]);
```

  - **`file` is a `char` array that contains the name of an executable file. Depending on your system settings, you may need the `./` prefix for files in the current directory.**
  - **`argv[]` is the argument passed to your main program**
  - **`argv[0]` is a pointer to a string that contains the program name**
  - **`argv[1]`, `argv[2]`, … are pointers to strings that contain the arguments**

execvp() : An Example 1/2

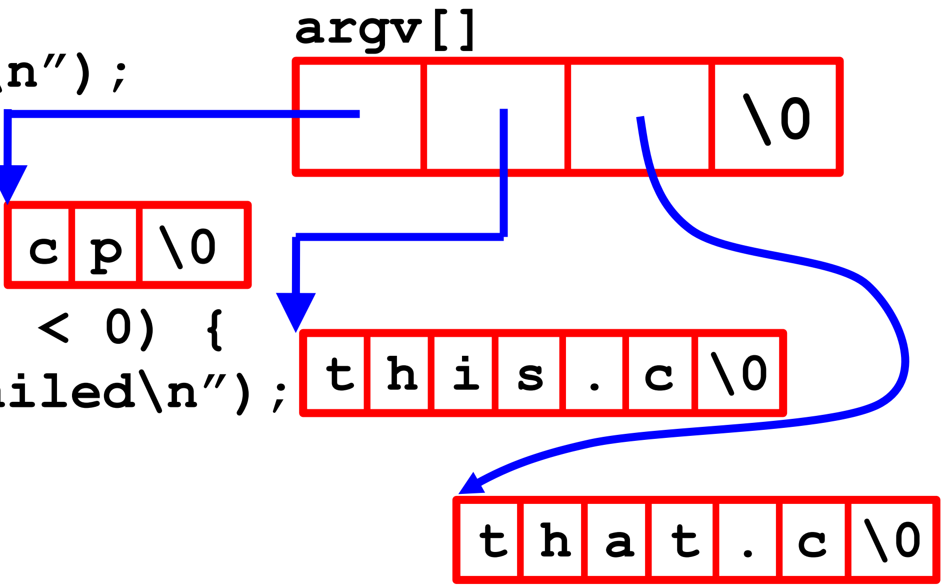


```
#include  <stdio.h>
#include  <unistd.h>

void main(void)
{
  char   prog[] = { "cp" };
  char   in[]   = { "this.c" };
  char   out[]  = { "that.c" };
  char   *argv[4];
  int    status;
  pid_t  pid;

  argv[0] = prog;  argv[1] = in;
  argv[2] = out;   argv[3] = '\0';
```

// see next slide

execvp() : An Example 2/2

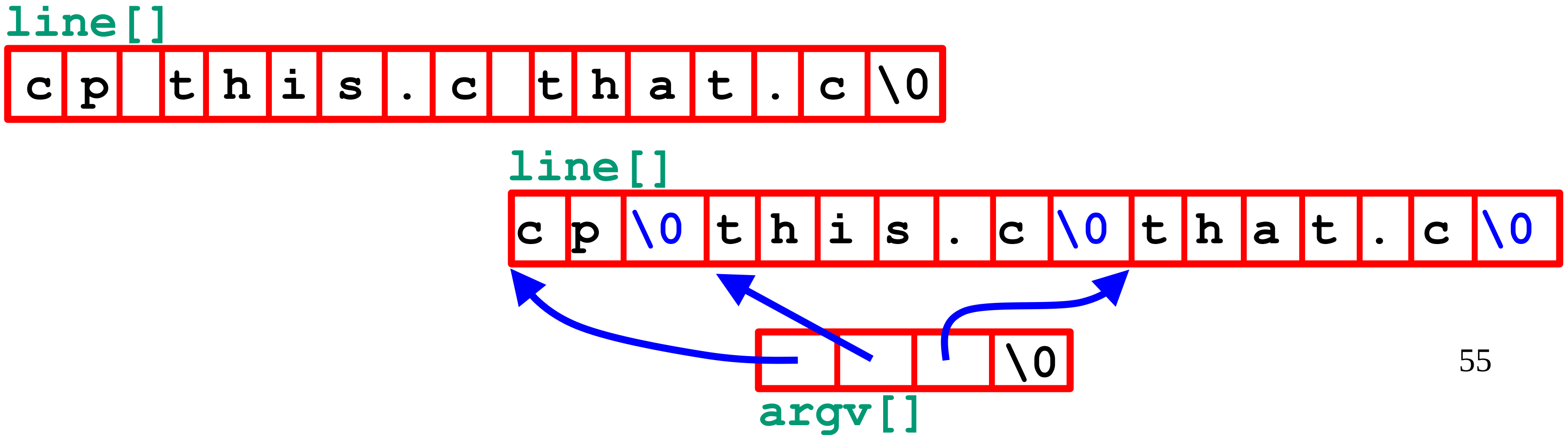
```
  if ((pid = fork()) < 0) {
       printf("fork() failed\n");
       exit(1);
    }
    else if (pid == 0)
       if (execvp(prog, argv) < 0) {
          printf("execvp() failed\n");
          exit(1);
       }
    else
       wait(&status);
}
```



execute program cp

A Mini-Shell: 1/3

```
void parse(char *line, char **argv)
{
   while (*line != '\0') { // not EOLN
      while (*line == ' ' || *line == '\t' || *line == '\n')
         *line++ = '\0';    // replace white spaces with 0
      *argv++ = line;       // save the argument position
      while (*line != '\0' && *line ! =' '
                            && *line!='\t' && *line != '\n')
         line++;            // skip the argument until ...
   }
   *argv = '\0';            // mark the end of argument list
}
```


line[]
c p t h i s . c t h a t . c \0
line[]
c p \0 t h i s . c \0 t h a t . c \0
\0
argv[]

A Mini-Shell: 2/3

```
void execute(char **argv)
{
   pid_t pid;
   int status;
   if ((pid = fork()) < 0) { // fork a child process
      printf("*** ERROR: forking child process failed\n");
      exit(1);
   }
   else if (pid == 0) {        // for the child process:
      if (execvp(*argv, argv) < 0) { // execute the command
         printf("*** ERROR: exec failed\n");
         exit(1);
      }
   }
   else {                      // for the parent:
      while (wait(&status) != pid) // wait for completion
         ;
   }
}
```

A Mini-Shell: 3/3

```
void main(void)
{
   char line[1024];   // the input line
   char *argv[64];    // the command line argument

   while (1) {        // repeat until done ....
      printf("Shell -> "); // display a prompt
      gets(line);     // read in the command line
      printf("\n");
      parse(line, argv);   // parse the line
      if (strcmp(argv[0], "exit") == 0) // is it an "exit"?
         exit(0);     // exit if it is
      execute(argv); // otherwise, execute the command
   }
}
```

Don't forget that `gets()` is risky! Use `fgets()` instead.

What is Shared Memory?

- The parent and child processes are run in independent and separate address spaces. All processes, parent and children included, do not share anything.
- A shared memory segment is a piece of memory that can be allocated and attached to an address space. Only those processes that have this memory segment attached can have access to it.
- But, race conditions can occur!

Procedure for Using Shared Memory

- Find a **key**. Unix uses this key for identifying shared memory segments.
- Use `shmget()` to allocate a shared memory.
- Use `shmat()` to attach a shared memory to an address space.
- Use `shmdt()` to detach a shared memory from an address space.
- Use `shmctl()` to deallocate a shared memory.

Keys: 1/2

- To use shared memory, include the following:

```
#include  <sys/types.h>
#include  <sys/ipc.h>
#include  <sys/shm.h>
```

- A key is a value of type `key_t`. There are three ways to generate a key:
  - Do it yourself
  - Use function `ftok()`
  - Ask the system to provide a private key.

Keys: 2/2

- Do it yourself:

```
key_t     SomeKey;
SomeKey = 1234;
```

- Use `ftok()` to generate one for you:

```
key_t = ftok(char *path, int ID);
```

  - `path` is a path name (e.g., `"./"`)
  - `ID` is a small integer (e.g., `'a'`)
  - Function `ftok()` returns a key of type `key_t`:

```
SomeKey = ftok("./", 'x');
```

- Keys are global entities. If other processes know your key, they can access your shared memory.
- Ask the system to provide a private key with `IPC_PRIVATE`.

Ask for a Shared Memory: 1/4

- **Include the following:**

```
#include  <sys/types.h>
#include  <sys/ipc.h>
#include  <sys/shm.h>
```

- **Use `shmget()` to request a shared memory:**

```
shm_id = shmget(
         key_t  key,      /* identity key    */
         int    size,     /* memory size     */
         int    flag);    /* creation or use */
```

- **`shmget()` returns a shared memory ID.**
- **The flag means permission, which is either `IPC_CREAT | 0666` for creation or `0666` for use only, where `0xxx` is a Unix permission.**

Ask for a Shared Memory: 2/4

- **The following creates a shared memory of size `struct Data` with a private key `IPC_PRIVATE`. This is a creation (`IPC_CREAT`) with read and write permission (`0666`).**

```
struct Data { int a; double b; char x; };
int         ShmID;

ShmID = shmget(
            IPC_PRIVATE,  /* private key */
            sizeof(struct Data), /* size */
            IPC_CREAT | 0666);/* cr & rw */
```

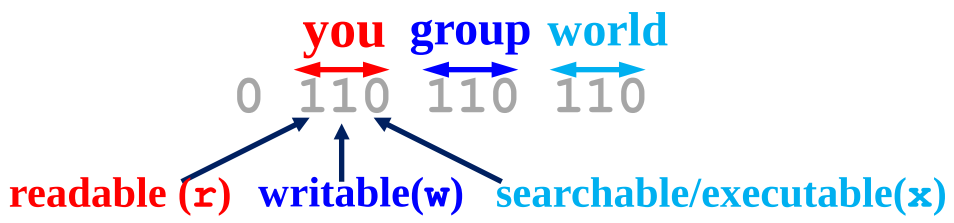
Ask for a Shared Memory: 3/4

- **The following creates a shared memory with a key based on the current directory:**

```
struct Data { int a; double b; char x;};
int     ShmID;
key_t   Key;

Key = ftok(“./”, ‘h’);
ShmID = shmget(
          Key,           /* a key */
          sizeof(struct Data),
          IPC_CREAT | 0666);
```

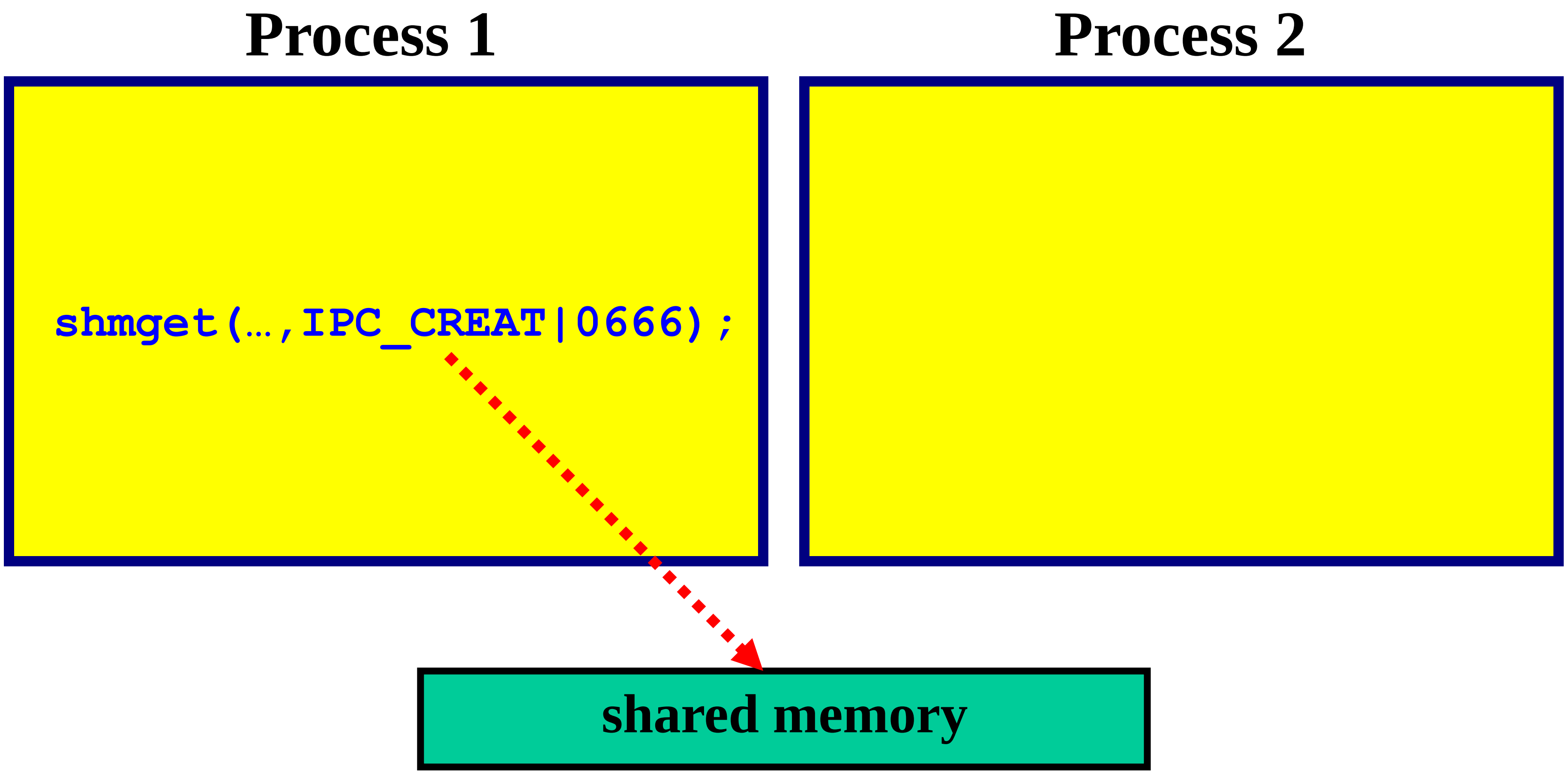
Ask for a Shared Memory: 4/4

- **When asking for a shared memory, the process that creates it uses `IPC_CREAT | 0666` and processes that access a created one use `0666`.**
- **`0666` is an octal number with a bit pattern**



- **If the return value is < 0 (Unix convention), the request was unsuccessful, and no shared memory is allocated.**
- **Create a shared memory before its use!**

After the Execution of shmget()



A shared memory is allocated; but is not part of the address space

Attaching a Shared Memory: 1/4

- Use `shmat()` to attach an existing shared memory to an address space:

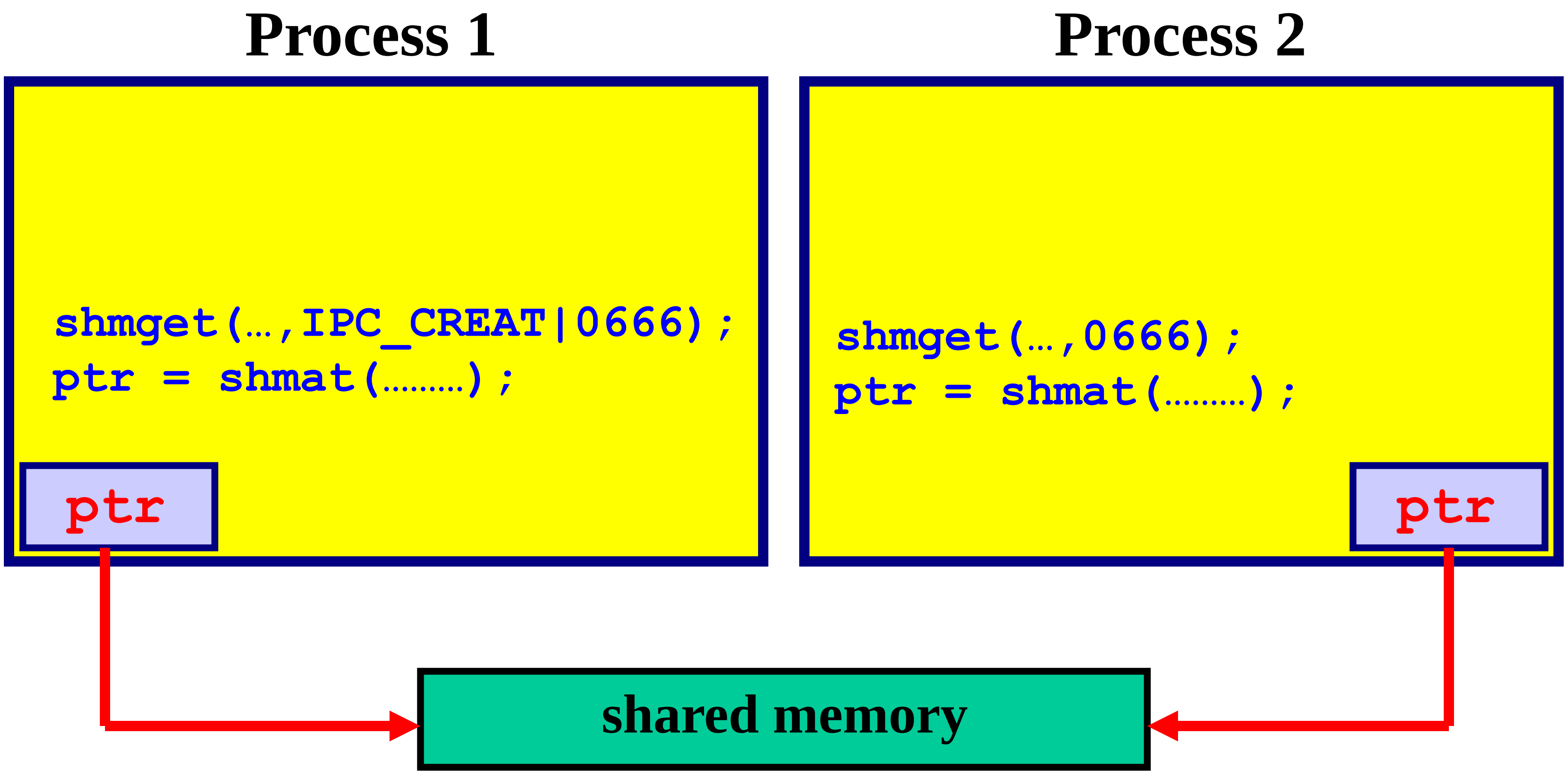
```
shm_ptr = shmat(
    int  shm_id, /* ID from shmget() */
    char *ptr,   /* use NULL here    */
    int  flag);  /* use 0 here       */
```

- `shm_id` is the shared memory ID returned by `shmget()`.
- Use `NULL` and `0` for the second and third arguments, respectively.
- `shmat()` returns a `void` pointer to the memory. If unsuccessful, it returns a negative integer.

Attaching a Shared Memory: 2/4

```
struct Data { int a; double b; char x;};
int     ShmID;
key_t   Key;
struct Data *p;

Key = ftok("./", 'h');
ShmID = shmget(Key, sizeof(struct Data),
               IPC_CREAT | 0666);
p = (struct Data *) shmat(ShmID, NULL, 0);
if ((int) p < 0) {
   printf("shmat() failed\n"); exit(1);
}
p->a = 1; p->b = 5.0; p->x = '.';
```

Attaching a Shared Memory: 3/4



```
shmget(…,IPC_CREAT|0666);
ptr = shmat(………);
```

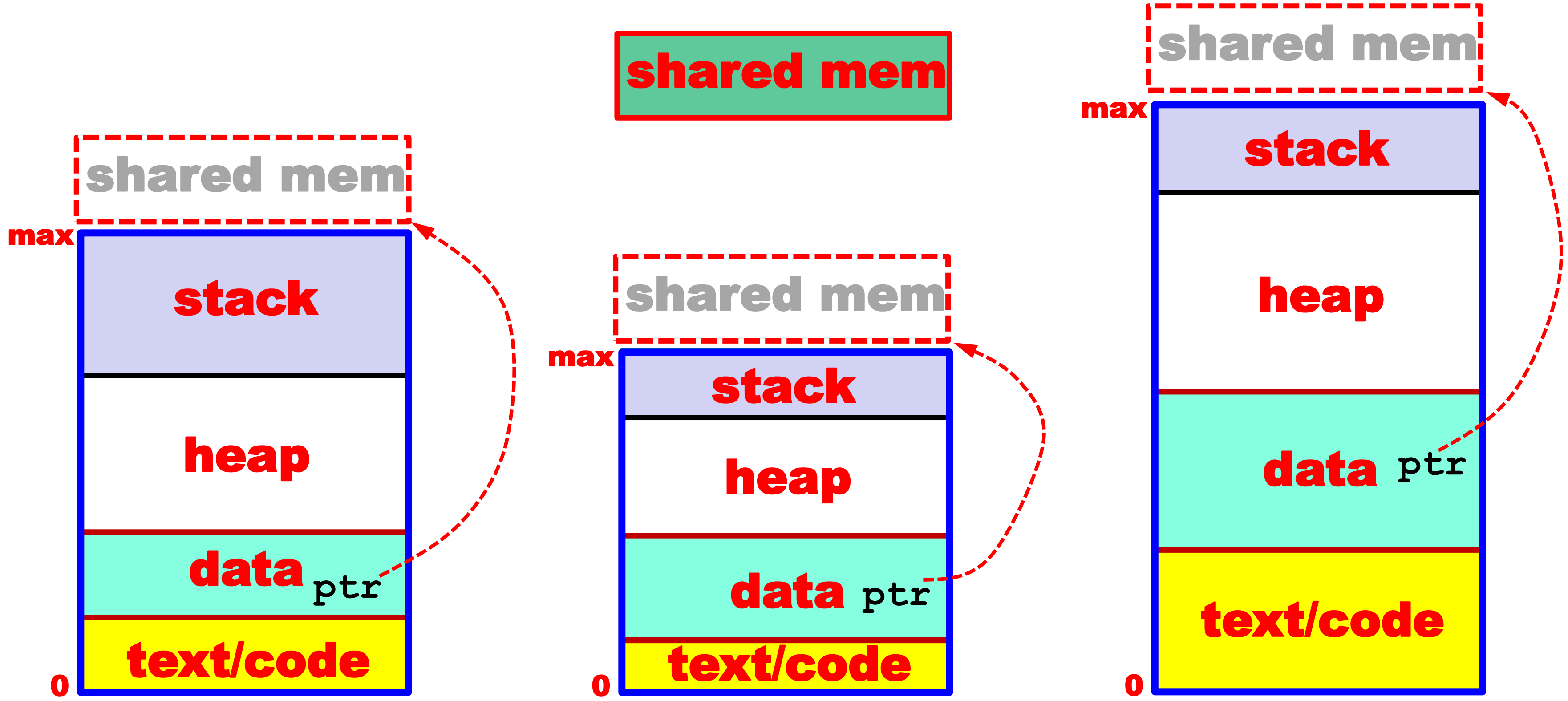
```
shmget(…,0666);
ptr = shmat(………);
```

Now processes can access the shared memory

Are the pointers returned to Process 1 and Process 2 the same?

Attaching a Shared Memory: 4/4

Are the pointers returned to the attaching processes the same?



Detaching/Removing Shared Memory

- To detach a shared memory, use

  ```
  shmdt(shm_ptr);
  ```

  `shm_ptr` is the pointer returned by `shmat()`.
- After a shared memory is detached, it is still there. You can attach and use it again.
- To remove a shared memory, use

  ```
  shmctl(shm_ID, IPC_RMID, NULL);
  ```

  `shm_ID` is the shared memory ID returned by `shmget()`. After a shared memory is removed, it no longer exists.

Communicating with a Child: 1/2

```
void main(int argc, char *argv[])
{
  int   ShmID, *ShmPTR, status;
  pid_t pid;

  ShmID = shmget(IPC_PRIVATE,4*sizeof(int),IPC_CREAT|0666);
  ShmPTR = (int *) shmat(ShmID, NULL, 0);
  ShmPTR[0] = getpid();        ShmPTR[1] = atoi(argv[1]);
  ShmPTR[2] = atoi(argv[2]);   ShmPTR[3] = atoi(argv[3]);
  if ((pid = fork()) == 0) {
     Child(ShmPTR);
     exit(0);
  }
  wait(&status);
  shmdt((void *) ShmPTR);  shmctl(ShmID, IPC_RMID, NULL);
  exit(0);
}
```

parent's process ID here

Communicating with a Child: 2/2

```
void Child(int  SharedMem[])
{
   printf("%d %d %d %d\n",  SharedMem[0],
          SharedMem[1], SharedMem[2], SharedMem[3]);
}
```

- **Why are `shmget()` and `shmat()` not needed in the child process?**

Communicating Among Separate Processes: 1/5

- Define the structure of a shared memory segment as follows:

```
#define  NOT_READY  (-1)
#define  FILLED     (0)
#define  TAKEN      (1)

struct Memory {
   int  status;
   int  data[4];
};
```

Communicating Among Separate Processes: 2/5

The "Server"

Prepare for a shared memory

```
int main(int argc, char *argv[])
{
   key_t            ShmKEY;
   int              ShmID, i;
   struct Memory    *ShmPTR;

   ShmKEY = ftok("./", 'x');
   ShmID = shmget(ShmKEY, sizeof(struct Memory),
                  IPC_CREAT | 0666);
   ShmPTR = (struct Memory *) shmat(ShmID, NULL, 0);
```

Communicating Among Separate Processes: 3/5

shared memory not ready

filling in data

```
   ShmPTR->status = NOT_READY;

   ShmPTR->data[0] = getpid();
   for (i = 1; i < 4; i++)
      ShmPTR->data[i] = atoi(argv[i]);

   ShmPTR->status = FILLED;
   while (ShmPTR->status != TAKEN)
      sleep(1);   /* sleep for 1 second */
   printf("My buddy is %ld\n", ShmPTR->data[0]);
   shmdt((void *) ShmPTR);
   shmctl(ShmID, IPC_RMID, NULL);
   exit(0);
}
```

wait until the data is taken

detach and remove shared memory

Communicating Among Separate Processes: 4/5

The "Client"

prepare for shared memory

```
int main(void)
{
   key_t          ShmKEY;
   int            ShmID;
   struct Memory  *ShmPTR;

   ShmKEY=ftok(“./”, ‘x’);
   ShmID = shmget(ShmKEY, sizeof(struct Memory), 0666);
   ShmPTR = (struct Memory *) shmat(ShmID, NULL, 0);
   while (ShmPTR->status != FILLED)
      ;
   printf(“%d %d %d %d\n”, ShmPTR->data[0],
      ShmPTR->data[1], ShmPTR->data[2], ShmPTR->data[3]);
   ShmPTR->data[0] = getpid();
   ShmPTR->status = TAKEN;
   shmdt((void *) ShmPTR);
   exit(0);
}
```

Communicating Among Separate Processes: 5/5

- The "server" must run first to prepare a shared memory.
- Run the server in one window, and run the client in another a little later.
- Or, run the server as a background process. Then, run the client in the foreground later:

```
server 1 3 5 &
client
```

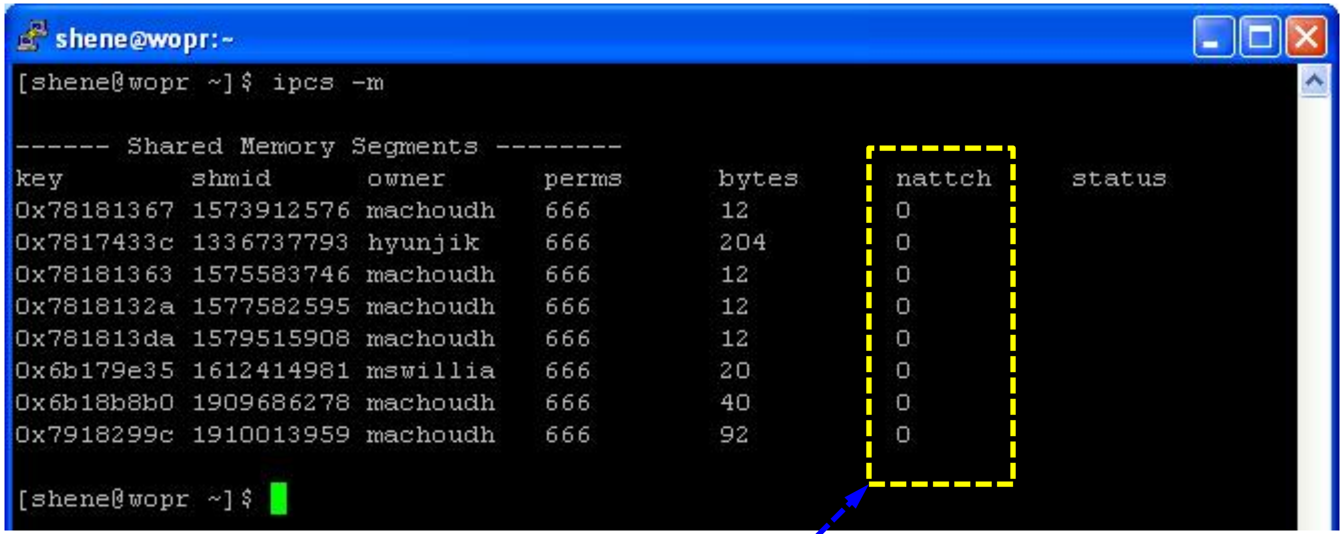
- This version uses busy waiting.
- One may use Unix semaphores for mutual exclusion.

Important Notes: 1/4

- If you do not remove your shared memory segments (e.g., program crashes before the execution of `shmctl()`), they will be in the system forever until the system is shut down. This will degrade the system performance.
- Use the `ipcs` command to check if you have shared memory segments left in the system.
- Use the `ipcrm` command to remove your shared memory segments.

Important Notes: 2/4

- Checking existing shared memory segments in the system, use `ipcs -m`, where `m` means shared memory.
- The following is a snapshot on `wopr`:



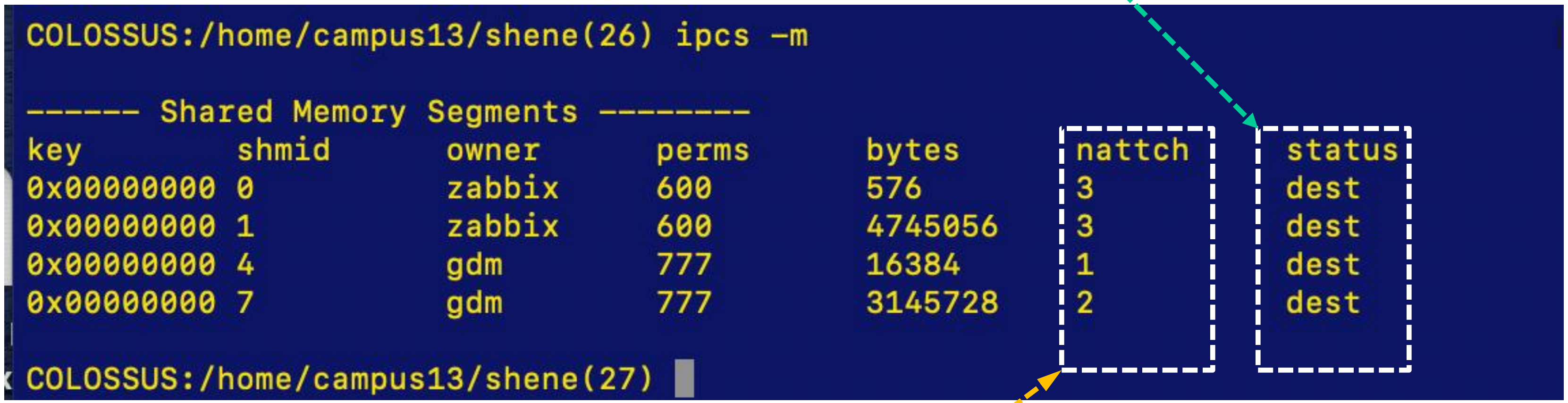
```
[shene@wopr ~]$ ipcs -m

------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      nattch     status
0x78181367 1573912576 machoudh   666        12         0
0x7817433c 1336737793 hyunjik    666        204        0
0x78181363 1575583746 machoudh   666        12         0
0x7818132a 1577582595 machoudh   666        12         0
0x781813da 1579515908 machoudh   666        12         0
0x6b179e35 1612414981 mswillia   666        20         0
0x6b18b8b0 1909686278 machoudh   666        40         0
0x7918299c 1910013959 machoudh   666        92         0

[shene@wopr ~]$
```

number of processes attached to a shared memory segment

Important Notes: 3/4

- Checking existing shared memory segments in the system, use `ipcs -m`, where `m` means shared memory.
- The following is a snapshot on `colossus`:

shared memory segment marked to be destroyed



```
COLOSSUS:/home/campus13/shene(26) ipcs -m

------ Shared Memory Segments --------
key        shmid      owner      perms      bytes      nattch     status
0x00000000 0          zabbix     600        576        3          dest
0x00000000 1          zabbix     600        4745056    3          dest
0x00000000 4          gdm        777        16384      1          dest
0x00000000 7          gdm        777        3145728    2          dest

COLOSSUS:/home/campus13/shene(27)
```

number of processes attached to a shared memory segment

Important Notes: 4/4

- To remove a shared memory, use the `ipcrm` command as follows:
  - `ipcrm -M` shm-key
  - `ipcrm -m` shm-ID
- You have to be the owner (or super user) to remove a shared memory.

The End