CS 370: OPERATING SYSTEMS [PROCESSES]

Computer Science
Colorado State University

Instructor: Louis-Noel Pouchet
Spring 2026

** Lecture slides created by: SHRIDEEP PALLICKARA

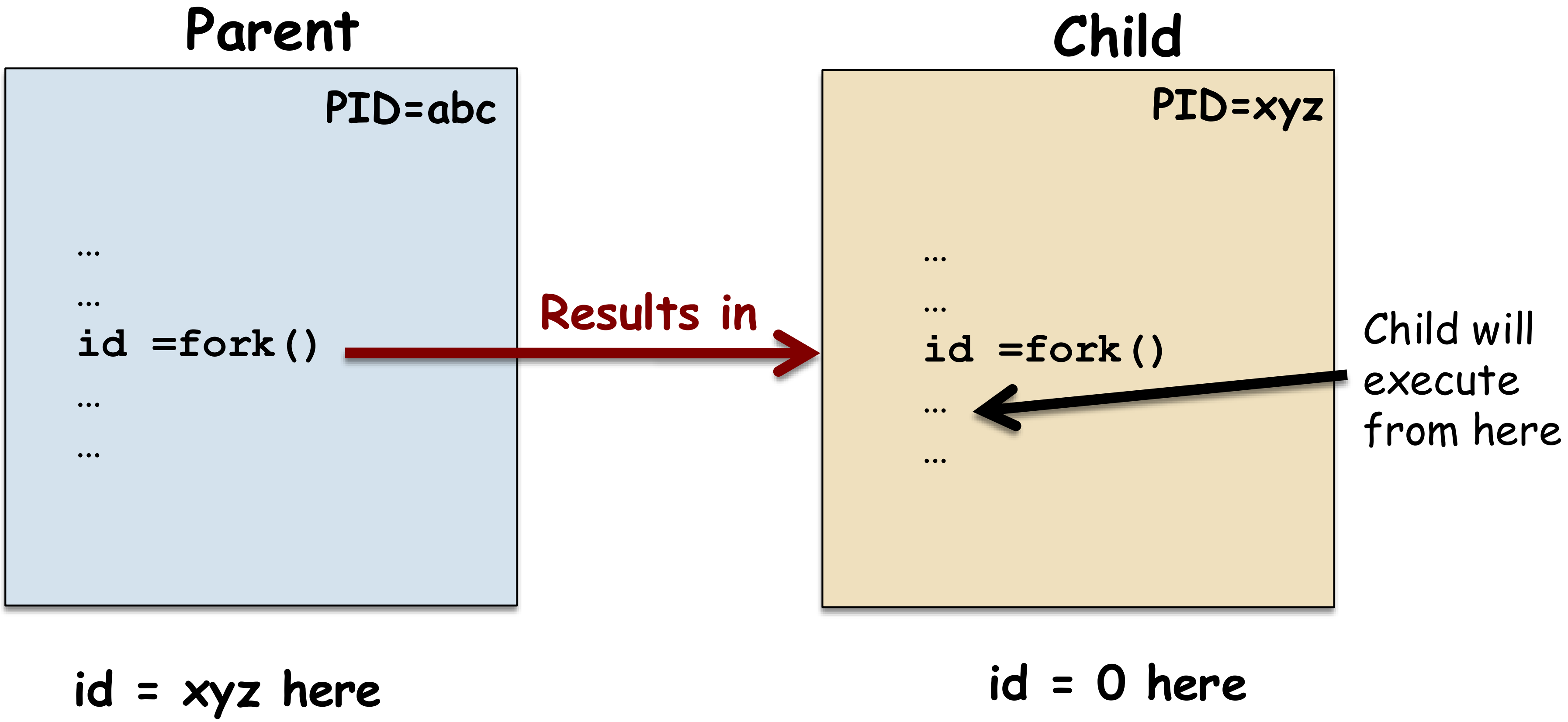
Topics covered in this lecture

- Operations on processes
  - Creation
  - Termination
- Process groups
- Buffer Overflows
  - One of the greatest security violations of all time

Fork()

All processes in UNIX are created using the fork() system call.

`fork()` results in the creation of 2 distinct processes



Parent

PID=abc

```
…
…
id =fork()
…
…
```

Results in

Child

PID=xyz

```
…
…
id =fork()
…
…
```

Child will execute from here

id = xyz here

id = 0 here

What happens when `fork()` fails?

- No child is created
- `fork()` returns **-1** and sets `errno`
  - `errno` is a global variable in `errno.h`

If a system is short on resources OR if limit on number of processes breached

- `fork()` sets `errno` to `EAGAIN`

- Some typical numbers for Solaris
  - `maxusers`: 2 less than number of MB of physical memory up to 1024
    - Set up to 2048 manually in `/etc/system` file
  - `mx_nprocs`: **Default:** `16 x maxusers + 10`
    min = 138, max = 30,000

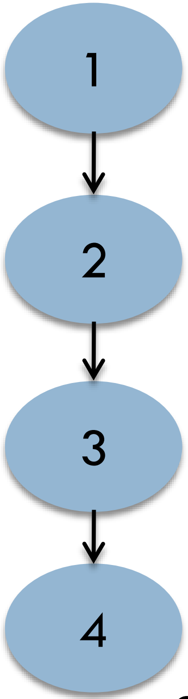
Take different paths depending on what happens with `fork()`

```
childpid = fork();
if (childpid == -1) {
    perror(“Failed to fork”);
    return 1;
}
if (childpid == 0) {
    ….. child specific processing
} else {
    ….. parent specific processing
}
```

Child (any process) can use **`getpid()`** to retrieve its process ID

Creating a chain of processes

```
for (int i=1; i < 4; i++) {
   if ((childid = fork())) {
       break;
   }
}
```



value of **i**
when process leaves loop

<u>For each iteration:</u>

Parent has non-ZERO childid

  So it breaks out

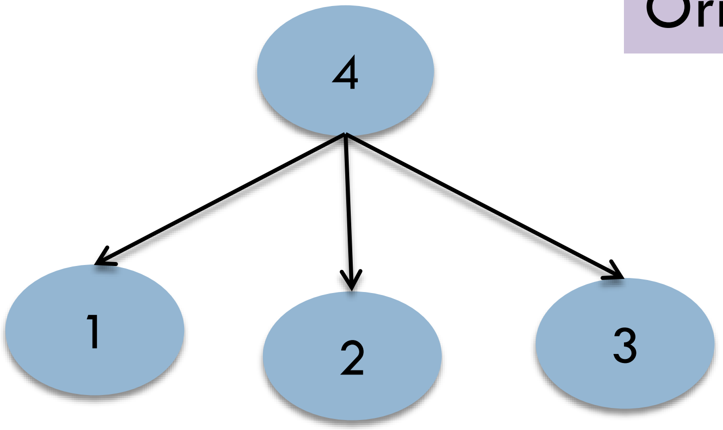
Child process

  Parent in NEXT iteration

Creating a process fan

```
for (int i=1; i < 4; i++) {
    if ((childid = fork()) == 0) {
         break;
    }
}
```

Newly created process breaks out
Original process continues

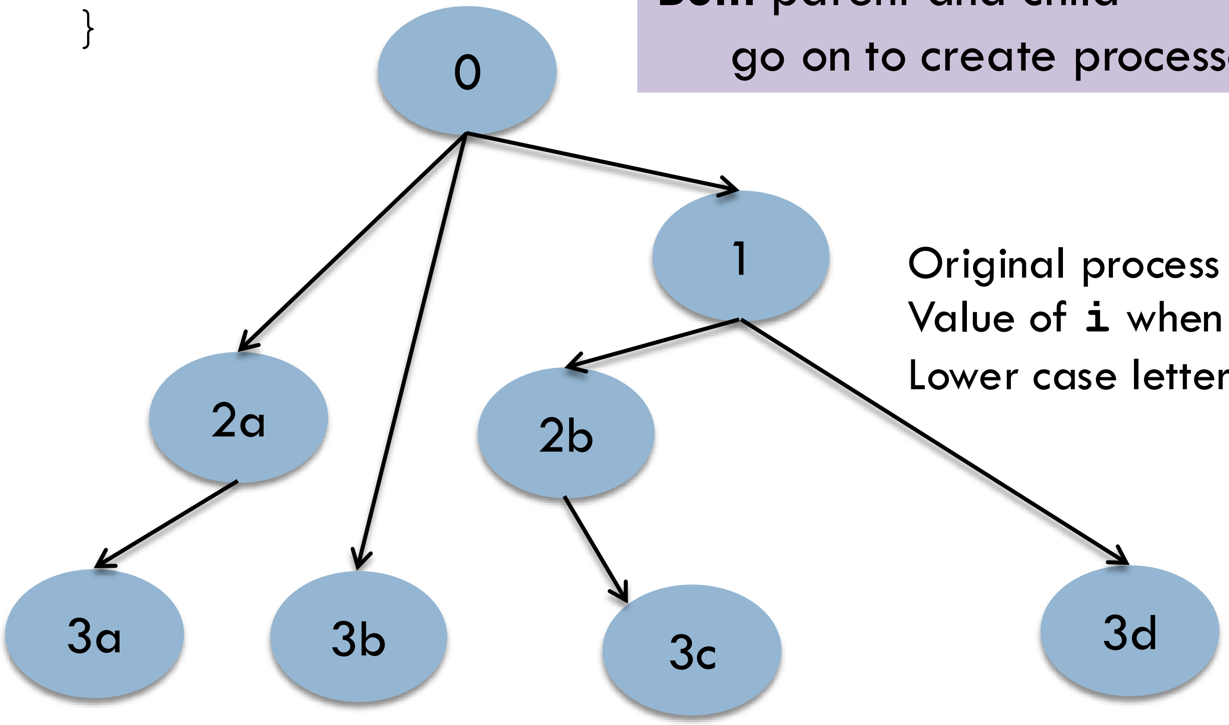


value of **i**
when process leaves loop

Creation of a process tree

```
int i=0;
for (i=1; i < 4; i++) {
   if ((childid = fork()) == -1) {
        break;
   }
}
```

Both parent and child go on to create processes in the next iteration



Original process has a **0** label
Value of **i** when created
Lower case letters: Process created with same **i**

Replacing a process's memory space with a new program

- □ Use `exec()` after the `fork()` in *one* of the two processes

- □ `exec()` does the following:
  1. **Destroys** memory image of program containing the call
  2. **Replaces** the invoking process's memory space with a new program
  3. Allows processes to go their **separate** ways

Replacing a process's memory space with a new program

- **TRADITION:**
  - Child executes **new** program
  - Parent executes **original** code

Launching programs using the shell is a two-step process

- Example: user types **`sort`** on the **shell**

① Shell `fork`s off a child process

② Child executes **`sort`**

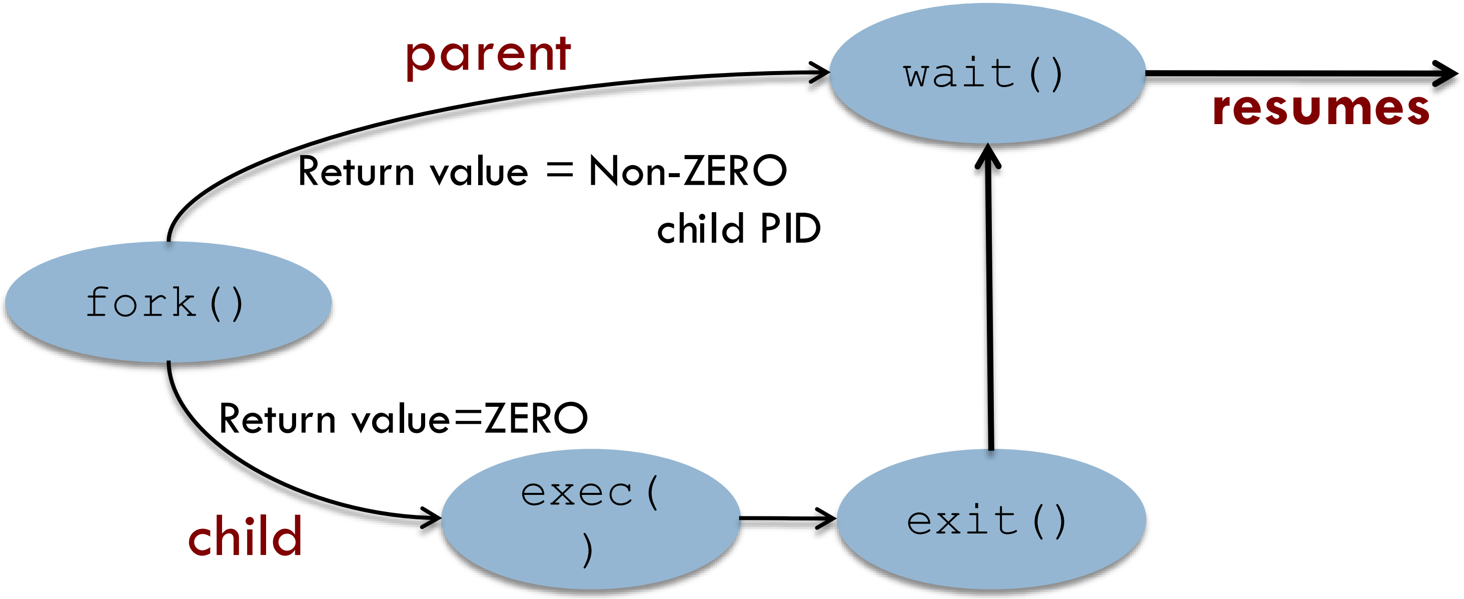
But why is this the case?

- Allows the child to manipulate its file descriptors
  - After the `fork()`
  - But before the `exec()`

- Accomplish **redirection** of standard input, standard output, and standard error

A parent can move itself from off the ready queue and await child's termination

- Done using the `wait()` system call.
- When child process completes, parent process resumes



`wait/waitpid` allows caller to suspend execution till a child's status is available

- Process status availability
  - Most commonly after termination
  - Also available if process is stopped

- `waitpid(pid, *stat_loc, options)`
  - `pid== -1` : any child
  - `pid > 0` : specific child
  - `pid == 0` : any child in the same **process group**
  - `pid < -1` :any child in process group abs(`pid`)

Process creation in Windows

□ `CreateProcess` handles

  ① Process creation

  ② Loading in a new program

□ Parent and child’s address spaces are **different** from the start

`CreateProcess` takes up to 10 parameters

- Program to be executed
- Command line parameters that feed program
- Security attributes
- Bits that control whether files are inherited
- Priority information
- Window to be created?

Process Management on Windows

- **WIN 32** has about 100 other functions
  - Managing & Synchronizing processes

PROCESS GROUPS

Process groups

- Process group is a *collection* of processes
- Each process has a **process group ID**
- Process group leader?
  - Process with `pid==pgid`
- **`kill`** treats negative `pid` as `pgid`
  - Sends signal to all constituent processes

Process Group IDs: When a child is created with `fork()`

① **Inherits** parent's process group ID

② **Parent can change** group ID of child by using `setpgid`

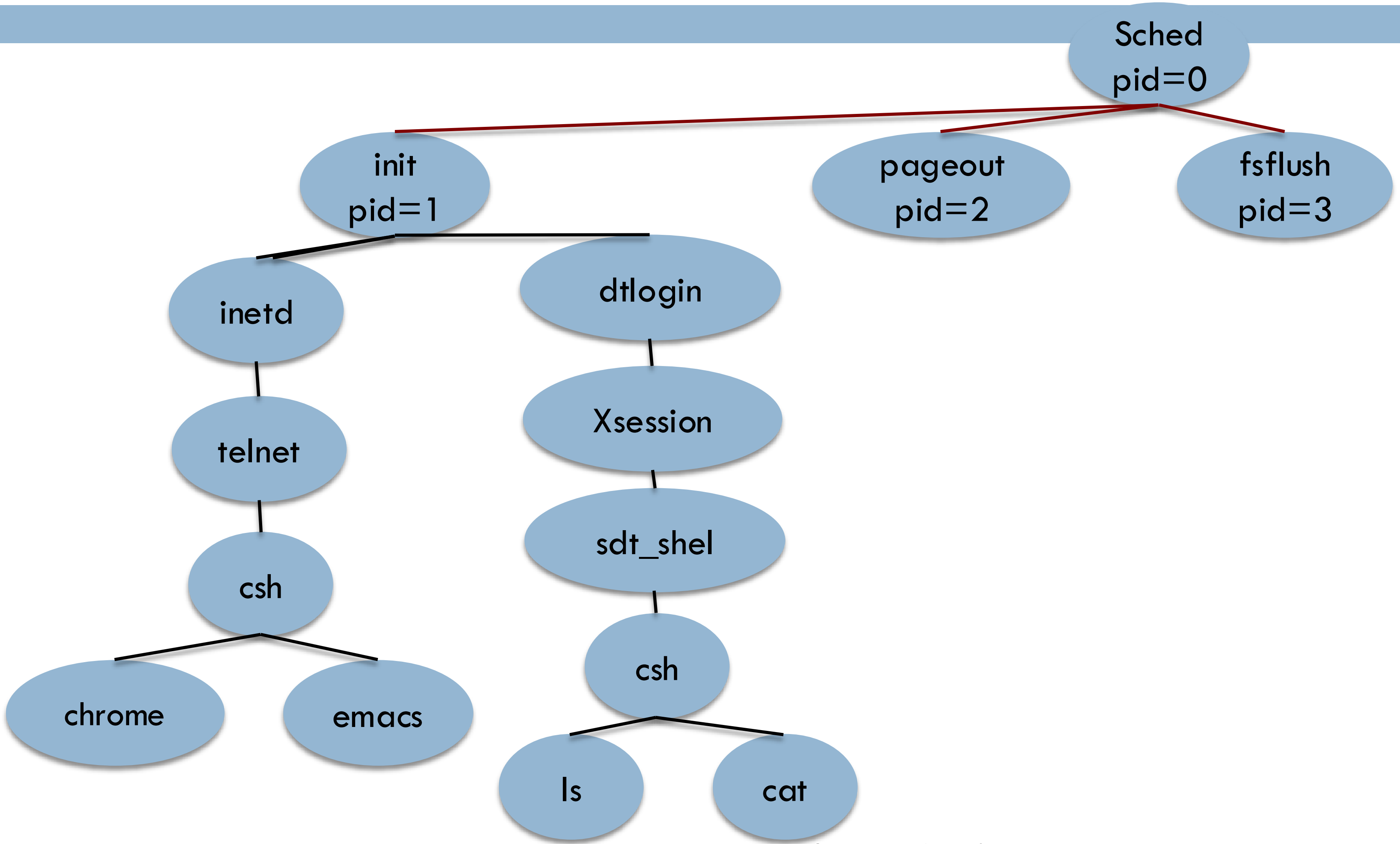
③ Child can **give itself** new process group ID

- Set process group ID = its process ID

Process groups

- It can contain processes which are:
  1. Parent (and further ancestors)
  2. Siblings
  3. Children (and further descendants)
- A process can <u>only</u> send **signals** to members of its process group

Example: Process tree in Solaris



Windows has no concept of a process hierarchy

- The only hint of a hierarchy?
  - When a process is created, parent is given a special *token* (called **handle**)
    - Use this to control the child

- However, parent is free to **pass** this token to some other process
  - **Invalidates** hierarchy

PROCESS TERMINATIONS

Process terminations

- Normal exit (voluntary)
  - E.g. successful compilation of a program
- Error exit (voluntary)
  - E.g. trying to compile a file that does not exist

Process terminations

- Fatal error (involuntary)
  - Program bug
    - Referencing non-existing memory, dividing by zero, etc

- Killed by another process (involuntary)
  - Execute system call telling OS to <u>kill some other</u> process
  - *Killer* must be authorized to do the *killing of the killee*
  - Unix: **`kill`** Win32: **`TerminateProcess`**

Process terminations:
This can be either normal or abnormal

- OS **deallocates** the process resources
    - Cancel pending timers and signals
    - Release virtual memory resources and locks
    - Close any open files
- Updates statistics
    - Process status and resource usage
- Notifies parent in response to a `wait()`

On termination a UNIX process DOES NOT fully release resources until a parent execute a wait() for it

- When the parent is not waiting when the child terminates?
  - The process becomes a **zombie**
- Zombie is an *inactive* process
  - Still has an entry in the process table
  - But is already dead, so cannot be killed easily!! ☺
- Zombie processes often come from error in programming: not properly waiting on all children created, changing the parent while children still active, etc.

Zombies and termination

- When a process terminates, its *orphaned* children and are *adopted* by a special process
  - This special system process is **`init`**

- Some more about the special process **`init`**
  1. Has a `pid` of 1
  2. Periodically executes wait() for children
  3. Children without a parent are adopted by init
     - Zombie processes are adopted by init after killing their parent, then cleaned by the periodic wait()

Normal termination of processes

- Return from `main`
- Implicit return from `main`
  - Function **falls off the end**
- Call to `exit`, `_Exit` or `_exit`

The C `exit` function

- Call user-defined exit handlers that were registered by the `atexit`
    - Invocation is in reverse order of registration
    - Execute the function pointed by func when process terminates

```
#include <stdlib.h>

int atexit(void (*func)())
```

Other things that the `exit` function does

- **Flushes** any open streams that have unwritten buffered data
- **Closes** all open streams
- **Remove** all temporary files
  - Created by `tmpfile()`

More info about the `exit` functions

- `_Exit` and `_exit` do not call user-defined exit handlers
  - POSIX does not specify what happens
- All functions (`exit`, `_Exit` and `_exit`) take a parameter: **`status`**
  - Indicates termination status of program
  - **0** is a **successful** termination
  - **Non-ZERO** values: Programmer defined **errors**

Abnormal termination

- Call `abort`
- Process signal that causes termination
  - Generated by an external event: keyboard `Ctrl-C`
  - Internal errors: Access illegal memory location
- Consequences
  - Core dump
  - User-installed exit handler not called

PROTECTION & SECURITY

Protection and Security

- Control access to system resources
  - Improve reliability
- Defend against use (misuse) by unauthorized or incompetent users
- Examples
  - Ensure process executes within its own space
  - Force processes to relinquish control of CPU
  - Device-control registers accessible only to the OS

Buffer overflows:

- When? Program copies data into variable for which it **has not allocated enough space**

```
char buf[80];
printf(“Enter your first name:”);
scanf(“%s”, buf);
```

If user enters string > 79 bytes ?

- The string AND string terminator do not fit.

Buffer Overflows: Fixing the example problem

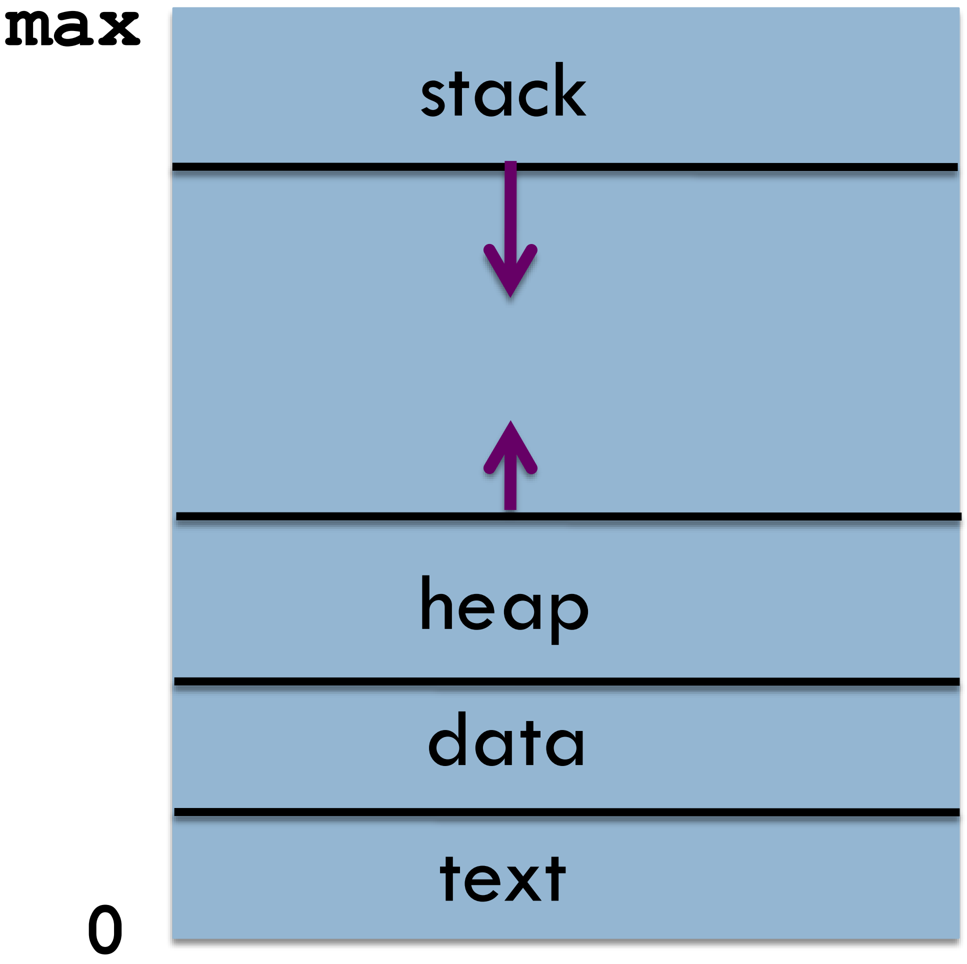
```
char buf[80];
printf(“Enter your first name:”);
scanf(“79%s”, buf);
```

Program now reads at most 79 characters into `buf`

Automatic variables (local variables)

- Allocated/deallocated automatically when program flow enters or leaves the variable’s scope
- Allocated on the program stack
- Stack grows from high-memory to low-memory

A process in memory



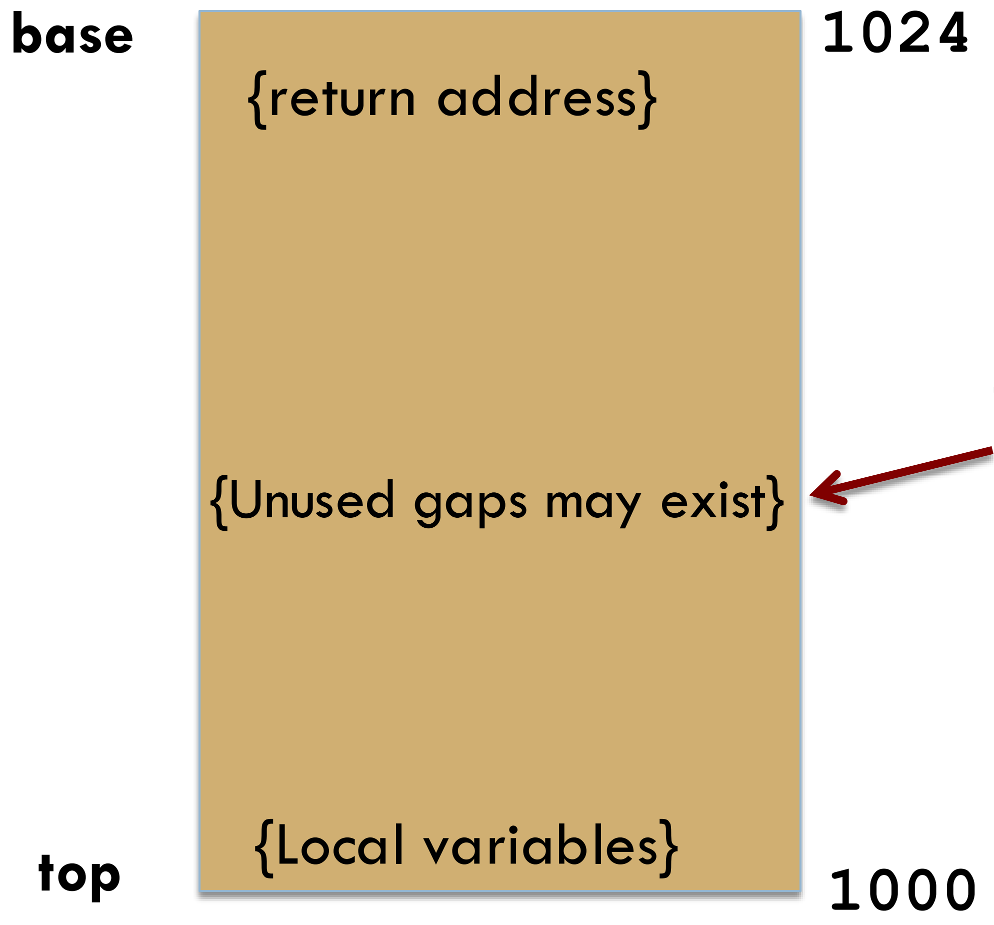
{Function parameters,
return addresses,
and local variables}

{Memory allocated dynamically during runtimes}

{Global variables}

{Program code}

A rough anatomy of the program stack

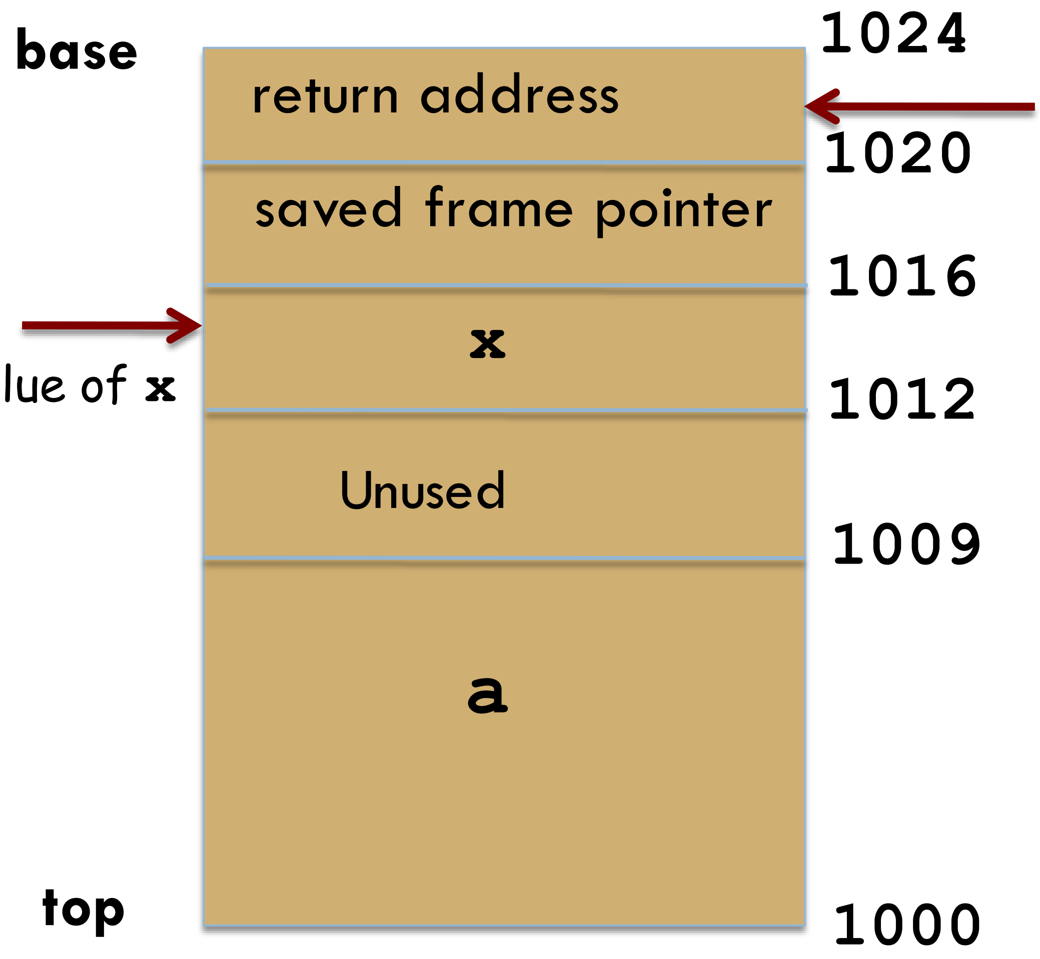


To align things on the word boundary

A function that checks password: Susceptible to buffer overflow

```
int checkpass(void) {
  int x;
  char a[9];
  x =0;
  printf(“Enter a short word: ”);
  scanf(“%s”, a);
  if (strcmp(a, “mypass”) == 0)
     x =1;
  return x;
}
```

Stack layout for our unsafe function



Overflow can change the value of **x**

A long password may overwrite this too

Problems with buffer overflow

- Function will try to return to address space **outside** the program
  - Segmentation fault or core dump
  - Programs may lose unsaved data
  - In the OS, such a function can cause the OS to crash!

One of the greatest security violations of all time: November 2, 1988

- Exploited 2 bugs in Berkeley UNIX
- Worm: Self replication program
- Bought down most of the Sun and VAX systems on the internet within a *few hours*

Worm had two programs

① Bootstrap (99 lines of C, `l1.c`)

② Worm proper

□ Both these programs compiled and executed on the system under attack

Synopsis of the worm's modus operandi

① Spread the bootstrap to machines

② Once the bootstrap runs:

- Connects back to its origins
- Download worm proper
- Execute worm

③ Worm then attempts to spread bootstrap

Infecting new machines: Method 1 & 2
Violate trust

- Method 1: Run the remote shell `rsh`
  - Machines used to trust each other, and would willingly run it
  - Use this to upload the worm
- Method 2: `sendmail`

Method 3: Buffer overflow in the `finger` daemon (finger name@site)

- **`finger`** daemon runs all the time on sites, and responds to queries
- The worm called **`finger`** with a handcrafted 536-byte string as a parameter.
  - Overflowed daemon's buffer & overwrote its stack
- Daemon did not return to `main()`, but to a procedure in the 536-bit string on stack
- Next try to get a shell by executing `/bin/sh`

Far too many worms can grind things to a halt

- Break user passwords
- Check for copies of worm on machine
  - Exit if there is a copy 6 out of 7 times
    - This is in place to cope with a situation where sys admin starts fake worm to fool the real one
- Use of 1 in 7 caused far too worms
  - Machines ground to a halt

Consequences

- $10K fine, 3 years probation and 400 hours community service
- Legal costs $150,000

The contents of the slide-set are based on the following references

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 3]
- *Andrew S Tanenbaum. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620* [Chapter 2]
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2.* [Chapters 2 & 3]
- *CS 451: Operating Systems (Colorado State University)* Help Session 2B*: Forking in C by Rink Dewri. Feb 1, 2010. Spring 2010: Instructor: Shrideep Pallickara, GTA: Rinku Dewri*