

CSCI 4061: Processes and Environment

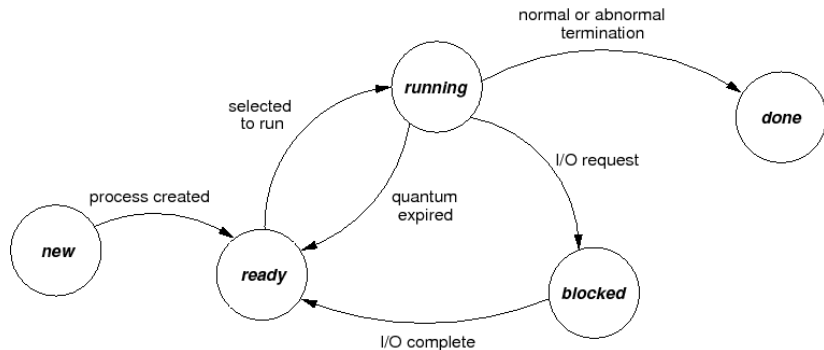
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Process: A “Running” Program

- ▶ Most OS's provide a **Process** abstraction
- ▶ Hardware like the CPU just sees a stream of instructions, bits stored, bytes on disk
- ▶ OS presents notion of
 - ▶ “These instructions are for this running program”
 - ▶ “This running program owns this part of memory”
 - ▶ “This file was opened by this running program”
- ▶ One stored program can create many Processes
- ▶ OS is responsible for managing the lives of Processes with fairness and security

Process Life Cycle



Source: Saverio Perugini, lecture notes

- ▶ **Processes** (running programs) can be in one of several states
- ▶ OS tracks these states and manages transitions between them
- ▶ OS uses some internal data structure to track process state, can report states via utilities like `top` and `ps`

ps and top show running process status

These shell commands show a STAT or S columns corresponding loosely to process states.

STAT	Meaning
<i>Common</i>	
R	running or runnable (on run queue)
S	interruptible sleep (waiting for an event to complete)
T	stopped, either by a job control signal or being traced.
Z	defunct ("zombie") process, terminated but not reaped by parent.
I	idle (kernel process/thread only)
<i>Less Common</i>	
D	uninterruptible sleep (usually IO)
W	paging (not valid since the 2.6.xx kernel)
X	dead (should never be seen)

Source: man page for ps

We'll continue to discuss Specifics of Zombines and Orphans



Handy Commands

- ▶ `top`: interactively observe top running processes, usually sorted by CPU usage
- ▶ `ps`: snapshot of running processes filtered on various criteria
- ▶ `watch`: repeatedly run a command showing its output on the screen

Interactively observe all processes sorting by top CPU usage

```
> top
```

press q to quit

Watch processes with command name yes refreshing every 0.1 seconds showing u-ser relevant information on the processes

```
> watch -n 0.1 'ps u -C yes'
```

Press `Ctrl-c` to end the watch

Terminal: Foreground/Background Processes

- ▶ Type a program into the terminal, press enter
- ▶ Starts a process in the **foreground** of the terminal
 - ▶ Input from user typing, output to terminal screen
- ▶ Jobs can be run in the **background** as well
 - ▶ Usually input must come from somewhere aside from user typing, output should go into a file or it will pollute the terminal

Key/Cmd	Effect
Ctrl-z	Stop/Suspend foreground process, gets prompt back
Ctrl-c	Terminate foreground process (usually)
ls &	Run program in background, gets prompt immediately
bg %2	Moves stopped Job 2 to background and continues it
fg %4	Moves background Job 4 to foreground
jobs	List jobs under the control of the terminal
kill %3	End job 3 nicely
kill -9 %3	End job 3 unequivocally

Exercise: Basic Job Control

Give a sequence of commands / keystrokes to...

Misbehaving

- ▶ Compile `no_interruptions.c` to a program named `invincible`
- ▶ Run `invincible`
- ▶ Try to end the process by sending it the interrupt signal
- ▶ In a separate terminal, end the `invincible` program

Edit / Build Seq

- ▶ Edit a source file like `collatz_funcs.c` with `vi` 🤢
- ▶ Suspend `vi` (don't quit it)
- ▶ Re-build program and run automated tests
- ▶ Terminate before completing tests
- ▶ Bring back `vi` to edit codes

Murdering Processes

Keystrokes to Remember

Ctrl-c Send the interrupt signal, kills most processes

Ctrl-z Send the stop signal, puts process to sleep

Easy to Kill

- ▶ yes spits output to the screen continuously
- ▶ End it from the terminal it started in
- ▶ Suspend it then, end it
- ▶ Kill it from a different terminal

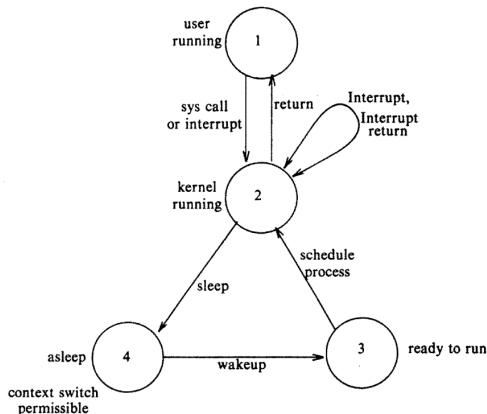
Harder to Kill

- ▶ Consider the program `no_interruptions.c`
- ▶ Ignores some common signals
- ▶ Need to use the big stick for this one:

```
kill -9 1234      OR  
pkill -9 a.out
```


States of a Living Process

- ▶ Note inclusion of Kernel/OS here
- ▶ **Interrupt and Sys Calls** start running code in the operating system
- ▶ Interrupt/Signal can come from software or hardware
- ▶ **Context switch** starts running another process, only happens when one process is safely tucked in and put to **sleep**



Source: *Design of the Unix Operating System* by Maurice Bach

Recall: Program Memory

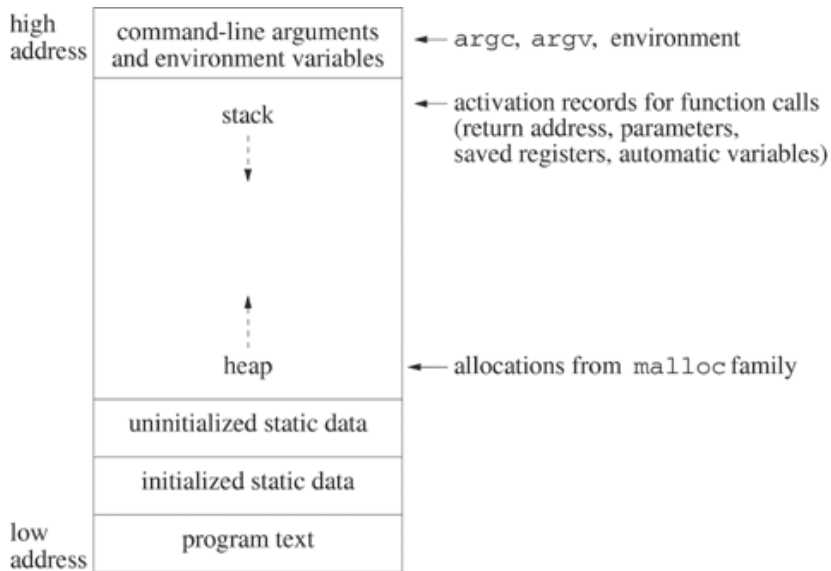
- ▶ What are the 4 memory areas to a C program we've discussed OR that you know from previous courses?
- ▶ Give an example of how one creates variables/values in each area of memory

Answers: Program Memory

- ▶ What are the 4 memory areas to a C program we've discussed OR that you know from previous courses?
 1. Stack: automatic, push/pop with function calls
 2. Heap: malloc() and free()
 3. Global: variables outside functions, static vars
 4. Text: Assembly instructions
- ▶ Give an example of how one creates variables/values in each area of memory

```
1  #include <stdlib.h>
2  int glob1 = 2;           // global var
3  int func(int *a){        // param stack var
4      int b = 2 * (*a);    // local stack var
5      return b;           // de-allocate locals in func()
6  }
7  int main(){              // main entry point
8      int x = 5;           // local stack var
9      int c = func(&x);    // local stack var
10     int *p = malloc(sizeof(int)); // local stack var that points into heap
11     *p = 10;              // modify heap memory
12     glob1 = func(p);      // allocate func() locals and run code
13     free(p);              // deallocate heap mem pointed to p
14     return 0;            // deallocate locals in main()
15 }
16 // all executable code is in the .text memory area as assembly instructions
```

More Detailed Process Memory

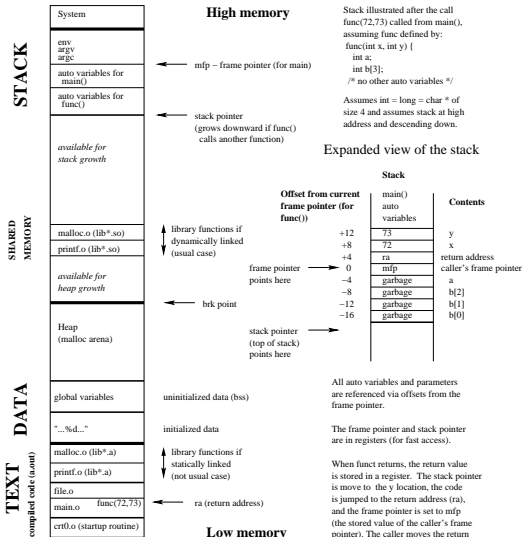


Source: *Unix Systems Programming, Robbins & Robbins*

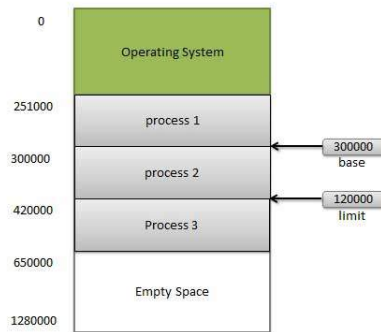
Yet *more* detailed view ([Link](#))

A detailed picture of the virtual memory image, by [Wolf Holzman](#)

Memory Layout (Virtual address space of a C process)



Unix Processes In Memory



Source: Tutorials Point

- ▶ Separate Memory Image for Each Process
- ▶ OS + Hardware keeps processes inside their own address space
- ▶ Consequence for program dynamic memory allocation?
- ▶ Problems with running system calls?

This picture should bother you

Shows a gross simplification but will suffice until later when we discuss **Virtual Memory** system which is maintained by the OS

Exercise: Memory Problems in C Programs

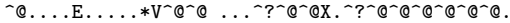
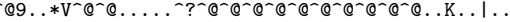
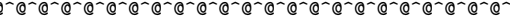
What you're up against

- ▶ Stack problems: References to stack variables that go away
- ▶ Segmentation Faults: Access memory out of bounds for whole program, via heap or via stack
- ▶ Null pointers dereference: Often results in a segfault as NULL translates to address 0x0000 which is off limits
- ▶ Use of uninitialized: variables don't have values by default, assign or get something random
- ▶ Memory Leaks: `malloc()` memory that is not used but never `free()`'d, program gobbles more and more memory
- ▶ Examine results of running `overflow.c`, **EXPLAIN OUTPUT**

Solutions

- ▶ Don't program in C
- ▶ Use a tool to help identify and fix problems
- ▶ **Valgrind** → FREE for Linux Programs

Code for overflow.c

```
1 // overflow.c: program traverses memory that it really ought not to by
2 // walking off the end of an array into parts unknown.
3
4 #include <stdio.h>
5 int main(int argc, char *argv[]){
6     char a[3] = {'A','B','C'};
7     int i = 0;
8     while(1){
9         printf("%c",a[i]);
10        i++;
11        if(i%40 == 0){
12            printf("\n");
13        }
14    }
15    return 0;
16 }
17
18 // ## COMPILE AND RUN
19 // > gcc overflow.c
20 // > ./a.out
21 // ABC..
22 // 
23 // 
24 // .....M.....
```


Valgrind: Memory Tool on Linux and Mac

- ▶ Valgrind catches most memory errors
 - ▶ Use of uninitialized memory
 - ▶ Reading/writing memory after it has been free'd
 - ▶ Reading/writing off the end of malloc'd blocks
 - ▶ Memory leaks
- ▶ Source line of problem happened (but not cause)
- ▶ Super easy to use, installed on lab machines
- ▶ Slows execution of program way down
- ▶ Usually install on Linux via

```
> sudo apt install valgrind
```



```
> gcc -g badmemory.c
> ./a.out
-714833203
0
1
4
9
16
0
1
...
5
6
7
8
Segmentation fault (core dumped)
# what now??
```

Valgrind on Common Problems in badmemory.c

```
> valgrind ./a.out
==2913308== Memcheck, a memory error detector
==2913308== Copyright (C) 2002-2017, and GNU GPL'd, by Julian Seward et al.
==2913308== Using Valgrind-3.15.0 and LibVEX; rerun with -h for copyright info
==2913308== Command: ./a.out
==2913308==
==2913308== Conditional jump or move depends on uninitialised value(s)
==2913308==    at 0x109189: main (badmemory.c:6)
==2913308==
0
1
4
9
==2913308== Invalid write of size 4
==2913308==    at 0x1091D2: main (badmemory.c:11)
==2913308==    Address 0x4a43050 is 0 bytes after a block of size 16 alloc'd
==2913308==    at 0x483877F: malloc (vg_replace_malloc.c:309)
==2913308==    by 0x1091AA: main (badmemory.c:9)
...
8
==2913308== Invalid read of size 4
==2913308==    at 0x10924E: main (badmemory.c:20)
==2913308==    Address 0x0 is not stack'd, malloc'd or (recently) free'd
==2913308== Process terminating with default action of signal 11 (SIGSEGV):
==2913308== dumping core
```

Debuggers

- ▶ There comes a day when `printf` just isn't enough
- ▶ On that day you will start compiling with `-g` to turn on the debugger
- ▶ Then you will run `gdb myprog`, set some breakpoints, and get to the root of the problem
- ▶ Debuggers are covered in earlier CSCI courses (like CSCI 2021); refer to those materials to review / refresh
<https://www-users.cs.umn.edu/~kauffman/2021/gdb>

Communicating Information to Programs

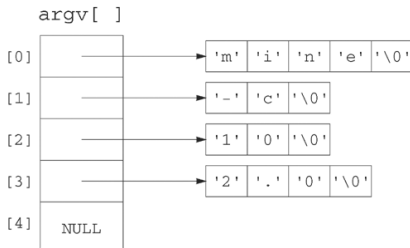
- ▶ Often programs need info from the outside world
 - ▶ What file to read/write, # of iterations to run, verbose/quiet output, report immediately, shutdown gracefully etc.
- ▶ A variety of mechanisms exist to convey such info to a program
 1. Command Line Arguments
 2. Environment Variables
 3. Signals
 4. Input/Output system calls and libraries
- ▶ Will now discuss 1 & 2 which are often used at program startup
- ▶ Alluded to Signals (#3) earlier (SIGKILL, SIGSTOP); Will discuss Signals in more detail later
- ▶ I/O calls (#4) will come soon (next lecture)

Exercise: Command Line Arguments

```
int main(int argc, char *argv[])
```

2-arg version of main() will be set up to have number of arguments and array of strings in it by whatever started it

```
> cat print13.c
#include <stdio.h>
int main(int argc, char *argv[]){
    printf("%s\n",argv[1]);
    printf("%s\n",argv[3]);
}
> gcc -o mine print13.c
> ./mine -c 10 2.0
-c
2.0
```



argc is 4 in this case

Print Args

Write a quick C program which prints **ALL** of its argv elements as strings. Print a special message if an arg is string --verbose

Answers: Command Line Arguments

File: 04-process-environment-code/print_args.c

```
1 // Print all the arguments in the argv array. Prints a special message
2 // if option is --verbose.
3
4 #include <stdio.h>
5 #include <string.h>
6
7 int main(int argc, char *argv[]){
8     printf("%d args received\n",argc);
9     for(int i=0; i<argc; i++){
10         printf("%d: %s\n",i,argv[i]);
11         if( strcmp(argv[i],"--verbose") == 0){
12             printf("Turning on VERBOSE output\n");
13         }
14     }
15     return 0;
16 }
```

Environment Variables

All programs can access **environment** variables, name/value pairs used to communicate and alter behavior.

Shell show/set variables

Done with echo \$VARNAME

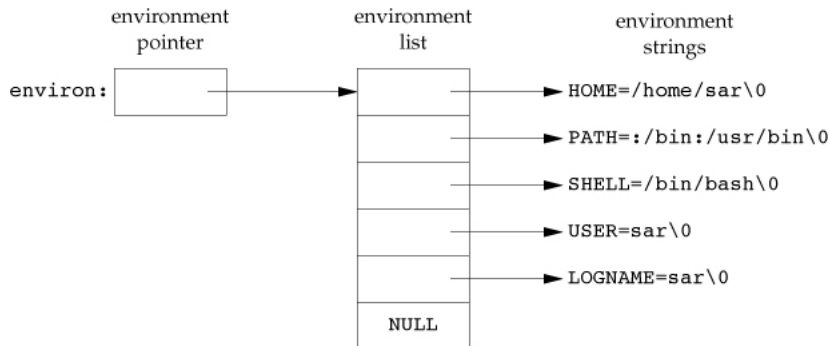
```
> echo $PAGER
less
> PAGER=cat
> echo $PAGER
cat
> echo "$PS1"
'>'
> PS1='wicked$ '
wicked$
> export x=1234    # in env
> y=5678           # not
```

Shell env

Show *all* environment

```
> env
JAVA8_HOME=/usr/lib/jvm/java-8-openjdk
PAGER=less
PWD=/home/kauffman/4061-F2017/lectures/04-processes
HOME=/home/kauffman
BROWSER=chromium
COLUMNS=79
MAIL=/var/spool/mail/kauffman
MANPATH=:/home/kauffman/local/man:/home/kauffman
PATH=/usr/local/sbin:/usr/local/bin:/usr/bin:/usr
PS1=>
x=1234
...
```

C Programs and Environment Vars



- ▶ Global variable `char **environ` provides array of environment variables in form `VARNAME=VALUE`, null terminated
- ▶ NOT suggested to use `environ` directly,
- ▶ Instead use library functions `getenv()` / `setenv()` to check/change

C Library for Environment Vars

The C Library Provides standard library functions for manipulating environment variables.

```
#include <stdlib.h>

char *getenv(const char *name);
// returns pointer to value associated with name, NULL if not found

int setenv(const char *name, const char *value, int rewrite);
// sets name to value. If name already exists in the environment, then
// (a) if rewrite is nonzero, the existing definition for name is
// first removed; or (b) if rewrite is 0, an existing definition for
// name is not removed, name is not set to the new value, and no error
// occurs. return: 0 if OK, -1 on error

int unsetenv(const char *name);
// removes any definition of name. It is not an error if such a
// definition does not exist. return: 0 if OK, -1 on error

int putenv(char *str);
// str is of form NAME=VALUE, alters environment accordingly. If name
// already exists, its old definition is first removed. Don't use with
// stack strings. Returns: 0 if OK, nonzero on error.
```

Exercise: Manipulate Environment Vars

Write a short C program which behaves as indicated in the demo

- ▶ Prints ROCK and VOLUME environment variables
- ▶ If ROCK is set to anything, change VOLUME to "11"

Use these functions

```
char *getenv(const char *name);  
// NULL if name not set  
// otherwise pointer to value  
  
int setenv(const char *name,  
           const char *value,  
           int rewrite);  
// Change name value pair,  
// if rewrite is 1,  
// overwrite previous definitions
```

Note the use of export to ensure child processes see the environment variables

```
> unset ROCK  
> unset VOLUME  
> gcc environment_vars.c  
> a.out  
ROCK not set  
VOLUME is not set  
> export VOLUME=7  
> a.out  
ROCK not set  
VOLUME is 7  
> export ROCK=yes  
> a.out  
ROCK is yes  
Turning VOLUME to 11  
VOLUME is 11  
> echo $VOLUME  
7
```

Note also that the program does not change the shell's values for ROCK: no child can change a parent's values (or mind)

Answers: Manipulate Environment Vars

See 04-process-environment-code/environment_vars.c

```
1 // environment_vars.c: solution to in-class exercise showing how to
2 // check and set environment variables via the standard getenv() and
3 // setenv() functions.
4 #include <stdlib.h>
5 #include <stdio.h>
6
7 int main(int argc, char *argv[]){
8
9     char *rock = getenv("ROCK");
10    if(rock == NULL){
11        printf("ROCK not set\n");
12    }
13    else{
14        printf("ROCK is %s\n",rock);
15        printf("Turning VOLUME to 11\n");
16        int fail = setenv("VOLUME","11",1);
17        if(fail){
18            printf("Couldn't change VOLUME\n");
19        }
20    }
21    char *volume = getenv("VOLUME");
22    if(volume == NULL){
23        volume = "not set";
24    }
25    printf("VOLUME is %s\n",volume);
26    return 0;
27 }
```