CSCI 4061: Processes and Environment

Chris Kauffman

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Logistics

Reading

- Stevens/Rago, Ch 7-8 (Procs / Env)
- Stevens/Rago Ch 3, 4, 5, 6 (I/O + Files)

Goals Today

- ~~Process Lifecycle~~
- ~~Killing programs~~
- Process memory layout
- Command Line Args
- Environment Variables
- Start I/O discussion

Labs/HWs

- Lab02 / HW02 due Mon
- Lab03 on Mon, `realloc()` function,
- HW03: on Mon `WNOHANG` and parents

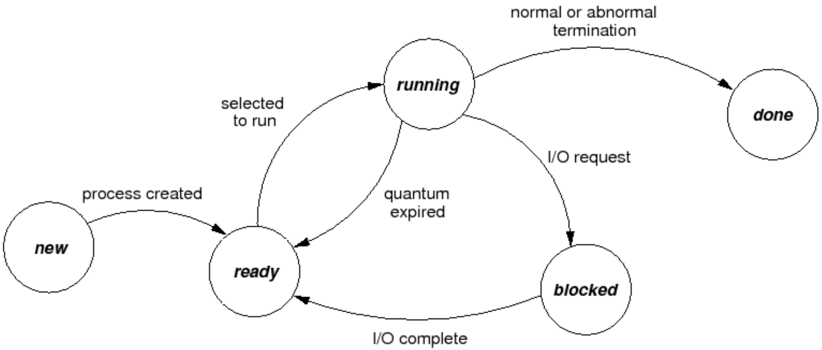
Project 1

- Up now
- Due Mon 2/22 11:59pm
- Partners allowed
- Will create Piazza post for finding partners

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
	Common
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)
	Less Common
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
- Stars 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 `invicible` 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

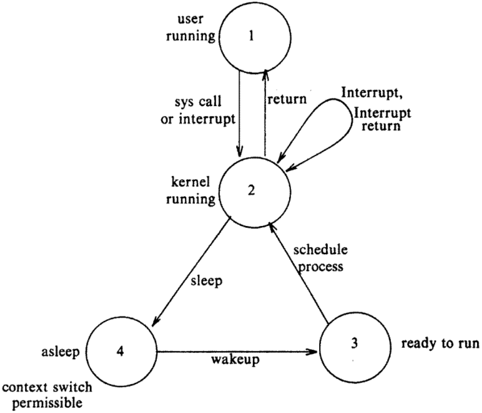
Harder to Kill

- 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

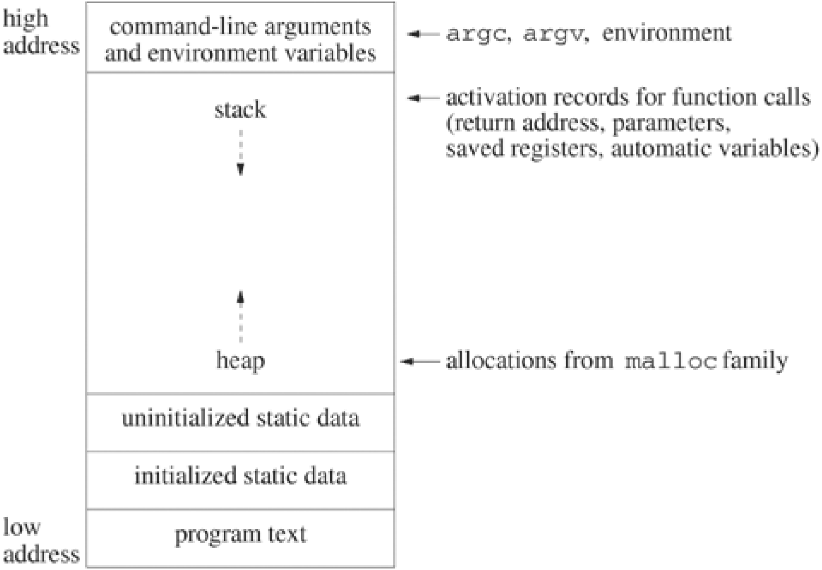
- What are the 4 memory areas to a C program we've discussed OR that you know from previous courses?
- Give an example of how one creates variables/values in each area of memory

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

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

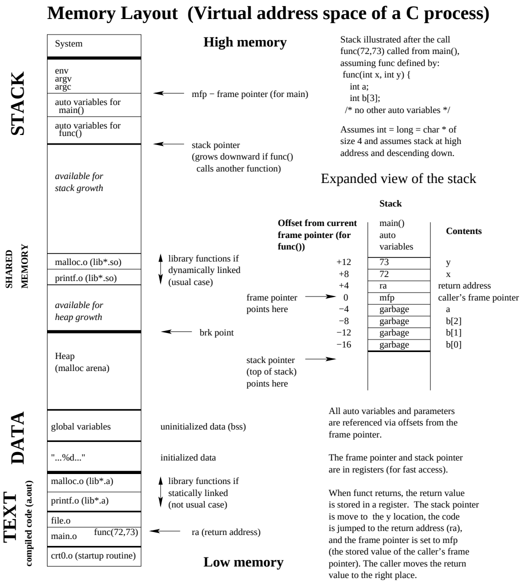
More Detailed Process Memory



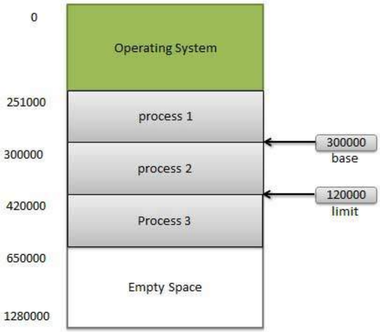
Source: Unix Systems Programming, Robbins & Robbins

Yet *more* detailed view (Link)

A detailed picture of the virtual memory image, by Wolf Holzman



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

```
// overflow.c: program traverses memory that it really ought not to by
// walking off the end of an array into parts unknown.

#include <stdio.h>
int main(int argc, char *argv[]){
  char a[3] = {'A','B','C'};
  int i = 0;
  while(1){
    printf("%c",a[i]);
    i++;
    if(i%40 == 0){
      printf("\n");
    }
  }
  return 0;
}

// ## COMPILE AND RUN
// > gcc overflow.c
// > ./a.out
// ABC..^@....E.....*V^@^@ ...^?^@^@X.^?^@^@^@^@^@^@.
// ^@^@^@9..*V^@^@.....^?^@^@^@^@^@^@^@^@^@^@..K..|..
// V^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^@^
// ......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

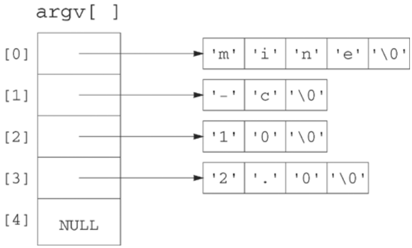
- Often programs need info from the outside world
  - What file to read/write, # of iterations to run, verbose/quiet output, report immediately, shutdown gracefully etc.
- A variety of mechanisms exist to convey such info to a program
  1. Command Line Arguments
  2. Environment Variables
  3. Signals
  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`

```
// Print all the arguments in the argv array. Prints a special message
// if option is --verbose.

#include <stdio.h>
#include <string.h>

int main(int argc, char *argv[]){
  printf("%d args received\n",argc);
  for(int i=0; i<argc; i++){
    printf("%d: %s\n",i,argv[i]);
    if( strcmp(argv[i],"--verbose") == 0){
      printf("Turning on VERBOSE output\n");
    }
  }
  return 0;
}
```

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`

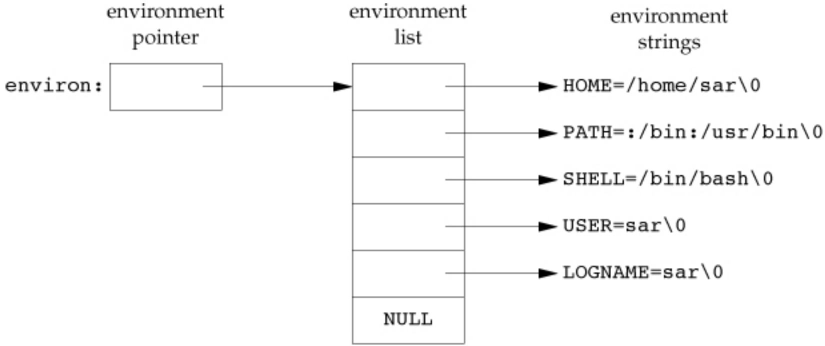
```
> echo $PAGER
less
> PAGER=cat
> echo $PAGER
cat
> echo "'$PS1'"
'>'
> PS1='wicked$ '
wicked$
> export x=1234   # in env
> y=5678          # not
```

Shell env

Show *all* environment

```
> env
JAVA8_HOME=/usr/lib/jvm/java-8-openjdk
PAGER=less
PWD=/home/kauffman/4061-F2017/lectures/04-proces
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:/us
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 sot
// 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`

```c
// environment_vars.c: solution to in-class exercise showing how to
// check and set environment variables via the standard getenv() and
// setenv() functions.
#include <stdlib.h>
#include <stdio.h>

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

  char *rock = getenv("ROCK");
  if(rock == NULL){
    printf("ROCK not set\n");
  }
  else{
    printf("ROCK is %s\n",rock);
    printf("Turning VOLUME to 11\n");
    int fail = setenv("VOLUME","11",1);
    if(fail){
      printf("Couldn't change VOLUME\n");
    }
  }
  char *volume = getenv("VOLUME");
  if(volume == NULL){
    volume = "not set";
  }
  printf("VOLUME is %s\n",volume);
  return 0;
}
```