Lab 2

Part 2

Admin

- Lab 2 has 2 parts with separate design docs and due dates
  - Part 1 Code due 4/22 (grace period and late days)
  - Part 2 Design due 4/24 (**no grace period or late days**)
  - Part 2 Code due 5/01 (grace period and late days)
- Pset 3 due tomorrow 4/19

Monitors

What the heck is a monitor?

- A monitor is made up of a lock and at least one condition variable

Why do we use monitors?

What the heck is a monitor?

- A monitor is made up of a lock and at least one condition variable

Why do we use monitors?

- Similar to locks but…
  - Allow processes to wait for certain conditions to become true while “holding lock” (waiter atomically releases the lock and reacquires the lock on wakeup).

Monitors in xk

- Lock
  - xk condition variable API only supports spinlock (an impl. choice)
- Condition
  - the shared data that threads are synchronizing on
  - E.g. for wait/exit this would be child's state
- Condition Variable
  - the waiter list is tracked by the process table
  - proc in SLEEPING state with the same `chan` are part of the same CV
  - `chan` is a pointer, can be anything (think of it as a cv identifier)

"Condition variable? I saw no mention of those in the provided code." ~ You, a free thinker.

No Condition Variables in xk

The starter code does *not* provide the object-oriented std::condition_variable API you can find in C++: LINK

Instead it provides the sleep and wakeup helper functions (which together can implement the monitor pattern)

- sleep ~= wait
- wakeup ~= broadcast

Sleep

- sleep(void* chan, struct spinlock* lk)
    - atomically release your current lock and grabs the process table (ptable) lock
        - if your current lock is the ptable lock do nothing
        - why might your current lock be the ptable lock?
    - sets myproc()->state to SLEEPING
    - sets myproc()->chan to whatever channel we are waiting on
    - yields so that scheduler can run another process

Wakeup

- wakeup(void* chan)
  - acquires the process table lock
  - looks for all SLEEPING processes with the given channel (chan)
    - sets each proc->state to RUNNABLE (ready)
    - proc->chan is also cleared to NULL

Monitors in xk

- You will use monitors to implement wait(), exit(), and pipe() for lab2!

wait(), exit()

- Coordinating children and parent processes

pipe()

- Coordinating reader and writer processes

Lab 2 - Pipe

What is a Pipe?

A pipe is essentially a queue of bytes with two ends:

- One end designated for input, the other for output

When you type **‘ls | wc’** into the shell, you are using a pipe!!!

- ‘ls’ lists the directory contents
- ‘wc’ counts the number of lines output from the ls command
- The pipe joins the output from ‘ls’ to the input of ‘wc’

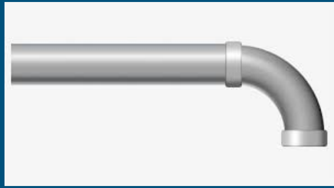
pipe(fds)

- Creates a pipe (kernel buffer) that can be read from/written to.
- From the user perspective: returns two new file descriptors
  - fds[0] = “read end”, O_RDONLY
  - fds[1] = “write end”, O_WRONLY
- Pipes allow processes to communicate with each other
  - Parent opens a pipe, forks a child (now they both have access to the pipe ends)
  - Typically each process only leaves one end open (closes the read end or the write end)

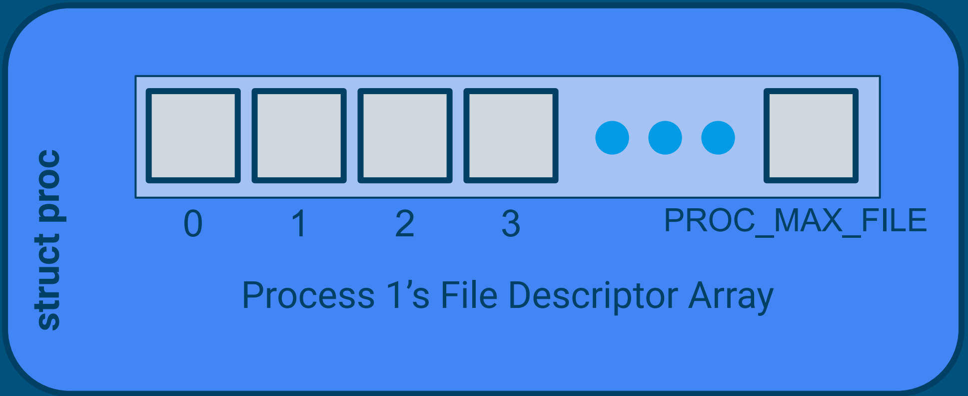
An Example to Illustrate Pipes

Now let's go through a demonstration of what happens as a sample user uses the pipe API (in the context of multiprocessing)!

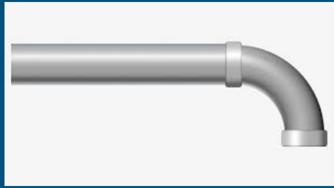
Pipe usage



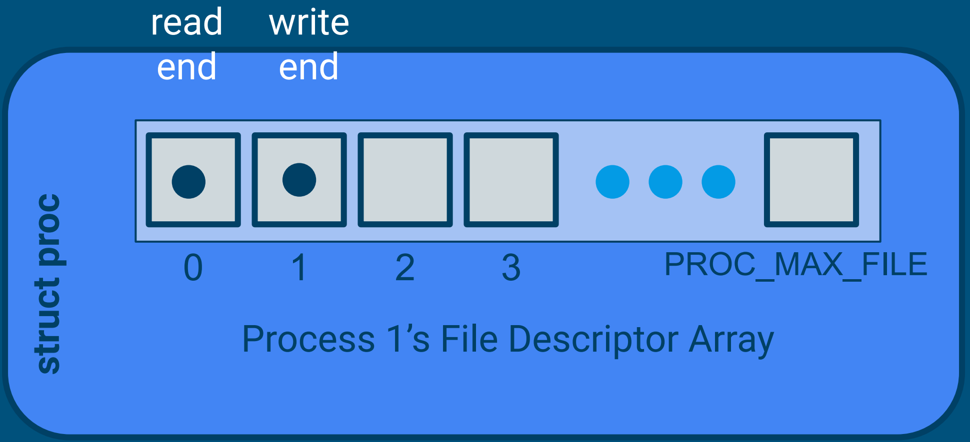
- Process 1 starts with no open files



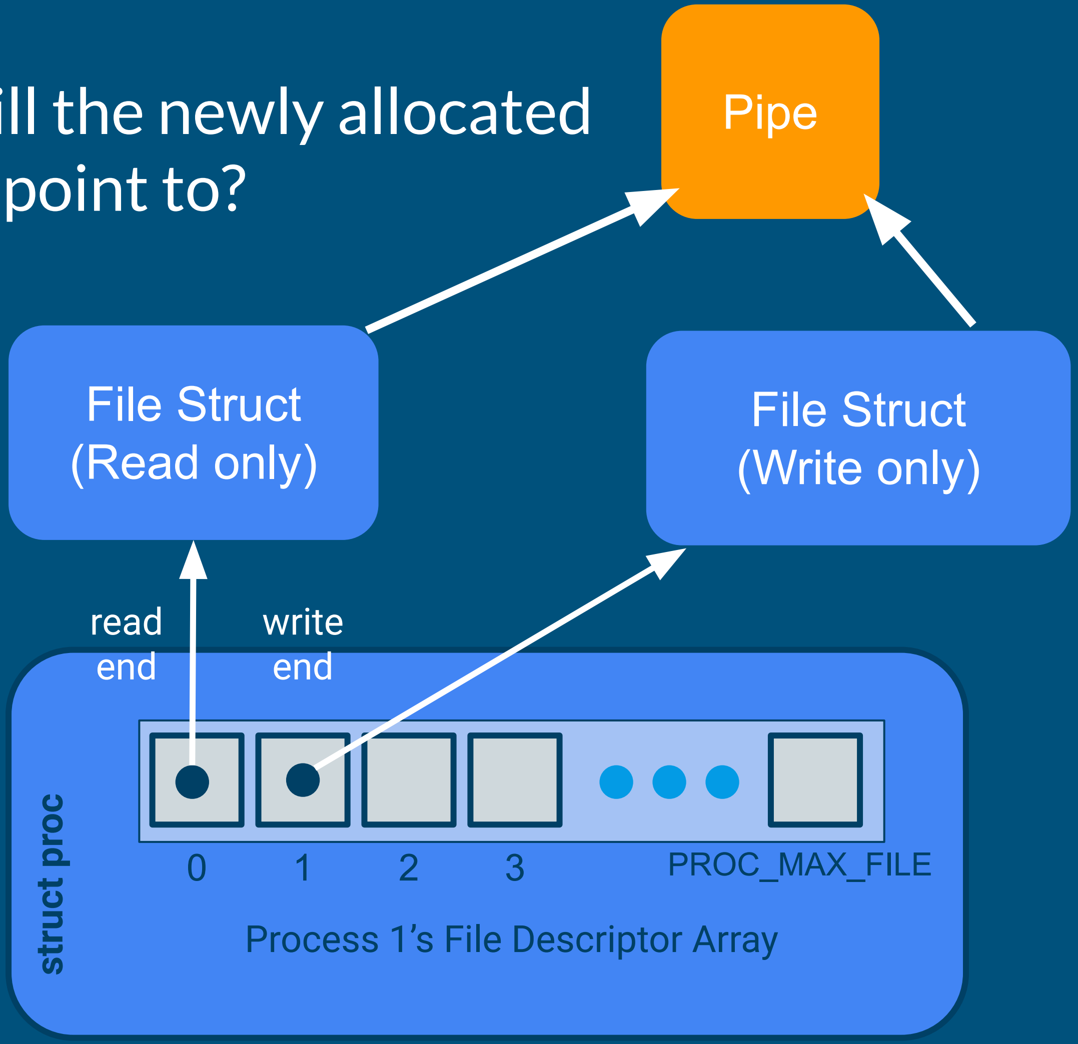
Pipe usage



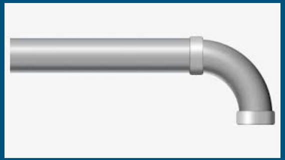
- Process 1 calls `pipe()`



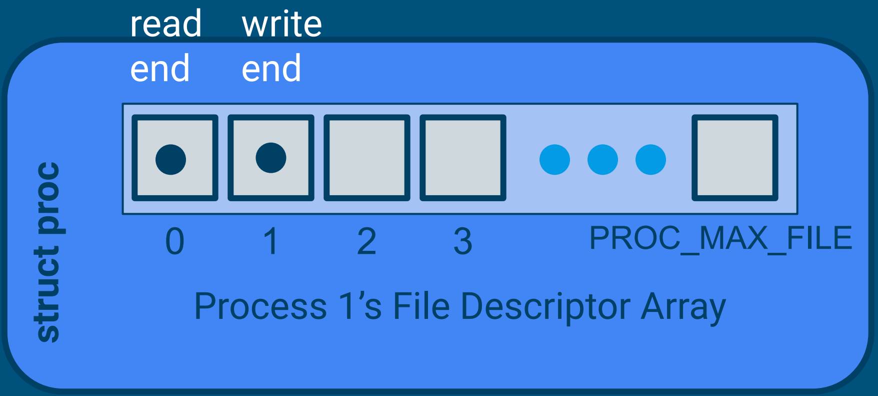
What will the newly allocated pipe fds point to?

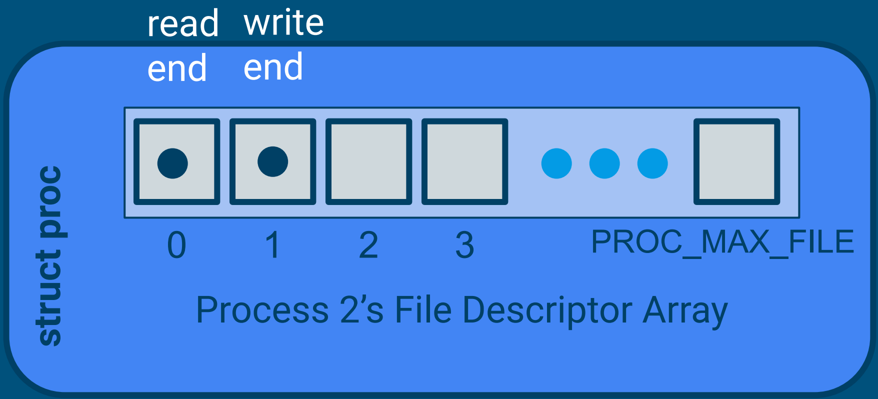


Pipe usage

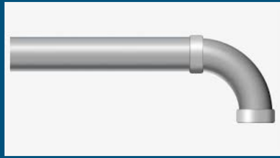


- Process 1 calls `fork()`, fd table is duplicated
  - **Note:** fork() is called by user and should not be called within the actual pipe() call

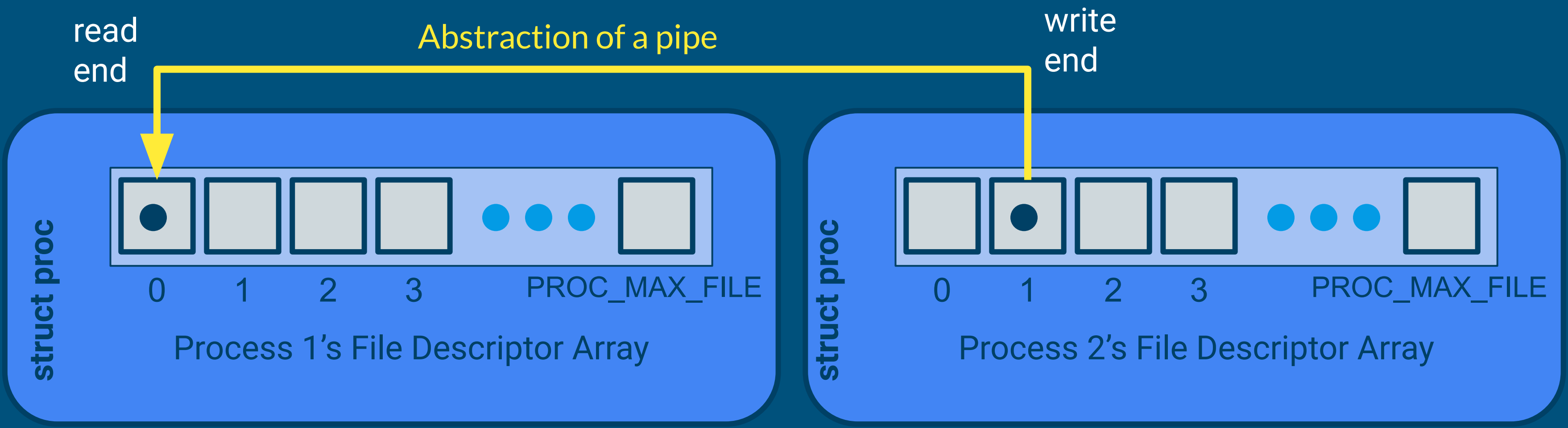




Pipe usage



- Process 1 `close(1)`, process 2 `close(0)`
- The process with the write end open is a writer, and the one with the read end open is a reader



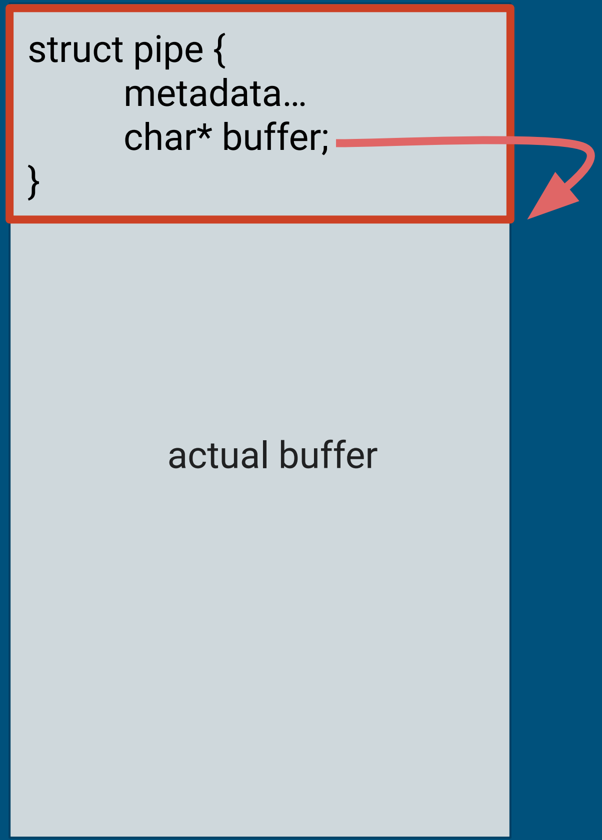
pipe FAQs

- When should pipe be allocated?
  - dynamically! when pipe() is called!
- How does xk do dynamic memory allocation?
  - hint: kstack is also dynamically allocated
  - `kalloc` allocates a page (4096 bytes) of memory from the kernel heap
    - wait, but how do I put a pipe onto the page?

struct pipe* p = kalloc();

p->buffer = ???

should be right past the struct, and what would that be?



a page of memory
(4096 bytes)

pipe FAQs

- When can you free the pipe and its buffer?
  - remember there may be multiple references to read end and write end
- Can we always write to or read from the buffer? (Hint: bounded buffer sync)
  - What if there's no room to write, or no data to read?
  - What happens if all read/write ends are closed?
- How will pipes integrate with the file syscalls?
  - Need a way to determine if a struct file is an inode or a pipe

Interaction with File API

Pipes are accessed through file descriptors.

This means you need to think through how the lab 1 syscalls will work when called on pipe file descriptors:

- `close`
- `dup`
- `read`
- `write`
- `stat`

What should pipe contain?

- What metadata/information do you need for pipe?

What should pipe contain?

- What metadata/information do you need for pipe?
    - Read offset
    - Write offset
    - # of bytes available in the buffer
    - Whether the read end is still open
    - Whether the write end is still open
    - Lock and condition variables
    - A way to track the active writer [why?]
- Similar to the bounded buffer problem

And that's pipe!

… But wait! There's more! (that you have to do in lab 2 part 2)

But wait! …. There's more! (in lab 2 part 2)

In lab 2 part 2 you are also implementing exec

exec(3) — Linux manual page

Lab 2 - exec

Motivation

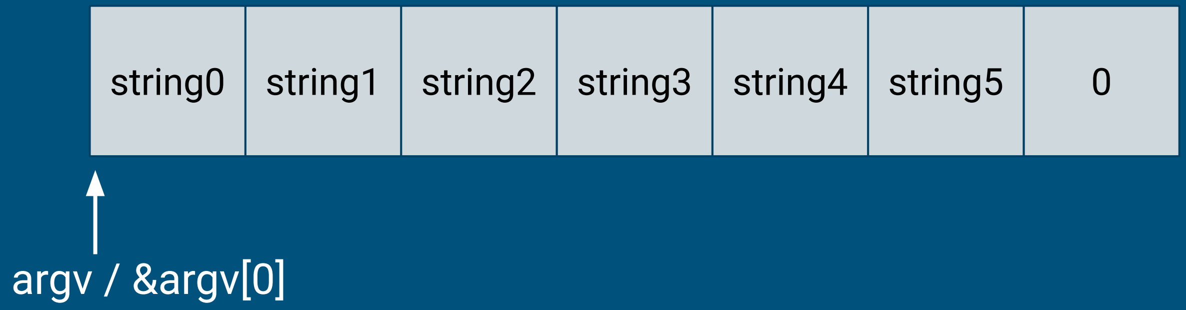
Why do we have exec?

- To let user code execute user programs!
  - E.g. Shell commands like ‘ls’ and ‘cat’ commands are exec’ed by the ‘sh’ program.

exec(program, args)

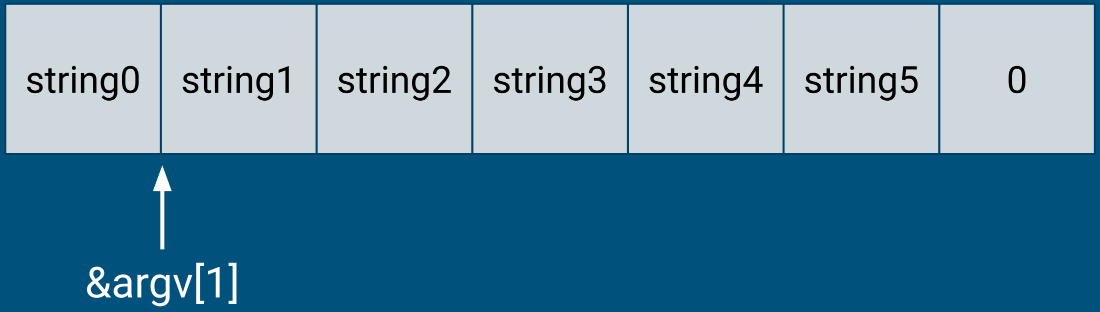
- Fully replaces the current program; it does not create a new process
- How do we replace the current program?
  - need to set up a new virtual address space and new registers states
  - and then switch to using the new VAS and register states
  - file descriptors and pid remain the same

exec(path, argv) arguments validation



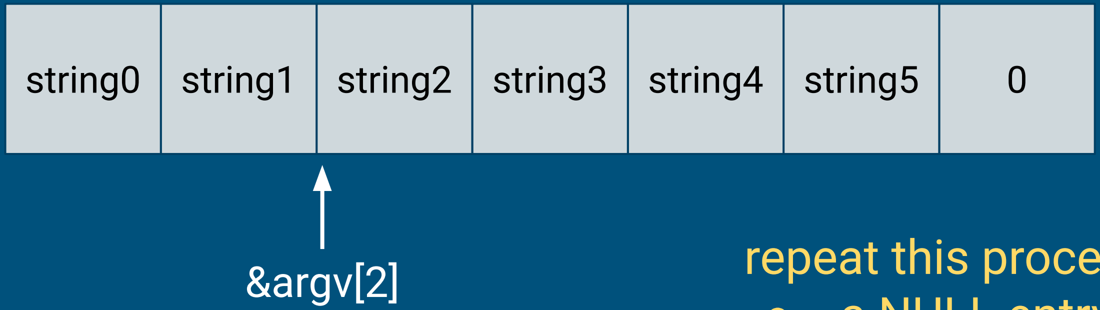
must be validated for an 8 byte pointer before we can access argv[0] and validate string0

exec(path, argv) arguments validation



must be validated for an 8 byte pointer before we can access argv[1] and validate string1

exec(path, argv) arguments validation



must be validated for an 8 byte pointer before we can access argv[2] and validate string2

repeat this process until

- a NULL entry is reached
- a validation error

`exec`(program, args)

- Setting up a new virtual address space (pseudocode)
  - `vspaceinit` for initialization
  - `vspaceloadcode` to load code
  - `vspaceinitstack` to allocate stack vregion
    - you still need to populate user stack with arguments
    - `vspacewritetova` to write data into the stack of the new VAS
  - `vspaceinstall` to swap in the new vspace
  - `vspacefree` to release the old vspace
- The swapover to the new vspace can be tricky to get right!
  - To swap: Assign the new vspace to current vspace

How are the args set up in exec?

Another look at main()

exec sets up the function arguments for main!

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

- argc: The number of elements in argv
- argv: An array of strings representing program arguments
  - First is always the name of the program
  - Argv[argc] = 0

Setting up the Stack

Quick Review: X86_64 Calling Conventions

From 351:

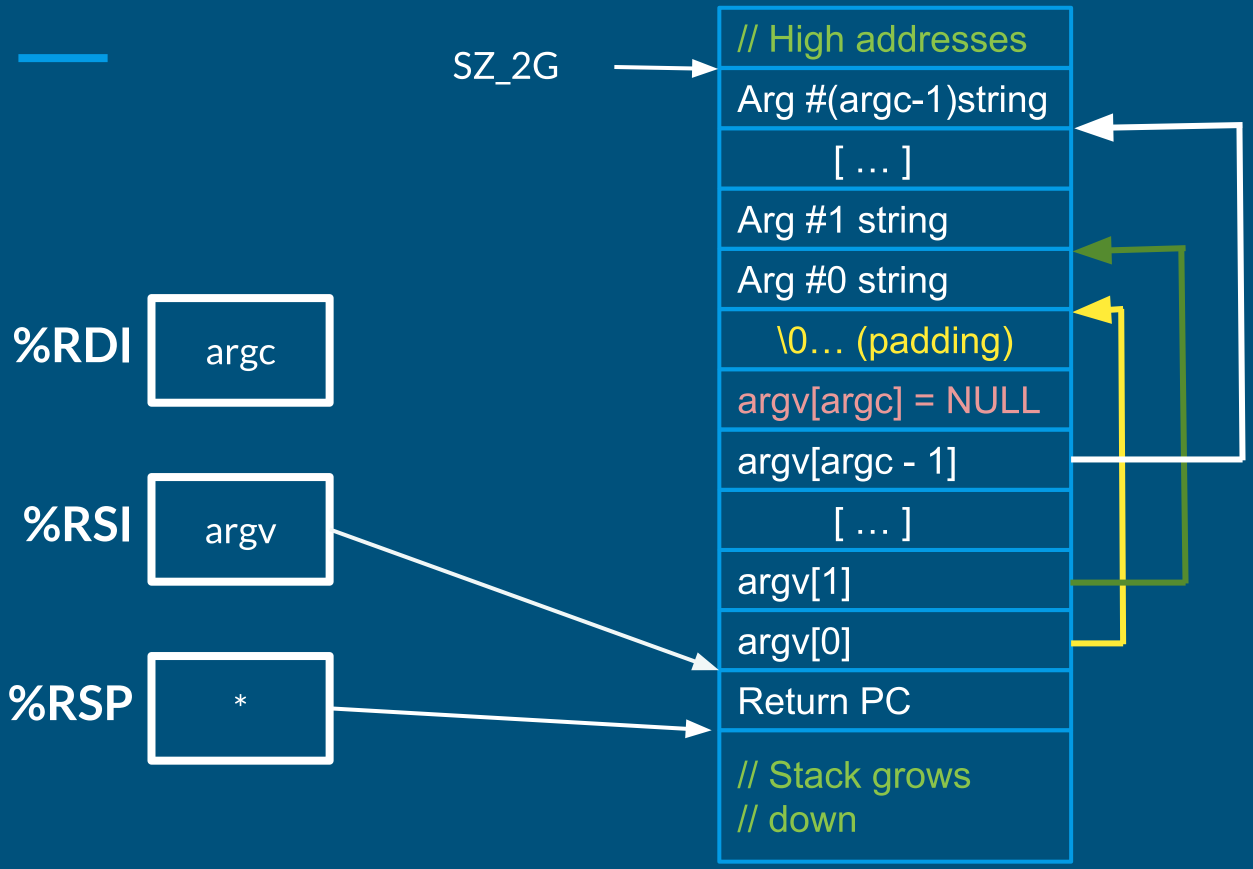
- `%rdi`: holds the first argument
- `%rsi`: holds the second argument
  - `%rdx`, `%rcx`, `%r8`, `%r9` comes next
  - overflows (arg7, arg8 …) onto the stack
- `%rsp`: points to the top of the stack (lowest address)

Quick Review: X86_64 Calling Conventions

From 351:

- Local variables are stored on the stack
- If an array is an argument, the array contents are stored on the stack and the register contains a pointer to the array’s beginning

Stack For User Process



- Since argv is an array of pointers, %RSI points to an array on the stack
- Since each element of argv is a char*, each element points to a string elsewhere on the stack
- Why? Alignment
- Why NULL pointer? Convention

Let’s Practice!

Practice Exercise 1

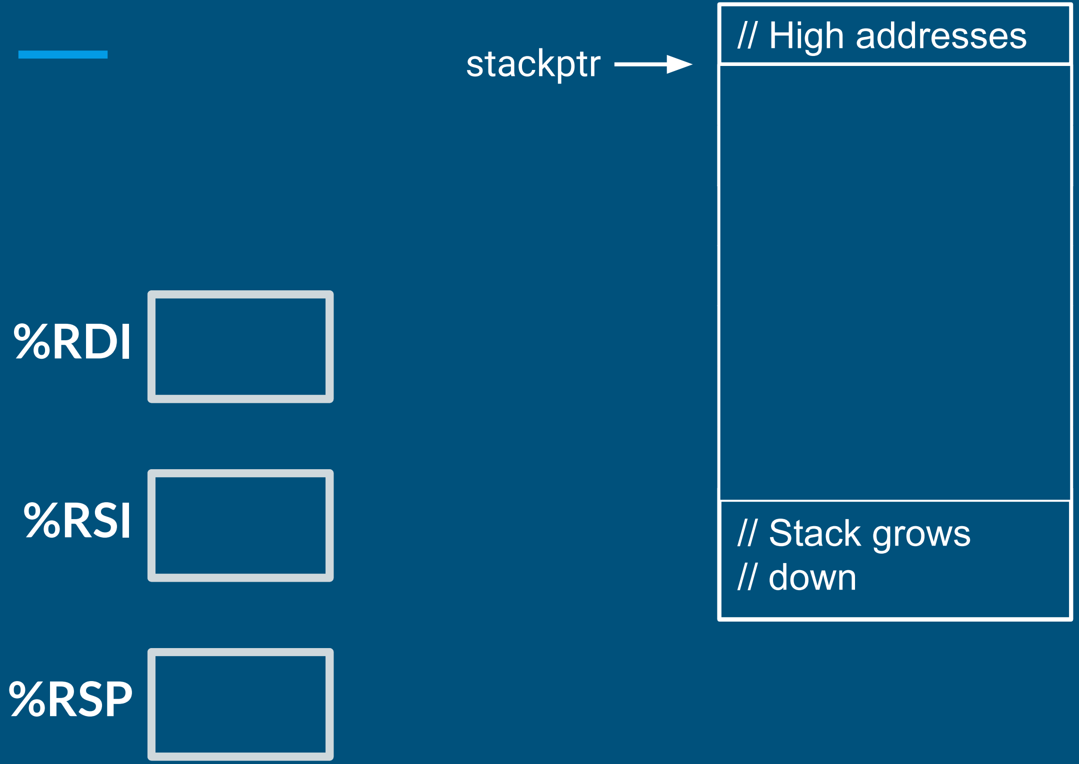
Stack grows down

Now it's your turn!

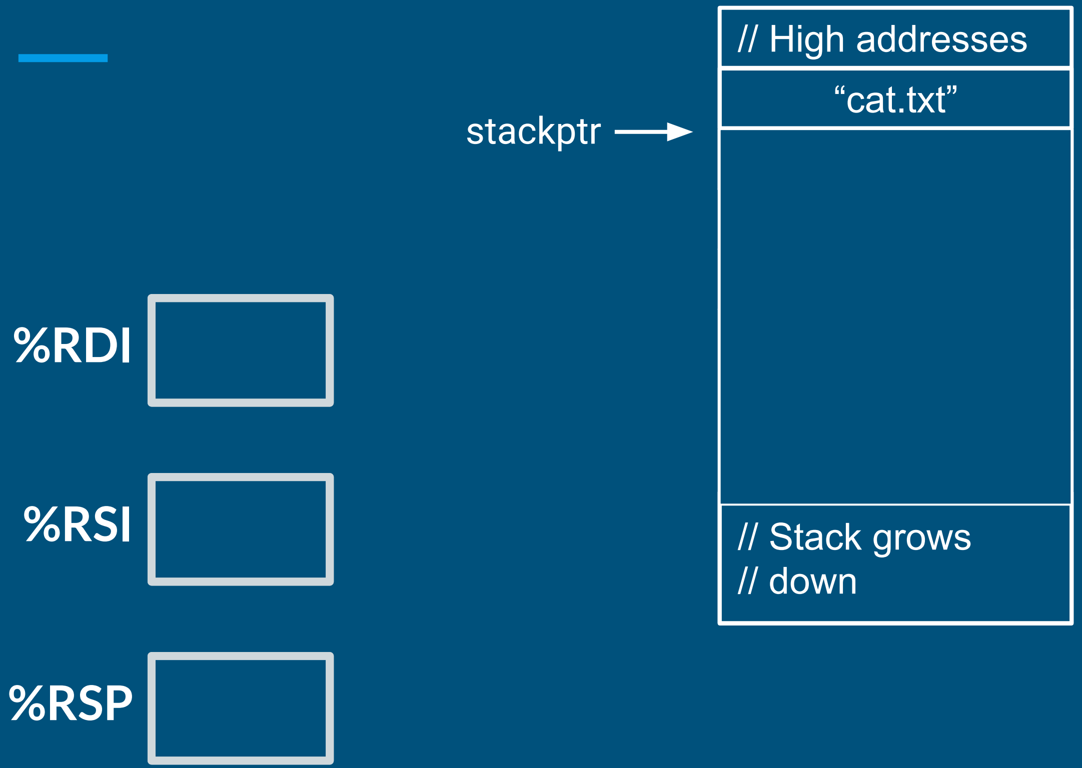
Draw stack layout and determine register values for exec() called with:

"cat cat.txt"

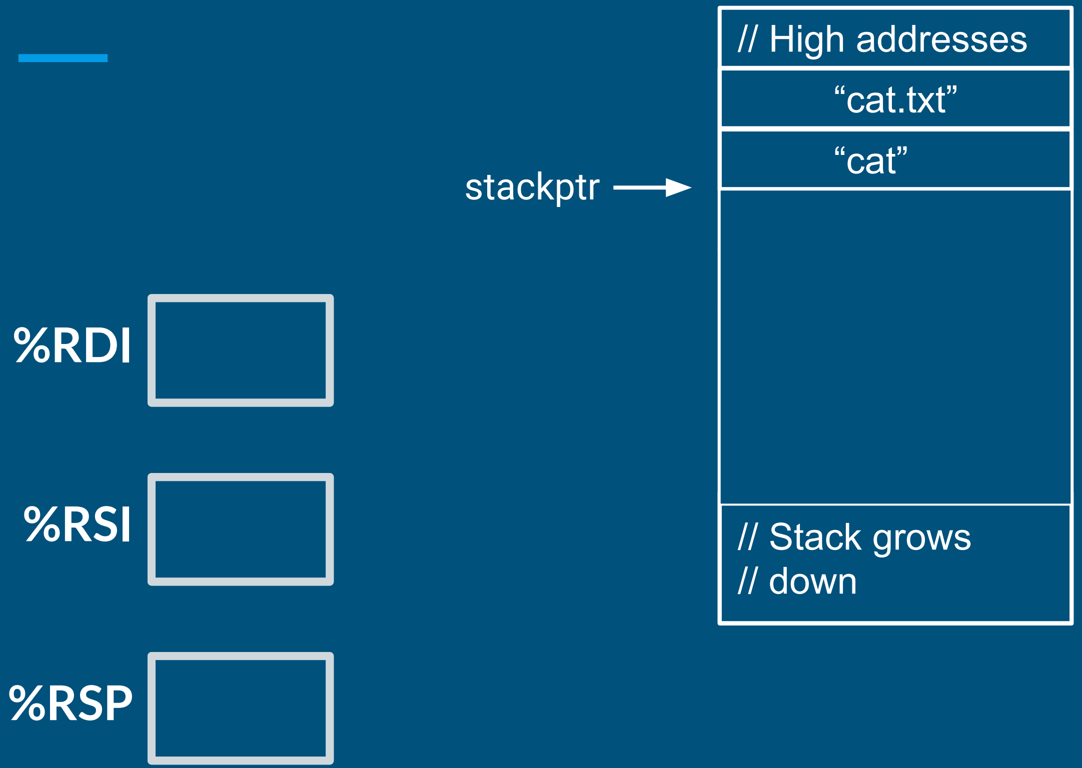
Practice Exercise 1: “cat cat.txt” Solution



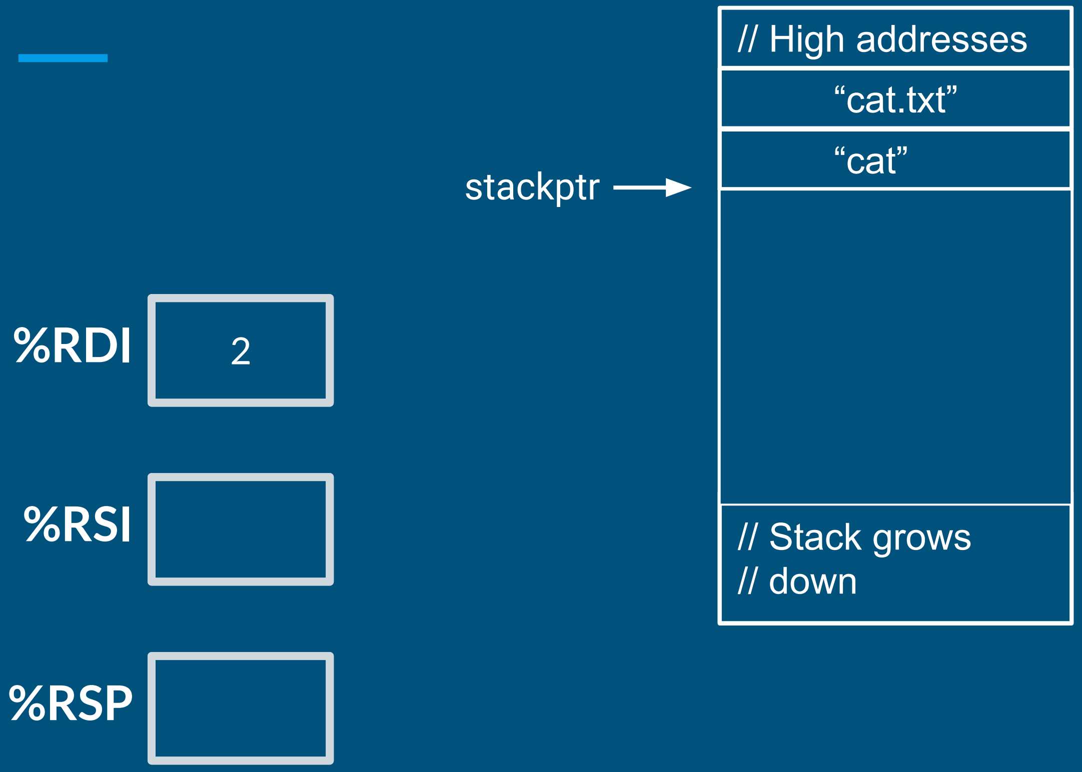
Practice Exercise 1: “cat cat.txt” Solution



Practice Exercise 1: “cat cat.txt” Solution

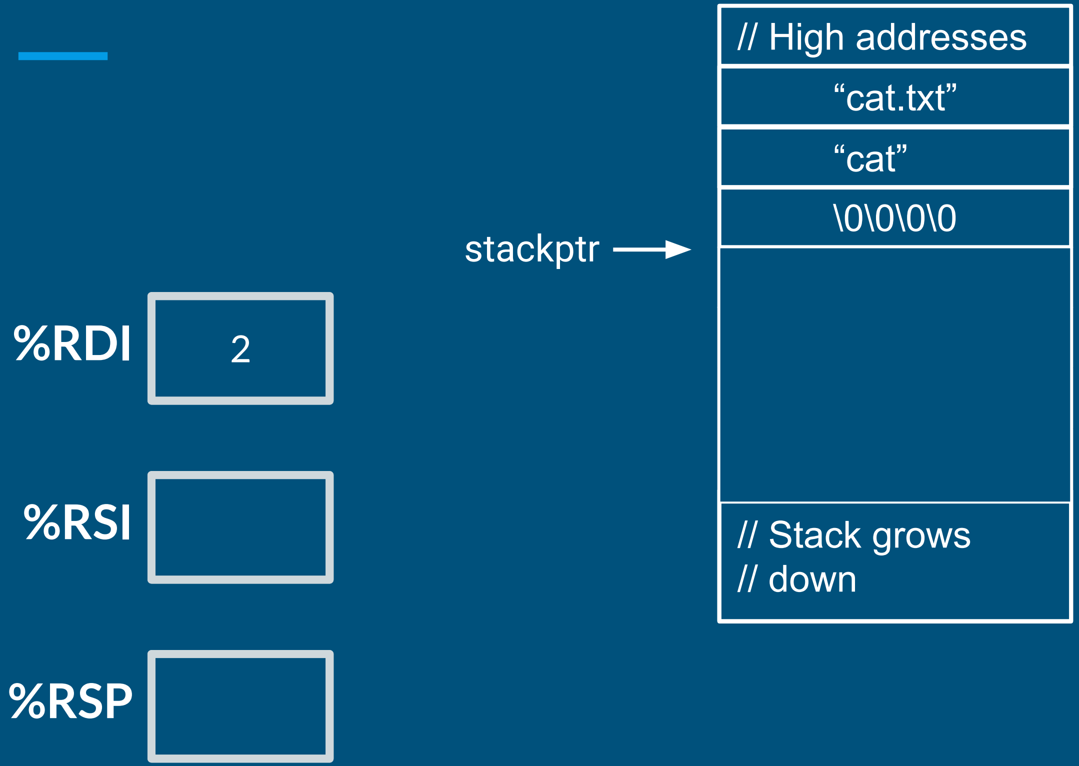


Practice Exercise 1: “cat cat.txt” Solution



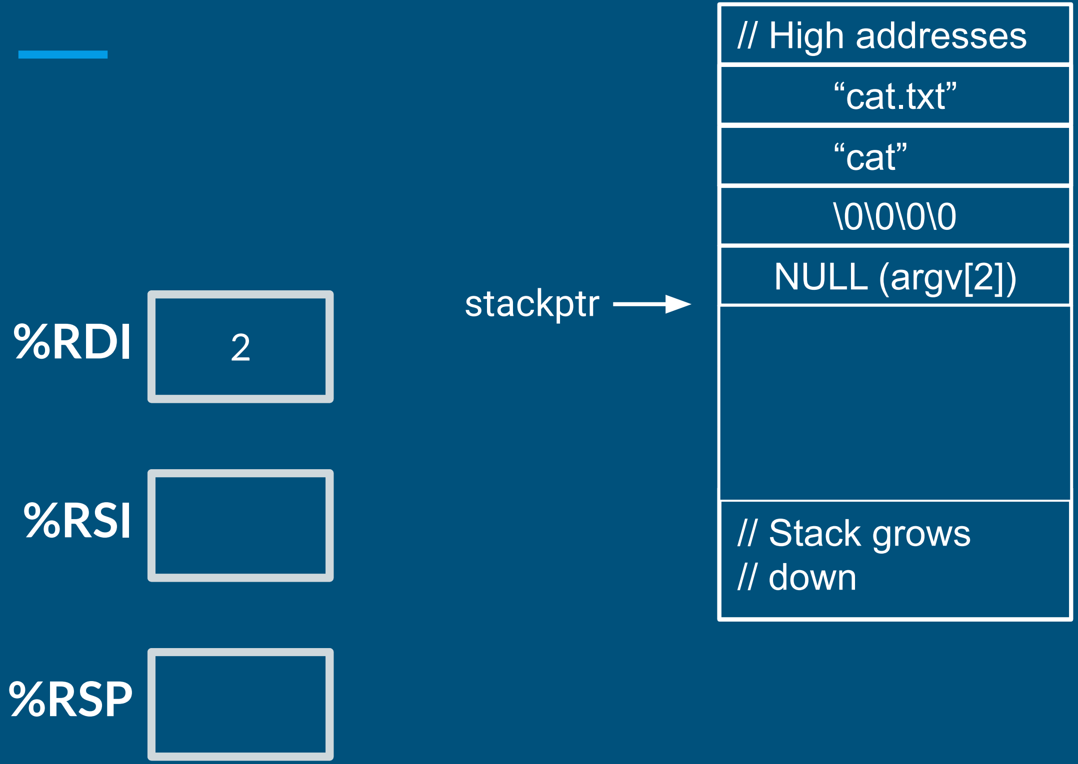
- RDI holds argc, which is 2

Practice Exercise 1: “cat cat.txt” Solution



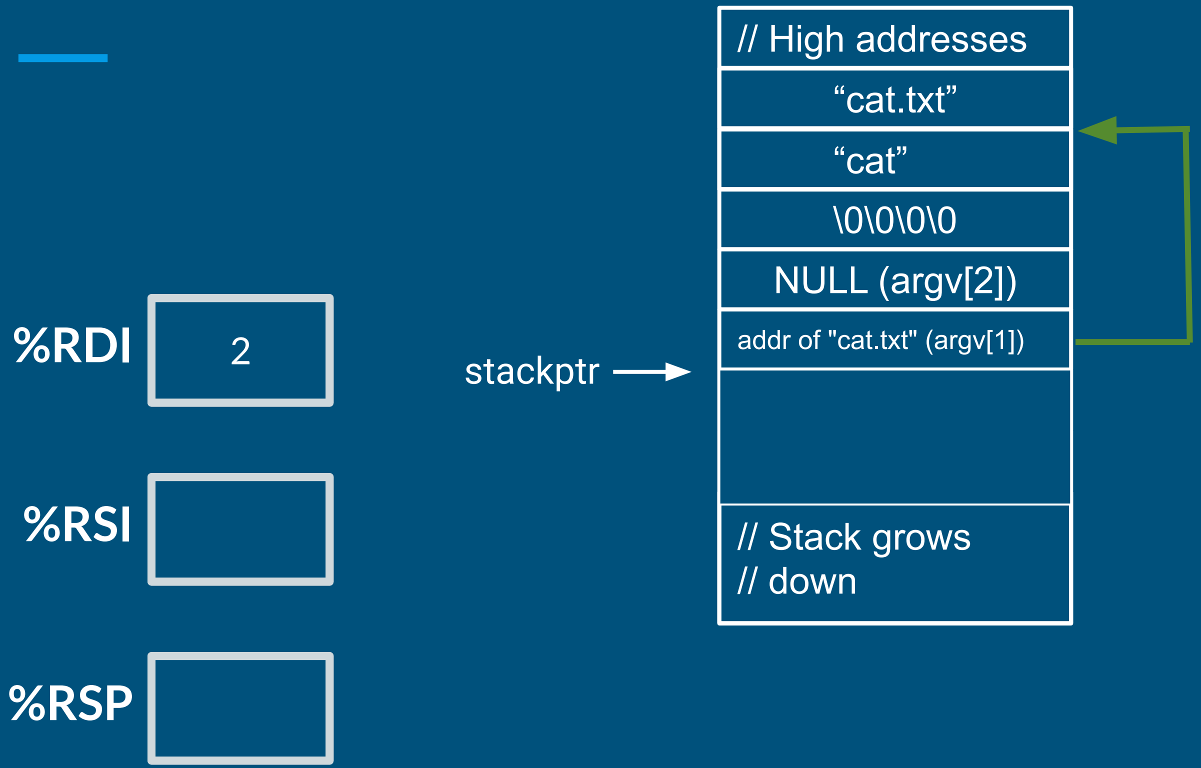
- RDI holds argc, which is 2

Practice Exercise 1: “cat cat.txt” Solution



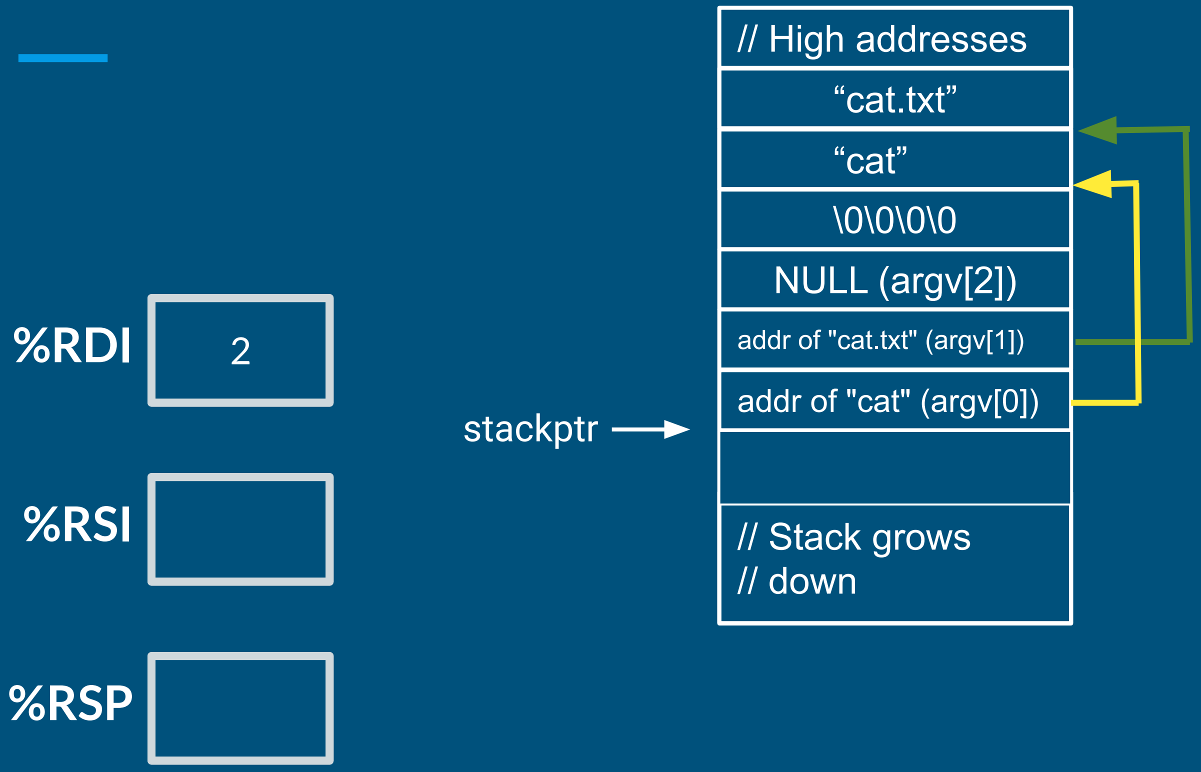
- RDI holds argc, which is 2

Practice Exercise 1: “cat cat.txt” Solution



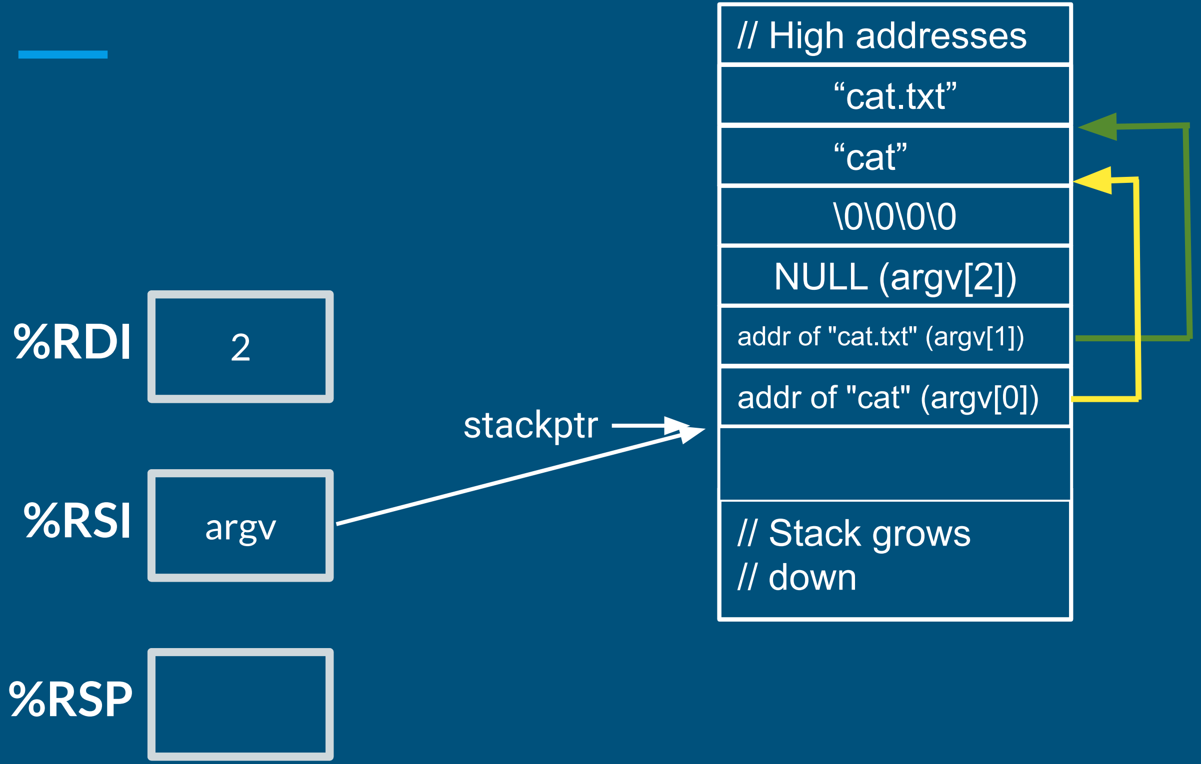
- RDI holds argc, which is 2

Practice Exercise 1: "cat cat.txt" Solution



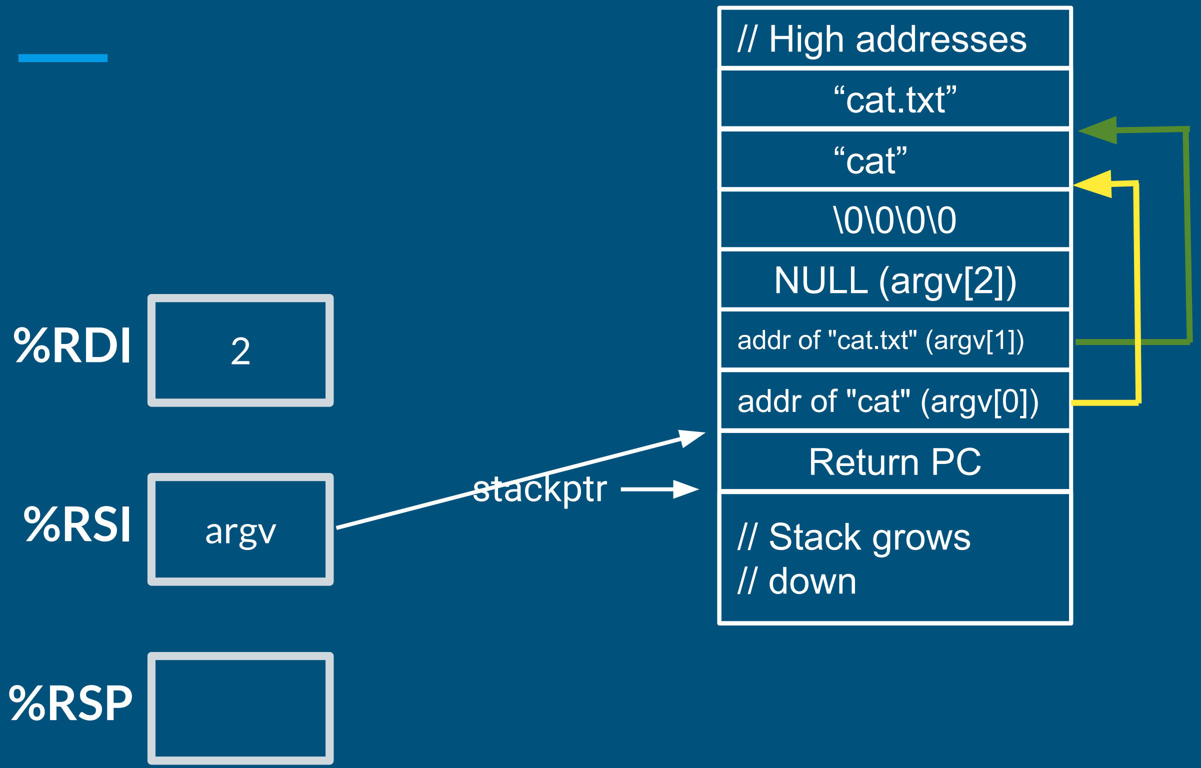
- RDI holds argc, which is 2

Practice Exercise 1: “cat cat.txt” Solution



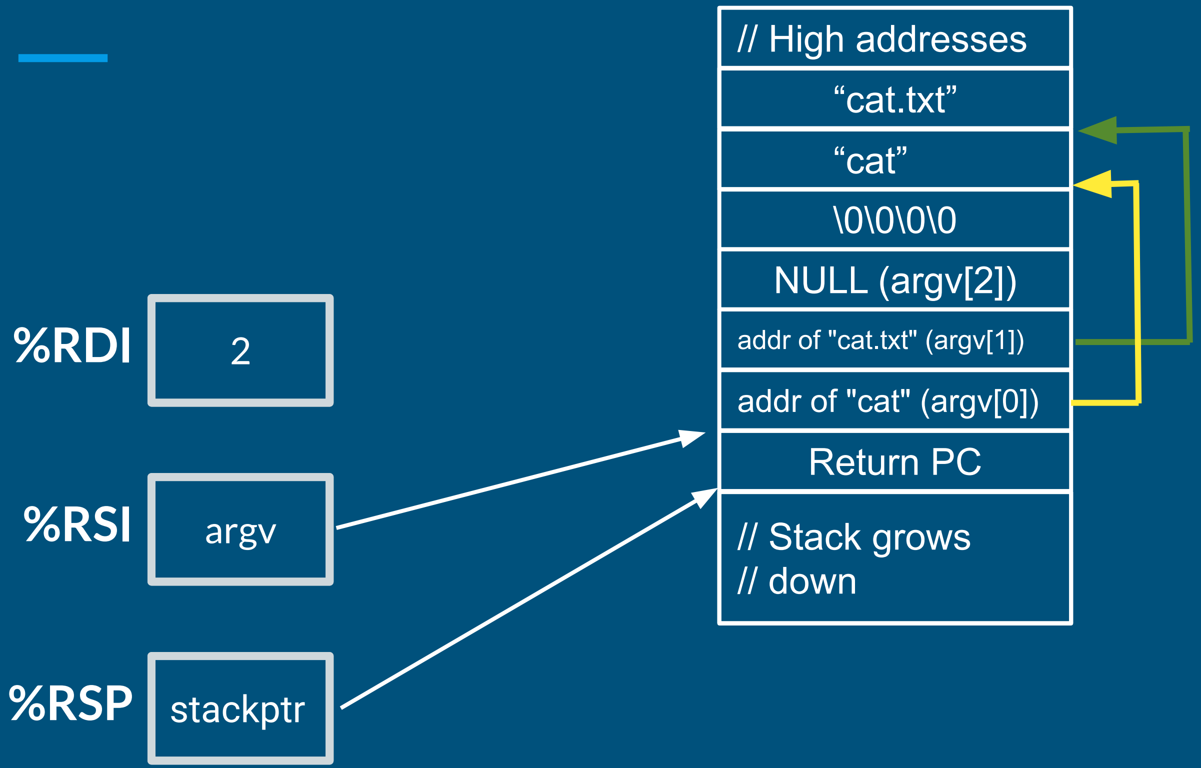
- RDI holds argc, which is 2
- RSI holds argv: the beginning of the argv array

Practice Exercise 1: "cat cat.txt" Solution



- RDI holds argc, which is 2
- RSI holds argv: the beginning of the argv array
- The specific value of the return PC doesn't matter (program exits from main without returning)

Practice Exercise 1: “cat cat.txt” Solution



- RDI holds argc, which is 2
- RSI holds argv: the beginning of the argv array
- The specific value of the return PC doesn’t matter (program exits from main without returning)
- RSP is properly set to the bottom of the stack.

Practice Exercise 2

%RDI

%RSI

%RSP

// High addresses

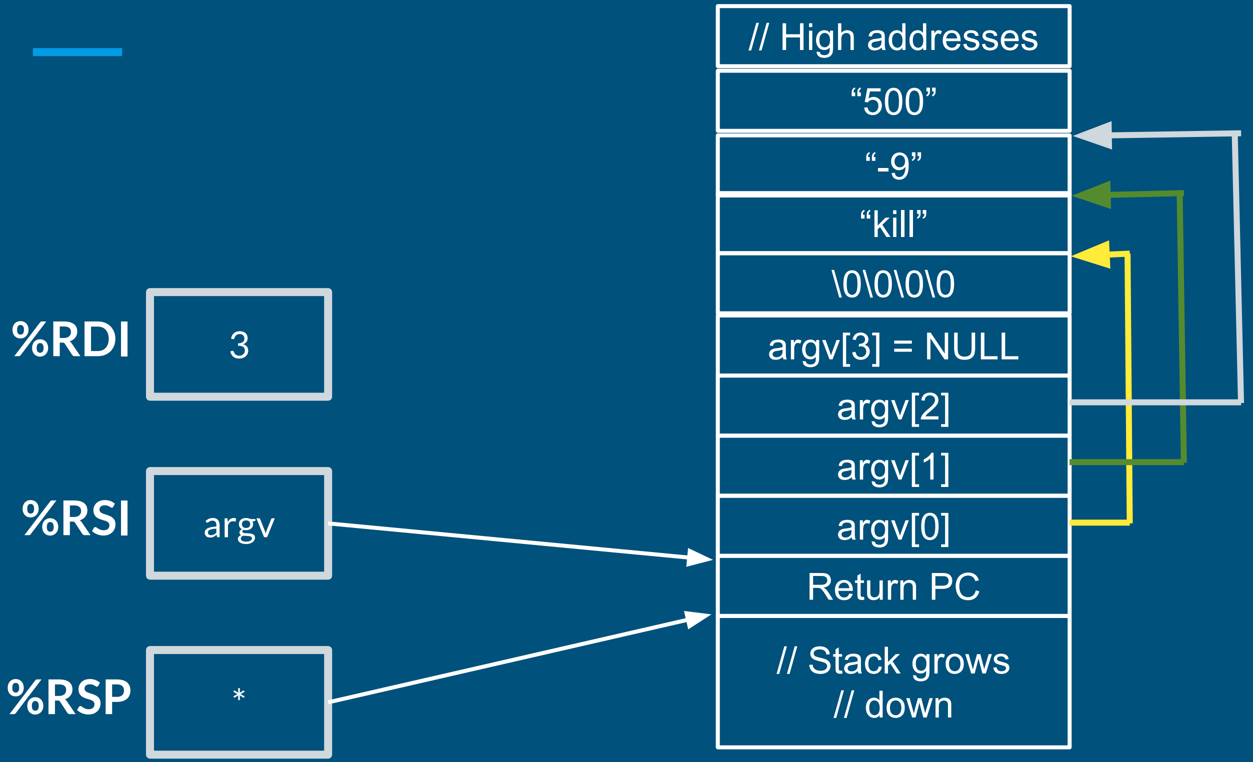
Stack grows down

Now it's your turn!

Draw stack layout and determine register values for exec() called with:

"kill -9 500"

Practice Exercise 2: “kill -9 500” Solution



- RDI holds argc, which is 3
- RSI holds argv: the beginning of the argv array
- RSP is properly set to the bottom of the stack.
- The specific value of the return PC doesn’t matter (program exits from main without returning)

Questions?