

A practical course on

Advanced systems programming in C/Rust

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Today's topic!

Processes

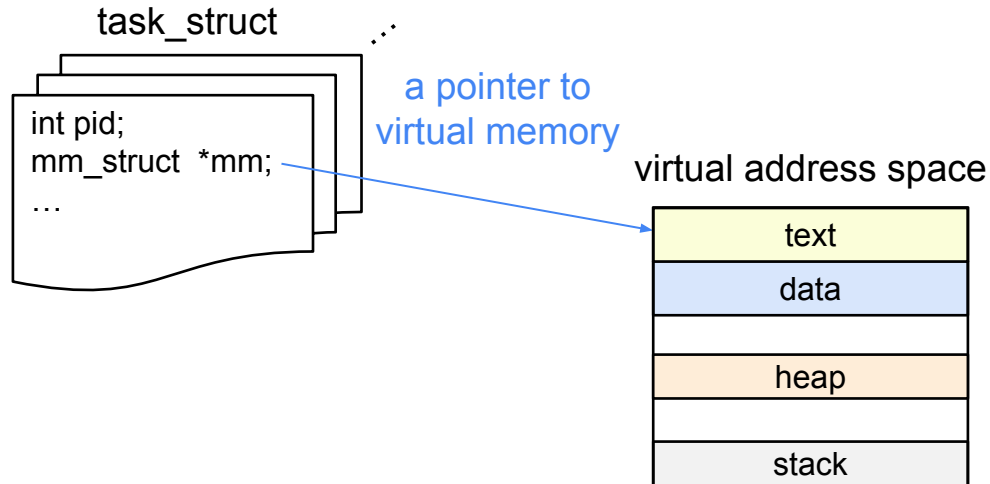
- What is a process?
 - the concept of a process
- Process creation
 - `fork()`, `exec()`, `wait()`
- Inter-process communication
 - `pipe()`
 - signals

What is a process?

- represents a specific program running in multi-tasking OS (e.g., Linux)
 - OS manages each program as a process
 - each process has an independent (virtual) address space
- Merits
 - Multi-tasking
 - Resource sharing (i.e., CPU, memory, I/O devices)
 - Fault-tolerance – a process crash does not affect other processes

Process management

- Process ID (PID)
 - an identification number gave by OS when the process is created
- Process descriptor
 - a special data structure storing each process info (i.e., task_struct in Linux)
 - pid, state, address space, scheduling priority, file descriptors, ...



Process creation

- We can use `fork()` system call
 - `fork()` does not ‘create’ a new process, but makes a copy of the caller process
 - The caller process is called *parent*, its duplicate is called *child*
- i.e., booting Linux kernel only creates the ‘init’ process
 - the init process is the parent of all the subsequent processes
- **Note:** ‘process’ and ‘thread’ are a bit different
 - a thread shares the virtual memory of its parent, but a process does not
 - we treat only the process here

- when fork() is called, the OS does:
 - replicate the entire virtual address space to a child
 - return a PID of the new child process
- waitpid() syscall
 - **int waitpid(pid_t pid, int *status, int options);**
 - wait for the exit of the child process specified by pid

```
1  pid_t pid = fork();
2
3  if (pid == -1) {
4      perror("fork failed");
5      exit(EXIT_FAILURE);
6  } else if (pid == 0) { // fork returns 0 for child
7      printf("Hello from the child process!\n");
8  } else {
9      int status;
10     (void)waitpid(pid, &status, 0);
11 }
```

Monitoring fork()

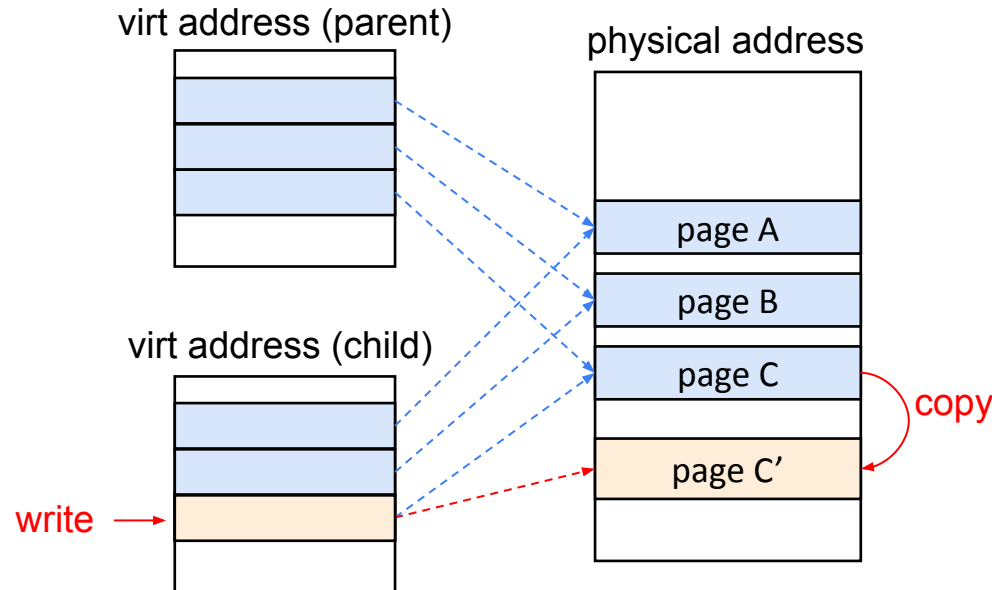
- `fork()` is originally implemented by `clone()` syscall
 - `clone` will also be later relevant when doing containers
- *strace* can be used for monitoring
 - a tool to trace system calls and signals
 - `-e` option : specify which events to trace
 - `-f` option : trace child processes in addition to the parent

```
$ strace -e clone bash -c 'ls -la && echo $?'  
clone(child_stack=NULL, flags=CLONE_CHILD_CLEARTID|CLONE_CHILD_SETTID|SIGCHLD,  
child_tidptr=0x7fd6187c6a10) = 19855
```

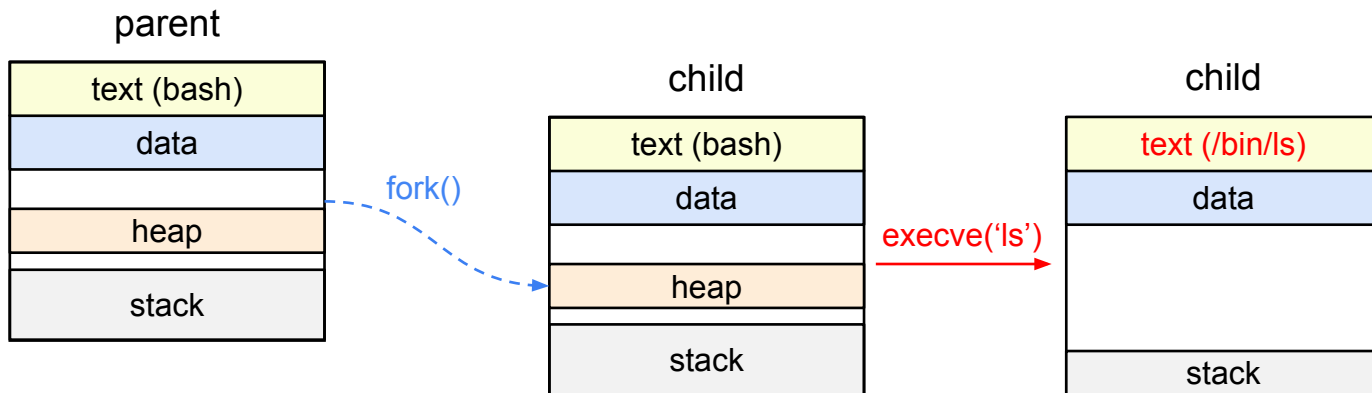
PID of a child process

Copy on write

- contents of memory are not copied unless being modified
 - child's share all pages of the parent first
 - when a process modifies a page, a copy of the physical page is created



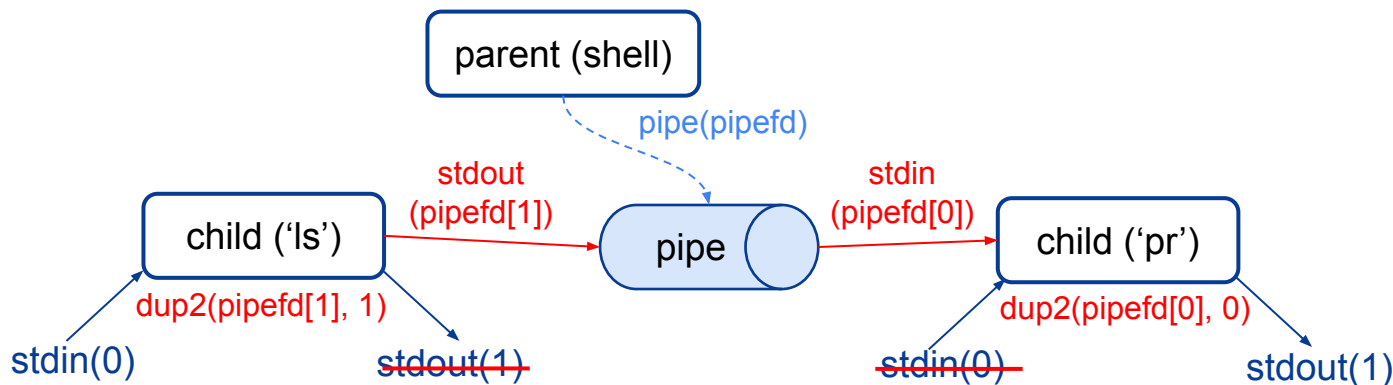
- how to execute a different program?
 - fork() just copies an entity of the parent process
- execve() syscall
 - **int execve (const char *pathname, char *const argv[], char *const envp[])**
 - resets virtual memory based on an executable file specified in *pathname* (i.e. elf file)
 - For scripts, OS reads shebangs from the file (!) a setup's specified executable
 - `#!/bin/sh`



Inter-process communication (IPC)

- Introduce two IPCs
 - pipe : like a File I/O
 - signals : like an interrupt
- file descriptor (fd): index into a per-process file descriptor table
 - each process has three standard fds: stdin(0), stdout(1), stderr(2)
 - opened fds are inherited from the parent to a child
 - unless O_CLOEXEC is specified as flag
- dup2() syscall
 - **int dup2(int oldfd, int newfd)**
 - duplicate *oldfd* using the number specified by *newfd*
 - if *newfd* was previously open, it is silently closed

- **int pipe2(int pipefd[2], int flags)**
 - produces a pipe, unidirectional byte stream
 - returns pipefd: pipefd[0] is a read end, pipefd[1] is a write end of the pipe
 - pipefds are not mapped to a file, but a physical page (VFS)
- dup2() is used to connect two processes via the pipe
 - e.g., `$ ls | pr`



- notify an asynchronous event to processes
 - e.g., a segmentation fault (SIGSEGV), an exit of child processes (SIGCHLD)
 - Signals are managed by a bitmask field (*long signal*) in `task_struct`
 - when SIGSEGV (11) is sent, the 11th bit of *signal* is set to 1
 - a process can block a specific signal
 - Only SIGSTOP (pause) and SIGKILL (terminate) cannot be blocked
- Signal handlers
 - When a process receives a non-blocked signal, a corresponding handler is invoked
 - Handlers are set by a process; otherwise, the OS performs the default action
 - e.g., `waitpid()` handles SIGCHLD

How to send signals

- `kill()` syscall
 - `int kill(pid_t pid, int sig)`
 - send the signal `sig` to a process specified by `pid`
 - some signals can be sent from a terminal (e.g., ctrl-c)
- examples of standard signals
 - other signals are listed by `$ kill -l`
 - real-time (RT) signals behave a little different

number	name	default action	terminal key-combo
2	SIGINT	terminate a process	Ctrl-c
9	SIGKILL	terminate a process (unblockable)	
17	SIGCHLD	child stopped or terminated	
19	SIGSTOP	pause a process (unblockable)	Ctrl-z

Thank you for listening!
see you in the Q&A session

References

- Linux virtual memory
 - <https://www.slideserve.com/cleave/virtual-memory>
- Linux processes and signals
 - https://www.bogotobogo.com/Linux/linux_process_and_signals.php
- Linux man-pages
 - <https://man7.org/linux/man-pages/man2/>