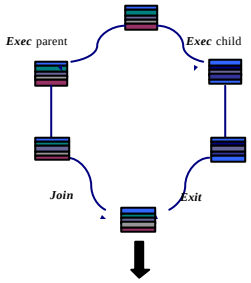
The Classical OS Model in Unix

Nachos Exec/Exit/Join Example

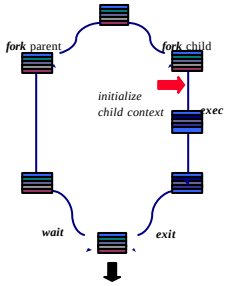


SpaceID pid = Exec("myprogram", 0);
Create a new process running the program "myprogram".

int status = Join(pid);
Called by the parent to wait for a child to exit, and "reap" its exit status. Note: child may have exited before parent calls Join!

Exit(status);
Exit with status, destroying process. Note: this is not the only way for a proess to exit!.

Unix *Fork/Exec/Exit/Wait* Example



int pid = fork();
Create a new process that is a clone of its parent.

exec*("program" *[, argvp, envp]*);
Overlay the calling process virtual memory with a new program, and transfer control to it.

exit(status);
Exit with status, destroying the process.

int pid = wait*(&status);
Wait for exit (or other status change) of a child.

Elements of the Unix Process and I/O Model

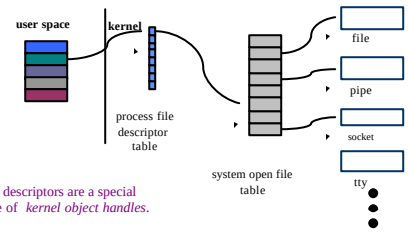
1. rich model for IPC and I/O: "*everything is a file*"
   file descriptors: most/all interactions with the outside world are through system calls to read/write from *file descriptors*, with a unified set of syscalls for operating on open descriptors of different types.
2. simple and powerful primitives for creating and initializing child processes
   fork: easy to use, expensive to implement
3. general support for combining small simple programs to perform complex tasks
   standard I/O and pipelines: good programs don't know/care where their input comes from or where their output goes

Unix File Descriptors

Unix processes name I/O and IPC objects by integers known as *file descriptors*.

- File descriptors 0, 1, and 2 are reserved by convention for *standard input*, *standard output*, and *standard error*.
  "Conforming" Unix programs read input from ***stdin***, write output to ***stdout***, and errors to ***stderr*** by default.
- Other descriptors are assigned by syscalls to open/create files, create pipes, or bind to devices or network sockets.
  pipe, socket, open, creat
- A common set of syscalls operate on open file descriptors independent of their underlying types.
  read, write, dup, close

Unix File Descriptors Illustrated



File descriptors are a special case of *kernel object handles*.

The binding of file descriptors to objects is specific to each process, like the virtual translations in the virtual address space.

Disclaimer: this drawing is oversimplified.

The Concept of Fork

The Unix system call for process creation is called *fork*().

The *fork* system call creates a child process that is a clone of the parent.

- Child has a (virtual) copy of the parent's virtual memory.
- Child is running the same program as the parent.
- Child *inherits* open file descriptors from the parent.

  (Parent and child file descriptors point to a common entry in the system open file table.)
- Child begins life with the same register values as parent.

The child process may execute a different program in its context with a separate *exec()* system call.

Example: Process Creation in Unix

```
int pid;
int status = 0;

if (pid = fork()) {
        /* parent */
        …..
        pid = wait(&status);
} else {
        /* child */
        …..
        exit(status);
}
```

*The **fork** syscall returns twice: it returns a zero to the child and the child process ID (pid) to the parent.*

*Parent uses **wait** to sleep until the child exits; **wait** returns child pid and status.*

***Wait** variants allow wait on a specific child, or notification of stops and other signals.*

What's So Cool About *Fork*

1. *fork* is a simple primitive that allows process creation without troubling with what program to run, args, etc.

   Serves some of the same purposes as threads.
2. *fork* gives the parent program an opportunity to initialize the child process…*especially* the open file descriptors.

   Unix syscalls for file descriptors operate on the current process.

   Parent program running in child process context may open/close I/O and IPC objects, and bind them to *stdin*, *stdout*, and *stderr*.

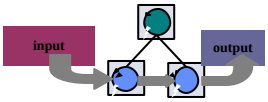
   Also may modify environment variables, arguments, etc.
3. Using the common *fork/exec* sequence, the parent (e.g., a command interpreter or shell) can transparently cause children to read/write from files, terminal windows, network connections, pipes, etc.

Producer/Consumer Pipes

```
char inbuffer[1024];
char outbuffer[1024];

while (inbytes != 0) {
      inbytes = read(stdin, inbuffer, 1024);
      outbytes = process data frominbuffer to outbuffer;
      write(stdout, outbuffer, outbytes);
}
```

Pipes support a simple form of parallelism with built-in *flow control*.



e.g.: *sort <grades | grep Dan | mail sprenkle*

Unix as an Extensible System

"Complex software systems should be built incrementally from components."

- independently developed
- replaceable, interchangeable, adaptable

The power of *fork/exec/exit/wait* makes Unix highly flexible/extensible...at the application level.

- write small, general programs and string them together

  general stream model of communication
- this is one reason Unix has survived

These system calls are also powerful enough to implement powerful command interpreters (*shell*).

The Shell

The Unix command interpreters run as ordinary user processes with no special privilege.

This was novel at the time Unix was created: other systems viewed the command interpreter as a trusted part of the OS.

Users may select from a range of interpreter programs available, or even write their own (to add to the confusion).

csh, *sh*, *ksh*, *tcsh*, *bash*: choose your flavor...or use *perl*.

Shells use *fork/exec/exit/wait* to execute commands composed of program filenames, args, and I/O redirection symbols.

Shells are general enough to run files of commands (*scripts*) for more complex tasks, e.g., by redirecting shell's *stdin*.

Shell's behavior is guided by *environment variables*.

Limitations of the Unix Process Model

The pure Unix model has several shortcomings/limitations:

- Any setup for a new process must be done in its context.
- Separated *Fork/Exec* is slow and/or complex to implement.

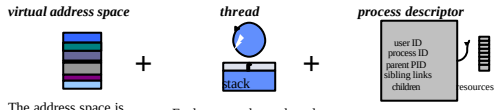
A more flexible process abstraction would expand the ability of a process to manage another externally.

This is a hallmark of systems that support multiple operating system "personalities" (e.g., NT) and "microkernel" systems (e.g., Mach).

Pipes are limited to transferring linear byte streams between a pair of processes with a common ancestor.

Richer IPC models are needed for complex software systems built as collections of separate programs.

Process Internals



The address space is represented by *page table*, a set of translations to physical memory allocated from a kernel *memory manager*.

The kernel must initialize the process memory with the program image to run.

Each process has a thread bound to the VAS.

The thread has a saved user context as well as a system context.

The kernel can manipulate the user context to start the thread in user mode wherever it wants.

Process state includes a file descriptor table, links to maintain the process tree, and a place to store the exit status.

Mode Changes for Exec/Exit

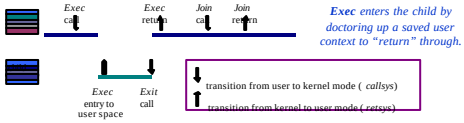
Syscall traps and "returns" are not always paired.

Exec "returns" (to child) from a trap that "never happened"

Exit system call trap never returns

system may switch processes between trap and return

In contrast, interrupts and returns are strictly paired.



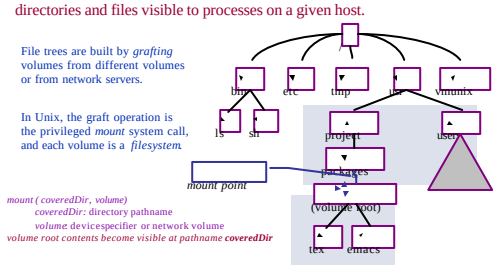
***Exec** enters the child by doctoring up a saved user context to "return" through.*

A Typical Unix File Tree

Each volume is a set of directories and files; a host's *file tree* is the set of directories and files visible to processes on a given host.

File trees are built by *grafting* volumes from different volumes or from network servers.

In Unix, the graft operation is the privileged *mount* system call, and each volume is a *filesystem*.



mount (coveredDir, volume)
coveredDir: directory pathname
volume devicespecifier or network volume
*volume root contents become visible at pathname **coveredDir***

Filesystems

Each file volume (*filesystem*) has a *type*, determined by its disk layout or the network protocol used to access it.

ufs (ffs), lfs, nfs, rfs, cdfs, etc.

Filesystemsare administered independently.

Modern systems also include "logical" pseudo-filesystems in the naming tree, accessible through the file syscalls.

procfs: the */proc* filesystem allows access to process internals.

mfs: the *memory file system* is a memory-based scratch store.

Processes access filesystems through common system calls.

Questions

A process is an execution of a program within a private virtual address space (VAS).

1. What are the system calls to operate on processes?
2. How does the kernel maintain the state of a process?
   Processes are the "basic unit of resource grouping".
3. How is the process virtual address space laid out?
   What is the relationship between the program and the process?
4. How does the kernel create a new process?
   How to allocate physical memory for processes?
   How to create/initialize the virtual address space?