Up until now we've talked about mostly static things: properties of files and users. Now we'll start looking at dynamic things: the programs that are actually running on the computer.

The login shell provides us with some tools for managing the programs we run. We've already talked about some of these, like pipes and redirects. We'll expand on these today, and add some new tools.

Then we'll talk about the underlying processes that actually do the work, and see how to control those, beyond what the shell can do for us.

Finally, we'll introduce one special process, called “init”.

But first, we'll talk a little more about the good old days...

Part 1: Terminals

Then

Now

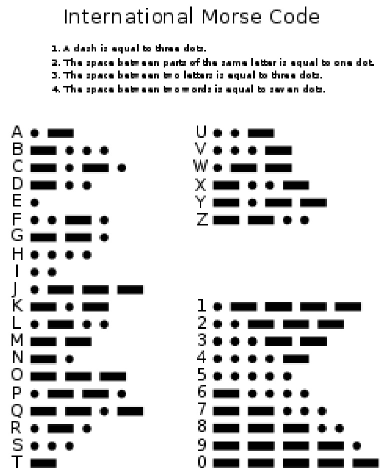
Long ago, people communicated with computers through terminals, like the one on the left, which were connected to the computer by serial communication lines. Bits sent back and forth through these serial lines represented characters typed on the keyboard, or text to display on the monitor.

Although few people use serial terminals any more, the basic mechanisms of communicating through a terminal persist. Now we use “terminal emulator” programs, like xterm or gnome-terminal, to communicate with the computer when we're running the X window system. Each of these terminal emulators behaves just like the old serial terminals. Whenever we talk to a command line, we're still communicating through a terminal (or “pseudo-terminal”) interface, just as we did long ago.

Because of this, it's useful to understand how information is passed to and from terminals.

Character Encoding:

1840s:



1963:

American Standard Code for Information Interchange (ASCII)

1000001	A	1010101	U
1000010	B	1010110	V
1000011	C	1010111	W
1000100	D	1011000	X
1000101	E	1011001	Y
1000110	F	1011010	Z
1000111	G		
1001000	H	0110001	1
1001001	I	0110010	2
1001010	J	0110011	3
1001011	K	0110100	4
1001100	L	0110101	5
1001101	M	0110110	6
1001110	N	0110111	7
1001111	O	0111000	8
1010000	P	0111001	9
1010001	Q		
1010010	R		
1010011	S		
1010100	T		

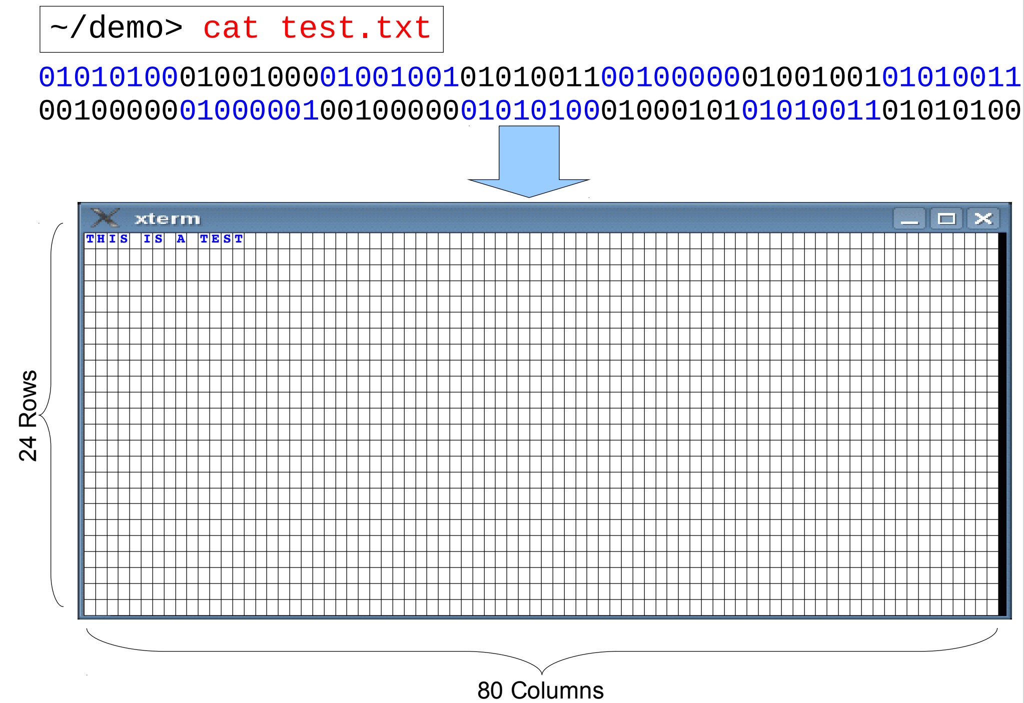
Prior to the 1960s, the most widespread way of communicating data electronically was morse code. When a telegram was sent, its text was encoded in morse code and transmitted through air or a wire to its destination, where it was decoded back into text.

Morse code was fine for human telegraphers, but it was clumsy for computers. In the 1960s the “American Standards Association” published a new, more computer-friendly way of transmitting text. This was called the American Standard Code for Information Interchange (ASCII).

In ASCII, each character is represented by 8 bits of information (1 byte). When you store text in a file on disk, the text is stored as ASCII characters. ASCII characters are also the way communications between a terminal (or pseudo-terminal) and a computer are encoded.

(Actually, other encodings like UTF-8 may be used these days, but the principle is the same. For simplicity, let's just assume everything is ASCII.)

Displaying Text on a Terminal:



If you type a command like "cat test.txt" at the command line, and test.txt is a text file containing the string "THIS IS A TEST", this is what happens. The data in the file is stored on disk as a string of binary ASCII characters. This data is sent to your terminal, which displays it by decoding the ASCII data back into characters.

Old-fashioned serial terminals typically displayed characters on a grid 80 characters wide and 24 characters tall. This is still the default size for most terminal emulator programs.

Also note that when you typed "cat test.txt", the terminal emulator converted your command into ASCII and transmitted it to your shell.

Information about Your Terminal:

What's the name of my terminal?

```
~/demo> tty
/dev/pts/5
```

A “pseudo-terminal” created for a terminal emulator window like xterm or gnome-terminal running under the X window system, or a remote login via ssh.

```
~/demo> tty
/dev/tty1
```

A “virtual console”. You'll see this if you sit down at a Linux computer that's not running X.

What type of terminal is it?

```
~/demo> echo $TERM
xterm
```

This says that the terminal is either the “xterm” terminal emulator, or some other program that acts like an xterm.

```
~/demo> echo $TERM
linux
```

This is what you'll see when sitting at a Linux computer that's not running X.

The “who” and “w” Commands:

The “who” command tells you who's logged in interactively, which terminals they're using, and when they logged in. (There's also some information about X displays, but we'll save that for later.)

```
~/demo> who
elvis     pts/8        2009-02-04 07:28 (:1001)
elvis     pts/12       2009-01-29 07:30 (:1000)
```

The “w” command gives you more information. It also tells you about each user's idle time and CPU usage, and tells you what program the user is currently running.

```
~/demo> w
 10:28:02 up 40 days, 5 min,  3 users,  load average: 0.18, 0.20, 0.12
USER     TTY      FROM              LOGIN@   IDLE   JCPU   PCPU WHAT
elvis     pts/8     :1001             07:28    2:59m  2.18s  0.09s -bin/tcsh
elvis     pts/12    :1000             29Jan09  6days  2.20s  0.10s -bin/tcsh
```

Note that both “who” and “w” may display inaccurate or misleading information about users who are logged in locally through terminal emulator windows under X. The information should be accurate for remote logins through ssh, though.

Part 2: Jobs

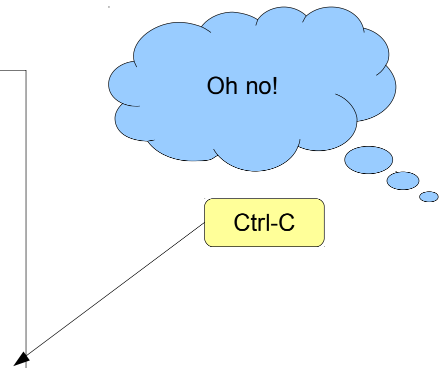
The bash and tcsh command line shells provide users with some tools to manage multiple simultaneous jobs.

Jobs are a convenient way of managing the underlying processes that are really doing the work. There are many mechanisms for starting and managing processes. The shell's job control mechanism is just one of them.

In this section, we'll talk about how the shell handles jobs, and then we'll move on to talking about the underlying processes in the next section.

Canceling a Command with Ctrl-C:

```
~/demo> myprogram
Processing number 0 ...
Processing number 0 ...
Processing number 0 ...
Processing number 0 ...
Processing number 0 ...
Processing number 0 ...
Processing number 0 ...
```



Most interactive command-line programs can be killed by typing Control-C (that is, holding down the “ctrl” key and pressing “c”). This sends a signal to the running process, telling it to terminate immediately. The process has the option of ignoring this signal, but most programs will honor it.

Oh no! I forgot to tell it to increment the count! It's in an infinite loop!

Suspending/Resuming with Ctrl-Z and "fg":

```
~/demo> myprogram
Processing number 0 ...
Processing number 1 ...
Processing number 2 ...
Processing number 3 ...
Processing number 4 ...
Processing number 5 ...
Processing number 6 ...

Suspended
~/demo> jobs
[1]  + Suspended                     myprogram

~/demo> fg
myprogram
Processing number 7 ...
Processing number 8 ...
Processing number 9 ...
Processing number 10 ...
```

Hold on a minute...

Ctrl-Z

Or, altenatively:
"fg %1"

You can suspend a running program by typing Ctrl-Z. The program will stop executing, but it will remain frozen in memory. You start it again with the "fg" command (for "foreground"). The "jobs" command will show you suspended jobs.

The number in square brackets at the beginning of the output is a "job specifier". If you have more than one job, you can tell fg which one to foreground by giving it the job specifier, preceded by a "%" sign. (E.g., "fg %1").

When you log out, you'll be warned if you have any suspended jobs. If you continue to log out, the jobs will die.

The “jobs” Command:

Here's an example showing the output of the “jobs” command when the shell is managing several jobs:

```
~/demo> jobs
[1]  + Suspended                     myprogram
[2]  - Suspended                     myprog2
[3]    Suspended                     otherprog
[4]    Suspended                     prog4
```

The columns are:

Job Specifier. This is a number that uniquely identifies the job. In commands like “fg”, you can choose a particular job by giving a “%” and the job specifier, like “fg %2”.

Current. A “+” in this field means that this is the “current” job. Commands like “fg”, if not explicitly given a job specifier, will operate on this job. A “-” in this field means that this is the “next” job. It will become the current job when the current job finishes.

State. This can be “Suspended”, “Running”, “Stopped” or “Done”.

Command. The name of the command being run by this job.

Sending Jobs to the Background with “bg”:

```
~/demo> myprogram
Processing number 0 ...
Processing number 1 ...

Suspended
~/demo> jobs
[1]  + Suspended                    myprogram

~/demo> bg
[1]    myprogram &

~/demo>
Processing number 7 ...
Processing number 8 ...
Processing number 9 ...
Processing number 10 ...
```

Ctrl-Z

We get a command prompt back

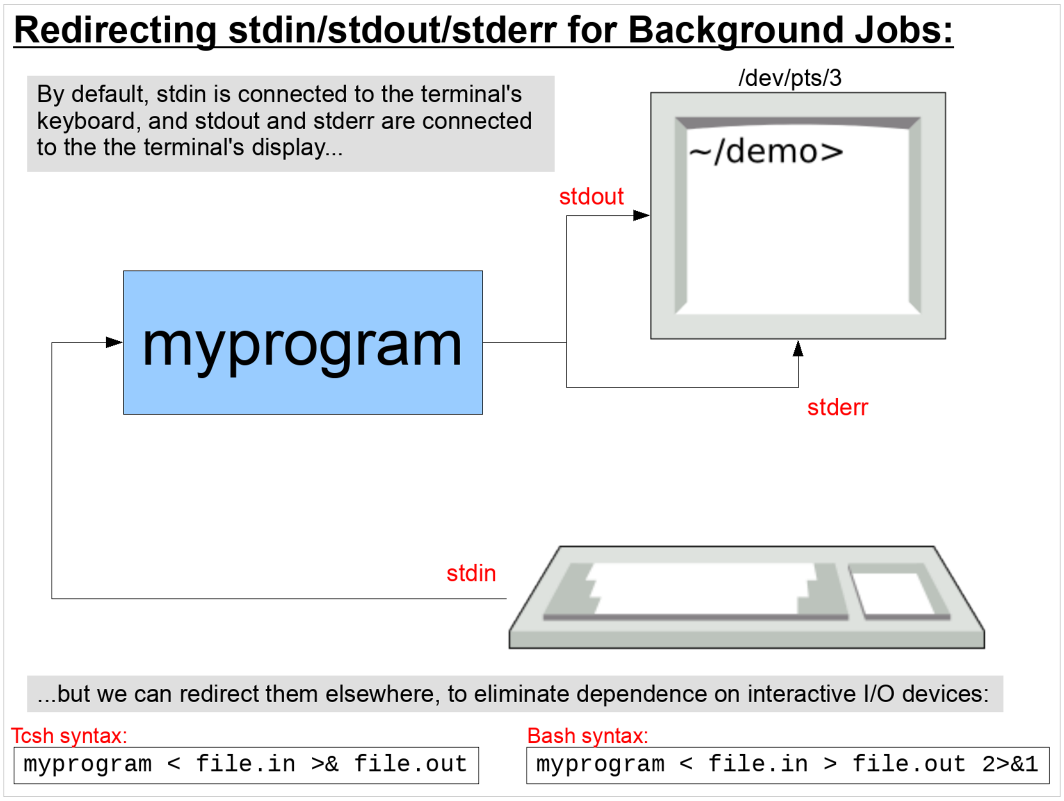
But any output will continue to pop up, whenever the program says anything.

If you want a job to continue running while you go on and do other things, you can use the “bg” (for “background”) command to put it into the background. The job will continue to run, and you'll see any output it generates.

This is useful, but it has two problems:

1. The output from your program may be annoying while you're trying to do other things.

2. If you log out, your backgrounded jobs may die. This will happen if the backgrounded job tries to read or write anything interactively. Once you've logged out, the program will get an error if it tries to ask you for input or write any output to the terminal, because those devices are no longer available.



If we can connect the I/O channels to something other than our current display and keyboard, we can think about putting the job in the background, logging out, and coming back later to check on it.

We've already seen how to redirect stdout and stderr. Now we see that stdin can be redirected also, with the “<” character.

The commands above say “run myprogram, reading input from 'file.in' and writing output and errors into 'file.out'.”

We could start the program this way, and then type Ctrl-Z to suspend it, and “bg” to background it, or....

Starting a Job in the Background:

Tcsh syntax:

```
~/demo> myprogram < /dev/null >& myprogram.out &
```

Bash syntax:

```
~/demo> myprogram < /dev/null > myprogram.out 2>&1 &
```

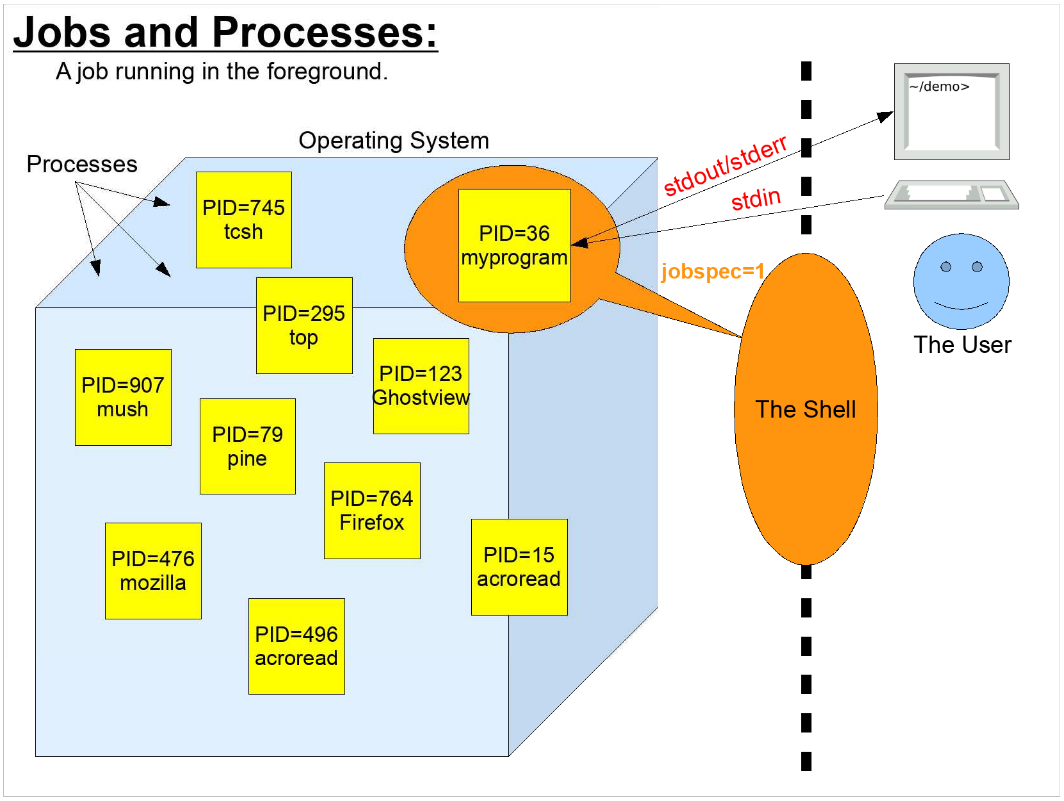
Appending an ampersand to the end of a command causes the command to be put into the background immediately.

```
~/demo> jobs
[1] + Running ./myprogram < /dev/null >& myprogram.out
```

If you don't need to give your program any input, and if you don't want to create an empty file to point stdin at, you can just use the handy “null device”, /dev/null. This should always be present.

By default, when the shell starts a program the program's stdin, stdout and stderr all point to the user's terminal. Remember the general principle in Linux that “everything is a file”? Well, the terminal appears to the operating system as though it were just another file, with a name like “/dev/pts/3” or some such. By default, the shell points stdin, stdout and stderr to this file, just as though you'd typed something like:

```
myprogram < /dev/pts/3 >& /dev/pts3
```



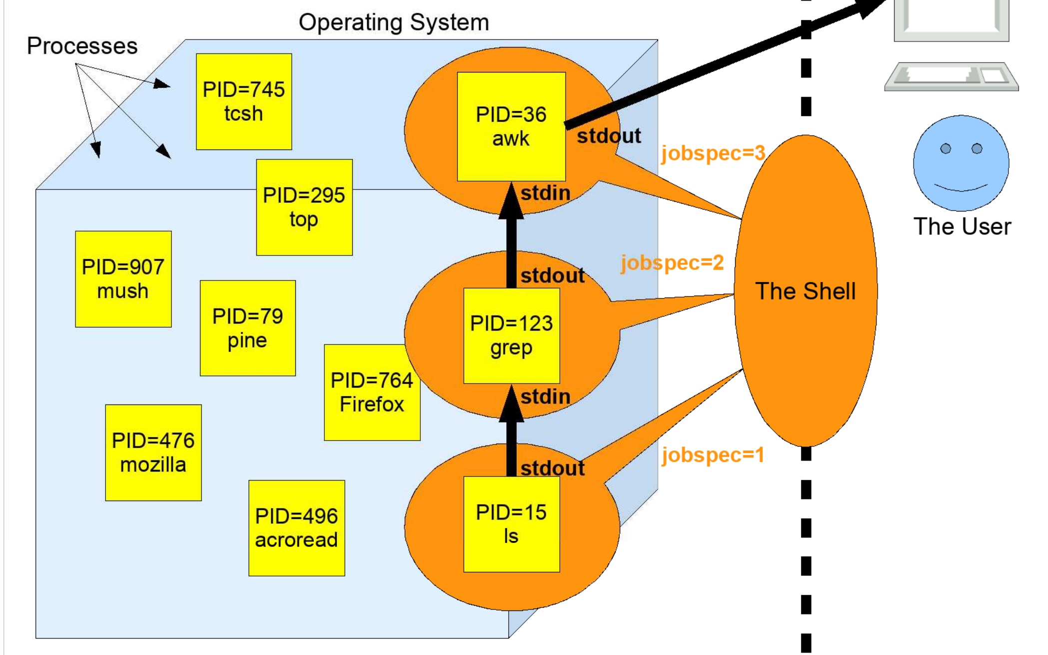
The shell's job control features just provide a convenient way of dealing with processes running in the operating system.

The shell's fg and bg commands, the jobs command, and all the tools for controlling jobs, are just handles to make the management of the underlying processes more convenient. You might think of the relationship between “job” and “process” as something like the relationship between bowling-ball-case and bowling ball.

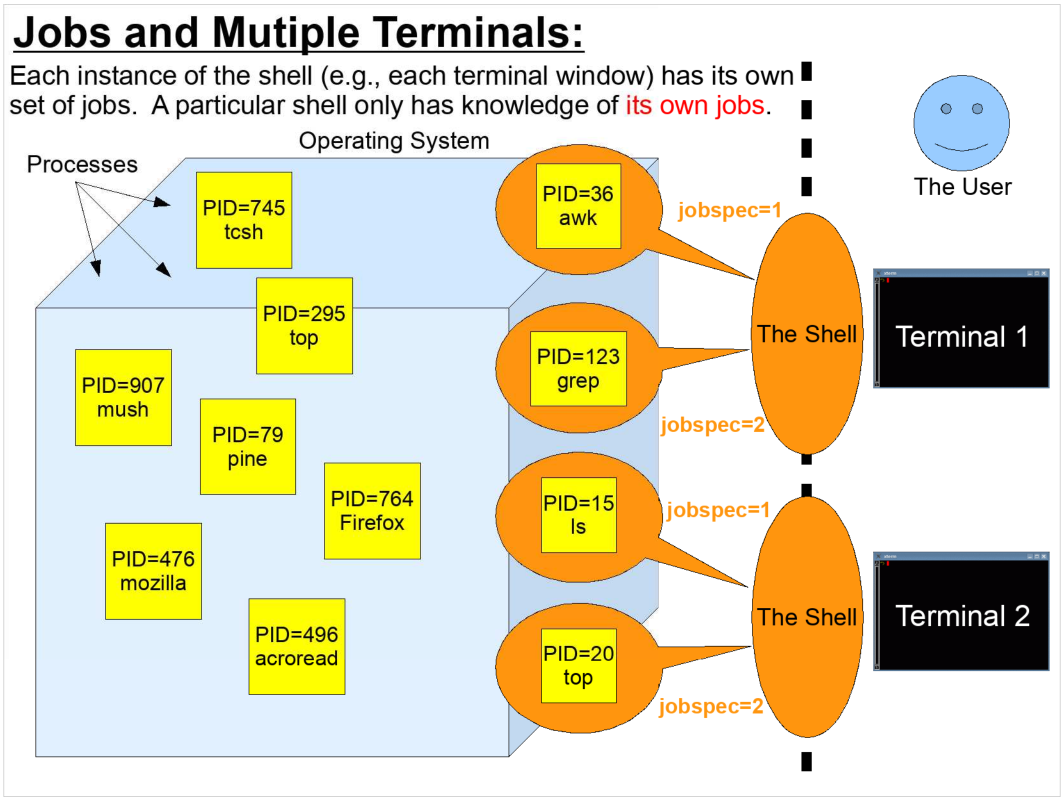
Jobs are just containers for processes spawned off by the shell. The shell gives you a convenient “job specifier” to refer to each job, separate from the “process ID” of the contained process. The shell can connect jobs to your terminal, or to each other, through the processes' stdin and stdout channels.

Pipelines:

The command ls -al | grep file.dat | awk '{print $2}'



The Shell creates pipelines by creating jobs and connecting the jobs' processes together through their stdin and stdout channels.

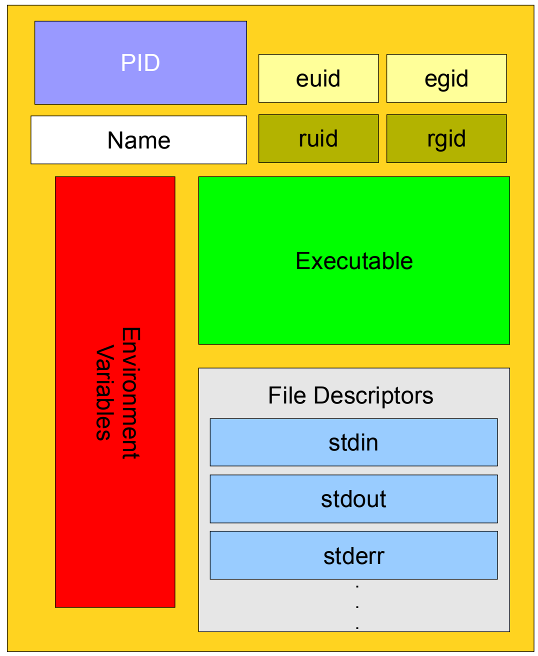


Notice that each shell has its own set of "job specifiers", but the "process IDs" (PIDs) are unique across the whole operating system.

Part 3: Processes

So, what are processes?

The Structure of a Process:



Every process has a unique numerical identifier called a “process ID” or “PID”, analogous to the UID for a user or the GID for a group.

The ownership of a process is specified by UID and GID values stored within the process. Each process has two pairs of these: “effective” UID and GID and “real” UID and GID.

Each process has an associated “executable”, which is usually a program stored on disk. (Sometimes the kernel will create processes on its own, and these don't point to a separate program.)

The process has a list of file descriptors, which point to the process's stdin/stdout/stderr and any other files the program currently has open for reading or writing.

The “ps” Command:

```
~/demo> ps
  PID TTY          TIME CMD
11387 pts/19   00:00:00 ps
30922 pts/19   00:00:00 tcsh
```

Just show processes belonging to me, and associated with the current terminal session. Or...

Show all processes, and show their “family trees”.

```
~/demo> ps auxf
USER       PID %CPU %MEM   VSZ  RSS TTY      STAT START   TIME COMMAND
root         1  0.0  0.1  2080  600 ?        Ss    2008   0:02 init [3]
root       372  0.0  0.1  2436  856 ?        S<s   2008   0:01 /sbin/udevd -d
root      4182  0.0  0.1 12144  696 ?        S<sl  2008   0:10 auditd
root      4184  0.0  0.1 12060  696 ?        S<sl  2008   0:05  \_ /sbin/audispd
root      4217  0.0  0.1  1728  576 ?        Ss    2008   0:09 syslogd -m 0
root      4220  0.0  0.0  1684  416 ?        Ss    2008   0:00 klogd -x
dbus      4386  0.0  0.2  2880 1140 ?        Ss    2008   0:02 dbus-daemon --system
root      4528  0.0  0.2 11440 1168 ?        Ssl   2008   0:01 automount
root      4552  0.0  0.1  1676  548 ?        Ss    2008   0:00 /usr/sbin/acpid
root      4626  0.0  0.1  2736  852 ?        Ss    2008   0:00 xinetd -stayalive -pidfile
root      4692  0.0  0.2  5284 1116 ?        Ss    2008   0:01 crond
root      4759  0.0  0.0  2260  448 ?        Ss    2008   0:00 /usr/sbin/atd
68        4887  0.0  0.7  5512 3532 ?        Ss    2008   0:01 hald
root      4888  0.0  0.2  3148  988 ?        S     2008   0:00  \_ hald-runner
68        4895  0.0  0.1  2008  792 ?        S     2008   0:00      \_ hald-addon-acpi: listening on
68        4899  0.0  0.1  2004  792 ?        S     2008   0:00      \_ hald-addon-keyboard: listening
root      4905  0.0  0.1  1960  628 ?        S     2008  52:22      \_ hald-addon-storage: polling
root      5134  0.0  0.2  2848 1332 ?        SN    2008   0:00 /usr/libexec/gam_server
root      5512  0.0  0.1  2320  752 ?        Ss    2008   0:01 /sbin/dhclient -1 -q -lf
root      5759  0.0  0.0  1948  356 ?        S     2008   0:00 /usr/sbin/smartd -q never
root      5770  0.0  0.2  2872 1256 ?        Ss    2008   0:00 login -- root
root     10665  0.3  0.2  4540 1404 tty1     Ss   17:53   0:00  \_ -bash
root     10697  0.0  0.1  4232  904 tty1     R+   17:54   0:00      \_ ps auxf
root      5771  0.0  0.0  1664  436 tty2     Ss+   2008   0:00 /sbin/mingetty tty2
root      5775  0.0  0.0  1668  440 tty3     Ss+   2008   0:00 /sbin/mingetty tty3
root      5785  0.0  0.0  1664  460 tty4     Ss+   2008   0:00 /sbin/mingetty tty4
root      5786  0.0  0.0  1668  436 tty5     Ss+   2008   0:00 /sbin/mingetty tty5
root      5787  0.0  0.0  1668  440 tty6     Ss+   2008   0:00 /sbin/mingetty tty6
root      5702  0.0  0.1  7044 1056 ?        Ss   Jan22   0:04 /usr/sbin/sshd
elvis     7123  0.0  0.2 10040 2860 ?        Ss   Jan30   0:00  \_ sshd: elvis@pts/0
elvis     7125  0.0  0.1  4532 1452 pts/0    Ss   Jan30   0:00      \_ -bash
elvis    27760  0.0  0.0  4212  904 pts/0    R+   18:00   0:00          \_ ps auxf
```

The “ps” command can shows information about processes, much as the “ls” command shows information about files.

The “user” field shows the username of the owner of each process.

%CPU and %Mem show what fraction of these resources the process is currently using.

VSZ and RSS are two measures of how much memory the process is using.

The TTY column shows the name of any terminal that's attached to this process.

The STAT column tells us what the process is currently doing. Entries beginning with “R” are running. Entries beginning with “S” are sleeping.

The “top” command:

The “top” command gives a continuously-updating display showing what's happening on a computer. It packs a lot of information into a small space. The upper part of the display has information about users, memory, load, etc., and the lower part of the display has information about processes. By default, the display is sorted so that processes using the largest fraction of the available CPU time are displayed at the top.

CPU Hog!

```
~/demo> top
top - 18:23:14 up 187 days,  8:08,  4 users,  load average: 1.05, 1.03, 1.00
Tasks: 215 total,   2 running, 213 sleeping,   0 stopped,   0 zombie
Cpu(s):  0.6%us,  0.2%sy,  0.0%ni, 99.0%id,  0.1%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:    4017152k total,  3990516k used,    26636k free,     3776k buffers
Swap:  2031608k total,   333196k used,  1698412k free,  3511864k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
32043 ef2p      25   0 70756  34m  14m R  100  0.9   4:24.05 analyzer
32197 bkw1a     15   0  2436  928  660 R    2  0.0   0:00.01 top
    1 root      15   0  2080  632  544 S    0  0.0   0:01.60 init
    2 root      RT  -5     0    0    0 S    0  0.0   0:19.57 migration/0
    3 root      34  19     0    0    0 S    0  0.0   0:14.26 ksoftirqd/0
    4 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/0
    5 root      RT  -5     0    0    0 S    0  0.0   0:12.85 migration/1
    6 root      34  19     0    0    0 S    0  0.0   0:04.38 ksoftirqd/1
    7 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/1
    8 root      RT  -5     0    0    0 S    0  0.0   0:09.87 migration/2
    9 root      39  19     0    0    0 S    0  0.0   0:03.24 ksoftirqd/2
   10 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/2
   11 root      RT  -5     0    0    0 S    0  0.0   0:11.41 migration/3
   12 root      34  19     0    0    0 S    0  0.0   0:03.63 ksoftirqd/3
```

Some interesting information:

- Uptime. This shows how long the computer has been running.

- Number of users currently logged in.

- Load average. Think of this as the average number of processes running at any given time. The three numbers are rolling averages over 1, 5 and 15 minutes.

- Memory. This shows the amount of total memory and free memory, and has data about swap space usage.

The “watch” Command:

Wouldn't it be nice if you could make any command continuously-updating, like top? You can, with the “watch” command. By default, watch re-executes a command every two seconds, and updates the display to show how the command's output has changed.

~/demo> watch w

```
Every 2.0s: w                                           Wed Feb  4 10:58:20
2009

 10:58:20 up 40 days, 35 min,  2 users,  load average: 0.06, 0.17, 0.13
USER     TTY      FROM              LOGIN@   IDLE   JCPU   PCPU WHAT
elvis     pts/12   :1000            29Jan09  6days  2.21s  0.10s -bin/tcsh
elvis     pts/8    :1001            07:28    2:59m  2.18s  0.09s -bin/tcsh
```

~/demo> watch stat junk.dat

```
Every 2.0s: stat junk.dat                               Wed Feb  4 11:02:43
2009

  File: `junk.dat'
  Size: 14              Blocks: 8          IO Block: 4096   regular file
Device: fd00h/64768d    Inode: 10321951    Links: 1
Access: (0644/-rw-r--r--)  Uid: (  500/   bkw1a)   Gid: (  501/   bkw1a)
Access: 2009-02-04 10:54:59.000000000 -0500
Modify: 2009-02-04 09:28:04.000000000 -0500
Change: 2009-02-04 09:28:04.000000000 -0500
```

Niceness:

One of the columns "top" displays is "NI", for "Niceness". Each process has a niceness value between -20 and 20. By default, processes start off with a niceness of zero. Processes with higher niceness are more willing to give up the CPU when another process wants to use it. Critical system processes are often run at negative niceness values, since it's important that they have access to the CPU when they need it. Low-priority processes may run with a very high niceness, so they only get the CPU when nothing else wants it. Non-root users can adjust the niceness of their processes, but they can't lower it below its initial value.

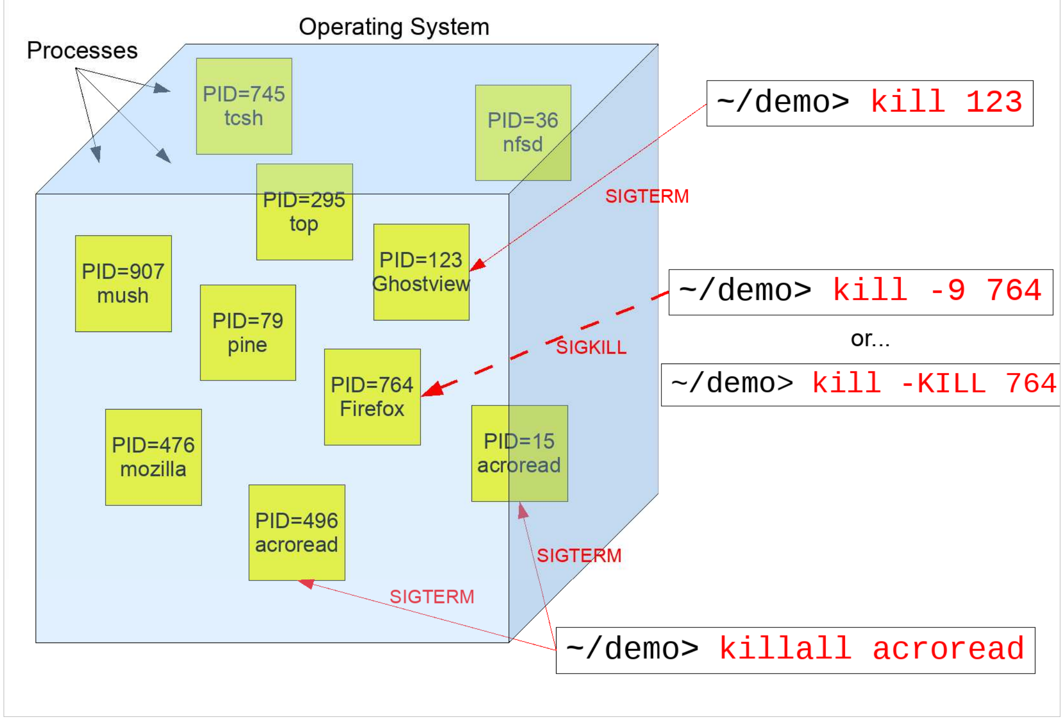
```
~/demo> renice 15 32043
```

(assuming I'm ef2p!)

```
~/demo> top
top - 18:23:14 up 187 days,  8:08,  4 users,  load average: 1.05, 1.03, 1.00
Tasks: 215 total,   2 running, 213 sleeping,   0 stopped,   0 zombie
Cpu(s):  0.6%us,  0.2%sy,  0.0%ni, 99.0%id,  0.1%wa,  0.0%hi,  0.0%si,  0.0%st
Mem:   4017152k total,  3990516k used,    26636k free,     3776k buffers
Swap:  2031608k total,   333196k used,  1698412k free,  3511864k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
32043 ef2p      25  15 70756  34m  14m R  100  0.9   4:24.05 analyzer
32197 bkw1a     15   0  2436  928  660 R    2  0.0   0:00.01 top
    1 root      15   0  2080  632  544 S    0  0.0   0:01.60 init
    2 root      RT  -5     0    0    0 S    0  0.0   0:19.57 migration/0
    3 root      34  19     0    0    0 S    0  0.0   0:14.26 ksoftirqd/0
    4 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/0
    5 root      RT  -5     0    0    0 S    0  0.0   0:12.85 migration/1
    6 root      34  19     0    0    0 S    0  0.0   0:04.38 ksoftirqd/1
    7 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/1
    8 root      RT  -5     0    0    0 S    0  0.0   0:09.87 migration/2
    9 root      39  19     0    0    0 S    0  0.0   0:03.24 ksoftirqd/2
   10 root      RT  -5     0    0    0 S    0  0.0   0:00.00 watchdog/2
   11 root      RT  -5     0    0    0 S    0  0.0   0:11.41 migration/3
   12 root      34  19     0    0    0 S    0  0.0   0:03.63 ksoftirqd/3
```

The “kill” and “killall” Commands:



How can we control a process? One way is by sending it “signals”.

The “kill” command can be used to send signals to processes. The name is misleading, because only some of the signals will normally result in killing the process. Killing processes was the original purpose of the command, and the name stuck even after the command's purpose was expanded. (Maybe a better name would be “signal”.)

By default, the “kill” command will send a “SIGTERM” signal to a process. You can modify this behavior by specifying a signal, either by number or by name.

Signals:

Signals are sent to processes as 5-bit values (0-31). This is the basic set of signals that should be available under any Unix-like operating system. Two of these signals, SIGKILL (9) and SIGSTOP (19) are special, because processes can't ignore them or catch them.

Signal	Value	Default Action	Comment	
SIGHUP	1	Term	Hangup detected on controlling terminal or death of controlling process	
SIGINT	2	Term	Interrupt from keyboard	Sent by Ctrl-C
SIGQUIT	3	Core	Quit from keyboard	
SIGILL	4	Core	Illegal Instruction	
SIGABRT	6	Core	Abort signal from abort(3)	
SIGFPE	8	Core	Floating point exception	
SIGKILL	9	Term	Kill signal	
SIGUSR1	10	Term	User-defined signal 1	
SIGSEGV	11	Core	Invalid memory reference	
SIGUSR2	12	Term	User-defined signal 2	
SIGPIPE	13	Term	Broken pipe: write to pipe with no readers	
SIGALRM	14	Term	Timer signal from alarm(2)	
SIGTERM	15	Term	Termination signal	
SIGCHLD	17	Ign	Child stopped or terminated	
SIGCONT	18	Cont	Continue if stopped	Sent by “fg” or “bg”
SIGSTOP	19	Stop	Stop process	
SIGTSTP	20	Stop	Stop typed at tty	Sent by Ctrl-Z
SIGTTIN	21	Stop	tty input for background process	
SIGTTOU	22	Stop	tty output for background process	

The SIGTTIN and SIGTTOU signals are received by a process when it tries unsuccessfully to read input or write output to a terminal. By default, these signals cause the process to stop, just as a SIGSTOP would do.

References like “alarm(2)” and “abort(3)” refer to man pages. For example, “alarm(2)” refers to the man page for the term “alarm” in section 2 of the man pages. You could view it by typing “man 2 alarm”.

Signal Actions:

Several pre-defined actions are available for processes to take when they receive a signal. Processes may also define their own signal-handling functions for any signals except SIGKILL and SIGSTOP.

Action	Description
Term	Terminate the process.
Ign	Ignore the signal.
Core	Terminate the process and dump core (see core(5)).
Stop	Stop the process.
Cont	Continue the process if it is currently stopped.
Catch	Call a predefined signal-handling function.

The /proc Filesystem:

The /proc directory doesn't exist on-disk. It's created in memory and kept up-to-date by the kernel. If you look into /proc, you'll see a bunch of directories, each with a number as its name. Each of these numbers is the PID of a process, and the directory contains information about the process with that PID. Here's a typical example:

```
[root@demo ~]# ls -l /proc/19335
total 0
dr-xr-xr-x   2 elvis elvis 0 Feb  3 15:13 attr
-r--------   1 elvis elvis 0 Feb  3 15:13 auxv
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 cmdline
-rw-r--r--   1 elvis elvis 0 Feb  3 15:13 coredump_filter
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 cpuset
lrwxrwxrwx   1 elvis elvis 0 Feb  3 15:13 cwd -> /home/elvis
-r--------   1 elvis elvis 0 Feb  3 15:13 environ
lrwxrwxrwx   1 elvis elvis 0 Feb  3 15:13 exe -> /usr/bin/top
dr-x------   2 elvis elvis 0 Feb  3 15:13 fd
-r--------   1 elvis elvis 0 Feb  3 15:13 limits
-r--------   1 elvis elvis 0 Feb  3 15:13 limits
-rw-r--r--   1 elvis elvis 0 Feb  3 15:13 loginuid
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 maps
-rw-------   1 elvis elvis 0 Feb  3 15:13 mem
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 mounts
-r--------   1 elvis elvis 0 Feb  3 15:13 mountstats
-rw-r--r--   1 elvis elvis 0 Feb  3 15:13 oom_adj
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 oom_score
lrwxrwxrwx   1 elvis elvis 0 Feb  3 15:13 root -> /
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 schedstat
-r--------   1 elvis elvis 0 Feb  3 15:13 smaps
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 stat
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 statm
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 status
dr-xr-xr-x   3 elvis elvis 0 Feb  3 15:13 task
-r--r--r--   1 elvis elvis 0 Feb  3 15:13 wchan
```

Open file descriptors.

```
0 -> /dev/pts/19
1 -> /dev/pts/19
2 -> /dev/pts/19
3 -> /proc/uptime
4 -> /proc/loadavg
5 -> /proc/stat
6 -> /proc/meminfo
```

Each entry is a symbolic link. The numerical name is the file descriptor. 0,1 and 2 are stdin,stdout and stderr.

The /proc filesystem contains everything you should need to know about processes running on the computer. Tools like “ps” and “top” look at /proc to get the data they display for you. You can also look at /proc directly if you want. Each file in /proc contains only plain text.

The “lsof” Command:

The lsof command can list the open files associated with a given process.

```
[root@demo ~]# lsof -p 19335
COMMAND   PID  USER   FD   TYPE DEVICE    SIZE       NODE NAME
top     19335 elvis  cwd    DIR  253,0    4096   29592275 /home/elvis
top     19335 elvis  rtd    DIR  253,0    4096          2 /
top     19335 elvis  txt    REG  253,0   62200   33185251 /usr/bin/top
top     19335 elvis  mem    REG  253,0   46680   34766935 /lib/libnss_files-2.5.so
top     19335 elvis  mem    REG  253,0  135032   34768080 /lib/libncurses.so.5.6
top     19335 elvis  mem    REG  253,0  125736   34766911 /lib/ld-2.5.so
top     19335 elvis  mem    REG  253,0 1614588   34766856 /lib/i686/nosegneg/libc-2.5.so
top     19335 elvis  mem    REG  253,0   53856   34768103 /lib/libproc-3.2.7.so
top     19335 elvis  mem    REG  253,0   16428   34766870 /lib/libdl-2.5.so
top     19335 elvis  mem    REG  253,0   95060   34768079 /lib/libtinfo.so.5.6
top     19335 elvis    0u   CHR 136,19                 21 /dev/pts/19
top     19335 elvis    1u   CHR 136,19                 21 /dev/pts/19
top     19335 elvis    2u   CHR 136,19                 21 /dev/pts/19
top     19335 elvis    3r   REG    0,3       0 4026531841 /proc/uptime
top     19335 elvis    4r   REG    0,3       0 4026531840 /proc/loadavg
top     19335 elvis    5r   REG    0,3       0 4026531853 /proc/stat
top     19335 elvis    6r   REG    0,3       0 4026531842 /proc/meminfo
```

Current working directory

Root directory

“Text” segment of a binary executable

File descriptors

Shared libraries, mapped into memory

The lsof command also gets its information from /proc.

The “fuser” Command:

The fuser command is like the inverse of lsof. It tells you what processes are using a given file or directory.

```
[root@demo ~]# fuser /usr/bin/top
/usr/bin/top:         19335e
```

```
[root@demo ~]# fuser /lib/libdl-2.5.so
/lib/libdl-2.5.so:       1m  1275m  1345m  1347m  2153m  2167m  4422m
4441m  4446m  8500m  8512m 12605m 12615m 12623m 12626m 13950m 13968m
14735m 14766m 15742m 15744m 18110m 18163m 18165m 18166m 18280m 18281m
18283m 18288m 18290m 18314m 18569m 18572m 18573m 18588m 18590m 18592m
18822m 18823m 18825m 18828m 18829m 18872m 18874m 18877m 18878m 18926m
18929m 18931m 18933m 18940m 18941m 18943m 18945m 18946m 18952m 18960m
18974m 19001m 19016m 19303m 19335m 20306m 20307m 20308m 20309m 20348m
23073m 23547m 26132m 26134m 26183m 26185m 26190m 26192m 26492m 26494m
26724m 26725m 26726m 26730m 26738m 26774m 26776m 26779m 26780m 26823m
26828m 26831m 26833m 26835m 26843m 26844m 26846m 26848m 26849m 26860m
26865m 27449m 27451m 27943m 27944m 28330m 28344m 28385m 28558m 29746m
29983m 30920m 31212m 31214m
```

Fuser, too, gets its information from /proc. The letters after the PIDs tell you how the file is being used by the given process. The “e” in the first example means that the process is executing this file.

The “strace” Command:

The strace command allows you to attach to a running process and see the system functions it calls as it works. This makes strace a very useful debugging tool.

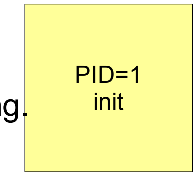
```
[root@demo ~]# strace -f -p 12345
ioctl(0, FIONREAD, [134917803]) = -1 ENOTTY
(Inappropriate ioctl for device)
read(0, "", 1) = 0
ioctl(0, FIONREAD, [134917803]) = -1 ENOTTY
(Inappropriate ioctl for device)
read(0, "", 1) = 0
ioctl(0, FIONREAD, [134917803]) = -1 ENOTTY
(Inappropriate ioctl for device)
read(0, "", 1) = 0
ioctl(0, FIONREAD, [134917803]) = -1 ENOTTY
(Inappropriate ioctl for device)
read(0, "", 1) = 0
ioctl(0, FIONREAD, [134917803]) = -1 ENOTTY
(Inappropriate ioctl for device)
```

The strace output above comes from a problem we recently had with someone's program. It shows that the process was trying to communicate with a terminal on stdin, and was continually calling the “read” and “ioctl” functions on file descriptor zero (stdin).

The program was running detached from a terminal, so the ioctl function failed (“ENOTTY”, means there was an error because there was no terminal available). Reconfiguring the program so that it didn't try to read from stdin fixed the problem.

Part 4: The “init” Process

The “init” Process:



• init is the first process started while a computer is booting.

• It always gets PID=1.

• Init is just a program, usually in /sbin/init. (The boot process has a built-in default value for this path, but it can be overridden manually at boot time.)

• It's init's responsibility to start up all of the other processes to complete the boot process.

• init reads the file /etc/inittab to see what processes need to be started.

• Entries in /etc/inittab are tied to specific “runlevels”. The runlevel is a number, usually between 0 and 6, that tells init which set of processes to start.

Note that only a few runlevels have standard meanings across all Linux distributions. Other than these standards, vendors are free to use the runlevels in any way they choose.

We'll talk much more about init when we start talking about network services. For now, this is just a quick introduction.

The /etc/inittab File:

```
# Default runlevel. The runlevels used by RHS are:
#   0 - halt (Do NOT set initdefault to this)
#   1 - Single user mode
#   2 - Multiuser, without NFS (The same as 3, if you do not have networking)
#   3 - Full multiuser mode
#   4 - unused
#   5 - X11
#   6 - reboot (Do NOT set initdefault to this)
#
id:5:initdefault:

# System initialization.
si::sysinit:/etc/rc.d/rc.sysinit

l0:0:wait:/etc/rc.d/rc 0
l1:1:wait:/etc/rc.d/rc 1
l2:2:wait:/etc/rc.d/rc 2
l3:3:wait:/etc/rc.d/rc 3
l4:4:wait:/etc/rc.d/rc 4
l5:5:wait:/etc/rc.d/rc 5
l6:6:wait:/etc/rc.d/rc 6

# Run gettys in standard runlevels
1:2345:respawn:/sbin/mingetty tty1
2:2345:respawn:/sbin/mingetty tty2
3:2345:respawn:/sbin/mingetty tty3
4:2345:respawn:/sbin/mingetty tty4
5:2345:respawn:/sbin/mingetty tty5
6:2345:respawn:/sbin/mingetty tty6

# Run xdm in runlevel 5
x:5:respawn:/etc/X11/prefdm -nodaemon
```

In this case, the default runlevel is 5

This gets run before anything else

These start up the appropriate processes for each runlevel

In runlevels 2,3,4 and 5, make sure the virtual console processes are always running

Keep the X display manager running in runlevel 5

Runlevels 0,1 and 6 (halt, single-user mode and reboot) are standard across all Linux distributions. The use of the other numbers varies widely. The example above is from a Red Hat-derived system.

... but wait....

Lennart Poettering, father of systemd

All of the preceding stuff about "init" was true for many years. Recently, though, many Linux distributions have replaced init with a new tool, "systemd". Systemd aims to replace init and other parts of the operating system with a highly integrated framework that manages booting, network services, and many other things.

Systemd is still highly controversial, and the community of Linux developers is split on whether systemd is a good thing or a bad thing.

We'll talk more about systemd when we address network services and how they're started.

Thanks!