CS631 - Advanced Programming in the UNIX Environment
–
Process Groups, Sessions, Signals

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Code reading

A volunteer, please...

Login Process

```
[...]
total memory = 768 MB
avail memory = 732 MB
timecounter: Timecounters tick every 10.000 msec
mainbus0 (root)
[...]
boot device: xbd3
root on xbd3a dumps on xbd3b
mountroot: trying lfs...
mountroot: trying ffs...
root file system type: ffs
init: copying out path ‘/sbin/init’ 11
[...]
Starting local daemons:.
Starting sendmail.
Starting sshd.
Starting snmpd.
Starting cron.

NetBSD/amd64 (panix.netmeister.org) (console)

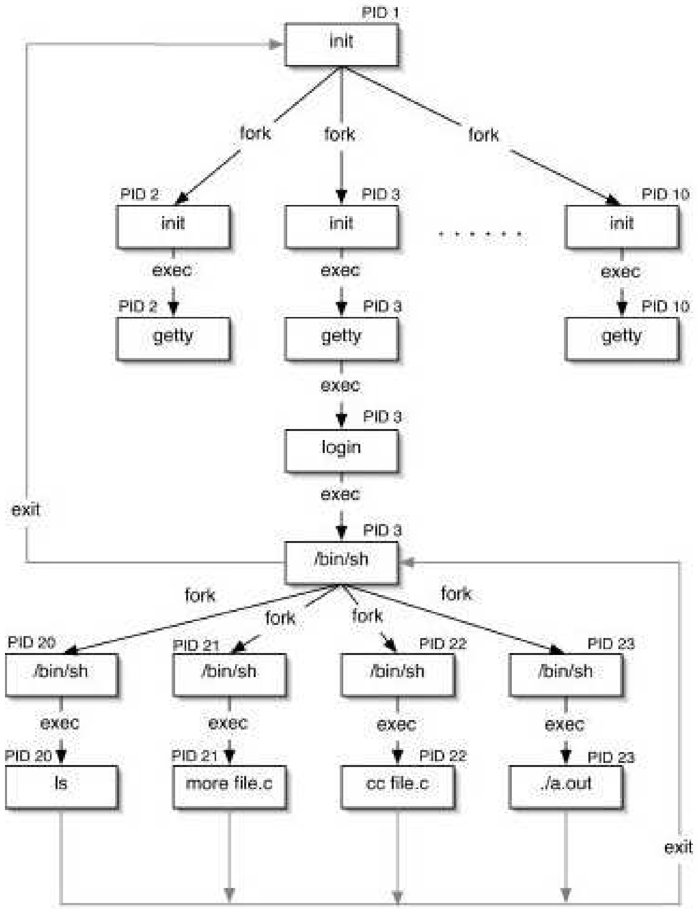
login: jschauma
Password:
Last login: Sat Sep 10 14:27:56 2011 on console
Copyright (c) 1982, 1986, 1989, 1991, 1993
    The Regents of the University of California.  All rights reserved.

NetBSD 5.0.2 (PANIX-VC) #2: Tue Oct 19 16:30:57 EDT 2010

Welcome to NetBSD!

$
```

Login Process



Login Process

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  - reads `/etc/ttys`

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  - opens terminal
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  - setuid(2) to user’s uid, exec(3) shell

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init(8)	⇒	getty(8)	# fork(2)
getty(8)	⇒	login(1)	# exec(3)
login(1)	⇒	`$SHELL`	# exec(3)
`$SHELL`	⇒	ls(1)	# fork(2) + exec(3)

Login Process

init(8) # PID 1, PPID 0, EUID 0

Login Process

init(8) # PID 1, PPID 0, EUID 0

getty(8) # PID *N*, PPID 1, EUID 0

Login Process

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Login Process

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getty(8) # PID *N*, PPID 1, EUID 0

login(1) # PID *N*, PPID 1, EUID 0

`$SHELL` # PID *N*, PPID 1, EUID *U*

Login Process

init(8)	# PID 1, PPID 0, EUID 0
getty(8)	# PID N, PPID 1, EUID 0
login(1)	# PID N, PPID 1, EUID 0
`$SHELL`	# PID N, PPID 1, EUID U
ls(1)	# PID M, PPID N, EUID U

```
pstree -hapun | more
```

Process Groups

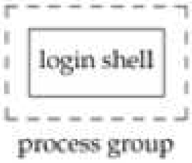
```
#include <unistd.h>

pid_t getpgrp(void);
pid_t getpgid(pid_t pid);
```

Returns: process group ID if OK, -1 otherwise

- in addition to having a PID, each process also belongs to a process group (collection of processes assocaited with the same job / terminal)
- each process group has a unique process group ID
- process group IDs (like PIDs) are positive integers and can be stored in a `pid_t` data type
- each process group can have a process group leader
  - leader identified by its process group ID == PID
  - leader can create a new process group, create processes in the group
- a process can set its (or its children's) process group using `setpgid(2)`

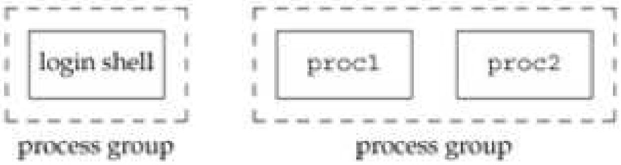
Process Groups



init ⇒ *login shell*

$

Process Groups



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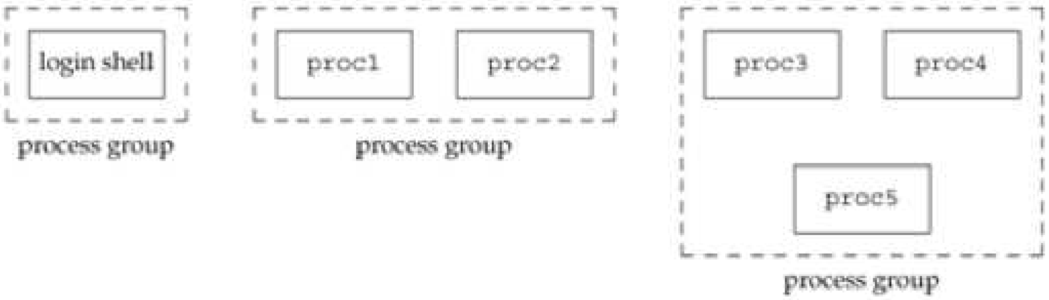
```
$ proc1 | proc2 &
[1] 10306
$
```

Process Groups



init ⇒ *login shell*

```
$ proc1 | proc2 &
[1] 10306
$ proc3 | proc4 | proc5
```

Process Groups and Sessions

```
#include <unistd.h>

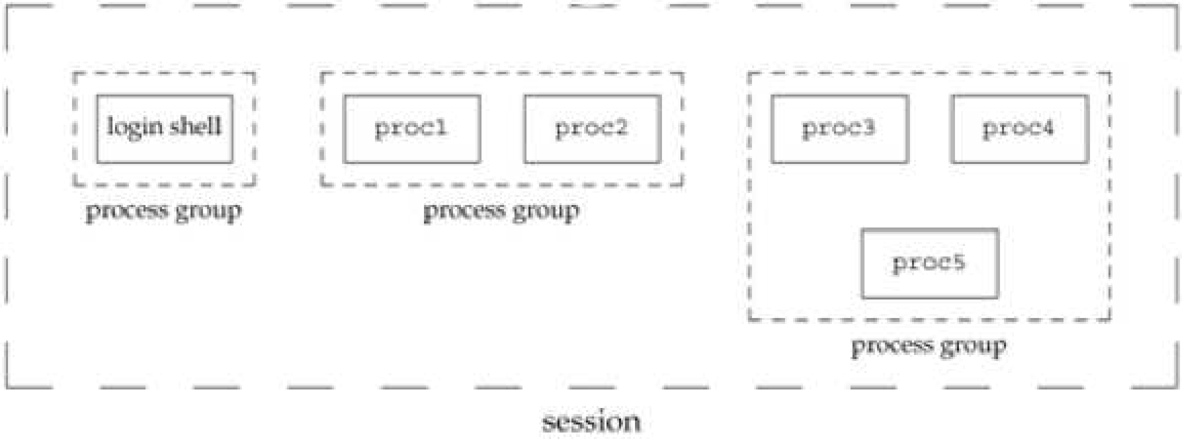
pid_t setsid(void);
                Returns: process group ID if OK, -1 otherwise
```

A session is a collection of one or more process groups.

If the calling process is not a process group leader, this function creates a new session. Three things happen:

- the process becomes the session leader of this new session
- the process becomes the process group leader of a new process group
- the process has no controlling terminal

Process Groups



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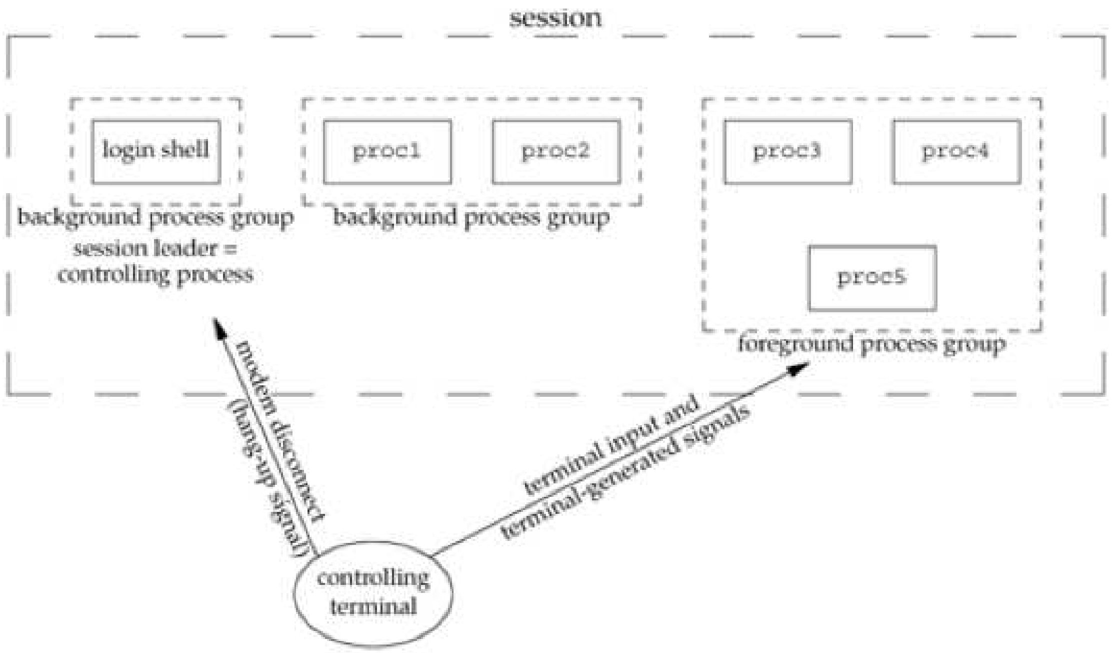
Process Groups and Sessions



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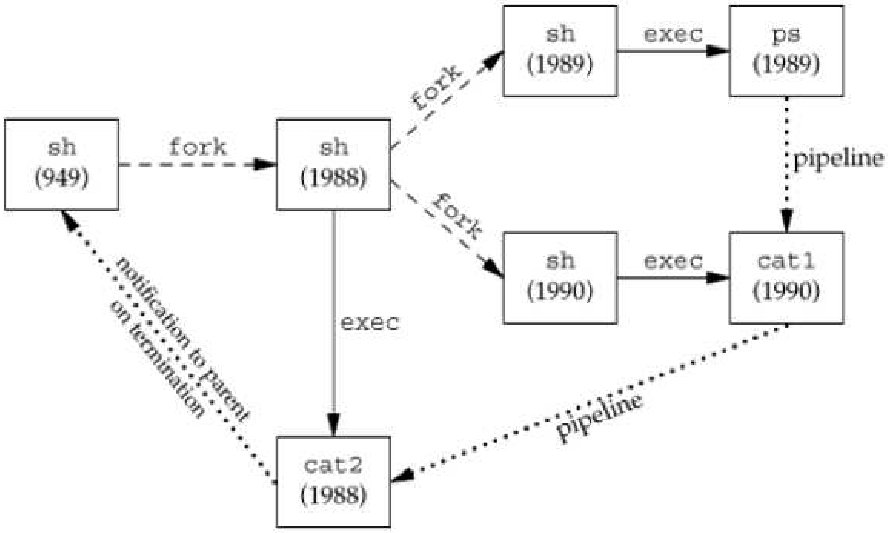
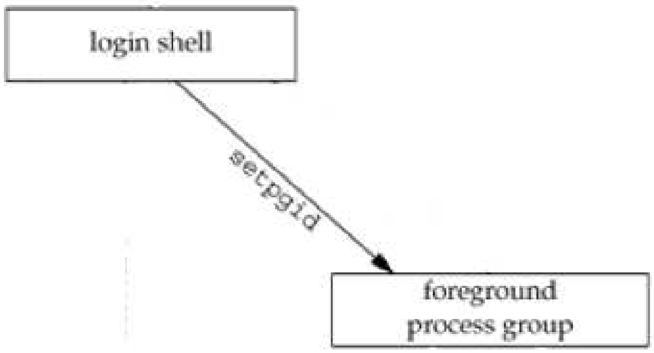
Process Groups and Sessions



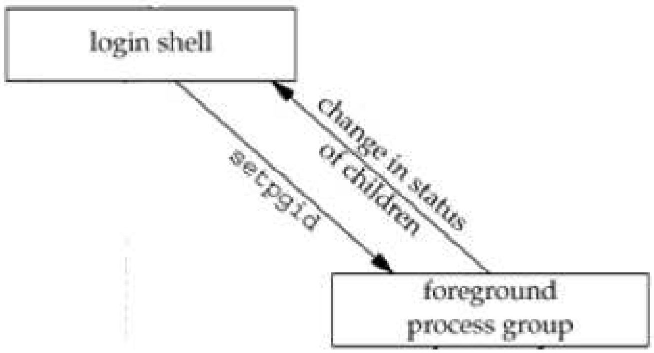
```
$ ( ps -o pid,ppid,pgid,sid,comm; sleep 1; ) | ./cat1 | ./cat2
  PID  PPID  PGRP  SESS COMMAND
 1989   949  7736   949 ps
 1990   949  7736   949 cat1
 1988   949  7736   949 cat2
  949 21401   949   949 ksh
```

Job Control



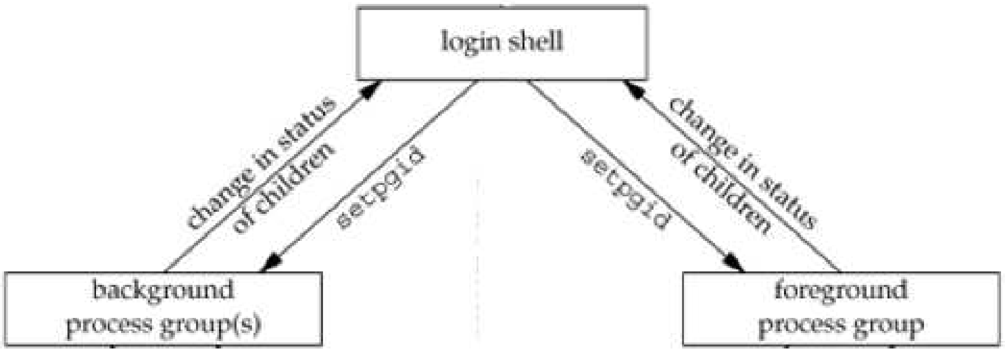
```
$ ps -o pid,ppid,pgid,sid,comm
  PID  PPID  PGRP  SESS COMMAND
24251 24250 24251 24251 ksh
24620 24251 24620 24251 ps
$
```

Job Control



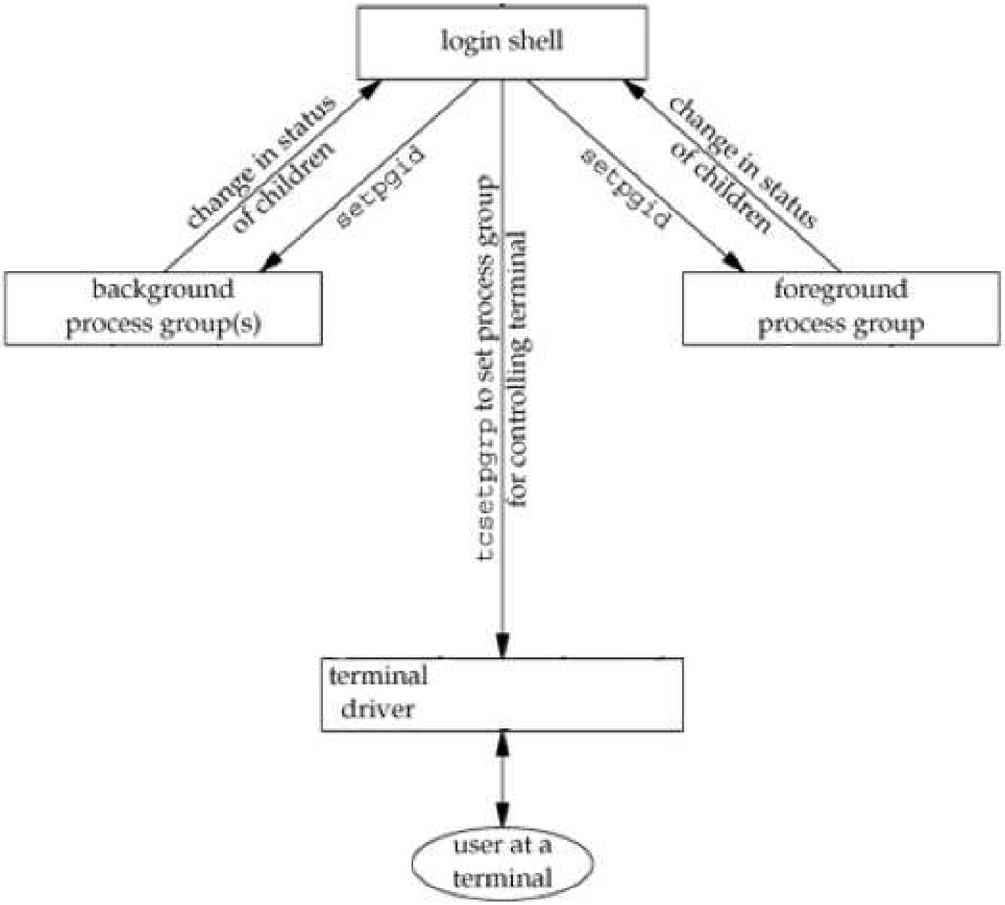
```
$ ps -o pid,ppid,pgid,sid,comm
  PID  PPID  PGRP  SESS COMMAND
24251 24250 24251 24251 ksh
24620 24251 24620 24251 ps
$ echo $?
0
$
```

Job Control


login shell
change in status of children
setpgid
setpgid
change in status of children
background process group(s)
foreground process group

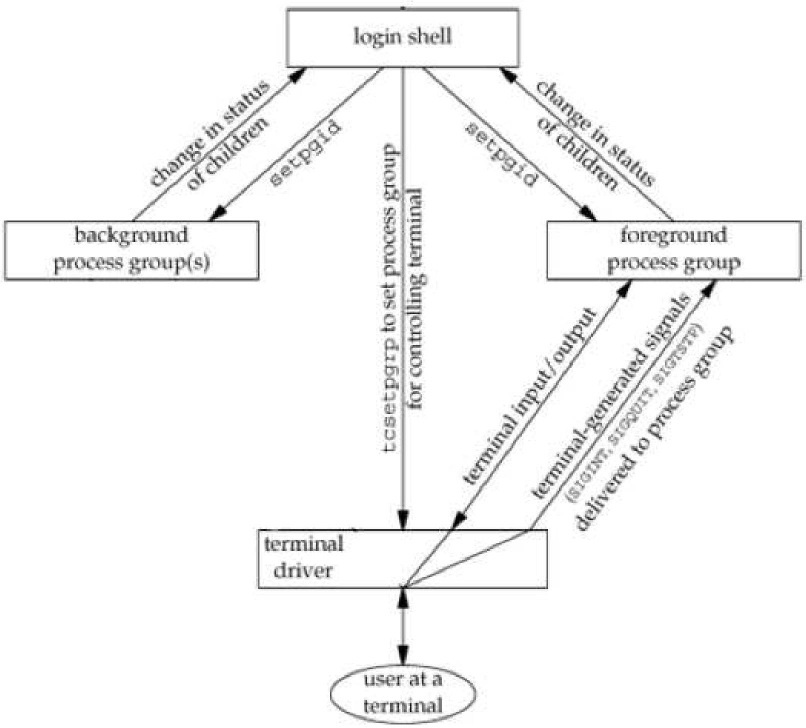
```
$ /bin/sleep 30 &
[1] 24748
$ ps -o pid,ppid,pgid,sid,comm
  PID  PPID  PGRP  SESS COMMAND
24251 24250 24251 24251 ksh
24748 24251 24748 24251 sleep
24750 24251 24750 24251 ps
$
[1] +  Done     /bin/sleep 30 &
$
```

Job Control


login shell
change in status of children
setpgid
tcsetpgrp to set process group for controlling terminal
setpgid
change in status of children
background process group(s)
foreground process group
terminal driver
user at a terminal

Job Control

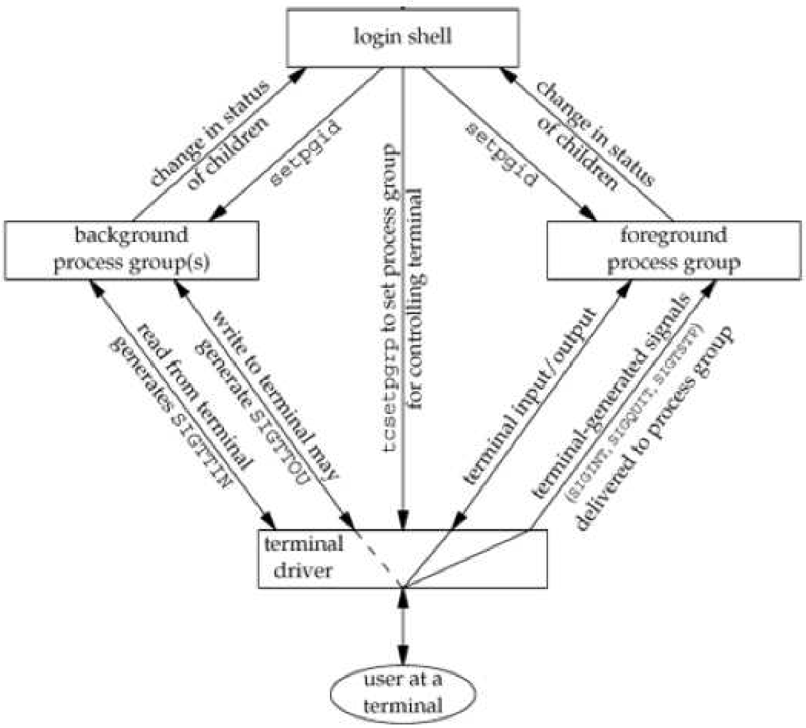
```
$ cat >file
Input from terminal,
Output to terminal.
^D
$ cat file
Input from terminal,
Output to terminal.
$ cat >/dev/null
Input from terminal,
Output to /dev/null.
Waiting forever...
Or until we send an interrupt signal.
^C
$
```


login shell
change in status of children
setpgid
background process group(s)
tcsetpgrp to set process group for controlling terminal
setpgid
change in status of children
foreground process group
terminal input/output
terminal-generated signals (SIGINT, SIGQUIT, SIGTSTP) delivered to process group
terminal driver
user at a terminal

Job Control

```
$ cat file &
[1] 2056
$ Input from terminal,
Output to terminal.

[1] +  Done             cat file &
$ stty tostop
$ cat file &
[1] 4655
$
[1] + Stopped(SIGTTOU)  cat file &
$ fg
cat file
Input from terminal,
Output to terminal.
$
```


login shell
change in status of children
setpgid
tcsetpgrp to set process group for controlling terminal
setpgid
change in status of children
background process group(s)
foreground process group
read from terminal generates SIGTTIN
write to terminal may generate SIGTTOU
terminal input/output
terminal-generated signals (SIGINT, SIGQUIT, SIGTSTP) delivered to process group
terminal driver
user at a terminal

Signals

Signal Concepts

Signals are a way for a process to be notified of asynchronous events.
Some examples:

- a timer you set has gone off (`SIGALRM`)
- some I/O you requested has occurred (`SIGIO`)
- a user resized the terminal ”window” (`SIGWINCH`)
- a user disconnected from the system (`SIGHUP`)
- ...

See also: `signal(2)`/`signal(3)`/`signal(7)` (note: these man pages vary significantly across platforms!)

Signal Concepts

Besides the asynchronous events listed previously, there are many ways to generate a signal:

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- `kill(2)` (a system call, not the unix command) performs the same task
- software conditions (other side of a pipe no longer exists, urgent data has arrived on a network file descriptor, etc.)

`kill(2)` and `raise(3)`

```
#include <sys/types.h>
#include <signal.h>

int kill(pid_t pid, int signo);
int raise(int signo);
```

- *pid* $>$ *0* – signal is sent to the process whose PID is `pid`
- *pid == 0* – signal is sent to all processes whose process group ID equals the process group ID of the sender
- *pid == -1* – POSIX.1 leaves this undefined, BSD defines it (see `kill(2)`)

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- Catch it. That is, have the kernel call a function which we define whenever the signal occurs.
- Accept the default. Have the kernel do whatever is defined as the default action for this signal

Signal Concepts

```
$ cc -Wall ../01-intro/simple-shell.c
$ ./a.out
$$ ^C
$ echo $?
130
$ cc -Wall ../01-intro/simple-shell2.c
$ ./a.out
$$ ^C
Caught SIGINT!

$$
```

signal(3)

```
#include <signal.h>

void (*signal(int signo, void (*func)(int)))(int);
```

Returns: previous disposition of signal if OK, `SIG_ERR` otherwise

signal(3)

```
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func can be:

- SIG_IGN which requests that we ignore the signal signo
- SIG_DFL which requests that we accept the default action for signal signo
- or the address of a function which should catch or handle a signal

Signal Examples

```
$ cc -Wall siguser.c
$ ./a.out
^Z
$ bg
$ ps | grep a.ou[t]
11106 ttys002    0:00.00 ./a.out
$ kill -USR1 11106
received SIGUSR1
$ kill -USR2 11106
received SIGUSR2
$ kill -INT 11106
$
[2]-  Interrupt               ./a.out
$
```

Program Startup

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A limitation of the `signal(3)` function is that we can only determine the current disposition of a signal by *changing* the disposition.

sigaction(2)

```
#include <signal.h>

int sigaction(int signo, const struct sigaction *act, struct sigaction *oact);
```

This function allows us to examine or modify the action associated with a particular signal.

```
struct sigaction {
        void (*sa_handler)();    /* addr of signal handler, or
                                    SIG_IGN or SIG_DFL */
        sigset_t sa_mask;        /* additional signals to block */
        int sa_flags;            /* signal options */
};
```

`signal(3)` is (nowadays) commonly implemented via `sigaction(2)`.

More advanced signal handling via signal sets

- `int sigemptyset(sigset_t *set)` – intialize a signal set to be empty
- `int sigfillset(sigset_t *set)` – initialize a signal set to contain all signals
- `int sigaddset(sigset_t *set, int signo)`
- `int sigdelset(sigset_t *set, int signo)`
- `int sigismember(sigset_t *set, int signo)`

Resetting Signal Handlers

Note: on some systems, invocation of the handler *resets* the disposition to `SIG_DFL`!

```
$ cc -DSLEEP=3 -Wall pending.c
$ ./a.out
=> Establishing initial signal hander via signal(3).
^\sig_quit: caught SIGQUIT (1), now sleeping
sig_quit: exiting (1)
=> Time for a second interruption.
^\sig_quit: caught SIGQUIT (2), now sleeping
sig_quit: exiting (2)
=> Establishing a resetting signal hander via signal(3).
^\sig_quit_reset: caught SIGQUIT (3), sleeping and resetting.
sig_quit_reset: restored SIGQUIT handler to default.
=> Time for a second interruption.
^\Quit: 3
$
```

Signal Queuing

Signals arriving while a handler runs are queued.

```
$ ./a.out >/dev/null
^\sig_quit: caught SIGQUIT (1), now sleeping
^\^\^\^\^\^\sig_quit: exiting (1)
sig_quit: caught SIGQUIT (2), now sleeping
^\^\^\^\sig_quit: exiting (2)
sig_quit: caught SIGQUIT (3), now sleeping
^\sig_quit: exiting (3)
sig_quit: caught SIGQUIT (4), now sleeping
sig_quit: exiting (4)
[...]
```

(Note that ”simultaneously” delivered signals may be ”merged” into one.)

Signal Queuing

Signals arriving while a handler runs are queued.
Unless they are blocked.

```
$ ./a.out
[...]
=> Establishing a resetting signal hander via signal(3).
^\sig_quit_reset: caught SIGQUIT (1), sleeping and resetting.
sig_quit_reset: restored SIGQUIT handler to default.
=> Time for a second interruption.
=> Blocking delivery of SIGQUIT...
=> Now going to sleep for 3 seconds...
^\
=> Checking if any signals are pending...
=> Checking if pending signals might be SIGQUIT...
Pending SIGQUIT found.
=> Unblocking SIGQUIT...
Quit: 3
```

Signal Queuing

Multiple identical signals are queued, but you can receive a different signal *while in a signal handler*.

```
$ ./a.out >/dev/null
^\sig_quit: caught SIGQUIT (1), now sleeping
^\^\^\^\^Csig_int: caught SIGINT (2), returning immediately
sig_quit: exiting (2)
sig_quit: caught SIGQUIT (3), now sleeping
^\^\sig_quit: exiting (3)
sig_quit: caught SIGQUIT (4), now sleeping
sig_quit: exiting (4)
[...]
```

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- certain `ioctl(3)`s
- certain IPC functions

Catching a signal during execution of one of these calls traditionally led to the process being aborted with an errno return of `EINTR`.

Interrupted System Calls

Previously necessary code to handle `EINTR`:

```
again:
        if ((n = read(fd, buf, BUFFSIZE)) < 0) {
                if (errno == EINTR)
                        goto again;  /* just an interrupted system call */
                /* handle other errors */
}
```

Nowadays, many Unix implementations automatically restart certain system calls.

Interrupted System Calls

```
$ cc -Wall eintr.c
$ ./a.out
^C
read call was interrupted
||
$ ./a.out
^\a

read call was restarted
|a|
$
```

Reentrant functions

An example of calling nonreentrant functions from a signal handler:

```
$ cc -Wall reentrant.c; ./a.out
in signal handler
in signal handler
in signal handler
no ’root’ found!
$ ./a.out
in signal handler
return value corrupted: pw_name = root
$ ./a.out
in signal handler
in signal handler
User jschauma not found!
$ ./a.out
in signal handler
in signal handler
Memory fault (core dumped)
```

Reentrant Functions

If your process is currently handling a signal, what functions are you allowed to use?

See p. 306 in Stevens for a list.

Homework

Read:

- Controlling Terminals: `tty(4)`, `termios(4)`

Read, try, play with and understand all examples.

Review the discussions around an issue we discovered in a previous class:

- `https://is.gd/x95eFp`
- `https://is.gd/Rqn03R`
- `https://is.gd/GYYE32`

(See following slides.)

An entertaining tangent in code exploration...

```
$ timeout 60 /bin/sh -c "ls | more"
```

vs

```
$ /bin/sh -c "timeout 60 /bin/sh -c \"ls | more\""
```

An entertaining tangent in code exploration...

```
$ timeout 60 /bin/sh -c "ls | more; sleep 60"

$ pstree -hapun
[...]
  |   |       `-ksh,10981
  |   |           `-sh,12044 -c timeout 60 /bin/sh -c "ls | more; sleep 30"
  |   |               `-timeout,12045 60 /bin/sh -c ls | more; sleep 30
  |   |                   `-sh,12046 -c ls | more; sleep 30
  |   |                       `-sleep,12049 30
[...]

$ ps x -o pid,ppid,pgid,sid,tpgid,stat,comm | egrep -v "(ssh|ps|egrep)"
  PID  PPID  PGID  SESS TPGID STAT COMMAND
 7676  7675  7676  7676  7676 Ss+  ksh
10981 10980 10981 10981 12044 Ss   ksh
12044 10981 12044 10981 12044 S+   sh
12045 12044 12045 10981 12044 S    timeout
12046 12045 12045 10981 12044 S    sh
12049 12046 12045 10981 12044 S    sleep
```

An entertaining tangent in code exploration...

```
$ /bin/sh -c timeout 60 "/bin/sh -c \"ls | more\""

$ pstree -hapun
[...]
  |   |       ‘-ksh,10981
  |   |           ‘-sh,12434 -c timeout 60 /bin/sh -c "ls | more"
  |   |               ‘-timeout,12435 60 /bin/sh -c ls | more
  |   |                   ‘-sh,12436 -c ls | more
  |   |                       |-ls,12437
  |   |                       ‘-more,12438
[...]

$ ps x -o pid,ppid,pgid,sid,tpgid,stat,comm | egrep -v "(ssh|ps|egrep)"
  PID  PPID  PGID  SESS TPGID STAT COMMAND
 7676  7675  7676  7676  7676 Ss+  ksh
10981 10980 10981 10981 12434 Ss   ksh
12434 10981 12434 10981 12434 S+   sh
12435 12434 12435 10981 12434 S    timeout
12436 12435 12435 10981 12434 T    sh
12437 12436 12435 10981 12434 T    ls
12438 12436 12435 10981 12434 T    more
```

An entertaining tangent in code exploration...

Use the source, Luke!

```
coreutils/src/timeout.c

  /* Ensure we're in our own group so all subprocesses can be killed.
     Note we don't just put the child in a separate group as
     then we would need to worry about foreground and background groups
     and propagating signals between them.  */
  if (!foreground)
    setpgid (0, 0);

[...]

      signal (SIGTTIN, SIG_DFL);
      signal (SIGTTOU, SIG_DFL);

      execvp (argv[0], argv);
```

An entertaining tangent in code exploration...

Use the source, Luke!

```
util-linux/text-utils/more.c

#define stty(fd,argp)  tcsetattr(fd,TCSANOW,argp)


    if (!no_tty) {
        signal(SIGQUIT, onquit);
        signal(SIGINT, end_it);
#ifdef SIGWINCH
        signal(SIGWINCH, chgwinsz);
#endif /* SIGWINCH */
        if (signal (SIGTSTP, SIG_IGN) == SIG_DFL) {
            signal(SIGTSTP, onsusp);
            catch_susp++;
        }
        stty (fileno(stderr), &otty);
```