CSC 374/407: Computer Systems II

Lecture 4

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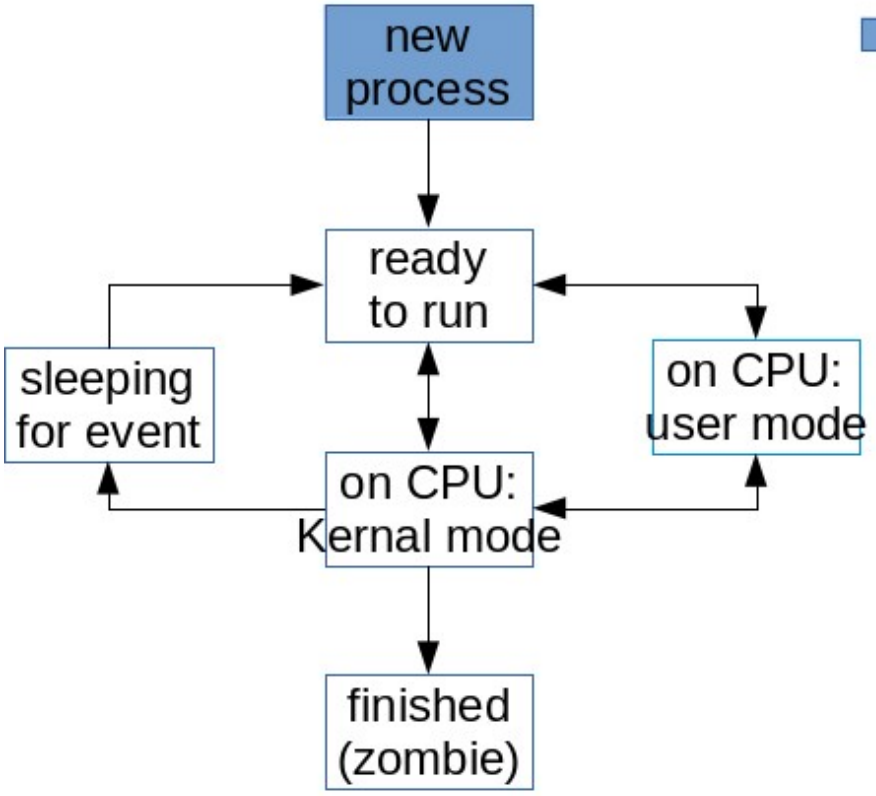
Reading

- Bryant & O'Hallaron "*Computer Systems, 3rd Ed.*"
  - Chapter 8: Exception Control Flow (8.5 Signals)
- Hoover "*System Programming*"
  - System Calls 7.1-7.4

Topics

- Signals
  - **`sigaction()`**
  - **`kill()`**
  - **`alarm()`**

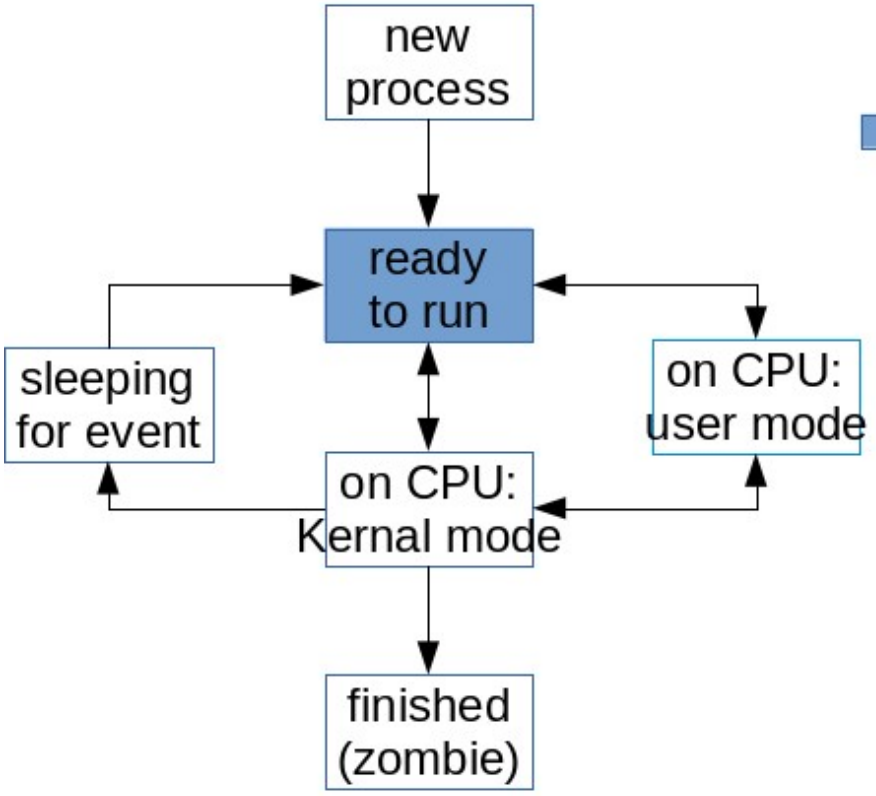
Recall fork system call (1)




```
$ ./example
int main ()
{
   int status;
   if (fork()==0)
   {
      puts("Hi!");
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (2)

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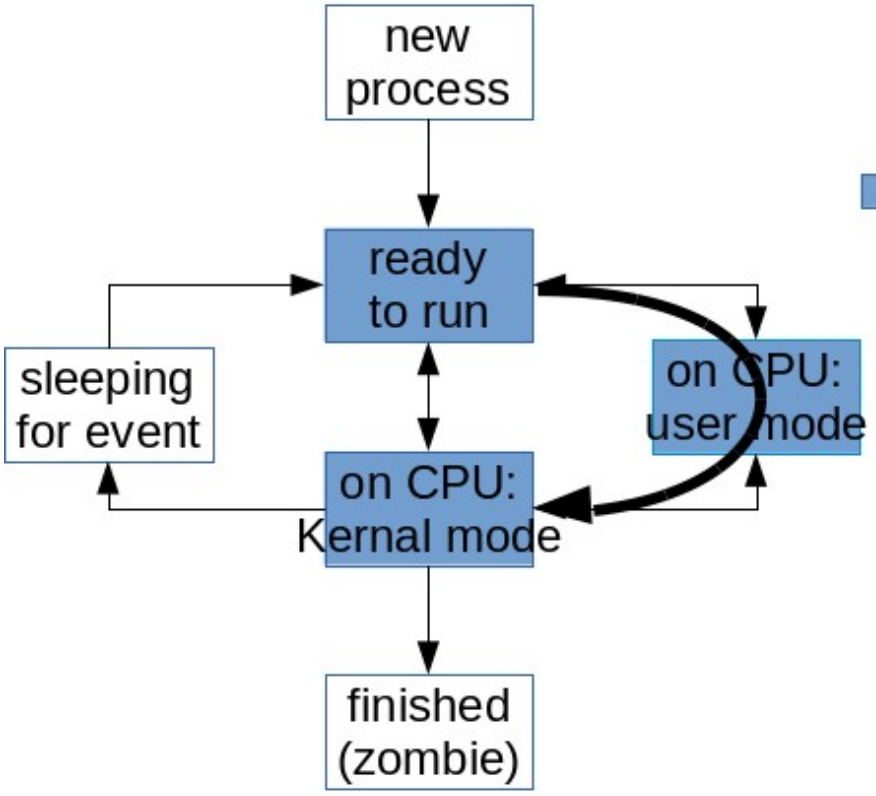
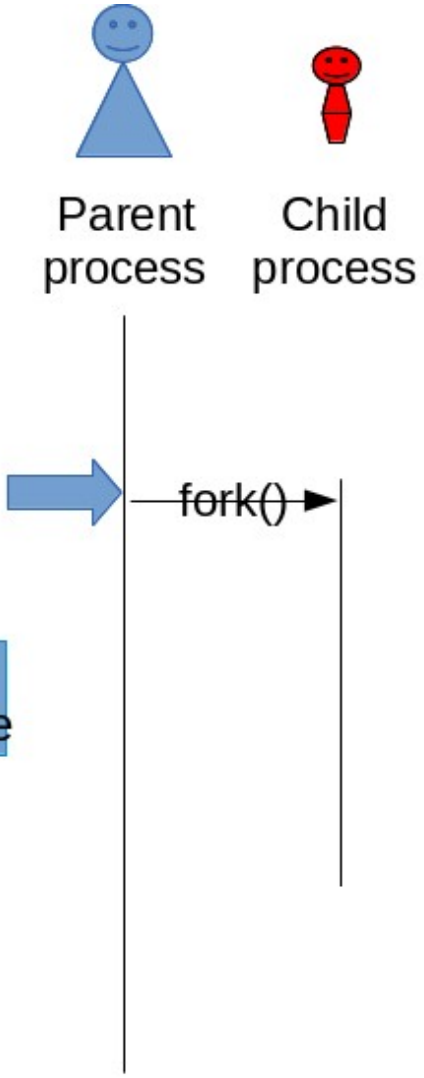
{
   int status;
   if (fork()==0)
   {
      puts("Hi!");
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (3)



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{
   int status;
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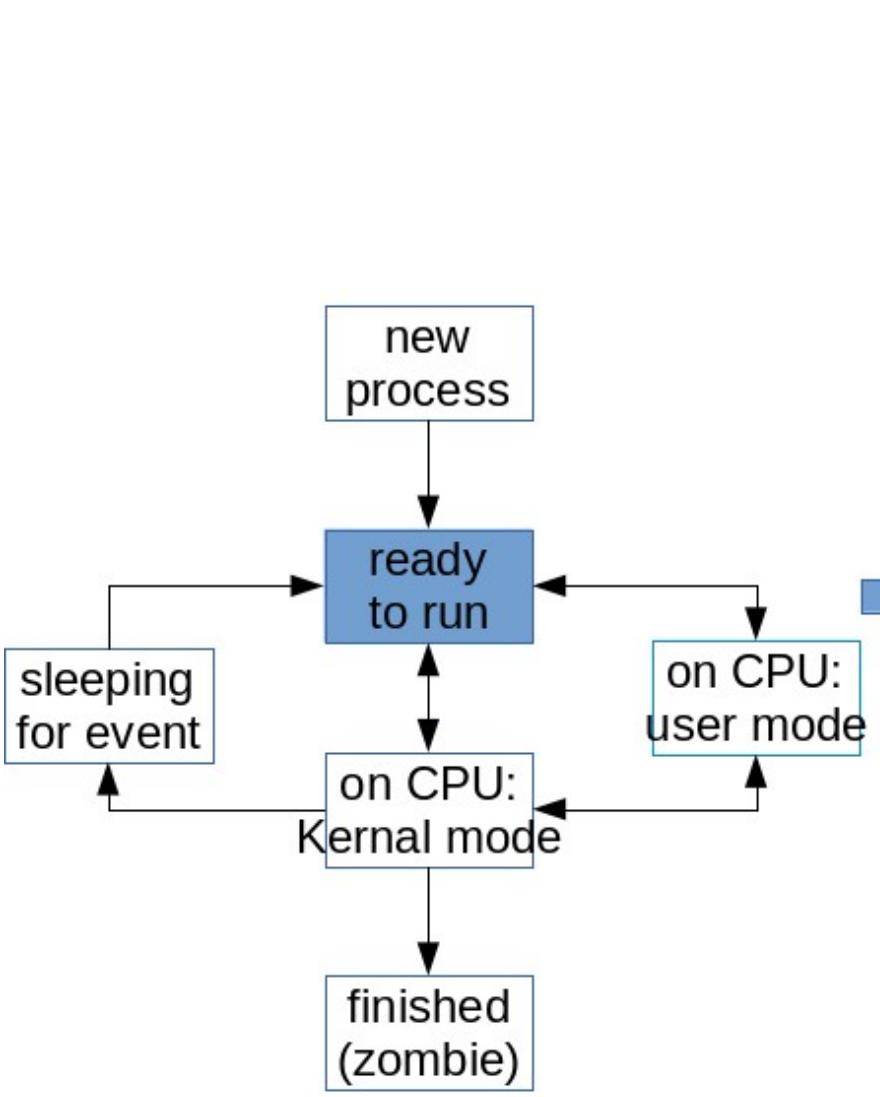
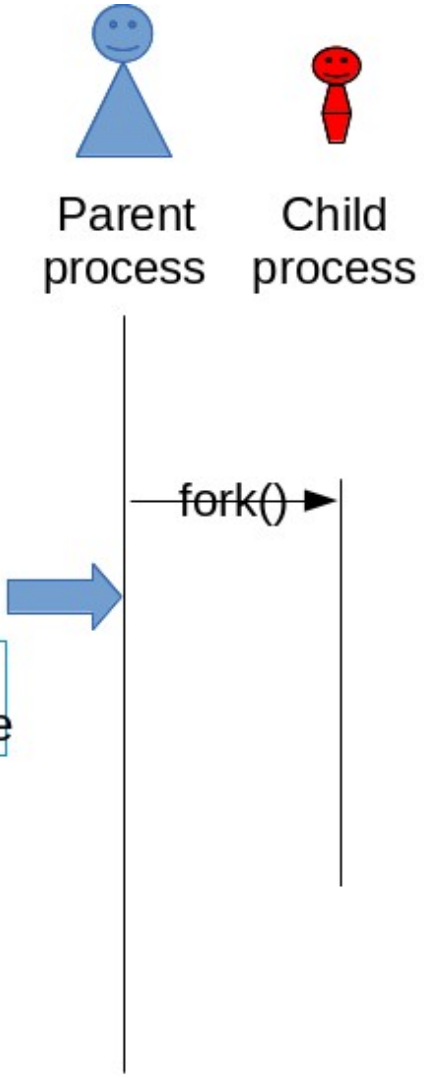
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (4)






```
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{
   int status;
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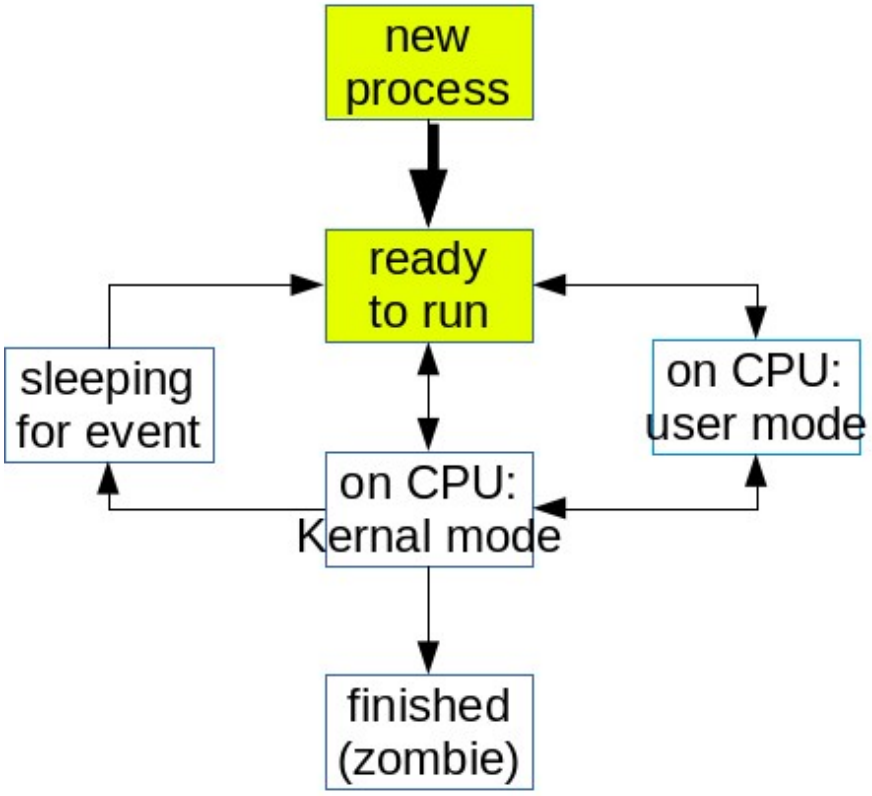
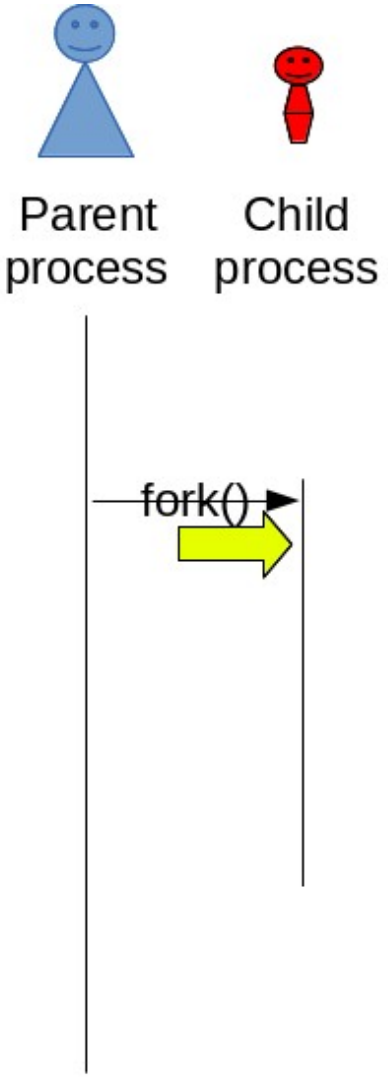
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (5)






```
$ ./example
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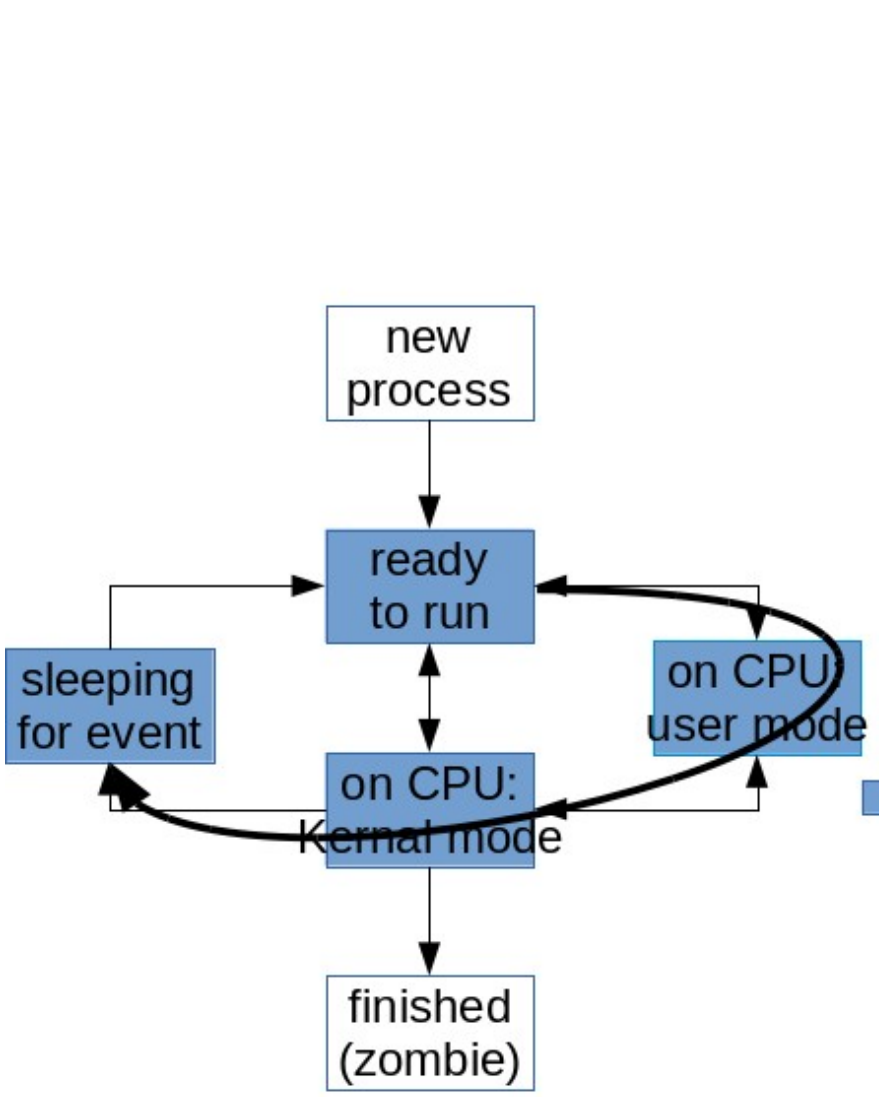
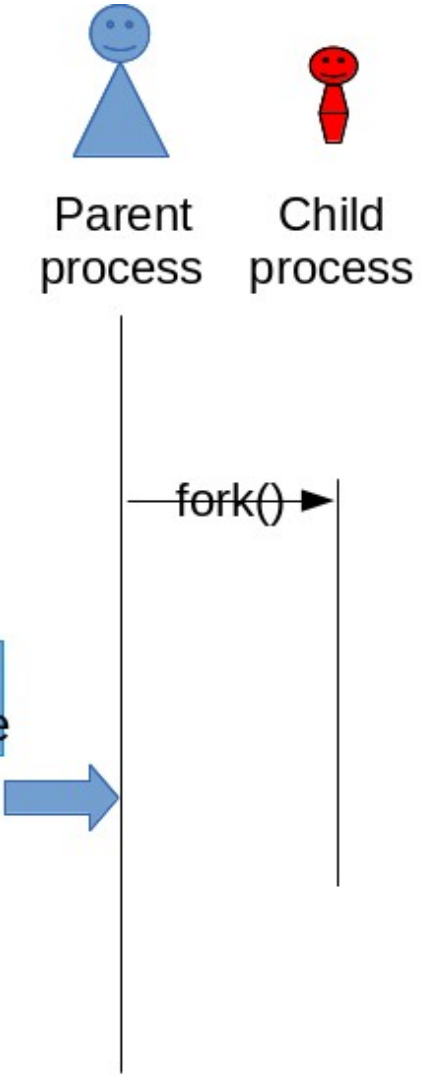
{
   int status;
   if (fork()==0)
   {
      puts("Hi!");
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (6)






```
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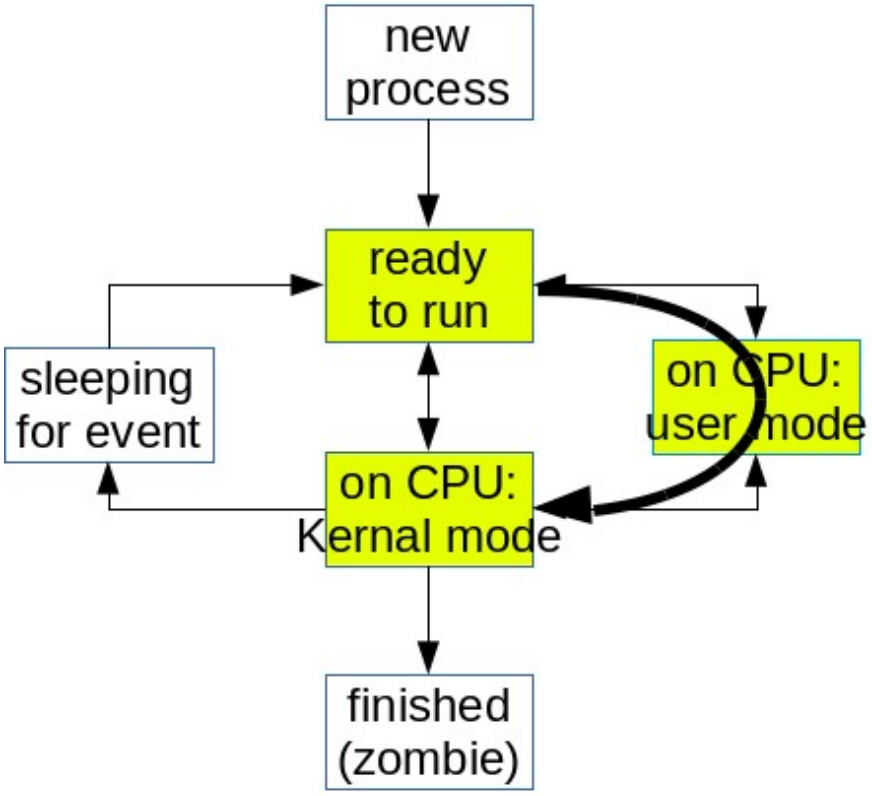
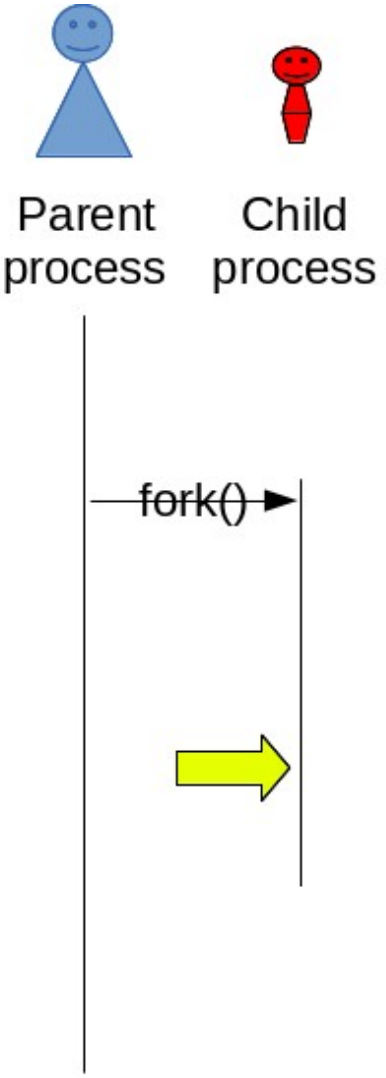
{
   int status;
   if (fork()==0)
   {
      puts("Hi!");
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (7)



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   if (fork()==0)
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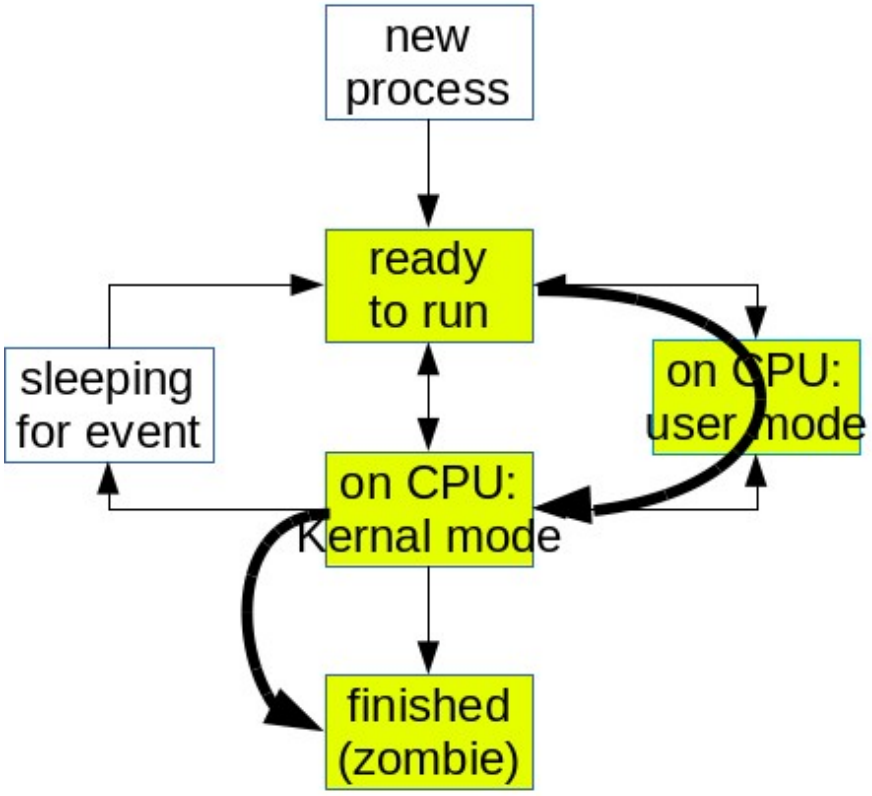
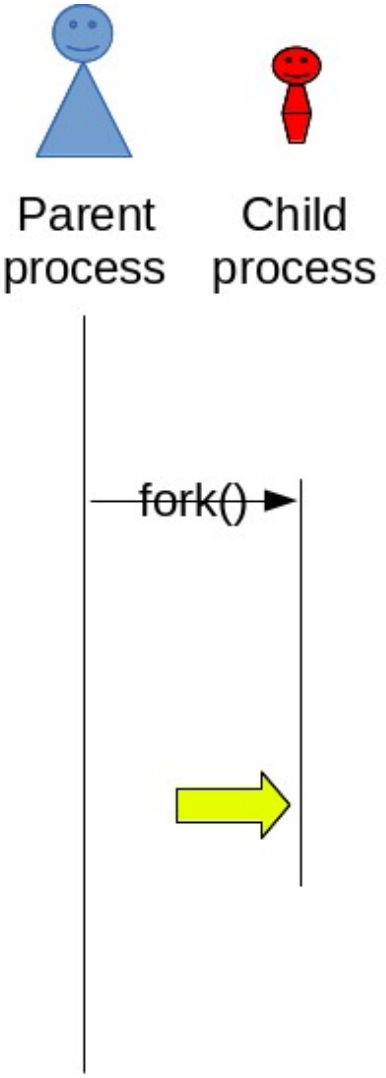
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (8)



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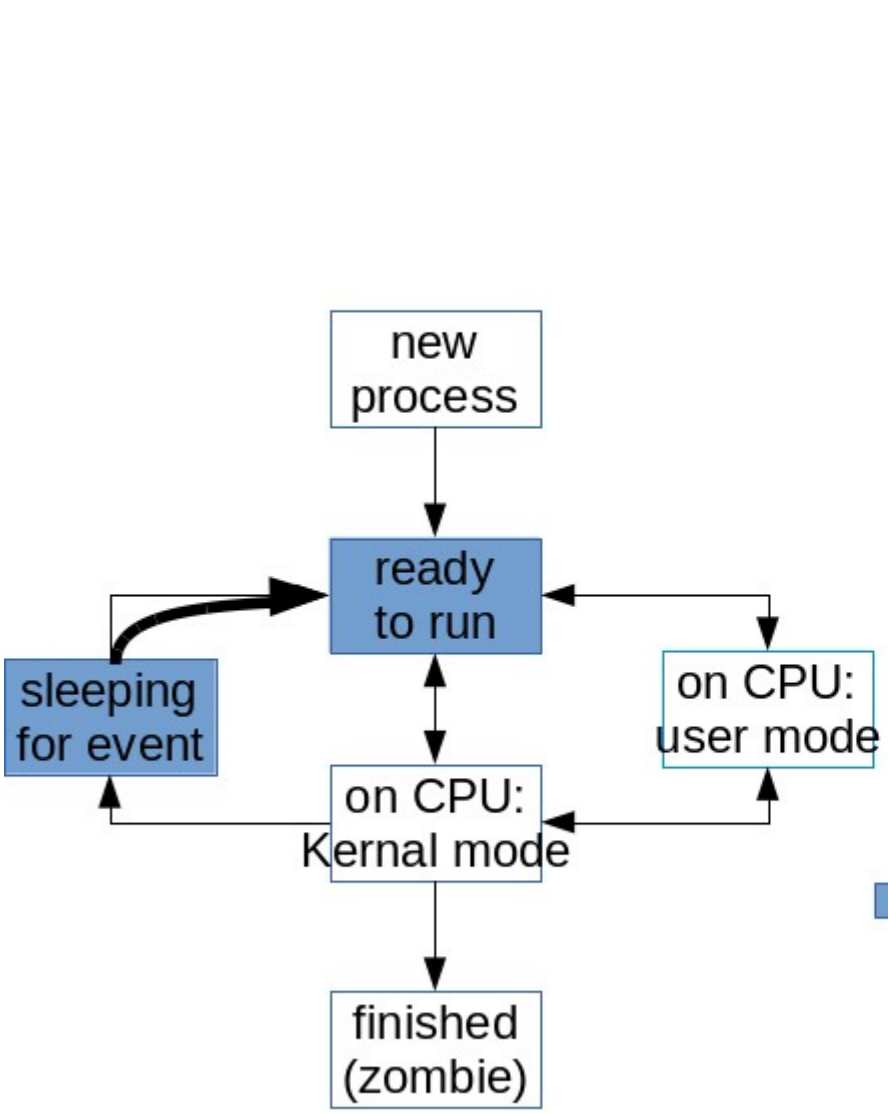
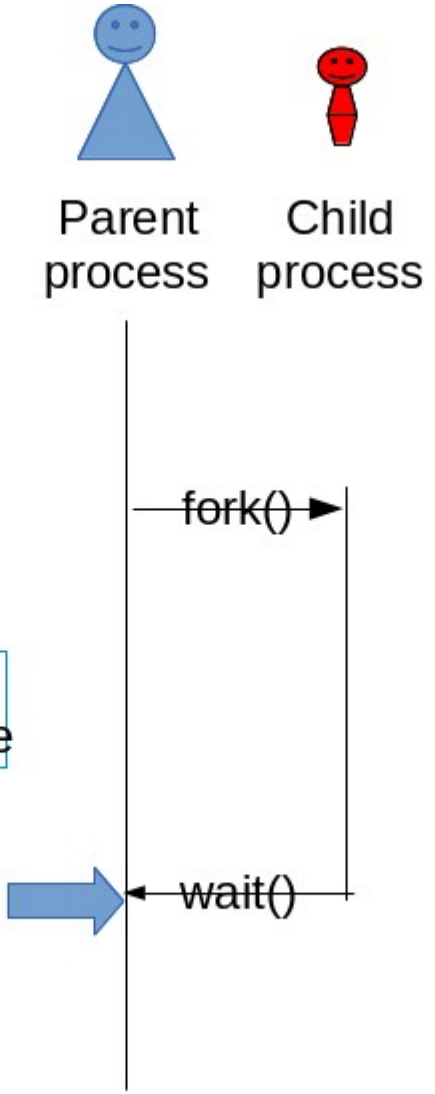
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (9)



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{
   int status;
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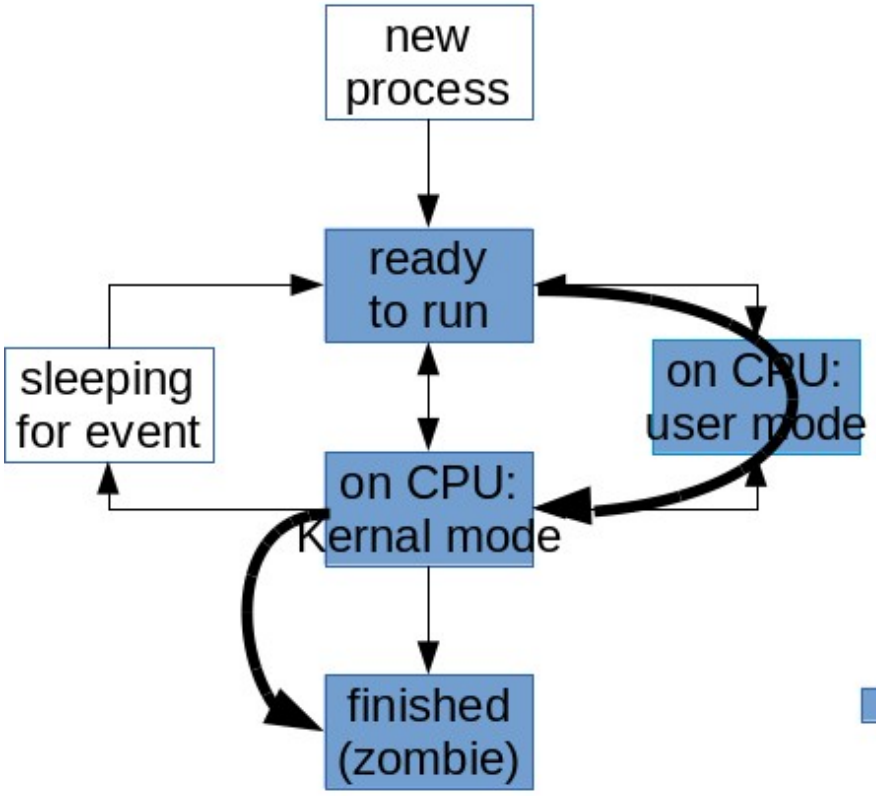
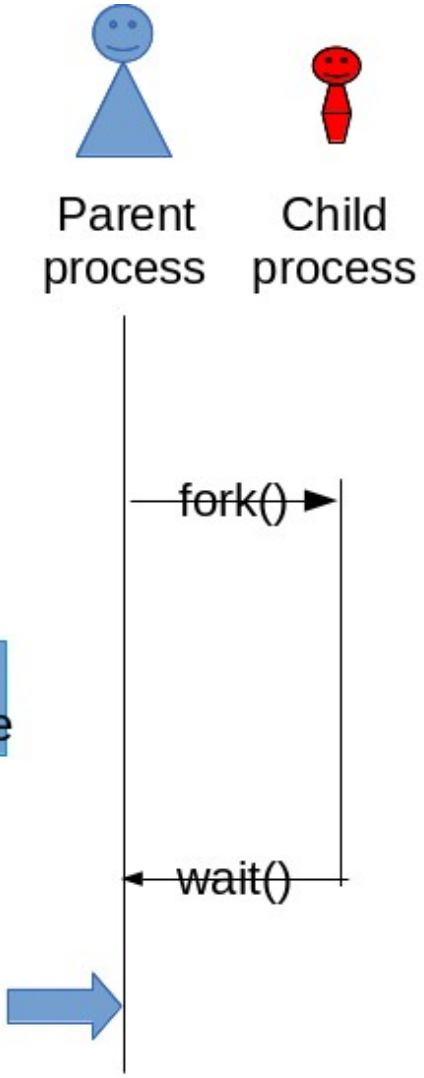
      return(0);
   }

   wait(&status);
   return(0);
}
```

Recall fork system call (10)






```
$ ./example
int main ()
{
   int status;
   if (fork()==0)
   {
      puts("Hi!");
      return(0);
   }

   wait(&status);
   return(0);
}
```

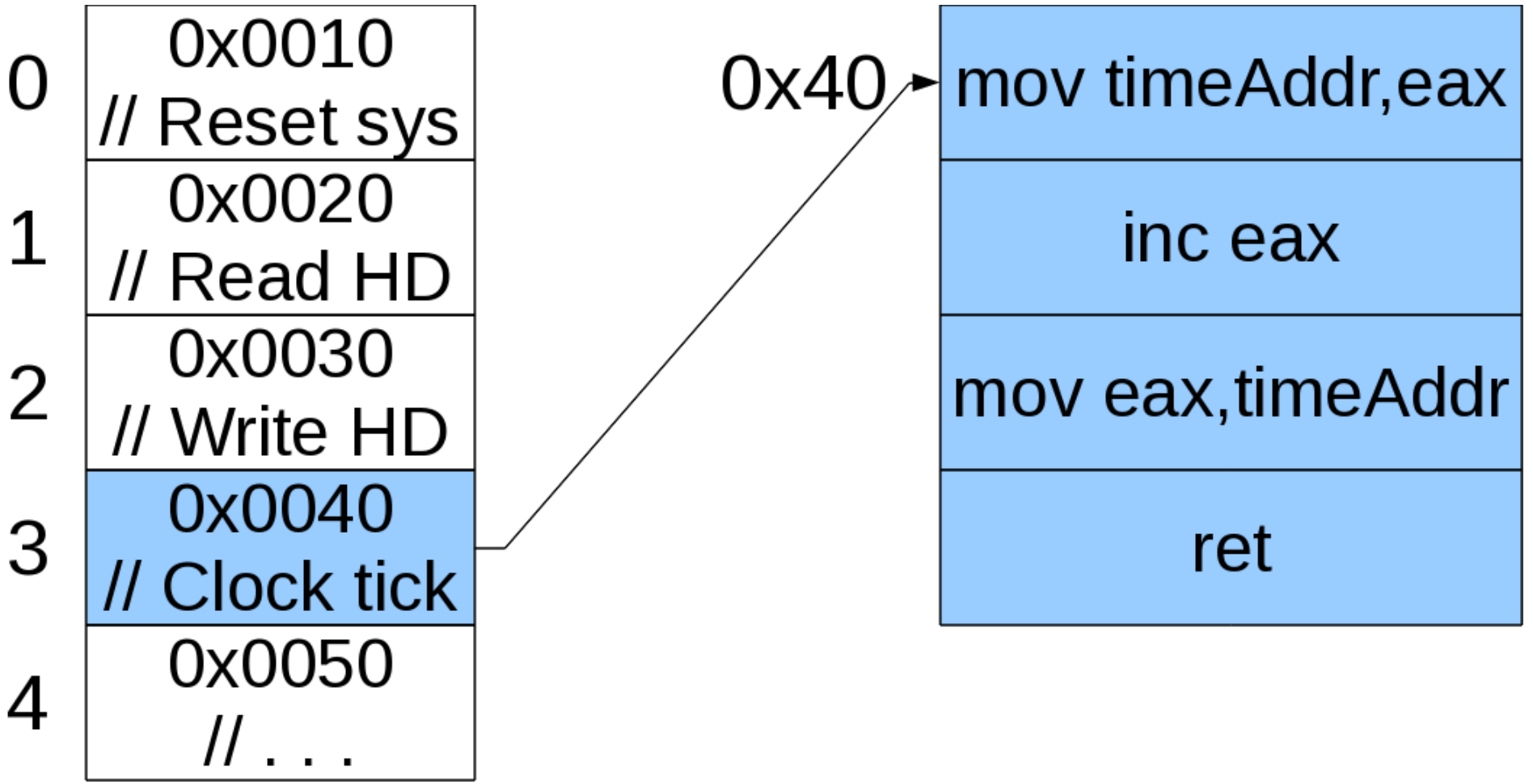
Remember the shell . . .

Let's re-write our simple shell program from last time.

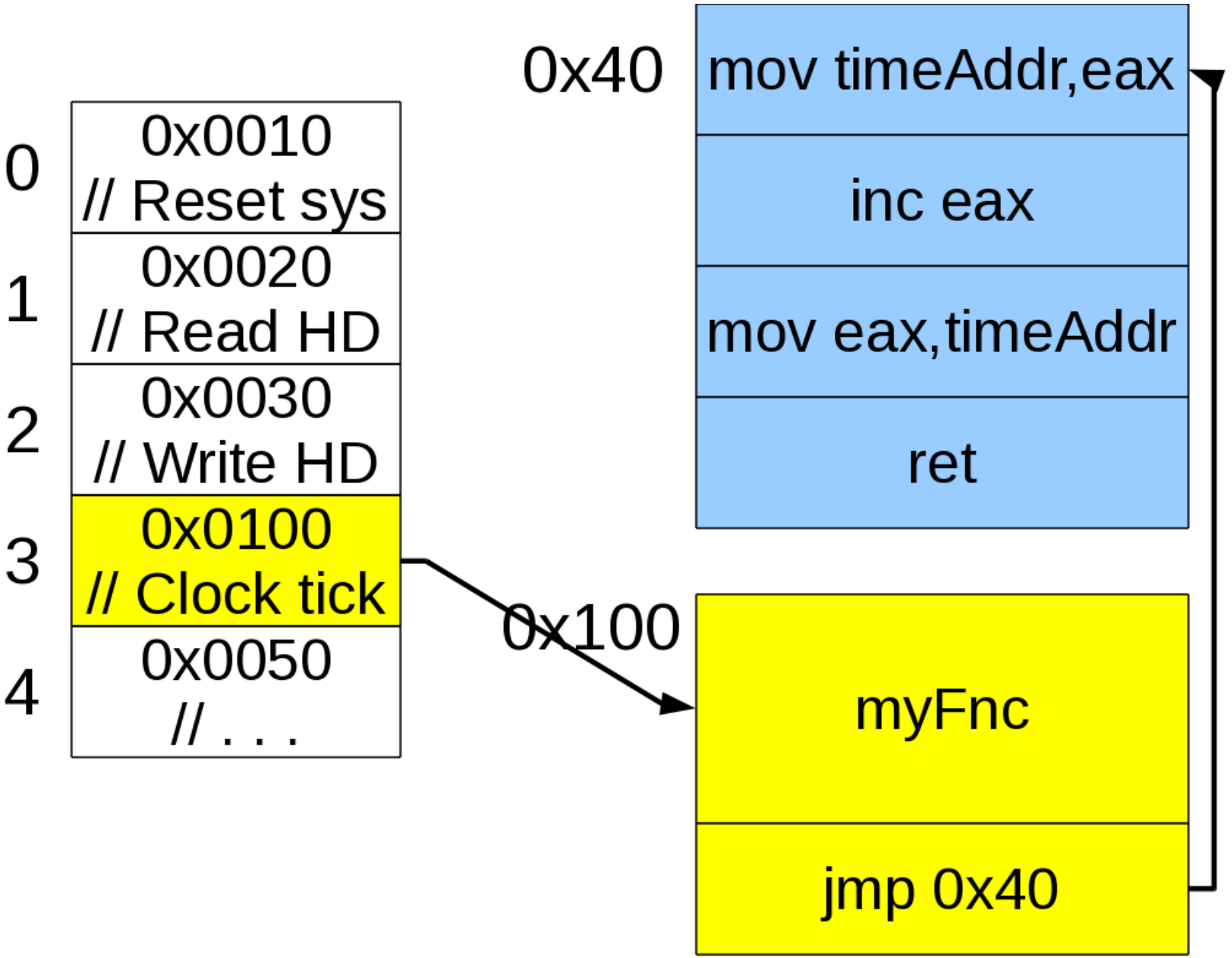
We may use:

- **`fork()`**
- **`execl(char* path, char* arg0, char* arg1, . . .)`**
- **`wait(int* statusPtr)`**
- **`waitpid(pid_t pid, int* statusPtr, int flag)`**

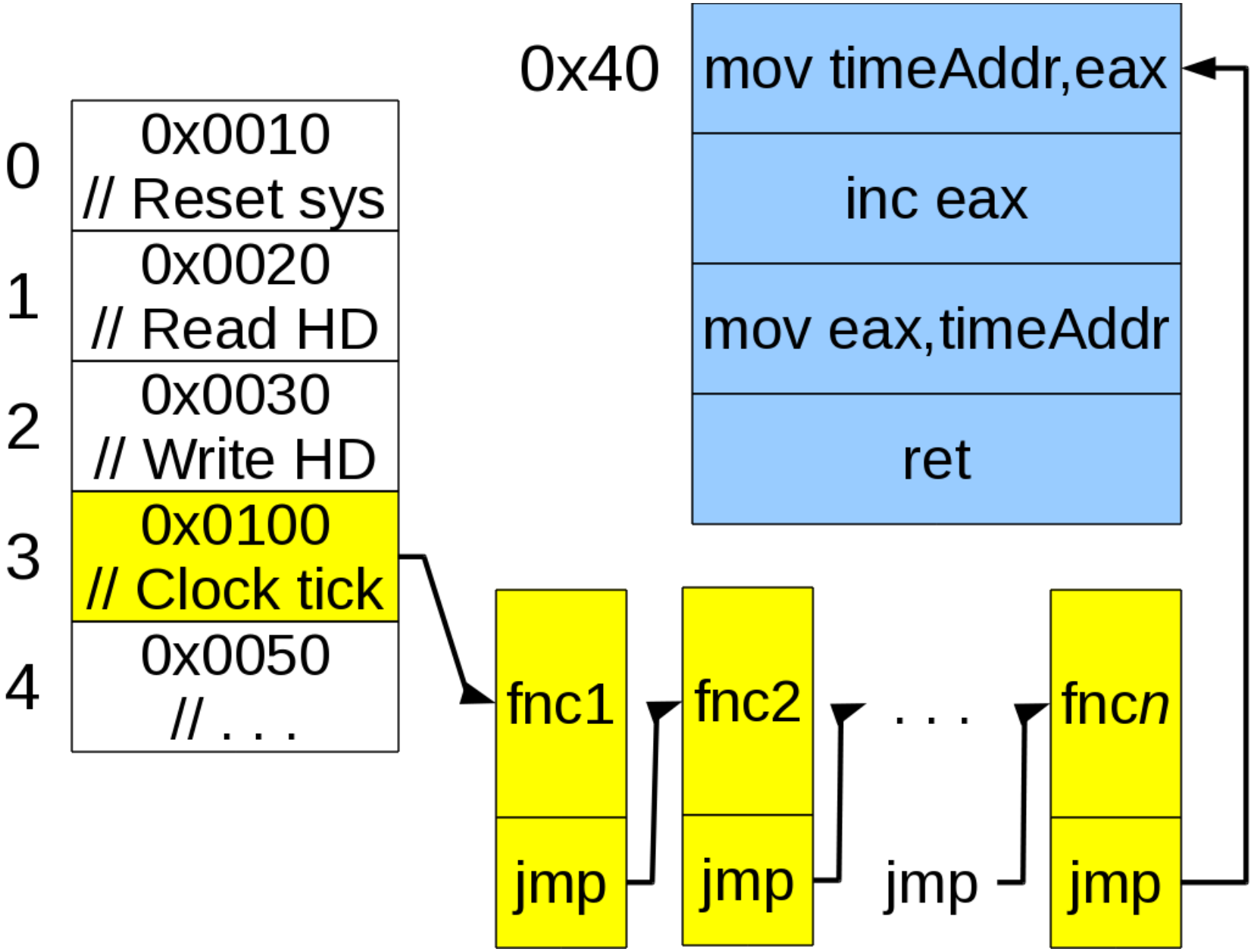
Remember: One interrupt vector table for whole computer



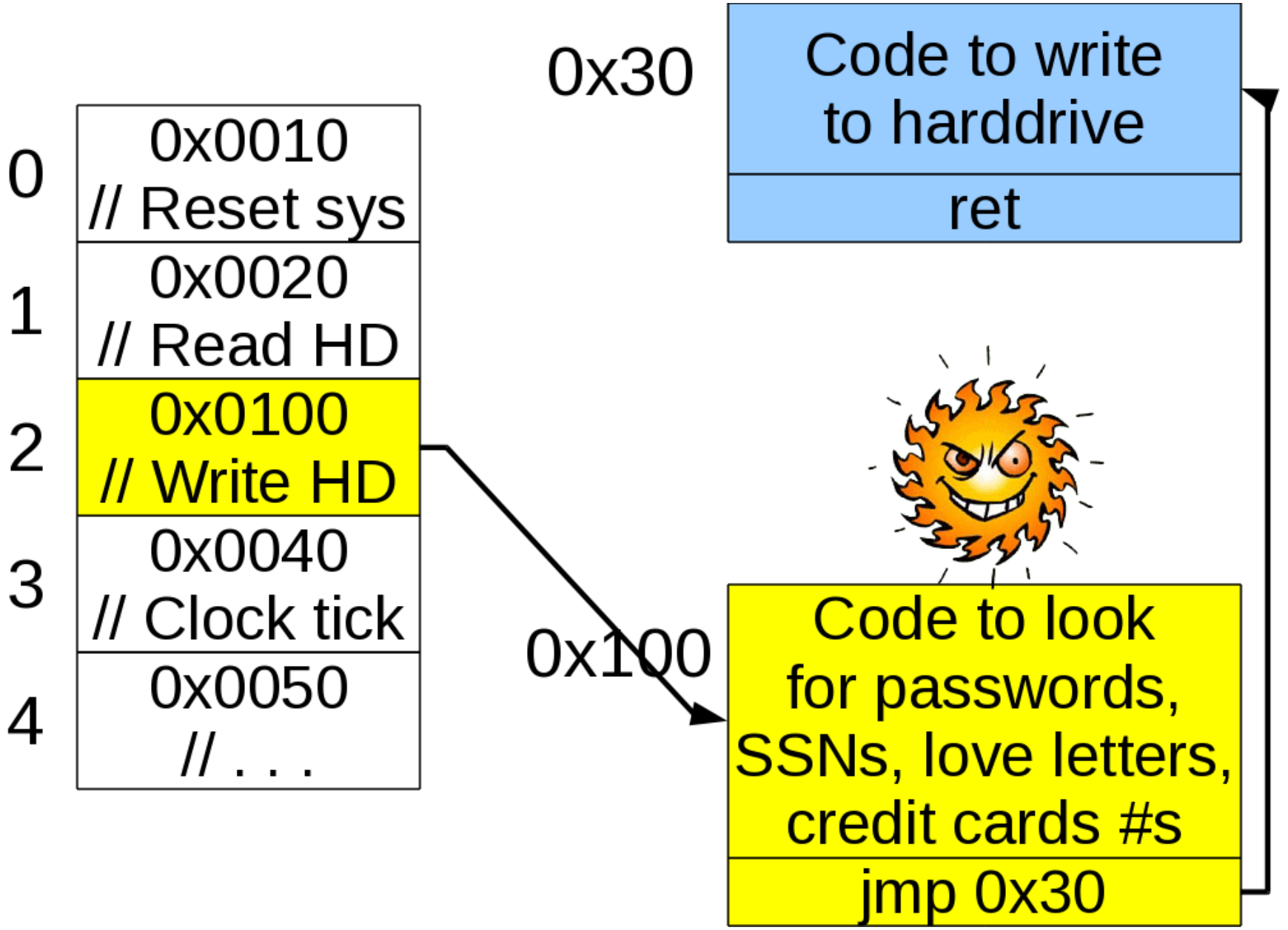
Remember how to do something periodically?



Is this technique efficient when there are many things to schedule?



Is this technique secure?



Signals: a better idea

The whole computer still has its interrupt table

- Nobody can mess with it except OS and ROM BIOS

Each process has its own "personal" interrupt table

It's "interrupts" include

- You set the alarm and went to **`sleep()`**, now it's ***Time to wake up!***
- ***Hey!*** One of your children just finished!
- Close things down and finish, *or less politely . . .*
- ***Die now, Punk!***

List of signals (Linux i386) (1)

The default actions are:

- **Term**: terminate the process
- **Core**: terminate the process and dump the core
- **Ign**: ignore the signal
- **Stop**: stop the process

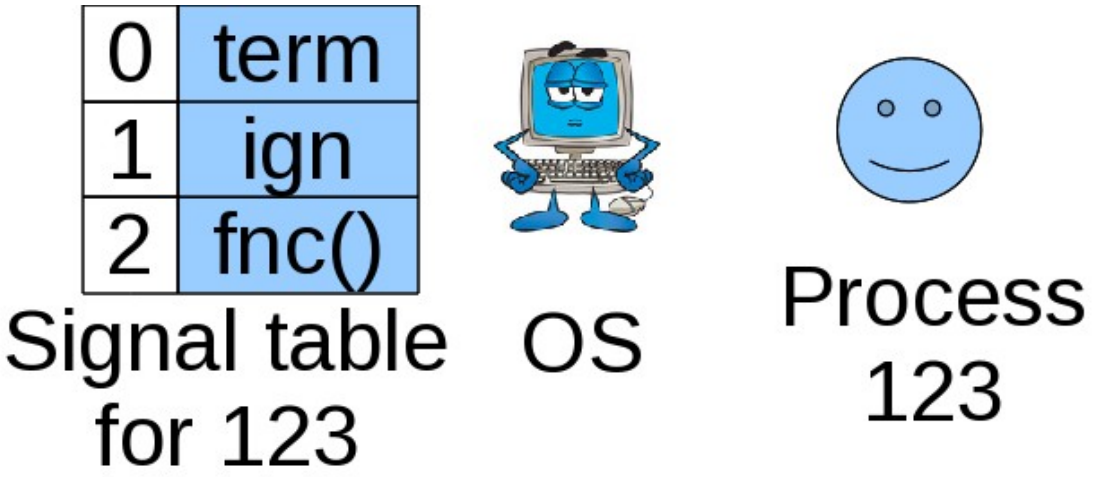
```
Signal   Value  Action   Comment
-----------------------------------
SIGHUP     1    Term    Hangup detected on controlling
                        terminal or death of controlling
                        process.
SIGINT     2    Term    Interrupt from keyboard (Ctrl-C)
SIGQUIT    3    Core    Quit 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
```

List of signals (Linux i386) (2)

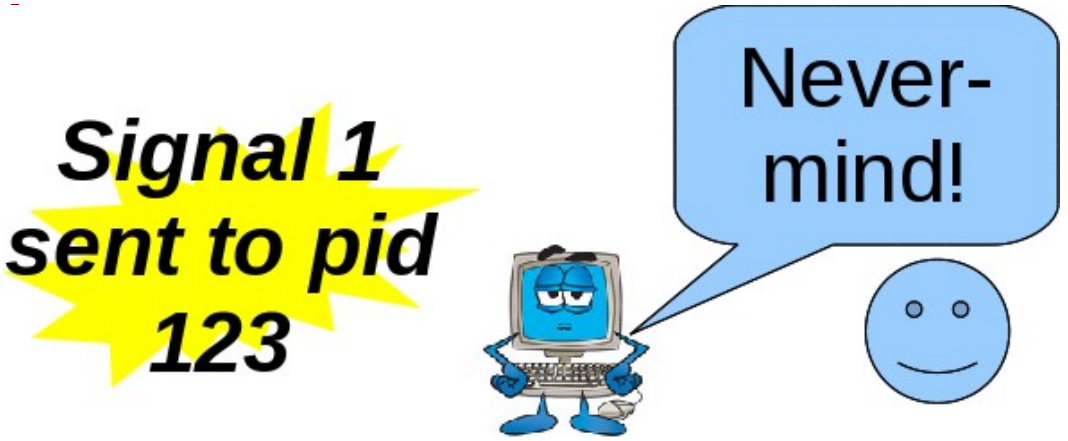
Signal	Value	Action	Comment
SIGSEGV	11	Core	Invalid memory reference
SIGPIPE	13	Term	Broken pipe: write to pipe with no readers
SIGALRM	14	Term	Timer signal from alarm(2)
SIGTERM	15	Term	Termination signal
SIGUSR1	10	Term	User-defined signal 1
SIGUSR2	12	Term	User-defined signal 2
SIGCHLD	17	Ign	Child stopped or terminated
SIGCONT	18		Continue if stopped
SIGSTOP	19	Stop	Stop process
SIGTSTP	20	Stop	Stop typed at tty
SIGTTIN	21	Stop	tty input for background process
SIGTTOU	22	Stop	tty output for background process

How OS handles signals (1)

Each process has its own signal table:



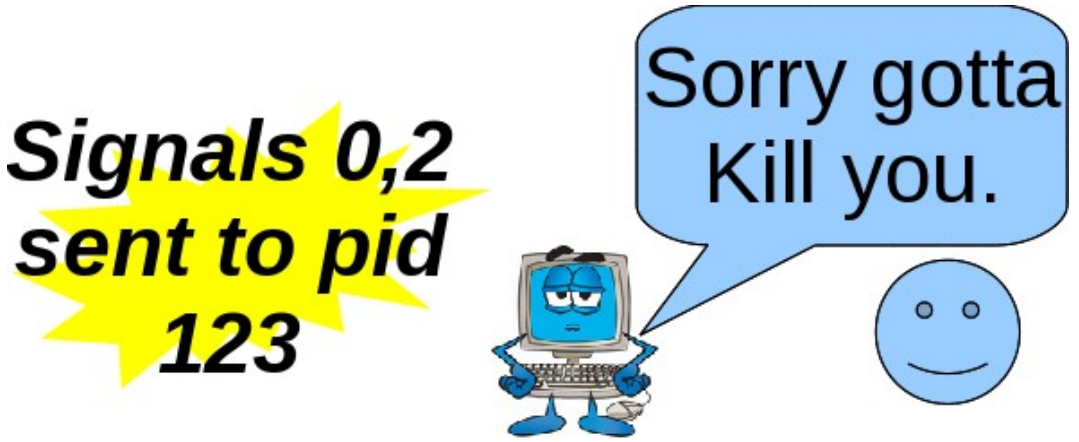
Some signals may be ignored or handled special



How OS handles signals (2)

Question: What happens if multiple signals *of different number* arrive around same time?

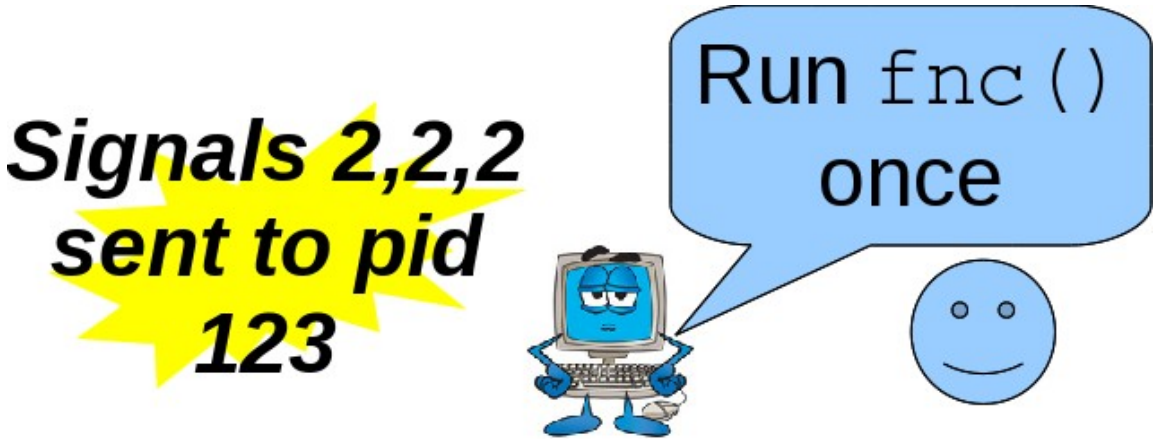
Answer: The lowest numbered signal takes precedence



How OS handles signals (3)

Question: What happens if multiple signals *of same number* are pending?

Answer: Because they are not buffered, any called routine will only be called once *and* should be clever enough to handle any number of waiting cases.



A look at those actions

Signals so serious that can't be trapped, ignored:

- `SIGSTOP`: Pause! (Restartable with `SIGCONT`)
- `SIGKILL`: **Die now! *Punk!***

Other serious signals include:

- ***`SIGILL`***: Illegal instruction (how could this happen?)
- ***`SIGSEGV`***: Illegal memory reference (how could this happen?)

Other signals are less serious

- ***`SIGCHLD`***: A child has finished (Hey, wouldn't **`wait()`** or **`waitpid()`** ***always*** catch this for us?)
- ***`SIGINT`***: Ctrl-C
- ***`SIGHUP`***: Controlling terminal hung-up (disconnected)

What does all this mean for me?

You the applications programmer get (some) control over your process' personal “interrupt table”

- Do the ***default action*** for this!
- ***Ignore*** that!
- Do it ***my way*** for the other!

sigaction()
(1) Defining a simple action

#include <signal.h>

```
int sigaction  (int                         signum,
                const struct sigaction* act,
                  struct sigaction*       oldact);
```

Where:

```
struct sigaction
{
  void (*sa_handler)(int); // Simple handler
  void (*sa_sigaction)(int, siginfo_t*, void*);
                           // Funkier sig handler
  sigset_t   sa_mask; // Sigs to allow in handler
  int        sa_flags;//
  void       (*sa_restorer)(void);
};
```

Doing it! (1)

```
#include <string.h>  // For memset()
#include <signal.h>

void    simpleHandle (int signalNum)
{
  //  Handling code here
}

int main ()
{
  // Set up struct to specify the new action.
  struct sigaction act;

  memset(&act,'\0',sizeof(act));
  . . .
```

Doing it! (2)

```
  //  Do this to do the DEFAULT ACTION
  act.sa_handler = SIG_DFL;//Handle by default
  sigaction(SIGINT,&act,NULL);

  //  or, Do this do IGNORE THE SIGNAL
  act.sa_handler = SIG_IGN;// Ignore SIGINT
  sigaction(SIGINT,&act,NULL);

  //  or, do this to HANDLE WITH YOUR FUNCTION
  act.sa_handler = simpleHandler;
                   // Handle with simpleHandler()
  sigaction(SIGINT,&act,NULL);
  . . .
}
```

Your turn!

Write a program that

1. Prints "***`You can't stop me! Ngyeah-ngyeah, ngyeah-ngyeah!`***"
2. Pauses for 2 seconds
3. Goes back to 1.

Indefinitely, and that ***cannot*** be stopped by **`Ctrl-C`**.

(***Question***: *Uh-oh! We've created a* MONSTER*! How can we stop it?*)

Sending signals to processes (1)

Oh no! The program from the previous slide is still running!

- ***Ctrl-C*** can't stop it!

If we could send **SIGKILL** (9) we could stop it, but how?

```
$ kill -9 <processId>
```

- ***Question***: How do we figure out the PID?

Forgive the *BLOODTHIRSTY* name, it should be called "**sendSignal**"

Sending signals to processes (2)

Process groups

- Each process belongs to a process group
- By default it's its parents group
- Can find out group **`pid_t getpgrp()`** in **`unistd.h`**.
- Can change group to one's own process id (or that of another process) **`int setpgid (pid_t pid, pid_t pgid)`**
- Can send signal to all processes in group by making process number negative

`$ kill -9 -<processGroupId>`

Back to the actions!

Handlers should have form **`void someName (int sigNum)`**

- ***QUESTION***: Why is the return type `void`?
- ***QUESTION***: Why does it take the signal number as the sole parameter?
- ***QUESTION***: If it is not OUR CODE that calls the signal handler then how can the signal handler ***see*** the state of our program? How can the signal handler ***change*** the state of our program? (Thru ***what type*** of variable?)

Your turn again!

Same as before, except this time each time the user does press `Ctrl-C` it randomly prints one of the following:

- "***`Ouch!`***"
- "***`Stop that!`***"
- "***`That hurts!`***"
- "***`Mercy!`***"

HINT: Use **`switch(rand()%4) {..}`** to jump to cases 0 to 3 randomly

Sending signals to processes (3)

Application programs can signal each other too!

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

int kill (pid_t procToSignal, int sigToSend);
```

Again, forgive the *BLOODTHIRSTY* name, it should be called "**`sendSignal()`**"

Back to the shell

Our shell program waited for child process to finish.

Revise it so that it may have multiple children (*ie*. one of the children can run in the “background”)

The background child process can finish at any time. (When it does `SIGCHLD` is sent to the parent.)

Reap the child so it doesn't remain a *ZOMBIE* too long.

HINT: use:

```
action.sa_flags =
  SA_NOCLDSTOP// No SIGCHLD on stop(pause) or resume
 |SA_RESTART; // If interrupted in sys call then
              //  restart sys call after sig handler
```

Back to the shell (2)

If multiple children finish around the same time will the different `SIGCHLD` signals be queued?

How can we revise our previous program to LEAVE NO ZOMBIES?

- ***HINT***: Install this signal handler:

```
void    sigChldHander   (int    sig)
{ pid_t pid;
  int   s;
  while( (pid=waitpid(-1,&s,WNOHANG)) > 0)
    if  (WIFEXITED(s) != 0)
      printf("%d returned %d\n",
             pid,WEXITSTATUS(s));
    else
      printf("%d crashed!\n",pid);
}
```

sigaction()
(2) Defining more complex actions

```
#include <signal.h>

int sigaction  (int                          signum,
                const struct sigaction*      act,
                  struct sigaction*            oldact);
```

Where:

```
struct sigaction
{
  void (*sa_handler)(int); // Simple handler
  void (*sa_sigaction)(int, siginfo_t*, void*);
                                  // Funkier sig handler
  sigset_t   sa_mask; // Sigs to allow in handler
  int        sa_flags;//
  void       (*sa_restorer)(void);
};
```

Look at all the goodies in `siginfo_t` (1)

```
siginfo_t
{
  int      si_signo;    // Signal number
  int      si_errno;    // An errno value
  int      si_code;     // Signal code
  int      si_trapno;   // Trap number that caused
                        // hardware-generated signal
                        // (unused on most archs.)
  pid_t    si_pid;      // Sending process ID
  uid_t    si_uid;      // User ID of sending proc
  int      si_status;   // Exit value or signal
  clock_t  si_utime;    // User time consumed
  clock_t  si_stime;    // System time consumed
  sigval_t si_value;    // Signal value
  int      si_int;      // POSIX.1b signal
  void    *si_ptr;      // POSIX.1b signal
  . . .
```

Look at all the goodies in `siginfo_t` (2)

```
  . . .
  int      si_overrun;  // Timer overrun count;
                        // POSIX.1b timers
  int      si_timerid;  // Timer ID;
                        // POSIX.1b timers
  void    *si_addr;     // Mem loc that caused fault
  long     si_band;     // Band event (was int in
                        // glibc 2.3.2 and earlier)
  int      si_fd;       // File descriptor
  short    si_addr_lsb; // Least sign. bit of addr.
                        // (since kernel 2.6.32)
}
```

sigaction() (Example 2a)

```
/*  More advanced sig handlers take   */
/* tell which process sent the signal */

#include <signal.h>
#include <string.h>
#include <stdio.h>

void    signal_handler
(int sig, siginfo_t* infoPtr, void* dataPtr)
{
  printf("signal:[%d], pid:[%d], uid:[%d]\n",
         sig,
         infoPtr->si_pid,
         infoPtr->si_uid );
  //  dataPtr is not used so much
}
```

sigaction() (Example 2b)

```
int main (int argc, char *argv[])
{
  struct sigaction sa;
  memset(&sa,'\0',sizeof(struct sigaction));
  sigemptyset(&sa.sa_mask );

  sa.sa_flags= SA_SIGINFO //Install sa_sigaction
                          // (as opposed to
                          //  sa_handler)
             | SA_RESTART;//If interrupted in
                          // sys call then
                          // restart sys call
                          // after signal handler

  sa.sa_sigaction = signal_handler;
  sigaction(SIGINT, &sa, NULL);
```

sigaction() (Example 2c)

```
  int i;
  for  (i = 0;  i < 60;  i++)
  {
    printf("%2d of 60\n",i);
    sleep (1);
  }
  return(EXIT_SUCCESS);
}
```

Our turn (1)!

There will be a parent process (“owner”) and a child (“Elmo”).

When Elmo receives **`SIGINT`**, somebody is trying to tickle it.

Elmo laughs when its owner tickles it (send **`SIGINT`**), but is weary of tickles from anyone else.

Our turn (2)!

The owner should:

(1) **`fork()`** a child, print its pid and keep it in var.
(2) Enter a **`for(i=0;i<4;i++)`** loop where:
  (a) process waits for user to press enter
  (b) process sends **`SIGINT`** to Elmo

Elmo should:

(1) Install an advanced **`SIGINT`** handler:
  (a) If the owner sent **`SIGINT`**, it prints
    "***Hee hee, that tickles!***"
  (b) If any other process sent **`SIGINT`**, it prints
    "***Elmo does not know you.***"
(2) Does **`while(1) sleep(1);`** awaiting tickling.

`sigaction()`

But wait! *There's more!*

Way more detail!

See ***`$ man sigaction`***

SIGALRM

```
#include <unistd.h>

unsigned int alarm(unsigned int secs);
```

If **`secs>0`** then tells OS "*Send **`SIGALRM`** to me **`secs`** seconds in the future*"

If **`secs==0`** then tells OS "*Clear any alarms I may have set*"

Either case returns number seconds until next (now cleared) alarm, or 0 if there were none.

Your turn!

Write a program that:

(1) Let's the user type in how many seconds they want to wait until an alarm goes off

(2) Continually prints "***Tick-tock***" until the alarm goes off. Then it prints "***Ding-ding***" and stops.

(3) If the user press `Ctrl-C` then it prints how many seconds are left and waits for the user to press `Enter`. Then it goes back to (2).

We don’t have time now, but also check out

- **`ualarm()`**: Like **`alarm()`**, but arguments are in microseconds, not second.
- **`sleep()`** and **`usleep()`**: Use **`SIGALRM`** signal to pause the process for given number of seconds (**`sleep()`**) or microseconds (**`usleep()`**)
- **`man sigaction`**: There is ***way*** more details on signals.
- **`signal()`**: The old-school way to install signal handlers.
- **`setjmp()`**, **`longjmp()`**: C’s inferior, pre-exception way to recover from errors.

Next time: *Threads!*

sigaction()
(3) Seeing what already is being done

```
#include <signal.h>

int sigaction  (int                          signum,
                const struct sigaction* act,
                  struct sigaction*          oldact);
```

Where:

```
struct sigaction
{
  void (*sa_handler)(int), // Simple handler
  void (*sa_sigaction)(int, siginfo_t*, void*);
                                // Funkier sig handler
  sigset_t   sa_mask; // Sigs to allow in handler
  int        sa_flags;//
  void       (*sa_restorer)(void);
};
```

`sigaction()` Continued!

Install `SIGINT` handler if not already ignoring:

```
int    main ()
{
  struct sigaction newAction, oldAction;

  //Define ctrlCHandler that wont block other sigs
  newAction.sa_handler = ctrlCHandler;
  sigemptyset (&newAction.sa_mask);
  newAction.sa_flags = 0;

  // See what is currently done for SIGINT
  sigaction (SIGINT, NULL, &oldAction);

  // Install new handler if not currently ignoring
  if (oldAction.sa_handler != SIG_IGN)
    sigaction (SIGINT, &newAction, NULL);
  . . .
```

`setjmp()` and `longjmp()`

Old school C way of doing error recovery

`int setjmp(jmp_buf j)`

- Memorize both position in code (**`%eip`**) and position on stack (**`%esp`**) inside buffer **`j`**.
- First time it's called returns 0 (so you know this is the installation case).

`void longjmp(jmp_buf j, int i)`

- ***Uh-oh!*** We have a hard-to-recover-from error!
- Set **`%eax`** to **`i`**, jump back to “safe” state described in **`j`**.

Use

```
jmp_buf j; // Put in global context

int main()
{
  if (setjmp(j) != 0)
  {
    // Handle error
  }
  attemptToDoSomethingErrorProne();
}

void attemptToDoSomethingErrorProne()
{
  if (haveMessedUp == 1)
    longjmp(j,1);
}
```

Abuse

```
/*  Question: Will this behave properly? */
jmp_buf j; // Put in global context

int main()
{
  foo();
  bar();
}

void foo ()
{
  if (setjmp(j) != 0)
  {
    // Handle error
  }
}
```

```
void bar ()
{
  if (haveMessedUp==1)
    longjmp(j,1);
}
```

Bottom line on `setjmp()` and `longjmp()`

If you use them be sure you longjmp() to a function that is still on the stack.

Question: What modern error-trapping technique is in C++, Java, etc. that makes this C construct not necessary?