Processes

CS31, Week 10

Prof. Jason Waterman

November 15, 2012

Topics for today

- The UNIX process abstraction
- Process lifecycle
  - Creating processes: forking
  - Running new programs within a process
  - Terminating and reaping processes
- Signaling processes

What is a process?

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  - A process is *an instance of a program in execution*.
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  - A process is *an instance of a program in execution*.
  - i.e., each process is running a program; there may be many processes running the same program
- A process provides
  - Private address space
    - Through the mechanism of virtual memory!
  - Illusion of exclusive use of processor

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  - 2) **Processor state**
    - The CPU registers associated with the running process
    - Includes general purpose registers, program counter, stack pointer, etc.
  - 3) **OS resources**
    - Various OS state associated with the process
    - Examples: page table, file table, network sockets, etc.

Context switches

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- Multiple processes can run simultaneously.
  - On a single CPU system, only one process is running on the CPU at a time.
    - But can have **concurrent** execution of processes
  - On a multi-CPU (or multi-core) system, multiple processes can run in **parallel**.
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- Switching a CPU from running one process to another is called a **context switch**.
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  - (1) Save the context of the currently running process,
  - (2) Restore the context of some previously preempted process
  - (3) Resume execution of the newly restored process
- Deciding when to preempt current process and restart previously preempted process is known as **scheduling**
  - Performed by part of the OS called a **scheduler**

Process IDs

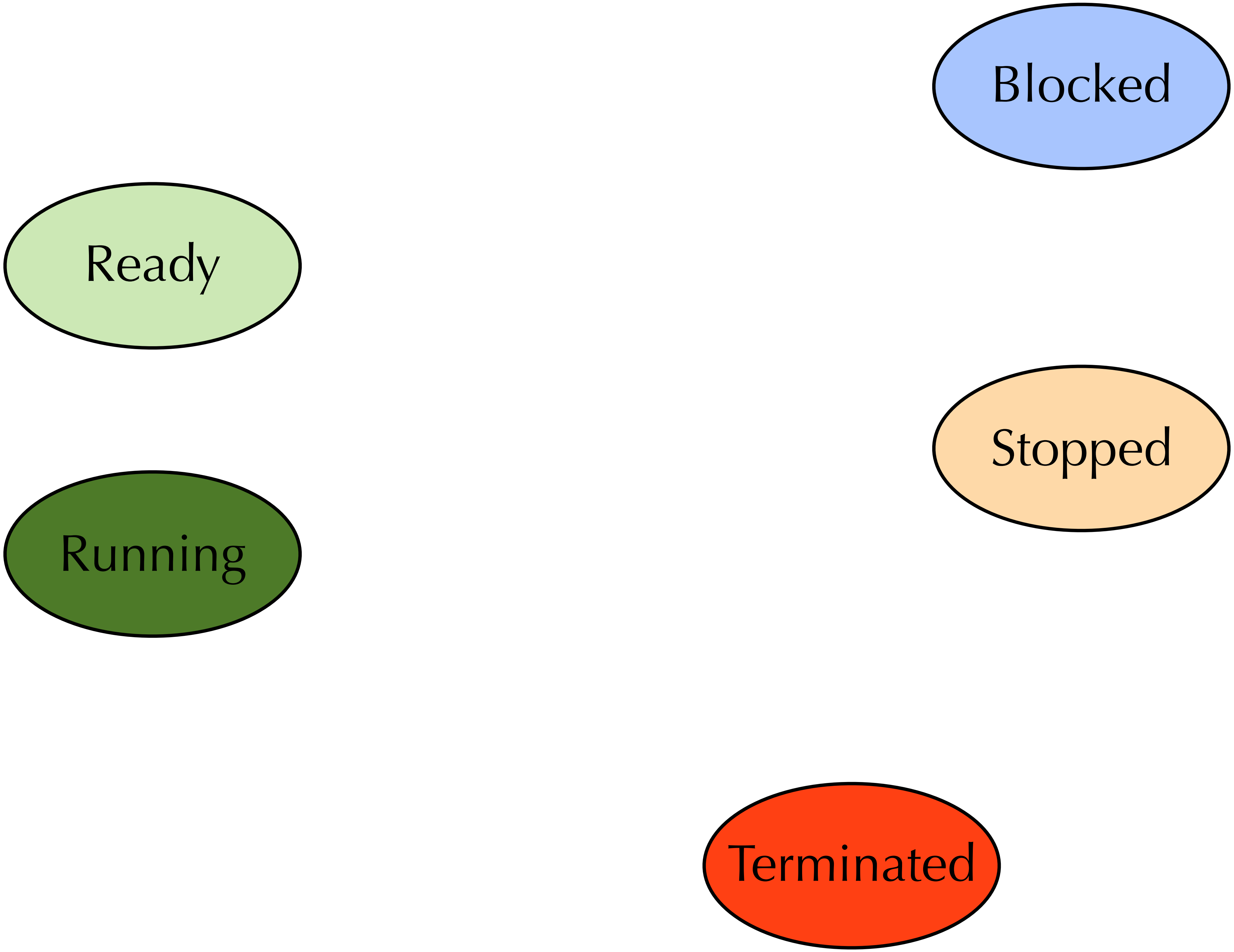
- Each process has a unique positive **process ID (PID)**
- `getpid` returns current process's PID
- `getppid` returns PID of parent of current process

```
pid_t getpid(void);
pid_t getppid(void);
```

Process states

- At any moment, a process is in one of several states:
  - **Ready**:
    - Process is waiting to be executed
  - **Running**:
    - Process is executing on a CPU
  - **Stopped**:
    - Process is *suspended* (due to receiving a certain **signal**) and will not be scheduled
    - More on signals soon…
  - **Waiting** (or **sleeping** or **blocked**):
    - Process is waiting for an event to occur, such as completion of I/O, timer, etc.
    - Why is this different than “ready” ?
  - **Terminated:**
    - Process is stopped permanently, e.g., by returning from `main`, or by calling `exit`
- As the process executes, it moves between these states
  - What state is the process in most of the time?

Process lifecycle



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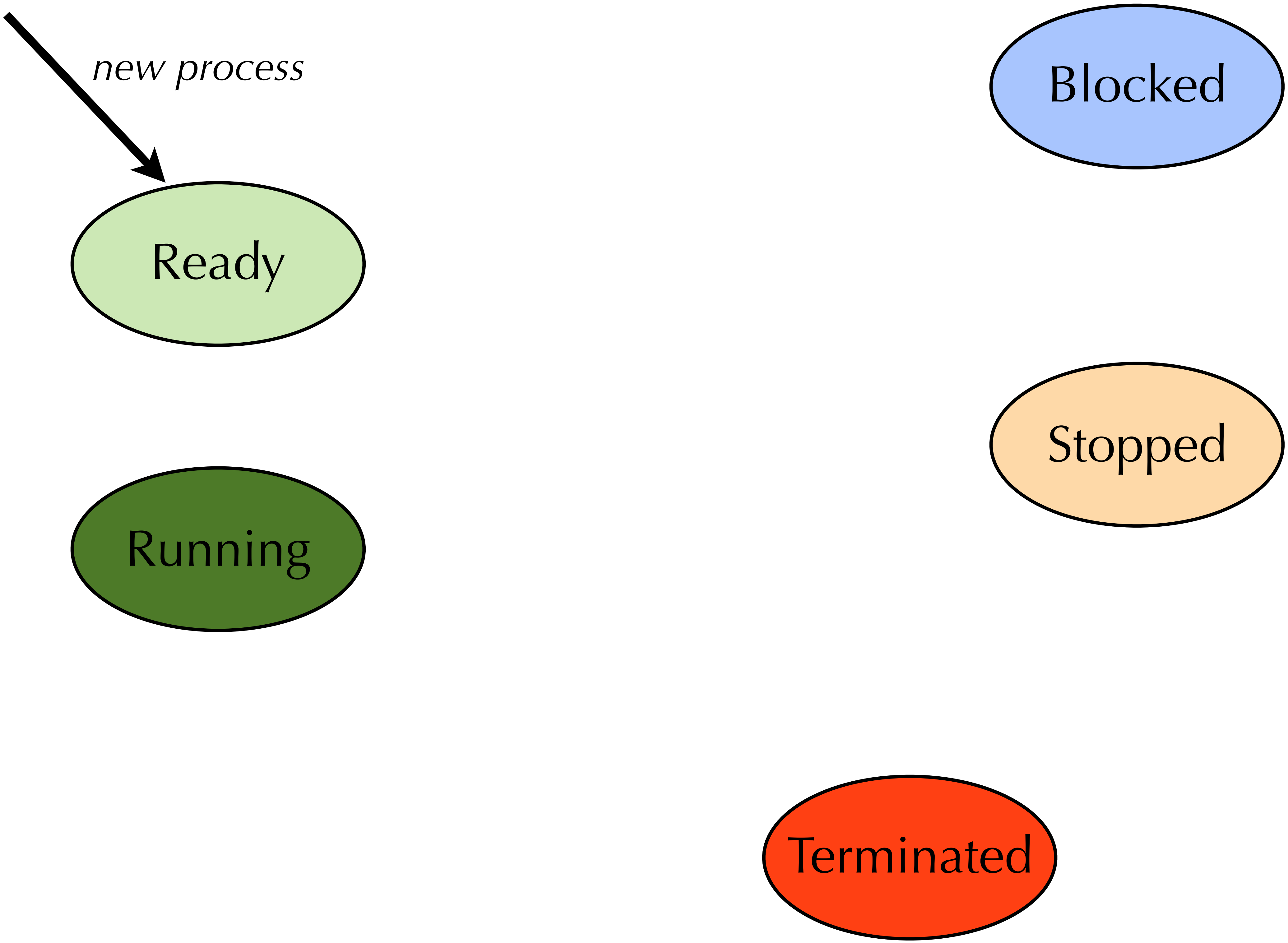

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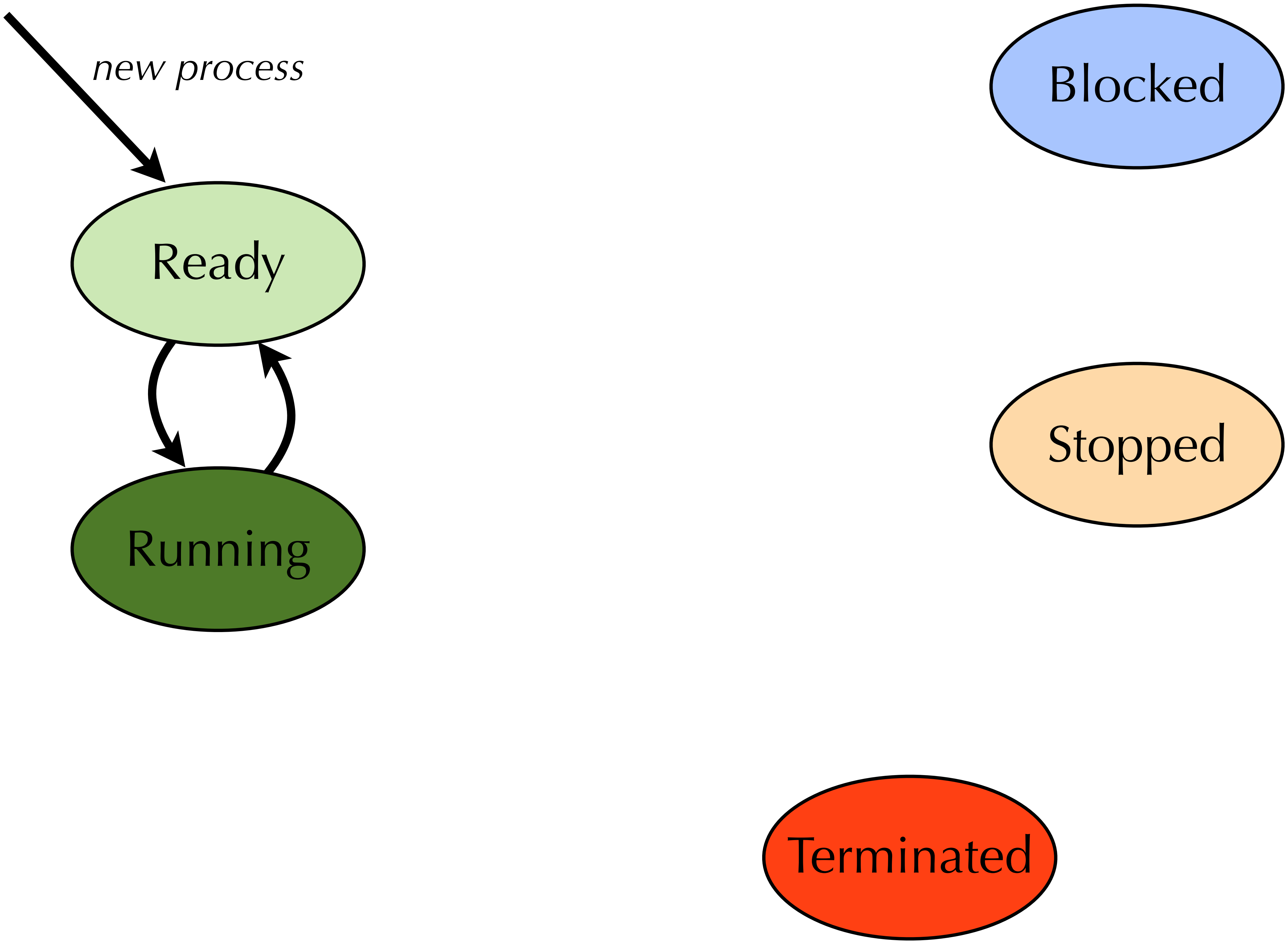

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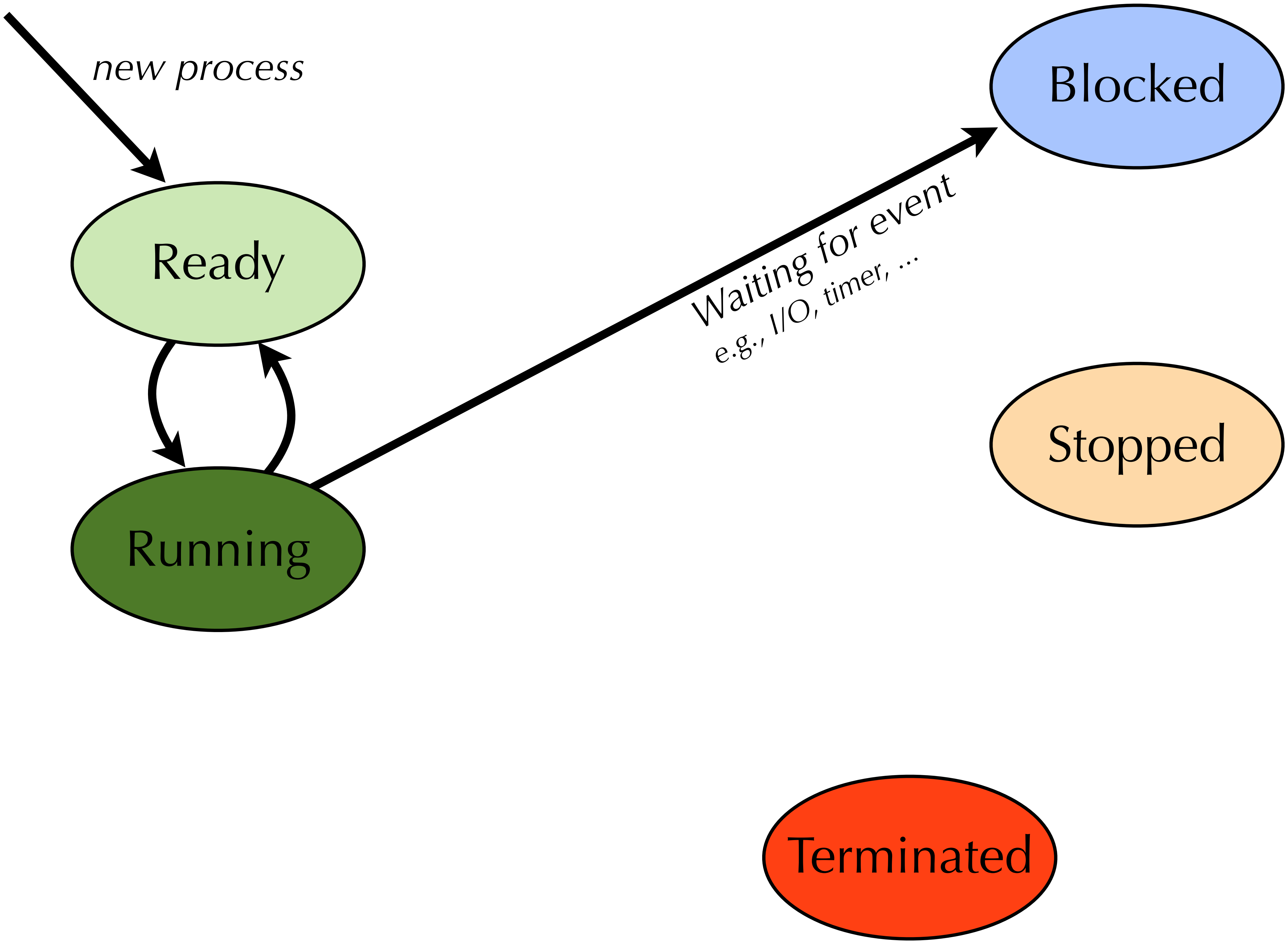

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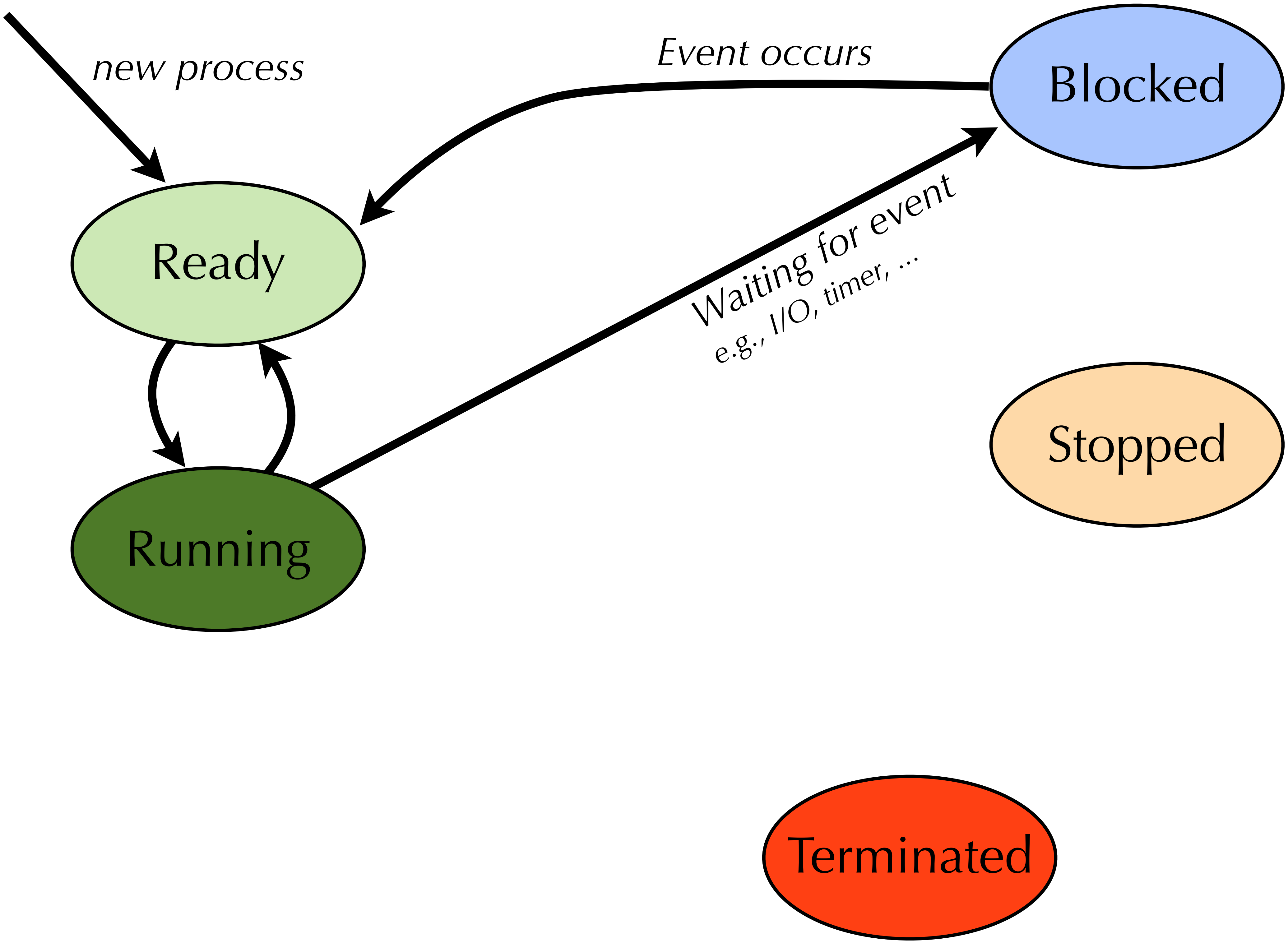

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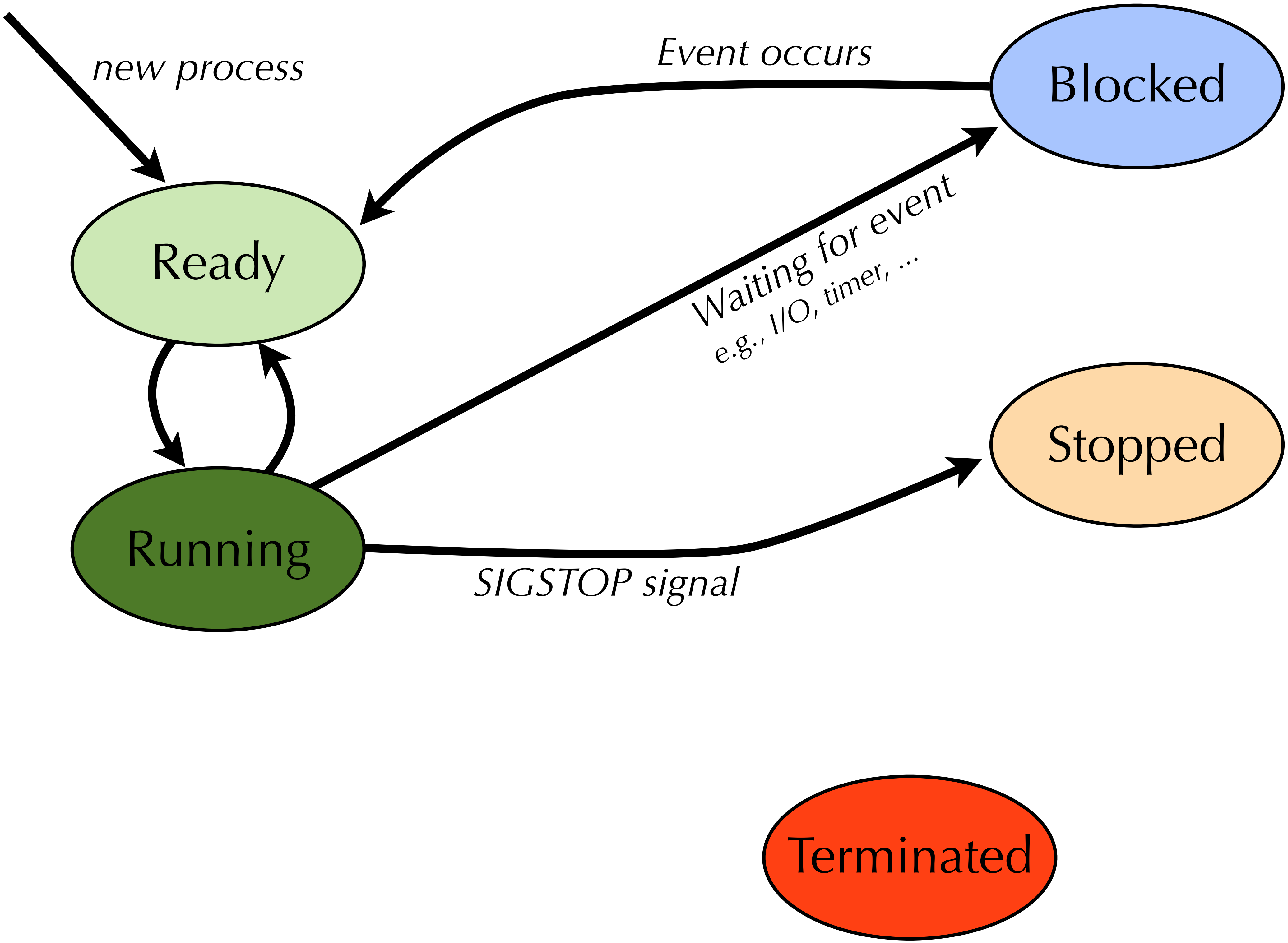

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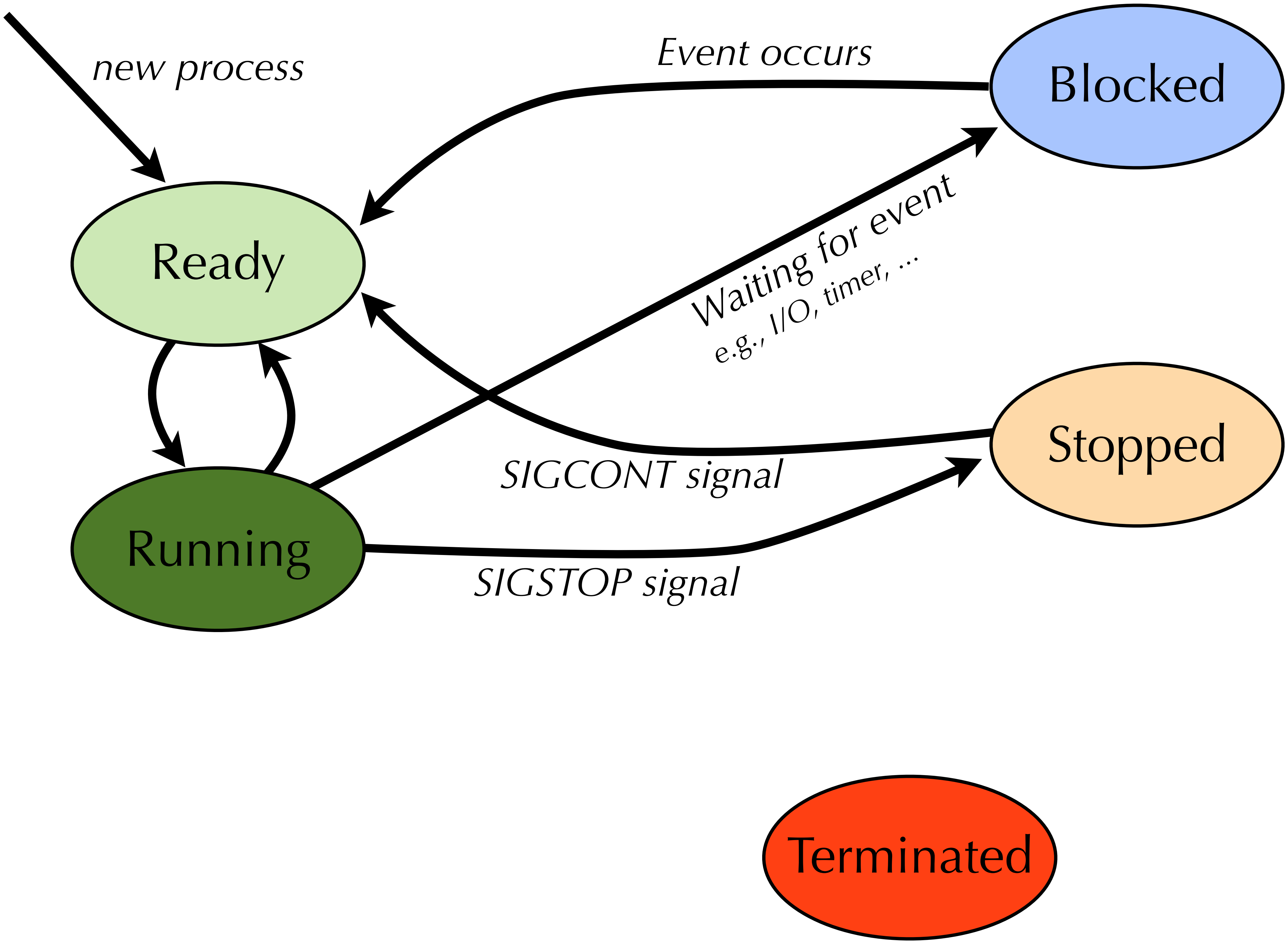

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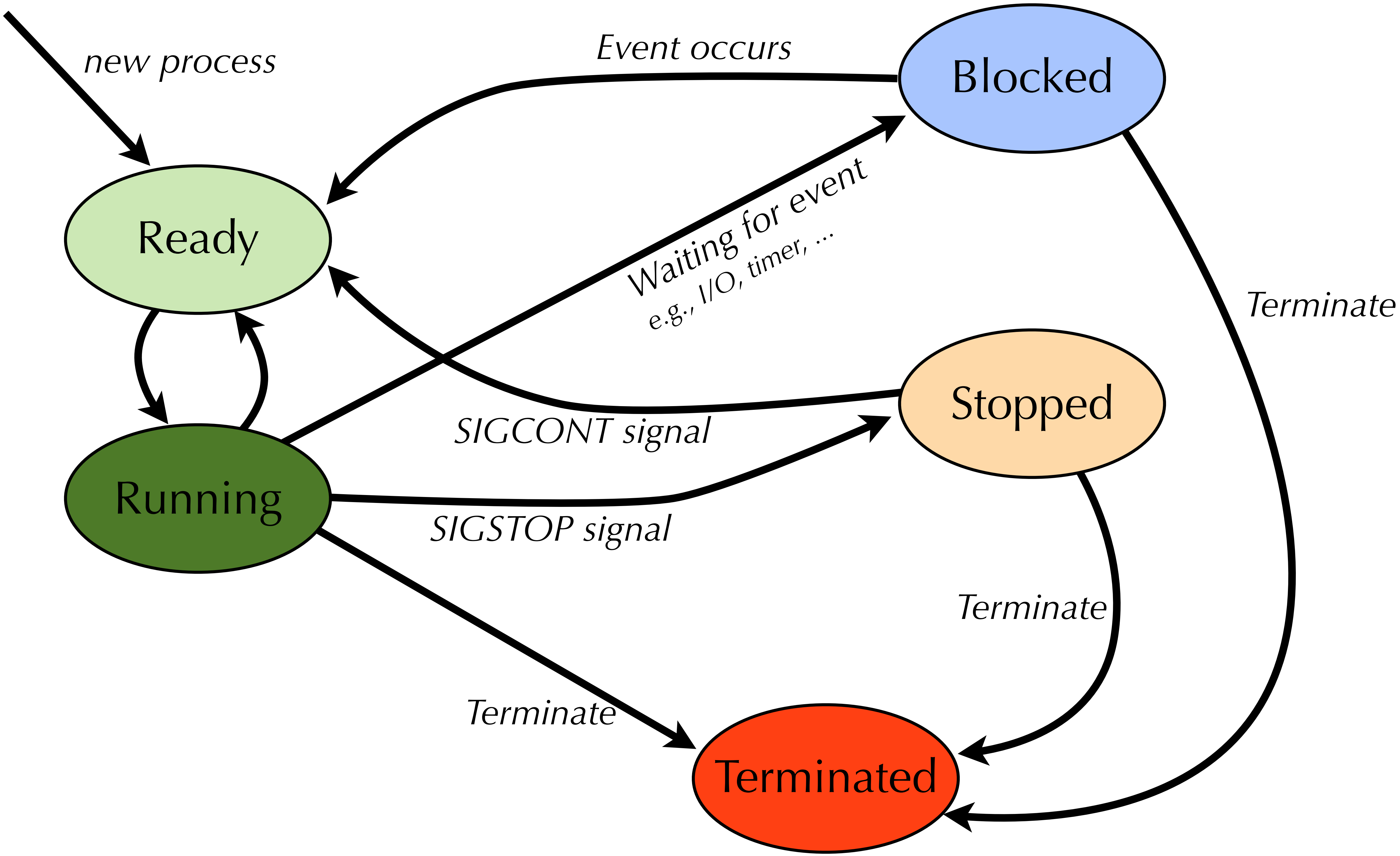

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- Chicken-and-egg problem: How does first process get created?
  - At boot time, the OS creates the first process, called `init`, which is responsible for starting up many other processes

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  - returns child's process ID (pid) to the parent process

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if (fork() == 0) {
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  - Fork is interesting (and often confusing) because it is called once but returns twice

Fork Example #1

- Parent and child process both run the same program.
  - Only difference is the return value from `fork()`
- Child's address space starts as an **exact copy** of parent's
  - They do not share the memory – instead they each have a private copy.
  - Also have the same open files with the same offsets into the files.
    - Includes stdin, stdout, and stderr

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```
void fork1()
{
    int x = 1;
    pid_t pid = fork();
    if (pid == 0) {
        printf("Child has x = %d\n", ++x);
    } else {
        printf("Parent has x = %d\n", --x);
    }
    printf("Bye from process %d with x = %d\n", getpid(), x);
}
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}
```

```
Parent has x = 0
Bye from process 9991 with x = 0
Child has x = 2
Bye from process 9992 with x = 2
```

Fork Example #2

- Key Points
  - Both parent and child can continue forking

```
void fork2()
{
    printf("L0\n");
    fork();
    printf("L1\n");
    fork();
    printf("Bye\n");
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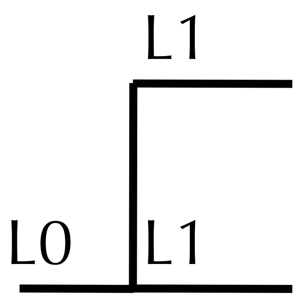

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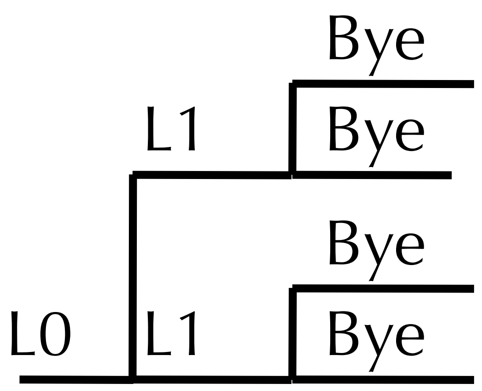

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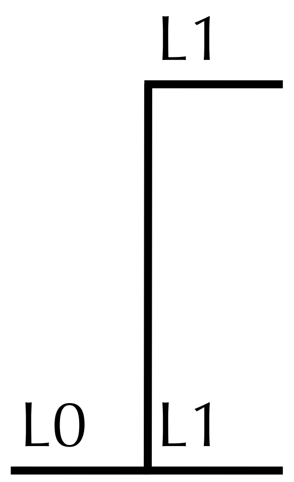

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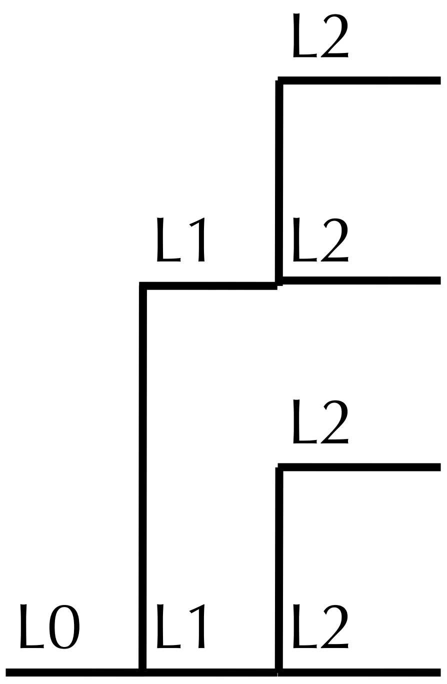

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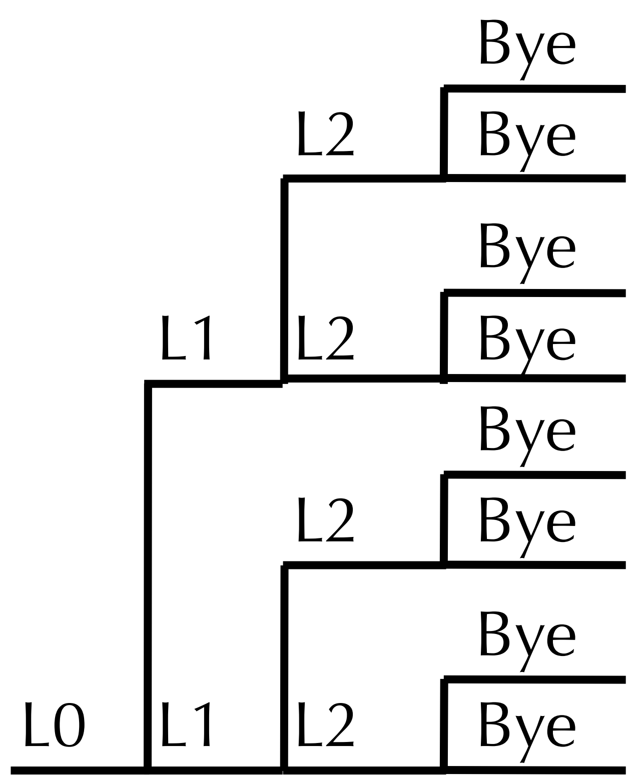

Fork Example #4

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```
void fork4()
{
    printf("L0\n");
    if (fork() != 0) {
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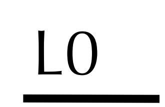

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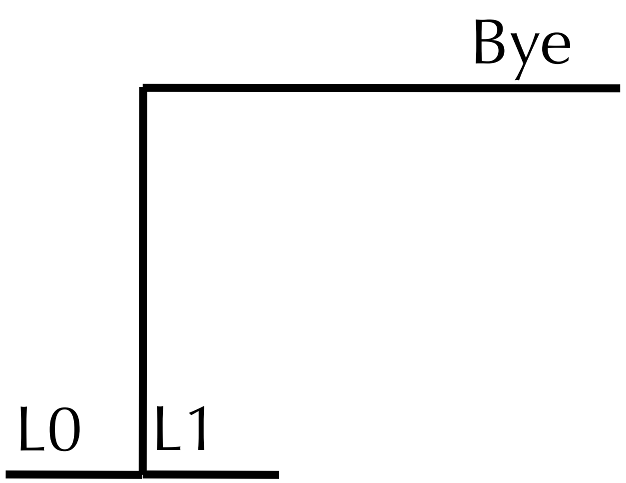

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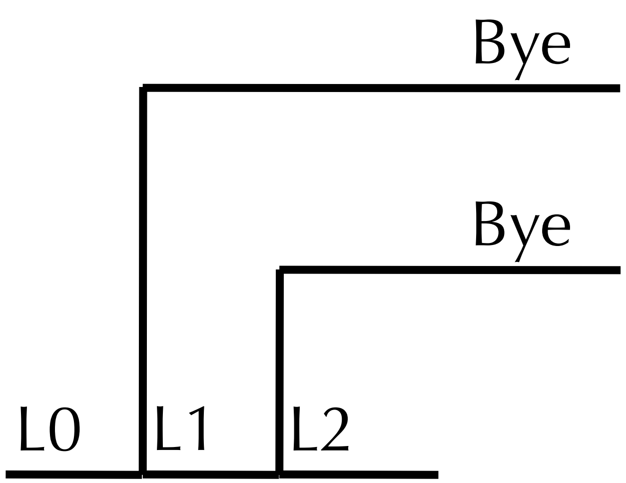

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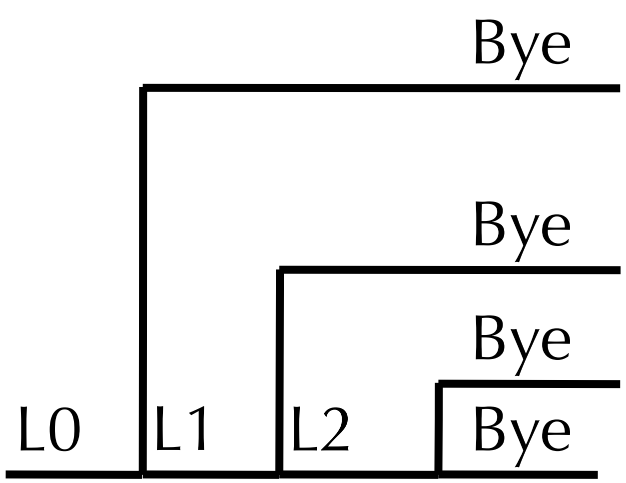

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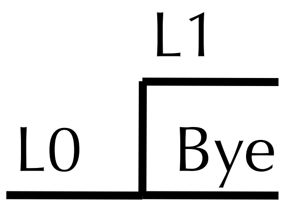

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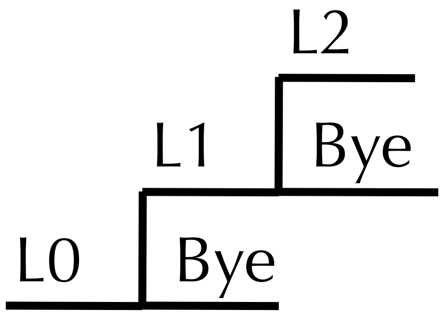

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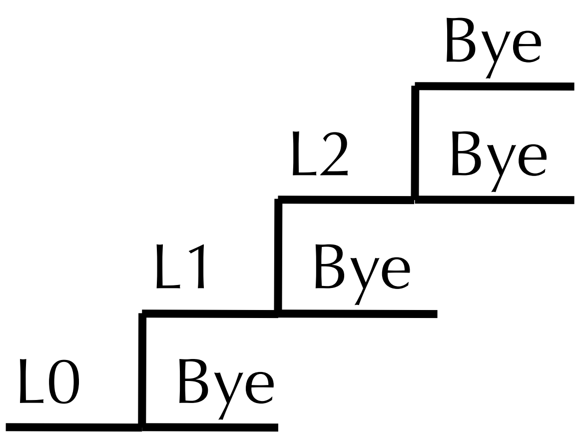

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```
int  execve(const  char  *filename,
                  char  *const  argv [],
                  char *const envp[]);
```
    - `filename`: name of executable file to run
    - `argv`: Command line arguments
    - `envp`: environment variable settings (e.g., $PATH, $HOME, etc.)

Starting new programs

- `execve()` does not fork a new process!
  - Rather, it replaces the address space and CPU state of the current process
  - Loads the new address space from the executable file and starts it from `main()`
  - So, to start a new program, use `fork()` followed by `execve()`

Using fork and exec

```
int main(int argc, char **argv) {
    if (fork() == 0)  {   /* Child process */
        char *newargs[3];
        printf(“Hello, I am the child process.\n”);
        newargs[0] = “/bin/echo”; /* Convention! Not required!! */
        newargs[1] = “some random string”;
        newargs[2] = NULL;      /* Indicate end of args array */
        if (execv(“/bin/echo”, newargs)) {
            printf(“warning: execv returned an error.\n”);
            exit(-1);
        }
        printf(“Child process should never get here\n”);
        exit(42);
    }
}
```

Intermission

You are a prisoner sentenced to death. The Emperor offers you a chance to live by playing a simple game. He gives you 50 black marbles, 50 white marbles and 2 empty bowls. He says, "Divide these 100 marbles into these 2 bowls, any way you like so long as you use all the marbles. Then I will blindfold you and mix the bowls around. You then can choose one bowl and remove ONE marble. If the marble is WHITE you will live, but if the marble is BLACK... you will die."

How do you divide the marbles up so that you have the greatest probability of choosing a WHITE marble?

http://www.braingle.com/

Intermission

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- The UNIX process abstraction
- Process lifecycle
    - Creating processes: forking
    - Running new programs within a process
    - Terminating and reaping processes
- Signaling processes

Terminating a process

- A process terminates for one of 3 reasons:
  - (1) return from the `main()` procedure
  - (2) call to the `exit()` function
  - (3) receive a signal whose default action is to terminate

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- `void exit(int exit_status)`
  - Exits a process with specified exit status.
  - By convention, status of 0 is a “normal” exit, non-zero indicates an error of some kind.
  - `atexit()` registers functions to be executed upon exit.

```
void cleanup(void) {
   printf("cleaning up\n");
}

void fork6() {
   atexit(cleanup);
   fork();
   exit(0);
}
```

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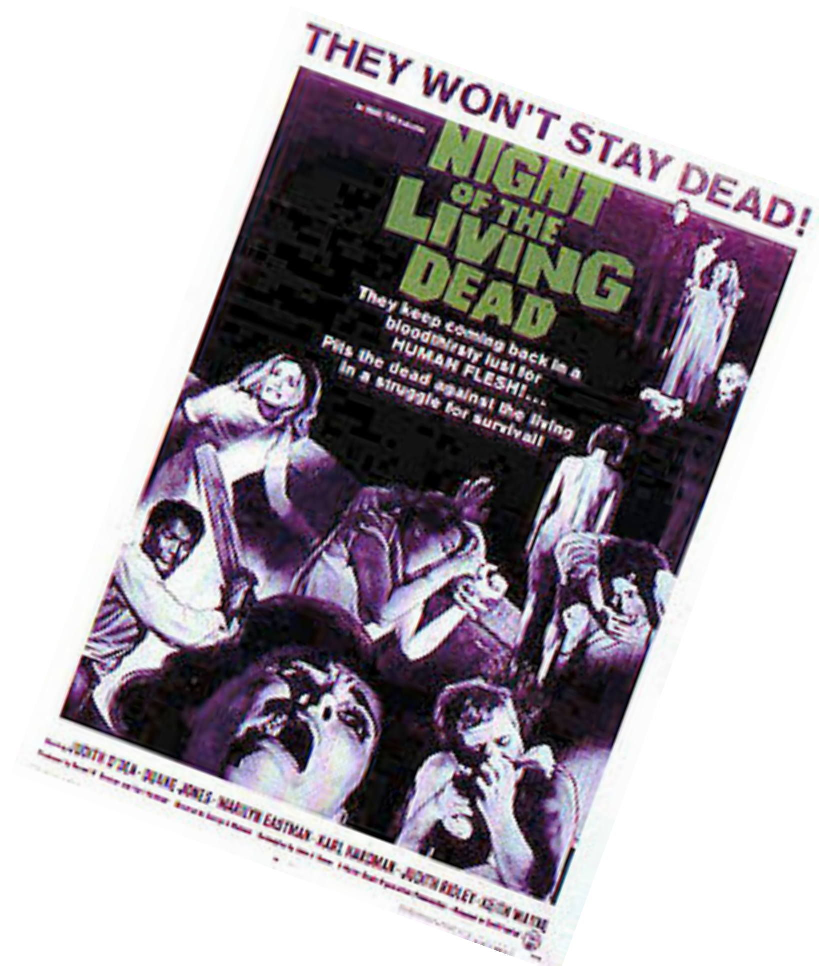
- When a process terminates (for whatever reason) OS does not remove it from system immediately
- Process stays until it is **reaped** by parent
    - When parent reaps a child process, OS gives the parent the exit status of child, and cleans up child

Zombies

- When a process terminates (for whatever reason) OS does not remove it from system immediately
- Process stays until it is **reaped** by parent
  - When parent reaps a child process, OS gives the parent the exit status of child, and cleans up child
  - A terminated process that has not been reaped is called a **zombie process**
- How do you reap a child process?



`wait`: Synchronizing with Children

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  - Suspends parent process until one of its children terminates
  - Return value is the pid of the child process that terminated
  - if `child_status != NULL`, it will point to the child's return status

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- `child_status` can be accessed using several macros:
  - `WIFEXITED(child_status) == 1` if child exited due to call to `exit()`
  - `WEXITSTATUS(child_status)` gives the return code passed to `exit()`
  - `WCOREDUMP(child_status) == 1` if child dumped core.
  - And others (see "`man 2 wait`")

wait: Synchronizing with Children

```
void fork9() {
   int child_status;

   if (fork() == 0) {
      printf("HC: hello from child\n");
   }
   else {
      printf("HP: hello from parent\n");
      wait(&child_status);
      printf("CT: child has terminated\n");
   }
   printf("Bye\n");
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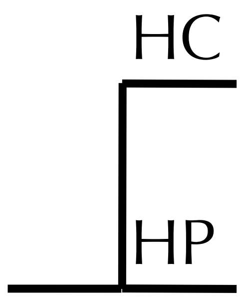

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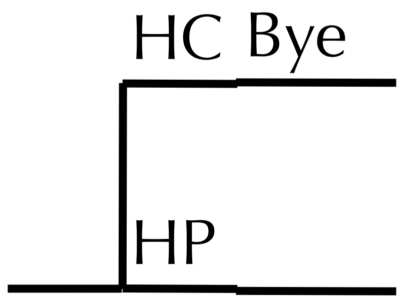

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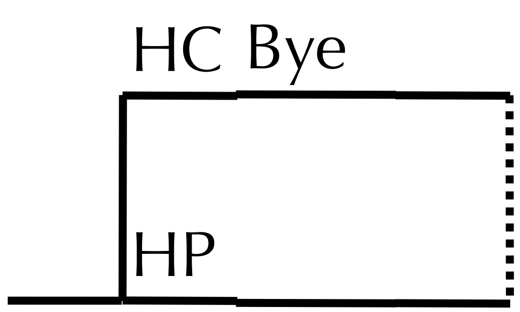

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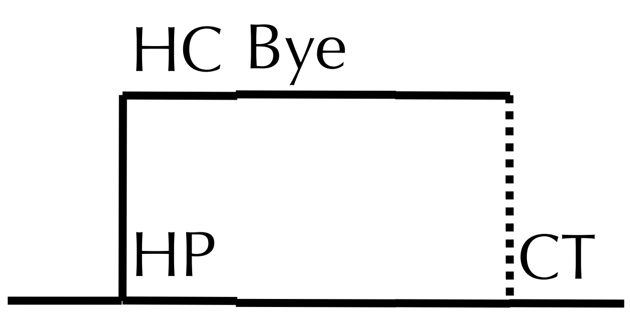

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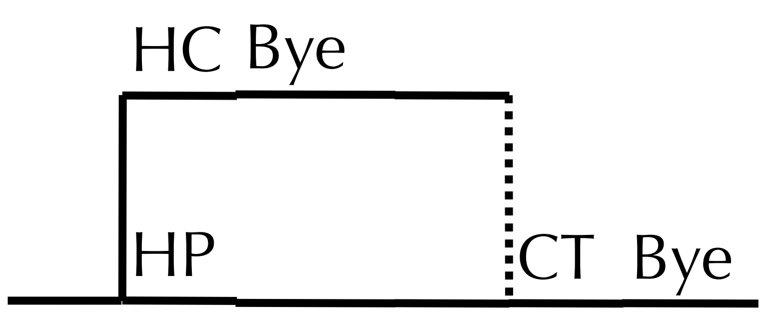

What if multiple child processes exit?

- `wait()` returns status of exited children in arbitrary order.

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```
#define N 10

void fork10()
{
    pid_t pid[N];
    int i, child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = wait(&child_status);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminate abnormally\n", wpid);
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What if multiple child processes exit?

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        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
                   wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminate abnormally\n", wpid);
    }
}
```

```
linux> ./fork10
Child 2625 terminated with exit status 195
Child 2627 terminated with exit status 197
Child 2626 terminated with exit status 196
Child 2624 terminated with exit status 194
Child 2623 terminated with exit status 193
Child 2622 terminated with exit status 192
Child 2621 terminated with exit status 191
Child 2620 terminated with exit status 190
...
```

`waitpid()`: Waiting for a specific process

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  - `options` can be used to specify if call should return immediately (with return value of 0) if no terminated children, and also whether we are interested in stopped processes
  - `status` encodes information about how child exited (or was stopped)

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  `int options)`

```
void fork11()
{
    pid_t pid[N];
    int i;
    int child_status;
    for (i = 0; i < N; i++)
        if ((pid[i] = fork()) == 0)
            exit(100+i); /* Child */
    for (i = 0; i < N; i++) {
        pid_t wpid = waitpid(pid[i], &child_status, 0);
        if (WIFEXITED(child_status))
            printf("Child %d terminated with exit status %d\n",
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        else
            printf("Child %d terminated abnormally\n", wpid);
    }
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void fork11()
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            printf("Child %d terminated with exit status %d\n",
                   wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
```

```
linux> ./fork11
Child 3064 terminated with exit status 100
Child 3065 terminated with exit status 101
Child 3066 terminated with exit status 102
Child 3067 terminated with exit status 103
Child 3068 terminated with exit status 104
Child 3069 terminated with exit status 105
Child 3070 terminated with exit status 106
...
```

Back to the zombies...

```
void zombie()
{
    if (fork() == 0) {
        /* Child */
        printf("Terminating Child, PID = %d\n",
               getpid());
        exit(0);
    } else {
        printf("Running Parent, PID = %d\n",
               getpid());
        while (1)
            ; /* Infinite loop */
    }
}
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Back to the zombies...

- Zombie example

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linux> ./zombie &
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    }
}
```

```
linux> ./zombie &
[1] 6639
Running Parent, PID = 6639
Terminating Child, PID = 6640
```

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               getpid());
        while (1)
            ; /* Infinite loop */
    }
}
```

```
linux> ./zombie &
[1] 6639
Running Parent, PID = 6639
Terminating Child, PID = 6640
linux> ps
  PID TTY          TIME CMD
 6585 ttyp9    00:00:00 tcsh
 6639 ttyp9    00:00:03 zombie
 6640 ttyp9    00:00:00 zombie <defunct>
 6641 ttyp9    00:00:00 ps
linux>
```

Back to the zombies...

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linux> ./zombie &
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- ps shows child process as “defunct”

Orphans

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  - Problem: All processes (except for init) need a parent process.
  - Orphan processes "adopted" by `init` (PID 1 on most UNIX systems)
  - If child subsequently terminates, it will be reaped by `init`
    - `init` reaps zombie orphans...

Nonterminating Child Example

```
void fork8()
{
    if (fork() == 0) {
        /* Child */
        printf("Running Child, PID = %d\n",
               getpid());
        while (1)
            ; /* Infinite loop */
    } else {
        printf("Terminating Parent, PID = %d\n",
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- Child process still active even though parent has terminated
- Must kill explicitly, or else will keep running indefinitely

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linux> ./fork8
Terminating Parent, PID = 6675
Running Child, PID = 6676
```

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void fork8()
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               getpid());
        exit(0);
    }
}
```

```
linux> ./fork8
Terminating Parent, PID = 6675
Running Child, PID = 6676
linux> ps
  PID TTY          TIME CMD
 6585 ttyp9    00:00:00 tcsh
 6676 ttyp9    00:00:06 fork8
 6677 ttyp9    00:00:00 ps
```

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    } else {
        printf("Terminating Parent, PID = %d\n",
               getpid());
        exit(0);
    }
}
```

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Terminating Parent, PID = 6675
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linux> ps
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 6585 ttyp9    00:00:00 tcsh
 6676 ttyp9    00:00:06 fork8
 6677 ttyp9    00:00:00 ps
linux> kill 6676
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    }
}
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Zombie orphan

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linux> kill 6639
[1]    Terminated
```

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```

- ps shows child process as “defunct”
- Killing parent allows child to be reaped

Topics for today

- The UNIX process abstraction
- Process lifecycle
  - Creating processes: forking
  - Running new programs within a process
  - Terminating and reaping processes
- Signaling processes

Signals

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- A **signal** is small message to notify a process of some system event
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Constant values may vary between platforms!

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    - Process can react in one of three ways:
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      - terminate (maybe dumping core)
      - **catch** a signal with a **signal handler** function

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  - At most one signal of each type is pending
  - Signals are not queued!
    - If process has pending signal of type *k*, then subsequent signals of type *k* are discarded

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- Process can **block** receipt of certain signals.
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- Any signal received at most once

Pending and blocking signals

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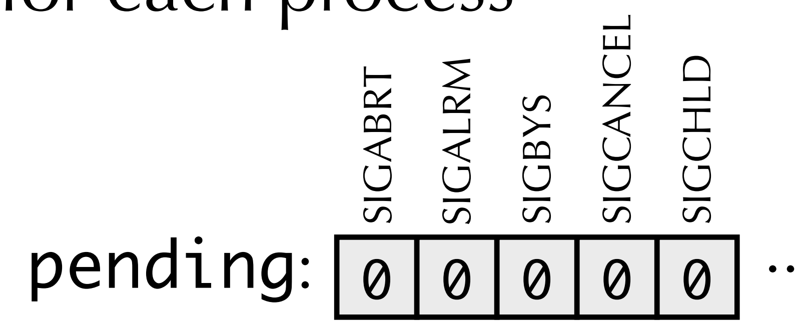

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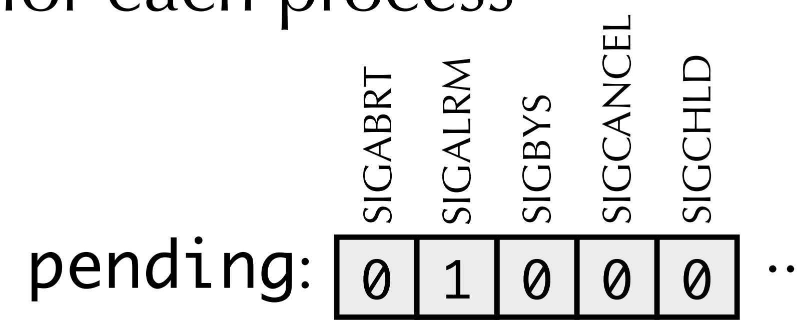

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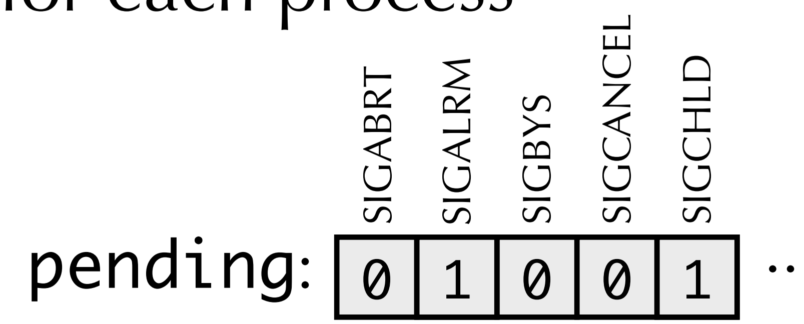

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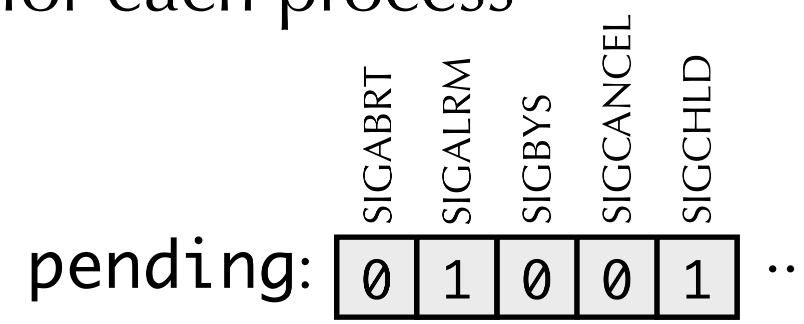

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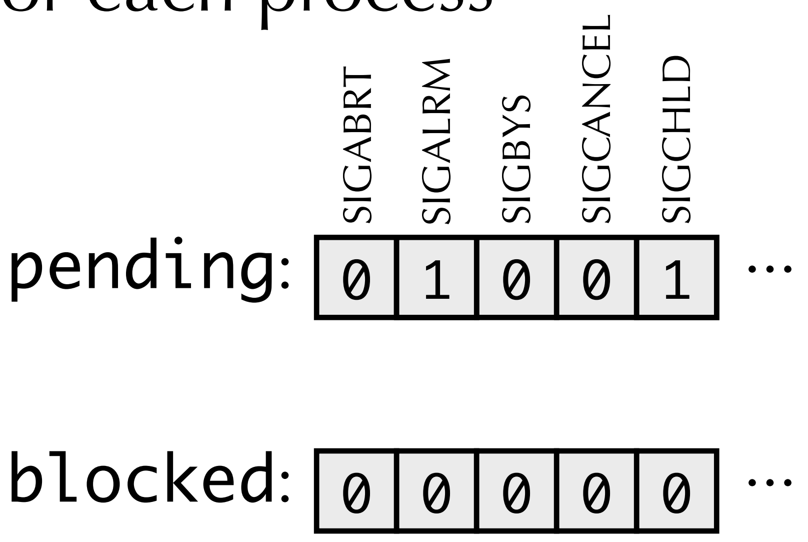

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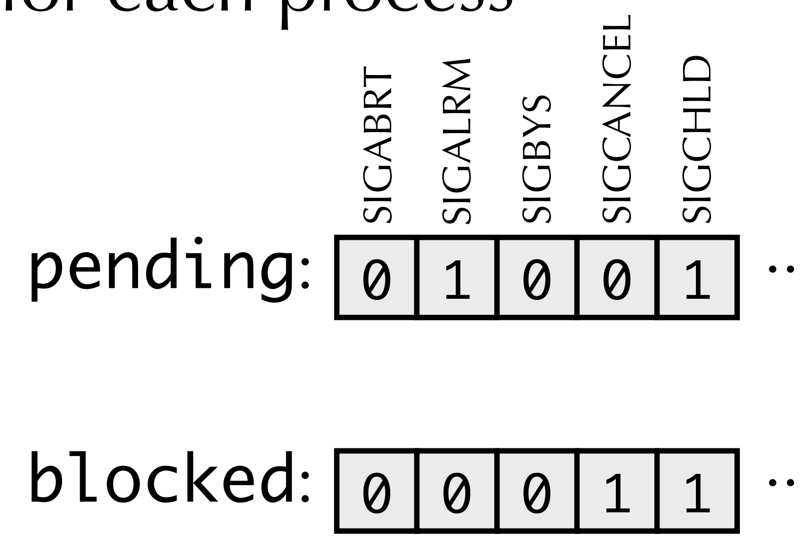

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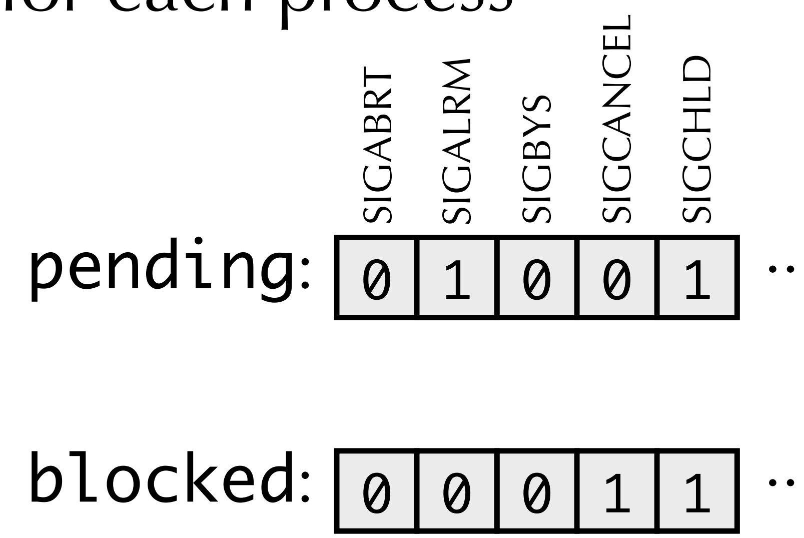

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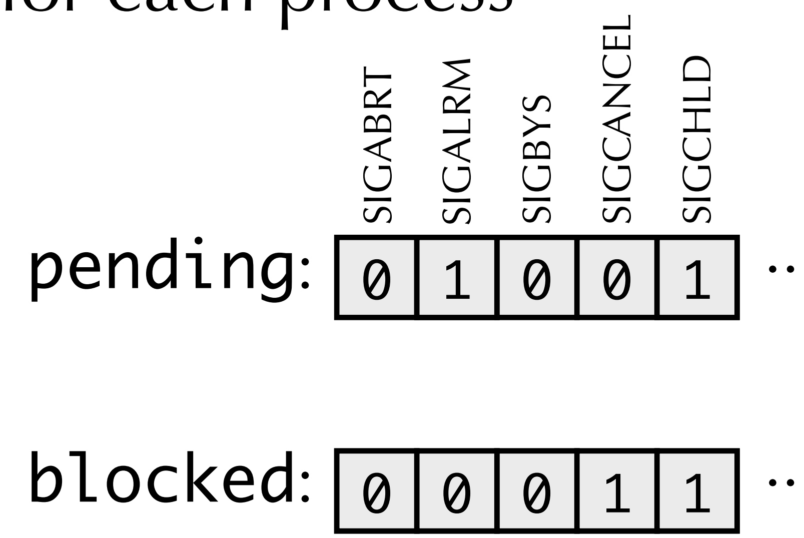

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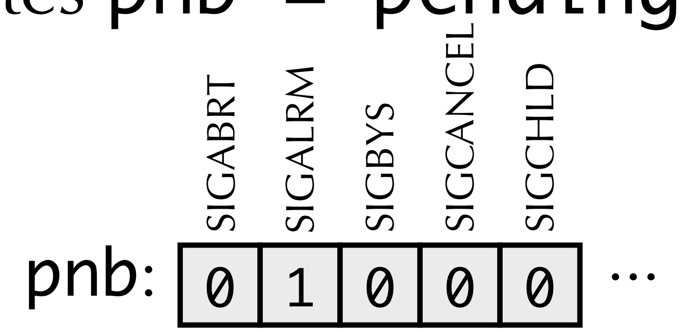

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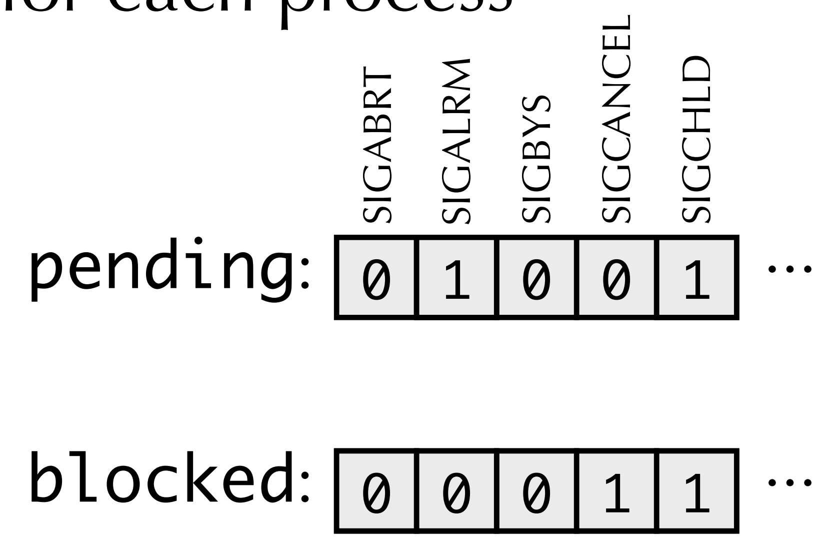

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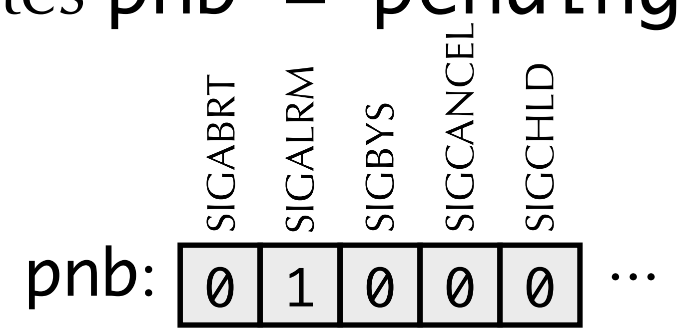

  - If `pnb == 0` then no signals to be received

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	SIGABRT	SIGALRM	SIGBYS	SIGCANCEL	SIGCHLD	
`pending`:	0	1	0	0	1	…
`blocked`:	0	0	0	1	1	…

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	SIGABRT	SIGALRM	SIGBYS	SIGCANCEL	SIGCHLD	
`pnb`:	0	1	0	0	0	…

  - If `pnb == 0` then no signals to be received
  - If `pnb != 0` then OS chooses a signal to be received, and triggers some action by process

Sending signals with kill

- kill programs sends an arbitrary signal to a process
  - E.g., `kill -9 24818` sends SIGKILL to process 24818
- Also a function: `kill(pid_t p, int signal)`

- Can send a signal to a specific process, or all processes in a **process group**
  - Every process belongs to a process group
  - Read textbook for more info

Default actions

- Each signal type has a predefined **default action**
- One of
  - The process terminates
  - The process terminates and dumps core
  - The process stops (until restarted by a SIGCONT signal)
  - The process ignores the action

Signal handlers

- `signal(int signum, handler_t *handler)`
  - Overrides default action for signals of kind `signum`
- Different values for `handler`
  - SIG_IGN: ignore signals of type `signum`
  - SIG_DFL: revert to the default action for signals of type `signum`
  - Otherwise, it is a function pointer for a **signal handler**
    - Function will be called on receipt of signal of type `signum`
    - Referred to as **installing** handler
    - Handler execution is called **handling** or **catching** signal
    - When handler returns, control flow of interrupted process continues

Signal handler example

```
void int_handler(int sig) {
    printf("Process %d received signal %d\n",
            getpid(), sig);
}

int main() {
    signal(SIGINT, int_handler);
    while (1)
        ;
}
```

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$ ./signaleg
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```
$ ./signaleg
^C
Process 319 received signal 2
```

Signal handler example

```c
void int_handler(int sig) {
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}
```

```
$ ./signaleg
^C
Process 319 received signal 2
^C
```

Signal handler example

```
void int_handler(int sig) {
    printf("Process %d received signal %d\n",
            getpid(), sig);
}

int main() {
    signal(SIGINT, int_handler);
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}
```

```
$ ./signaleg
^C
Process 319 received signal 2
^C
Process 319 received signal 2
```

Signal handler example

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void int_handler(int sig) {
    printf("Process %d received signal %d\n",
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int main() {
    signal(SIGINT, int_handler);
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}
```

```
$ ./signaleg
^C
Process 319 received signal 2
^C
Process 319 received signal 2
^C
```

Signal handler example

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```
$ ./signaleg
^C
Process 319 received signal 2
^C
Process 319 received signal 2
^C
Process 319 received signal 2
```

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        ;
}
```

```
$ ./signaleg
^C
Process 319 received signal 2
^C
Process 319 received signal 2
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Process 319 received signal 2
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```
$ kill -9 319
```

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int main() {
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}
```

```
$ ./signaleg
^C
Process 319 received signal 2
^C
Process 319 received signal 2
^C
Process 319 received signal 2
Killed
```

```
$ kill -9 319
```

Signal handlers as concurrent flows

- Signal handlers run **concurrently** with main program
  - Signal handler is not a separate process
  - Concurrent here means "non-sequential", as opposed to "parallel"