System calls

- Programming interface to the services provided by the OS
  - Application can think of OS as providing a library of services
  - Much care spent in keeping interface interface secure
    - E.g., parameters are copied to kernel space before they are checked
- Mostly accessed through an API (Application Programming Interface)
  - Win32, POSIX, Java API

The Skinny

- Syscall interface allows separation of concern
  - Innovation
  - Narrow
    - Simple
    - Powerful
    - Highly portable
    - Robust

Asynchronous notifications in user space

- Interrupts inform kernel of asynchronous events — what about processes?
  - Signals (UNIX); Asynchronous events (Windows)
- Why?
  - Pre-empting user level threads
  - Asynchronous I/O
  - Suspending/resuming a process (e.g., for debugging)
  - Adapting to changing HW resources provided by OS (e.g., memory)
- Upon receipt
  - Ignore
  - Terminate process
  - Catch through handler
“Everything must change, so that everything can stay the same”

T. di Lampedusa

Booting an OS Kernel

Interrupts/Exceptions
- Hardware-defined
- Interrupt vector for handlers (kernel)
- Interrupt stack (kernel)
- Interrupt masking (kernel)
- Processor state (kernel)

Signals/Upcalls
- Kernel-defined
- Handlers (user)
- Signal stack or process stack (user)
- Signal masking (user)
- Processor State (user)

Booting an OS Kernel

1. BIOS copies Bootloader, checking its cryptographic hash to make sure it has not been tampered with.

Booting an OS Kernel

2. Bootloader copies OS Kernel, checking its cryptographic hash.

Booting an OS Kernel

BIOS

Basic Input/Output System
- In ROM; includes the first instructions fetched and executed

BIOS copies Bootloader, checking its cryptographic hash.
Booting an OS Kernel

BIOS | Bootloader | OS Kernel | Login app
--- | --- | --- | ---

3. Kernel initializes its data structures (devices, interrupt vector table, etc)

4. Kernel: Copies first process from disk
   Changes PC and sets mode bit to 1
   And the dance begins!

Booting an OS Kernel

BIOS | Bootloader | OS Kernel | Login app
--- | --- | --- | ---

Shall we dance?

- All processes are progeny of that first process
- Created with a little help from its friend...
  - via system calls!

CreateProcess (Windows)

fork + exec (UNIX)
Starting a new process: the recipe

1. Allocate & initialize PCB
2. Create and initialize a new address space
3. Load program into address space
4. Allocate user-level and kernel-level stacks.
5. Initialize HW context to begin execution at start
6. Copy arguments (if any) to the base of the user-level stack
7. Inform scheduler that a new process is ready
8. Transfer control to user mode

Which API?

Windows: CreateProcess System Call (simplified)

```c
if (!CreateProcess(
    NULL,         // No module name (use command line)
    argv[1],      // Command line
    NULL,         // Process handle not inheritable
    NULL,         // Thread handle not inheritable
    FALSE,        // Set handle inheritance to FALSE
    0,            // No creation flags
    NULL,         // Use parent's environment block
    NULL,         // Use parent's starting directory
    &si,          // Pointer to STARTUPINFO structure
    &pi )         // Ptr to PROCESS_INFORMATION structure
)
```

Unix: `fork()` and `exec()`

```c
fork()

int pid = fork()
```

- Creates a complete copy (child) of the invoking process (parent)
- Returns twice (!), to both the parent and the child process, setting pid to different values
  - for the child: pid := 0;
  - for the parent: pid := child’s process id

In action

```c
#include <stdio.h>
#include <unistd.h>

int main() {
    int child_pid = fork();
    if (child_pid == 0) { // child process
        printf("I am process #%d\n", getpid());
        return 0;
    } else { // parent process
        printf("I am the parent of process #%d\n", child_pid);
        return 0;
    }
}
```

Possible outputs?
Which API?

Unix: fork() and exec()

**fork()**
- `int pid = fork();`
- Creates a complete copy (child) of the invoking process (parent)
- Returns twice (!), to both the parent and the child process, setting pid to different values
  - for the child: pid := 0;
  - for the parent: pid := child's process id

**exec()**
- Loads executable in memory & starts executing it
  - code, stack, heap are overwritten
  - the process is now running a different program!

wait() and exit()

- **wait()** causes parent to wait until child terminates
  - parent gets return value from child
  - if no children alive, wait() returns immediately
- **exit()** is called after program terminates
  - closes open files
  - deallocates memory
  - deallocates most OS structures
  - checks if parent is alive. If so...

Creating and managing processes

<table>
<thead>
<tr>
<th>Syscall</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>fork()</td>
<td>Create a child process as a clone of the current process. Return to both parent and child. Return child's pid to parent process; return 0 to child</td>
</tr>
<tr>
<td>exec(proc, args)</td>
<td>Run the application prog in the current context with the specified args</td>
</tr>
<tr>
<td>wait(&amp;status)</td>
<td>Pause until some child process has exited</td>
</tr>
<tr>
<td>exit(status)</td>
<td>Tell kernel current process is complete and its data structures (stack, heap, code) should be garbage collected. May keep PCB.</td>
</tr>
<tr>
<td>kill(pid, type)</td>
<td>Send a signal of a specified type to a process (a bit of an over-dramatic misnomer...)</td>
</tr>
</tbody>
</table>

In action

```c
main() {
  pid = fork();
  if (pid==0) 
    exec(B);
  else
    wait(&status);
  exit(3);
}
```
## In action

```c
main() {
    ... exit(3);
}
```

```c
pid = fork();
if (pid==0)
    exec(B);
else
    wait(&status);
```

### What is a shell?

**Job control system**

- Runs programs on behalf of the user
- Allows programmer to create/manage set of programs
  - `sh` Original Unix shell (Bourne, 1977)
  - `csh` BSD Unix C shell (`tcsh` enhances it)
  - `bash` “Bourne again” shell
- Every command typed in the shell starts a child process of the shell
- Runs at user-level. Uses syscalls: fork, exec, etc.

### The Unix shell (simplified)

```
while(! EOF)
    read input
    handle regular expressions
    int pid = fork(); // create child
    if (pid == 0) { // child here
        exec("program", argc, argv0,...);
    }
    else { // parent here
        ...
    }
```

### More on signals

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Default Action</th>
<th>Corresponding Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>SIGINT</td>
<td>Terminate</td>
<td>Interrupt (e.g., CTRL-C from keyboard)</td>
</tr>
<tr>
<td>9</td>
<td>SIGKILL</td>
<td>Terminate</td>
<td>Kill program (cannot override or ignore)</td>
</tr>
<tr>
<td>14</td>
<td>SIGALRM</td>
<td>Terminate</td>
<td>Timer signal</td>
</tr>
<tr>
<td>17</td>
<td>SIGCHLD</td>
<td>Ignore</td>
<td>Child stopped or terminated</td>
</tr>
<tr>
<td>20</td>
<td>SIGSTP</td>
<td>Stop until SIGCONT</td>
<td>Stop signal from terminal (e.g., CTRL-Z from keyboard)</td>
</tr>
</tbody>
</table>
```c
int main() {
    pid_t pid[N];
    int i, child_status;

    for (i = 0; i < N; i++) // N forks
        if ((pid[i] = fork()) == 0) {
            while(1); // child infinite loop
        }
    /* Parent terminates the child processes */
    for (i = 0; i < N; i++) { // parent continues executing
        printf("Killing proc. %d\n", pid[i]);
        kill(pid[i], SIGINT);
    }
    /* Parent reaps terminated children */
    for (i = 0; i < N; i++) {
        pid_t wpid = wait(&child_status);
        if (WIFEXITED(child_status)) // parent checks for each child's exit
            printf("Child %d terminated w/exit status %d\n", wpid, WEXITSTATUS(child_status));
        else
            printf("Child %d terminated abnormally\n", wpid);
    }
    exit(0);
}
```

```c
void int_handler(int sig) {
    printf("Process %d received signal %d\n", getpid(), sig);
    exit(0);
}
```

```c
void int_handler(int sig) {
    printf("Process %d received signal %d\n", getpid(), sig);
    exit(0);
}
```

**Kernel Operation (conceptual, simplified)**

- Initialize devices
- Initialize "first process"
- while (TRUE) {
  - while device interrupts pending
    - handle device interrupts
  - while system calls pending
    - handle system calls
  - if run queue is non-empty
    - select a runnable process and switch to it
  - otherwise
    - wait for device interrupt
}

**CPU Scheduling**