Process Management

Process Abstraction in Unix

Lecture 2b – Unix Case study

Overview

- Process in Unix
  - Identification
  - Information
  - Creation
  - Termination
  - Parent-Child Synchronization

- Process states in Unix

- Implementation Issues

Process Abstraction in Unix

Identification

- PID: Process ID (an integer value)

Information

- Process State:
  - Running, Sleeping, Stopped, ***Zombie***
- Parent PID:
  - PID of the parent process
- Cumulative CPU time:
  - Total amount of CPU time used so far
- etc

- Unix Command for process information:
  - **`ps`** (short for process status)

Process Creation in Unix: `fork()`

- The main way to create a new process

Header File	`#include <unistd.h>` #include <sys/types.h>
Syntax	`int fork( );`

  - Returns:
    - **`PID`** of the newly created process (for parent process) OR
    - **`0`** (for child process)

- Header files are system dependent
  - "***`man fork`***" to locate the right files for your system!

Process Creation in Unix: `fork()` (cont)

- Behavior:
  - Creates a new process (known as ***child process***)
  - Child process is a **duplicate** of the current executable image
    - i.e., same code, same address space, etc.
    - Memory in child is a **COPY** of the parent (i.e., not shared)
      - Implemented using copy-on-write
  - Child **differs only in:**
    - Process id (PID)
    - Parent (PPID)
      - Parent = The process which executed the fork()
    - **`fork()`** return value

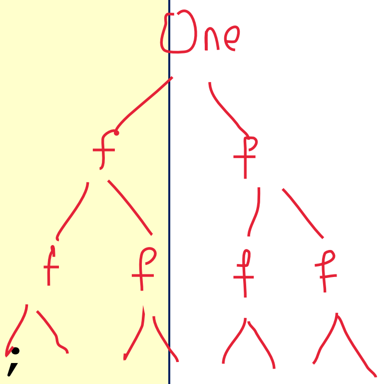
`fork()` : Example

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>

int main()
{
    printf("I am ONE\n");
    fork();
    printf("I am seeing DOUBLE\n");

    return 0;
}
```

int main ()
{
printf ("I am ONE n");
fork();
fork();
fork();
printf ("I am seeing DOUBLE n");
return 0;
}



- Question:
  - What do you think is the output?

I am ONE
I am seeing DOUBLE
I am seeing DOUBLE

`fork( )`: Example Explained

- **Both** parent and child processes continue executing after `fork( )`

- A common usage is to use the parent/child process differently
  - For example:
    - The parent spawn off a child to carry out some work
    - And then the parent is ready to take another task
  - **Use the return value of `fork( )` to distinguish parent and child**

`fork()`: Parent and Child Example

when without the sleep statement, if the parent ends before the child process has run

the PPID for the child process will not be the original PPID / parent

this is because the parent will exit and return, thus the child process is now an orpharn - and will be adopted by init

```
... ...
int result;

result = fork();
if (result != 0){
    printf("P:My Id is %i\n",getpid());
    printf("P:Child Id is %i\n",result);
} else {
    printf("C:My Id is %i\n", getpid() );
    printf("C:Parent Id is %i\n", getppid() );
}
... ...
```

Parent Process

Child Process

`fork()`: Independent Memory Space

```
...  ...
int var = 1234;
int result;

result = fork();
if (result != 0){
    printf("Parent: Var is %i\n", var);
    var++;
    printf("Parent: Var is %i\n", var);
} else {
    printf("Child: Var is %i\n", var);
    var--;
    printf("Child: Var is %i\n", var);
}
...  ...
```

- Question:
  - Is there ONE or TWO `var` variable? the variable is similar to being passed by value

Executing A New Program/Image

- `fork()` itself is not useful:
  - You still need to provide the full code for the child process
  - What if we want to execute ***another existing program*** instead?
- Make use of the `exec()` system calls family
  - Many variants:
    - `execv`, `execl`, `execle`, `execlv`, `execlp`, etc.
  - Will touch on:
    - `execl`
  - Others are similar ("man XXX" to find out more)

Sidetrack: Command Line Argument in C

- You can pass arguments to a program in C
  - e.g. **`a.exe 1 2 3 hello`**

```
int main( int argc, char* argv[] )
{
    //use argc and argv
}
```

- **`argc:`**
  - Number of command line arguments
  - Including the program name itself
- **`argv:`**
  - A char strings array
  - Each element in **`argv[]`** is a C character string

C Command Line Argument: Example

```c
int main( int argc, char* argv[] )
{    int i;

     for (i = 0; i < argc; i++){
          printf("Arg %i: %s\n",i, argv[i] );
     }
     return 0;
}
```

- Example Run:

```
a.out 123 hello world
```

- Output:

```
Arg 0: a.out
Arg 1: 123
Arg 2: hello
Arg 3: world
```

`execl()` System Call

- To **replace** current executing process image with a new one
  - Code replacement
  - PID and other information still intact

Header File	`#include <unistd.h>`
Syntax	`int execl( const char *path, const char *arg0, ..., const char *argN, NULL );`

```
int execl( const char *path,
           const char *arg0,
           ...,
           const char *argN, NULL );
```

- **`path`**: Location of the executable
- **`arg0`**, …, **`argN`**: Command Line Argument(s)
- **`NULL`**: To indicate end of argument list

`execl()`: Simple Example

```
int main()
{
    execl( "/bin/ls", "ls", "-al", NULL);
}
```

this command will immediately exit the program, thus any code immediately after this will not run

- Note:
  - **`Path`** = “/**`bin/ls`**"
    - The "**`dir`**" command in unix, to list the files in directory
  - **`arg0`** = "**`ls`**"
    - The program name
  - **`arg1`** = "**`-al`**"
- The above is exactly the same as executing:

  `ls -al`

Hmm… `fork()` + `exec()` ?

- By combining the two mechanisms, we can:
  - Spawn off a child process
    - Let the child process perform a task through `exec()`
  - Meanwhile, the parent process is still around
    - To accept another request

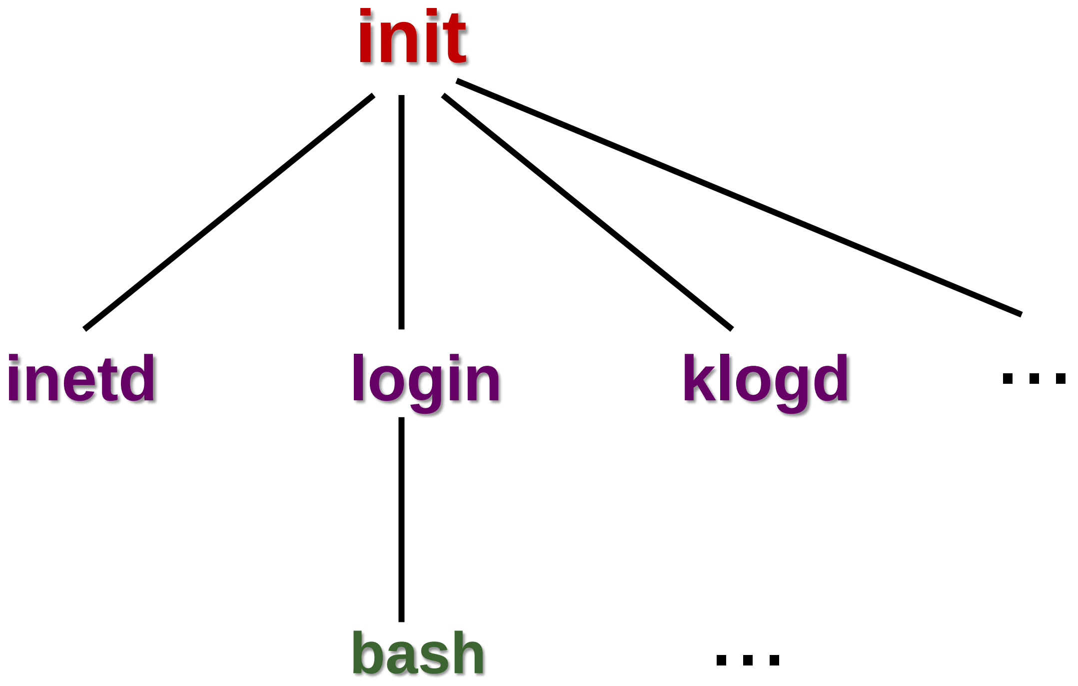
- This combination of mechanisms is the main way in Unix:
  - To get a new process for running a new program

The Master Process

- Question:
  - If every process has parent, then which process is the "commonest ancestor"?

- Special initial process:
  - `init` process
  - Created in kernel at boot up time
  - Traditionally has a PID = 1
  - Watches for other processes and respawns where needed
- **`fork()`** creates process tree:
  - `init` is the root process

Process Tree Example (simplified)



Note: just a simple example, actual process tree varies according to Unix setup

Process Termination in Unix

- To end execution of process:

Header File	`#include <stdlib.h>`
Syntax	`void exit( int status );`

  - Status is returned to the parent process (more later)
  - Unix Convention:
    - **0** = Normal Termination (successful execution)
    - **!0** = To indicate problematic execution
  - The function **does not return!**

Process On Exit

- Process finished execution
  - **Most** system resources used by process are released on exit
    - E.g. File descriptors
      - Each opened file in C has a file descriptor attach to it
      - Similar to File object in Java, File Stream Object in C++

zombie processes

  - Some basic process resources **not releasable**:
    - PID & status needed
      - For parent-children synchronization
    - Process accounting info, e.g., cpu time

➔ Process table entry **may be** still needed

Implicit `exit()`

- Most programs have no explicit exit() call
- Example:

```
int main()
{
    printf("Just to say goodbye!\n");
}
```

- Return from `main()` implicitly calls `exit()`
  - Open files also get flushed automatically!

Parent/Child Synchronization in Unix

- Parent process can wait for child process to terminates

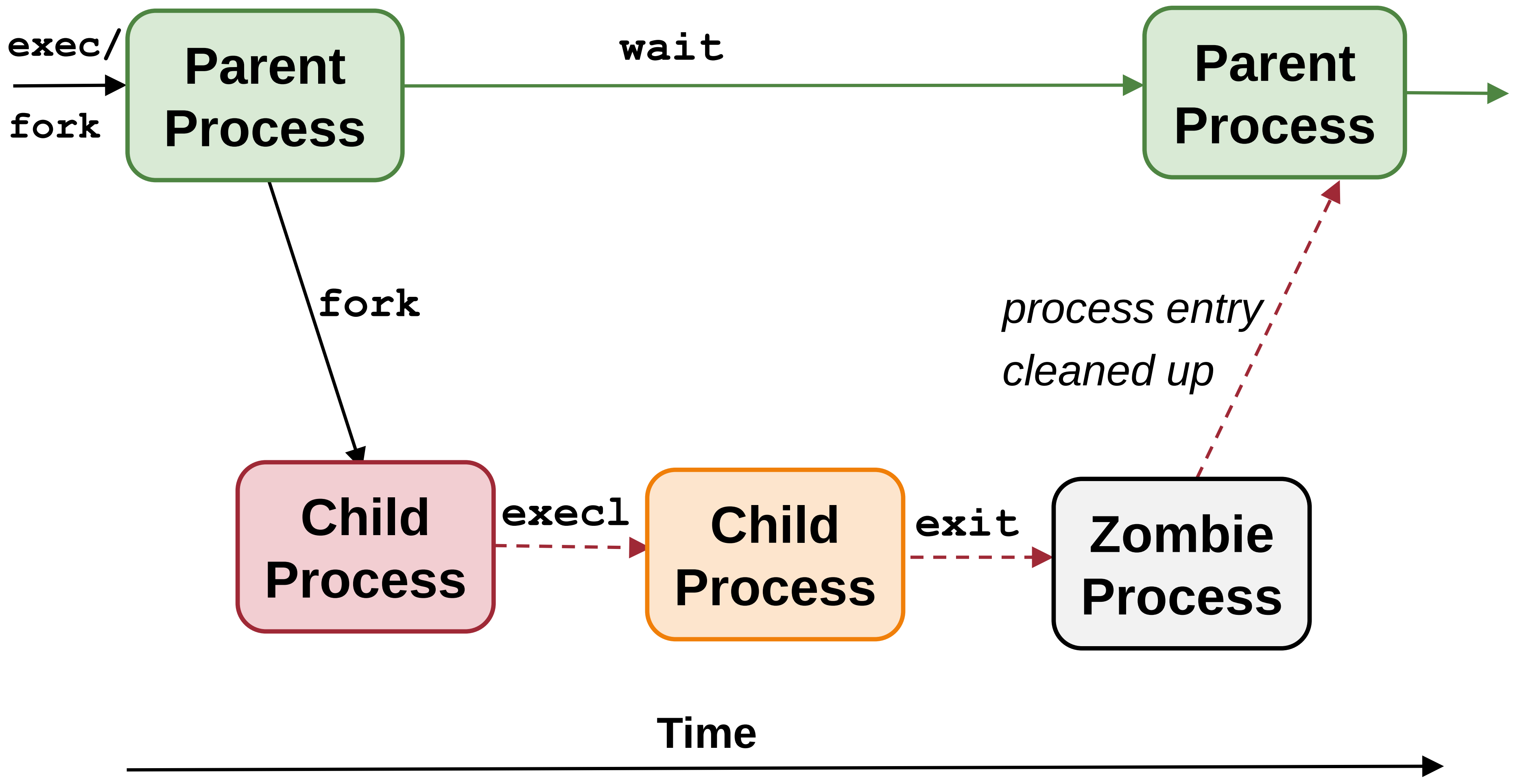
Header File	
	`#include <sys/types.h>` `#include <sys/wait.h>`
Syntax	`int wait( int *status );`

  - Returns the PID of the terminated child process
  - status (passed by address):
    - Stores the exit status of the terminated child process
    - Use **`NULL`** if you do not need/want this info

Parent/Child Synchronization in Unix

- Behavior:
  - The call is blocking:
    - Parent process blocks until at least one child terminates
  - The call cleans up ***remainder*** of child system resources
    - Those not removed on **`exit()`**
    - Kill zombie process ☺
- Other variants of **`wait()`** :
  - **`waitpid()`**
    - Wait for a specific child process
  - **`waitid()`**
    - Wait for any child process to **change status**
  - etc.

Process Interaction in Unix



Note: example uses one ordering of execution, others are possible!

`wait()` "creates" zombies!!

- On process exit: (see previous slide)
  - most of the resources are released
  - becomes ***zombie***

  - **Cannot delete** all process info
    - What if parent asks for the info in a wait() call?
    - Can be **cleaned up** only when `wait()` happens

  - **Cannot kill** zombie
    - The process is already **dead**!

Zombie Process and Orphan Process

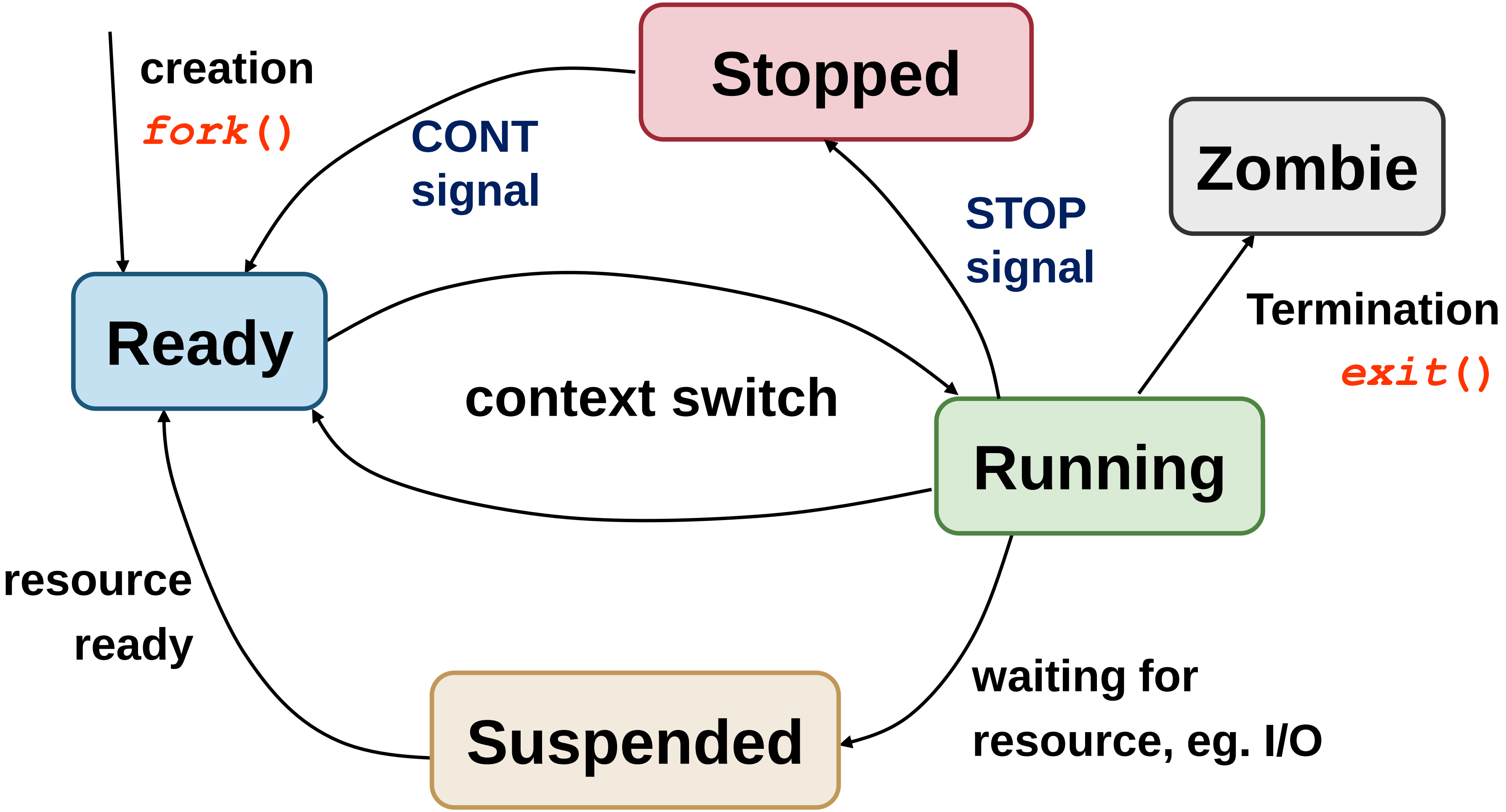
1. Orphan: parent process terminates before child process:
   - `init` process becomes "pseudo" parent of child processes
   - Child termination sends signal to `init`, which utilizes **`wait()`** to cleanup

2. Zombie: Child process terminates before parent but parent did not call `wait`:
   - Child process become a zombie process
   - Can fill up process table
     - May need a reboot to clear the table on older Unix implementations

Summary of Unix Process System calls

- **`fork()`**:
  - Process creation
- **`exec()`** family:
  - Change executing image/program
  - `execl`, `execv`, `execve`, `execle`, `execvp`
- **`exit()`**:
  - Process termination
- **`wait()`** family:
  - Get exit status, synchronize with child
  - `wait`, `waitpid`, `waitid`, `etc`
- **`getpid()`** family:
  - Get process information
  - `getpid`, `getppid`, etc

Process State Diagram in Unix



IMPLEMENTATION ISSUES

Implementing `fork()`

- Behavior of **`fork()`** :
  - Makes an almost exact copy of parent process
- Simplified implementation:
  1. Create address space of child process
  2. Allocate **`p'`** = new **`PID`**
  3. Create kernel process data structures
     - E.g. Entry in Process Table
  4. Copy kernel environment of parent process
     - E.g., Priority (for process scheduling)
  5. Initialize child process context:
     - **`PID`**= **`p'`**, **`PPID=parent`** id, zero CPU time

Implementing `fork()` (cont)

6. Copy memory regions from parent
   - Program, Data, Stack
   - Very expensive operation that can be optimized (more later)
7. Acquires shared resources:
   - Open files, current working directory, etc.
8. Initialize hardware context for child process:
   - Copy registers, etc., from parent process
9. Child process is now ready to run
   - add to scheduler queue

Memory Copy Operation

- Memory copy is very expensive:
  - Potentially need to copy the whole memory space
- Observations:
  - The child process will not access the whole memory range right away
  - Additionally:
    - If child just read from a location:
      - Remain unchanged
      - Can use a shared version

        Since text data are fixed and cannot be changed
        - thus copying it will be very wasteful
    - Only when write is perform on a location:
      - Then two independent copies are needed

Memory Copy Optimization

memory

Parent Child

- **Copy on Write** is a possible optimization for memory copy operation:
  - Only duplicate a “memory location” when it is written to
  - Otherwise parent and child share the same “memory location”

change variable

P : a=10

- Note that, actually:
  - Memory is organized into memory pages
    - A consecutive range of memory locations
  - Memory is managed on a page level
    - Instead of individual location
  - **Will be covered in details in Memory Management part of lecture**

a=10 mem → copy Mem a=0

P C

Modern Take on `fork()`

- `fork()` system call is part of the Unix design
  - inherited by most (all?) variants

- However, it is not versatile:
  - A thorough duplication of the parent process

- There are scenarios where a partial duplication may be preferred:
  - e.g. parent and child shares some of the memory regions, or some other resources

- Linux provides `clone()` which supersedes `fork()`

Summary

- Covered most of the process operations available in Unix:
  - Creation through **`fork()`**
  - Change execution through **`exec()`**
  - Termination through **`exit()`**
  - Synchronization (Parent ←→ Child) through **`wait()`**
- Process States
  - Process state diagram
- Implementation issues with **`fork()`**