Process Management

Process Abstraction in Unix

Lecture 3 – 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>`
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
    - Data in child is a **COPY** of the parent (ie.not shared)
  - 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;
}
```

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

`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 order
  - **Use the return value of `fork( )` to distinguish parent and child**

fork( ): Parent and Child Example

```
... ...
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?

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", "-l", NULL);
}
```

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

  `ls -l`

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
- Question:
  - Have you used something similar before?

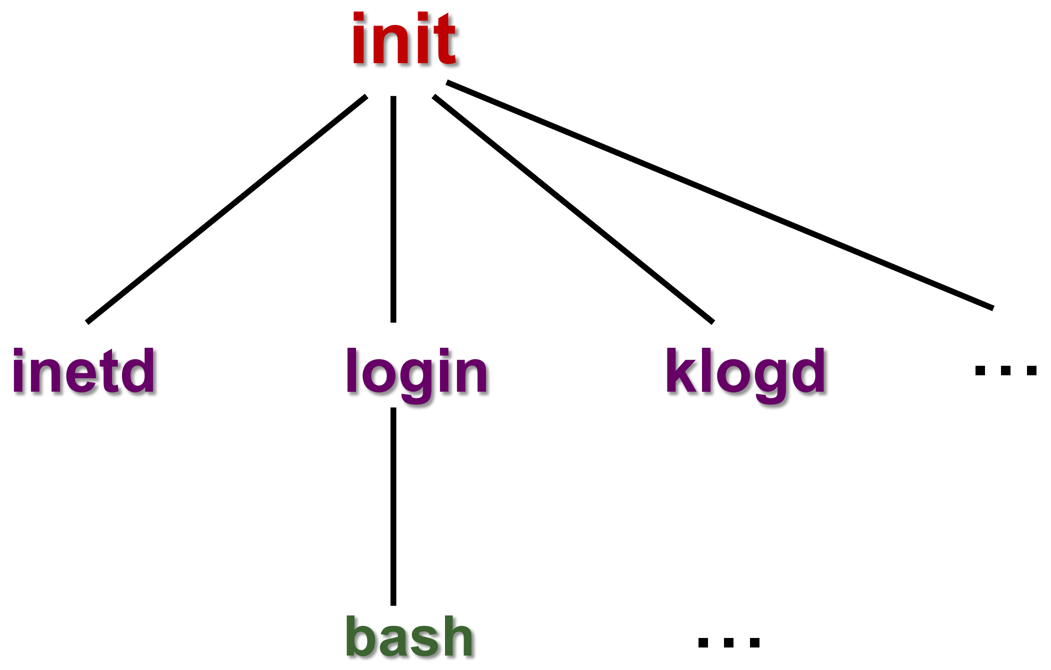
- This combination of mechanisms is the main way in Unix:
  - To get a new process for running a new program

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++
  - 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

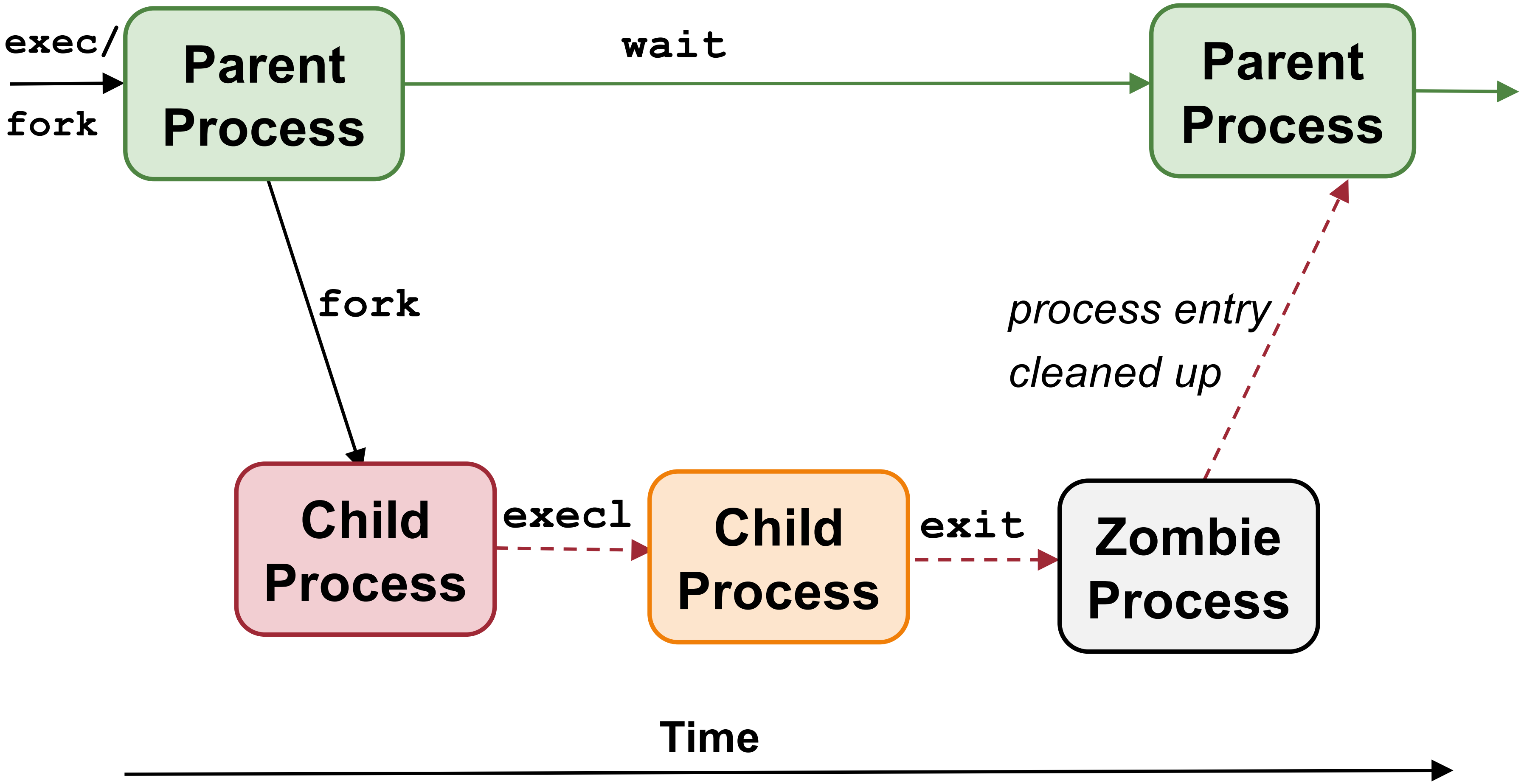
Header File	
	`#include <sys/types.h>` `#include <sys/wait.h>`
Syntax	`int wait( int *status );`

- 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)
  - becomes ***zombie***
  - **Cannot delete** all process info
    - What if parent ask for the info in a wait() call?
    - Remainder of process data structure can be **cleaned up**
      - only when `wait()` happens
  - **Cannot kill** zombie
    - The process is already **dead**!

Zombie Process (2 Cases)

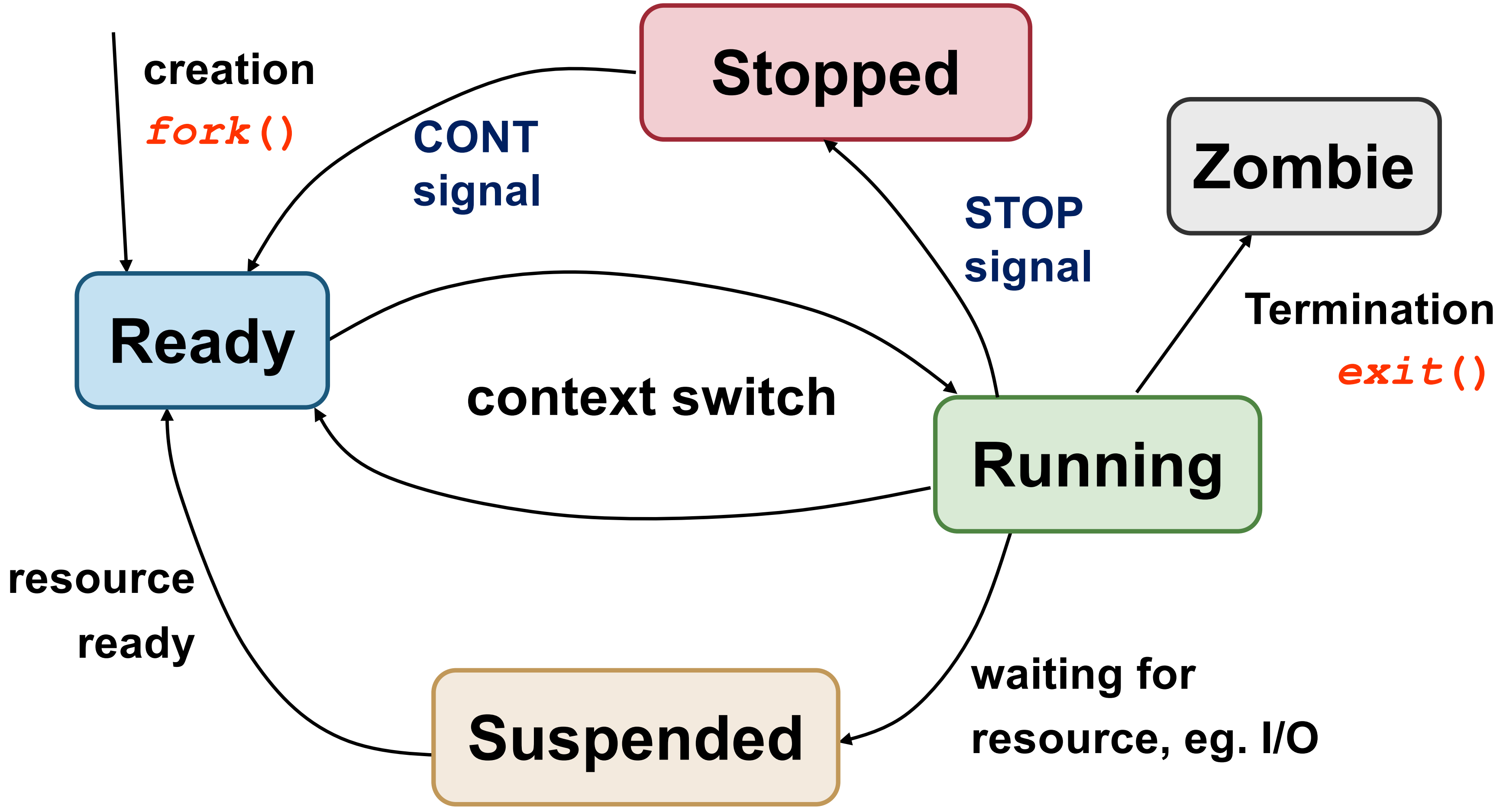
1. Parent process terminates before child process:
   - `init` process becomes "pseudo" parent of child processes
   - Child termination sends signal to `init`, which utilizes **`wait()`** to cleanup

2. 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
    - Only when write is perform on a location:
      - Then two independent copies are needed

Memory Copy Optimization

- **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"
- 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**

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 share 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()`**