



I/O Management

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Goals of this Lecture

- Help you to learn about:
 - The Unix **stream** concept
 - Standard C I/O functions
 - Unix system-level functions for I/O
 - How the standard C I/O functions use the Unix system-level functions
 - Additional abstractions provided by the standard C I/O functions

Streams are a powerful Unix abstraction

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Stream Abstraction



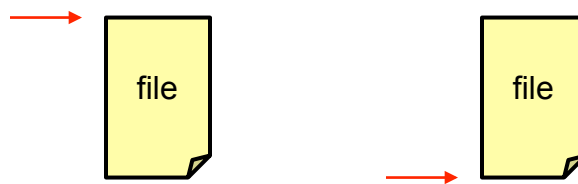
- Any source of input or destination for output
 - E.g., keyboard as input, and screen as output
 - E.g., files on disk or CD, network ports, printer port, ...
- Accessed in C programs through file pointers
 - E.g., `FILE *fp1, *fp2;`
 - E.g., `fp1 = fopen("myfile.txt", "r");`
- Three streams provided by `stdio.h`
 - Streams **`stdin`**, **`stdout`**, and **`stderr`**
 - Typically map to keyboard, screen, and screen
 - Can redirect to correspond to other streams
 - E.g., `stdin` can be the output of another program
 - E.g., `stdout` can be the input to another program

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Sequential Access to a Stream



- Each stream has an associated file position
 - Starting at beginning of file (if opened to read or write)
 - Or, starting at end of file (if opened to append)



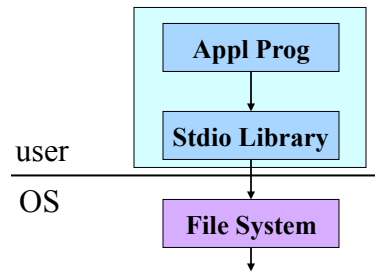
- Read/write operations advance the file position
 - Allows sequencing through the file in sequential manner
- Support for random access to the stream
 - Functions to learn current position and seek to new one

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Standard I/O Functions



- **Portability**
 - Generic I/O support for C programs
 - Specific implementations for various host OSes
 - Invokes the OS-specific system calls for I/O
- **Abstractions for C programs**
 - Streams
 - Line-by-line input
 - Formatted output
- **Additional optimizations**
 - Buffered I/O
 - Safe writing



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Example: Opening a File



- **`FILE *fopen("myfile.txt", "r")`**
 - Open the named file and return a stream
 - Includes a mode, such as "r" for read or "w" for write
- **Creates a FILE data structure for the file**
 - Mode, status, buffer, ...
 - Assigns fields and returns a pointer
- **Opens or creates the file, based on the mode**
 - Write ('w'): create file with default permissions
 - Read ('r'): open the file as read-only
 - Append ('a'): open or create file, and seek to the end

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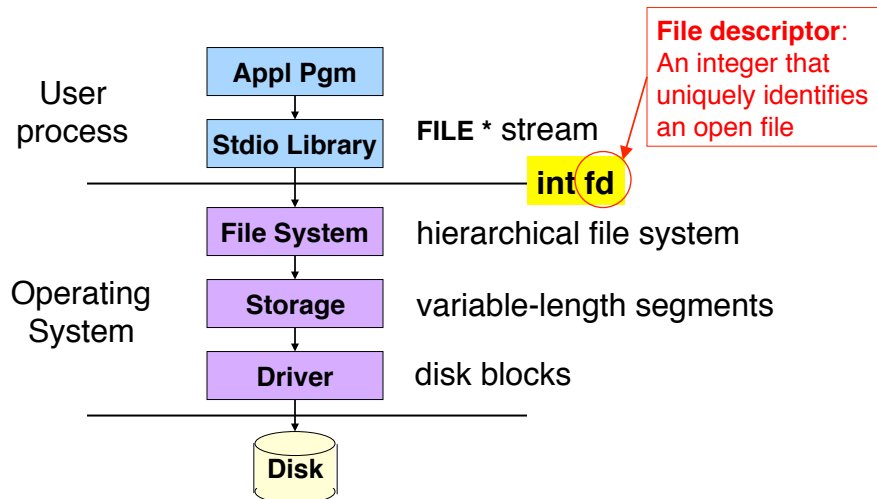
Example: Formatted I/O



- `int fprintf(fp1, "Number: %d\n", i)`
 - Convert and write output to stream in specified format
- `int fscanf(fp1, "FooBar: %d", &i)`
 - Read from stream in format and assign converted values
- Specialized versions
 - `printf(...)` is just `fprintf(stdout, ...)`
 - `scanf(...)` is just `fscanf(stdin, ...)`

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Layers of Abstraction



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System-Level Functions for I/O



- ```
int creat(char *pathname, mode_t mode);
```
- Create a new file named `pathname`, and return a file descriptor
- ```
int open(char *pathname, int flags, mode_t mode);
```
- Open the file `pathname` and return a file descriptor
- ```
int close(int fd);
```
- Close `fd`
- ```
int read(int fd, void *buf, int count);
```
- Read up to `count` bytes from `fd` into the buffer at `buf`
- ```
int write(int fd, void *buf, int count);
```
- Writes up to `count` bytes into `fd` from the buffer at `buf`
- ```
int lseek(int fd, int offset, int whence);
```
- Assigns the file pointer of `fd` to a new value by applying an `offset`

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Example: `open ()`



- **Converts a path name into a file descriptor**
 - `int open(const char *pathname, int flags, mode_t mode);`
- **Arguments**
 - Pathname: name of the file
 - Flags: bit flags for `O_RDONLY`, `O_WRONLY`, `O_RDWR`
 - Mode: permissions to set if file must be created
- **Returns**
 - File descriptor (or a -1 if an error)
- **Performs a variety of checks**
 - E.g., whether the process is entitled to access the file
- **Underlies `fopen ()`**

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Example: read ()

- Reads bytes from a file descriptor
 - `int read(int fd, void *buf, int count);`
- Arguments
 - File descriptor: integer descriptor returned by `open ()`
 - Buffer: pointer to memory to store the bytes it reads
 - Count: maximum number of bytes to read
- Returns
 - Number of bytes read
 - Value of 0 if nothing more to read
 - Value of -1 if an error
- Performs a variety of checks
 - Whether file has been opened, whether reading is okay
- Underlies `getchar ()` , `fgets ()` , `scanf ()` , etc.

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Example: A Simple getchar ()

```
int getchar(void) {
    char c;
    if (read(0, &c, 1) == 1)
        return c;
    else return EOF;
}
```

- Read one character from `stdin`
 - File descriptor 0 is `stdin`
 - `&c` points to the buffer
 - 1 is the number of bytes to read
- Read returns the number of bytes read
 - In this case, 1 byte means success

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Making getchar () More Efficient



- Poor performance reading one byte at a time
 - Read system call is accessing the device (e.g., a disk)
 - Reading one byte from disk is very time consuming
 - Better to read and write in *larger chunks*
- Buffered I/O
 - Read a large chunk from disk into a buffer
 - Dole out bytes to the user process as needed
 - Discard buffer contents when the stream is closed
 - Similarly, for writing, write individual bytes to a buffer
 - And write to disk when full, or when stream is closed
 - Known as “flushing” the buffer

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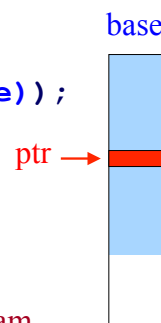
Better getchar () with Buffered I/O



```
int getchar(void) {
    static char base[1024];
    static char *ptr;
    static int cnt = 0;
    if (cnt-- > 0) return *ptr++;

    cnt = read(0, base, sizeof(base));
    if (cnt <= 0) return EOF;
    ptr = base;
    return getchar();
}
```

} persistent variables



But, many functions may read (or write) the stream...

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Details of FILE in stdio.h (K&R 8.5)



```
#define OPEN_MAX 20 /* max files open at once */

typedef struct _iobuf {
    int cnt; /* num chars left in buffer */
    char *ptr; /* ptr to next char in buffer */
    char *base; /* beginning of buffer */
    int flag; /* open mode flags, etc. */
    char fd; /* file descriptor */
} FILE;
extern FILE _iob[OPEN_MAX];

#define stdin (&_iob[0])
#define stdout (&_iob[1])
#define stderr (&_iob[2])
```

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A Funny Thing About Buffered I/O



- The standard library also buffers **output**; example:

```
int main(void) {
    printf("Step 1\n");
    sleep(10);
    printf("Step 2\n");
    return 0;
}
```

- Run “a.out > out.txt &” and then “tail -f out.txt”
 - To run a.out in the background, outputting to out.txt
 - And then to see the contents on out.txt
- Neither line appears till ten seconds have elapsed
 - Because the output is being buffered
 - Add fflush(stdout) to flush the output buffer
 - fclose() also flushes the buffer before closing

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Summary



- System-level I/O functions provide simple abstractions
 - Stream as a source or destination of data
 - Functions for manipulating streams
- Standard I/O library builds on system-level functions
 - Calls system-level functions for low-level I/O
 - Adds buffering
- Powerful examples of abstraction
 - Application pgms interact with streams at a high level
 - Standard I/O library interact with streams at lower level
 - Only the OS deals with the device-specific details

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Process Management

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Goals of this Lecture



- Help you learn about:
 - Creating new processes
 - Programmatically redirecting stdin, stdout, and stderr
 - (Appendix) communication between processes via pipes
- Why?
 - Creating new processes and programmatic redirection are fundamental tasks of a Unix **shell** (see Assignment 7)
 - A power programmer knows about Unix shells, and thus about creating new processes and programmatic redirection

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Why Create a New Process?



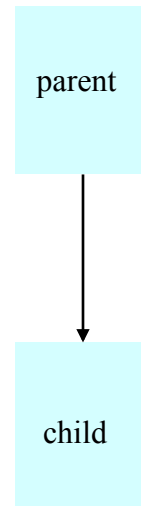
- Run a new program
 - E.g., shell executing a program entered at command line
 - Or, even running an entire pipeline of commands
 - Such as `wc -l * | sort | uniq -c | sort -nr`
- Run a new thread of control for the same program
 - E.g., a Web server handling a new Web request
 - While continuing to allow more requests to arrive
 - Essentially time sharing the computer
- Underlying mechanism
 - A process executes `fork()` to create a child process
 - (Optionally) child process does `exec()` of a new program

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Creating a New Process



- **Cloning an existing process**
 - Parent process creates a new child process
 - The two processes then run concurrently
- **Child process inherits state from parent**
 - Identical (but separate) copy of virtual address space
 - Copy of the parent's open file descriptors
 - Parent and child share access to open files
- **Child then runs independently**
 - Executing independently, including invoking a new program
 - Reading and writing its own address space



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Fork System-Level Function



- **fork () is called once**
 - But returns twice, once in each process
- **Telling which process is which**
 - Parent: `fork ()` returns the child's process ID
 - Child: `fork ()` returns 0

```
pid = fork();
if (pid != 0) {
    /* in parent */
    ...
} else {
    /* in child */
    ...
}
```

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Fork and Process State



- **Inherited**
 - User and group IDs
 - Signal handling settings
 - Stdio
 - File pointers
 - Root directory
 - File mode creation mask
 - Resource limits
 - Controlling terminal
 - All machine register states
 - Control register(s)
 - ...
- **Separate in child**
 - Process ID
 - Address space (memory)
 - File descriptors
 - Parent process ID
 - Pending signals
 - Time signal reset times
 - ...

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Example: What Output?



```
int main(void)
{
    pid_t pid;
    int x = 1;

    pid = fork();
    if (pid != 0) {
        printf("parent: x = %d\n", --x);
        exit(0);
    } else {
        printf("child: x = %d\n", ++x);
        exit(0);
    }
}
```

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Executing a New Program



- `fork()` copies the state of the parent process
 - Child continues running the parent program
 - ... with a copy of the process memory and registers
- Need a way to invoke a new program
 - In the context of the newly-created child process
- Example

program

NULL-terminated array
Contains command-line arguments
(to become "argv[]" of `ls`)

```
execvp("ls", argv);  
fprintf(stderr, "exec failed\n");  
exit(EXIT_FAILURE);
```

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Waiting for the Child to Finish



- Parent should wait for children to finish
 - Example: a shell waiting for operations to complete
- Waiting for a child to terminate: `wait()`
 - Blocks until some child terminates
 - Returns the process ID of the child process
 - Or returns -1 if no children exist (i.e., already exited)
- Waiting for specific child to terminate: `waitpid()`
 - Blocks till a child with particular process ID terminates

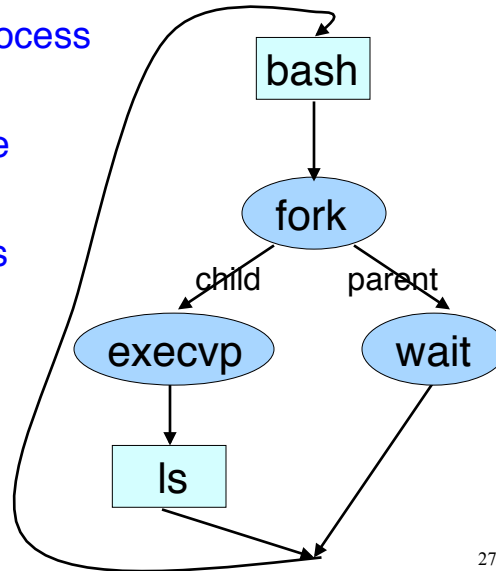
```
#include <sys/types.h>  
#include <sys/wait.h>  
pid_t wait(int *status);  
pid_t waitpid(pid_t pid, int *status, int options);
```

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Example: A Simple Shell



- Shell is the parent process
 - E.g., bash
- Parses command line
 - E.g., "ls -l"
- Invokes child process
 - `fork()`, `execvp()`
- Waits for child
 - `wait()`



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Simple Shell Code



```
Parse command line  
Assign values to somepgm, someargv  
pid = fork();  
if (pid == 0) {  
    /* in child */  
    execvp(somepgm, someargv);  
    fprintf(stderr, "exec failed\n");  
    exit(EXIT_FAILURE);  
}  
/* in parent */  
pid = wait(&status);  
Repeat the previous
```

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Simple Shell Trace (1)

Parent Process

```

Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous

```

Parent reads and parses command line
 Parent assigns values to **somepgm** and **someargv**



Simple Shell Trace (2)

Parent Process

```

Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous

```

Child Process

```

Parse command line
Assign values to somefile, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous

```

executing
concurrently

fork () creates child process
 Which process gets the CPU first? Let' s assume the parent...

Simple Shell Trace (3)



Parent Process

child's pid

Child Process

```
Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

```
Parse command line
Assign values to somefile, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

executing concurrently

In parent, pid != 0; parent waits; OS gives CPU to child

Simple Shell Trace (4)



Parent Process

0

Child Process

```
Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

```
Parse command line
Assign values to somefile, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

executing concurrently

In child, pid == 0; child calls `execvp()`

Simple Shell Trace (5)



Parent Process

```
Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

Child Process

somepgm

executing
concurrently

In child, *somepgm* overwrites shell program;
`main()` is called with *someargv* as `argv` parameter

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Simple Shell Trace (6)



Parent Process

```
Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

Child Process

somepgm

executing
concurrently

Somepgm executes in child, and eventually exits

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Simple Shell Trace (7)



Parent Process

```
Parse command line
Assign values to somepgm, someargv
pid = fork();
if (pid == 0) {
    /* in child */
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
Repeat the previous
```

Parent returns from `wait()` and proceeds

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Combined Fork/Exec/Wait



- Common combination of operations
 - `fork()` to create a new child process
 - `exec()` to invoke new program in child process
 - `wait()` in the parent process for the child to complete
- Single call that combines all three
 - `int system(const char *cmd);`
- Example

```
int main(void) {
    system("echo Hello world");
    return 0;
}
```

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Fork and Virtual Memory



- Incidentally...
- Question:
 - `fork()` duplicates an entire process (text, bss, data, rodata, stack, heap sections)
 - Isn't that *very* inefficient???!?
- Answer:
 - Using virtual memory, not really!
 - Upon `fork()`, OS creates virtual pages for child process
 - Each child virtual page points to real page (in memory or on disk) of parent
 - OS duplicates real pages incrementally, and only if/when "write" occurs

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Redirection



- Unix allows programmatic redirection of `stdin`, `stdout`, or `stderr`
- How?
 - Use `open()`, `creat()`, and `close()` system calls
 - Described in **I/O Management** lecture
 - Use `dup()` system call...

```
int dup(int oldfd);
```

- Create a copy of the file descriptor `oldfd`. After a successful return from `dup()` or `dup2()`, the old and new file descriptors may be used interchangeably. They refer to the same open file description and thus share file offset and file status flags. Uses the lowest-numbered unused descriptor for the new descriptor. Return the new descriptor, or -1 if an error occurred.

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Redirection Example



How does shell implement “somepgm > somefile”?

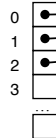
```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Redirection Example Trace (1)



Parent Process

File
descriptor
table

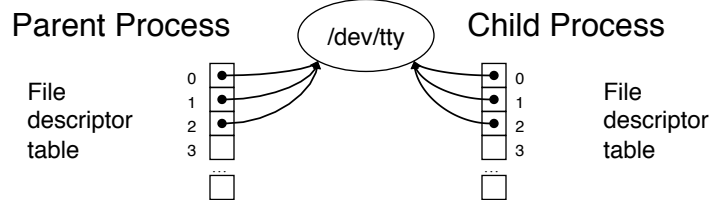


/dev/tty

```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Parent has file descriptor table; first three point to “terminal”

Redirection Example Trace (2)

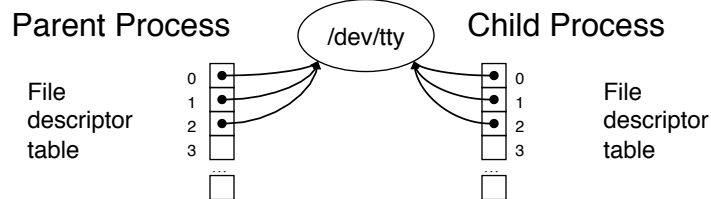


```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Parent forks child; child has identical file descriptor table 41

Redirection Example Trace (3)

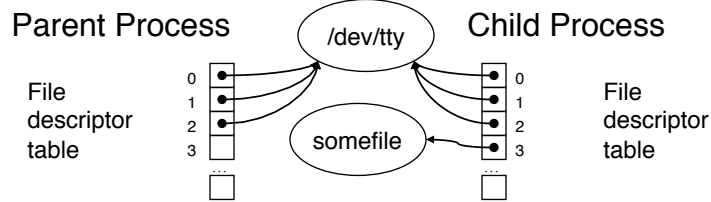


```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Let's say parent gets CPU first; parent waits 42

Redirection Example Trace (4)



```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

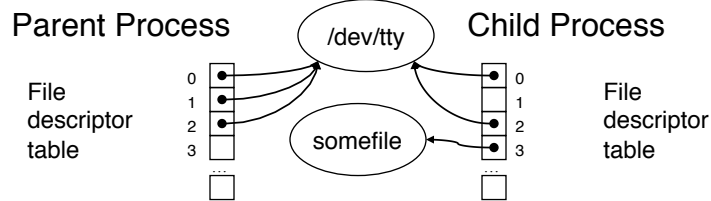
```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

Child gets CPU; child creates somefile

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Redirection Example Trace (5)



```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

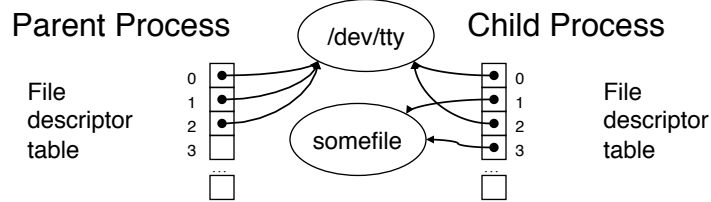
```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

Child closes file descriptor 1 (stdout)

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Redirection Example Trace (6)



```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

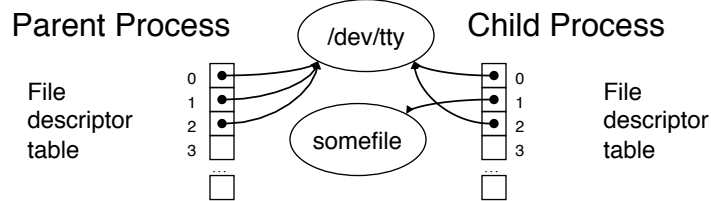
```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

Child duplicates file descriptor 3 into first unused spot

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Redirection Example Trace (7)



```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

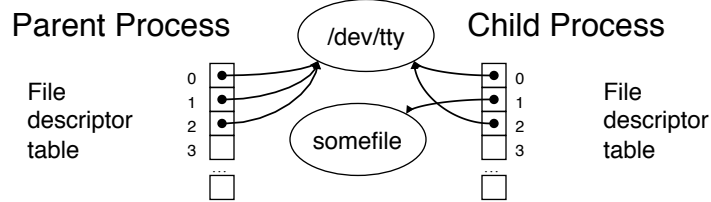
```

pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
    
```

Child closes file descriptor 3

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Redirection Example Trace (8)



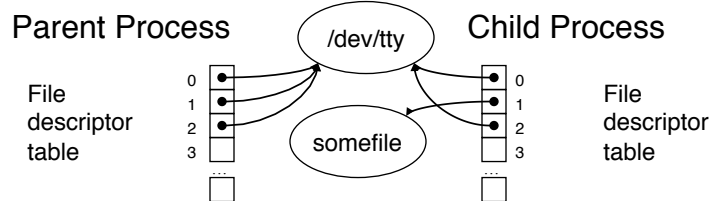
```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Child calls execvp()

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Redirection Example Trace (9)



```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somepgm, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

```
somepgm
```

Somepgm executes with stdout redirected to somefile

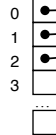
48

Redirection Example Trace (10)



Parent Process

File
descriptor
table



/dev/tty

```
pid = fork();
if (pid == 0) {
    /* in child */
    fd = creat("somefile", 0640);
    close(1);
    dup(fd);
    close(fd);
    execvp(somefile, someargv);
    fprintf(stderr, "exec failed\n");
    exit(EXIT_FAILURE);
}
/* in parent */
pid = wait(&status);
```

Somepgm exits; parent returns from `wait()` and proceeds⁴⁹

The Beginnings of a Unix Shell



- A shell is mostly a big loop
 - Parse command line from stdin
 - Expand wildcards ('*')
 - Interpret redirections ('<', and '>')
 - `fork()`, `dup()`, `exec()`, and `wait()`, as necessary
- Start from the code in earlier slides
 - And edit till it becomes a Unix shell
 - This is the heart of the last programming assignment

Summary



- **System-level functions for creating processes**
 - `fork()` : process creates a new child process
 - `wait()` : parent waits for child process to complete
 - `exec()` : child starts running a new program
 - `system()` : combines fork, wait, and exec all in one
- **System-level functions for redirection**
 - `open()` / `creat()` : to open a file descriptor
 - `close()` : to close a file descriptor
 - `dup()` : to duplicate a file descriptor

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Appendix



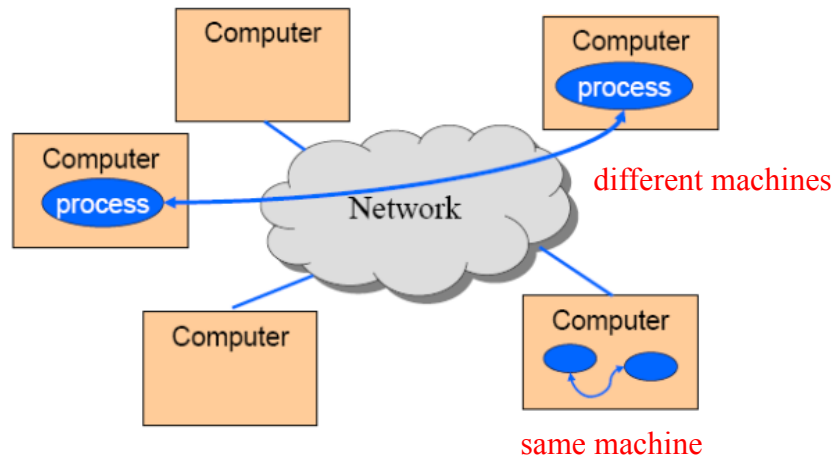
Inter-Process Communication (IPC)

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IPC



- Mechanism by which two processes exchange information and coordinate activities



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IPC Mechanisms



- Pipes
 - Processes on the same machine
 - Allows parent process to communicate with child process
 - Allows two “sibling” processes to communicate
 - Used mostly for a pipeline of filters
- Sockets
 - Processes on any machines
 - Processes created independently
 - Used for client/server communication (e.g., Web)

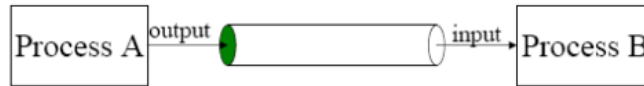
Both provide abstraction of an “ordered stream of bytes”

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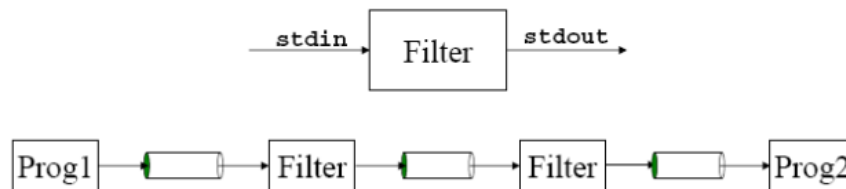
Pipes



- Provides an interprocess communication channel



- A filter is a process that reads from `stdin` and writes to `stdout`



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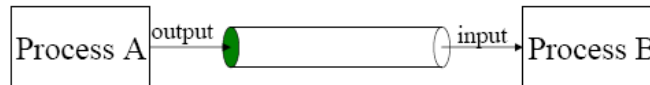
Example Use of Pipes



- Compute a histogram of content types in my e-mail
 - Many e-mail messages, consisting of many lines
 - Lines like “Content-Type: image/jpeg” indicate the type
- Pipeline of Unix commands
 - Identifying content type: `grep -i Content-Type *`
 - Extracting just the type: `cut -d" " -f2`
 - Sorting the list of types: `sort`
 - Counting the unique types: `uniq -c`
 - Sorting the counts: `sort -nr`
- Simply running this at the shell prompt:
 - `grep -i Content-Type * | cut -d" " -f2 | sort | uniq -c | sort -nr`

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Creating a Pipe



- Pipe is a communication channel abstraction
 - Process A can write to one end using “write” system call
 - Process B can read from the other end using “read” system call
- System call

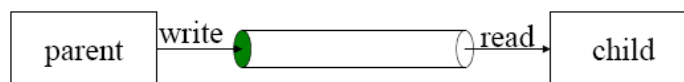
```
int pipe( int fd[2] );
return 0 upon success -1 upon failure
fd[0] is open for reading
fd[1] is open for writing
```
- Two coordinated processes created by `fork` can pass data to each other using a pipe.

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Pipe Example



```
int pid, p[2];
...
if (pipe(p) == -1)
    exit(1);
pid = fork();
if (pid == 0) {
    close(p[1]);
    ... read using p[0] as fd until EOF ...
}
else {
    close(p[0]);
    ... write using p[1] as fd ...
    close(p[1]); /* sends EOF to reader */
    wait(&status);
}
```



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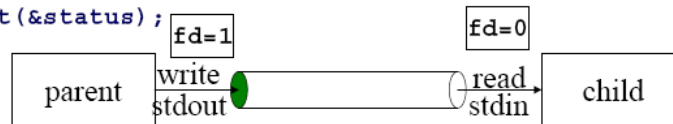
Pipes and Stdio



```
int pid, p[2];
if (pipe(p) == -1)
    exit(1);
pid = fork();
if (pid == 0) {
    close(p[1]);
    dup2(p[0], 0);
    close(p[0]);
    ... read from stdin ...
}
else {
    close(p[0]);
    dup2(p[1], 1);
    close(p[1]);
    ... write to stdout ...
    wait(&status);
}
```

child makes stdin (0)
the read side of the pipe

parent makes stdout (1)
the write side of the pipe



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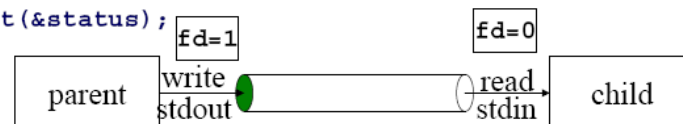
Pipes and Exec



```
int pid, p[2];
if (pipe(p) == -1)
    exit(1);
pid = fork();
if (pid == 0) {
    close(p[1]);
    dup2(p[0], 0);
    close(p[0]);
    execl(...);
}
else {
    close(p[0]);
    dup2(p[1], 1);
    close(p[1]);
    ... write to stdout ...
    wait(&status);
}
```

child process

invokes a new program



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