## Princeton University

Computer Science 217: Introduction to Programming Systems

# I/O Management

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## Goals of this Lecture

Help you to learn about:

- The C/Unix **file** abstraction
- Standard C I/O
  - Data structures & functions
- Unix I/O
  - Data structures & functions
- The implementation of Standard C I/O using Unix I/O
- Programmatic redirection of stdin, stdout, and stderr
- Pipes

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## Agenda

**The C/Unix file abstraction**

Unix I/O system calls

C's Standard IO library (FILE *)

Implementing standard C I/O using Unix I/O

Redirecting standard files

Pipes

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## C/Unix File Abstraction

Problem:

- At the physical level…
- Code that **reads** from **keyboard** is very different from code that reads from **disk**, etc.
- Code that **writes** to **video screen** is very different from code that writes to **disk**, etc.
- Would be nice if application programmer didn't need to worry about such details

Solution:

- **File**: a sequence of bytes
- C and Unix allow application program to treat any data source/destination as a **file**

Commentary: **Beautiful** abstraction!

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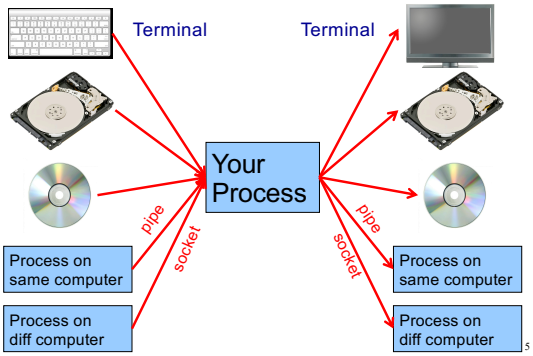
## Data Sources and Destinations

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## C/Unix File Abstraction

Each file has an associated **file position**

- Starts at beginning of file (if opened to read or write)
- Starts at end of file (if opened to append)


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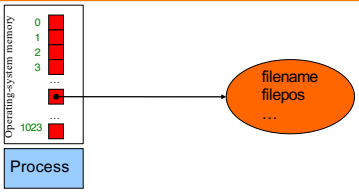
## Unix I/O Data Structures




**File descriptor**: Integer that uniquely identifies an open file
**File descriptor table**: an array
Indices are file descriptors; elements are pointers to file tables
One unique file descriptor table for each process
**File table**: a structure
In-memory surrogate for an open file
Created when process opens file; maintains file position

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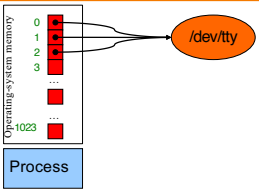
## Unix I/O Data Structures




At process start-up files with fd 0, 1, 2 are open automatically
(By default) each references file table for a file named /dev/tty
**/dev/tty**
In-memory surrogate for the terminal
**Terminal**
Combination keyboard/video screen

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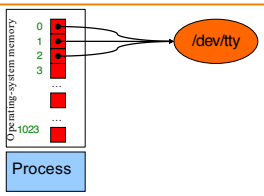
## Unix I/O Data Structures




Read from stdin ⇒ read from fd 0
Write to stdout ⇒ write to fd 1
Write to stderr ⇒ write to fd 2

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## System-Level Functions

As noted in the ***Exceptions and Processes*** lecture…

Linux system-level functions for **I/O management**

| Function | Description |
|---|---|
| read() | Read data from file descriptor<br>Called by getchar(), scanf(), etc. |
| write() | Write data to file descriptor<br>Called by putchar(), printf(), etc. |
| open() | Open file or device<br>Called by fopen(…, "r") |
| close() | Close file descriptor<br>Called by fclose() |
| creat() | Open file or device for writing<br>Called by fopen(…, "w") |
| lseek() | Change file position<br>Called by fseek() |

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## System-Level Functions

As noted in the ***Exceptions and Processes*** lecture..

Linux system-level functions for **I/O redirection** and **inter-process communication**

| Function | Description |
|---|---|
| dup() | Duplicate an open file descriptor |
| pipe() | Create a channel of communication between processes |

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## Agenda

The C/Unix file abstraction
**Unix I/O system calls**
C's Standard IO library (FILE *)
Implementing standard C I/O using Unix I/O
Redirecting standard files
Pipes

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## Unix I/O Functions

```
int creat(char *filename, mode_t mode);
```

- Create a new empty file named **filename**
  - **mode** indicates permissions of new file
- Implementation:
  - Create new empty file on disk
  - Create file table
  - Set first unused file descriptor to point to file table
  - Return file descriptor used, -1 upon failure

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## Unix I/O Functions

```
int open(char *filename, int flags, …);
```

- Open the file whose name is **filename**
  - **flags** often is **O_RDONLY**
- Implementation (assuming **O_RDONLY**):
  - Find existing file on disk
  - Create file table
  - Set first unused file descriptor to point to file table
  - Return file descriptor used, -1 upon failure

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## Unix I/O Functions

```
int close(int fd);
```

- Close the file **fd**
- Implementation:
  - Destroy file table referenced by element **fd** of file descriptor table
    - As long as no other process is pointing to it!
  - Set element **fd** of file descriptor table to **NULL**

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## Unix I/O Functions

```
int read(int fd, void *buf, int count);
```

- Read into **buf** up to **count** bytes from file **fd**
- Return the number of bytes read; 0 indicates end-of-file

```
int write(int fd, void *buf, int count);
```

- Writes up to **count** bytes from **buf** to file **fd**
- Return the number of bytes written; -1 indicates error

```
int lseek(int fd, int offset, int whence);
```

- Set the file position of file **fd** to file position **offset**. **whence** indicates if the file position is measured from the beginning of the file (**SEEK_SET**), from the current file position (**SEEK_CUR**), or from the end of the file (**SEEK_END**)
- Return the file position from the beginning of the file

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## Unix I/O Functions

Note

- Only 6 system-level functions support all I/O from all kinds of devices!

Commentary: **Beautiful** interface!

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## Unix I/O Example 0

Proto-getchar()

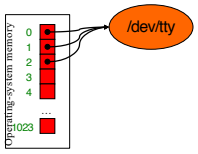
```
#include <string.h>
#include <unistd.h>

int proto_getchar(void)
{  char buf[1];
   int n;

   n = read(0, buf, 1);
   if (n==1)
      return buf[0];
   else return EOF;
}
```

# of bytes to (try to) read

0 is the file descriptor of the standard input




and the problem is . . . too slow.

Does a system call for every character.

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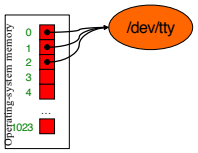
## Unix I/O Example 1

Write “hello, world\n” to /dev/tty

```
#include <string.h>
#include <unistd.h>
int main(void)
{  char hi[] = "hello, world\n";
   size_t countWritten = 0;
   size_t countToWrite = strlen(hi);
   while (countWritten < countToWrite)
      countWritten +=
         write(1, hi + countWritten,
               countToWrite - countWritten);
   return 0;
}
```




To save space, no error handling code is shown

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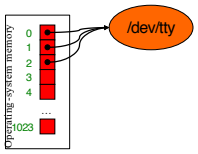
## Unix I/O Example 2

```
#include <fcntl.h>
#include <unistd.h>
int main(void)
{  enum {BUFFERSIZE = 10};
   int fdIn, fdOut;
   int countRead, countWritten;
   char buf[BUFFERSIZE];
   fdIn = open("infile", O_RDONLY);
   fdOut = creat("outfile", 0600);
   for (;;)
   {  countRead =
         read(fdIn, buf, BUFFERSIZE);
      if (countRead == 0) break;
      countWritten = 0;
      while (countWritten < countRead)
         countWritten +=
            write(fdOut,
               buf + countWritten,
               countRead - countWritten);
   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

Copy all bytes from infile to outfile

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## Unix I/O Example 2

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         countWritten +=
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   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

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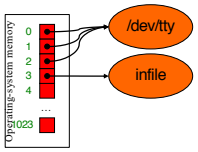


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## Unix I/O Example 2

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      if (countRead == 0) break;
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      while (countWritten < countRead)
         countWritten +=
            write(fdOut,
               buf + countWritten,
               countRead - countWritten);
   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

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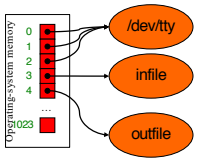


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## Unix I/O Example 2

```
#include <fcntl.h>
#include <unistd.h>
int main(void)
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   int fdIn, fdOut;
   int countRead, countWritten;
   char buf[BUFFERSIZE];
   fdIn = open("infile", O_RDONLY);
   fdOut = creat("outfile", 0600);
   for (;;)
   {  countRead =
         read(fdIn, buf, BUFFERSIZE);
      if (countRead == 0) break;
      countWritten = 0;
      while (countWritten < countRead)
         countWritten +=
            write(fdOut,
               buf + countWritten,
               countRead - countWritten);
   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

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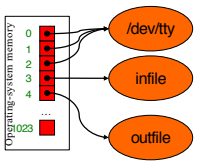


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## Unix I/O Example 2

```
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   int countRead, countWritten;
   char buf[BUFFERSIZE];
   fdIn = open("infile", O_RDONLY);
   fdOut = creat("outfile", 0600);
   for (;;)
   {  countRead =
         read(fdIn, buf, BUFFERSIZE);
      if (countRead == 0) break;
      countWritten = 0;
      while (countWritten < countRead)
         countWritten +=
            write(fdOut,
               buf + countWritten,
               countRead - countWritten);
   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

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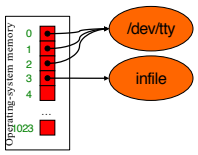


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## Unix I/O Example 2

```
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#include <unistd.h>
int main(void)
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   int fdIn, fdOut;
   int countRead, countWritten;
   char buf[BUFFERSIZE];
   fdIn = open("infile", O_RDONLY);
   fdOut = creat("outfile", 0600);
   for (;;)
   {  countRead =
         read(fdIn, buf, BUFFERSIZE);
      if (countRead == 0) break;
      countWritten = 0;
      while (countWritten < countRead)
         countWritten +=
            write(fdOut,
               buf + countWritten,
               countRead - countWritten);
   }
   close(fdOut);
   close(fdIn);
   return 0;
}
```

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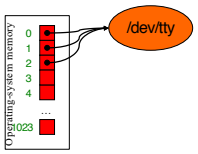


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## Agenda

The C/Unix file abstraction

Unix I/O system calls

**C's Standard IO library (FILE *)**

Implementing standard C I/O using Unix I/O

Redirecting standard files

Pipes

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## Standard C I/O Data Structure

We want 1-character-at-a-time I/O (getc(), putc())

We want a-few-characters-at-a-time I/O (scanf, printf)

We *could* do this with read() and write() system calls,

BUT IT WOULD BE TOO SLOW to do 1 syscall per byte

Solution: Buffered input/output as an Abstract Data Type

The **FILE** ADT

- A `FILE` object is an in-memory surrogate for an opened file
  - Created by `fopen()`
  - Destroyed by `fclose()`
- Used by reading/writing functions

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## Standard C I/O Functions

Some of the most popular:

```
FILE *fopen(const char *filename, const char *mode);
```

- Open the file named `filename` for reading or writing
- `mode` indicates data flow direction
  - "r" means read; "w" means write, "a" means append)
- Creates `FILE` structure
- Returns address of `FILE` structure

```
int fclose(FILE *file);
```

- Close the file identified by `file`
- Destroys `FILE` structure whose address is `file`
- Returns 0 on success, EOF on failure

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## Standard C Input Functions

Some of the most popular:

```
int fgetc(FILE *file);
```

- Read a char from the file identified by `file`
- Return the char on success, `EOF` on failure

```
int getchar(void);
```

- Same as `fgetc(stdin)`

```
char *fgets(char *s, int n, FILE *file);
```

- Read at most `n` characters from `file` into array `s`
- Returns s on success, `NULL` on failure

```
char *gets(char *s);
```

- Essentially same as `fgets(s, INT_MAX, stdin)`
- *Buffer overflow waiting to happen*

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## Standard C Input Functions

Some of the most popular:

```
int fscanf(FILE *file, const char *format, ...);
```

- Read chars from the file identified by `file`
- Convert to values, as directed by `format`
- Copy values to memory
- Return count of values successfully scanned

```
int scanf(const char *format, ...);
```

- Same as `fscanf(stdin, format, …)`

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## Standard C Output Functions

Some of the most popular:

`int fputc(int c, FILE *file);`
- Write `c` (converted to a char) to file
- Return `c` on success, `EOF` on failure

`int putchar(int c);`
- Same as `fputc(c, stdout)`

`int fputs(const char *s, FILE *file);`
- Write string `s` to `file`
- Return non-negative on success, `EOF` on error

`int puts(const char *s);`
- Essentially same as `fputs(s, stdout)`



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## Standard C Output Functions

Some of the most popular:

`int fprintf(FILE *file, const char *format, ...);`
- Write chars to the file identified by `file`
- Convert values to chars, as directed by `format`
- Return count of chars successfully written
- Works by calling `fputc()` repeatedly

`int printf(const char *format, ...);`
- Same as `fprintf(stdout, format, ...)`



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## Standard C I/O Functions

Some of the most popular:

`int fflush(FILE *file);`
- On an output file: write any buffered chars to `file`
- On an input file: behavior undefined
- `file` == `NULL` ⇒ flush buffers of **all** open files

`int fseek(FILE *file, long offset, int origin);`
- Set the file position of `file`
- Subsequent read/write accesses data starting at that position
- Origin: `SEEK_SET`, `SEEK_CUR`, `SEEK_END`

`int ftell(FILE *file);`
- Return file position of `file` on success, -1 on error



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## Standard C I/O Example 1

Write "hello, world\n" to `stdout`

```
#include <stdio.h>
int main(void)
{  char hi[] = "hello world\n";
   size_t i = 0;
   while (hi[i] != '\0')
   {  putchar(hi[i]);
      i++;
   }
   return 0;
}
```

Simple
Portable
Efficient (via buffering)

```
#include <stdio.h>
int main(void)
{  puts("hello, world");
   return 0;
}
```

```
#include <stdio.h>
int main(void)
{  printf("hello, world\n");
   return 0;
}
```



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## Standard C I/O Example 2

Copy all bytes from infile to outfile

```
#include <stdio.h>
int main(void)
{  int c;
   FILE *inFile;
   FILE *outFile;
   inFile = fopen("infile", "r");
   outFile = fopen("outfile", "w");
   while ((c = fgetc(inFile)) != EOF)
      fputc(c, outFile);
   fclose(outFile);
   fclose(inFile);
   return 0;
}
```

Simple
Portable
Efficient (via buffering)



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## Standard C Buffering

Question: Exactly when are buffers flushed?

Answers:

If reading from a file
(1) When buffer is empty



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## Standard C Buffering

Question: Exactly when are buffers flushed?

Answers:

If writing to an ordinary file
- (1) File's buffer becomes full
- (2) Process calls `fflush()` on that file
- (3) Process terminates normally

If writing to `stdout` (in addition to previous)
- (4) `stdout` is bound to terminal and `'\n'` is appended to buffer
- (5) `stdin` and `stdout` are bound to terminal *and* read from `stdin` occurs

If writing to `stderr`
- Irrelevant; `stderr` is unbuffered

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## Standard C Buffering Example

```
#include <stdio.h>
int main(void)
{  int dividend, divisor, quotient;

   printf("Dividend: ");
   scanf("%d", &dividend);

   printf("Divisor: ");
   scanf("%d", &divisor);

   printf("The quotient is ");
   quotient = dividend / divisor;
   printf("%d\n", quotient);
   return 0;
}
```

Output buffered
Buffer flushed
Output buffered
Buffer flushed
Output buffered
Buffer flushed

```
$ pgm
Dividend: 6
Divisor: 2
The quotient is 3
$
```

```
$ pgm
Dividend: 6
Divisor: 0
Floating point exception
$
```

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## Agenda

The C/Unix file abstraction

Unix I/O system calls

C's Standard IO library (FILE *)

**Implementing standard C I/O using Unix I/O**

Redirecting standard files

Pipes

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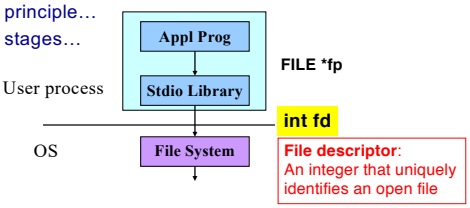
## Standard C I/O

Question:
- How to implement standard C I/O data structure and functions using Unix I/O data structures and functions?

Answer:
- In principle…
- In stages…

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## Implementing `getchar` and `putchar`

`getchar()` calls `read()` to read one byte from fd 0

`putchar()` calls `write()` to write one byte to fd 1

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

```
int putchar(int c)
{  if (write(1, &c, 1) == 1)
      return c;
   else
      return EOF;
}
```

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## Implementing Buffering

Problem: poor performance
- `read()` and `write()` access a physical device (e.g., a disk)
- Reading/writing one char at a time can be time consuming
- Better to read and write in larger blocks
  - Recall ***Storage Management*** lecture

Solution: buffered I/O
- **Read** a large block of chars from source device into a buffer
  - Provide chars from buffer to the client as needed
- **Write** individual chars to a buffer
  - "Flush" buffer contents to destination device when buffer is full, or when file is closed, or upon client request

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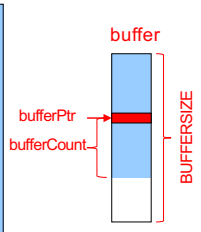
## Implementing `getchar` Version 2

`getchar()` calls `read()` to read multiple chars from fd 0 into buffer

```
int getchar(void)
{  enum {BUFFERSIZE = 4096}; /*arbitrary*/
   static unsigned char buffer[BUFFERSIZE];
   static unsigned char *bufferPtr;
   static int bufferCount = 0;
   if (bufferCount == 0) /* must read */
   {  bufferCount =
         read(0, buffer, BUFFERSIZE);
      if (bufferCount <= 0) return EOF;
      bufferPtr = buffer;
   }
   bufferCount--;
   bufferPtr++;
   return (int)(*(bufferPtr-1));
}
```



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## Implementing `putchar` Version 2

`putchar()` calls `write()` to write multiple chars from buffer to fd 1

```
int putchar(int c)
{  enum {BUFFERSIZE = 4096};
   static char buffer[BUFFERSIZE];
   static int bufferCount = 0;
   if (bufferCount == BUFFERSIZE) /* must write */
   {  int countWritten = 0;
      while (countWritten < bufferCount)
      {  int count =
            write(1, buffer+countWritten, BUFFERSIZE-countWritten);
         if (count <= 0) return EOF;
         countWritten += count;
      }
      bufferCount = 0;
   }
   buffer[bufferCount] = (char)c;
   bufferCount++;
   return c;
}
```

Real implementation also flushes buffer at other times



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## Implementing the `FILE` ADT

Observation:
- `getchar()` reads from `stdin` (fd 0)
- `putchar()` writes to `stdout` (fd 1)

Problem:
- How to read/write from/to files other than `stdin` (fd 0) and `stdout` (fd 1)?
- Example: How to define `fgetc()` and `fputc()`?

Solution:
- Use `FILE` structure



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## Implementing the `FILE` ADT

```
enum {BUFFERSIZE = 4096};

struct File
{  unsigned char  buffer[BUFFERSIZE];  /* buffer */
   int            bufferCount; /* num chars left in buffer */
   unsigned char *bufferPtr;   /* ptr to next char in buffer */
   int            flags;       /* open mode flags, etc. */
   int            fd;          /* file descriptor */
};

typedef struct File FILE;

/* Initialize standard files. */
FILE *stdin  = …
FILE *stdout = …
FILE *stderr = …
```

Derived from K&R Section 8.5

More complex on our system



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## Implementing `fopen` and `fclose`

`f = fopen(filename, "r")`
- Create new `FILE` structure; set `f` to point to it
- Initialize all fields
- `f->fd = open(filename, …)`
- Return `f`

`f = fopen(filename, "w")`
- Create new `FILE` structure; set `f` to point to it
- Initialize all fields
- `f->fd = creat(filename, …)`
- Return `f`

`fclose(f)`
- `close(f->fd)`
- Destroy `FILE` structure



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## Implementing `fgetc`

```
int fgetc(FILE *f)
{  if (f->bufferCount == 0) /* must read */
   {  f->bufferCount =
         read(f->fd, f->buffer, BUFFERSIZE);
      if (f->bufferCount <= 0) return EOF;
      f->bufferPtr = f->buffer;
   }
   f->bufferCount--;
   f->bufferPtr++;
   return (int)(*(f->bufferPtr-1));
}
```

- Accepts FILE pointer f as parameter
- Uses fields within f
- Reads from f->fd instead of 0



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## Implementing `fputc`

```
int fputc(int c, FILE *f)
{  if (f->bufferCount == BUFFERSIZE) /* must write */
   {  int countWritten = 0;
      while (countWritten < f->bufferCount)
      {  int count =
            write(f->fd, f->buffer+countWritten,
                  BUFFERSIZE-countWritten);
         if (count <= 0) return EOF;
         countWritten += count;
      }
      f->bufferCount = 0;
   }
   f->buffer[f->bufferCount] = (char)c;
   f->bufferCount++;
   return c;
}
```

Real implementation also flushes buffer at other times

- Accepts FILE pointer f as parameter
- Uses fields within f
- Writes to f->fd instead of 1



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## Implementing Standard C I/O Functions

| Standard C Function | In Unix Implemented by Calling |
|---|---|
| fopen() | **open()** or **creat()** |
| fclose() | **close()** |



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## Implementing Standard C I/O Functions

| Standard C Function | In Unix Implemented by Calling |
|---|---|
| fgetc() | **read()** |
| getchar() | fgetc() |
| fgets() | fgetc() |
| gets() | fgets() |
| fscanf() | fgetc() |
| scanf() | fscanf() |



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## Implementing Standard C I/O Functions

| Standard C Function | In Unix Implemented by Calling |
|---|---|
| fputc() | **write()** |
| putchar() | fputc() |
| fputs() | fputc() |
| puts() | fputs() |
| fprintf() | fputc() |
| printf() | fprintf() |



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## Implementing Standard C I/O Functions

| Standard C Function | In Unix Implemented by Calling |
|---|---|
| fflush() | **write()** |
| fseek() | **lseek()** |
| ftell() | **lseek()** |



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## Agenda

The C/Unix file abstraction

Unix I/O system calls

C's Standard IO library (FILE *)

Implementing standard C I/O using Unix I/O

**Redirecting standard files**

Pipes



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## Redirection

Unix allows programmatic redirection of **`stdin`**, **`stdout`**, or **`stderr`**

How?

- Use **`open()`**, **`creat()`**, and **`close()`** system-level functions
- Use **`dup()`** system-level function

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

- Create a copy of file descriptor **`oldfd`**
- Old and new file descriptors may be used interchangeably; they refer to the same open file table and thus share file position and file status flags
- Uses the lowest-numbered unused descriptor for the new descriptor
- Returns the new descriptor, or -1 if an error occurred.

Paraphrasing man page

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## Redirection Example

How does shell implement **`somepgm > somefile`**?

```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

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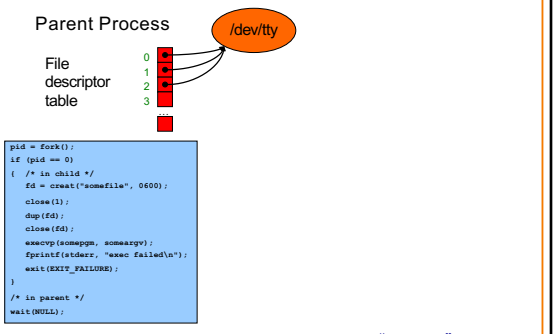
## Redirection Example Trace (1)




```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

Parent has file descriptor table; first three point to "terminal"

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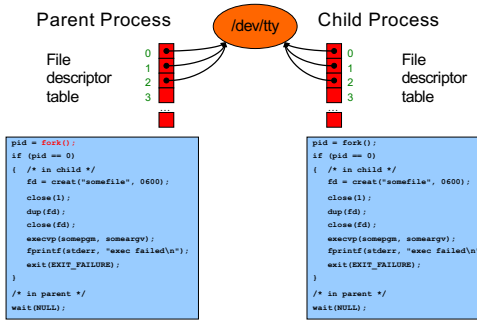
## Redirection Example Trace (2)




```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

Parent forks child; child has identical-but distinct file descriptor table

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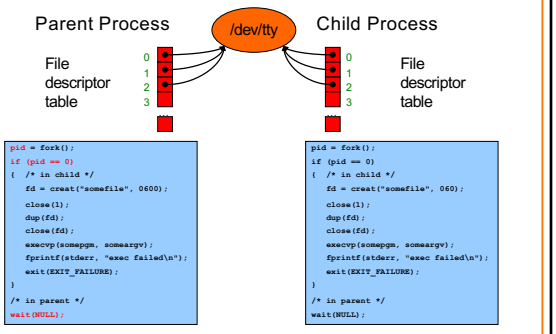
## Redirection Example Trace (3)




```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 060);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

Let's say OS gives CPU to parent; parent waits

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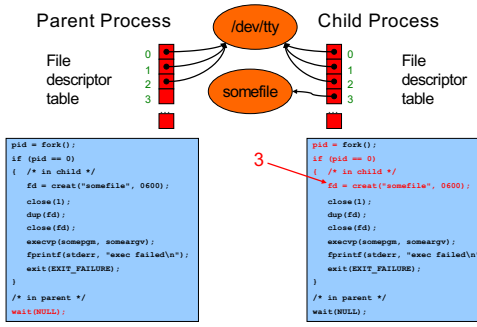
## Redirection Example Trace (4)




```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

OS gives CPU to child; child creates somefile

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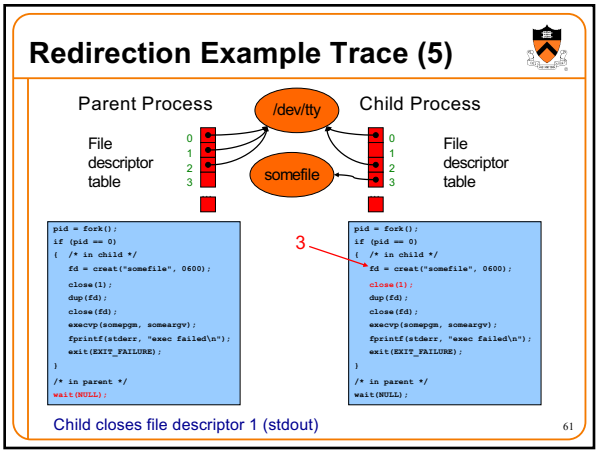
## Redirection Example Trace (5)




Child closes file descriptor 1 (stdout)

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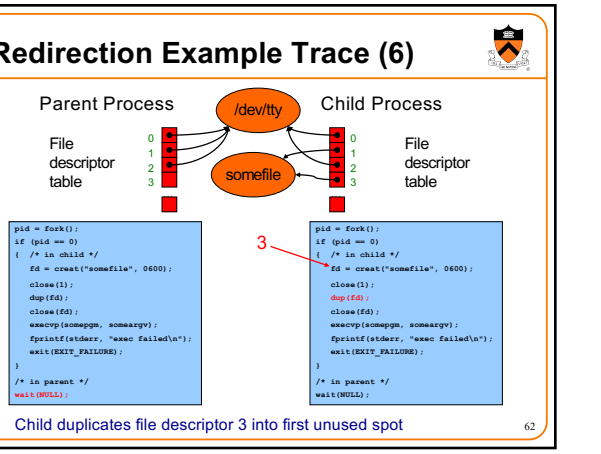
## Redirection Example Trace (6)




Child duplicates file descriptor 3 into first unused spot

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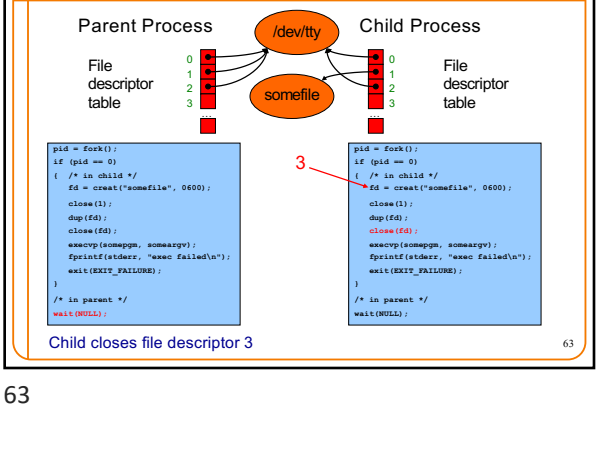
## Redirection Example Trace (7)




Child closes file descriptor 3

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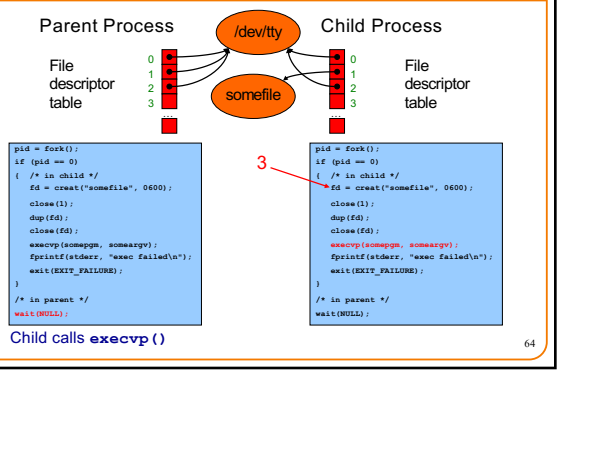
## Redirection Example Trace (8)




Child calls `execvp()`

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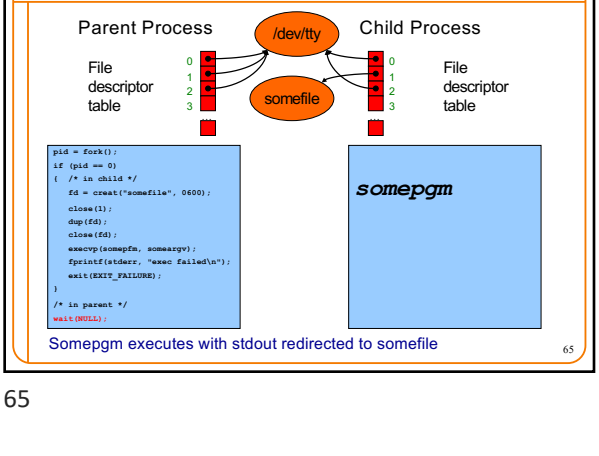
## Redirection Example Trace (9)




Somepgm executes with stdout redirected to somefile

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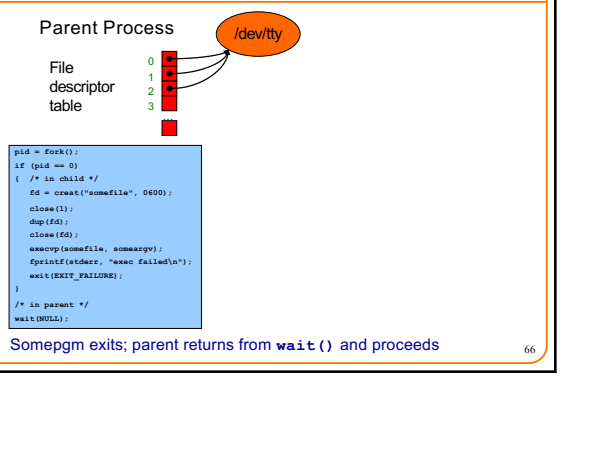
## Redirection Example Trace (10)




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

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## Agenda

The C/Unix file abstraction

Unix I/O system calls

C's Standard IO library (FILE *)

Implementing standard C I/O using Unix I/O

Redirecting standard files

**Pipes**



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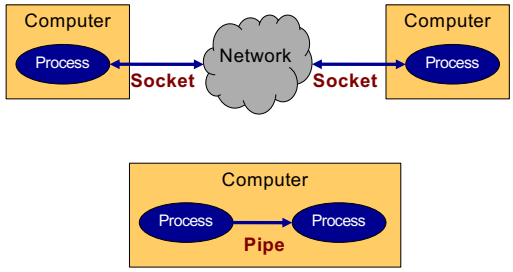
## Inter-Process Communication (IPC)



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## IPC Mechanisms

**Socket**

- Mechanism for **two-way** communication between processes on **any computers** on same network
- Processes created independently
- Used for client/server communication (e.g., Web)

**Pipe**

- Mechanism for **one-way** communication between processes on the **same computer**
- Allows parent process to communicate with child process
- Allows two "sibling" processes to communicate
- Used mostly for a **pipeline** of **filters**

Both support **file** abstraction



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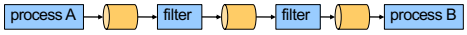
## Pipes, Filters, and Pipelines

**Pipe**


**Filter**: Program that reads from stdin and writes to stdout


**Pipeline**: Combination of pipes and filters



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## Pipeline Examples

When debugging your shell program…

`grep alloc *.c`

- In all of the .c files in the working directory, display all lines that contain "alloc"

`cat *.c | decomment | grep alloc`

- In all of the .c files in the working directory, display all non-comment lines that contain "alloc"

`cat *.c | decomment | grep alloc | more`

- In all of the .c files in the working directory, display all non-comment lines that contain "alloc", one screen at a time



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## Creating a Pipe

`int pipe(int pipefd[2])`

- `pipe()` creates a pipe, a unidirectional data channel that can be used for interprocess communication
- The array `pipefd` is used to return two file descriptors referring to the ends of the pipe
- `pipefd[0]` refers to the read end of the pipe
- `pipefd[1]` refers to the write end of the pipe
- Data written to the write end of the pipe is buffered by the kernel until it is read from the read end of the pipe
  - Quoting `man -s2 pipe`



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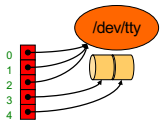
## Pipe Example 1 (1)

Parent process sends data to child process

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

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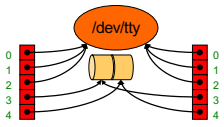
## Pipe Example 1 (2)

Parent process sends data to child process

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```

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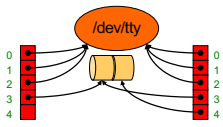
## Pipe Example 1 (3)

Parent process sends data to child process

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```

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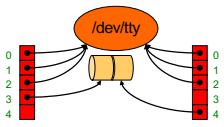
## Pipe Example 1 (4)

Parent process sends data to child process

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(p[1]);
   /* Read from fd p[0] */
   exit(0);
}
/* in parent */
close(p[0]);
/* Write to fd p[1] */
wait(NULL);
```

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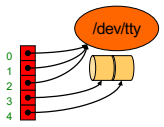
## Pipe Example 2 (1)

Parent sends data to child through stdin/stdout

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

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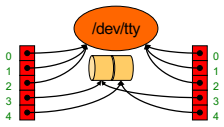
## Pipe Example 2 (2)

Parent sends data to child through stdin/stdout

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```




```
p[0] = 4
p[1] = 3
```

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```

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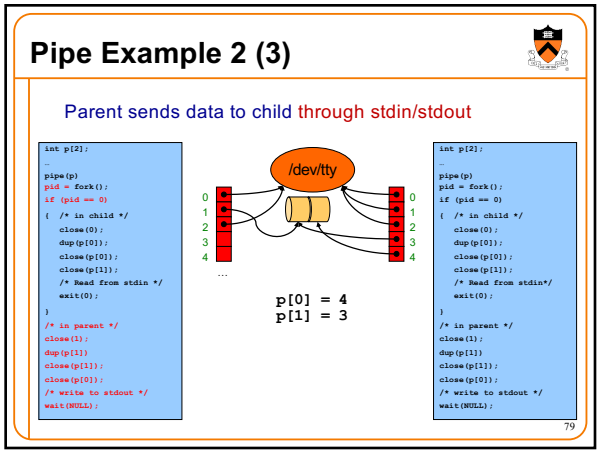
## Pipe Example 2 (3)



Parent sends data to child through stdin/stdout

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```



```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin*/
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```

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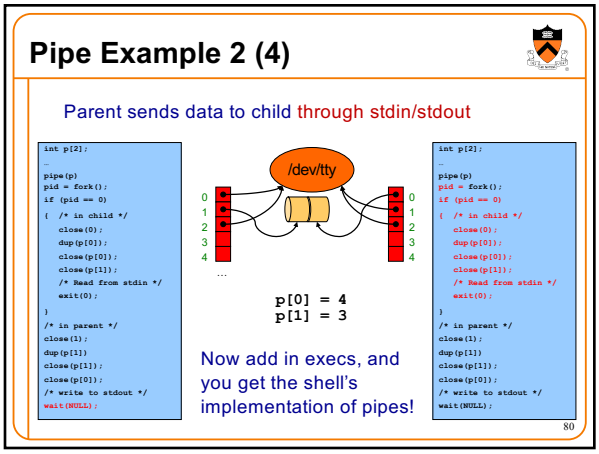
## Pipe Example 2 (4)



Parent sends data to child through stdin/stdout

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```



Now add in execs, and you get the shell's implementation of pipes!

```
int p[2];
…
pipe(p)
pid = fork();
if (pid == 0)
{  /* in child */
   close(0);
   dup(p[0]);
   close(p[0]);
   close(p[1]);
   /* Read from stdin */
   exit(0);
}
/* in parent */
close(1);
dup(p[1])
close(p[1]);
close(p[0]);
/* write to stdout */
wait(NULL);
```

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## Summary

The C/Unix file abstraction

Unix I/O

- File descriptors, file descriptor tables, file tables
- **`creat()`**, **`open()`**, **`close()`**, **`read()`**, **`write()`**, **`lseek()`**

C's Standard I/O

- **`FILE`** structure
- **`fopen()`**, **`fclose()`**, **`fgetc()`**, **`fputc()`**, …

Implementing standard C I/O using Unix I/O

- Buffering

Redirecting standard files

- **`dup()`**

Pipes

- **`pipe()`**

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