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
- (If time) The implementation of Standard C I/O using Unix I/O
- Programmatic redirection of stdin, stdout, and stderr
- (If time) Pipes

System-Level Functions Covered

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

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

Number	Function	Description
0	read()	Read data from file descriptor Called by getchar(), scanf(), etc.
1	write()	Write data to file descriptor Called by putchar(), printf(), etc.
2	open()	Open file or device Called by fopen(…, "r")
3	close()	Close file descriptor Called by fclose()
85	creat()	Open file or device for writing Called by fopen(…, "w")
8	lseek()	Change file position Called by fseek()

System-Level Functions

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

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

Number	Function	Description
32	dup()	Duplicate an open file descriptor
22	pipe()	Create a channel of communication between processes

Agenda

The C/Unix file abstraction

Standard C I/O

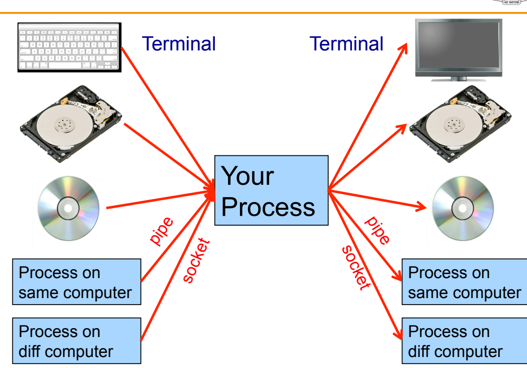
Unix I/O

(If time) Implementing standard C I/O using Unix I/O

Redirecting standard files

(If time) Pipes

Data Sources and Destinations



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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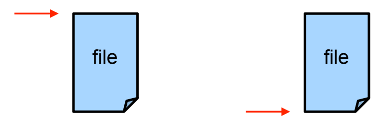
C/Unix File Abstraction

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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Standard C I/O Data Structure

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)`
- Incredibly dangerous!!!

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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, …)`

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)`

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, ...)`

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

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;
}
```


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)

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;
}
```

- `printf("Dividend: ");` → Output buffered
- `scanf("%d", &dividend);` → Buffer flushed
- `printf("Divisor: ");` → Output buffered
- `scanf("%d", &divisor);` → Buffer flushed
- `printf("The quotient is ");` → Output buffered
- `printf("%d\n", quotient);` → Buffer flushed

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

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

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The C/Unix file abstraction

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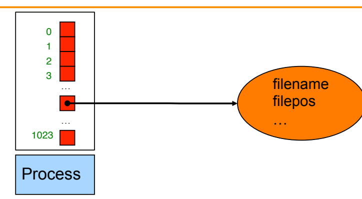
Unix I/O Data Structures



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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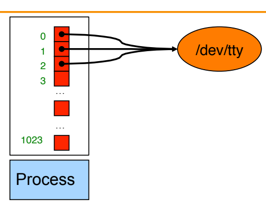
Unix I/O Data Structures



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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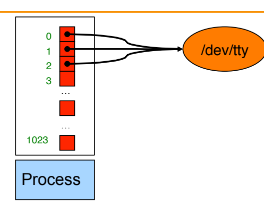
Unix I/O Data Structures



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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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

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

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`**

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

Unix I/O Functions

Note

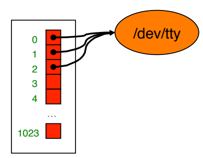
- Only 6 system-level functions support all I/O from all kinds of devices!

Commentary: **Beautiful** interface!

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;
}
```

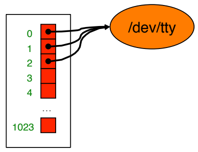


To save space, no error handling code is shown

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

```
#include <fcntl.h>
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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;
}
```

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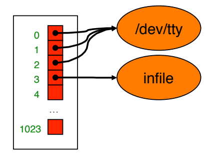

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Unix I/O Example 2

```
#include <fcntl.h>
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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;
}
```
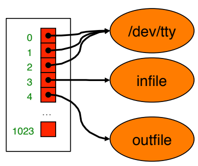

3
4



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Unix I/O Example 2

```
#include <fcntl.h>
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   fdIn = open("infile", O_RDONLY);
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   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;
}
```
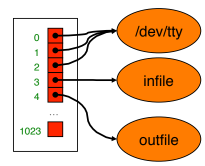

3
4



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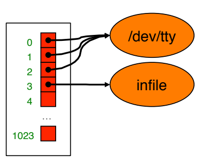
Unix I/O Example 2

```
#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;
}
```

3
4



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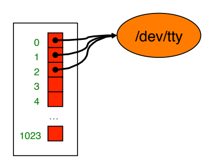
Unix I/O Example 2

```
#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;
}
```

3
4



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Agenda

The C/Unix file abstraction

Standard C I/O

Unix I/O

(If time) Implementing standard C I/O using Unix I/O

Redirecting standard files

(If time) Pipes

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…

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;
}
```


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

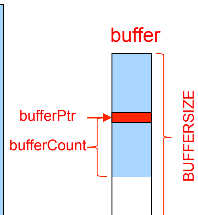
Solution: buffered I/O

- **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

Implementing `getchar` Version 2

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

```
int getchar(void)
{  enum {BUFFERSIZE = 512}; /*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));
}
```



Implementing `putchar` Version 2

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

```
int putchar(int c)
{  enum {BUFFERSIZE = 512};
   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

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 = 512};

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()	
fseek()	**lseek()**
ftell()	**lseek()**

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Agenda

The C/Unix file abstraction

Standard C I/O

Unix I/O

(If time) Implementing standard C I/O using Unix I/O

Redirecting standard files

(If time) Pipes

52

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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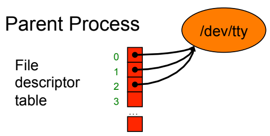
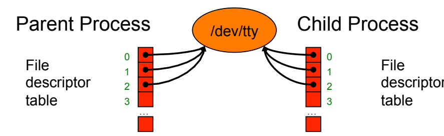
Redirection Example Trace (1)




```c
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”

Redirection Example Trace (2)

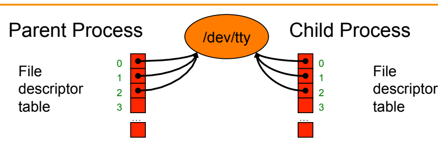



```c
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

```c
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

Redirection Example Trace (3)

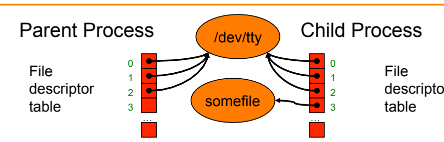



```c
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

```c
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

Redirection Example Trace (4)



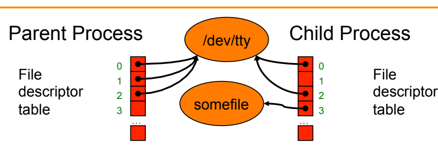

```c
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

3

```c
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

Redirection Example Trace (5)



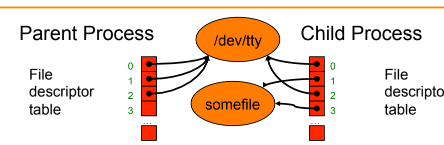

```c
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

3

```c
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);
```

Child closes file descriptor 1 (stdout)

Redirection Example Trace (6)



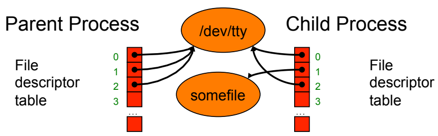

```c
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

3

```c
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);
```

Child duplicates file descriptor 3 into first unused spot

Redirection Example Trace (7)



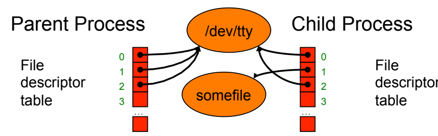

```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

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);
```

Child closes file descriptor 3

Redirection Example Trace (8)



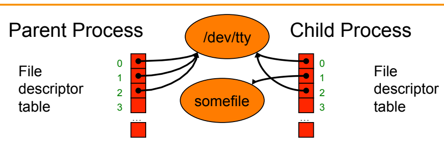

```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepgm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

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);
```

Child calls `execvp()`

Redirection Example Trace (9)

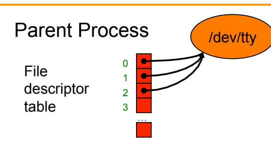



```
pid = fork();
if (pid == 0)
{  /* in child */
   fd = creat("somefile", 0600);
   close(1);
   dup(fd);
   close(fd);
   execvp(somepfm, someargv);
   fprintf(stderr, "exec failed\n");
   exit(EXIT_FAILURE);
}
/* in parent */
wait(NULL);
```

somepgm

Somepgm executes with stdout redirected to somefile

Redirection Example Trace (10)




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

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

Agenda

The C/Unix file abstraction

Standard C I/O

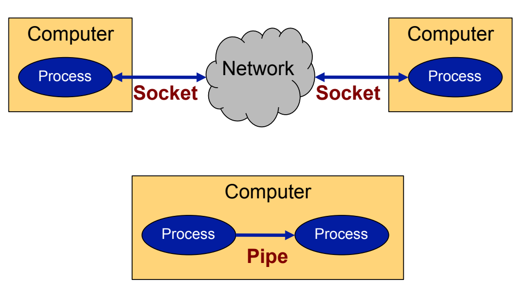
Unix I/O

(If time) Implementing standard C I/O using Unix I/O

Redirecting standard files

(If time) Pipes

Inter-Process Communication (IPC)



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)

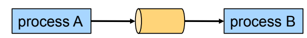
Pipe

- 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

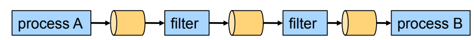
Pipes, Filters, and Pipelines

Pipe



Filter: Program that reads from stdin and writes to stdout

Pipeline: Combination of pipes and filters



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

Creating a Pipe

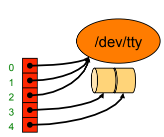
`int pipe(int pipefd[2])`

- `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`

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);
```

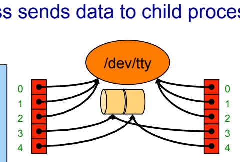



```
p[0] = 4
p[1] = 3
```


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);
```



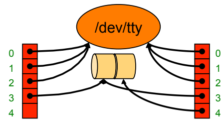

```
p[0] = 4
p[1] = 3
```

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

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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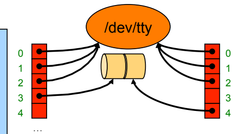
Pipe Example 1 (4)

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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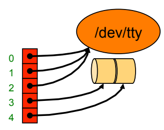
Pipe Example 2 (1)

Parent process sends data to child process using standard C functions

```
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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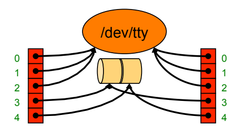
Pipe Example 2 (2)

Parent process sends data to child process using standard C functions

```
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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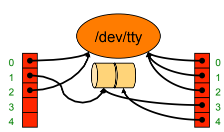
Pipe Example 2 (3)

Parent process sends data to child process using standard C functions

```
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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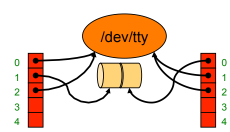
Pipe Example 2 (4)

Parent process sends data to child process using standard C functions

```
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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Summary

The C/Unix file abstraction

Standard C I/O
- **FILE** structure
- **fopen()**, **fclose()**, **fgetc()**, **fputc()**, …

Unix I/O
- File descriptors, file descriptor tables, file tables
- **creat()**, **open()**, **close()**, **read()**, **write()**, **lseek()**

(If time) Implementing standard C I/O using Unix I/O
- Buffering

Redirecting standard files
- **dup()**

(If time) Pipes
- **pipe()**