File I/O

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Unix files

- **A Unix file is a sequence of *m* bytes:**
  - $B_0, B_1, \ldots, B_k, \ldots, B_{m-1}$
- **All I/O devices are represented as files:**
  - **/dev/sda1** (hard disk partition)
  - **/dev/tty2** (terminal)
- **Even the kernel is represented as a file:**
  - **/dev/kmem** (kernel memory image)
  - **/proc** (kernel data structures)

Unix File Types

- **Regular file**
  - Binary or text file
  - Unix does not know the difference!
- **Directory file**
  - A file that contains the names and locations of other files.
- **Device special files**
  - Terminals (character special) and disks (block special)
- **FIFO (named pipe)**
  - A file type used for inter-process communication
- **Socket**
  - A file type used for network communication between processes

Unix I/O

- **Characteristics**
  - The elegant mapping of files to devices allows kernel to export simple interface called Unix I/O.
  - All input and output is handled in a consistent and uniform way (“byte stream”)
- **Basic Unix I/O operations (system calls):**
  - Opening and closing files
    - open() and close()
  - Changing the current file position (seek)
    - lseek()
  - Reading and writing a file
    - read() and write()

Opening Files

- **Opening a file informs the kernel that you are getting ready to access that file.**

```
int fd;   /* file descriptor */
if ((fd = open("/etc/hosts", O_RDONLY)) < 0) {
   perror("open");
   exit(1);
}
```

- **Returns a small identifying integer file descriptor**
  - fd == -1 indicates that an error occurred
- **Each process created by a Unix shell begins life with three open files associated with a terminal:**
  - 0: standard input
  - 1: standard output
  - 2: standard error

Closing Files

- Closing a file informs the kernel that you are finished accessing that file.

```
int fd;     /* file descriptor */
int retval; /* return value */

if ((retval = close(fd)) < 0) {
   perror("close");
   exit(1);
}
```

- Closing an already closed file is a recipe for disaster in threaded programs (more on this later)
- Moral: Always check return codes, even for seemingly benign functions such as *close()*

Reading Files

- **Reading a file copies bytes from the current file position to memory, and then updates file position.**

```
char buf[512];
int fd;       /* file descriptor */
int nbytes;   /* number of bytes read */

/* Open file fd ...  */
/* Then read up to 512 bytes from file fd */
if ((nbytes = read(fd, buf, sizeof(buf))) < 0) {
   perror("read");
   exit(1);
}
```

- **Returns number of bytes read from file** fd **into** buf
  - **nbytes < 0** indicates that an error occurred.
  - short counts (**nbytes < sizeof(buf)**) are possible and are not errors!

Writing Files

- **Writing a file copies bytes from memory to the current file position, and then updates current file position.**

```
char buf[512];
int fd;       /* file descriptor */
int nbytes;   /* number of bytes read */
/* Open the file fd ... */
/* Then write up to 512 bytes from buf to file fd */
if ((nbytes = write(fd, buf, sizeof(buf)) < 0) {
   perror("write");
   exit(1);
}
```

- **Returns number of bytes written from *buf* to file *fd*.**
  - **nbytes < 0** indicates that an error occurred.
  - As with reads, short counts are possible and are not errors!

File Offset

- **An offset of an opened file can be set explicitly by calling** *lseek()*

```
char buf[512];
int fd;       /* file descriptor */
off_t pos;    /* file offset */

/* Get current file offset */
pos = lseek(fd, 0, SEEK_CUR);
/* The file offset is incremented by written bytes */
write(fd, buf, sizeof(buf));
/* Set file position to the first byte of the file */
pos = lseek(fd, 0, SEEK_SET);
```

- **Returns the new offset of the file** *fd*.
  - **nbytes < 0** indicates that an error occurred.
  - An offset can be set beyond the end of the file.
    - If data is written at that point, a file "hole" is created.

Unix I/O Example

- **Copying standard input to standard output one byte at a time.**

```
int main(void)
{
    char c;

    while(read(0, &c, 1) != 0)
        write(1, &c, 1);
    exit(0);
}
```

Dealing with Short Counts

- **Short counts can occur in these situations:**
  - Encountering (end-of-file) EOF on reads.
  - Reading text lines from a terminal.
  - Reading and writing network sockets or Unix pipes.
- **Short counts does not occur in these situations:**
  - Reading from disk files (except for EOF)
  - Writing to disk files.

- **How should you deal with short counts in your code?**
  - One way is to use the RIO (Robust I/O) package from your textbook's *csapp.c* file (Appendix B).

File Metadata

- **Data about data, in this case file data.**
  - Maintained by kernel, accessed by users with the *stat* and *fstat* functions.

```
/* Metadata returned by the stat and fstat functions */
struct stat {
    dev_t         st_dev;      /* device */
    ino_t         st_ino;      /* inode */
    mode_t        st_mode;     /* protection and file type */
    nlink_t       st_nlink;    /* number of hard links */
    uid_t         st_uid;      /* user ID of owner */
    gid_t         st_gid;      /* group ID of owner */
    dev_t         st_rdev;     /* device type (if inode device) */
    off_t         st_size;     /* total size, in bytes */
    unsigned long st_blksize;  /* blocksize for filesystem I/O */
    unsigned long st_blocks;   /* number of blocks allocated */
    time_t        st_atime;    /* time of last file access */
    time_t        st_mtime;    /* time of last file modification */
    time_t        st_ctime;    /* time of last inode change */
};                            /* statbuf.h included by sys/stat.h */
```

Accessing File Metadata


```
/* statcheck.c - Querying and manipulating a file's meta data */

int main (int argc, char **argv)
{
    struct stat st;
    char *type, *readok;

    stat(argv[1], &st);
    if (S_ISREG(st.st_mode)) /* file type */
        type = "regular";
    else if (S_ISDIR(st.st_mode))
        type = "directory";
    else
        type = "other";
    if ((st.st_mode & S_IRUSR)) /* OK to read? */
        readok = "yes";
    else
        readok = "no";

    printf("type: %s, read: %s\n", type, readok);
    exit(0);
}
```

```
bass> ./statcheck statcheck.c
type: regular, read: yes
bass> chmod 000 statcheck.c
bass> ./statcheck statcheck.c
type: regular, read: no
```

Standard I/O Functions

- **The C standard library (libc.a) contains a collection of higher-level standard I/O functions**
  - Documented in Appendix B of K&R.

- **Examples of standard I/O functions:**
  - Opening and closing files (*fopen* and *fclose*)
  - Reading and writing bytes (*fread* and *fwrite*)
  - Reading and writing text lines (*fgets* and *fputs*)
  - Formatted reading and writing (*fscanf* and *fprintf*)

Standard I/O Streams

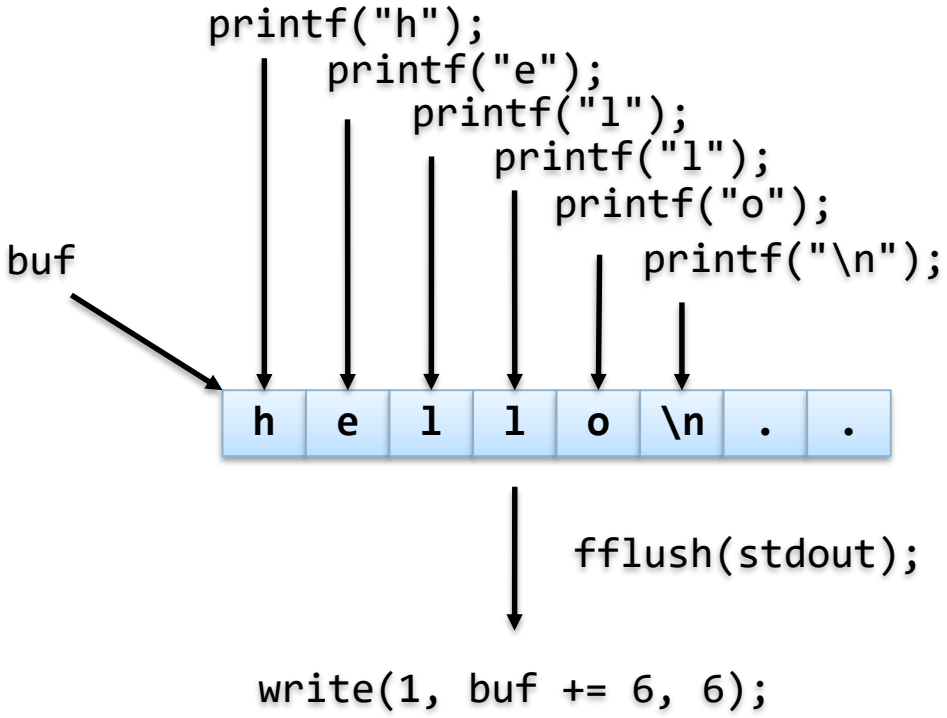
- **Standard I/O models open files as streams**
  - Abstraction for a file descriptor and a buffer in memory
- **C programs begin life with three open streams (defined in stdio.h)**
  - **stdin** (standard input)
  - **stdout** (standard output)
  - **stderr** (standard error)

```
#include <stdio.h>
extern FILE *stdin;  /* standard input (descriptor 0) */
extern FILE *stdout; /* standard output (descriptor 1) */
extern FILE *stderr; /* standard error (descriptor 2) */

int main() {
    fprintf(stdout, "Hello, world\n");
}
```

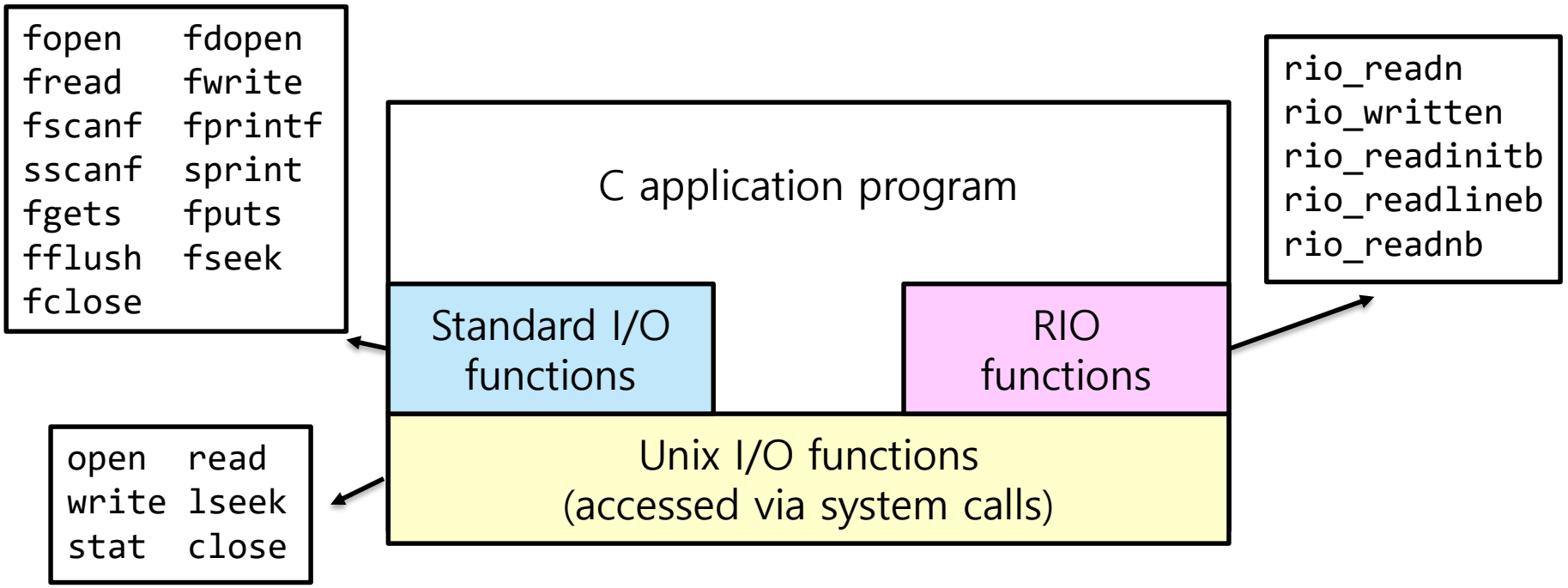
Buffering in Standard I/O

- **Standard I/O functions use buffered I/O**



Unix I/O vs. Standard I/O

- **Standard I/O are implemented using low-level Unix I/O.**



- **Which ones should you use in your programs?**

Pros/Cons of Unix I/O

- **Pros**
  - The most general and lowest overhead form of I/O.
    - All other I/O packages are implemented on top of Unix I/O functions.
  - Unix I/O provides functions for accessing file metadata.

- **Cons**
  - System call overheads for small-sized I/O.
  - Dealing with short counts is tricky and error prone.
  - Efficient reading of text lines requires some form of buffering, also tricky and error prone.
  - These issues are addressed by the standard I/O.

Pros/Cons of Standard I/O

- **Pros**
  - Buffering increases efficiency by decreasing the number of *read()* and *write()* system calls.
  - Shout counts are handled automatically.

- **Cons**
  - Provides no function for accessing file metadata.
  - Standard I/O is not appropriate for input and output on network sockets.
    - But there is a way using *fdopen()*

Summary

- **Unix file I/O**
  - *open()*, *read()*, *write()*, *close()*, …
  - A uniform way to access files, I/O devices, network sockets, kernel data structures, etc.
- **When to use standard I/O?**
  - When working with disk or terminal files.
- **When to use raw Unix I/O**
  - When you need to fetch file metadata.
  - When you read or write network sockets or pipes.
  - In rare cases when you need absolute highest performance.

Exercise

- **Lab exercise #2:**
  - Let's make ***xcat***, ***xcp*** utilities.
  - ***xcat*** prints a file on the standard output.
  - ***xcp*** copies contents of a file into a new file.
  - Basically, executing ***xcat*** and ***xcp*** will be same as executing ***cat*** and ***cp*** without any options, respectively.

- **Your job is to make xcat and xcp by using system calls provided by Linux.**