UNIX and C Programming (COMP1000)

Lecture 6: Input and Output

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Textbook Reading (Hanly and Koffman)

For more information, see the weekly reading list on Blackboard.

- **Chapter 11: Text and Binary File Processing**
  Consider reading Sections 10.1 and 10.2 (in Chapter 10) beforehand. These introduce structs, which are used in some of the examples in Chapter 11.

Outline

Introduction to I/O

- Reading from and writing to files is a crucial part of any programming language.
- Virtually all programs need to do it (in the real world).
- Files provide permanent storage — “persistence” — unlike variables in memory.

Opening and Closing Files

- Before reading/writing a file, the file must be “opened”.
- After reading/writing, the file must be “closed”.
- If you’re reading from a file, the file must exist.
- If you’re writing to a file, you can choose whether:
  - the file will be created or overwritten, OR
  - the file will be appended to.

Streams

- Most input and output uses “streams”.
- Characters go in one end and out the other — a queue.
- When you read a file:
  - Each character in the file is fed into the stream.
  - Your program reads and removes characters from the stream.
  - Often your program must wait for characters to become available.
- When you write to a file:
  - Your program feeds characters into the stream.
  - Characters are progressively removed from the stream and written to disk.
- A stream is created when you open a file.

Streams — Visualisation

- Here, `program` reads from `file1.txt` and writes to `file2.txt`
- However, you can have as many streams as you like!
- Characters "flow" through each input stream *to* the program.
- More characters "flow" through each output stream *from* the program.

Buffering (1)

- File I/O is slow, compared to memory-based operations.
- Usually, characters to be read/written are stored temporarily in "buffers" (inside a stream).
- This allows characters to be read/written in large chunks — more efficient than one-at-a-time.
- Buffering often happens transparently, in the middle of a stream.

Buffering (2)

Input Buffering

- If you read one character from a file, the OS actually feeds a much larger chunk of the file into the stream.
- When you want the next character, it's already waiting in the buffer.

Output Buffering

- If you write one character to a file, the OS delays the actual write until enough characters accumulate, or the file is closed.
- If you *don't* close a file, you'll lose everything still in the output buffer.

Flushing Output Buffers

- Output buffers can be “flushed”.
- This (also) happens automatically when a file is closed.
- Flushing an output buffer writes the output to disk immediately.

Seeking

- Normally a file is read/written sequentially.
- At any given moment, the stream "points" to a particular location in the file.
  - The first character on the first line is 0.
  - Each subsequent character is one greater than the previous.
- This is the location where characters will next be read or written.
- Jumping to another location (either forwards or backwards) is called "seeking".
- You must know the exact *byte* location.
- You cannot jump straight to a particular line number.

Man Pages (Manual Pages)

- You're about to be assaulted with many new C functions.
- The UNIX "man" utility can display documentation (as mentioned before).
- This command will display the man page for the `strlen()` function:

```
[user@pc]$ man 3 strlen
```

- Standard C functions are located in section 3 of the manual.
- You can omit the section number:

```
[user@pc]$ man strlen
```

(...but you may get a page from the wrong section!)

Man Page Example

```
STRLEN(3)     Linux Programmer's Manual    STRLEN(3)

NAME        strlen - calculate the length of a string

SYNOPSIS    #include <string.h>
        size_t strlen(const char *s);

DESCRIPTION
The strlen() function calculates the length of
the string s, not including the terminating '\0'
character.

RETURN VALUE
The strlen() function returns the number of
characters in s.
```

Man Page Information

As shown on the previous slide, each man page lists:

- `NAME` — The function name and purpose.
- `SYNOPSIS` —
  - The header file you must `#include`.
  - The function prototype/declaration.
- `DESCRIPTION` — A description of the function.
- `RETURN VALUE` — A description of the return value.

More information is also listed, including notes, bugs and related functions (“`SEE ALSO`”).

Introduction to File I/O in C

- Uses the `stdio.h` library.
- File I/O is closely related to terminal I/O — `printf()` and `scanf()`.
- Make good use of man pages!

FILE Pointers

- When you open a file in C you get a "FILE" pointer (FILE*).
- The FILE* is used to access the stream.
- When you read/write a open file (stream), you must supply the FILE*.

Note

- You never need to deal with the FILE type itself, only FILE*.
- You just pass the pointer around to various C functions.

FILE Pointers — Concept and Reality

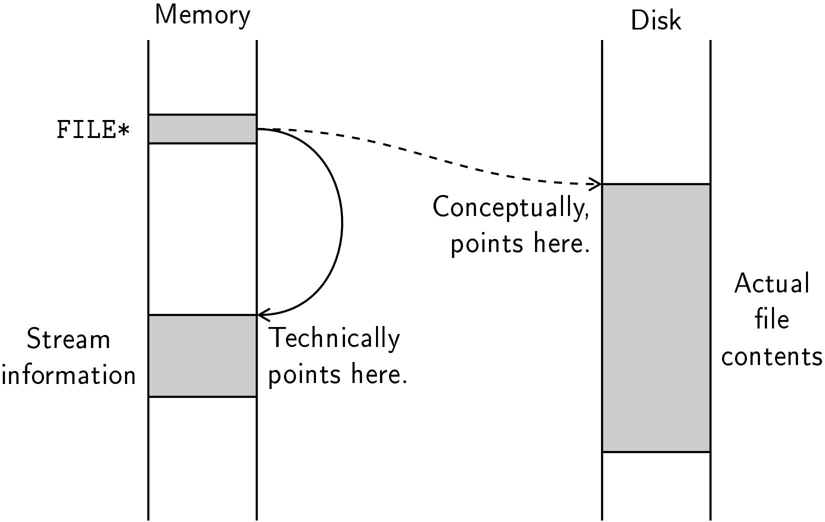
Reality

- A `FILE*` points to a `FILE` (of course) — a chunk of information in memory used to access a stream.
- A `FILE*` is really just a normal pointer.

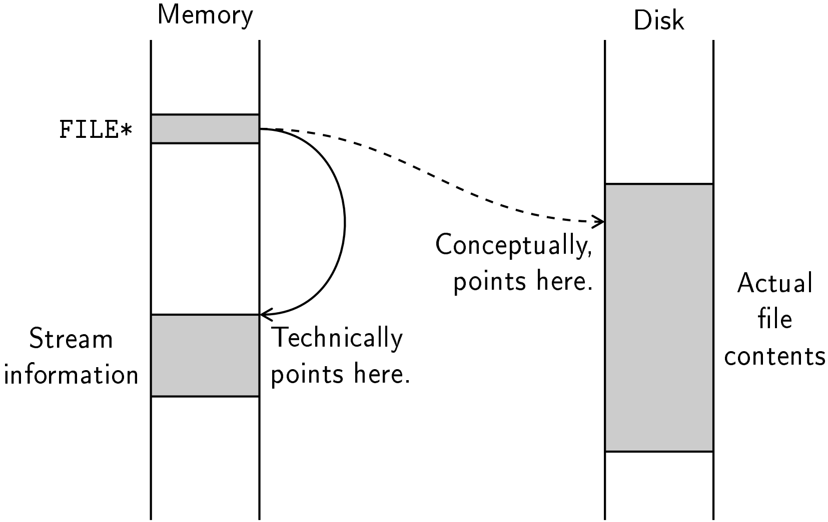
Concept

- You can *think* of a `FILE*` as a pointer to a place in a file.
- When you read/write, the pointer automatically moves forward.

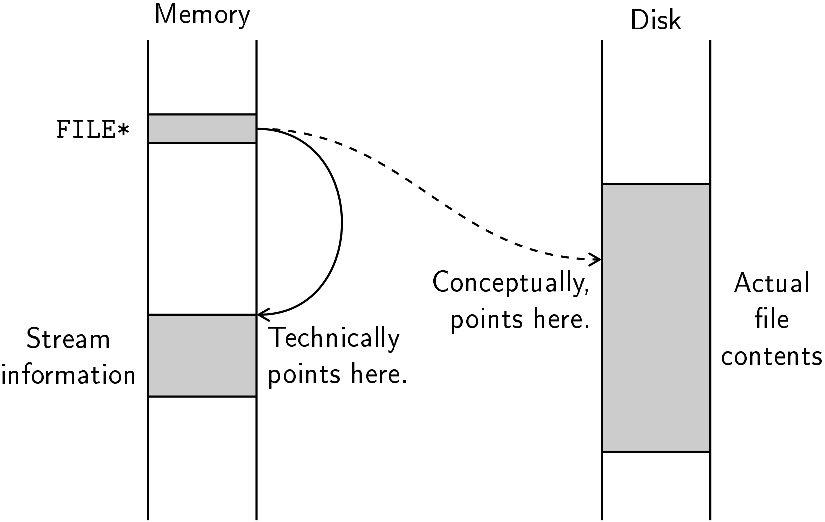
FILE Pointers — Visualisation



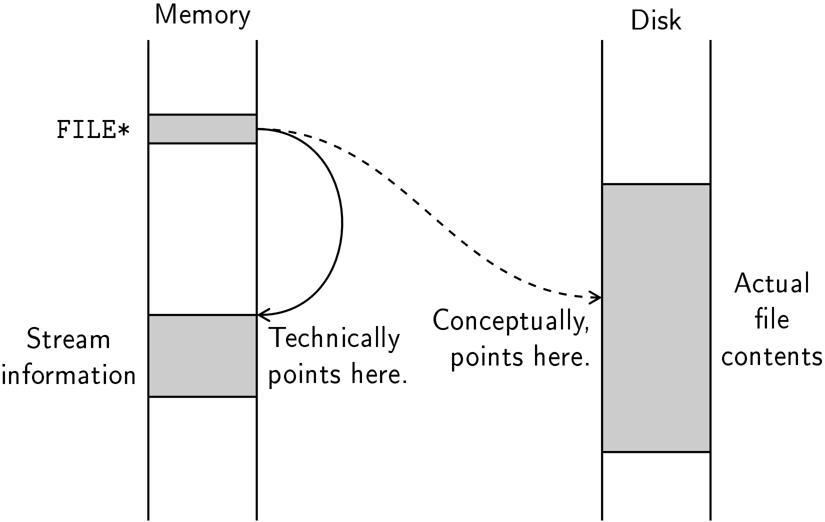
FILE Pointers — Visualisation



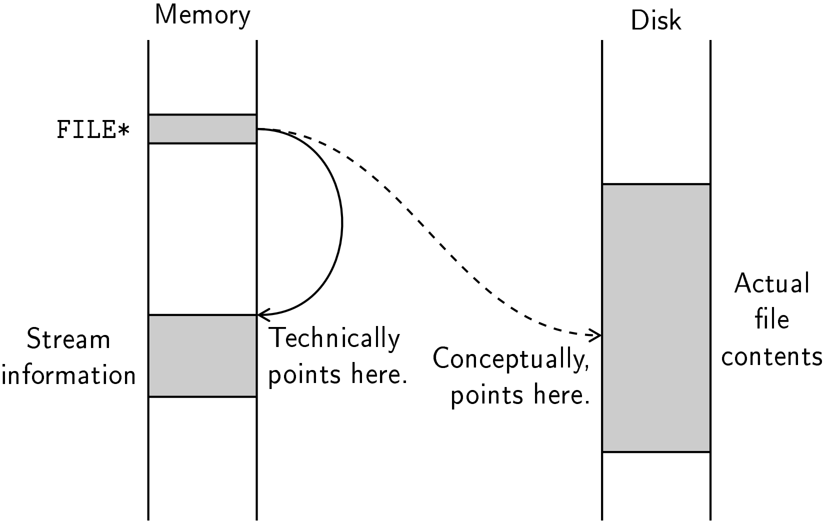
FILE Pointers — Visualisation



FILE Pointers — Visualisation



FILE Pointers — Visualisation



Opening and Closing Files in C

The `fopen()` function

- Opens a file.
- Takes two `char*` (string) parameters — a filename and a "mode" string.
- Returns `FILE*`, or `NULL` if the file couldn't be opened.

The `fclose()` function

- Closes a file.
- Takes a `FILE*` parameter.
- Returns an `int` indicating whether an error occurred.

Opening and Closing Files — Example

```c
#include <stdio.h>

...

FILE* f;
f = fopen("filename.txt", "r");

... /* Read from the file */

fclose(f);
```

(Be careful — we haven't checked for errors here!)

File Modes

- The second parameter to `fopen()` is the “mode” string.
- Indicates what you want to do with the file.
- Always a *string*, even if only 1 character long.

Basic modes

`"r"`	read from a file (starting at the beginning)
`"w"`	write to a file (create or overwrite the file)
`"a"`	write to a file (starting at the end — “appending”)

"Update" Modes

- Adding a "+" to the mode allows both reading and writing.
- This makes the stream bi-directional.
- You can switch between reading and writing (but you can't do both simultaneously).
- Going from reading to writing, you must perform a seek.
- Going from writing to reading, you must perform a seek *or* flush.

"Update" modes

`"r+"`	read & write (starting at the beginning)
`"w+"`	read & write (create or overwrite the file)
`"a+"`	read & write (starting at the end)

Text and Binary Modes

- Microsoft Windows distinguishes between "text" and "binary" modes.
- In "binary mode", the file is read/written as-is.
- In "text mode", Windows fiddles with some special characters.
- **Text mode is the default, but will corrupt binary files (under Windows)!**
- To select binary mode, place "b" in the mode string (e.g. `"rb"`, `"wb"`).
- UNIX (e.g. Linux and OS X) does not need this — the "b" flag is accepted but ignored.

Errors

- File I/O is error-prone.
- Possible errors include:
  - Trying to read a file that doesn't exist.
  - Trying to write to a file when the disk is full.
  - Trying to read/write to a file when you don't have permission.
  - Disk hardware errors.
- I/O errors are not necessarily your fault (though they might be).

Error Checking and Handling

- Your program should detect errors and handle them gracefully.
- Newer languages (like Java) deal with I/O errors by throwing "exceptions", which can be caught and handled.
- C leaves it up to you to *check* when an error occurs.
- Output helpful error messages.

Error Checking: Opening Files

- Recall that `fopen()` returns `NULL` if a file can't be opened.
- You should *check* for this (with an `if` statement):

```
FILE* f = fopen("file.txt", "r");
if(f == NULL) {
    printf("Error: could not open 'file.txt'\n");
}
else {
    ... /* Read from the file */

    fclose(f);
}
```

Error Handling — perror()

- Don't leave the user to figure out what went wrong!
- The perror() function determines what the error was and prints out a relevant message.
- Takes a char* — a prefix to the error message.
- Returns void, and prints out the parameter plus the error.

```
FILE* f = fopen("file.txt", "r");
if(f == NULL) {
    perror("Error opening 'file.txt'");
}
else { ... /* Read and close the file */ }
```

Possible output (say file.txt does not exist):

```
Error opening 'file.txt': No such file or directory
```

More Error Checking — ferror()

- The ferror() function checks whether an error has occurred.
- Takes a FILE* parameter (must be non-NULL).
- Returns an int — zero (no error) or non-zero (error).

```
FILE* f = fopen("file.txt", "r");
if(f == NULL) { ... }
else {
    ... /* Read from the file */

    if(ferror(f)) {
        perror("Error reading from 'file.txt'\n");
    }
    fclose(f);
}
```

Reading and Writing

- Reading usually uses mode `"r"`.
- Writing usually uses mode `"w"`.
- Every read or write will move the `FILE` pointer forward.
- However, there are different functions to read/write data, based on the **type** of data:
  - Strings with embedded values.
  - Individual characters.
  - Lines of text.
  - Binary data.
- You may also need different algorithms, based on the file format.
- You may (or may not!) know how many data elements are stored in the file.

Checking for the End of File (EOF)

- How big is the file? You don't always know.
  - (You can find the number of bytes, but each data element may occupy an unknown number of bytes.)
- The read functions – `fscanf`, `fgets`, `fgetc` – will all tell you when the file has ended.
- That's the trick: you *won't know* until *after* you try to read past the end of file.
  - The last read operation always fails (unless you know in advance how many reads you can do).

Basic File Reading Algorithm

```
int done = FALSE;
do {
    Attempt a read operation
    if(the read succeeded)
        Store the data (e.g. in an array)
    else
        done = TRUE;
}
while(!done);

if(ferror(the file pointer))
    Handle error and de-allocate any stored data
else
    Success
```

fprintf() and fscanf()

- Like printf() and scanf(), but used with files.
- Both take an extra FILE* parameter (first).

fprintf() example

```
FILE* f = fopen("output.txt", "w");
int number;
...
fprintf(f, "The number is %d\n", number);
```

`fscanf()` continued

- `fscanf()` returns *either*:
  - the number of items successfully read, OR
  - the preprocessor constant `EOF` (end-of-file), but only if it doesn't read anything first.
- Compare the return value to the number you expected:

```
FILE* f = fopen("input.txt", "r");
int x, y, z, nRead;
...
nRead = fscanf(f, "%d %d %d", &x, &y, &z);
if(nRead != 3)
    /* An error or end of file occurred. */
```

3 items

Note on `EOF`

- `EOF` is a preprocessor constant, guaranteed to be *some* negative integer.

fputc() and fgetc()

- fputc() writes one character to an output stream.
- fgetc() reads one character from an input stream.

fputc() example

```
FILE* f = fopen("output.txt", "w");
char ch;
...
fputc(ch, f);
```

fgetc() continued

- fgetc() returns an int (not a char) – why?
- Because, if it fails, it returns EOF.
- EOF is a negative integer, not representable as a char value.

```
FILE* f = fopen("input.txt", "r");
int ch;
...
ch = fgetc(f);
if(ch == EOF)
    /* Error or end-of-file. */
else
    /* Success -- typecast ch to a char. */
```

Writing a line of text — `fputs()`

- `fputs()` writes a string, plus a new line (`'\n'`).
- Takes two parameters: `char*` and `FILE*`.

Example

```
FILE* f = fopen("output.txt", "w");
char* str = "Hello world";
...
fputs(str, f);
```

(Here, the `FILE*` parameter comes *last*.)

Reading a line of text — fgets()

- fgets() reads a string, taking 3 parameters:
  - char* — an array to store the text.
  - int — the size of the array.
  - FILE* — an input stream.
- Stops at the next newline, or the size of the array *minus 1* (whichever comes first).

```
#define INPUT_SIZE 21
...
FILE* f = fopen("input.txt", "r");
char str[INPUT_SIZE];
...
if(fgets(str, INPUT_SIZE, f) == NULL)
    /* Error or end-of-file. */
else
    /* Success -- you can safely use str. */
```

Other Reading/Writing Functions

These functions are all essentially redundant:

`getc()` and `putc()`

Reads/writes a character (like `fputc()` but with possible side-effects).

`getchar()` and `putchar()`

Reads/writes a character from/to the terminal.

`gets()` and `puts()`

Reads/writes a line of text from/to the terminal.

Warning

`gets()` **should never be used**, because there's no way to prevent buffer overflows. Use `fgets()` instead.

Multiple Files Example

This copies “input.txt” to “output.txt”, inserting dashes:

```
FILE *inFile = fopen("input.txt", "r");
FILE *outFile = fopen("output.txt", "w");
int ch;
... /* Error checking */
do {
    ch = fgetc(inFile);
    if(ch != EOF) {
        fputc((char)ch, outFile);
        fputc('-', outFile);
    }
} while(ch != EOF);
... /* More error checking */
fclose(inFile);
fclose(outFile);
```

Flushing — `fflush()`

- An output stream can be flushed with `fflush()`.
- This may be useful in programs that run for a very long time:
  - number crunching
  - event logging
  - databases
- Flushing an output stream can help prevent data loss (if the program, OS or computer crashes).

Binary files

- Many files are not human-readable — these are often called "binary" files. . .
  - . . . even though all data in computing is binary!
- All files are made up of bytes — 8-bit integers.
- In a text file, bytes represent characters — printable symbols. Characters in turn form words, numbers, etc.
- In a binary file, bytes *directly* represent integers, real numbers, etc. They do not (generally) represent characters.

Binary file formats

- There are no words, lines or paragraphs in a binary file.
- Each data item occupies a fixed number of bytes.
- `int`s, `double`s, etc. are stored as they would be in memory.
  - A 32-bit `int` always occupies 32 bits, i.e. 4 bytes (remember `sizeof`?).
  - Compare this to text files, where a 32-bit `int` could be 1 byte (e.g. "2") or 10 bytes (e.g. "2000000000").
- Due to fixed sizes, there are no spaces or other delimiters around data items — no need to separate them.
- This makes it impossible to distinguish between them, unless you know the precise format in advance.

Reading and Writing Binary Data

- The `fread()` and `fwrite()` functions deal with binary data.
- (Under Windows, you'll need the `"rb"` or `"wb"` modes.)
- When writing to a binary file, no conversion is done.
  - Before writing the `int` 123 to a text file, it must be converted to the string `"123"` (i.e. a sequence of digit characters).

Writing binary data — `fwrite()`

- Writes an array of data (of any type).
- Takes four parameters:
  - `void*` — a pointer to the data to write.
  - `int` — the size of each data element to write.
  - `int` — the total number of elements to write.
  - `FILE*` — an output stream.

```
#define LENGTH 5
...
int data[LENGTH] = {10, 20, 30, 40, 50};
FILE* f = fopen("output.txt", "wb");
...
fwrite(data, sizeof(int), LENGTH, f);
```

(Note: "`sizeof(int)`" gives you the number of bytes in an `int`.)

Reading binary data — `fread()`

- Reads an array of data (of any type).
- Takes the same four parameters as `fwrite()`:
  - `void*` — a pointer to an array to read into.
  - `int` — the size of each data element to read.
  - `int` — the *maximum* number of elements to read.
  - `FILE*` — an input stream.
- Returns the number of elements *actually* read (like `fscanf`).

```
#define MAXLEN 5
...
int data[MAXLEN], length;
FILE* f = fopen("input.txt", "rb");
...
length = fread(data, sizeof(int), MAXLEN, f);
if(length < MAXLEN) ... /* EOF, error or success? */
```

Seeking — fseek()

- Can position the FILE pointer anywhere in the file.
- Mostly useful with binary files — you know where something ought to be.
- Can be used in three ways:
  - Move the file pointer f to 15 bytes after the start of the file:

    ```
    fseek(f, 15, SEEK_SET);
    ```

  - Moves the file pointer f 15 bytes back from its current location:

    ```
    fseek(f, -15, SEEK_CUR);
    ```

  - Moves the file pointer f to 15 bytes before the end of the file:

    ```
    fseek(f, -15, SEEK_END);
    ```

Seeking — `rewind()` and `ftell()`

`rewind()`

- Resets the `FILE` pointer to the start of the file.
- This may be useful when you need to read a file multiple times.
- `rewind(f)` is equivalent to `fseek(f, 0, SEEK_SET)`.

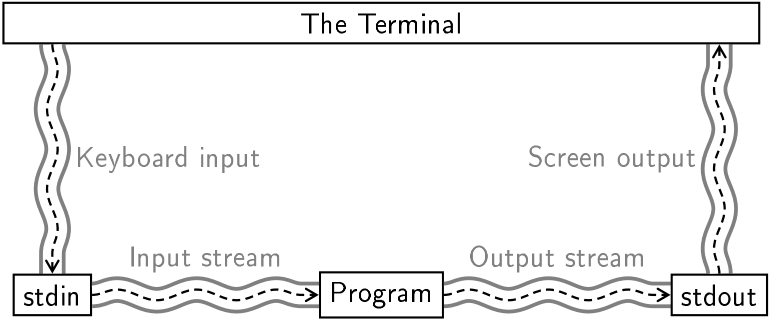
`ftell()`

- Reports the current location within a file.
- Takes a `FILE*`.
- Returns the location as a `long` (indicating the number of bytes from the start of the file).

Standard Streams

- Not all streams are connected to a file
- In C, there are three special, pre-defined `FILE` pointers:
  - `stdin` (“standard input”) — reads from the terminal
  - `stdout` (“standard output”) — writes to the terminal
  - `stderr` (“standard error”) — also writes to the terminal
- These do not need to be opened or closed.
- `fprintf(stdout, ...)` is equivalent to `printf(...)`
- `fscanf(stdin, ...)` is equivalent to `scanf(...)`

Standard Streams — Visualisation



- To the program, stdin and stdout look like ordinary files…
- …except they're actually connected to the terminal, not to the disk.

Redirection

- The UNIX shell (sh, csh, bash, etc.) can "redirect" the standard streams — most commonly `stdin` and `stdout`:
- Say you normally run "`program`" with parameters "`...`":

```
[user@pc]$ ./program ...
```

- Standard output can be redirected to a file, instead of the terminal:

```
[user@pc]$ ./program ... >output.txt
```

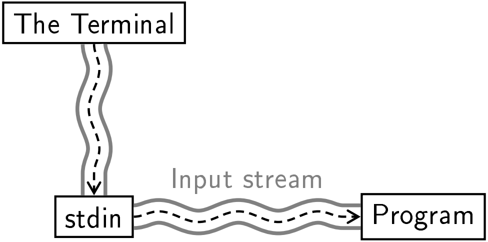
- Standard input can be redirected so that it comes from a file:

```
[user@pc]$ ./program ... <input.txt
```

- You can also do both at once:

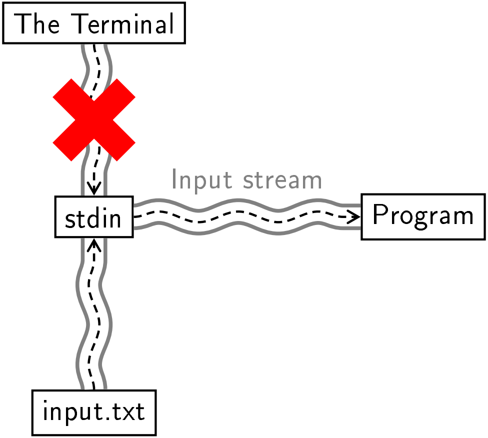
```
[user@pc]$ ./program ... <input.txt >output.txt
```

Redirecting Stdin — Visualisation



- This is standard input, *un*redirected (i.e. as normal)

Redirecting Stdin — Visualisation



- Stdin has been redirected from the terminal to input.txt
- The program doesn't know that stdin has changed

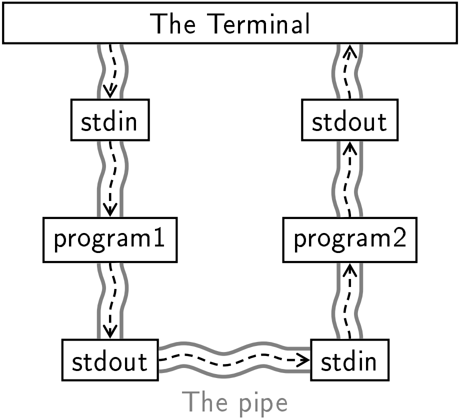
Piping

- Piping is a special form of redirection.
- The UNIX shell can "pipe" the output of one program to the input of another.
- On the command-line:

```
[user@pc]$ ./program1 ...  | ./program2 ...
```

(The "|" symbol is called the "pipe" character.)
- This will cause both `program1` and `program2` to run simultaneously
- Whatever `program1` outputs (e.g. with `printf()`), `program2` can read in (e.g. with `scanf()`)
- Most UNIX commands are designed with this in mind.

Piping — Visualisation



- Program1 sends data to program2 via the pipe
- Neither program (necessarily) realises this is happening

Coming Up

- The next lecture will look at `structs` and linked lists.