Computer Programming

File I/O. Preprocessor Macros

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Files and streams

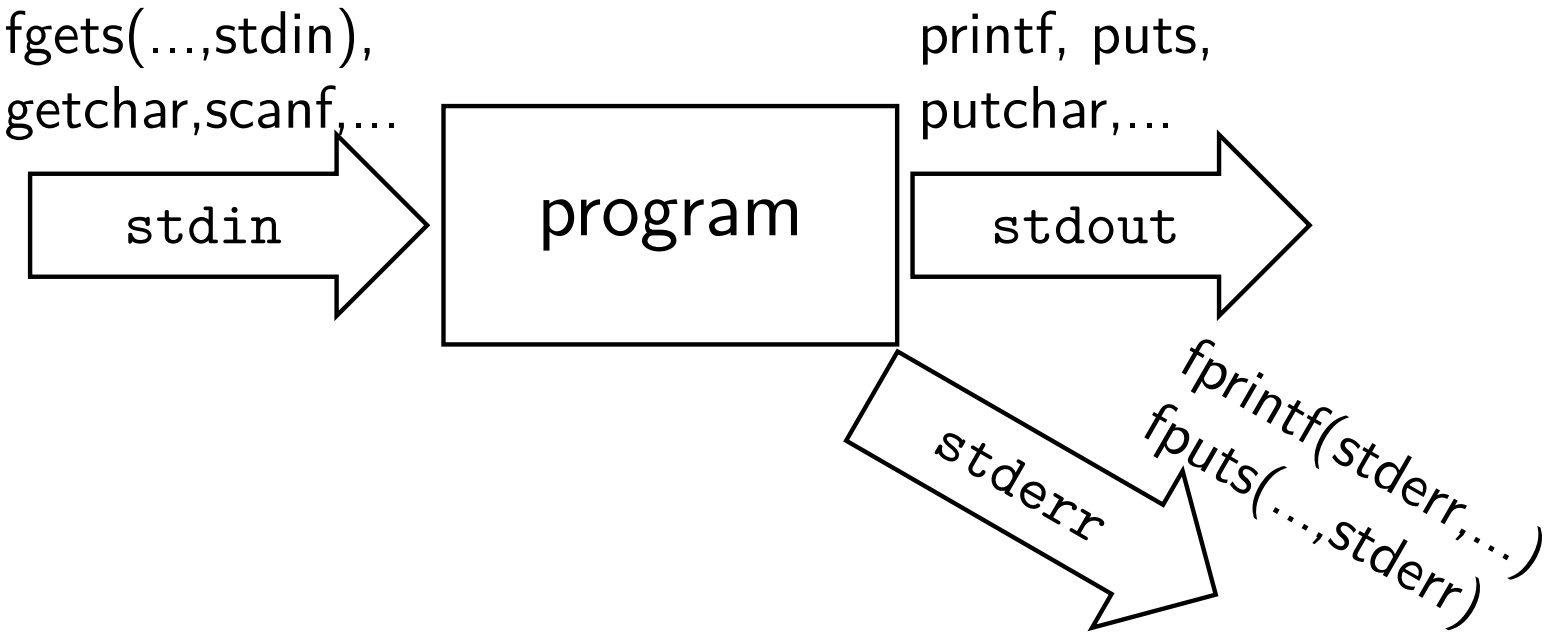
A *file* is a data resource on persistent storage (e.g. disk).
File contents are typically sequences of bytes.

A *stream* is a program's view (logical view) of a file, also as sequence of characters (bytes). character = byte

a communication "channel" between program and outside world

So far, we've used *standard input*, *output*, and *error* streams.

Input and output so far



`stdin` default: from keyboard

`stdout` default: to screen

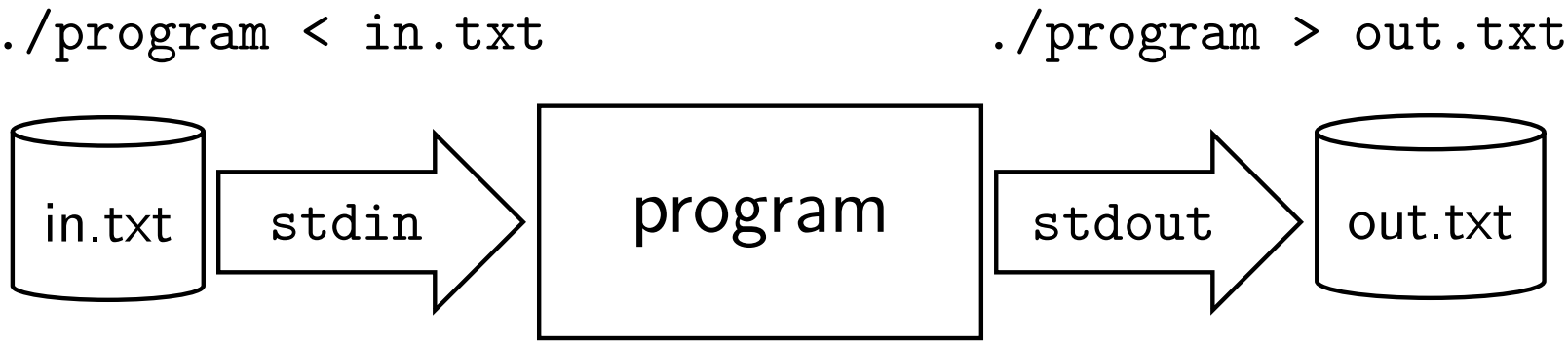
`stderr` default: to screen

all three have type `FILE *`

different logical purpose (results vs. errors)

These *streams* are automatically open when program runs

Input/output redirection

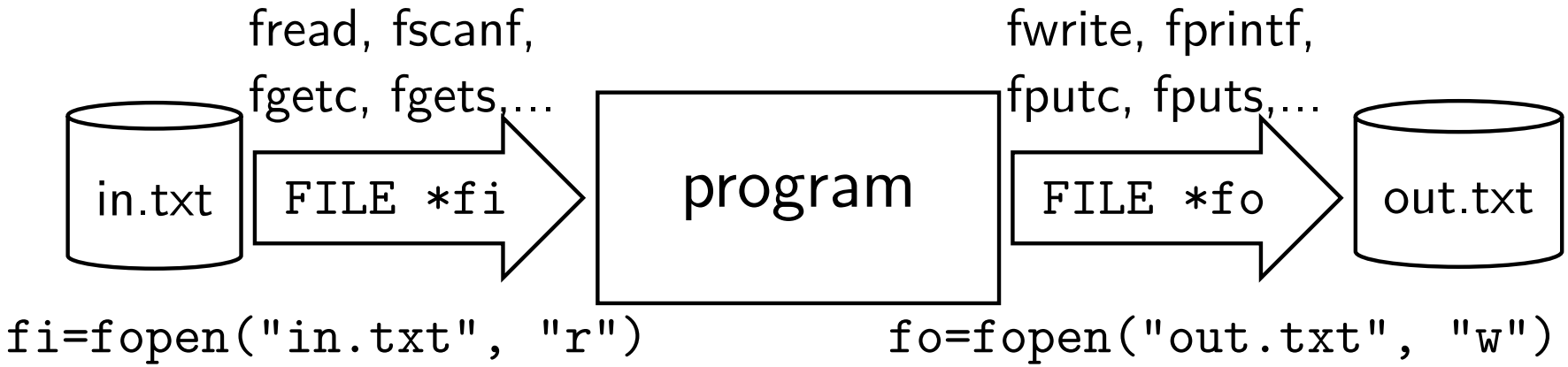


Can *redirect* standard streams to files *from command line*:
$\Rightarrow$ without change, programs doing "usual" I/O work with files!

input:	`program < in.txt`	will read from `in.txt`
output:	`program > out.txt`	will write to `out.txt`
both:	`program < in.txt > out.txt`	
stderr:	`program 2> err.txt`	(2 is stderr descriptor)

Remember: can run command from C with `system` (`stdlib.h`)

Working with files from C



To work with files, a program must

1. associate a stream with a file, by *opening* the file.
   C uses the type `FILE *` to represent streams
2. work with the stream (`FILE *`) just like with `stdin` / `stdout`
   using the *same or similar functions* from `stdio.h`
3. *close* the file

That's all we need to work with files!

Simple: show contents of text file

File name is 1st commandline argument (check that argc is 2)

```
#include <stdio.h>

int main(int argc, char *argv[]) {
  FILE *f;
  char buf[80];
  if (argc == 2 && (f = fopen(argv[1], "r"))) {
    while (fgets(buf, sizeof(buf), f)) fputs(buf, stdout);
    fclose(f);
  } // else report error
}
```

Text and binary streams

Text files are files with human-readable content:
`.txt` files, programs `.c`, `.c++`, web pages `.html`, `.xml` files, etc.

Text streams contain *characters* grouped in *lines* terminated by `\n`

Conversions may occur in reading/writing text streams.
e.g. *end of line* is `\r\n` in Windows vs. `\n` in Unix
C standard guarantees one-to-one correspondence if:
- text contains only printable chars, tab and newline
- no newline is immediately preceded by spaces
- last character is a newline

Binary files are not human-readable as character sequences:
`.exe`, `.mp3`, though they may contain text: `.doc`, `.pdf`

Binary streams record data as-is .
The sequence of characters read is *exactly the same* as was written

$\Rightarrow$ Any file (including text) may be opened as binary stream

File opening modes

`r`: open for reading (file must exist)
`w`: open for writing (truncated to length 0 if existing, else created)
`a`: open for appending (writing at end of file; created if inexistent)
any writes go to *current* end-of-file, regardless of using `fseek`

First character (`r`, `w`, `a`) of opening mode may be followed by:
`+` (`r+`, `w+`, `a+`): open as stated, but can use for input *and* output
to write after a read, *must* set position (`fseek`), unless `EOF`
to read after a write, *must* set position (`fseek`) or `fflush`
`a+`: initial read position implementation-defined (glibc: at start)

`b`: opens binary file (otherwise: text; no explicit text mode)

`x`: (eXclusive) may be last char *only* in `w` mode
file must not exist; no shared access allowed (if system support)

Examples: `rb+` (read/write, binary), `wx`, `wb+x`, `a+x`, etc.

Opening and closing files

```
FILE *fopen (const char *pathname, const char *mode)
```

arg. 1: *file name* (absolute or relative to current directory)

arg. 2: *string* with *open mode*: `r`, `w`, or `a`; optionally `+`, `b`, `x`

```
FILE *f1 = fopen("/home/u/t.txt", "r"); // fixed name, avoid
FILE *f2 = fopen(argv[2], "w"); // 2nd arg, check argc>=3 first
```

```
char name[128];              // read name from input, uncommon
if (scanf("%127s", name) == 1) {
  FILE *f = fopen(name, "ab+"); // open binary, append+read
  if (!f) { /* not opened, handle error */ }
}
```

Returns a `FILE *` (a stream) used by *all other functions*

returns `NULL` on error (*MUST test!*)

```
int fclose(FILE *stream)
```

Writes any buffered data to disk, closes file

Returns 0 on success, `EOF` on error. *SHOULD also test!*

(tell user if save of precious data failed!)

File input/output

character-based

```
int fputc(int c, FILE *stream) // write char to file; also putc
int fgetc(FILE *stream) // read char from file; also getc
int ungetc(int c, FILE *stream) // puts ONE char back in stream
```

line-based (one text line)

```
int fputs(const char *s, FILE *stream) // writes string as is
int puts(const char *s) // writes string + \n to stdout
char *fgets(char *s, int size, FILE *stream)
// reads line into s, max. size-1 chars incl. \n, adds \0
```

formatted I/O (same as `printf/scanf`, from file in first arg)

```
int fscanf (FILE *stream, const char *format, ...)
int fprintf(FILE *stream, const char *format, ...)
```

Working with files

Typical sequence for working with files (name on command line)

```c
#include <errno.h>
#include <stdio.h>
int main(int argc, char *argv[])
{
  if (argc != 2) {
    fprintf(stderr, "correct usage: program filename\n");
    return 1;  // or some other error code
  }
  FILE *fp = fopen(argv[1], "r"); // or some other mode
  if (!fp) { perror("error on open"); return errno; }

  // use file: getc, fscanf, fgets, fprintf, etc.

  if (fclose(fp)) { perror("error on close"); return errno; }
  return 0;
}
```

Error functions

`int feof(FILE *stream)` nonzero if at `EOF`

`int ferror(FILE *stream)` nonzero if file had errors

Do *NOT* loop while ~~`!feof(f)`~~ :

`EOF` is *NOT detected* when *at* end, only when trying to read *past* it

$\Rightarrow$ loop *while read OK*; if not, check `feof(f)` or `ferror(f)`

Error codes

`int errno` global variable declared in `errno.h`

contains code of last error in a library function

(illegal operation, file not found, not enough memory, etc.)

`void perror(const char *s)` function from `stdio.h`

prints user message `s`, a colon `:` and then the error description

(same as given by `char *strerror(int errnum)` from `string.h`)

Direct I/O (binary format)

Read/write bytes as-is, without conversion, from/to binary streams

```
size_t fread(void *ptr, size_t size, size_t nmemb, FILE *strm)
size_t fwrite(void *ptr, size_t size, size_t nmemb, FILE *strm)
```

read/write to/from address `ptr` `nmemb` objects of `size` bytes each
just like repeated calls to `fgetc`/`fputc`

Return value: *number* of *complete* objects read/written
If smaller than requested, find reason from `feof` and `ferror`

Use `fread`/`fwrite` if *byte order* same in memory and in file
(as specified in docs for file format: `.bmp`, `.jpg`, `.zip` etc.)

big endian, most significant byte first: `0xcafebabe`=`0xca` `0xfe` `0xba` `0xbe`
little endian, least significant byte first: Intel x86 (`0xbe` `0xba` `0xfe` `0xca`)

Otherwise, read/write number byte by byte, (de)compose in needed order

File positioning

Reading and writing use the same *file position indicator*

`long ftell(FILE *stream)` returns position from start of file

`int fseek(FILE *stream, long offset, int whence)`
Sets file position indicator to `offset`; 3rd arg is reference point:
start (`SEEK_SET`), current point (`SEEK_CUR`), end(`SEEK_END`)

`void rewind(FILE *stream)` sets file position indicator to start
same as `fseek(stream, 0L, SEEK_SET); clearerr(stream);`

Use (re)positioning to skip parts of the file on reading,
or to write a selected part

MUST use `fseek`/`fflush` when switching between read and write!

Positioning may not be possible in any file (e.g. `stdin/stdout`)

`int fflush(FILE *stream)`
writes unwritten data buffers for the given file

Chars, ints and EOF revisited

Files (and standard input) contain *bytes (chars)*

`EOF` is NOT a char (the *point* is to distinguish it from any char!)

- chars read by `getchar` or `getc` are **`unsigned`**, `EOF` is `-1`
- variable read w/ `getchar`/`getc` must be **`int`** so it can fit either

`scanf`, `fgets`, `fread` read arrays of *bytes (chars)*

- need no **`int`**, since they report end-of-file differently
- `EOF` can never be in an array read (since it's *NOT a char*)

*Don't mix **`signed`** and **`unsigned`**!* **`char`** *may* be signed

If reading char as **`int`**, compare to an int: `0xFF`, `0xDA`, etc.

- or if declaring `unsigned char buf[]`

If declared as **`char`**, compare with a char: `'\xff'`, `'\xda'`, etc.

C preprocessor: Macros

Preprocessing is done *before* actual compilation: `cpp` or `gcc -E`

object-like macro

```
#define NAME      replacement
#define LEN       20
```

function-like macro

```
#define NAME(arg1,...,argn)   replacement
#define MAX(a,b)          ((a)>(b)?a:b)
#define NAME(arg1,arg2,...)   replacement
```

can use `VA_ARGS` to refer to extra arguments

symbol witout value: used in conditional compilation

```
#define   NEEDS_MATH_H
#undef    SOME_DEFINED_NAME // undefine a defined macro
```

More about macros

Macros are NOT ~~variables~~. The are like find-replace in a text, actual compiler never sees macros, just code after replacement.

CAREFUL with macros!

Place args *and* body in parantheses (avoid precedence errors)

```
#define SQR(a)          ((a)*(a))
```

code might have: `~SQR(2+3)` `~((2+3)*(2+3))`

all sets of parantheses are needed now!

Don't use macros with side-effects if arg evaluated twice:

```
#define MAX(x,y)        ((x) > (y) ? (x) : (y))
```

BAD use: ~~`MAX(++a,b)`~~

Advanced macros: from tokens to strings

In macro replacements:

`# arg` produces string literal for tokens represented by `arg`

`x ## y` produces string concatenation of tokens for `x` and `y`

```
#define STR(s)          #s
#define STRSUB(s)       STR(s)
#define JOIN(x,y)       x ## y
#define SFMT(m)         STRSUB(JOIN(%m,s))
#define MAX             32

scanf(SFMT(MAX), s);  // scanf("%32s", s); stepwise:

SFMT(32)
STRSUB(JOIN(%32,s))
STR(%32s)
"%32s"
```

Conditional compilation

C preprocessor supports conditionals, using *constant* expressions
only the corresponding branch of the code will be compiled

```
// convert from byte buffer (least significant first) to int
#if __BYTE_ORDER__ == __ORDER_BIG_ENDIAN__
// if both symbols are #define'd and their value is equal
// compile code for big-endian architectures
uint16_t x = b[0] | b[1] << 8; // different order
#else
// code for little-endian architecures
uint16_t x = *(uint16_t *)b; // same order
#endif
```

also: `#elif` meaning else if ...

`#ifdef NAME`	if `NAME` is defined
`#ifndef NAME`	if `NAME` is not defined

Header file inclusion and conditional compilation

header file inclusion

`#include <file.h>` search in system directories

`#include "file.h"` search current dir first, then system

conditional compilation: e.g. to avoid multiple inclusion

```
#ifndef _MYHEADER_H
#define _MYHEADER_H
// contents will not be compiled twice even if included twice
#endif
```