

Input/Output and Standard C Library

Jan Faigl

Department of Computer Science

Faculty of Electrical Engineering

Czech Technical University in Prague

Lecture 06

B3B36PRG – C Programming Language



Overview of the Lecture

■ Part 1 – Input and Output

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O

K. N. King: chapters 22

■ Part 2 – Selected Standard Libraries

Standard library – Selected Functions

Error Handling

K. N. King: chapters 21, 23, 24, 26, and 27



Part I

Input and Output



Text vs Binary Files

- There is not significant difference between text and binary files from the machine processing perspective
- Text files are oriented to be a human readable
 - In text files, bytes represent characters
 - The content is usually organized into lines
 - Different markers for the *end-of-line* are used (1 or 2 bytes)
 - There can be a special marker for the *end-of-file* (Ctrl-Z)
It is from CP/M and later used in DOS. It is not widely used in Unix like systems.
 - For parsing text files, we can use
 - Character oriented functions – `putchar()`, `getchar()`, `putc()`, `getc()`
 - Functions for formatted i/o – `printf()` and `scanf()` as shortcuts for the `fprintf()` and `fscanf()` with the `stdin` and `stdout` streams
 - Line oriented functions – `puts()`, `gets()` and variants `fputs()`, `fgets()`
- Text files can be considered as a sequence of bytes
 - Numeric values as text need to be parsed and formatted in writing
- Numbers in binary files may deal with byte ordering

E.g., ARM vs x86



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



File open

- Functions for input/output are defined in the standard library `<stdio.h>`
- The file access is through using a pointer to a file (stream) `FILE*`
- File can be opened using `fopen()`

`FILE* fopen(const char * restrict path, const char * restrict mode);`

Notice, the restrict keyword

- Operations with the files are
 - Stream oriented – sequential reading/writing
 - The **current position in the file is like a cursor**
 - At the opening the file, the cursor is set to the beginning of the file
- The mode of the file operations is specified in the `mode` parameter
 - `"r"` – reading from the file
 - The program (user) needs to have sufficient rights for reading from the file.*
 - `"w"` – writing to the file
 - A new file is created if it does not exist; otherwise the content of the file is cleared.*
 - `"a"` – append to the file – the cursor is set to the end of the file
 - The modes can be combined, e.g., `"r+"` open the file for reading and writing

See [man fopen](#)



fopen(), fclose(), and feof()

- Test the file has been opened

```
1 char *fname = "file.txt";
2
3 if ((f = fopen(fname, "r")) == NULL) {
4     fprintf(stderr, "Error: open file '%s'\n", fname);
5 }
```

- Close file – `int fclose(FILE *stream);`

```
1 if (fclose(f) == EOF) {
2     fprintf(stderr, "Error: close file '%s'\n", fname);
3 }
```

- Test of reaching the end-of-file (EOF) – `int feof(FILE *stream);`



File Positioning

- Every stream has the cursor, i.e., an associated file position
- The position can be set using `offset` relatively to `whence`
- `int fseek(FILE *stream, long offset, int whence);`
where `whence`
 - `SEEK_SET` – set the position from the beginning of file
 - `SEEK_CUR` – relatively to the current file position
 - `SEEK_END` – relatively to the end of file

If the position is successfully set, `fseek()` returns 0

- `void rewind(FILE *stream);` sets the position to the beginning of file
- The position can be stored and set by the functions
`int fgetpos(FILE * restrict stream, fpos_t * restrict pos);`
`int fsetpos(FILE *stream, const fpos_t *pos);`

See [man fseek](#), [man rewind](#), etc



File Stream Modes

- Modes in the `fopen()` can be combined

FILE* `fopen(const char * restrict path, const char * restrict mode);`

- `"r"` open for reading
 - `"w"` Open for writing (file is created if it does not exist)
 - `"a"` open for appending (set cursor to the end of file or create a new file if it does not exists)
 - `"r+"` open for reading and writing (starts at beginning)
 - `"w+"` open for reading and writing (truncate if file exists)
 - `"a+"` open for reading and writing (append if file exists)
- There are restrictions for the combined modes with `"+"`
 - We cannot switch from reading to writing without calling a file-positioning function or reaching the end of file
 - We cannot switch from writing to reading without calling `fflush()` or calling a file-positioning function.



Temporary Files

- `FILE* tmpfile(void);` – creates a temporary file that exists until it is closed or the program exists
- `char* tmpnam(char *s);` – generates a name for a temporary file
 - If `s` is `NULL`, it creates a name and store it in a static variable and return a pointer to it
 - Otherwise it copies the string into the provided character array (`s`) and returns the pointer to the first character of the array



File Buffering

- `int fflush(FILE *stream);` – flushes buffer for the given `stream`
 - `fflush(NULL);` – flushes all buffers (all output streams)
- Change the buffering mode, size, and location of the buffer
`int setvbuf(FILE * restrict stream, char * restrict buf, int mode, size_t size);`

The `mode` can be one of the following macros

`_IOFBF` – full buffering. Data are read from the stream when buffer is empty and written to the stream when it is full

`_IOLBF` – line buffering. Data are read or written from/to the stream one line at a time

`_IONBF` – no buffer. Direct reading and writing without buffer

```
#define BUFFER_SIZE 512
char buffer[BUFFER_SIZE];
```

```
setvbuf(stream, buffer, _IOFBF, BUFFER_SIZE);
```

- `void setbuf(FILE * restrict stream, char * restrict buf);`
– similar to `setvbuf()` but with default mode



Detecting End-of-File and Error Conditions

- Three possible errors can occur during reading data (e.g., `fscanf`)
 - **End-of-file** – we reach the end of file

Or, the stream is closed, e.g., `stdin`
 - **Read error** – the read function is unable to read data from the stream
 - **Matching failure** – the read data does not match the requested format
- Each stream (`FILE*`) has two indicators:
 - **error indicator** – indicates that a read or write error occurs
 - **end-of-file indicator** – is set when the end of file is reached
- The indicators can be read (tested if the indicator is set or not) and clear the error and eof indicators
 - `int ferror(FILE *stream);`
 - `void clearerr(FILE *stream);`
 - `int feof(FILE *stream);`



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



Reading and Writing Single Byte

- Basic function for reading from `stdin` and `stdout` are
 - `getchar()` and `putchar()`
 - Both function return `int` value, to indicate an error (`EOF`)
 - The written and read values are converted to `unsigned char`
- The variants of the function for the specific stream are
 - `int getc(FILE *stream);` and `int putc(int c, FILE *stream);`
 - `getchar()` is equivalent to `getc(stdin)`
 - `putchar()` is equivalent to `putc()` with the `stdout` stream
- Reading byte-by-byte (`unsigned char`) can be also used to read binary data, e.g., to construct 4 bytes length `int` from the four byte (`char`) values



Example – Copy using `getc()` and `putc()` 1/2

- Simple copy program based on reading bytes from `stdin` and writing them to `stdout`

```
1 int c;
2 int bytes = 0;
3 while ((c = getc(stdin)) != EOF) {
4     if (putc(c, stdout) == EOF) {
5         fprintf(stderr, "Error in putc");
6         break;
7     }
8     bytes += 1;
9 }
```

`lec06/copy-getc_putc.c`



Example – Copy using `getc()` and `putc()` 2/2

- We can count the number of bytes and need time to copy the bytes

```
1  #include <sys/time.h>
2  ...
3
4  struct timeval t1, t2;
5  gettimeofday(&t1, NULL);
6
7  ... // copy the stdin -> stdout
8
9  gettimeofday(&t2, NULL);
10 double dt = t2.tv_sec - t1.tv_sec + ((t2.tv_usec - t1.
      tv_usec) / 1000000.0);
11 double mb = bytes / (1024 * 1024);
12 fprintf(stderr, "%.21f MB/sec\n", mb / dt);  lec06/copy-getc_putc.c
```

- Example of creating random file and using the program

```
clang -O2 copy-getc_putc.c
dd bs=512m count=1 if=/dev/random of=/tmp/rand1.dat
1+0 records in
1+0 records out
536870912 bytes transferred in 7.897227 secs (67982205 bytes/sec)
./a.out < /tmp/rand1.dat >/tmp/rand2.dat
326.10 MB/sec
```



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



Line Oriented I/O

- A whole (text) line get be read by

```
char* gets(char *str);
```

```
char* fgets(char * restrict str, int size, FILE * restrict stream);
```

- `gets()` cannot be used securely due to lack of bounds checking
- A line can be written by `fputs()` an `puts()`
- `puts()` write the given string and a **newline character** to the `stdout` stream
- `puts()` and `fputs()` return a non-negative integer on success and **EOF** on error

See [man fgets](#), [man fputs](#)



Formatted I/O – fscanf()

- `int fscanf(FILE *file, const char *format, ...);`
- It return number of read items, e.g., for the input
record 1 13.4
- The statement `int r = fscanf(f, "%s %d %lf\n", str, &i, &d);`
- sets (in the case of success) the variable `r` to the value 3
`r == 3`
- For reading strings, it is necessary to respect the size of the allocated memory, e.g., by using the limited length of the read string
`char str[10];`
`int r = fscanf(f, "%9s %d %lf\n", str, &i, &d);`

`lec06/file_scanf.c`



Formatted I/O – fprintf()

■ `int fprintf(FILE *file, const *format, ...);`

```
int main(int argc, char *argv[])
{
    char *fname = argc > 1 ? argv[1] : "out.txt";
    FILE *f;
    if ((f = fopen(fname, "w")) == NULL) {
        fprintf(stderr, "Error: Open file '%s'\n", fname);
        return -1;
    }
    fprintf(f, "Program arguments argc: %d\n", argc);
    for (int i = 0; i < argc; ++i) {
        fprintf(f, "argv[%d]='%s'\n", i, argv[i]);
    }
    if (fclose(f) == EOF) {
        fprintf(stderr, "Error: Close file '%s'\n", fname);
        return -1;
    }
    return 0;
}
```

lec06/file_printf.c



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



Block Read/Write

- We can use `fread()` and `fwrite()` to read/write a block of data

```
size_t fread(void * restrict ptr,  
             size_t size, size_t nmemb,  
             FILE * restrict stream);
```

```
size_t fwrite(const void * restrict ptr,  
             size_t size, size_t nmemb,  
             FILE * restrict stream);
```

Use `const` to indicate (`ptr`) is used only for reading



Block Read/Write – Example 1/4

- Program to read/write a given (as `#define BSIZE`) number of `int` values using `#define BUFSIZE` length buffer
- Writing is enabled by the optional program argument `-w`
- File for reading/writing is a mandatory program argument

```
1  #include <stdio.h>
2  #include <string.h>
3  #include <errno.h>
4  #include <assert.h>
5  #include <stdbool.h>
6  #include <stdlib.h>
7
8  #include <sys/time.h>
9
10 #ifndef BUFSIZE
11 #define BUFSIZE 32768
12 #endif
13
14 #ifndef BSIZE
15 #define BSIZE 4098
16 #endif
17
17 int main(int argc, char *argv[])
18 {
19     int c = 0;
20     _Bool read = true;
21     const char *fname = NULL;
22     FILE *file;
23     const char *mode = "r";
24     while (argc-- > 1) {
25         fprintf(stderr, "DEBUG: argc: %d '%s'\n", argc, argv[argc]);
26         if (strcmp(argv[argc], "-w") == 0) {
27             fprintf(stderr, "DEBUG: enable writing\n");
28             read = false; // enable writing
29             mode = "w";
30         } else {
31             fname = argv[argc];
32         }
33     } // end while
```

lec06/demo-block_io.c



Block Read/Write – Example 2/4

```
34 file = fopen(fname, mode);
35 if (!file) {
36     fprintf(stderr, "ERROR: Cannot open file '%s', error %d - %s\n", fname, errno, strerror(errno));
37     return -1;
38 }
39 int *data = (int*)malloc(BSIZE * sizeof(int));
40 assert(data);
41 struct timeval t1, t2;
42 gettimeofday(&t1, NULL);
43 if (read) {                                     /* READ FILE */
44     fprintf(stderr, "INFO: Read from the file '%s'\n", fname);
45     c = fread(data, sizeof(int), BSIZE, file);
46     if (c != BSIZE) {
47         fprintf(stderr, "WARN: Read only %i objects (int)\n", c);
48     } else {
49         fprintf(stderr, "DEBUG: Read %i objects (int)\n", c);
50     }
51 } else {                                         /* WRITE FILE */
52     char buffer[BUFSIZE];
53     if (setvbuf(file, buffer, _IOFBF, BUFSIZE)) { /* SET BUFFER */
54         fprintf(stderr, "WARN: Cannot set buffer");
55     }
56     fprintf(stderr, "INFO: Write to the file '%s'\n", fname);
57     c = fwrite(data, sizeof(int), BSIZE, file);
58     if (c != BSIZE) {
59         fprintf(stderr, "WARN: Write only %i objects (int)\n", c);
60     } else {
61         fprintf(stderr, "DEBUG: Write %i objects (int)\n", c);
62     }
63     fflush(file);
64 }
65 gettimeofday(&t2, NULL);
```

lec06/demo-block_io.c



Block Read/Write – Example 3/4

```

66 double dt = t2.tv_sec - t1.tv_sec + ((t2.tv_usec - t1.tv_usec) / 1000000.0);
67 double mb = (sizeof(int) * c) / (1024 * 1024);
68 fprintf(stderr, "DEBUG: feof: %i ferror: %i\n", feof(file), ferror(file));
69 fprintf(stderr, "INFO: %s %lu MB\n", (read ? "read" : "write"), sizeof(int)*BSIZE/(1024 * 1024));
70 fprintf(stderr, "INFO: %.2lf MB/sec\n", mb / dt);
71 free(data);
72 return EXIT_SUCCESS;
73 }

```

- Default `BUFSIZE` (32 kB) to write/read 10^8 integer values (~480 MB)

```
clang -DBSIZE=100000000 demo-block_io.c && ./a.out -w a 2>&1 | grep INFO
```

```
INFO: Write to the file 'a'
```

```
INFO: write 381 MB
```

```
INFO: 10.78 MB/sec
```

```
./a.out a 2>&1 | grep INFO
```

```
INFO: Read from the file 'a'
```

```
INFO: read 381 MB
```

```
INFO: 1683.03 MB/sec
```

- Try to read more elements results in `feof()`, but not in `ferror()`

```
clang -DBSIZE=200000000 demo-block_io.c && ./a.out a
```

```
DEBUG: argc: 1 'a'
```

```
INFO: Read from the file 'a'
```

```
WARN: Read only 100000000 objects (int)
```

```
DEBUG: feof: 1 ferror: 0
```

```
INFO: read 762 MB
```

```
INFO: 1623.18 MB/sec
```

lec06/demo-block_io.c



Block Read/Write – Example 4/4

- Increased write buffer `BUFSIZE` (128 MB) improves writing performance

```
clang -DBSIZE=100000000 -DBUFSIZE=134217728 demo-block_io.c && ./a.out -w aa 2>&1 | grep INFO
INFO: Write to the file 'aa'
INFO: write 381 MB
INFO: 325.51 MB/sec
```

- But does not improve reading performance, which relies on the standard size of the buffer

```
clang -DBSIZE=100000000 -DBUFSIZE=134217728 demo-block_io.c && ./a.out aa 2>&1 | grep INFO
INFO: Read from the file 'aa'
INFO: read 381 MB
INFO: 1693.39 MB/sec
```

`lec06/demo-block_io.c`



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



Blocking and Non-Blocking I/O Operations

- Usually I/O operations are considered as **blocking requested**
 - System call does not return control to the application until the requested I/O is completed
 - It is motivated that we need all the requested data and I/O operations are usually slower than the other parts of the program.
We have to wait for the data anyway
 - It is also called **synchronous** programming
- **Non-Blocking** system calls do not wait for unrelated I/O to complete, and thus do not block the application
 - It is suitable for network programming, multiple clients, graphical user interface, or when we need to avoid “deadlock” or too long waiting due to slow or not reliable communication
 - Call for reading requested data will read (and “return”) only data that are actually available in the input buffer
- **Asynchronous** programming with **non-blocking** calls
 - Return control to the application immediately
 - Data are transferred to/from buffer “on the background”

Call back, triggering a signal, etc.



Non-Blocking I/O Operations – Example

- Setting the file stream (file descriptor) to the `O_NONBLOCK` mode

Also for socket descriptor

- For reading from regular files it does not too much sense to use non-blocking operations
- Reading from block devices such as serial port, e.g., `/dev/ttyS10` may be more suitable
 - We can set `O_NONBLOCK` flag for a file descriptor using `fcntl()`

```
#include <fcntl.h> // POSIX
```

```
// open file by the open() system call that return a file descriptor  
int fd = open("/dev/ttyUSB0", O_RDWR, S_IRUSR | S_IWUSR);
```

```
// read the current settings first  
int flags = fcntl(fd, F_GETFL, 0);
```

```
// then, set the O_NONBLOCK flag  
fcntl(fd, F_SETFL, flags | O_NONBLOCK);
```

- Then, calling `read()` will provide the requested number of bytes are fewer bytes that are currently available in the buffer



Outline

File Operations

Character Oriented I/O

Text Files

Block Oriented I/O

Non-Blocking I/O

Terminal I/O



Key Press without Enter

- Reading character from `stdin` can be made by the `getchar()` function
- However, the input is buffered to read line, i.e., it is necessary to press Enter key by default
- We can avoid that by setting the terminal to a `raw` mode

```
#include <stdio.h>
#include <ctype.h>

int c;
while ((c = getchar()) != 'q') {
    if (isalpha(c)) {
        printf("Key '%c' is alphabetic;", c);
    } else if (isspace(c)) {
        printf("Key '%c' is space character;", c);
    } else if (isdigit(c)) {
        printf("Key '%c' is decimal digit;", c);
    } else if (isblank(c)) {
        printf("Key is blank;");
    } else {
        printf("Key is something else;");
    }
    printf("  ascii: %s\n",
          isascii(c) ? "true" : "false");
}
return 0;
```

lec06/demo-getchar.c



Key Press without Enter – Example

- We can switch the `stdin` to the `raw` mode using `termios`

```
void call_termios(int reset)
{
    static struct termios tio, tioOld;
    tcgetattr(STDIN_FILENO, &tio);
    if (reset) {
        tcsetattr(STDIN_FILENO, TCSANOW, &tioOld);
    } else {
        tioOld = tio; //backup
        cfmakeraw(&tio);
        tcsetattr(STDIN_FILENO, TCSANOW, &tio);
    }
}
```

- Or we can use the `stty` tool

```
void call_stty(int reset)
{
    if (reset) {
        system("stty -raw");
    } else {
        system("stty raw");
    }
}
```

- Usage `clang demo-getchar.c -o demo-getchar`

- Standard "Enter" mode: `./demo-getchar`
- Raw mode using `termios`: `./demo-getchar termios`
- Raw mode using `stty`: `./demo-getchar stty`

`lec06/demo-getchar.c`



Part II

Selected Standard Libraries



Outline

Standard library – Selected Functions

Error Handling



Standard Library

- The C programming language itself does not provide operations for input/output, more complex mathematical operations, nor:
 - string operations
 - dynamic allocation
 - run-time error handling
- These and further functions are included in the standard library that is a part of the C compiler
 - **Library** – the compiled code is linked to the program, e.g., `libc.so`
Viz e.g., `ldd a.out`
 - **Header files** contain function prototypes, types, macros, etc.

<assert.h>	<inttypes.h>	<signal.h>	<stdlib.h>
<complex.h>	<iso646.h>	<stdarg.h>	<string.h>
<ctype.h>	<limits.h>	<stdbool.h>	<tgmath.h>
<errno.h>	<locale.h>	<stddef.h>	<time.h>
<fenv.h>	<math.h>	<stdint.h>	<wchar.h>
<float.h>	<setjmp.h>	<stdio.h>	<wctype.h>



Standard library – Overview

- `<stdio.h>` – Input and output (including formatted)
- `<stdlib.h>` – Math function, dynamic memory allocation, conversion of strings to number.
 - Sorting – `qsort()`
 - Searching – `bsearch()`
 - Random numbers – `rand()`
- `<limits.h>` – Ranges of numeric types
- `<math.h>` – Math functions
- `<errno.h>` – Definition of the error values
- `<assert.h>` – Handling runtime errors

- `<ctype.h>` – character classification, e.g., see `lec06/demo-getchar.c`
- `<string.h>` – Strings and memory transfers, i.e., `memcpy()`
- `<locale.h>` – Internationalization
- `<time.h>` – Date and time



Standard Library (POSIX)

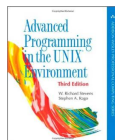
Relation to the operating system (OS)

POSIX – Portable Operating System Interface

- `<stdlib.h>` – Function calls and OS resources
- `<signal.h>` – Asynchronous events
- `<unistd.h>` – Processes , read/write files, ...
- `<pthread.h>` – Threads (POSIX Threads)
- `<threads.h>` – Standard thread library in C11



Advanced Programming in the UNIX Environment, 3rd edition, *W. Richard Stevens, Stephen A. Rago* Addison-Wesley, 2013, ISBN 978-0-321-63773-4



Mathematical Functions

- `<math.h>` – basic function for computing with “real” numbers
 - Root and power of floating point number `x`

```
double sqrt(double x);, float sqrtf(float x);
```
 - `double pow(double x, double y);` – power
 - `double atan2(double y, double x);` – *arctan* y/x with quadrant determination
 - Symbolic constants – `M_PI`, `M_PI_2`, `M_PI_4`, etc.
 - `#define M_PI 3.14159265358979323846`
 - `#define M_PI_2 1.57079632679489661923`
 - `#define M_PI_4 0.78539816339744830962`
 - `isfinite()`, `isnan()`, `isless()`, ... – comparison of “real” numbers
 - `round()`, `ceil()`, `floor()` – rounding and assignment to integer
- `<complex.h>` – function for complex numbers *ISO C99*
- `<fenv.h>` – function for control rounding and representation according to IEEE 754.



Variable Arguments <stdarg.h>

- It allows to write a function with a variable number of arguments

Similarly as in the functions `printf()` and `scanf()`

- The header file <stdarg.h> defines

- Type `va_list` and macros
- `void va_start(va_list ap, parmN);` – initiate `va_list`
- `type va_arg(va_list ap, type);` – fetch next variable
- `void va_end(va_list ap);` – cleanup before function return
- `void va_copy(va_list dest, va_list src);`

`va_copy()` has been introduced in C99

- We have to pass the number of arguments to the functions with variable number of arguments



Example – Variable Arguments <stdarg.h>

```
1  #include <stdio.h>
2  #include <stdarg.h>
3
4  int even_numbers(int n, ...);
5  int main(void)
6  {
7      printf("Number of even numbers: %i\n", even_numbers(2, 1, 2));
8      printf("Number of even numbers: %i\n", even_numbers(4, 1, 3, 4, 5));
9      printf("Number of even numbers: %i\n", even_numbers(3, 2, 4, 6));
10     return 0;
11 }
12
13 int even_numbers(int n, ...)
14 {
15     int c = 0;
16     va_list ap;
17     va_start(ap, n);
18     for (int i = 0; i < n; ++i) {
19         int v = va_arg(ap, int);
20         (v % 2 == 0) ? c += 1 : 0;
21     }
22     va_end(ap);
23     return c;
24 }
```



Outline

Standard library – Selected Functions

Error Handling



Error handling

- Basic error codes are defined in `<errno.h>`
- These codes are used in standard library as indicators that are set in the global variable `errno` in a case of an error during the function call, e.g.,
 - If file open `fopen()` fails, it returns `NULL`, which does not provide the cause of the failure
- The cause of failure can be stored in the `errno` variable
- Text description of the numeric error codes are defined in `<string.h>`
 - String can be obtain by the function

```
char* strerror(int errnum);
```



Example – errno

■ File open

```
1 #include <stdio.h>
2 #include <errno.h>
3 #include <string.h>
4
5 int main(int argc, char *argv[]) {
6     FILE *f = fopen("soubor.txt", "r");
7     if (f == NULL) {
8         int r = errno;
9         printf("Open file failed errno value %d\n", errno);
10        printf("String error '%s'\n", strerror(r));
11    }
12    return 0;
13 }
```

lec06/errno.c

■ Program output if the file does not exist

```
Open file failed errno value 2
String error 'No such file or directory'
```

■ Program output for an attempt to open a file without having sufficient access rights

```
Open file failed errno value 13
String error 'Permission denied'
```



Testing macro `assert()`

- We can add tests for particular value of the variables, for debugging
- Such test can be made by the macro `assert(expr)` from `<assert.h>`
- IF `expr` is not logical 1 (`true`) the program is terminated and the particular line and the name of the source file is printed
- Macro includes particular code to the program

It provides a relatively straightforward way to evaluate and indicate possible errors, e.g., due to a wrong function argument.

- We can disable the macro by definition of the macro `NDEBUG`

[man assert](#)

- Example

```
#include <stdio.h>
#include <assert.h>

int main(int argc, char *argv[])
{
    assert(argc > 1);
    printf("program argc: %d\n", argc);
    return 0;
}
```

[lec06/assert.c](#)



Example of `assert()` Usage

- Compile the program the `assert()` macro and executing the program with/without program argument

```
clang assert.c -o assert
./assert
Assertion failed: (argc > 1), function main, file assert.c
, line 5.
zsh: abort      ./assert
./assert 2
start argc: 2
```

- Compile the program without the macro and executing it with/without program argument

```
clang -DNDEBUG assert.c -o assert
./assert
program start argc: 1
./assert 2
program start argc: 2
```

lec06/assert.c



Long Jumps

- The `goto` statement can be used only within a function
- `<setjmp.h>` defines function `setjmp()` and `longjmp()` for jumps across functions
- `setjmp()` stores the actual state of the registers and if the function return non-zero value, the function `longjmp()` has been called
- During `longjmp()` call, the values of the registers are restored and the program continues the execution from the location of the `setjmp()` call

We can use `setjmp()` and `longjmp()` to implement handling exceptional states similarly as `try-catch`

```

1  #include <setjmp.h>
2  jmp_buf jb;
3  int compute(int x, int y);
4  void error_handler(void);
5  if (setjmp(jb) == 0) {
6      r = compute(x, y);
7      return 0;
8  } else {
9      error_handler();
10     return -1;
11 }
12 int compute(int x, int y) {
13     if (y == 0) {
14         longjmp(jb, 1);
15     } else {
16         x = (x + y * 2);
17         return (x / y);
18     }
19 }
20 void error_handler(void) {
21     printf("Error\n");
22 }
```



Communication with the Environment – <stdlib.h>

- The header file <stdlib.h> defines standard program return values `EXIT_FAILURE` and `EXIT_SUCCESS`
- A value of the environment variable get be retrieved by the `getenv()`

```
1 #include <stdio.h>
2 #include <stdlib.h>
3
4 int main(void)
5 {
6     printf("USER: %s\n", getenv("USER"));
7     printf("HOME: %s\n", getenv("HOME"));
8     return EXIT_SUCCESS;
9 }
```

lec06/demo-getenv.c

- `void exit(int status);` – the program is terminated as it will be by calling `return(status)` in the `main()` function.
- We can register a function that will be called at the program exit by the `int atexit(void (*func)(void));`
- The program can be aborted by calling `void abort(void)`, in this case, registered functions by the `atexit()` are not called



Example – atexit(), abort(), and exit()

```

1  #include <stdio.h>
2  #include <stdlib.h>
3  #include <string.h>
4
5  void cleanup(void);
6  void last_word(void);
7
8  int main(void)
9  {
10     atexit(cleanup); // register function
11     atexit(last_word); // register function
12     const char *howToExit = getenv("HOW_TO_EXIT");
13     if (howToExit && strcmp(howToExit, "EXIT") == 0) {
14         printf("Force exit\n");
15         exit(EXIT_FAILURE);
16     } else if (howToExit && strcmp(howToExit, "ABORT") == 0) {
17         printf("Force abort\n");
18         abort();
19     }
20     printf("Normal exit\n");
21     return EXIT_SUCCESS;
22 }
23
24 void cleanup(void)
25 {
26     printf("Perform cleanup at the program exit!\n");
27 }
28
29 void last_word(void)
30 {
31     printf("Bye, bye!\n");
32 }

```

■ Example of usage

```
clang demo-atexit.c -o atexit
```

```

% ./atexit; echo $?
Normal exit
Bye, bye!
Perform cleanup at the program exit!
0

% HOW_TO_EXIT=EXIT ./atexit; echo $?
Force exit
Bye, bye!
Perform cleanup at the program exit!
1

% HOW_TO_EXIT=ABORT ./atexit; echo $?
Force abort
zsh: abort HOW_TO_EXIT=ABORT ./atexit
134

```

lec06/demo-atexit.c



Summary of the Lecture



Topics Discussed

- I/O operations
 - File operations
 - Character oriented input/output
 - Text files
 - Block oriented input/output
 - Non-blocking input/output
 - Terminal input/output
- Selected functions of standard library
 - Overview of functions in standard C and POSIX libraries
 - Variable number of arguments
 - Error handling
- Next: Parallel programming



Topics Discussed

- I/O operations
 - File operations
 - Character oriented input/output
 - Text files
 - Block oriented input/output
 - Non-blocking input/output
 - Terminal input/output
- Selected functions of standard library
 - Overview of functions in standard C and POSIX libraries
 - Variable number of arguments
 - Error handling

- Next: Parallel programming

