

Input/Output and Standard C Library

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Lecture 06

PRG(A) – C Programming Language

Part I

Input and Output

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
- Part 2 – Selected Standard Libraries
 - Standard library – Selected Functions
 - Error Handling

K. N. King: chapters 22

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

Text vs Binary Files

- There is no 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

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

## File Positioning

- Every stream has a 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*

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

- Test if 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 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 exist)
 - "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

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);`

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

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

Line Oriented I/O

- A whole line (text) can 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
- Alternatively, the line can be read by `getline()`

```
ssize_t getline(char ** restrict linep, size_t * restrict linecapp,
FILE * restrict stream);
```

Expand the buffer via realloc(), see man getline

*Capacity of the buffer, or if *linep==NULL (if linep points to NULL) a new buffer is allocated*

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

- We can count the number of bytes, and thus the time needed to copy the file

```
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
```

Formatted I/O – fscanf()

- `int fscanf(FILE *file, const char *format, ...);`

- It returns a 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

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 1/5

- Program to read/write a given (as `#define NUMB`) 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 <stdbool.h>
5 #include <stdlib.h>
6
7 #include <sys/time.h>
8
9 #include "my_assert.h"
10
11 #ifndef BUFSIZE
12 #define BUFSIZE 32768
13 #endif
14
15 #ifndef NUMB
16 #define NUMB 4098
17 #endif
18
19 int main(int argc, char *argv[])
20 {
21     int c = 0;
22     _Bool read = true;
23     const char *fname = NULL;
24     FILE *file;
25     const char *mode = "r";
26     while (argc-- > 1) {
27         fprintf(stderr, "DEBUG: argc: %d '%s'\n", argc, argv[argc]);
28         if (strcmp(argv[argc], "-w") == 0) {
29             fprintf(stderr, "DEBUG: enable writting\n");
30             read = false; // enable writing
31             mode = "w";
32         } else {
33             fname = argv[argc];
34         }
35     } // end while

```

lec06/demo-block_io.c

Block Read/Write – Example 2/5

```

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

```

lec06/demo-block_io.c

Block Read/Write – Example 3/5

```

58     fprintf(stderr, "INFO: Write to the file '%s'\n", fname);
59     c = fwrite(data, sizeof(int), NUMB, file);
60     if (c != NUMB) {
61         fprintf(stderr, "WARN: Write only %i objects (int)\n", c);
62     } else {
63         fprintf(stderr, "DEBUG: Write %i objects (int)\n", c);
64     }
65     fflush(file);
66 }
67
68 gettimeofday(&t2, NULL);
69 double dt = t2.tv_sec - t1.tv_sec + ((t2.tv_usec - t1.tv_usec) / 1000000.0);
70 double mb = (sizeof(int) * c) / (1024 * 1024);
71 fprintf(stderr, "DEBUG: feof: %i ferror: %i\n", feof(file), ferror(file));
72 fprintf(stderr, "INFO: %s %lu MB\n", (read ? "read" : "write"), sizeof(int)*NUMB/(1024 *
73     1024));
74 fprintf(stderr, "INFO: %.2lf MB/sec\n", mb / dt);
75 free(data);
76 return EXIT_SUCCESS;
77 }
    
```

lec06/demo-block_io.c

Block Read/Write – Example 5/5

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

```

clang -DNUMB=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 -DNUMB=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

Block Read/Write – Example 3/5

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

```

clang -DNUMB=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: 2214.03 MB/sec
    
```

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

```

clang -DNUMB=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

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 make 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

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);
        tio.c_lflag &= ~ECHO; // assure echo is disabled
        tio.c_oflag |= OPOST; // enable output postprocessing
        tcsetattr(STDIN_FILENO, TCSANOW, &tio);
    }
}
```

- Or we can use the `stty` tool
- Usage `clang demo-getchar.c -o demo-getchar`

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

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

lec06/demo-getchar.c

Part II

Selected Standard Libraries

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.

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

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



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

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
- `<fenv.h>` – function for control rounding and representation according to IEEE 754.

ISO C99

man math

Variable Arguments <stdarg.h>

- It allows writing 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

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 obtained by the function
 - `char* strerror(int errnum);`

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 }

```

lec06/demo-va_args.c

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`

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 }
```

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`

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") ==
17     0) {
18         printf("Force abort\n");
19         abort();
20     }
21     printf("Normal exit\n");
22     return EXIT_SUCCESS;
23 }
24
25 void cleanup(void)
26 {
27     printf("Perform cleanup at the program exit!\n");
28 }
29
30 void last_word(void)
31 {
32     printf("Bye, bye!\n");
33 }

```

```

■ 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