

# Input/Output and Standard C Library

Jan Faigl

Department of Computer Science  
Faculty of Electrical Engineering  
Czech Technical University in Prague

Lecture 06

PRG(A) – 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
- 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

## Part I Input and Output

### 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 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

### 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 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 "r"
  - 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.

### 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);`

### 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

### 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

### 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

**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
    - Read error – the read function is unable to read data from the stream
    - Matching failure – the read data does not match the requested format
 Or, the stream is closed, e.g., stdin
- 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);

### 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 struct timeval t1, t2;
4 gettimeofday(&t1, NULL);
5 ... // copy the stdin -> stdout
6 ...
7 gettimeofday(&t2, NULL);
8 double dt = t2.tv_sec - t1.tv_sec + ((t2.tv_usec - t1.tv_usec) / 1000000.0);
9 double mb = bytes / (1024 * 1024);
10 fprintf(stderr, "%.2lf 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 – 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

**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)
  - putc() 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

### 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() or 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 linecap,
FILE * restrict stream);
```

Expand the buffer via realloc(), see man fgets

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

### 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 #include <sys/time.h>
7 #include "my_assert.h"
8 #include "my_assert.h"
9 #ifndef BUFSIZE
10 #define BUFSIZE 32768
11 #endif
12 #ifndef NUMB
13 #define NUMB 4096
14 #endif
15 #ifndef NMB
16 #define NMB 4096
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 writing\n");
30             read = false; // enable writing
31             mode = "w";
32         } else {
33             fname = argv[argc];
34         }
35     } // end while
36
37     lec06/demo-block_io.c

```

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### 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 != NULL, _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     }
59 }
60
61 lec06/demo-block_io.c

```

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### 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
78 lec06/demo-block_io.c

```

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### 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

```

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### Block Read/Write – Example 5/5

- Increased write buffer `BUFSIZE` (128 MB) improves writing performance
- 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 -w a 2>&1 | grep INFO
INFO: write 381 MB
INFO: 325.51 MB/sec

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

```

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### 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.*

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### 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

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### 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 '%c' is blank", c);
    } else {
        printf("Key is something else");
    }
    printf(" ascii: %s\n", isascii(c) ? "true" : "false");
}
return 0;

```

lec06/demo-getchar.c

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### 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");
    }
}

```

lec06/demo-getchar.c

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Standard library – Selected Functions Error Handling

# Part II

## Selected Standard Libraries

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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`
    - Header files contain function prototypes, types, macros, etc.
 

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

*Viz e.g., `1dd a.out`*

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Standard library – Selected Functions Error Handling

### 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

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Standard library – Selected Functions Error Handling


### 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



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Standard library – Selected Functions Error Handling

### 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. *man math*

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Standard library – Selected Functions Error Handling

### 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

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Standard library – Selected Functions Error Handling

### 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*

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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);`

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### 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'

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### 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

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### 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

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### 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 }
```

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### 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

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### 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
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lec06/demo-atexit.c
```

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Topics Discussed

## Summary of the Lecture

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Standard library – Selected Functions Error Handling

### 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

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