Input/Output and Standard C Library

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Lecture 06

B3B36PRG – C Programming Language

Overview of the Lecture

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 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 exists; 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`

File Operations Character Oriented I/O Text Files Block Oriented I/O Non-Blocking I/O Terminal I/O

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

- Test if the file has been opened

```c
char *fname = "file.txt";

if ((f = fopen(fname, "r")) == NULL) {
  fprintf(stderr, "Error: open file '%s'\n", fname);
}
```

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

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

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

File Operations Character Oriented I/O Text Files Block Oriented I/O Non-Blocking I/O Terminal I/O

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 Operations Character Oriented I/O Text Files Block Oriented I/O Non-Blocking I/O Terminal I/O

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

```c
#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);`

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

```
int c;
int bytes = 0;
while ((c = getc(stdin)) != EOF) {
   if (putc(c, stdout) == EOF) {
      fprintf(stderr, "Error in putc");
      break;
   }
   bytes += 1;
}
```

lec06/copy-getc_putc.c

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

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

```
#include <sys/time.h>
...

struct timeval t1, t2;
gettimeofday(&t1, NULL);

... // copy the stdin -> stdout

gettimeofday(&t2, NULL);
double dt = t2.tv_sec - t1.tv_sec + ((t2.tv_usec - t1.
    tv_usec) / 1000000.0);
double mb = bytes / (1024 * 1024);
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
```


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, site_t *
  restrict linecapp, FILE * restrict stream);
  ```

  Exapnd the buffer via realloc()*, see* man fgetline

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

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, ...);`

```c
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

```c
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

```c
#include <stdio.h>
#include <string.h>
#include <errno.h>
#include <assert.h>
#include <stdbool.h>
#include <stdlib.h>

#include <sys/time.h>

#ifndef BUFSIZE
#define BUFSIZE 32768
#endif

#ifndef BSIZE
#define BSIZE 4098
#endif
```

```c
int main(int argc, char *argv[])
{
   int c = 0;
   _Bool read = true;
   const char *fname = NULL;
   FILE *file;
   const char *mode = "r";
   while (argc-- > 1) {
      fprintf(stderr, "DEBUG: argc: %d '%s'\n", argc, argv[argc]);
      if (strcmp(argv[argc], "-w") == 0) {
         fprintf(stderr, "DEBUG: enable writting\n");
         read = false; // enable writting
         mode = "w";
      } else {
         fname = argv[argc];
      }
   } // end while
```

lec06/demo-block_io.c

Block Read/Write – Example 2/4

```c
   file = fopen(fname, mode);
   if (!file) {
      fprintf(stderr, "ERROR: Cannot open file '%s', error %d - %s\n", fname, errno, strerror(errno));
      return -1;
   }
   int *data = (int*)malloc(BSIZE * sizeof(int));
   assert(data);
   struct timeval t1, t2;
   gettimeofday(&t1, NULL);
   if (read) {                                                  /* READ FILE */
      fprintf(stderr, "INFO: Read from the file '%s'\n", fname);
      c = fread(data, sizeof(int), BSIZE, file);
      if (c != BSIZE) {
         fprintf(stderr, "WARN: Read only %i objects (int)\n", c);
      } else {
         fprintf(stderr, "DEBUG: Read %i objects (int)\n", c);
      }
   } else {                                                     /* WRITE FILE */
      char buffer[BUFSIZE];
      if (setvbuf(file, buffer, _IOFBF, BUFSIZE)) { /* SET BUFFER */
         fprintf(stderr, "WARN: Cannot set buffer");
      }
      fprintf(stderr, "INFO: Write to the file '%s'\n", fname);
      c = fwrite(data, sizeof(int), BSIZE, file);
      if (c != BSIZE) {
         fprintf(stderr, "WARN: Write only %i objects (int)\n", c);
      } else {
         fprintf(stderr, "DEBUG: Write %i objects (int)\n", c);
      }
      fflush(file);
   }
   gettimeofday(&t2, NULL);
```

lec06/demo-block_io.c

Block Read/Write – Example 3/4

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

- Default `BUFSIZE` (32 kB) to write/read 10^8 integer values ($\sim$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

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 transfered 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

```c
#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`

```c
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

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

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

<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 erros

- <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

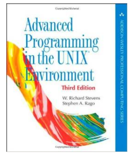
Standard Library (POSIX)

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 quadrand 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(), ... – comparision 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

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

Example – Variable Arguments <stdarg.h>

```c
#include <stdio.h>
#include <stdarg.h>

int even_numbers(int n, ...);
int main(void)
{
   printf("Number of even numbers: %i\n", even_numbers(2, 1, 2));
   printf("Number of even numbers: %i\n", even_numbers(4, 1, 3, 4, 5));
   printf("Number of even numbers: %i\n", even_numbers(3, 2, 4, 6));
   return 0;
}

int even_numbers(int n, ...)
{
   int c = 0;
   va_list ap;
   va_start(ap, n);
   for (int i = 0; i < n; ++i) {
      int v = va_arg(ap, int);
      (v % 2 == 0) ? c += 1 : 0;
   }
   va_end(ap);
   return c;
}
```

lec06/demo-va_args.c

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

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


Example – errno

- File open

```c
#include <stdio.h>
#include <errno.h>
#include <string.h>

int main(int argc, char *argv[]) {
   FILE *f = fopen("soubor.txt", "r");
   if (f == NULL) {
      int r = errno;
      printf("Open file failed errno value %d\n", errno);
      printf("String error '%s'\n", strerror(r));
   }
   return 0;
}
```

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

```c
#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

```c
#include <setjmp.h>
jmp_buf jb;
int compute(int x, int y);
void error_handler(void);
if (setjmp(jb) == 0) {
   r = compute(x, y);
   return 0;
} else {
   error_handler();
   return -1;
}
int compute(int x, int y) {
   if (y == 0) {
      longjmp(jb, 1);
   } else {
      x = (x + y * 2);
      return (x / y);
   }
}
void error_handler(void)  {
   printf("Error\n");
}
```


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()

```c
#include <stdio.h>
#include <stdlib.h>

int main(void)
{
   printf("USER: %s\n", getenv("USER"));
   printf("HOME: %s\n", getenv("HOME"));
   return EXIT_SUCCESS;
}
```

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()

```c
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

void cleanup(void);
void last_word(void);

int main(void)
{
   atexit(cleanup); // register function
   atexit(last_word); // register function
   const char *howToExit = getenv("HOW_TO_EXIT");
   if (howToExit && strcmp(howToExit, "EXIT") == 0) {
      printf("Force exit\n");
      exit(EXIT_FAILURE);
   } else if (howToExit && strcmp(howToExit, "ABORT") == 0) {
      printf("Force abort\n");
      abort();
   }
   printf("Normal exit\n");
   return EXIT_SUCCESS;
}

void cleanup(void)
{
   printf("Perform cleanup at the program exit!\n");
}

void last_word(void)
{
   printf("Bye, bye!\n");
}
```

- 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