1 C Standard Library Overview for Linux

1.1 Introduction

This collection provides a number of examples and cheatsheets for commonly used `libc` functions and system calls for the Linux operating system. It gives a short description of each function and provides examples for their usage.
Functions are grouped in several categories, which cover specific use cases, respectively. For each category an overview of the involved functions and files is given followed by an example for the typical usage of these functions. After the usage example, a more detailed description of each function is given.
However, cheatsheets **can not** replace the thorough study of the corresponding manpages for more detailed information. Manpages can be retrieved using the following command:

```
man [<section>] <function>
```

Please use the following compiler flags for your exercises. These are the flags used to compile your Linux submissions.

```
CFLAGS = -std=c11 -pedantic -D_XOPEN_SOURCE=700 -Wall -Werror -O3
```

1.2 Cheatsheets (aka SPiC-Zettel)

- Errno Variable
  Explanation of the `errno` variable.
- Memory
  List of functions: malloc(), free()
  Functions to (de-)allocate memory.
- Strings
  List of functions: strlen(), strcpy(), strcat()
  Functions to analyze and manipulate C strings.
- File System
  List of functions:
  - **directory handling**: opendir(), closedir(), readdir()
  - **file handling**: fopen(), fclose(), stat(), lstat()

  Functions for file and directory handling (i.e., opening/closing files and retrieving metadata).
- Input/Output
  List of functions: printf(), fprintf(), fgetc(), fgets(), fputc(), fputs(), perror(), feof(), ferror()
  Functions for (formatted) input and output.
- Processes
  List of functions: exit(), wait(), waitpid(), fork(), execl(), execv(), execlp(), execvp(), strtok()
  Functions to create new processes and wait for the termination of processes. Furthermore, functions to execute a new program in a process.

- Signals
  List of functions: kill(), sigemptyset(), sigfillset(), sigaddset(), sigdelset(), sigismember(), sigprocmask(), sigaction(), sigsuspend()
  Functions to deliver, synchronize, and wait for POSIX signals in Linux.
- Threads
  List of functions: pthread_create(), pthread_exit(), pthread_join(), pthread_mutex_init(), pthread_mutex_lock(), pthread_mutex_unlock(), pthread_mutex_destroy()
  Functions to create, synchronize, and wait for POSIX threads (pthreads).

2 Module Documentation

2.1 File System

Files

- file dirent.h
- file stdio.h
- file stat.h
- file types.h

Functions

- DIR * opendir (const char *name)
  Open a directory.
- int closedir (DIR *dirp)
  Close a directory.
- struct dirent * readdir (DIR *dirp)
  Read an entry of a directory.
- FILE * fopen (const char *pathname, const char *mode)
  Open a file.
- int fclose (FILE *fp)
  Close a file.
- int stat (const char *path, struct stat *buf)
  Retrieve metadata of a file.
- int lstat (const char *path, struct stat *buf)
  Retrieve metadata of a file.

2.1.1 Detailed Description

Checking whether a regular file exists, open it, and close it:

```c
char *file = "./testfile";

// get file metadata
struct stat sbuf;
if (lstat(file, &sbuf) == -1){
    perror("lstat");
    exit(EXIT_FAILURE);
}

// check file type
if (!S_ISREG(sbuf.st_mode)) {
    fprintf(stderr, "%s is not a regular file.", file);
    exit(EXIT_FAILURE);
}

// open file
FILE *fd = fopen(file, "r+");
if (fd == NULL) {
     perror("fopen");
     exit(EXIT_FAILURE);
}

// use file
// [...]

// close file, check for errors (like full disk)
if (fclose(fd) != 0) {
    perror("fclose");
    exit(EXIT_FAILURE);
}
```

Iterating over all entries of a directory. Be aware, that readdir() also returns hidden files (starting with a `.`) including the two entries pointing to the current directory (`.`) and the parent directory (`..`).

```c
const char *path = "test/";

// open directory
DIR *dir = opendir(path);
if (dir == NULL) {
    perror("opendir");
    exit(EXIT_FAILURE);
}

// iterate over directory entries
struct dirent *dirent;
while (errno = 0, (dirent = readdir(dir)) != NULL) {
    printf("%s\n", dirent->d_name);
}
if (errno != 0) {
    perror("readdir");
    exit(EXIT_FAILURE);
```



```c
}

// close directory
closedir(dir);
```

2.1.2 Function Documentation

2.1.2.1 opendir()

```
DIR* opendir (
                const char * name )
```

The opendir() function opens a directory stream according to `name`. The stream is positioned at the first entry of the directory. Opened directories must be closed by closedir().

Parameters

name	name of the directory to be opened

Return values

*DIR**	on success
N↩ ULL	on error, `errno` is set

2.1.2.2 closedir()

```
int closedir (
                DIR * dirp )
```

A directory opened by the opendir() function, can be closed by the closedir() function, which frees all allocated resources.
We do not expect error handling when closing directories, so simply do:

```c
closedir(dir);
```

Parameters

dirp	directory stream to be closed

2.1.2.3 readdir()

```
struct dirent* readdir (
                DIR * dirp )
```

The readdir() function reads the next entry from an opened directory stream pointed to by `dirp`. It allocates a `struct dirent` structure and returns a pointer to the allocated structure con-

taining the information about the next directory entry. The caller of readdir() must not provide (or free) memory for the `struct dirent` structure.
readdir() returns `NULL` if an error occurs or if the end of the directory stream is reached. To be able to distinguish these two events, a caller must set the `errno` variable to 0 before **each** call of readdir(). If `errno` is still 0 after readdir() returned `NULL` the end of the directory stream has been reached, otherwise an error has occurred.
The `struct dirent` contains information about a directory entry. The most important information are the inode number and the name of the entry:

```
struct dirent {
   ino_t          d_ino;       // Inode number
   [...]
   char           d_name[256]; // Null-terminated filename
};
```

Parameters

dirp	directory stream to read next entry from

Return values

dirent∗	pointer to the next directory entry
NULL	on error (`errno` is set) or if the end of the directory stream is reached

2.1.2.4 fopen()

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

The fopen() (**f**ile **open**) function opens the file at `pathname` with the mode as specified in `mode`. Opened files must be closed by fclose().
The path in `pathname` can specify a relative (based on the current working directory) or an absolute path.
Valid file modes are:

Mode	Description
`r`	read only
`r+`	read and write
`w`	write only, create file if it does not exist yet
`w+`	read and write file, create file if it does not exist yet
`a`	write only, append only, create file if it does not exist yet
`a+`	write append only, read from beginning only, create file if it does not exist yet

Parameters

pathname	path to file
mode	file mode

Return values

FILE∗	on success
N↩ ULL	on error, `errno` is set

2.1.2.5 fclose()

```
int fclose (
              FILE * fp )
```

A file opened by the fopen() function, can be closed with the fclose() (**f**ile **close**) function, which writes all remaining buffered operations to the file and frees all allocated resources.

Parameters

fp	file stream to be closed

Return values

0	on success
EOF	on error, `errno` is set

2.1.2.6 stat()

```
int stat (
              const char * path,
              struct stat * buf )
```

The stat() function retrieves information about the file pointed to by `path`. If `path` is a symbolic link, stat() returns information about the underlying file instead of the link itself. Be aware that the caller is responsible to provide the memory for the `struct stat` structure pointed to by `buf`!
The `struct stat` contains, amongst others, the following information:

```
struct stat {
   [...]
   ino_t     st_ino;         // Inode number
   mode_t    st_mode;        // File type and mode
   nlink_t   st_nlink;       // Number of hard links
   uid_t     st_uid;         // User ID of owner
   gid_t     st_gid;         // Group ID of owner
```

```
    [...]
    off_t     st_size;        // Total size, in bytes
    [...]
};
```

The st_mode field encodes the file type and permissions. In order to check whether a file is regular file, a symbolic link, or a directory, some macros exist:

```
struct stat buf;
stat(pathname, &buf);
[...] // error handling
if (S_ISREG(buf.st_mode)) { printf("regular file"); }
if (S_ISDIR(buf.st_mode)) { printf("directory "); }
if (S_ISLNK(buf.st_mode)) { printf("link"); } // only with lstat()
```

Parameters

path	file to be analyzed
buf	pointer to a buffer storing the retrieved information

Return values

0	on success
-1	on error, errno is set

2.1.2.7 lstat()

```
int lstat (
              const char * path,
              struct stat * buf )
```

The lstat() function retrieves information about the file pointed to by path. If path is a symbolic link, lstat() returns information about the link itself instead of the underlying file. Be aware that the caller is responsible to provide the memory for the struct stat structure pointed to by buf!
For more details see the stat() function.

Parameters

path	file to be analyzed
buf	pointer to a buffer storing the retrieved information

Return values

0	on success
-1	on error, errno is set

2.2 Errno Variable

Files

- file errno.h

Variables

- int errno

  Error code set by various library functions.

2.2.1 Detailed Description

The errno variable is an integer variable and set by system calls and library functions to indicate the source of an error. The errno is undefined, except when a system call or library function indicates an error (e.g., by a special return value) and the corresponding manpage states that in case of an error the errno variable is set. From this follows that the value of the errno is undefined after a successful call to a system call or library function. Furthermore, no system call or library functions sets the errno to 0.
There are rare cases, where the errno is not only used to indicate the source of an error, but is also used to detect an error (e.g., readdir()). If the errno is used to detect an error (and not, as usually, the return value) it is explicitly stated in the manpages. In this case the errno must be manually set to 0 before calling the function to be able to check if the function changed the value. Except for these rare cases setting the errno manually is never correct, unless one is writing a library function (e.g., malloc()).
The errno variable is a thread-local variable, which means every POSIX thread has a separate errno. Hence, the access of errno must not be synchronized against other POSIX threads.
Wrong usage of errno:

```
char *s = malloc(1024);
if (s == NULL) {
    fprintf(stderr, "malloc: ");

    // now the errno is undefined, because of a successful
    // or unsuccessful call to fprintf()

    // wrong: strerror() uses an undefined value to generate the string
    fprintf(stderr, "%s\n", strerror(errno));
    exit(EXIT_FAILURE);
}

char *s = malloc(1024);
if (s == NULL) {
    // wrong: original errno value is overwritten!
    errno = ENOMEM;
    perror("malloc");
    exit(EXIT_FAILURE);
}

errno = 0; // wrong: setting errno has no effect here
```

```c
char *s = malloc(1024);
if (errno != 0) {
    // wrong: errno can be != 0 even if malloc() is successful
    // NOTE: There are rare exceptions (e.g., readdir()).
    perror("malloc");
    exit(EXIT_FAILURE);
}
```

Correct usage of `errno`:

```c
char *s = malloc(1024);
if (s == NULL) {
    perror("malloc");
    exit(EXIT_FAILURE);
}

errno = 0;
struct dirent *entry = readdir(dirp);
if (entry != NULL) {
    // process entry
} else if (errno != 0) { // explicitly stated in man page
    perror("readdir");
    exit(EXIT_FAILURE);
}
```

2.3 Threads

Files

- file pthread.h

Functions

- int pthread_create (pthread_t *thread, const pthread_attr_t *attr, void *(*start_routine)(void *), void *arg)

  Create a thread.
- void pthread_exit (void *retval)

  Exit a thread.
- int pthread_join (pthread_t thread, void **retval)

  Wait for a thread.
- int pthread_detach (pthread_t thread)

  Detach a thread.
- int pthread_mutex_init (pthread_mutex_t *mutex, const pthread_mutexattr_t *mutexattr)

  Create a mutex.
- int pthread_mutex_lock (pthread_mutex_t *mutex)

  Lock a mutex.

- int pthread_mutex_unlock (pthread_mutex_t *mutex)

  Unlock a mutex.
- int pthread_mutex_destroy (pthread_mutex_t *mutex)

  Destroy a mutex.

2.3.1 Detailed Description

This page shows a simplified interface for POSIX threads (pthreads). Threads are a more lightweight method to use the concurrency potential of modern multi-core processors, compared to the process concept of Linux.

Disclaimer: Some parts of the interface are simplified. This page does not replace a thorough study of the manpages for the respective functions!

The `pthread_*()` function family does not set the `errno` variable to indicate the error cause, but instead returns an error value (or 0 on success). Thus, the return value of `pthread_*()` functions can be usually assigned to `errno` (except otherwise stated) and in case of an error perror() can be used to print a meaningful error message. Be aware, that the `errno` is not a global but a thread-local variable, hence each thread has its own `errno`.

If you intend to use this library, make sure to run your `gcc` with the appropriate flags.

`-pthread -std=c11 -Werror -Wall -pedantic -D_XOPEN_SOURCE=700 -O3`

Minimal `pthread` example:

```c
static int counter = 0;

// Function the threads execute
void *thread_func(void *arg) {
    pthread_mutex_t *mutex = (pthread_mutex_t *) arg;

    // do stuff concurrently
    for (unsigned int i = 0; i < 1000; i++) {
        pthread_mutex_lock(mutex);
        counter++;
        pthread_mutex_unlock(mutex);
    }

    pthread_exit(NULL);
}

int main(int argc, char *argv[]) {
    // create mutex
    pthread_mutex_t mutex;
    errno = pthread_mutex_init(&mutex, NULL);
    if (errno != 0) {
        perror("pthread_mutex_init");
        exit(EXIT_FAILURE);
    }

    // create and start threads
    pthread_t threads[4];
```

```
    for (unsigned int i = 0; i < 4; i++) {
        errno = pthread_create(&(threads[i]), NULL, thread_func,
                               (void *) &mutex);
        if (errno != 0) {
            perror("pthread_create");
            exit(EXIT_FAILURE);
        }
    }

    // wait until threads terminate
    for (unsigned int i = 0; i < 4; i++) {
        errno = pthread_join(threads[i], NULL);
        if (errno != 0) {
            perror("pthread_join");
            exit(EXIT_FAILURE);
        }
    }

    pthread_mutex_destroy(&mutex);

    printf("counter: %i\n", counter);
}
```

2.3.2 Function Documentation

2.3.2.1 pthread_create()

```
int pthread_create (
            pthread_t * thread,
            const pthread_attr_t * attr,
            void *(*)(void *) start_routine,
            void * arg )
```

The pthread_create() function creates and starts a new thread within the calling process. The new thread will initially execute the function specified in `start_routine`, which receives a `void *` pointer as parameter and returns a `void *` pointer. The argument handed over to the new thread is specified in `arg`.
The pthread_create() function uses the pointer in `thread` to store the thread id in the underlying `pthread_t` variable, which can be used to identify a thread in further `pthread_*` function calls.
The attributes for the new thread are specified in `attr`. For default attributes `NULL` can be used.
A thread that has been created with pthread_create() must be joined with pthread_join() or marked as detached using pthread_detach() in order to free the resources associated with the thread. This is similar to fork() and waitpid() for processes.

Parameters

thread	pointer to the thread id

Parameters

attr	thread attributes (`NULL` for default attributes)
start_routine	function the thread initially executes
arg	argument for `start_routine`

Return values

0	on success
!=0	on error

2.3.2.2 pthread_exit()

```
void pthread_exit (
            void * retval )
```

The pthread_exit() function terminates the calling thread with the return value in `retval`.
This function never returns.

Parameters

retval	return value visible to a pthread_join() caller

2.3.2.3 pthread_join()

```
int pthread_join (
            pthread_t thread,
            void ** retval )
```

The pthread_join() function waits for the thread in `thread` to terminate. If the thread has already been terminated, the pthread_join() function returns immediately. The return value of the terminated thread can be retrieved by `retval`.
Be aware that threads marked as detached (pthread_detach()) can not be joined anymore!
Example code

```
void *retval;

errno = pthread_join(thread, &retval);
if (errno != 0) {
    perror("pthread_join");
    exit(EXIT_FAILURE);
}

printf("Exit code of thread: %p\n", retval);
```

Parameters

thread	thread to wait for
retval	buffer for a pointer to the return value

Return values

0	on success
!=0	on error

2.3.2.4 pthread_detach()

```
int pthread_detach (
            pthread_t thread )
```

The pthread_detach() function marks the thread in `thread` detached. This automatically frees all resources, when the threads exits. Once a thread is marked as detached it can not be joined using pthread_join() anymore!

Parameters

thread	thread to detach

Return values

0	on success
!=0	on error

2.3.2.5 pthread_mutex_init()

```
int pthread_mutex_init (
            pthread_mutex_t * mutex,
            const pthread_mutexattr_t * mutexattr )
```

The pthread_mutex_init() function initializes a pthread mutex. It receives a pointer to a `pthread_mutex_t` type and a pointer to the attributes in `mutexattr`. For default attributes `NULL` can be used for `mutexattr`. If a mutex should be destroyed the pthread_mutex_destroy() function can be used.

```
pthread_mutex_t mutex;
errno = pthread_mutex_init(&mutex, NULL);
if (errno != 0) {
    perror("pthread_mutex_init");
    exit(EXIT_FAILURE);
}
```


Parameters

mutex	mutex to be initialized
mutexattr	attributes for `mutex` (`NULL` for default)

Return values

0	on success
!=	on error

2.3.2.6 pthread_mutex_lock()

```
int pthread_mutex_lock (
            pthread_mutex_t * mutex )
```

The pthread_mutex_lock() function blocks the current thread, until it successfully acquired the mutex in `mutex`. When this function returns, the thread can safely assume to be the only thread inside of the critical section guarded by `mutex`.

Parameters

mutex	mutex to lock

2.3.2.7 pthread_mutex_unlock()

```
int pthread_mutex_unlock (
            pthread_mutex_t * mutex )
```

The pthread_mutex_unlock() function releases the mutex in `mutex`.

Parameters

mutex	mutex to unlock

2.3.2.8 pthread_mutex_destroy()

```
int pthread_mutex_destroy (
            pthread_mutex_t * mutex )
```

The pthread_mutex_destroy() function destroys the mutex in `mutex`. After this function returns, pthread_mutex_lock() and pthread_mutex_unlock() must **not** be called with this mutex as argument anymore.

Parameters

mutex	mutex to destroy

2.4 Signals

Files

- file signal.h

Data Structures

- struct sigaction

Functions

- int kill (pid_t pid, int sig)

  Send signal to a process.
- int sigemptyset (sigset_t *set)

  Empty signal set.
- int sigfillset (sigset_t *set)

  Fill signal set.
- int sigaddset (sigset_t *set, int signum)

  Add signal to set.
- int sigdelset (sigset_t *set, int signum)

  Remove signal from set.
- int sigismember (const sigset_t *set, int signum)

  Test signal's membership.
- int sigprocmask (int how, const sigset_t *set, sigset_t *oset)

  Change signal mask of a process.
- int sigaction (int sig, const struct sigaction *act, struct sigaction *oact)

  Set action for a signal.
- int sigsuspend (const sigset_t *mask)

  Wait for a signal.

2.4.1 Detailed Description

This set of functions and system calls control the signal handling of processes in Linux. A signal asynchronously interrupts the execution of a process and has great similarities with interrupts as known from the microcontroller programming. This includes the arising problems of asymmetric program interruption, for example, lost wake-up and synchronization problems.
A complete list of all signals and further information can be found at `man 7 signal`. The action values mean, that the default action is either to terminate the process (**Term**), to terminate the process and generate a core dump (**Core**) or to ignore a signal (**Ign**). An excerpt of the available signals is shown here:

Signal	Default Action	Description
SIGINT	**Term**	interrupt from keyboard (Ctrl-C)

Signal	Default Action	Description
SIGQUIT	**Core**	quit from keyboard
SIGKILL	**Term**	kill signal (non blockable)
SIGSEGV	**Core**	invalid memory reference
SIGALRM	**Term**	timer signal
SIGTERM	**Term**	termination signal
SIGUSR1	**Term**	user-defined signal 1
SIGUSR2	**Term**	user-defined signal 2
SIGCLD/SIGCHLD	**Ign**	child stopped/terminated

The following examples show some typical use cases for the presented functions.
Install a new action for SIGINT

```
static void sigint_handler(int signum) { ... }

int main(int argc, char *argv[]) {
    struct sigaction act, oldact;

    // signal mask during handling of a signal
    // (handled signal itself is automatically blocked)
    sigemptyset(&act.sa_mask);

    // set signal handler (also possible: SIG_DFL (default action)
    // and SIG_IGN (ignoring))
    act.sa_handler = sigint_handler;

    // set flags
    act.sa_flags = SA_RESTART;

    if (sigaction(SIGINT, &act, &oldact) == -1) {
        perror("sigaction");
        exit(EXIT_FAILURE);
    }

    [...]
```

Block and unblock a signal:

```
sigset_t set, oldset;

// initialize set (first empty set, then add SIGINT)
sigemptyset(&set);
sigaddset(&set, SIGINT);

// block SIGINT and get previous signal mask
if (sigprocmask(SIG_BLOCK, &set, &oldset) == -1) {
    perror("sigprocmask");
```

```
    exit(EXIT_FAILURE);
}

// SIGINT is blocked
[...]

// unblock SIGINT
if (sigprocmask(SIG_UNBLOCK, &set, NULL) == -1) {
    perror("sigprocmask");
    exit(EXIT_FAILURE);
}
```

Only allow one signal

```
sigset_t set, oldset;

// initialize set (first add all signals, then remove SIGINT)
sigfillset(&set);
sigdelset(&set, SIGINT);

// install new signal mask and get previously installed signal mask
if (sigprocmask(SIG_SETMASK, &set, &oldset) == -1) {
    perror("sigprocmask");
    exit(EXIT_FAILURE);
}

// all signals are blocked except for SIGINT
[...]
```

2.4.2 Data Structure Documentation

2.4.2.1 struct sigaction

Data Fields

- void(* sa_handler)(int)
- sigset_t sa_mask
- int sa_flags

Field Documentation

2.4.2.1.1 sa_handler

```
void(* sa_handler) (int)
```

Pointer to the function, which will be installed for the associated signal. The installed function must have one parameter, where the incoming signal is encoded, and no return value. Instead of a pointer to a handler function the two special values `SIG_IGN` (ignore occurences of this signal) or `SIG_DFL` (restore the default action for this signal) can be used.

2.4.2.1.2 sa_mask

```
sigset_t sa_mask
```


Specifies a signal mask with signals, which are blocked during the handling of the associated signal. The signal itself will be implicitly added to the signal mask (except `SA_NODEFER` is used in `sa_flags`). Usually, an empty signal mask can be used.

2.4.2.1.3 sa_flags

```
int sa_flags
```

Specifies further options for the signal handling process. It is formed by a bitwise `OR` of zero or more options. Usually, it is set to `SA_RESTART`.

2.4.3 Function Documentation

2.4.3.1 kill()

```
int kill (
            pid_t pid,
            int sig )
```

The kill() system call can be used to send the signal specified in `sig` to the process specified in `pid`. The kill() function can also be used to send the signal to multiple processes, see `man 2 kill` for more details.

Parameters

pid	pid of the receiving process
sig	signal to be sent

Return values

0	on success
-1	on error, `errno` is set

2.4.3.2 sigemptyset()

```
int sigemptyset (
            sigset_t * set )
```

The sigemptyset() function empties a given signal set.
We do not expect error handling when setting signal masks.

Parameters

set	pointer to the signal set

2.4.3.3 sigfillset()

```
int sigfillset (
```

```
                sigset_t * set )
```

The sigfillset() function fills a signal set, that is, all signals are included.
We do not expect error handling when setting signal masks.

Parameters

set	pointer to the signal set

2.4.3.4 sigaddset()

```
int sigaddset (
                sigset_t * set,
                int signum )
```

The sigaddset() function adds the signal `signum` to the signal set in `set`.
We do not expect error handling when setting signal masks.

Parameters

set	pointer to the signal set
signum	signal to be added

2.4.3.5 sigdelset()

```
int sigdelset (
                sigset_t * set,
                int signum )
```

The sigdelset() function removes the signal `signum` from the signal set `set`.
We do not expect error handling when setting signal masks.

Parameters

set	pointer to the signal set
signum	signal to be removed

2.4.3.6 sigismember()

```
int sigismember (
                const sigset_t * set,
                int signum )
```

The sigismember() function determines whether the signal `signum` is a member of the signal set `set`.

Parameters

set	pointer to the signal set
signum	signal to be tested

Return values

1	signal is a member
0	signal is **not** a member

2.4.3.7 sigprocmask()

```
int sigprocmask (
                int how,
                const sigset_t * set,
                sigset_t * oset )
```

The sigprocmask() function is used to manipulate or get the currently installed signal mask. The signal mask is the set of signals that are currently blocked.
The new installed signal mask is specified in the struct pointed to by `act` (`act` can be `NULL` if no new signal mask should be installed). If `oact` is not `NULL` the previously installed signal mask is saved.
Instead of setting a new signal mask, the current set can be manipulated by adding or removing the signals specified in `act` depending on the value of `how`. The possible values for `how` are:

Value	Description
`SIG_BLOCK`	add signals in `set` to the set of currently blocked signals
`SIG_UNBLOCK`	remove signals in `set` from the set of currently blocked signals
`SIG_SETMASK`	set the set of currently block signals to the signals in `set`

Parameters

how	determines how the signal mask is changed
set	pointer to the signal set
oset	copy of previous signal set

Return values

0	on success
-1	on error, `errno` is set

2.4.3.8 sigaction()

```
int sigaction (
               int sig,
               const struct sigaction * act,
               struct sigaction * oact )
```

The sigaction() function is used to change the action taken by a process, when receiving a specific signal. For each signal a default action is specified, which can be overwritten by sigaction() (except for SIGKILL and SIGSTOP).
The new installed action for the signal `sig` is specified in the struct pointed to by `act` (`act` can be NULL if no new action should be installed). If `oact` is not NULL the previous action is saved. For further information about the content of `act` and `oact` see the documentation of struct sigaction.

Parameters

sig	signal to change action for
act	action to take
oact	copy of previous action

Return values

0	on success
-1	on error, errno is set

2.4.3.9 sigsuspend()

```
int sigsuspend (
               const sigset_t * mask )
```

The sigsuspend() function temporarily replaces the signal mask of the process with `mask` and then suspends the execution of the process until it receives a signal in an atomic way.
If the signal terminates the process, this function does not return. If the signal is caught, this function returns after the execution of the signal handler and the old signal mask is restored.
The return value of sigsuspend() is always -1 and can be ignored.

Parameters

mask	temporary signal mask

2.5 Input/Output

Files

- file stdio.h

Functions

- int printf (const char *format,...)

  Print formatted data to `stdout`
- int fprintf (FILE *stream, const char *format,...)

  Print formatted data to `stream`.
- int fgetc (FILE *stream)

  Read a character.
- char * fgets (char *s, int size, FILE *stream)

  Read a string.
- int fputc (int c, FILE *stream)

  Write a character.
- int fputs (const char *s, FILE *stream)

  Write a string.
- void perror (const char *s)

  Print an error message.
- int feof (FILE *stream)

  Test end-of-file indicator of a file stream.
- int ferror (FILE *stream)

  Test error indicator of a file stream.

2.5.1 Detailed Description

This code snippet illustrates the usage of fgetc() and fputc():

```
int c;
while ((c = fgetc(stdin)) != EOF) {
    if (fputc((unsigned char) c, stdout) == EOF) {
        perror("fputc");
        exit(EXIT_FAILURE);
    }
}
if (ferror(stdin)) {
    // error
}

// no error; end of file reached
```

This code snippet illustrates the usage of fgets() and fputs():

```
char buffer[1024];
char *check;

// reads at most 1023 characters per iteration
while ((check = fgets(buffer, 1024, stdin)) != NULL) {
    if (fputs(buffer, stdout) == EOF) {
```

```
        perror("fputs");
        exit(EXIT_FAILURE);
    }
}
if (ferror(stdin)) {
    // error
}

// alternative to ferror():
// if (feof(stdin)) {
//     // no error; end of file reached
// } else {
//     // error
// }
```

2.5.2 Function Documentation

2.5.2.1 printf()

```
int printf (
              const char * format,
               ...  )
```

The printf() (**print f**ormatted) function produces output according to a format string as specified in `format` and writes it `stdout`. The format string defines the structure of the output (i.e., how many and which additional arguments) and the additional parameter of the printf() function are used to replace the arguments in the format string with actual data. It is important that the number of additional parameter matches the number of arguments of the format string.
An argument in the format string starts with a %. The following table shows some important arguments, however, there are several more options described in the manpage of printf() (`man 3 printf`):

Type	Description
i, d	integer
u	unsigned integer
f	floating point
p	pointer
s	string
c	character

Example:

```
int i = 5;
char c = 'a';
void *p = &i;
```



```
printf("Hello World!\n");                    // no arguments
printf("$> i: %i\n$> c: %c\n$> f: %f\n \
        $> p: %p\n", i, c, 3.14, p);         // including arguments

// produces:
Hello world!
$> i: 5
$> c: a
$> f: 3.140000
$> p: 0x7ffebe5dbe34
```

We do not expect error handling for printf().

Parameters

format	format string
...	arguments

Return values

>=0	number of characters printed
<0	on error, `errno` is set

2.5.2.2 fprintf()

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

The fprintf() (**f**ile stream **print f**ormatted) function is very similar to printf(), except that it does not write to `stdout`, but to `stream`.
For more details see printf().

```
// both lines write to stdout
fprintf(stdout, "Hello world!\n");
printf("Hello world!\n");

// write to stderr
fprintf(stderr, "Error in file '%s' at line %u\n", __FILE__, __LINE__);
```

Parameters

stream	file stream to write
format	format string, see printf()
...	arguments

Return values

>=0	number of characters printed
<0	on error, errno is set

2.5.2.3 fgetc()

```
int fgetc (
            FILE * stream )
```

The fgetc() (**f**ile stream **get c**haracter) function returns an `unsigned char` casted to an int read from a `stream` or returns `EOF`.
fgetc() returns `EOF` on error or when the end of the file is reached. To distinguish these two events the feof() or ferror() function can be used. Be aware, that the return value of fgetc() must be saved in an `int` (and **not** in an `unsigned char`) in order to distinguish `EOF` and 0xFF (which is the character ÿ when interpreted as ISO-8859-1).

Parameters

stream	file stream to read

Return values

EOF	on error **or** end of file, `errno` is set on error
!=EOF	`unsigned char` read from `stream`

2.5.2.4 fgets()

```
char* fgets (
            char * s,
            int size,
            FILE * stream )
```

The fgets() (**f**ile stream **get s**tring) function reads at most `size-1` characters from `stream` and saves them in the buffer pointed to by `s`. It terminates the string in `s` with a null byte (`\0`).
fgets() reads in characters until it finds a newline character (`\n`) or it has read `size-1` characters. If an error occurred or the end of file was reached it returns `NULL`. The ferror() and feof() functions can be used to distinguish these two events.

Parameters

s	buffer to write to
size	size of the buffer
stream	file stream to read

Return values

NULL	on error **or** end of file, `errno` is set on error
!=NULL	pointer to `s`

2.5.2.5 fputc()

```
int fputc (
            int c,
            FILE * stream )
```

The fputc() (**f**ile stream **put c**haracter) function writes the character `c` to `stream`.
We do not expect error handling when using fputc().

Parameters

c	char to print (casted to an `int`)
stream	file stream to write

Return values

EOF	on error **or** end of file, `errno` is set on error
!=EOF	printed char

2.5.2.6 fputs()

```
int fputs (
            const char * s,
            FILE * stream )
```

The fputs() (**f**ile stream **put s**tring) function writes the string pointed to by `s` to `stream`.

Parameters

s	string to be printed
stream	file stream to write

Return values

>=0	on success
EOF	on error, `errno` is set

2.5.2.7 perror()

```
void perror (
                const char * s )
```

The perror() (**p**rint **error**) function produces an error message on `stderr` printing the string in `s` followed by a human-readable description of the value in `errno`. This is especially helpful after a failed call to a system or library function, which sets the `errno` variable (e.g., malloc()).

Parameters

s	string printed before the actual error message

2.5.2.8 feof()

```
int feof (
                FILE * stream )
```

The feof() (**f**ile stream **e**nd **o**f **f**ile) function tests the `EOF` indicator of `stream`.

Parameters

stream	file stream to test

Return values

0	end-of-file indicator is not set
!=0	end-of-file indicator is set

2.5.2.9 ferror()

```
int ferror (
                FILE * stream )
```

The ferror() (**f**ile stream **error**) function tests the error indicator of `stream`.

Parameters

stream	file stream to test

Return values

0	error indicator is not set
!=0	error indicator is set

2.6 Memory

Files

- file stdlib.h

Functions

- void * malloc (size_t size)

  Allocate memory.
- void free (void *ptr)

  Free allocated memory.

2.6.1 Detailed Description

With malloc() (**m**emory **alloc**ation) a program can request memory from the operating system. The allocated memory is usable until it is free()'d again. It is important, that programs always check if a malloc() call was successful and free their memory after usage, otherwise a so-called memory leak exists.

```
// allocate memory
char *s = malloc(strlen("Hello World\n") + 1);
if (s == NULL) {
    perror("malloc");
    exit(EXIT_FAILURE);
}

// use allocated memory
strcpy(s, "Hello World\n");
printf("%s", s);

// free allocated memory
free(s);
```

2.6.2 Function Documentation

2.6.2.1 malloc()

```
void* malloc (
                size_t size )
```

The malloc() function allocates `size` bytes at the heap and returns a pointer to the allocated memory or `NULL` if an error has been occurred. Be aware, that the memory is not initialized after a successful call to malloc().

Parameters

size	number of bytes to be allocated

Return values

NULL	on error, `errno` is set
!=NULL	pointer to allocated memory

2.6.2.2 free()

```
void free (
            void * ptr )
```

The free() function frees the memory pointed to by `ptr`, which must have been returned by a previous call to malloc(). Otherwise, or if `free(ptr)` has already been called before, undefined behavior occurs. If `ptr` is `NULL`, no operation is performed.

Parameters

ptr	pointer to buffer

2.7 Processes

Files

- file stdlib.h
- file string.h
- file types.h
- file wait.h
- file unistd.h

Functions

- void exit (int status)

  Terminate process.
- char * strtok (char *str, const char *delim)

  Tokenize string.
- pid_t wait (int *wstatus)

  Wait for a child process.
- pid_t waitpid (pid_t pid, int *wstatus, int options)

  Wait for a child process.
- pid_t fork (void)

  Fork new process.
- int execl (const char *path, const char *argo,..., NULL)

  Execute a program.
- int execv (const char *path, char *const argv[ ])

  Execute a program.
- int execlp (const char *file, const char *argo,..., NULL)

  Execute a program.
- int execvp (const char *file, char *const argv[ ])

  Execute a program.

2.7.1 Detailed Description

Example of how to create a new process, which executes a program, and wait for the new process to terminate.

```c
// create new process
pid_t pid = fork();
if (pid == 0) {
    // child executes new program
    execlp("ls", "ls", "-A", NULL);
    // execlp() only returns on error
    perror("exec");
    exit(EXIT_FAILURE);
} else if (pid < 0) {
    // fork had an error
    perror("fork");
    exit(EXIT_FAILURE);
}

// parent waits for child to terminate
int status;
if (waitpid(pid, &status, 0) < 0) {
     perror("waitpid");
     exit(EXIT_FAILURE);
}
```

The `exec*()` function family allows for the execution of a new executable within a process. The differences are:

Function	Searches `PATH`	Array of Arguments	List of Arguments
execl()	✗	✗	✓
execlp()	✓	✗	✓
execv()	✗	✓	✗
execvp()	✓	✓	✗

2.7.2 Function Documentation

2.7.2.1 exit()

```
void exit (
            int status )
```

The exit() function terminates the current process with the exit code as specified in `status`. This function does **not** return.
Examples for typically used exit codes: `EXIT_SUCCESS` (0), `EXIT_FAILURE`.

Parameters

status	exit code

2.7.2.2 strtok()

```
char* strtok (
                char * str,
                const char * delim )
```

The strtok() (**str**ing **tok**enize) function tokenizes the string pointed to by `str`. For the first call the pointer to the string to be tokenized must be provided. For all subsequent tokens for the same string `NULL` must be used for `str`. Be aware, that strtok() manipulates the parsed string (e.g., inserts \0). Each call of strtok() returns a pointer to the next token or `NULL` if no more tokens are available.
The strtok() function is especially useful to prepare the arguments for a execv() or execvp() system call.
Example:

```
const char *delim = "|-";
strcpy(buffer, "This|is-an|example!";
printf("%s\n", buffer);

char *tok = strtok(buffer, delim);
while (tok != NULL) {
    printf("%s ", tok);
    tok = strtok(NULL, delim);
}
printf("\n");

// produces
$> This|is-an|example!
$> This is an example!
```

Parameters

str	string to be tokenized
delim	delimiter

Return values

NULL	no more token
!=NULL	pointer to next token

2.7.2.3 wait()

```
pid_t wait (
                int * wstatus )
```

The wait() function blocks, until at least one child process has been terminated. The call of `wait(&status)` is equivalent to `waitpid(-1, &status, 0)`. For more information see waitpid().

Parameters

wstatus	pointer to an integer value, where wait() will store further information

Return values

pid	of the terminated child process
-1	on error, `errno` is set

2.7.2.4 waitpid()

```
pid_t waitpid (
                pid_t pid,
                int * wstatus,
                int options )
```

The waitpid() function blocks until the child process defined by `pid` terminates. The value of `pid` can be one of the following values:

Value	Description
`< -1`	wait for any child process where the process group ID equals the absolute value of `pid`
`-1`	wait for any child process
`0`	wait for any child process where the process group ID equals the ID of the calling process
`> 0`	wait for the child process with the defined `pid`

The value in `options` can be used to further manipulate the behavior of waitpid().

Value	Description
`WNOHANG`	do not block if no child has been terminated (immediately return)
`WUNTRACED`	also return if a child has been stopped
`WCONTINUED`	also return if a child has been resumed (`SIGCONT`)

If `wstatus` is not `NULL`, waitpid() stores further information about the termination of the child process in the underlying `int`. Be aware that the caller must provide the memory for the `int` and only hands over a pointer! Some macros can be used to extract these information.

Macro	Description
`WIFEXITED(wstatus)`	True if child terminated by calling exit()
`WEXITSTATUS(wstatus)`	Returns the exit code if `WIFEXITED` is true
`WIFSIGNALED(wstatus)`	True if child terminated because of a signal
`WTERMSIG(wstatus)`	Returns the signal number if `WIFSIGNALED` is true

Example:

```
int status;
if (waitpid(child, &status, WNOHANG) < 0) {
    perror("waitpid");
    exit(EXIT_FAILURE);
}
```

Parameters

pid	defines child process to wait for
wstatus	pointer to an integer value, where waitpid() will store further information
options	further options

Return values

0	on success
-1	on error, `errno` is set

2.7.2.5 fork()

```
pid_t fork (
                void  )
```

fork() creates a new process by duplicating the calling process. Duplicating means it executes the same program and has the same state (variable values, opened files, ...). The child and parent process can be distinguished by the return value of fork(). For detailed information about differences between the child and the parent see the manpage of fork() (`man 2 fork`).
If a child process terminates it must be collected by using wait() or waitpid(), otherwise it remains in a *zombie* state and consumes system resources.

```
pid_t pid = fork();
if (pid == 0) printf("child\n");
if (pid < 0)  printf("error\n");
if (pid > 0)  printf("parent\n");
```


Return values

0	child process
>0	child's pid
<0	on error, `errno` is set

2.7.2.6 execl()

```
int execl (
              const char * path,
              const char * arg0,
               ...,
              NULL  )
```

The execl() function (**exec** arg **l**ist) replaces the currently executed program with the program as specified in `path`. It hands over all parameters after the `path` parameter (i.e., `arg0`, `arg1`, ...) as arguments for the newly executed program. By convention the first argument is the name of the program itself and the last parameter **must** be a `NULL` pointer. Because all arguments are handed over in a list, the number of arguments is fixed at compile time. This is the most important difference to the execv() and execvp() function.
Any `exec*()` function only returns, if an error occurs. The `errno` is set appropriately, so call `perror("exec");` after the call to a `exec*()` function.
Example to execute the program `ls -lA`:

```
execl("/bin/ls", "/bin/ls", "-lA", NULL);
perror("exec");
```

Parameters

path	path to the executable
arg0	first argument (by convention: executable file name)
...	all further arguments (terminated by a `NULL` pointer)

Returns

-1 on error, `errno` is set

2.7.2.7 execv()

```
int execv (
```

```
                const char * path,
                char *const argv[] )
```

The execv() function (**exec** arg **v**ector) replaces the currently executed program with the program as specified in `path`. It hands over the `argv` parameter as arguments to the newly executed program. By convention the first argument (`argv[0]`) is the name of the program itself and the last parameter **must** be a `NULL` pointer. Because of the usage of a array for the arguments, the number of arguments is not fixed at compile time, but can be determined at run time. This is the most important difference to the execl() and execlp() function.
Any `exec*()` function only returns, if an error occurs. The `errno` is set appropriately, so call `perror("exec");` after the call to a `exec*()` function.
Example to execute the program `ls -lA`:

```
char *args[3];
args[0] = "/bin/ls";
args[1] = "-lA";
args[2] = NULL;

execv(args[0], args);
perror("exec");
```

Parameters

path	path to the executable
argv	array of arguments (terminated by `NULL` pointer)

Returns

-1 on error, `errno` is set

2.7.2.8 execlp()

```
int execlp (
                const char * file,
                const char * arg0,
                 ...,
                NULL  )
```

Same as execl(), but also searches the `PATH` environment variable if `file` does not contain a slash `/`. This means regular shell commands like `ls` are available.
See execl() for further information.

Returns

-1 on error, `errno` is set

2.7.2.9 execvp()

```
int execvp (
                const char * file,
                char *const argv[] )
```

Same as execv(), but also searches the `PATH` environment variable if `file` does not contain a slash `/`. This means regular shell commands like `ls` are available.
See execv() for further information.

Returns

-1 on error, `errno` is set

2.8 Strings

Files

- file string.h

Functions

- size_t strlen (const char *s)

  Calculate the length of a string.
- char * strcpy (char *dest, const char *src)

  Copy a string.
- char * strcat (char *dest, const char *src)

  Append a string to another string.

2.8.1 Detailed Description

The functions in string.h allow for an easy manipulation of C strings. Always remember to allocate the memory for the trailing `\0` after a C string and be aware, that strlen() does **not** include the terminating `\0` in the string length.

```
// allocate some memory
char string_a[5+1], string_b[7+1];
char string[5+7+1];

// copy substrings into memory
strcpy(string_a, "Hello");
strcpy(string_b, " World!");

// concatenate the two strings
strcpy(string, string_a);
strcat(string, string_b);
printf("%s", string); // $> Hello World!

// determine the length of the concatenated string
size_t siz = strlen(string); // siz = 12 (5+7)
```

2.8.2 Function Documentation

2.8.2.1 strlen()

```
size_t strlen (
            const char * s )
```

The strlen() (**str**ing **len**gth) function calculates the length of the string pointed to by `s`, **excluding** the terminating `\0`.

Parameters

s	string under test

Returns

number of chars in `s`

2.8.2.2 strcpy()

```
char* strcpy (
            char * dest,
            const char * src )
```

The strcpy() (**str**ing **c**o**py**) function copies the string pointed to by `src`, including the terminating `\0`, to the buffer pointed to by `dest`.
The strings may not overlap, and the destination string `dest` must be large enough to receive the copy.

Parameters

dest	buffer, where to copy to
src	buffer to be copied

Returns

pointer to `dest`

2.8.2.3 strcat()

```
char* strcat (
            char * dest,
            const char * src )
```

The strcat() (**str**ing con**cat**enate) function appends the string pointed to by `src` to the string pointed to by `dest`. Thereby, the terminating `\0` of `dest` is overwritten. The concatenated string in `dest` is terminated by a `\0` again.

If `dest` is not large enough to include both strings, the program behavior is unpredictable.

Parameters

dest	buffer, where to append to
src	buffer to be appended

Returns

pointer to `dest`