

Exercises in System Level Programming (SLP) – Summer Term 2025

Exercise 10

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Lehrstuhl für Informatik 4
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Presentation Assignment 5

Files & File Streams



- In- and output implemented via buffered file streams
- `FILE *fopen(const char *path, const char *mode);`
 - Opens a file for reading or writing (depending on mode)
 - Returns a pointer to the created file stream
 - `r` Read
 - `r+` Read & write
 - `w` Write; file is possibly created or contents are replaced
 - `w+` Read & write; file is truncated to zero length or created
 - `a` Writing at the end of the file; file is possibly created
 - `a+` Writing at the end of the file; reading at the start; file is possibly created
- `int fclose(FILE *fp);`
 - Flushes all buffered data to the file stream
 - Afterwards file is closed



- File streams opened by default

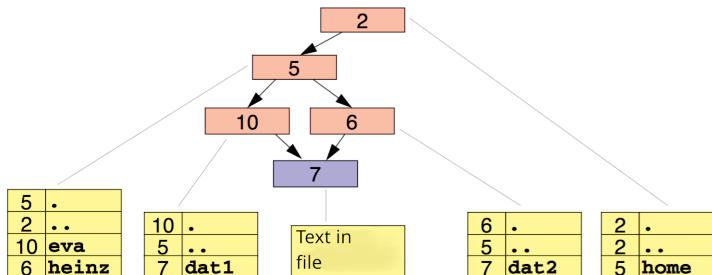
`stdin` Inputs

`stdout` Outputs

`stderr` Error messages

- `int fgetc(FILE *stream);`
 - Reads one character from stream
- `char *fgets(char *s, int size, FILE *stream);`
 - Reads at most size characters into a buffer
 - Stops on line break and EOF
- `int fputc(int c, FILE *stream);`
 - Writes one character to stream
- `int fputs(const char *s, FILE *stream);`
 - Writes a null terminated string (without the trailing null character)

POSIX File-System Interface



inode: Contains file attributes & references to data blocks

File: Block with arbitrary data

Directory: Special file with pairs of names & inode number



- `DIR *opendir(const char *name);`
 - Opens a directory
 - Returns a pointer to the directory stream
- `struct dirent *readdir(DIR *dirp);`
 - Reads one entry from the directory stream and returns a pointer to the data structure `struct dirent`
- `int closedir(DIR *dirp);`
 - Closes the directory stream



```
01 struct dirent {
02     ino_t      d_ino;          // inode number
03     off_t      d_off;          // not an offset; see NOTES
04     unsigned short d_reclen;    // length of this record
05     unsigned char d_type;       // type of file; not supported
06                               // by all filesystem types
07     char        d_name[256];    // filename
08 };
```

- Taken from the man page `readdir(3)`
- Only `d_name` and `d_ino` are mandated by POSIX
- Relevant for us: file name (`d_name`)



- Error handling by setting and checking of errno:

```
01 #include <errno.h>
02 // [...]
03     DIR *dir = opendir("/home/eva/"); // Error handling!!
04
05     struct dirent *ent;
06     while(1) {
07         errno = 0;
08         ent = readdir(dir);
09         if(ent == NULL) {
10             break;
11         }
12         // no further break instructions inside the loop
13         // [...]
14     }
15
16     // EOF or error?
17     if(errno != 0) { // error
18         // [...]
19     }
20     closedir(dir);
```



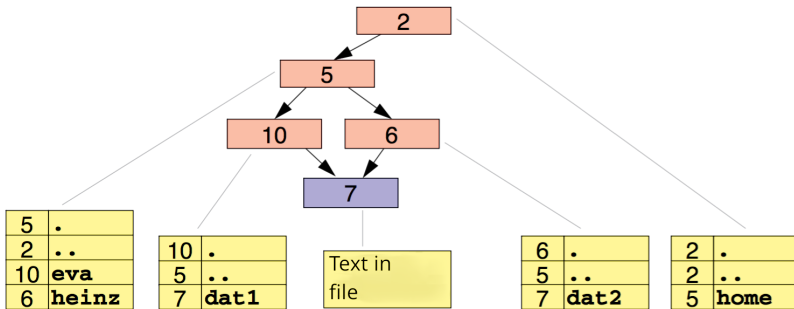
- `readdir(3)` returns **only name and inode number** of a directory entry
- Further information can be found in the **inode**
- `int stat(const char *path, struct stat *buf);`
 - Returns information about an entry (follows symlinks)
- `int lstat(const char *path, struct stat *buf);`
 - Returns information about an entry (does **not** follow symlinks)



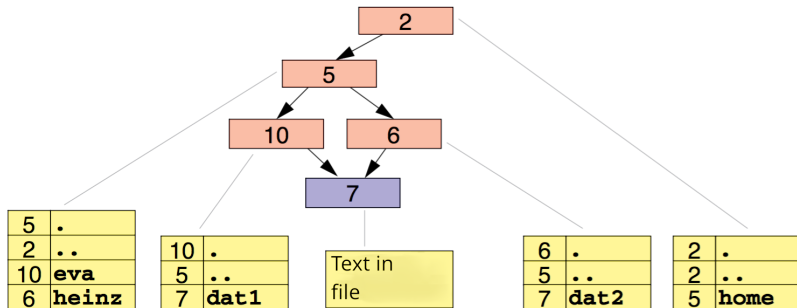
- Contents of the inode are i.a.:
 - Device ID and inode number
 - Owner and group ID
 - File type and permissions
 - File size
 - Time stamp (last changed, accessed, ...)
 - ...

- The type of the file is encoded in the field `st_mode`
 - Regular file, directory, symbolic link, ...
 - For easy decoding
 - `S_ISREG(m)` - is it a regular file?
 - `S_ISDIR(m)` - is directory?
 - `S_ISCHR(m)` - is character device?
 - `S_ISLNK(m)` - is symbolic link?

Example

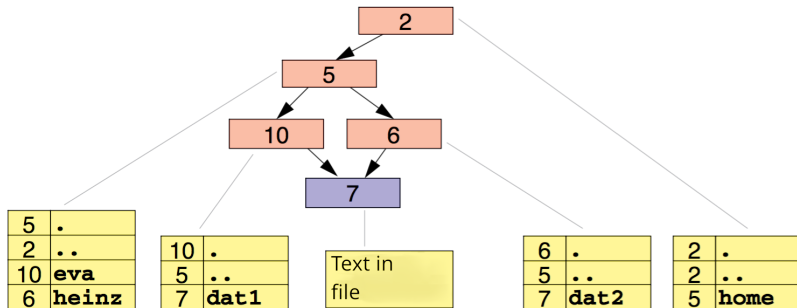


```
01 $> find /
02 /home
03 /home/eva
04 /home/eva/dat1
05 /home/heinz
06 /home/heinz/dat2
```



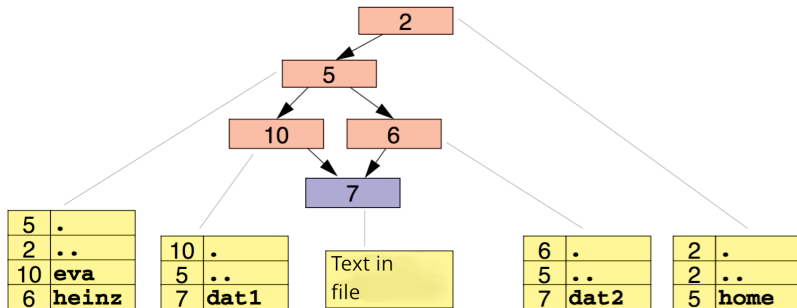
```

01 DIR *dir = opendir("/home/eva/");
02 if(dir == NULL) {
03     perror("opendir");
04     exit(EXIT_FAILURE);
05 }
  
```



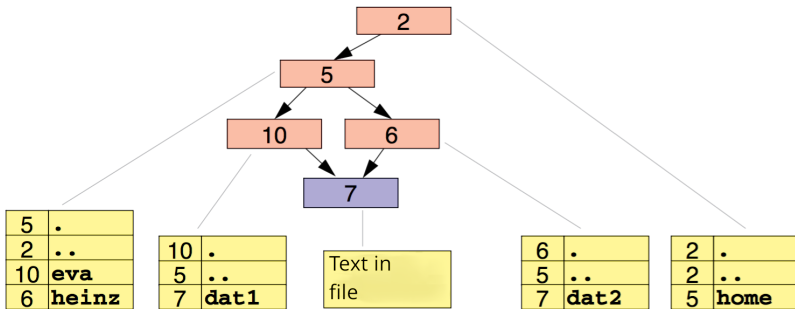
```

01 struct dirent *ent;
02 errno = 0;
03 while((ent = readdir(dir)) != NULL) {
04     //...
05     errno = 0;
06 }
07 if(errno != 0) { perror("readdir"); exit(EXIT_FAILURE); }
  
```



```

01 char path[len];
02 strcpy(path, "/home/eva/");
03 strcat(path, ent->d_name); // d_name = "dat1"
04
05 struct stat buf;
06 if(lstat(path, &buf) == -1) {
07     perror("lstat"); exit(EXIT_FAILURE);
08 }
  
```



```

01 FILE *file = fopen(path, "r");
02 if(file == NULL) {
03     perror("fopen");
04     exit(EXIT_FAILURE);
05 }
    
```



Minimal implementation of cat:

```
01 FILE *f = fopen(path, "r");
02 if(f == NULL) die("fopen");
03
04 char buf[1024];
05 while(fgets(buf, 1024, f) != NULL) {
06     printf("%s", buf);
07 }
08
09 if(ferror(f) != 0) die("fgets");
10 if(fclose(f) != 0) die("fclose");
```

```
01 $> tail -n 1 num.dat
02 499999
03 $> ./cat num.dat && echo "Success" || echo "Failed"
04 1
05 2
06 [...]
07 499999
08 Success
```



Minimal implementation of cat:

```
01 FILE *f = fopen(path, "r");
02 if(f == NULL) die("fopen");
03
04 char buf[1024];
05 while(fgets(buf, 1024, f) != NULL) {
06     printf("%s", buf);
07 }
08
09 if(ferror(f) != 0) die("fgets");
10 if(fclose(f) != 0) die("fclose");
```

```
01 $> ./cat num.dat > dir/file && echo "Success" || echo "Failed"
02 Success
03 $> tail -n 1 dir/file
04 35984
```

- Why is not the whole file written?
- Why is no error message printed?



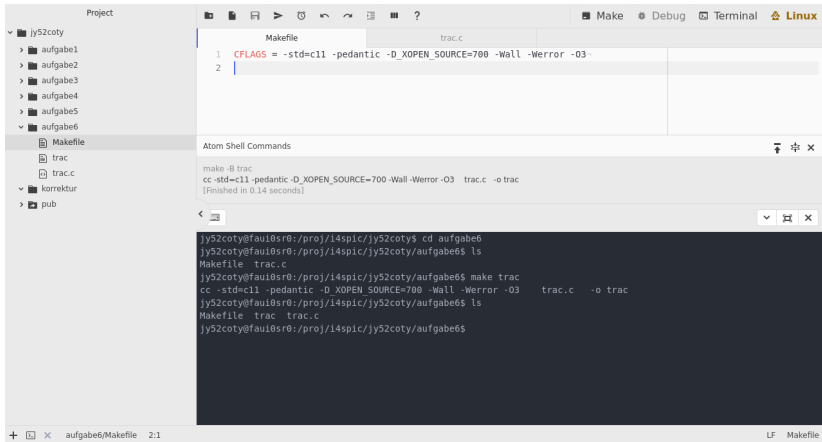
```
01 $> ls -lh num.dat
02 -rw-rw-r-- user group 3,3M Jan 01 00:00 num.dat
03
04 $> ls -lh dir/file
05 -rw-rw-r-- user group 200K Jan 01 00:00 tmp/file
06
07 $> df dir/
08 Filesystem      Size  Used Avail Use% Mounted on
09 tmpfs           200K  200K    0 100% /home/user/dir
```

- stdout can be redirected to a file
- Writing to a file can go wrong
 - No room for the data
 - Missing permissions
 - Broken drive
- Error handling for *relevant* outputs
 - What is important?
 - Error handling for `printf(3)` difficult
- For our exercises: No error handling required for `printf(3)`

- make: Build management tool
- Automatically builds program from its source files
- Only rebuilds parts of the program that have changed

```
01 CFLAGS = -pedantic -Wall -Werror -O3 -std=c11 -D_XOPEN_SOURCE=700
02
03 trac.o: trac.c
04     gcc $(CFLAGS) -c -o trac.o trac.c
05
06 trac: trac.o
07     gcc $(CFLAGS) -o trac trac.o
```

- Object file `trac.o` is built from source file `trac.c` (compiler)
- Binary `trac` is built from object file `trac.o` (linker)



The screenshot shows the SPiC-IDE interface. On the left is a 'Project' tree with folders 'jy52coty', 'aufgabe1', 'aufgabe2', 'aufgabe3', 'aufgabe4', 'aufgabe5', 'aufgabe6', and files 'Makefile', 'trac', 'trac.c', 'korrektur', and 'pub'. The 'Makefile' is selected. The main editor shows the 'Makefile' content:

```
1 CFLAGS = -std=c11 -pedantic -D_XOPEN_SOURCE=700 -Wall -Werror -O3
2
```

Below the editor is the 'Atom Shell Commands' panel, which shows the command 'make -B trac' and its output:

```
make -B trac
cc -std=c11 -pedantic -D_XOPEN_SOURCE=700 -Wall -Werror -O3  trac.c -o trac
[Finished in 0.14 seconds]
```

At the bottom is a terminal window showing the execution of the command 'make trac' in the directory 'aufgabe6':

```
jy52coty@fau10sr0:/proj/i4spic/jy52coty/aufgabe6$ cd aufgabe6
jy52coty@fau10sr0:/proj/i4spic/jy52coty/aufgabe6$ ls
Makefile  trac.c
jy52coty@fau10sr0:/proj/i4spic/jy52coty/aufgabe6$ make trac
cc -std=c11 -pedantic -D_XOPEN_SOURCE=700 -Wall -Werror -O3  trac.c -o trac
jy52coty@fau10sr0:/proj/i4spic/jy52coty/aufgabe6$ ls
Makefile  trac.c
jy52coty@fau10sr0:/proj/i4spic/jy52coty/aufgabe6$
```

- SPiC-IDE detects makefiles (Make Button)
 - ⇒ alternatively: `make <binary>`
- `make` has built in rules (sufficient for SLP)
 - ⇒ only compiler flags (CFLAGS) have to be provided

Task: printdir



- Iteration over all directories given as parameters
 - Output of all contained entries with size and name
 - Output of amount of regular files and their total size (per directory)
 - Relevant functions:
 - `opendir(3)`
 - `readdir(3)`
 - `stat(2)`
 - string functions
 - Error handling:
 - Informative error messages
 - Catch each wrong user input
- ⇒ Always assume the (malicious) SUP (Stupidest User Possible) ☺

Hands-on: `sgrep`

Screencast: <https://www.video.uni-erlangen.de/clip/id/19103>



```
01 # Usage: ./sgrep <text> <files...>
02 $ ./sgrep "SLP" exam.tex task.tex
03 Exam of lecture SLP
04 SLP task
05 SLP is cool
```

- Simplified version of command line tool `grep(1)`
- Searches multiple files for a given string
- Procedure:
 - Read files line by line
 - Search for the string in every line
 - Possibly print out the line on `stdout`
- Pay attention to sensible error handling
 - Report missing files and continue with next file
 - Display error messages using `stderr`



■ Helpful functions:

- `fopen(3)` ⇒ Opens a file
- `fgets(3)` ⇒ Reads one line
- `fputs(3)` ⇒ Prints one line
- `fclose(3)` ⇒ Closes a file
- `strstr(3)` ⇒ Searches for a sub-string

```
01 char *strstr(const char *haystack, const char *needle);
```

```
01 # Usage: ./sgrep [-i] <text> <files...>
02 $ ./sgrep -i "SLP" exam.tex task.tex
03 exam.tex:13: Exam of lecture SLP
04 task.tex:32: SLP task
05 task.tex:56: SLP is cool
```

■ Extensions

- Implement `strstr(3)` on your own
- Print file name and line number in front of every line
- Ignore capitalization with the option `-i`