Exercises in System Level Programming (SLP) – Summer Term 2024

Exercise 11

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Presentation Assignment 6

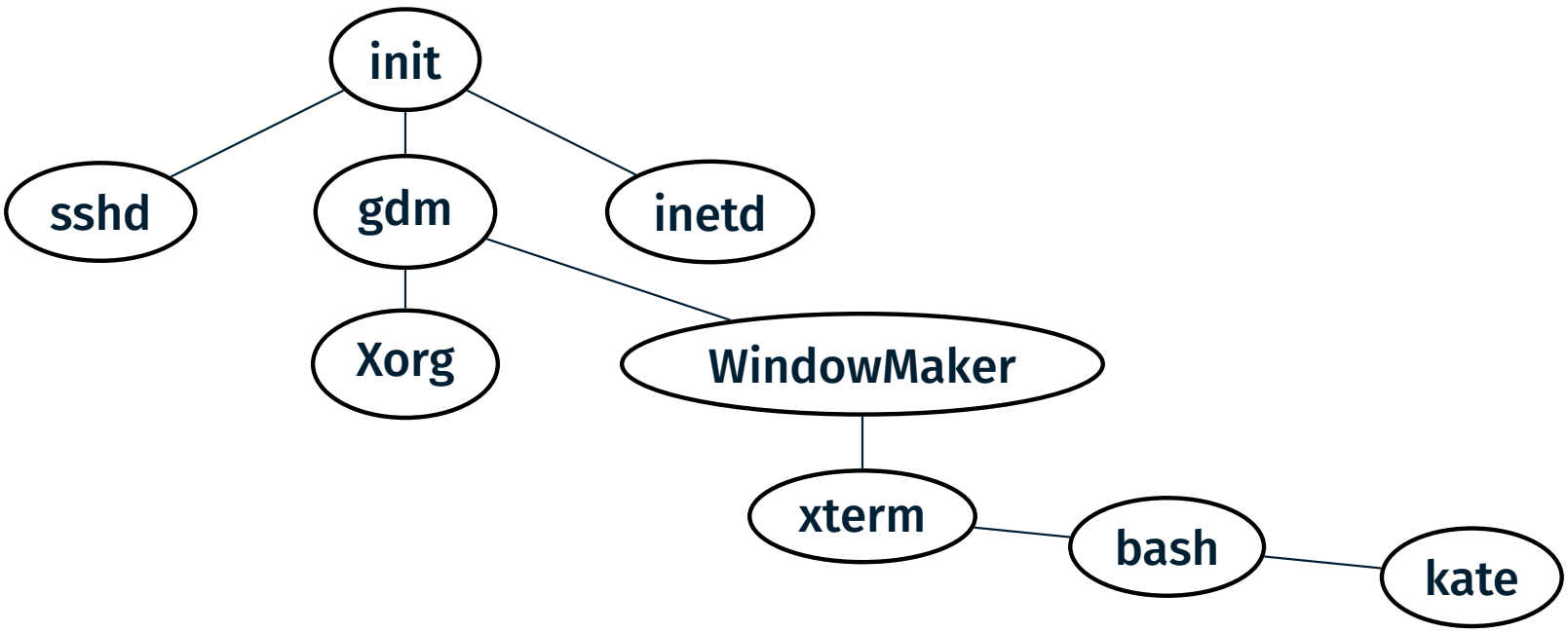
Processes

Processes

- Processes are an execution environment for programs
  - Have a process ID (PID, positive integer)
  - Execute a program
- Each process is assigned resources they need
  - Memory
  - Address space
  - Opened files
  - …
- Visualization of processes: `ps(1)`, `pstree(1)`, `htop(1)`

Process Hierarchy

- Between all processes, a parent-child relation exists
  - The first process is started by the system kernel (e. g. *init*)
  - A tree of processes is created $\rightsquigarrow$ process hierarchy



- **kate** is a child of **bash**, **bash** is a child of **xterm**

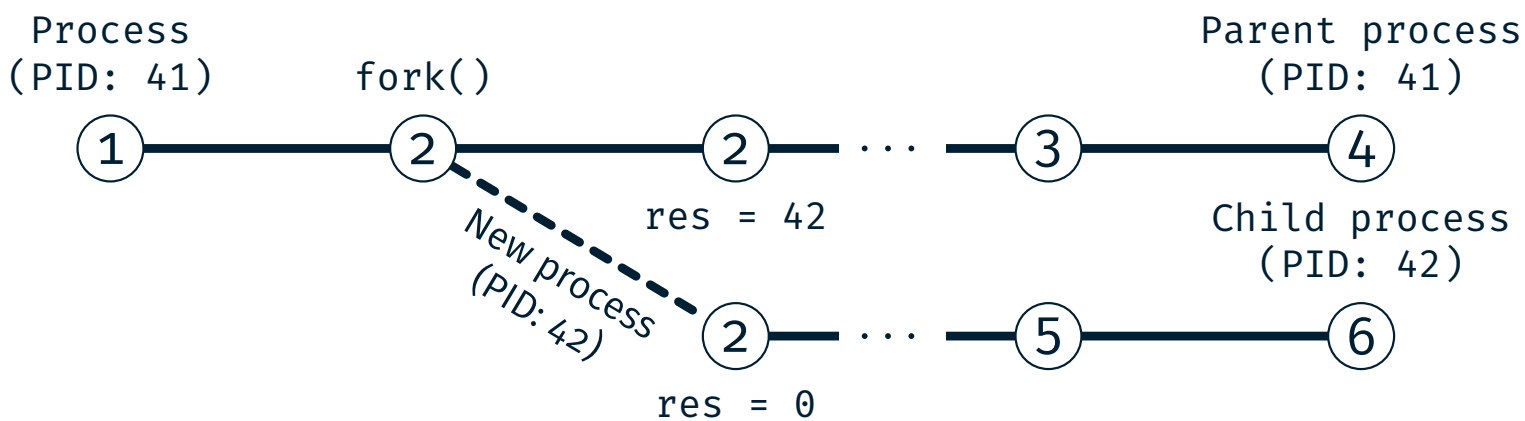
Create Child Processes (1)

```
01 pid_t fork(void);
```

- Creates a new child process
- Exact copy of the parent process:
  - Data and stack segment (copy)
  - Text segment (shared use)
  - File descriptors (open files)
  - **Exception:** Process ID
- Parent and child process both return from the call to `fork(2)`
- Difference is the returned value of `fork(2)`
  - Parent: PID of the child
  - Child: 0
  - Error: `-1`

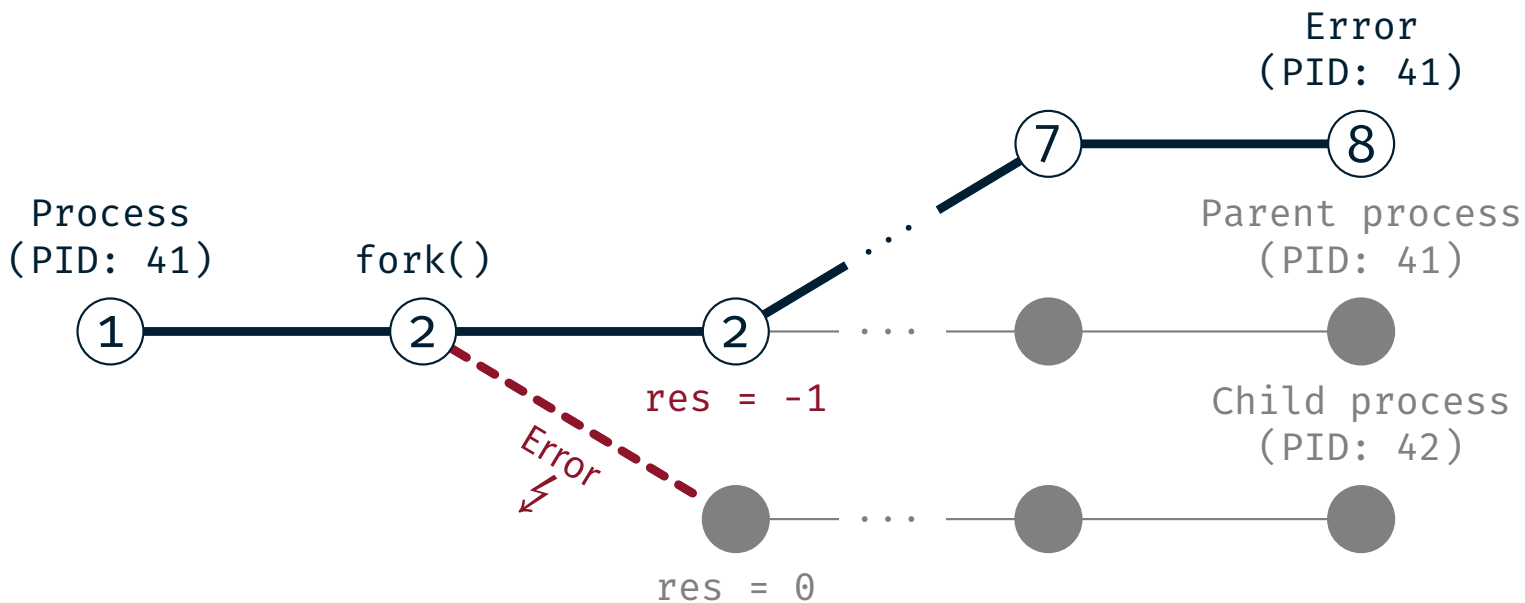
Create Child Processes (2)

```c
printf("Process (PID: %d)", getpid());
pid_t res = fork();
if(res > 0) {
    printf("Parent process (PID: %d)", getpid());
} else if(res == 0) {
    printf("Child process (PID: %d)", getpid());
} else {
    printf("Error (PID: %d)", getpid());
    // [...] Error handling
}
```



Create Child Processes (2)

```
01 printf("Process (PID: %d)", getpid());
02 pid_t res = fork();  // Has an error ↯
03 if(res > 0) {
04     printf("Parent process (PID: %d)", getpid());
05 } else if(res == 0) {
06     printf("Child process (PID: %d)", getpid());
07 } else {
08     printf("Error (PID: %d)", getpid());
09     // [...] Error handling
10 }
```



Waiting for a Child Process (1)

```
01 pid_t wait(int *status);
```

- `wait(2)` is blocking until an arbitrary child process terminates
- Returns
  - `> 0` Process ID of the child process
  - `-1` Error
- `status` contains the reason for the termination:
  - `WIFEXITED(status)` `exit(3)` or return from `main()`
  - `WIFSIGNALED(status)` Process terminated by signal
  - `WEXITSTATUS(status)` Exit status
  - `WTERMSIG(status)` Signal number
- Further macros: see documentation `wait(2)`

Waiting for a Child Process (2)

```
01 pid_t waitpid(pid_t pid, int *status, int options);
```

- `waitpid(2)` is blocking until a certain child process terminates

  `pid > 0` Child process with process ID pid

  `pid = -1` Arbitrary child process

  …

- Options:

  `WNOHANG` Returns immediately if no child terminated (not blocking)

  …

- Returns

  `> 0` Process ID of the child process

  `0` No process has terminated (when using `WNOHANG`)

  `-1` Error – details see `waitpid(2)`

Terminate Processes

```
01 void exit(int status);
```

- Terminates the currently running process with the given exit status
- Frees all resources that were used by the process
  - Memory
  - File descriptors
  - Process management data
  - ...
- Process enters a so called *zombie* state
  - Makes it possible for the parent to react to its termination
  - Zombie processes still use some resources

  $\Rightarrow$ Parent has to keep up with its zombies
- If the parent terminates before its child:

$\Rightarrow$ Passed on to the `init` process and cleared by it

Execute Programs (1)

```
01 int execl(const char *path, const char *arg0, ..., NULL);
02 int execv(const char *path, char *const argv[]);
```

- Replaces the currently running program within the process
  - **Is replaced:** text-, data- and stack segment
  - **Remains:** file descriptors, working directory, ...
- Calling parameters for `exec(3)`
  - Path of the new program
  - Arguments for the `main()` function
- Static number of arguments: `execl(3)`
- Dynamic number of arguments: `execv(3)`
- Last argument: `NULL` pointer
- `exec(3)` only returns in case of an error

PATH Environment Variable

- Finding executable programs using the PATH variable

```
01 $> cp dat dat-copy
02 $> ls
03 dat dat-copy                    # no file 'cp'
04
05 $> echo $PATH                   # PATH contains
06 /usr/local/bin:/usr/bin:/bin    #    - /usr/local/bin/
07                                 #    - /usr/bin/
08                                 #    - /bin/
09 $> which cp
10 /bin/cp                         # 'cp' is in /bin/
11
12 $> ls /bin/                     # /bin/ contains many
13 [...]                           # more common programs
14 rm
15 cp
16 ls
17 [...]
```

Execute Programs (2)

```
01 int execlp(const char *file, const char *arg0, ..., NULL);
02 int execvp(const char *file, char *const argv[]);
```

- Like `execl(3)`/`execv(3)` and searching in PATH

Examples:

```
01 // absolute path and static list of arguments
02 execl("/bin/cp", "/bin/cp", "x.txt", "y.txt", NULL);
03
04 // Searching in PATH and static list of arguments
05 execlp("cp", "cp", "x.txt", "y.txt", NULL);
06
07 // Searching in PATH and dynamic list of arguments
08 char *args[] = { "cp", "dat", ..., "copy/", NULL };
09 execvp(args[0], args);
```

Example: fork(2), exec(3) and wait(2)

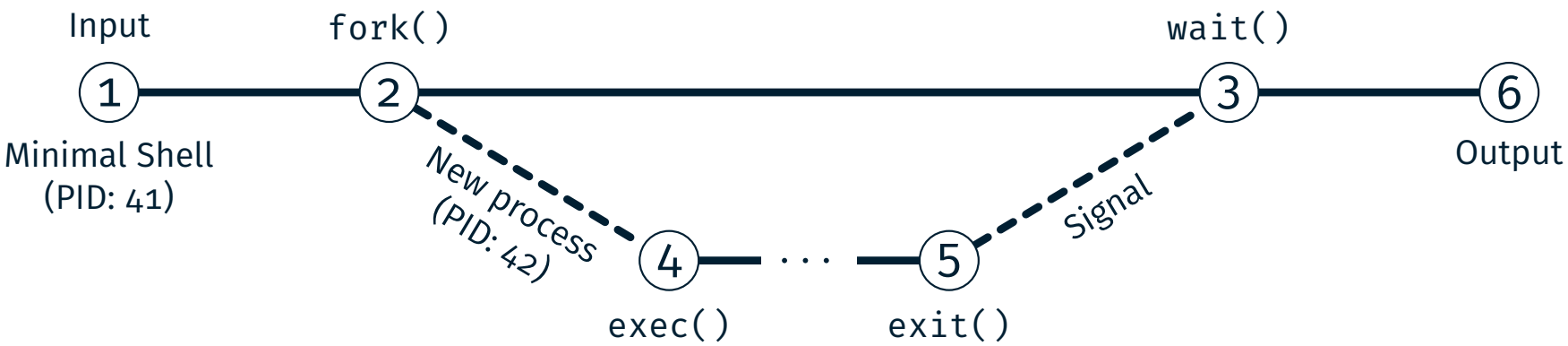
```c
static void die(const char *reason) {
    perror(reason); exit(EXIT_FAILURE);
}

// [...] Process runs
pid_t res = fork();
if(res > 0) { // Parent process
    int status;
    pid_t term_pid = wait(&status);
    if(term_pid == -1) { // Error in wait()
        die("wait");
    } else {
        printf("Child %d terminated\n", term_pid);
    }
} else if(res == 0) { // Child process
    execlp("cp", "cp", "dat", "dat-copy", NULL);
    // Error in execlp(3)
    die("execlp");
} else {  // Error -- No child process created
    die("fork");
}
```

Minimal Shell

Functionality of a Minimal Shell

1. Wait for the user input
2. Create a new process
3. Parent: wait for termination of the child
4. Child: start program
5. Child: program terminates
6. Parent: Output the exit status of the child



Reading from Standard Input with fgets

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

- `fgets(3)` reads one line from the given channel
- `'\n'` is stored as well
- Maximum `size-1` characters + final `'\0'`
- In case of an error or EOF, NULL is returned

⇒ Distinction using `ferror(3)` or `feof(3)`

```
01 char buf[23];
02 while (fgets(buf, 23, stdin) != NULL) {
03     // buf contains line
04 }
05
06 if(ferror(stdin)) {  // Error
07     [...]
08 }
```

String Manipulation with `strtok(3)`

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

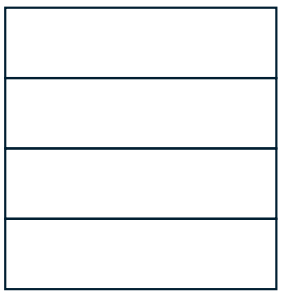
- `strtok(3)` breaks the string into tokens
- Tokens are separated by delimiters
- Each call returns a pointer to the next token
- `delim:` string that contains all delimiters (e.g. `" \t\n"`)
- `str:`

  first call pointer to the string

  all following calls `NULL`

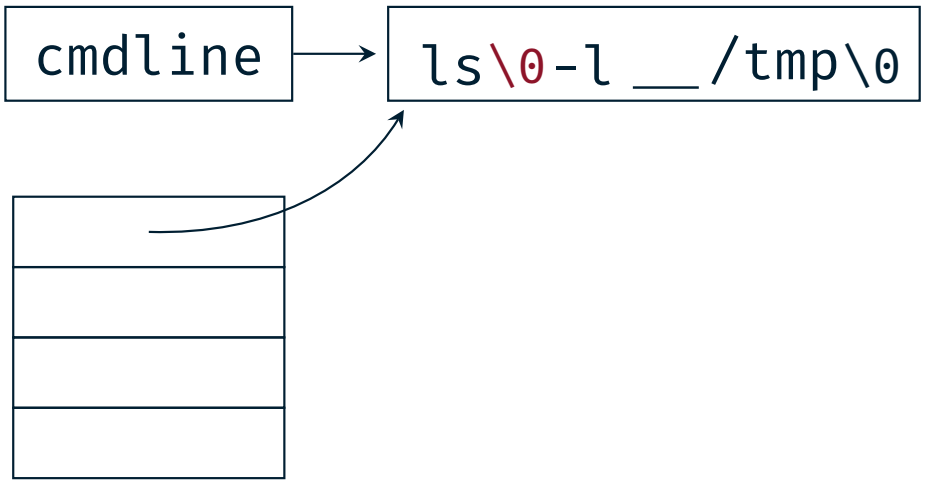
- Consecutive delimiters are skipped
- Delimiters after a token are replaced by `'\0'`
- At the end of the string: `strtok(3)` returns `NULL`

String Manipulation with `strtok(3)`



```
01 char cmdline[] = "ls -l  /tmp";
02 char *a[4];
03 a[0] = strtok(cmdline, " ");
04 a[1] = strtok(NULL, " ");
05 a[2] = strtok(NULL, " ");
06 a[3] = strtok(NULL, " ");
```

String Manipulation with `strtok(3)`

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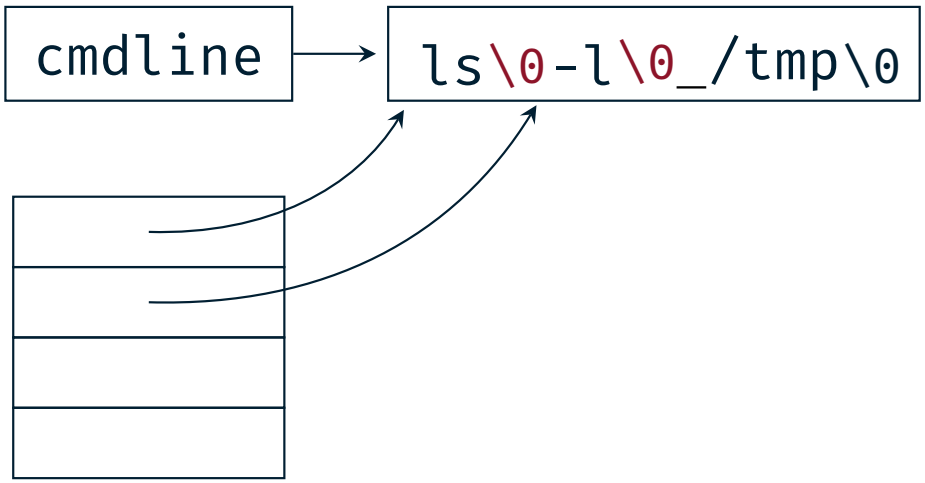


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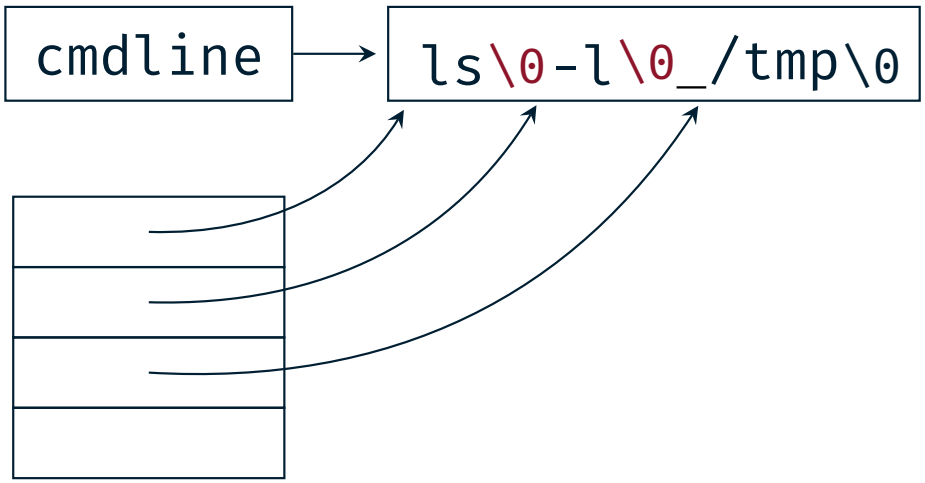


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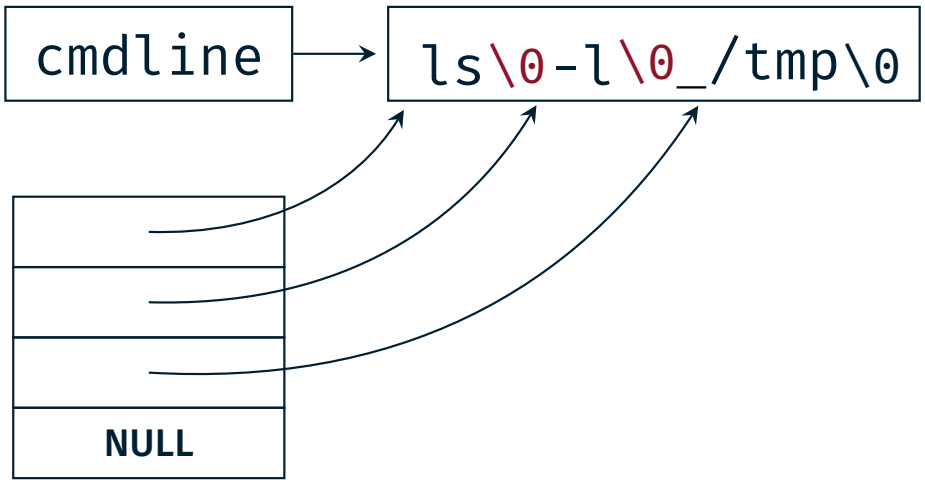
String Manipulation with `strtok(3)`

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02 char *a[4];
03 a[0] = strtok(cmdline, " ");
04 a[1] = strtok(NULL, " ");
05 a[2] = strtok(NULL, " ");
06 a[3] = strtok(NULL, " ");
```

Assignment: `mish`

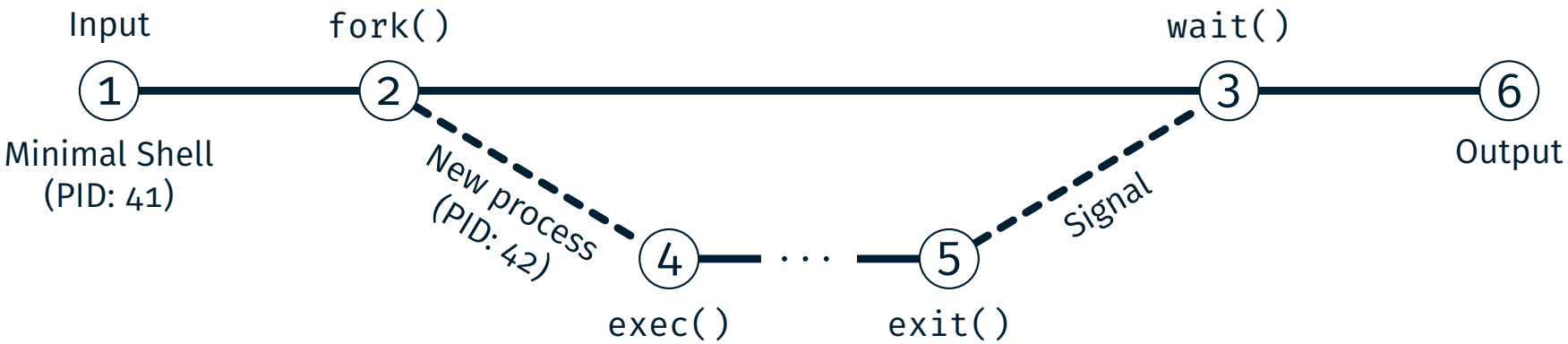
Assignment: `mish` - Part a)

- Simple shell (**mi**ni **sh**ell) for executing commands
- Typical procedure:
  - Output a prompt
  - Wait for user input
  - Tokenize the input
    - Command name
    - Arguments
  - Create a new process
    - **parent:** waits for termination of the child
    - **child:** executes the command
  - Output the exit status

Assignment: `mish` - Part a)

- Repetition: basic cycle of a minimal shell

1. Waiting for a input from the user
2. Creating a new process
3. Parent: Waiting foe the termination of the child
4. Child: Starting the program
5. Child: Program terminates
6. Parent: Outputting the status of the child



Assignment: `mish` - Part a)

Examples:

```
01 # Regular termination with Exit (Exitstatus = 0)
02 mish> ls -l
03 ...
04 Exit status [2110] = 0
05
06 # Invalid/empty input
07 mish>
08 mish> foo
09 foo: No such file or directory
10 Exit status [7342] = 1
11
12 # Termination by signal (here SIGINT = 2)
13 mish> sleep 10
14 Signal [1302] = 2
```

Excursion: `fflush(3)`

- Prompt does not print a `'\n'`
- Standard library buffers `stdout` line by line

⇒ The line buffer has to be flushed with `fflush(3)` after an output

Test Programs

- Test programs: `/proj/i4spic/<idm>/pub/aufgabe8/`
- `spic-wait` (without paramter)

```
01 mish> /proj/i4spic/[...]/spic-wait
02 [...]
03 - send 'SIGPIPE' to this process
04   Command: kill -PIPE 3372
05   Expected Output: Signal [3372] = 13
06
07 [...]
08
09 Signal [3372] = 13
10 mish>
```

```
01
02
03
04
05
06
07
08 $> kill -PIPE 3372
09
10
```

- `spic-wait (with parameter)`

```
01 mish> /proj/i4spic/<idm>/pub/aufgabe8/spic-wait 15
02 Sending signal 15 (Terminated) to myself (PID: 4239)
03 Signal [4239] = 15
04 mish>
```

Test Programs

- Test programs: `/proj/i4spic/<idm>/pub/aufgabe8/`
- `spic-wait` (without paramter)

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02 [...]
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07 [...]
08
09 Signal [3372] = 13
10 mish>
```

```
01
02
03
04
05
06
07
08 $> kill -PIPE 3372
09
10
```

- `spic-wait (with parameter)`

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03 Signal [4239] = 15
04 mish>
```

Test Programs

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09 Signal [3372] = 13
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```

```
01
02
03
04
05
06
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```

- `spic-wait (with parameter)`

```
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02 Sending signal 15 (Terminated) to myself (PID: 4239)
03 Signal [4239] = 15
04 mish>
```

Test Programs

- `spic-exit`

```
01 mish> /proj/i4spic/<idm>/pub/aufgabe8/spic-exit 12
02 Exiting with status 12
03 Exit status [6272] = 12
04 mish>
```

Template

```
01 // DESCRIPTION:
02 //   printStatus() examines the termination of a process and
03 //   prints the source of the exit (signal or exit) and the
04 //   exit code or signal number, respectively.
05 //
06 // PARAMETER:
07 //   pid:    PID of the exited child process
08 //   status: Status bits as retrieved from waitpid(2)
09 //
10 static void printStatus(pid_t pid, int status) {
11     // TODO IMPLEMENT
12 }
```

- `/proj/i4spic/<idm>/pub/aufgabe8/mish_vorlage.c`
- The template does **not** contain:
  - all functions, description of functionality, variables, etc.
- Template does not replace making your own considerations about the structure
- During development, it could be useful to omit the flag `Werror` in the makefile

Hands-on: run

Screencast: `https://www.video.uni-erlangen.de/clip/id/19832`

Hands-on: run

```
01 ./run <programm> <param0> [params...]
```

- `run` receives a program name and a list of parameters
  - Creates a new process for each parameter
  - Executes the given program and passes a parameter to it
  - Waits for the termination and continues with the handling of the next parameter
- Example call: `./run echo Car House Cat`
- Generated program calls:
  - `echo Car`
  - `echo House`
  - `echo Cat`
- (System-) Calls: `fork(2)`, `exec(3)`, `wait(2)`
- Keep in mind the error handling