

Exercises in System Level Programming (SLP) – Summer Term 2026

Exercise 12

Arne Vogel
Maxim Ritter von Onciul
Eva Dengler

Lehrstuhl für Informatik 4
Friedrich-Alexander-Universität Erlangen-Nürnberg



Lehrstuhl für Informatik 4
Systemsoftware



Friedrich-Alexander-Universität
Faculty of Engineering

Presentation Assignment 7

Signals



- Usage of signals
 - Signaling kernel events to a process
 - Signaling events between processes
- Similar to interrupts on AVR
- Two types of signals
 - Synchronous signals: Triggered by process activity (trap)
 - ⇒ Access to invalid memory, invalid instruction
 - Asynchronous signals: Triggered “from outside” (interrupt)
 - ⇒ Timer, keyboard input
- Default signal handlers already defined



- The standard behavior for most signals is the termination of the process, some signals additionally create a core dump.
 - SIGALRM (Term): Alarm clock (`alarm(2)`, `setitimer(2)`)
 - SIGCHLD (Ign): Child process terminated, stopped, or continued
 - SIGINT (Term): Terminal interrupt signal (Shell: CTRL-C)
 - SIGQUIT (Core): Terminal quit signal (Shell: CTRL-\)
 - SIGKILL (cannot be caught or ignored): Kill
 - SIGTERM (Term): Termination signal; standard signal of `kill(1)`
 - SIGSEGV (Core): Invalid memory reference
 - SIGUSR1, SIGUSR2 (Term): User-defined signal 1/2
- Refer to `signal(7)`



- Shell command `kill(1)`

```
01 kill -USR1 <pid>
```

- Parameter: Signal number or signal without “SIG” prefix

- System call `kill(2)`

```
01 int kill(pid_t pid, int signo);
```



- Configuration with the help of a variable of the type `sigset_t`
- Helper functions configure the signal mask
 - `sigemptyset(3)`: Remove all signals from a mask
 - `sigfillset(3)`: Add all signals to a mask
 - `sigaddset(3)`: Add one signal to a mask
 - `sigdelset(3)`: Remove one signal from a mask
 - `sigismember(3)`: Query, whether a signal is included in a mask
- Set signals are blocked
- AVR analogue: EIMSK-register



- Setting the mask with

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

- how: Operation

- SIG_SETMASK: Sets an absolute signal mask
- SIG_BLOCK: Blocks signals relative to the current mask
- SIG_UNBLOCK: Unblocks signals relative to the current mask

- oset: Stores copy of old signal mask (optional)

- The signal mask is inherited when using fork(2)/exec(3)



Examples

```
01 sigset_t set;  
02 sigemptyset(&set);  
03 sigaddset(&set, SIGUSR1);  
04 sigprocmask(SIG_BLOCK, &set, NULL); /* Blocks SIGUSR1 */
```

- AVR analogue: Blocking critical sections (`cli()`, `sei()`)



■ Configuration using the struct sigaction

```
01 struct sigaction {  
02     void (*sa_handler)(int); // Handler function  
03     sigset_t sa_mask;        // Additionally blocked signals  
04     int sa_flags;            // More settings  
05 }
```

- Signal handler can be configured with sa_handler:
 - SIG_IGN: Ignore signal
 - SIG_DFL: Set to default signal handler
 - Function pointer
- SIG_IGN and SIG_DFL can be inherited with exec(3), function pointers can't. Why?
- AVR analogue: ISR(. .), alarm handler



■ Configuration with the help of the struct sigaction

```
01 struct sigaction {  
02     void (*sa_handler)(int); // Handler function  
03     sigset_t sa_mask;        // Additionally blocked signals  
04     int sa_flags;            // More settings  
05 }
```

- During the handling of a signal, following signals are disabled:
 - Signal mask upon the signal occurred
 - Additionally: Triggered signal
 - Additionally: Signals in sa_mask

⇒ Synchronization of multiple signal handlers with sa_mask



- Configuration with the help of the struct `sigaction`

```
01 struct sigaction {  
02     void (*sa_handler)(int); // Handler function  
03     sigset_t sa_mask;        // Additionally blocked signals  
04     int sa_flags;            // More settings  
05 }
```

- `man signal` shows the function `signal()`, which should NOT be used
- `sa_flags` influence the behavior when the signal is received
- For SLP: `sa_flags=SA_RESTART`



■ Configuration with the help of the struct sigaction

```
01 struct sigaction {  
02     void (*sa_handler)(int); // Handler function  
03     sigset_t sa_mask;        // Additionally blocked signals  
04     int sa_flags;            // More settings  
05 }
```

■ Applying the configuration

```
01 #include <signal.h>  
02  
03 int sigaction(int sig, const struct sigaction *act,  
04               struct sigaction *oact);
```



```
01 struct sigaction {  
02     void (*sa_handler)(int); // Handler function  
03     sigset_t sa_mask;        // Additionally blocked signals  
04     int sa_flags;            // More settings  
05 }
```

■ Installing a handler for SIGUSR1

```
01 #include <signal.h>  
02 static void my_handler(int sig) {  
03     // [...]  
04 }  
05  
06 int main(int argv, char *argv[]) {  
07     struct sigaction action;  
08     action.sa_handler = my_handler;  
09     sigemptyset(&action.sa_mask);  
10     action.sa_flags = SA_RESTART;  
11     sigaction(SIGUSR1, &action, NULL);  
12     // [...]  
13 }
```



- Problem: Waiting for a signal inside a critical section
 1. Unblock the signal
 2. *Passively* wait for the signal (go to *sleep mode*)
 3. Block signal
 4. Execute critical section
- Operations have to be executed atomically as one!

```
01 #include <signal.h>
02 int sigsuspend(const sigset_t *mask);
```

1. sigsuspend(2) sets a temporary signal mask
 2. Process is blocked until a signal is received
 3. Signal handler is executed
 4. sigsuspend(2) restores the original signal mask
- AVR analogue: Sleep loop, sleep_cpu()



- Block SIGUSR1 inside the critical section
- Wait for the signal

```
01 sigset_t sync_mask, old_mask;
02 sigemptyset(&sync_mask);
03 sigaddset(&sync_mask, SIGUSR1);
04
05 sigprocmask(SIG_BLOCK, &sync_mask, &old_mask);
06 while(!event) {
07     sigsuspend(&old_mask);
08 }
09 sigprocmask(SIG_SETMASK, &old_mask, NULL);
```



Description	Interrupts	Signals
Install handler	ISR() macro	sigaction(2)
Trigger	Hardware	Processes with kill(2) or operating system
Synchronization	cli(), sei()	sigprocmask(2)
Waiting for signals	sei(); sleep_cpu()	sigsuspend(2)

- Signals and interrupts are **similar concepts**
- Synchronization can usually be implemented identical

Task: mish



Handling the signal SIGINT

- Configuring the signal handler for CTRL+C
- SIGINT is send to all processes in the terminal

```
01 $> ./mish
02 mish> sleep 2
03 Exit status [5321] = 0
04 mish> sleep 10000
05 ^C                # CTRL+C
06 $>
```

⇒ On CTRL+C both sleep and mish get terminated

- Changing the signal handler:
 - Parent: ignore the signal (SIG_IGN)
 - Child: default behaviour (SIG_DFL)



Collection of zombie processes

- Until now: collection with `waitpid(2)` (blocking)
- Signal `SIGCHLD` indicates that a child process changed its state
 - child process got stopped
 - child process terminated
- Now: collection with `waitpid(2)` (not blocking)
- Waiting for the change of state with `sigsuspend(2)`



Support for background processes

- Commands with trailing '&'
⇒ background process
- Example: `./sleep 10 &`
- Output of the process ID and the prompt
- Afterwards new commands should be receivable

```
01 # Starting a background process with &
02 mish> sleep 10 &
03 Started [2110]
04 mish> ls
05 Makefile mish mish.c
06 Exit Status [2115] = 0
07 ...
08 Exit status [2110] = 0
```



Support for background processes

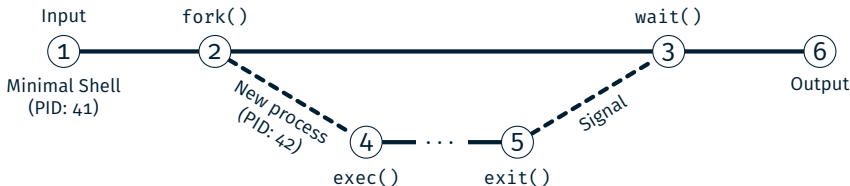
- While waiting for the termination of foreground processes, all terminating background processes should be collected immediately

```
01 # Starting multiple background processes
02 mish> sleep 3 &
03 Started [2110]
04 mish> sleep 5 &
05 Started [2115]
06 mish> sleep 10 &
07 Started [2118]
08
09 # Starting a foreground process
10 mish> sleep 20
11 Exit Status [2110] = 0      # sleep 3 &
12 Exit Status [2115] = 0      # sleep 5 &
13 Exit Status [2118] = 0      # sleep 10 &
14 Exit Status [2121] = 0      # sleep 20
15 mish>
```



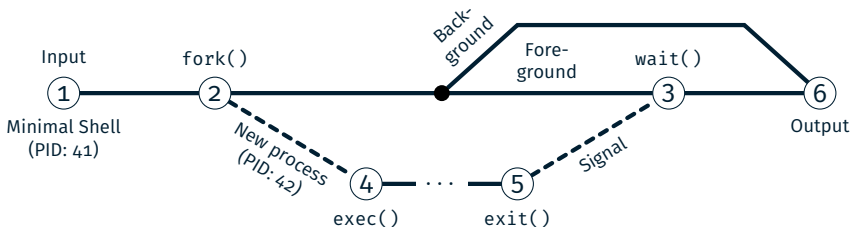
■ Extension of the basic cycle

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



■ Extension of the basic cycle

1. Waiting for input from the user
2. Creating a new process
3. Parent: Waiting for the termination of the child (*only foreground*)
4. Child: Starting program
5. Child: Program terminates
6. Parent: Outputting the state of the child





Next Week: Mock Exam (link to PDF will be on the website)

Hands-on: Stopwatch

Screencast: <https://www.video.uni-erlangen.de/clip/id/19835>



```
01 $ ./stopwatch
02 Press Ctrl+C (SIGINT) to start and stop
03 ^CStarted...
04 1 sec
05 2 sec
06 3 sec
07 4 sec
08 ^CStopped.
09 Duration: 4 sec 132 msec
```

■ Procedure:

- Stopwatch is started by signal SIGINT
 - Each second, the current duration is printed (format: "3 sec")
- Stopwatch is stopped again by the next occurrence of SIGINT
 - Prints duration incl. milliseconds (format: "4 sec 132 msec")
 - Terminates afterwards

■ Internally, SIGALRM and `setitimer(2)` are used

■ Remember to protect critical sections



1. Install signal handler: `sigaction(2)`

```
01 struct sigaction act;
02 act.sa_handler = SIG_DFL; // Signature of the handler: void f(int
    ↳  signal)
03 act.sa_flags = SA_RESTART;
04 sigemptyset(&act.sa_mask);
05 sigaction(SIGINT, &act, NULL);
```

2. Blocking/Unblocking of signals: `sigprocmask(2)`

```
01 sigset_t set;
02 sigemptyset(&set);
03 sigaddset(&set, SIGUSR1);
04 sigprocmask(SIG_BLOCK, &set, NULL); /* Blocks SIGUSR1 */
05 // critical section
06 sigprocmask(SIG_UNBLOCK, &set, NULL); /* Unblocks SIGUSR1 */
```



3. Waiting for signals: sigsuspend(2)

```
01 sigprocmask(SIG_BLOCK, &set, &old); /* Blocks signals */
02 while(event == 0){
03     sigsuspend(&old); /* Waits for signals */
04 }
05 sigprocmask(SIG_SETMASK, &old, NULL); /* Unblocks signals */
```



- Configure timer with `setitimer(2)`

```
01 #include <sys/time.h>
02
03 int setitimer(int which, const struct itimerval *new_value,
04               struct itimerval *old_value);
```

- Parameters:

which Here: `ITIMER_REAL` (physical time)

new_value Setting the new Configuration

old_value Reading the old configuration

- `SIGALRM`: Timer is expired or alarm occurred

→ Default handling: terminate program

→ Install custom signal handler



■ Structures for configuration

```
01 struct timeval {  
02     time_t      tv_sec;          /* seconds */  
03     suseconds_t tv_usec;        /* microseconds */  
04 };
```

Describes time interval with `tv_sec` s and `tv_usec` μ s

```
01 struct itimerval {  
02     struct timeval it_interval; /* Interval for periodic timer */  
03     struct timeval it_value;    /* Time until next expiration */  
04 };
```

First alarm after interval `it_value`
afterwards periodic alarm with interval `it_interval`

■ Special values

`it_interval = {0, 0}` Single shot alarm

`it_value = {0, 0}` Cancel alarm