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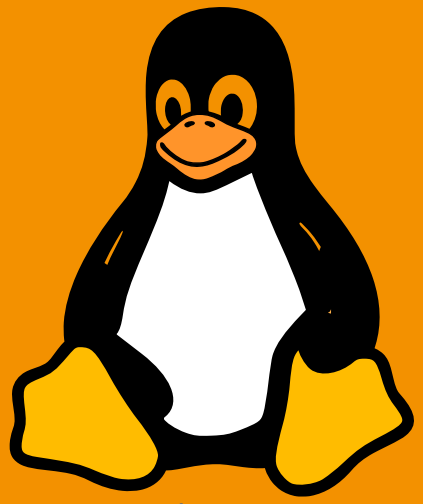
OS 6 – Synchronisation 1



source: iconspng.com

The lecture is based on the work and the documents of Prof. Dr. Ludwig Frank

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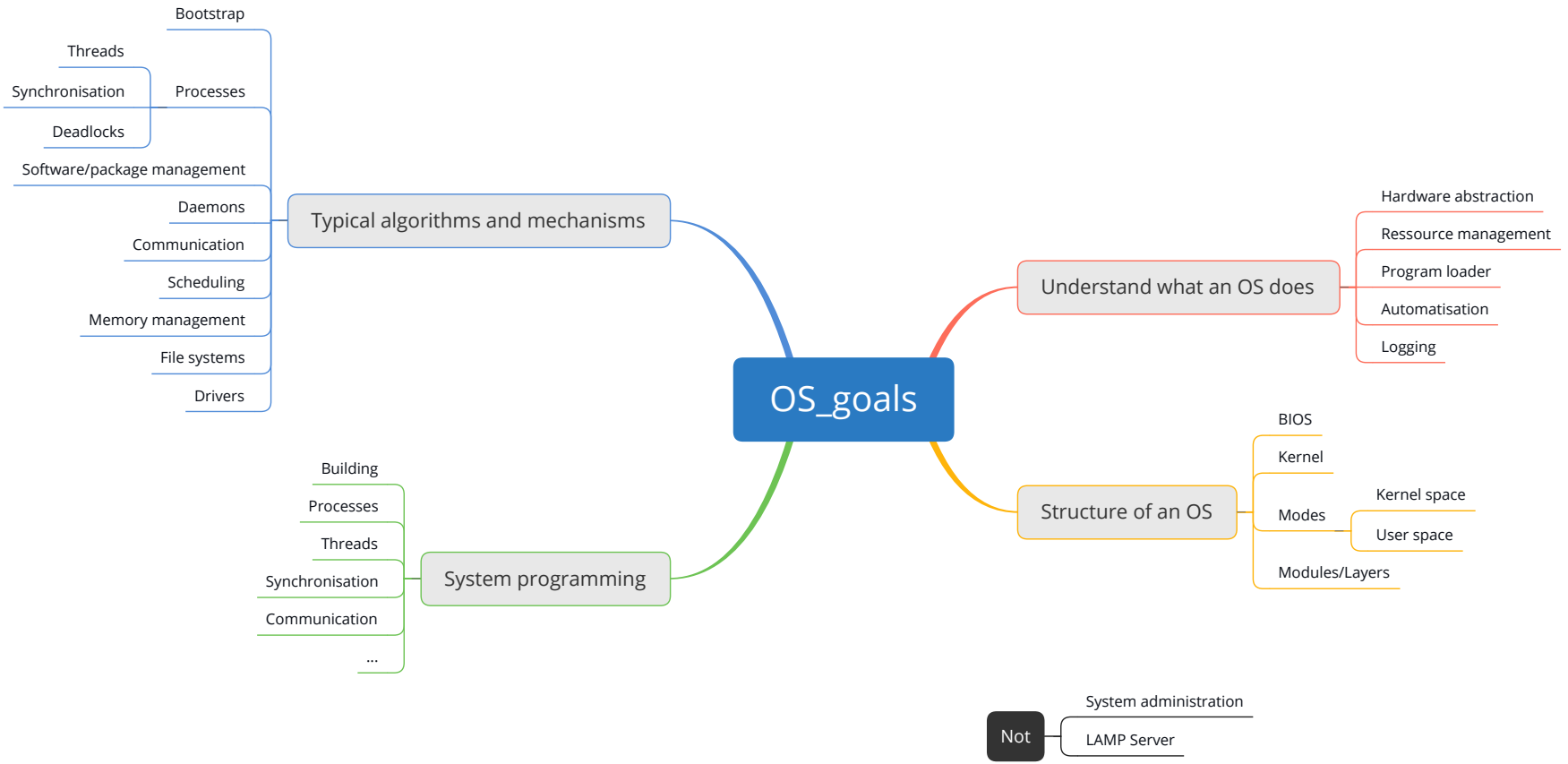
Goal



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Goal

OS::Synchronisation

- Understand synchronisation problems
- Mutual exclusion
- Semaphore (theoretical, practical)
- Lock-Files

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Intro

Parallelisation with processes and threads is nice, but...

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A problematic example

```
1  int global_counter = 0;

2  void* thread1() {
3    while(1) {
4      //increase counter
5      int counter = global_counter;
6      counter = counter + 1;
7      global_counter = counter;
8
9      produce_something(counter);
10   }
11 }
22 int main() {
23     //start threads...
24 }
```

```
12 void* thread2() {
13   while(1) {
14     //increase counter
15     int counter = global_counter++;
16
17
18
19     produce_something(counter);
20   }
21 }
```

The problem (1)

- Cause
  - Parallel read/write
  - Parallel use
- Problem
  - Read of unfinished data
  - (Partial) overwrite of data
- May occur **sporadic**: looks like undefined behaviour
- These kind of **bugs** are often **very hard to find**

It is called **race condition** (Konkurrenzbedingung)

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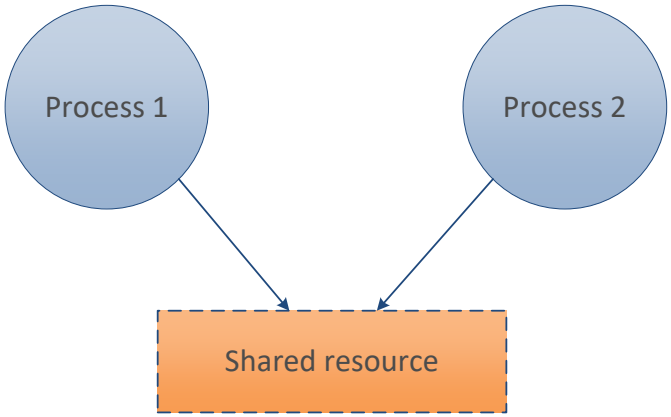
The problem (2)



Critical section

```
1 { //critical_section
2   //work with shared resource:
3   //- read/write
4   //- use
5 }
```

Solution: Mutual exclusion

"Gegenseiter Ausschluss"

- **Only one** process can **access** the **critical section**
- **Others** have to **wait**

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Towards synchronisation

Towards a synchronisation solution...

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Idea 1: Lock variables

```
1  int global_counter = 0;
2  int global_lock = 0;

3  void* thread1() {
4    while(1) {
5      while(global_lock == 1) {} //busy wait
6
7      global_lock = 1;
8        //increase counter
9        int counter = global_counter;
10       counter = counter + 1;
11       global_counter = counter;
12     global_lock = 0;
13
14     produce_something(counter);
15   }
16 }
```

```
17 void* thread2() {
18   while(1) {
19     while(global_lock == 1) {} //busy wait
20
21     global_lock = 1;
22       //increase counter
23       int counter = global_counter;
24       counter = counter + 1;
25       global_counter = counter;
26     global_lock = 0;
27
28     produce_something(counter);
29   }
30 }
```

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Idea 1: Lock variables (analysis)

```
1  int global_counter = 0;
2  int global_lock = 0;

3  void* thread1() {
4    while(1) {
5      while(global_lock == 1) {} //busy wait
6      //thread1 see: global_lock==0
7      //!! INTERRUPT: activate thread2 !!
8
9
10
11
12
13
14     global_lock = 1;
15     //...
16   }
17 }
```

```
18 void* thread2() {
19    while(1) {
20
21
22
23       while(global_lock == 1) {} //busy wait
24
25       global_lock = 1;
26         //increase counter
27         int counter = global_counter;
28         //!! INTERRUPT: activate thread1 !!
29
30
31    }
32 }
```

Problem: Both threads are in the critical section. **Solution useless!!!**

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Idea 2: Disable interrupts

```
1  int global_counter = 0;
2
3  void* thread1() {
4    while(1) {
5      disable_interrupts();
6        //increase counter
7        int counter = global_counter;
8        counter = counter + 1;
9        global_counter = counter;
10     enable_interrupts();
11
12     produce_something(counter);
13   }
14 }
```

Pro

- Easy solution

Con

- Only works on single core CPUs
- May disturb the scheduling
- May disturb the realtime behaviour
- Some interrupts can't be deactivated (depends on hardware)
- Danger: A process/thread doesn't activate interrupts again
- Program error in critical section

Conclusion

- Only in some parts of the OS kernel possible

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Semaphore

A working solution with semaphores...

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Semaphore: Idea

Idea

Instead of busy wait, a process/thread blocks (sleeps) until the critical area is free.

Operations

Operation	Description
`seminit(s, value)`	Creates and **initialises a semaphore (s)** with a value. The value is a number that specifies the number of processes that can simultaneously enter the critical area.
`P(s)`	**Wait** until the critical area is free (`value--`).
`V(s)`	**Releases** the critical area (`value++`).

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Semaphore: Usage

Basic usage

```
1 seminit(s, 1);
2
3 P(s);
4 //critical area..,
5 V(s);
```

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Semaphore: Types

Types	Initialisation	Description
Mutex	`seminit(s, 1)`	A **mutex** semaphore is used for **mutual exclusion**. Typically initialised with 1.
Binary	`seminit(s, 0)`	A **binary** semaphore is used when there is only **one shared resource**. Initialisation with 0/1 possible.
Counting	`seminit(s, N)`	A **counting semaphore** is used to handle more than one shared resource. Typically initialised with the number N of shared resources. Initialisation with 0/N possible.

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Semaphore: The role of the OS

The OS

- provides semaphores
- ensures that the `P()`/`V()` operations are atomic

The OS can reach this with

- disable process/thread changes (temporarily)
- disable interrupts (temporarily) (also process changes are not possible than)
- **use of a test-and-set (non-interruptible atomic) CPU instruction**

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Semaphore: Example implementation

Pseudo C code*

```
1  //Semaphore struct with a value and
2  //an internal list of waiting
3  //processes/threads
4  struct Semaphore
5  {
6    int value;
7    struct ProcessList process_list;
8  };
9  //initialises a semaphore with a value
10 void seminit(struct Semaphore* s, int value)
11 {
12   s->value=value;
13 }
```

```
14 void P(struct Semaphore* s)
15 {
16   if (s->value > 0) {
17     s->value--;
18   } else {
19     append_to(pid, s->process_list);
20     sleep(); //sleep indefinitely
21   }
22 }
23 void V(struct Semaphore* s)
24 {
25   if (is_empty(s->process_list)) {
26     s->value++;
27   } else {
28     int pid=pop_any(s->process_list);
29     wakeup(pid);
30   }
31 }
```

*Is used to demonstrate the internal functionality of `P()/V()`

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Counting semaphore example 1

Example with two threads and a mutual exclusion critical area:

Step	Thread	Operation	Semaphore value	Comment
0		`seminit(s, 1)`	1	semaphore is initialised with 1
1	thread 1	`P(s)`	0	thread 1 can enter the critical area
2	thread 2	`P(s)`	0	thread 2 has to wait
3	thread 1	`V(s)`	0	thread 1 leaves the critical area
4	thread 2		0	thread 2 wakes up and enters the critical area
5	thread 2	`V(s)`	1	thread 2 leaves the critical area

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Counting semaphore example 2

Example with three threads and an critical area where 2 threads can enter simultaneously:

Step	Thread	Operation	Semaphore value	Comment
0		`seminit(s, 2)`	2	semaphore is initialised with 2
1	thread 1	`P(s)`	1	thread 1 can enter the critical area
2	thread 2	`P(s)`	0	thread 2 can enter the critical area
3	thread 3	`P(s)`	0	thread 3 has to wait
4	thread 2	`V(s)`	0	thread 2 leaves the critical area
5	thread 3		0	thread 3 wakes up and enters the critical area
6	thread 3	`V(s)`	1	thread 3 leaves the critical area
7	thread 1	`V(s)`	2	thread 1 leaves the critical area

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Mutual exclusion: Pseudo C code

```
1  int global_counter = 0;
2  seminit(s, 1); //declare and initialise semaphore

3  void* thread1() {
4    while(1) {
5      P(s);
6        //increase counter
7        int counter = global_counter;
8        counter = counter + 1;
9        global_counter = counter;
10     V(s);
11
12     produce_something(counter);
13   }
14 }
27 int main() {
28     //start threads...
29 }
```

```
15 void* thread2() {
16   while(1) {
17     P(s);
18       //increase counter
19       int counter = global_counter;
20       counter = counter + 1;
21       global_counter = counter;
22     V(s);
23
24     produce_something(counter);
25   }
26 }
```

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Mutual exclusion: Example C code

Mutual exclusion with the POSIX semaphore API and named semaphores.

`sem_overview`: `http://man7.org/linux/man-pages/man7/sem_overview.7.html`

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Mutual exclusion: Example C code

Includes and definitions

```c
#include <stdio.h>     //printf, perror
#include <stdlib.h>    //EXIT_FAILURE, EXIT_SUCCESS
#include <fcntl.h>     //flags: O_CREAT, O_EXCL
#include <semaphore.h> //sem_open, sem_wait, sem_post, sem_close, sem_unlink
#include <pthread.h>   //pthread_*

#define SEMAPHORE_NAME "/global_counter" //name of semaphore
sem_t*   semaphore = NULL;               //pointer to semaphore
const int     PERM = 0600;               //permission to the semaphore (6 = r/w)

int global_counter = 0;                  //global counter
const int        N = 100000;             //number of iterations per thread
```

- semaphore.h: http://man7.org/linux/man-pages/man7/sem_overview.7.html
- https://www.softprayog.in/programming/posix-semaphores

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Mutual exclusion: Example C code

Semaphore functions

```
15 void create_semaphore() {
16     semaphore = sem_open(SEMAPHORE_NAME, O_CREAT, PERM, 1);
17     if(semaphore == SEM_FAILED){
18         perror("Error when creating the semaphore ...\n");
19         exit(EXIT_FAILURE);
20     }
21 }
22
23 void delete_semaphore() {
24     if(sem_close(semaphore) == -1){
25         perror("Error can't close semaphore ...\n");
26         exit(EXIT_FAILURE);
27     }
28
29     if(sem_unlink(SEMAPHORE_NAME) == -1) {
30         perror("Error can't delete (unlink) semaphore ...\n");
31         exit(EXIT_FAILURE);
32     }
33 }
```

- sem_open(): http://man7.org/linux/man-pages/man3/sem_open.3.html
- sem_close(): http://man7.org/linux/man-pages/man3/sem_close.3.html
- sem_unlink(): http://man7.org/linux/man-pages/man3/sem_unlink.3.html

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Mutual exclusion: Example C code

Thread function

```
35 //thread function
36 void* thread() {
37     for(int i = 0; i < N; ++i) {
38         sem_wait(semaphore); //P(s)
39             int counter = global_counter++;
40         sem_post(semaphore); //V(s)
41
42         //produce_something_with(counter);
43     }
44
45     return NULL;
46 }
```

- sem_wait(): http://man7.org/linux/man-pages/man3/sem_wait.3.html
- sem_post(): http://man7.org/linux/man-pages/man3/sem_post.3.html

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Mutual exclusion: Example C code

Main function

```
48 int main(int argc, char** argv) {
49     create_semaphore();
50
51     //start threads
52     pthread_t thread_id1, thread_id2;
53     pthread_create(&thread_id1, NULL, &thread, NULL); //error handling as usual...
54     pthread_create(&thread_id2, NULL, &thread, NULL);
55
56     //join threads
57     pthread_join(thread_id1, NULL); //error handling as usual...
58     pthread_join(thread_id2, NULL);
59
60     delete_semaphore();
61
62     //print result
63     printf("Counter: %d\n", global_counter);
64
65     return EXIT_SUCCESS;
66 }
```

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Linux commands

Named semaphores can be found in

`/dev/shm`

Example:

```
ls -l /dev/shm
-rw------- 1 flo flo 32 Nov 4 15:18 sem.global_counter
```

Remove a semaphore on the shell:

```
rm /dev/shm/sem.global_counter
```

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Mutual exclusion with lock files

Idea

- Use a file to simulate `P()`/`V()` operations
- The process/thread that can acquire the file lock can enter the critical section
- Not discussed in detail in this lecture

flock function

```
1 //flock - apply or remove an advisory lock on an open file
2 int flock(int fd, int operation);
```

For the interested people: `https://linux.die.net/man/2/flock`

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Summary and outlook

Summary

- Synchronisation problems
- Mutual exclusion
- Semaphore (theoretical, practical)
- (Lock-Files)

Outlook

- Producer-consumer problem
- Reader-writer problem
- Monitor concept