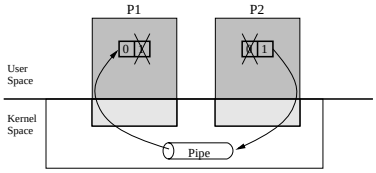
Labinstruction 2, Process Synchronization

- Process communication
- Shared memory
- Semaphores
- Signals
- Labinstruction

Process communication



Mechanisms:

- **pipes** - have we already looked at, no structured information.
- **message queues** - like pipes but with structured messages.
- **shared memory** - several processes can write and read to the same memory block.
- **semaphores** - used to synchronize access to common data structures.
- **signals** - software interrupts. Processes can define how to handle signals.

System V IPC

IPC = Interprocess Communication. A set of mechanisms for: Message Queues, Shared memory and Semaphores.

Message Queues

- Similar to pipes - they provide us with a mechanism to allow related processes to communicate.
- While a pipe can only be used to send "flat" messages (i.e. stream model), message queues can be used to send structured messages.
- We will not be looking at message queues in the lab course.

Shared memory

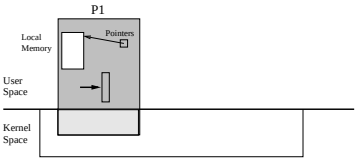
Problem:

- Global variables and memory obtained with `malloc(3)` are local to the calling process.
- Processes created with `fork()` get only *copies* of all data, so subsequent changes are local to the process that made them.
- Sometimes we want to allow separate cooperating processes to share access to the *same* data structure, i.e. changes are seen by other processes.

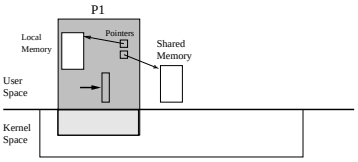
Shared memory addresses these problems.

- One process allocates shared memory for common data structures, maintains pointer.
- Other processes created using `fork()` get copy of pointer but *same* allocated block.
- Subsequent changes to structure are seen by all processes.

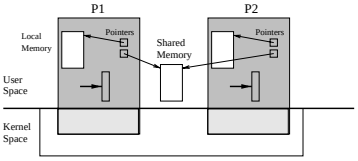
Shared memory, continued.



After P1 has allocated local memory.



After P2 has allocated shared memory.



After a new process, P2, has been created using `fork()`. P2 gets a copy of P1's local memory block. Both P1 and P2 can access the same shared memory block. There is no difference in the usage of the different memories.

Shared memory, continued

- `malloc(3)` is a way of dynamically allocating memory: `void *malloc(size_t m);`
- `malloc(3)` returns a `void` pointer to a block of at least `size` bytes suitably aligned, or `NULL` on failure. The size of `m` is normally calculated with the `sizeof` operator to be movable between architectures.
- The pointer has to be type converted to a pointer of a suitable memory type:

```
int *ip;          /* Declare an integer pointer */
ip = (int *) malloc(100 * sizeof(int));
    /* Allocate a block of size of 100 integers */
ip[5] = 3;        /*  Put 3 in the 6:th element */
```

- For shared memory we have two operations defined, corresponding to the standard library functions `malloc(3)` and `free(3)`:
  - `void *shmalloc(size_t size);` – allocate a block of `size` bytes of shared memory.
  - `int shfree(void *ptr);` – release a block of shared memory.
- There is no manual pages available for these shared memory functions.

Synchronization

We need a way to synchronize access to the common data objects. Code example:

```
/* Some initialization */
int *sh_var = NULL;
sh_var = (int *) shmalloc(sizeof(int));
*sh_var = 1;

/* Create a new process */
fork();

/* Both processes goes here */
if(*sh_var == 1)
{
   do_something();
   *sh_var = (*sh_var) + 1;
}
```

Indeterministic behaviour:
`sh_var` might both have 2 and 3 as its final value.

- `sh_var = 2`: if one process runs the `if`- statement, calls `do_something()` and increases `sh_var` without getting interrupted.
- `sh_var = 3`: if one gets interrupted after the `if`- statement but before the increase of `sh_var`. The second one will also run the body of the `if`- statement, because `sh_var` still is equal to 1. Both processes will finally increase the `sh_var` variable.

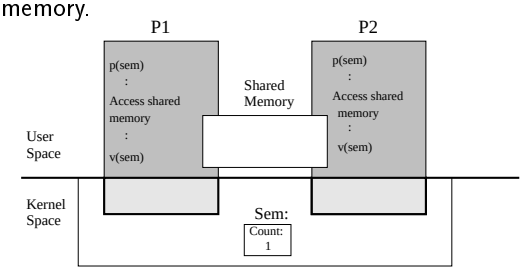
Semaphores

Semaphores are used to synchronize access to common data structures, such as those created using the shared memory facility.

- Abstract datatype with two operations defined on it `semwait` (or `p`) and `semsignal` (or `v`).
- Each semaphore has an internal counter to represent the number of available resources,e.g how many processes are allowed to simultaneous access a object.
- Each time a process does `semwait` on a semaphore, the counter is decremented with 1 and the process is allowed to proceed. However, if the counter was at zero, then `semwait` will cause the calling process to block until another process increments the counter again.
- `semsignal` increments the counter with 1, and if any processes are blocked waiting for the semaphore at the time, one of them (but we don't know which one) will be unblocked and allowed to proceed.

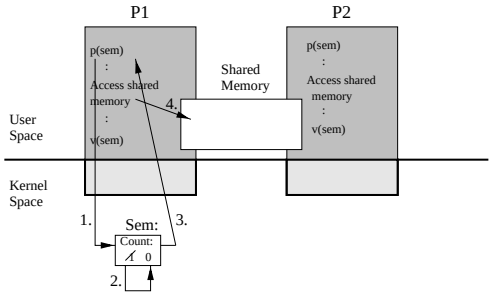
Semaphores continued

A semaphore can be used to synchronize access to shared memory.



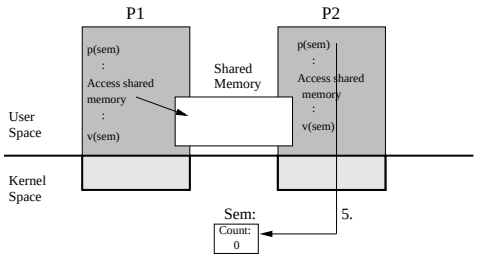
- **Mutual exclusion:** Only one process at a time shall have access to an object. By using a semaphore with 1 as its internal counter only one process at a time can access the shared memory.
- **Critical sections:** The sections in the code where the shared memory is accessed. These must mutual exclusive between the processes.

Semaphores continued



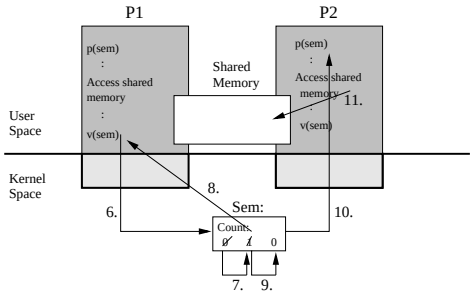
1. Process P1 wants to read from shared memory and makes a `p(sem)` system call.
2. The OS gets control and decreases the internal counter of the semaphore.
3. The control is returned to P1.
4. P1 can access and manipulate the shared memory.

Semaphores continued



5. Process P2 also wants to read from the shared memory and makes a `p(sem)` system call. But when the internal counter of the semaphore is equal to zero the calling process will be blocked.

Semaphores continued



6. When P1 doesn't want to access the shared memory any more it makes a `v(sem)` call.
7. The OS gets control and increases the internal counter of the semaphore.
8. The control is returned to P1 that continues executing.
9. Next time P2 gets scheduled by OS the OS sees that it is suspended on the semaphore and that the internal counter of the semaphore is equal to 1. The OS decreases the internal counter of the semaphore.
10. The control is returned to P2.
11. P2 can access and manipulate the shared memory.

Semaphores continued

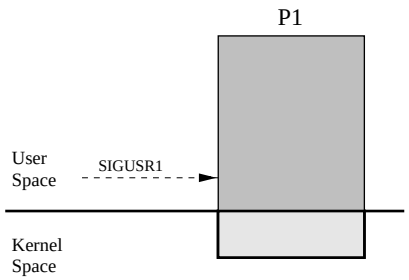
The standard operations on semaphores are:

- `semid_t semcreate(int n);` – create a semaphore with an initial count of `n`.
- `int semwait(semid_t sem);` – obtain the semaphore `sem`.
- `int semsignal(semid_t sem);` – release the semaphore `sem`.
- `int semdestroy(semid_t sem);` – free the semaphore `sem`.

These operations, like `shmalloc()` and `shfree()`, are declared in `process_synch/ipc.h` in the course directory `/stud/docs/kurs/os/`.

Signals

- *Signals* are short (one byte) messages sent to a process, usually in response to some abnormal event.
  For example: `SIGKILL == 9`.
- Signals are asynchronous and can be sent to a process at anytime, independent of the process state.
- The effect of receiving a signal is much like the occurrence of a software trap.
- There are 29 system defined signals.
- There are 2 user defined signals.



Process P1 get a `SIGUSR1` signal.

Handling Signals

A process receiving a signal can act in a number of different ways, in particular:

- it can perform the *default action* associated with the signal.
- it can *ignore* the signal. This means that all such signals are to be discarded (i.e. never delivered).
- it can *block* the signal. The kernel queues blocked signals for delivery at some later time.
- it can *catch* the signal, by installing a special *signal handler* to respond to and deal with the signal.

There are 2 notable exceptions to this rule: `SIGKILL` and `SIGSTOP` cannot be caught, blocked or ignored – we must use the default action.

Default Actions

The default action for most signals is to terminate. In addition, many of the signals cause the receiving process to dump core.

These signals cause the process to terminate:

- `SIGHUP` hangup
- `SIGINT` interrupt
- `SIGKILL` kill (cannot be caught, blocked, or ignored)
- `SIGPIPE` write on a pipe or other socket with no one to read it
- `SIGTERM` software termination signal
- `SIGXCPU` cpu time limit exceeded
- `SIGUSR1` user-defined signal 1
- `SIGUSR2` user-defined signal 2

These cause the process to terminate and dump core:

- `SIGQUIT` quit
- `SIGTRAP` trace trap
- `SIGABRT` abort
- `SIGFPE` arithmetic exception
- `SIGBUS` bus error
- `SIGSYS` bad argument to system call

Default Actions

Some of the signals cause the process to stop, i.e. block until allowed to continue:

- `SIGSTOP` stop (cannot be caught, blocked, or ignored)
- `SIGTSTP` stop signal generated from keyboard
- `SIGTTIN` background read attempted from control terminal
- `SIGTTOU` background write attempted to control terminal

These signals are normally ignored:

- `SIGCONT` continue after stop
- `SIGURG` urgent condition present on socket
- `SIGCHLD` child status has changed
- `SIGIO` I/O is possible on a descriptor
- `SIGWINCH` window changed

Signal Actions

If a process wishes to *ignore* a particular signal, say `SIGUSR1`, it must do the following:

```
signal(SIGUSR1, SIG_IGN);
```

It can restore the default action like this:

```
signal(SIGUSR1, SIG_DFL);
```

A signal can be blocked, i.e. queued for delivery at a later time:

```
mask=sigmask(SIGUSR1);
org_mask=sigblock(mask);
```

If the process later wants the default action for the signal to be reinstated, it can do this:

```
sigsetmask(org_mask);
```

At this time, queued signals will be delivered.

Catching signals

To *catch* a signal, we must first declare (and define) a function to act as a signal handler:

```
void sigusr1_handler()
{
   fprintf(stderr,"Ouch!\n");
}
```

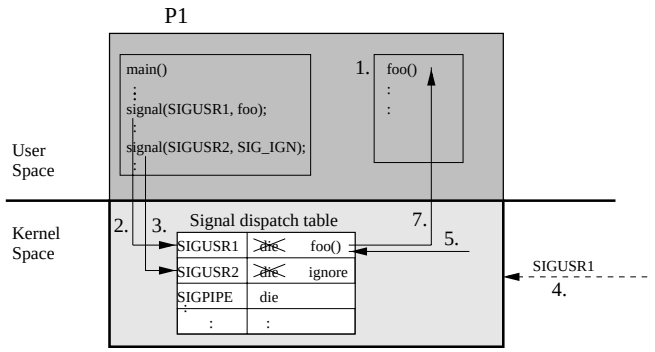
Then the process must register the function with the kernel:

```
signal(SIGUSR1, sigusr1_handler);
```

Later, when the process receives the signal (`SIGUSR1` in this case), the function `sigusr1_handler` will be called.

Different handlers can be created for different signals.

Catching signals, continued



1. foo() is declared.
2. `main()` calls `signal(SIGUSR1, foo)` which declares `foo()` as `SIGUSR1` signal handler.
3. `main()` calls `signal(SIGUSR2, SIG_IGN)` which tells the kernel to ignore the `SIGUSR2` signal.
4. Later the process gets a `SIGUSR1` signal.
5. The signal handler for `SIGUSR1`, will be looked up in the signal dispatch table.
6. (The system reinstalls the default handler for `SIGUSR1`.)
7. The function `foo()` is found and called.

Sending Signals

We can send some of the more common signals directly from the keyboard.

`stty` shows us (among other things) what keys to use:

```
$ stty -a
[...]
susp   intr   quit
^Z     ^C     ^\
```

Here we see that the following mappings are in effect:

Ctrl-Z ⇒ `SIGTSTP`
Ctrl-C ⇒ `SIGINT`
Ctrl-\ ⇒ `SIGQUIT`

When we press any of these keys, the corresponding signal is sent to the foreground process in that window.

Sending Signals, cont.

We can use the program `kill(1)` to send signals to our processes.

Send `SIGTERM` to a process with process identifier 16743:

```
$ kill 16743
```

Send `SIGKILL` to a process (can't be ignored):

```
$ kill -KILL 16743 or  kill -9 16743
```

Stop a process:

```
$ kill -STOP 16743
```

Continue a process after `SIGSTOP`:

```
$ kill -CONT 16743
```

Sending Signals, cont.

We can use the system call `kill(2)` to send signals between processes:

```
#include <signal.h>
kill(pid,SIGUSR1);
```

(We assume here that the receiving process handles `SIGUSR1`)

Whenever a child process exits, a `SIGCHLD` signal is automatically sent to the parent. This gives us a simple way to avoid zombies:

```
void child_handler()
{
   int status;
   wait(&status);
   signal(SIGCHLD, child_handler);
}

main() {
...
signal(SIGCHLD, child_handler);
...
}
```

Lab 2 - Process Synchronization

This lab consists of three parts (as before):

- Using the tools that are available
- Adding synchronization to an existing program
- Writing a program that solves one of the "classical" synchronization problems

Tools

Goal: learn how to examine and manage IPC objects.

The two tools we will use are:

- `ipcs` – examine IPC objects
- `ipcrm` – remove IPC objects

Steps:

- Read the manual pages!
- Use the test program found in the course directory to create IPC objects
- IPC is an expensive resource - determine system limits

Adding Synchronization

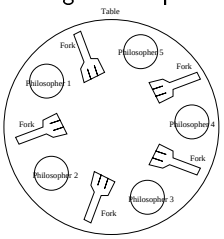
Goal: Put synchronization in the right places to make the pencil program work appropriately.

- The program simulates a pencil factory.
- The program creates a number of processes to make pencils, and one process to provide them with supplies when necessary.
- Read the section in the lab handout on synchronisation theory for an introduction.
- The compiled version in the course directory works correctly.
- Add necessary synchronisation mechanisms only in `manufacture` and `supply` functions.
- Not necessary to hand in entire program, just these two functions.

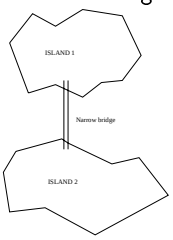
Classical synchronization problem

Choose one of the two suggested problems:

Dining Philosophers



Narrow Bridge



You need to solve the problem and show informally that it is correct:

- Describe the necessary conditions for deadlock and how to avoid it
- Explain deadlock and starvation in terms of the problem you are solving
- Show why your solution is deadlock free
- Show how you have avoided starvation

Compiling

The "real" interface to the System V IPC functions is rather complex so a simple one has been provided for the lab. It is declared in `ipc.h` and defined in `libipc.a`.

- Make (soft) links to the files in your work directory:

```
$ ln -s /stud/docs/kurs/os/process_synch/libipc.a .
$ ln -s /stud/docs/kurs/os/process_synch/ipc.h .
```

- include `ipc.h` in your program

```
#include "ipc.h"
```

- compile with:

```
$ gcc -o prog prog.c -L. -lipc
```

Finally

Remove all IPC objects!!!!!!!!!

They will not disappear when you log out!