Real-Time Operating Systems (0_KRI)
The POSIX Standard I

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Outline

The POSIX Standard

- The first version of the POSIX (Portable Operating System Interface for Computing Environments) standard was published between 1988 and 1990. It specifies a standard way for applications to interact with the operating system.
- Nowadays, POSIX is a set of over 30 standardisation documents, which span from the definition of the basic services an operating system shall provide, up to the specification of analysis methods to check whether a given operating system complies with the standard.
- Among these documents, of special interest for us is the System Interfaces (XSH) volume of IEEE Std 1003.1-2004, which specifies a C language interface between applications and the operating system, and includes real-time extensions.
- The standard defines the semantics of the system services, the way of using them by means of the C language, including notes on portability and error detection and recovery.

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POSIX and Real-Time

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Since 1993, the POSIX standard was extended to make it more suitable and useful for real-time applications. In particular, the following extension were adopted:

Standard	Description
1003.1b	Basic real-time extensions; first published in 1993
1003.1c	Threads extensions; published in 1995
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Where is the Standard?

The Open Group

The main volumes of IEEE Std 1003.1-2004, also known as the "Single UNIX Specification, Version 3", are available for download (free registration required), at the following URL:

http://www.unix.org/version3/online.html

Dynamic vs. Static Process Creation

- In some real-time applications the set of processes needed to carry out the job is known in advance, and remains the same for the whole life of the system.
- Accordingly, several real-time operating systems support the static configuration of the set of processes to be executed, and can take advantage from the additional information they have available about them.
- Instead, POSIX provides a set of functions to dynamically create new processes at will. In particular, `fork` duplicates the calling process and `exec` replaces the current process image with a new one.
- In addition, the `exit` function terminates the calling process, `wait` blocks the calling process until one of its child processes terminates, and `kill` sends a signal to a process.

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Process Hierarchy

In POSIX, processes are organized as a hierarchical tree.

- When the operating system is booted, it crafts the ancestor of all other processes, traditionally named `init`.
- When a process creates another process, by invoking `fork`, it becomes its parent.
- Each process has exactly one parent, and zero or more children.
- Each process has its own process identifier, that is guaranteed to uniquely identify it during all its lifetime.
- The process identifier is used whenever it is necessary to make a reference to the process, for example when sending it a signal.

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Semantics of Fork

```
pid_t fork(void);
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- `fork` creates a new process that is almost an exact copy of the calling process. After a successful `fork`, both processes execute concurrently the statements that follow the `fork` call.
- The two processes mainly differ for the following:
  - The child process has its own, unique process identifier.
  - The return value of `fork` is the reserved value 0 in the child process, and the process identifier of the child in the parent.
  - The child process has its own copy of the parent's descriptors, but they reference the same underlying objects.
- The reserved value -1 is returned by `fork` to inform the caller that an error occurred. In this case, as for many other functions, the `errno` variable gives more information about the error.

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An Example of Fork

Process X (parent)

```
1.  ... A ...
2.  r = fork();
3a. ... B ...
```

Process Y (child)

```
    ... A ...
    r = fork();
3b. ... B ...
```

- The parent executes the statement `A`, and then `fork`.
- `fork` creates the child process.
- Both processes concurrently execute the statement `B`.
- The parent and the child process have different values of `r` after the `fork`:
  - `r` is 0 in the child process.
  - `r` is the child process identifier (always $\neq 0$) in the parent process.
- For example, in `B` we may evaluate `if (r) ...` to distinguish between the parent and the child.

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An Example of Exec

Process X

```
1. ... A ...
2. x = execve("newp",...); » » » main() (of "newp")
   ... B ...
```

- "`exec`" is the generic name of a group of functions; `execve` is one of them.
- Process X executes the statement `A`, then `execve()`.
- The statement `B`, that follows the `execve()` call, is never executed, unless `execve()` fails.
- Instead, the execution continues at the entry point of the new executable image, that has been loaded from file `newp`.
- The process identifier does not change.

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Process Termination

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

- The `exit` function explicitly terminates the calling process when invoked.
- The function makes the low-order 8 bits of the `status` argument available to the parent process.
- The same result can also be obtained implicitly, by using `return` from `main()`. In this case, the behavior is the same as calling `exit` with the returned value. Moreover, reaching the end of `main()` is the same as performing `exit(0)`.
- In any case, a number of cleanup activities are carried out before terminating, for example:
  - Call the cleanup functions registered with `atexit` and `on_exit`.
  - Flush and close all open streams.
  - Unlink all temporary files.

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Waiting for Process Termination

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

- This function returns to the calling process the `status` information about one of its terminated children, waiting for child termination if necessary.
- Upon successful completion, `wait` return value is the process identifier of the child for which it is giving the status information.
- In this case, `status` contains the exit code of the child in its low-order 8 bits, and other status information in the others.
- `wait` returns to the caller prematurely, with the reserved return value -1, if an error occurs.
- An extended function, `waitpid`, allows the caller to be more specific about which children it is interested in, and to set additional options.

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- Upon successful completion, `wait` return value is the process identifier of the child for which it is giving the status information.
- In this case, `status` contains the exit code of the child in its low-order 8 bits, and other status information in the others.
- `wait` returns to the caller prematurely, with the reserved return value -1, if an error occurs.
- An extended function, `waitpid`, allows the caller to be more specific about which children it is interested in, and to set additional options.

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Order of Termination and Wait

The standard does not make any assumption on the relative order between the child termination and the parent waiting for it.

- A child can terminate before its parent waits for it. In this case, barring some special circumstances, it is transformed into a *zombie* process, that is:
  - its process identifier remains allocated, and
  - its status information remains available for later retrieval.
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Killing a Process

Voluntary and involuntary termination

Besides voluntary termination, a POSIX process can also be terminated involuntarily, as a consequence of catching a signal raised against it by another process.

- The involuntary termination of a process is prone to several nasty side effects, especially when the process is involved in concurrent programming activities.
- As a consequence, except for several special signals, each process has some freedom to decide whether to catch signals or not, and how to react to them.
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int kill(pid_t pid, int sig);
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- The `kill` function sends a signal to the process whose process identifier is `pid`.
- The `sig` specifies which signal shall be sent, among the signal types supported by the system.
- Like many other POSIX functions, `kill` returns to the caller an integer value that is zero if it was executed succesfully, and is -1 otherwise.
- Several special values of `pid` are used to indicate that the signal shall be sent to a group of processes.
- The right for a process to send a signal to another process is subject to some security-related restrictions, related to their owning users and to their relative position in the process hierarchy.

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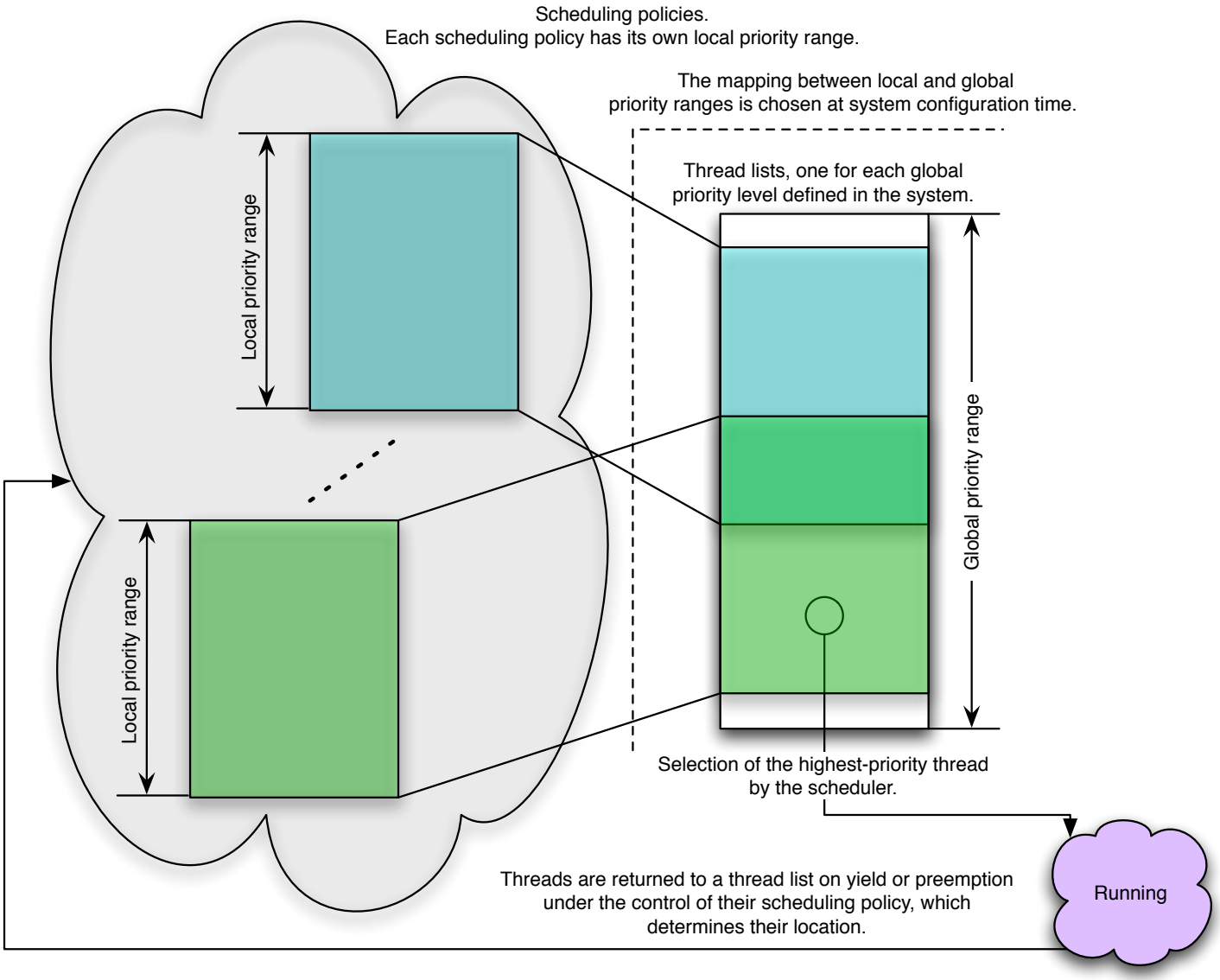

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- The abstract POSIX scheduling model foresees an ordered thread list for each global priority level defined in the system. It contains all ready threads for that priority.
- To assign a CPU, the scheduler extracts the thread from the head of the highest-priority, non-empty thread list (like the fixed priority scheduling with priority classes does). That thread becomes running and is removed from the list.
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- The mapping of each local priority range, one for each scheduling policy, into the global priority range is defined during system configuration, and cannot change thereafter.
- Partial or total overlaps between different local priority ranges when they are mapped into the global priority range are allowed.
- The standard specifies the following scheduling policies:

`SCHED_FIFO`: First in, first out
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- When a running thread is preempted, that thread is placed at the head of the thread list it belongs to.
- When a thread transitions from blocked to ready, it is placed at the tail of the thread list it belongs to.
- When the priority of a running or ready thread is modified, it is placed at the tail of the thread list that corresponds to its new priority, except when `pthread_setschedprio` has been used.
- In the latter case, the placement depends on the sign of the priority change, namely:
  - If the priority has been increased, it is placed at the tail.
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SCHED_RR, SCHED_OTHER

- The `SCHED_RR` scheduling policy is quite similar to `SCHED_FIFO`, but:
  - When the system detects that a thread has been running for a full quantum, it is forced to return to the ready state, and placed at the tail of the thread list it belongs to, thus forcing a rescheduling.
  - The length of the quantum is a system configuration parameter and cannot be changed dynamically.
- The `SCHED_OTHER` scheduling policy is the default scheduling policy of the operating system, and may be unsuitable for real-time.
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Scheduler Control

The process-level functions for scheduler control are:

Nome	Scopo
`sched_get_priority_max`	Maximum priority of a policy
`sched_get_priority_min`	Minimum priority of a policy
`sched_getparam`	Get scheduling parameters
`sched_getscheduler`	Get scheduling policy
`sched_rr_get_interval`	Round robin quantum length
`sched_setparam`	Set scheduling parameters
`sched_setscheduler`	Set scheduling policy and its parameters
`sched_yield`	Voluntary yield

Include `sched.h` before using any of these functions.

Priority Range

These functions return the maximum and minimum priority value allowed for a given scheduling policy:

```
int sched_get_priority_max(
   int POLICY);

int sched_get_priority_min(
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Both functions have `POLICY` as argument, to uniquely identify a scheduling policy, and return an integer priority value. The symbolic constants to be used for `POLICY` are defined in `sched.h`.

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These functions get and set the scheduling parameters of a process:

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- Simple policies, like `SCHED_FIFO` and `SCHED_RR`, have only one scheduling parameter, namely `.sched_prio`. It represents the priority of the process.
- More complex policies, for example `SCHED_SPORADIC`, have more parameters.
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Scheduling Policy

These functions get and set both the scheduling policy and the scheduling parameters of a process:

```
int sched_getscheduler(
   pid_t PID);

int sched_setscheduler(
   pid_t PID,
   int POLICY,
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- `sched_getscheduler` returns an integer that represents the current scheduling policy of process `PID`.
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Other Functions

- The function:

```
int sched_rr_get_interval(
   pid_t PID,
   struct timespec *INTERVAL);
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  stores into the data structure pointed by `INTERVAL` the round-robin quantum length for process `PID`. It returns zero on success, a non-zero value on error.

- The function:

```
int sched_yield(
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Semaphores

The following functions of IEEE Std 1003.1-2004 are related with semaphores:

Nome	Scopo
`sem_init`	Initialize an unnamed semaphore
`sem_destroy`	Destroy an unnamed semaphore
`sem_open`	Create/open a named semaphore
`sem_close`	Close a named semaphore
`sem_unlink`	Remove a named semaphore
`sem_wait`	*P*() on a semaphore
`sem_post`	*V*() on a semaphore
`sem_trywait`	Non-blocking *P*() (polling)
`sem_getvalue`	Get current semaphore value

The `SEM_VALUE_MAX` macro, defined in `semaphore.h`, gives the maximum value allowed for semaphores.

Initialization

The following function creates a fresh, unnamed semaphore:

```
int sem_init(
   sem_t *SEM,
   int PSHARED,
   unsigned int VALUE);
```

The function:

- Initializes the data structure, pointed by `SEM`, that will represent the semaphore.
- Sets the initial value of the semaphore to `VALUE`.
- The `PSHARED` argument, when not zero, indicates that the semaphore may be shared among multiple processes (the semaphore is always shared among all threads belonging to the same process).

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The following function destroys an unnamed semaphore:

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int sem_destroy(
   sem_t * SEM);
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- When destroying a semaphore, all process blocked on it are unblocked immediately.
- These processes get to know that the semaphore has been destroyed because, in this case, `sem_wait` returns a non-zero error code.

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Semaphore Sharing

- `sem_init` creates unnamed semaphores, hence they can be used only by the processes that know their descriptor.
- The descriptor (when stored into a global variable) is implicitly shared among all threads belonging to the same process, because they share the same address space.
- By contrast, copying a descriptor does non produce a valid descriptor. Hence, the usual address space inheritance mechanism put in place by `fork()` does not produce valid descriptors.
- To share a descriptor, it is necessary to store it into a shared memory segment, and map it into the address spaces of all the processes interested in it.

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Named Semaphores – Open

A process can gain access to a named semaphore by invoking:

```
sem_t *sem_open(
   const char *NAME, int OFLAG, ...);
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Where:

- `NAME` is the name of the semaphore.
- `OFLAG` contains a set of flags that change several aspects of the function behavior (like with `open()`).
- The additional arguments depend on the value of `OFLAG`.

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`OFLAG` is the inclusive or of a set of flags that change several aspects of the behavior of `sem_open`. The most important ones are:

`O_CREAT` when set allows `sem_open` to create the semaphore if it does not exist yet.

`O_EXCL` when set together with `O_CREAT`, makes `sem_open` fail if the semaphore already exists.

The value of `OFLAG` determines which additional arguments must follow `OFLAG` itself in the argument list. For example, if `OFLAG` contains `O_CREAT` two additional arguments are required, to specify the protection attributes of the semaphore and its initial value. `sem_open` returns a null pointer on error.

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Named Semaphores – Close/Unlink

- The function:

```
int sem_close(
   sem_t *SEM);
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  cuts the link between the calling process and the semaphore `SEM`, and returns a non-zero value on error. No more operations on `SEM` are allowed after a successful invocation of `sem_close`.

- The function:

```
int sem_unlink(
   const char *NAME);
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  asks the system to delete the semaphore `NAME` as soon as the number of processes linked to it drops to zero. It returns a non-zero value on error.

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P() and Polling

A thread executes a *P*() on a semaphore (either blocking or non-blocking), by means of the functions:

```
int sem_wait(sem_t *SEM);
   int sem_trywait(sem_t *SEM);
```

- `sem_wait` is equivalent to the abstract synchronization primitive *P*() and is a cancellation point. It returns a non-zero value on error: in particular, the destruction of an unnamed semaphore while one or more processes are waiting on it is reported as an error condition.
- `sem_trywait` is the non-blocking variant of `sem_wait`. If it is unable to immediately conclude the *P*() (becase the semaphore value is zero at the moment), `sem_trywait` immediately returns to the caller a non-zero value instead of waiting.
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The function:

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is the timed variant of `sem_wait`, where `ABS_TIMEOUT` represents an absolute time reference. When it is unable to conclude the *P*() before that time, this function returns a non-zero error code.

- When the function fails, the value of `errno` gives more information about the exact nature of the error (it may actually be a timeout, or something else).
- Specifying an absolute time reference, instead of a relative reference, is useful to contain the uncertainty of time measurements in the system.

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$V()$ and Semaphore Value

- A thread executes a $V()$ on semaphore `SEM` through the function:

```
int sem_post(sem_t *SEM);
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`sem_post` never blocks the caller, and is not a cancellation point. It is forbidden to increment a semaphore beyond the maximum value `SEM_VALUE_MAX`.

- It is possible to get the current value of semaphore `SEM` and store it into the location pointed by `SVAL` with the function:

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Is sem_getvalue useful?

`sem_getvalue` is not as useful as it seems, because it is not executed atomically with respect to any other synchronization primitive.

For example, this is not a valid substitute for `sem_trywait`:

```
sem_t sem;
int sval, wait_result;
...
sem_getvalue(&sem, &sval);
if(sval > 0)  wait_result = sem_wait(&sem);
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Another process may change the semaphore value between the invocation of `sem_getvalue` and `sem_wait`.

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Shared Memory

The main functions dealing with shared memory are:

Nome	Scopo
`shm_open`	Open/create a shared memory segment
`close`	Close a shared memory segment
`shm_unlink`	Remove a shared memory segment
`mmap`	Map a shared memory segment into the caller's address space
`munmap`	Remove a mapping made by `mmap`

Include `sys/mman.h` before using any of these functions.

Open/Close/Unlink (I)

The functions:

```
int shm_open(const char *NAME, int OFLAG,
    mode_t MODE);
int close(int FD);
int shm_unlink(const char *NAME);
```

do the same as their counterparts for named semaphores, but work on shared memory segments. Each shared memory segment is represented by a file descriptor, that is, an integer value.

Open/Close/Unlink (II)

- Opening a shared memory segment does not automatically perform any mapping of the segment into the address space of the calling process. Hence, `sem_open` does not make the shared memory segment addressable in any way.
- The standard does not specify whether the contents of shared memory segments are preserved across system bootstraps.
- `shm_open` returns either a file descriptor (never negative), or a negative value (on error). Both `close` and `shm_unlink` return a non-zero value on error.

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Mapping – mmap()

The function:

```
void *mmap(
   void *ADDR, size_t LEN,
   int PROT, int FLAGS,
   int FILDES, off_t OFF);
```

maps a portion of the shared memory segment `FILDES` starting from the given offset `OFF` into the caller's address space.

- `LEN` represents the size of the mapping, in bytes.
- `PROT` denotes how the mapped region can be accessed. It is the bitwise inclusive or of: `PROT_READ`, `PROT_WRITE`, and `PROT_EXEC`.
- `ADDR` allows the caller to "suggest" to the system where in the address space the mapped region should be placed.
- `FLAGS` indicates how the mapped region will be manipulated (see the next slide).

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- `ADDR` allows the caller to "suggest" to the system where in the address space the mapped region should be placed.
- `FLAGS` indicates how the mapped region will be manipulated (see the next slide).

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The function:

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mmap() Flags

The `FLAGS` argument of `mmap()` is the bitwise inclusive or of a set of flags. The most important ones are:

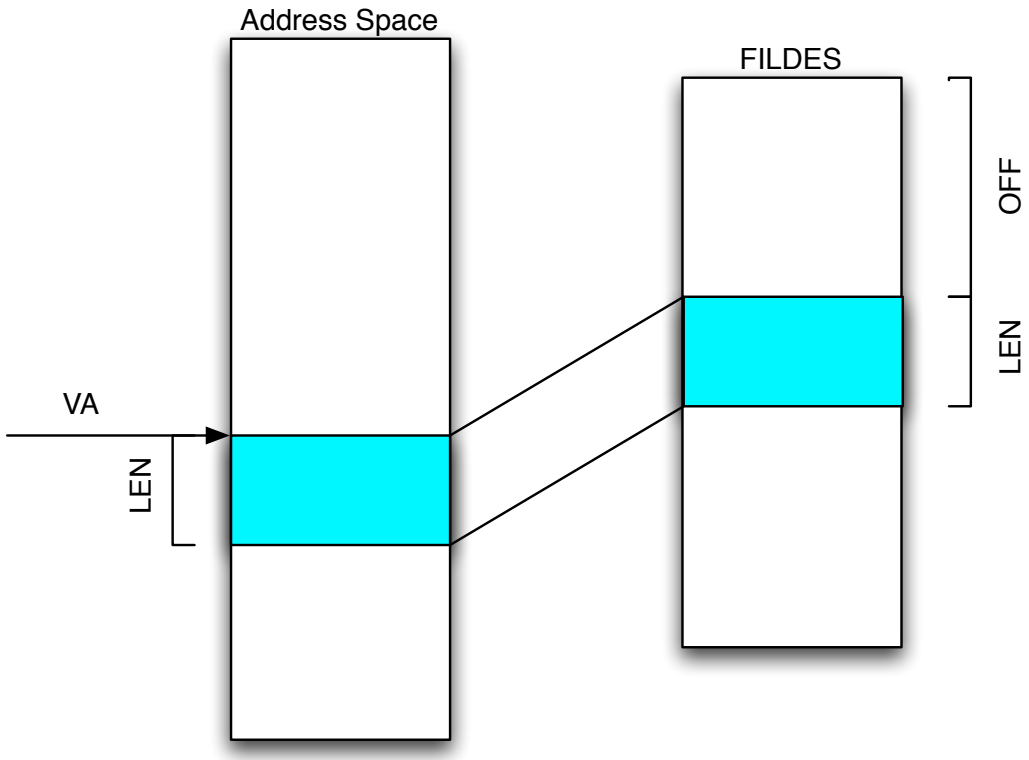
`MAP_SHARED`: Any update made to the mapped region will be global, hence it will be seen by any other process.

`MAP_PRIVATE`: The updates will be kept private to each process (copy on write).

`MAP_FIXED`: Forces the system to obey the suggestion given by `ADDR`. Its use requires a deep knowledge of the address space organization adopted by the operating system, to avoid damaging it.

Mapping – Summary

`mmap` returns the starting address `VA` of the mapped region inside the caller's address space. It returns a null pointer on error.



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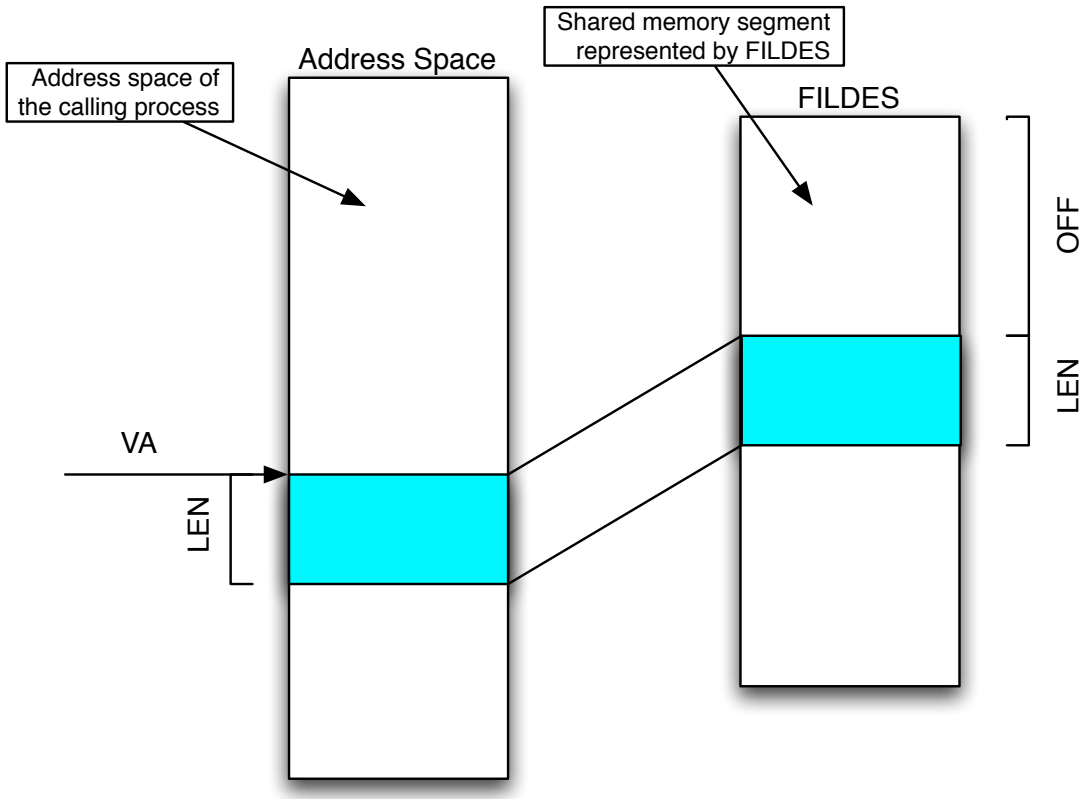

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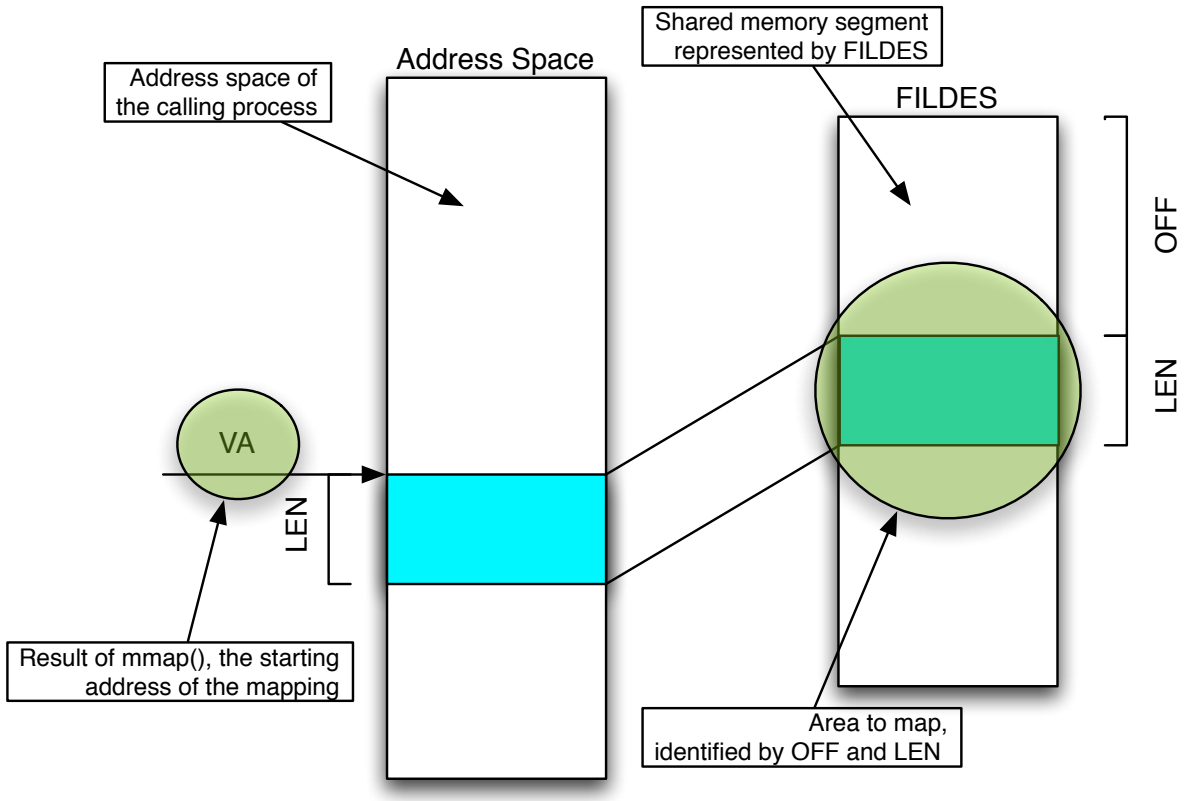

Mapping – munmap()

The function:

```
int munmap(
   void *VA,
   size_t LEN);
```

removes any mapping (made by `mmap`) from the portion of the caller's address space that starts at address `VA`, for `LEN` bytes.

- `munmap` returns a negative value on error.
- Both `mmap` and `munmap` work only if addresses are correctly aligned to a multiple of the memory page size in use by the system.
- For the sake of portability, the page size can be obtained through the `sysconf` function (with argument `_SC_PAGESIZE`).

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Message Queues

The main functions dealing with message queues are:

Nome	Scopo
`mq_open`	Open/create a message queue
`mq_close`	Close a message queue
`mq_receive`	Receive a message
`mq_send`	Send a message
`mq_notify`	Asynchronous notification
`mq_timedreceive`	Timed variant of `mq_receive`
`mq_timedsend`	Timed variant of `mq_send`
`mq_getattr`	Get message queue attributes
`mq_setattr`	Set message queue attributes
`mq_unlink`	Remove a message queue

Include `mqueue.h` before using any of these functions.

Open/Close/Unlink

The functions:

```
mqd_t mq_open(const char *NAME, int OFLAG, ...);
   int mq_close(mqd_t MQDES);
   int mq_unlink(const char *NAME);
```

do the same as their counterparts for named semaphores, but operate on message queues, represented by an opaque data type, `mqd_t`. When `mq_open` is invoked to create a new message queue, its optional arguments are used to denote its attributes.

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struct mq_attr

The `mq_attr` structure represents the attributes of a message queue, and contains the following fields:

- `long mq_flags`: Flags (O_NONBLOCK).
- `long mq_maxmsg`: Maximum number of messages.
- `long mq_msgsize`: Maximum size of each message.
- `long mq_curmsgs`: Number of messages currently in the mailbox.

It is possible to get the attributes of a message queue after its creation, by means of `mq_getattr`, and set `mq_flags` by means of `mq_setattr`.

Sending a Message

The function:

```
int mq_send(
   mqd_t MQDES,
   const char *MSG_PTR, size_t MSG_LEN,
   unsigned MSG_PRIO);
```

sends the message pointed by `MSG_PTR`, of `MSG_LEN` bytes, to the message queue `MQDES` and returns a non-zero integer on error.

- The `MSG_PRIO` argument is the message priority, between `0` e `MQ_PRIO_MAX` (defined in `mqueue.h`).
- `mq_timedsend` is the timed variant of `mq_send` and allows the caller to specify an absolute time limit to complete the send.

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Receiving a Message

The function:

```
ssize_t mq_receive(
   mqd_t MQDES,
   char *MSG_PTR, size_t MSG_LEN,
   unsigned *MSG_PRIO);
```

receives the oldest message with the highest priority currently residing in the message queue `MQDES`, stores it starting at address `MSG_PTR` up to a maximum of `MSG_LEN` bytes, and removes it from the message queue.

- The function returns either the actual size of the message just received, or a negative value on error.
- It also stores into the location pointed by `MSG_PRIO` the priority of the message just received.
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Blocking in mq_send and mq_receive

mq_send

If the message queue is full, the behavior depends on the value of the `O_NONBLOCK` flag in the `mq_flags` of the queue:

- if the flag is set, the function fails immediately;
- else, it waits until there is enough space in the queue to perform the send.

mq_receive

If the message queue is empty, the behavior depends on the value of the `O_NONBLOCK` flag in the `mq_flags` of the queue:

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Asynchronous Notification

The function:

```
int mq_notify(
   mqd_t MQDES,
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allows the calling process to register for an asynchronous notification about the availability of messages in the message queue `MQDES`. The notification will be performed as specified by the `NOTIFICATION` argument, and will be carried out when the queue transitions from an empty to a non-empty state. At the same time, the registration will be removed.

The notification is performed as specified in the `.sigev_notify` field of `struct sigevent`.

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The notification can be performed in three different ways, depending on the value of the `.sigev_notify` field of `struct sigevent`:

1. No notification: any pending registration is removed. In the future the process will explicitly wait for a message to arrive (for example, by calling `mq_receive`).
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Memory Management

Nome	Scopo
`mlock`	“Lock” a range of virtual range and force it to reside in main memory.
`mlockall`	Perform `mlock` on the whole address space of the calling process.
`mprotect`	Set the protection attributes of a range of virtual addresses with respect to read, write and execute operations.
`munlock`	“Unlock” a range of virtual addresses.
`munlockall`	“Unlock” the whole address space of the calling process.

Include `sys/mman.h` before using any of these functions.

Asynchronous I/O

- The usual semantics of the *read* and *write* system calls is synchronous: the calling process waits until the operation it requested has been (at least partially, for *write*) executed.
- For real-time applications, it is often not a good idea to tie so closely a process with I/O timings.
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Asynchronous I/O – Functions

The following functions deal with asynchronous I/O:

Nome	Scopo
`aio_read`	Read request
`aio_write`	Write request
`aio_cancel`	Cancel a pending I/O request
`aio_error`	Get the result (success/failure) of an operation
`aio_return`	Get the status (bytes read/written) of an operation
`aio_fsync`	Asynchronous synchronization (!)
`aio_suspend`	Wait for asynchronous I/O to complete

Include `aio.h` before using any of these functions.

Asynchronous I/O Requests

Each asynchronous I/O request is specified and represented by means of a `struct aiocb` data structure. It contains the following fields:

Tipo	Nome	Scopo
`int`	`aio_fildes`	File descriptor
`off_t`	`aio_offset`	File offset
`volatile void *`	`aio_buf`	I/O buffer pointer
`size_t`	`aio_nbytes`	Transfer size
`int`	`aio_reqprio`	Priority
`struct sigevent`	`aio_sigevent`	Notification mechanism

Like with message queues, processes can either wait for an asynchronous I/O request to complete by means of an explicit `aio_suspend`, or associate an asynchronous notification request (to be carried out through either a function or a signal) with each I/O request, by means of the `.aio_sigevent` field.

Clocks & Timers

On POSIX systems, time is expressed and measured by means of:

- One or more *time bases*, or clocks, with known resolution and of which it is possible to get the value on request. All systems shall implement, at least, `CLOCK_REALTIME`.
- Zero or more per-process timers, using a specific clock as their timing reference.
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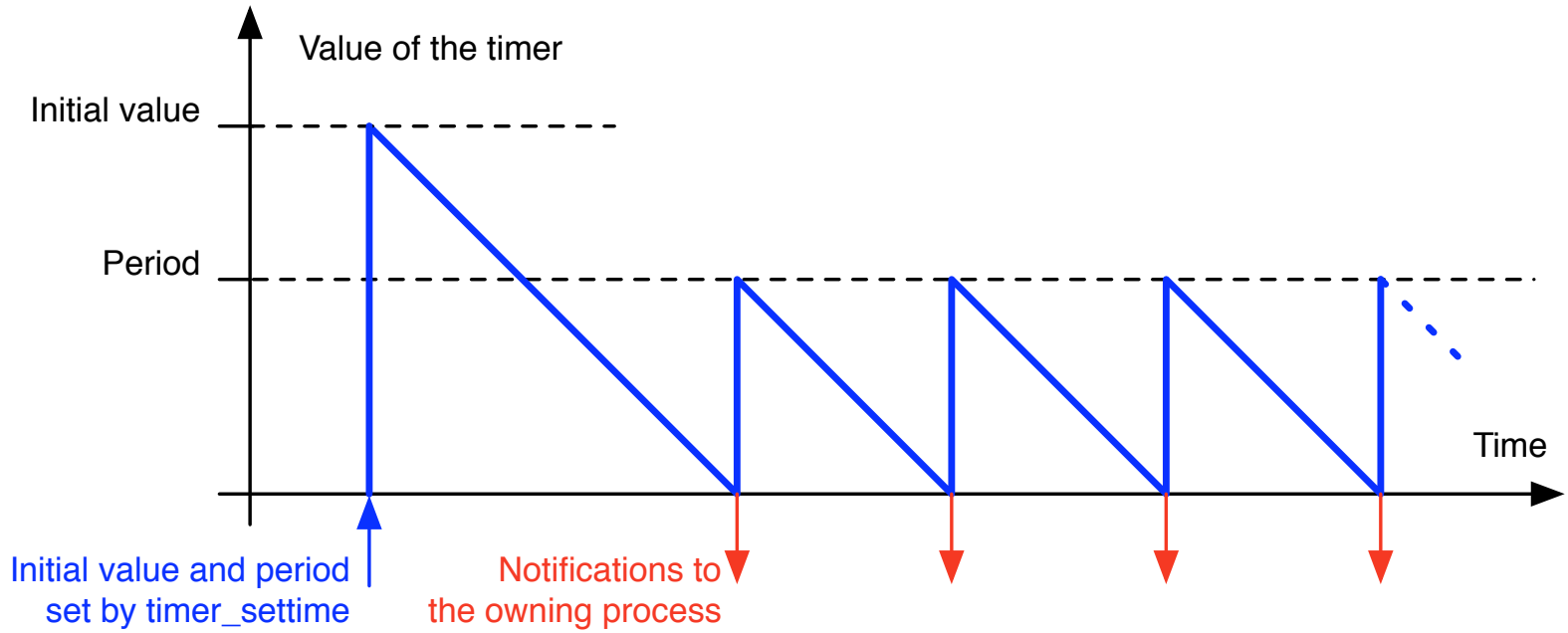
How are Timers Updated?



- The system decrements each timer with a non-zero value using its clock as a reference.
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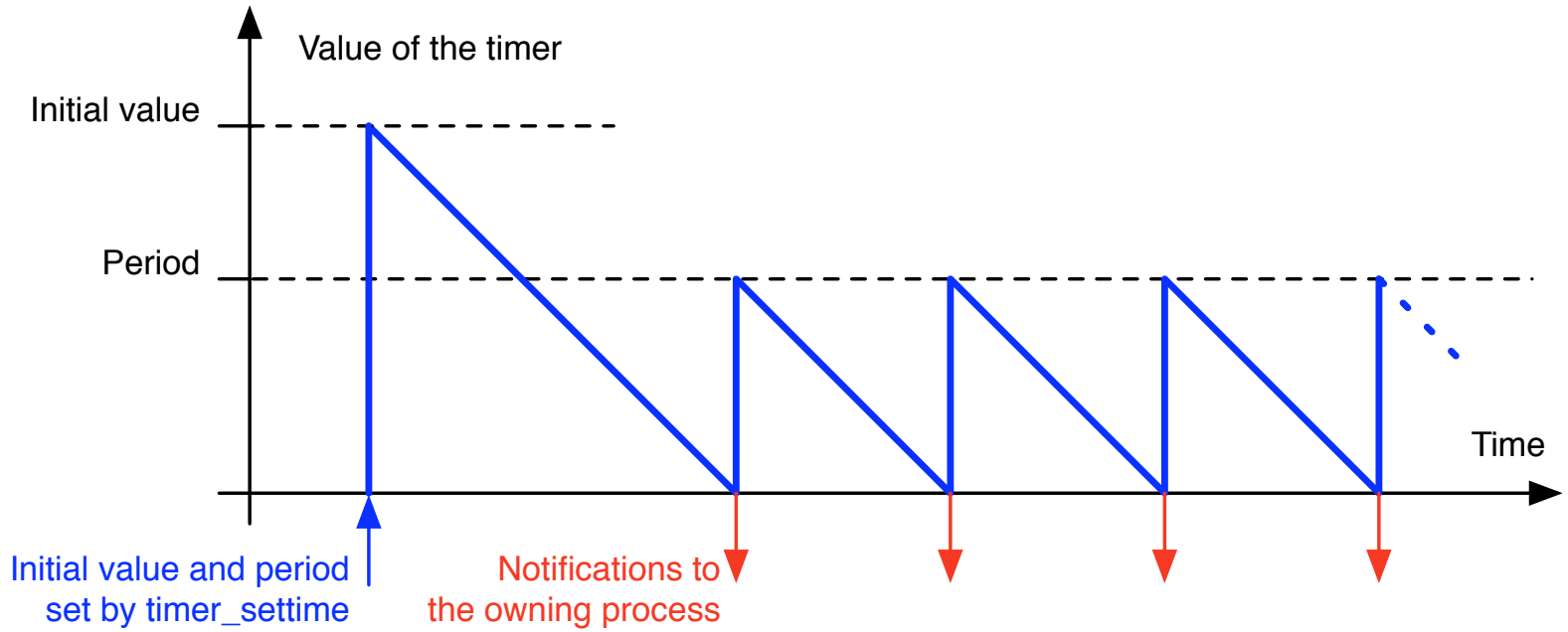

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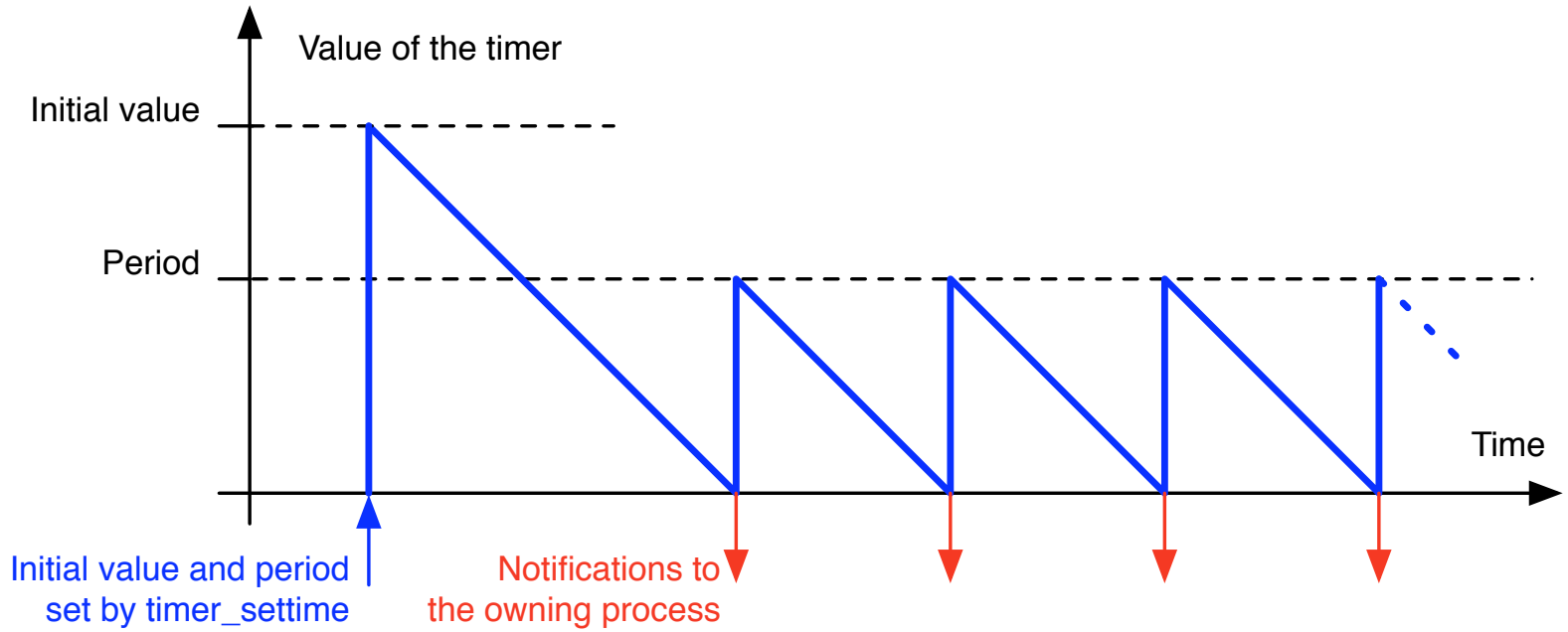

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Clock Manipulation

It is possible to get the resolution and the current value of a clock, as well as setting its value (privileged processes only) by means of:

Nome	Scopo
`clock_getres`	Get the resolution of a clock
`clock_gettime`	Get the current value of a clock
`clock_settime`	Set the value of a clock

Time Representation

Both the resolution and the value of a clock are represented through a `struct timespec` with the following fields:

Type	Name	Purpose
`time_t`	`tv_sec`	Seconds
`long`	`tv_nsec`	Nanoseconds

Clock values are relative to an absolute time reference known as the epoch. For historic reasons, on Unix systems the reference has been set to January 1st, 1970, 00:00 UTC.

Include `time.h` before using any of these functions.

Timer Manipulation

Each process can create and manage its timers by means of the following functions:

Nome	Scopo
`timer_create`	Create a timer
`timer_delete`	Destroy timer
`timer_gettime`	Get the value and period of a timer
`timer_settime`	Set the value and period of a timer
`timer_getoverrun`	Read the *overrrun count*

Include `time.h` before using any of these functions.

Timer Creation

The function:

```
int timer_create(
   clockid_t CLOCKID, struct sigevent *EVP,
            timer_t *TIMERID);
```

creates a fresh timer, local to the calling process, using the clock `CLOCKID` as reference, and stores its descriptor into the location pointed by `TIMERID`. It returns a non-zero value on error.

- Like with message queues, `EVP` specifies how the process shall be notified of expirations. Usually, it is not a good idea to specify "no notification".
- After creation, the timer is inactive: it must be given a value and (optionally) a period by means of `timer_settime`.

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Timer Value and Period

- The function:

```
int timer_settime(timer_t TIMERID, int FLAGS,
   const struct itimerspec *VALUE,
   struct itimerspec *OVALUE);
```

  atomically sets the timer `TIMERID` to a new value and period, as specified by `VALUE`, and stores its old value and period into the location pointed by `OVALUE`.

- Instead, the function:

```
int timer_gettime(timer_t TIMERID,
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  simply stores into the location pointed by `VALUE` the current value and period of `TIMERID`.

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struct itimerspec

The `struct itimerspec` has the following fields:

Type	Name	Purpose
`struct timespec`	`it_value`	Timer value
`struct timespec`	`it_interval`	Period

- Setting the timer value to zero disables the timer.
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- The `FLAGS` argument of `timer_settime` allows the caller to specify whether `it_value` holds a value that is relative to the execution time of the function, or an absolute value.

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Overrun counter

- The standard specifies that each timer can have no more than one pending notification, otherwise the amount of memory needed to keep track of them would be unbounded.
- Hence, if a timer expires again while the previous notification is still pending, the new notification is lost.
- However, the function:

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