

Shared Memory Segments and POSIX Semaphores ¹

Alex Delis
alex.delis -at+ nyu.edu

November 2017

¹Acknowledgements to Prof. T. Stamatopoulos, M. Avidor, A. Deligiannakis, S. Evangelatos, V. Kanitkar and K. Tsakalozos.

IPCs (System V)

- ▶ Three types of IPCs:
 - ▶ **Message Queues** (not discussed)
 - ▶ **Shared Memory**
 - ▶ **Semaphores** (POSIX Interface)
- ▶ Each IPC structure is referred to by a **non-negative integer identifier**.
 - ▶ When an IPC is created, the program responsible for this creation provides a key of type `key_t`.
 - ▶ The Operating System converts this key into an **IPC identifier**.

Keys in the IPC Client-Server Paradigm

⇒ Keys can be created in **three ways**:

1. The “server” program creates a new structure by specifying a private key that is `IPC_PRIVATE`.
 - ▶ Client has to **become explicitly aware** of this private key.
 - ▶ This is often accomplished with the help of a file generated by the server and then looked-up by the client.
2. Server and client **do agree** on a key value (often defined and hard-coded in the header).
3. Server and client can agree on a pathname to an existing file in the file system AND a project-ID (0..255) and then call `ftok()` to **convert** these two values into a **unique** key!

Keys

- ▶ Keys help identify resources and offer access to the internal structures of the 3 IPC mechanisms (through systems calls):

```
struct msqid_ds // for message queues
struct shmid_ds // for shared segments
struct semid_ds // for semaphores
```

- ▶ Wrongly accessing resources returns -1
- ▶ Access rights for IPC mechanisms: read/write stored in struct ipc_perm
- ▶ Included header files:

```
#include <sys/ipc.h>
#include <sys/types.h>
```

The ftok() system call

- ▶ converts a pathname and a project identifier to a (System V) IPC-key

- ▶

```
key_t ftok(const char *pathname, int proj_id)
```

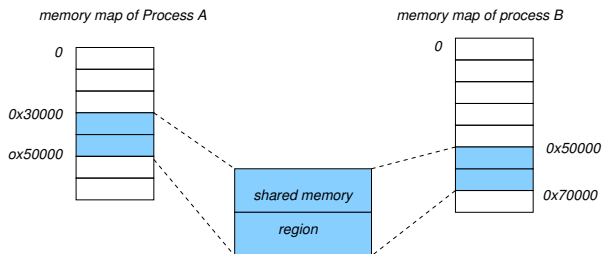
- ▶ Calling the ftok():

```
if ( (thekey=ftok("/tmp/ad.tempfile", 23)) == -1)
    perror("Cannot create key from /tmp/ad.tempfile");
```

- ▶ The file /tmp/ad.tempfile must be accessible by the invoking process.

Shared Memory

- ▶ A **shared memory region** is a portion of physical memory that is shared by multiple processes.



- ▶ In this region, structures can be set up by processes and others may read/write on them.
- ▶ Synchronization among processes using the segment (if required) is achieved with the help of **semaphores**.

Creating a shared segment with `shmget()`

```
#include <sys/ipc.h>
#include <sys/shm.h>

int shmget(key_t key, size_t size, int shmflg)
```

- ▶ returns the **identifier** of the shared memory segment associated with the value of the argument `key`.
- ▶ the returned **size** of the segment is equal to `size` rounded up to a multiple of `PAGE_SIZE`.
- ▶ `shmflg` helps designate the access rights for the segment (`IPC_CREAT` and `IPC_EXCL` are used in a way similar to that of message queues).
- ▶ If `shmflg` specifies *both* `IPC_CREAT` and `IPC_EXCL` and a shared memory segment already exists for `key`, then `shmget()` fails with `errno` set to `EEXIST`.

Attach- and Detach-ing a segment: `shmat()`/`shmdt()`

```
void *shmat(int shmid, const void *shmaddr, int shmflg)
```

- ▶ attaches the shared memory segment identified by `shmid` to the address space of the calling process.
- ▶ If `shmaddr` is `NULL`, the OS chooses a suitable (unused) address at which to attach the segment (frequent choice).
- ▶ Otherwise, `shmaddr` must be a page-aligned address at which the attach occurs.

```
int shmdt(const void *shmaddr)
```

- ▶ detaches the shared memory segment located at the address specified by `shmaddr` from the address space of the calling process.

The system call `shmctl()`

```
int shmctl(int shmid, int cmd, struct shmid_ds *buf)
```

- ▶ performs the control operation specified by `cmd` on the shared memory segment whose identifier is given in `shmid`.
- ▶ The `buf` argument is a pointer to a `shmid_ds` structure:

```
struct shmid_ds {  
    struct ipc_perm shm_perm;      /* Ownership and permissions */  
    size_t          shm_segsz;     /* Size of segment (bytes) */  
    time_t          shm_atime;     /* Last attach time */  
    time_t          shm_dtime;     /* Last detach time */  
    time_t          shm_ctime;     /* Last change time */  
    pid_t           shm_cpid;      /* PID of creator */  
    pid_t           shm_lpid;      /* PID of last shmat(2)/shmdt(2) */  
    shmatt_t        shm_nattch;    /* No. of current attaches */  
    ...  
};
```

The system call `shmctl()`

Usual values for `cmd` are:

- ▶ `IPC_STAT`: copy information from the kernel data structure associated with `shmid` into the `shmid_ds` structure pointed to by `buf`.
- ▶ `IPC_SET`: write the value of some member of the `shmid_ds` structure pointed to by `buf` to the kernel data structure associated with this shared memory segment, updating also its `shm_ctime` member.
- ▶ `IPC_RMID`: mark the segment to be destroyed. The segment will be destroyed after the last process detaches it (i.e., `shm_nattch` is zero).

Use Cases of Calls

- Only one process creates the segment:

```
int id;  
id = shmget(IPC_PRIVATE, 10, 0666);  
if ( id == -1 ) perror("Creating");
```

- Every (interested) process attaches the segment:

```
int *mem;  
mem = (int *) shmat (id, (void *)0, 0);  
if ( (int)mem == -1 ) perror("Attachment");
```

- Every process detaches the segment:

```
int err;  
err = shmdt((void *)mem);  
if ( err == -1 ) perror("Detachment");
```

- Only one process has to remove the segment:

```
int err;  
err = shmctl(id, IPC_RMID, 0);  
if ( err == -1 ) perror("Removal");
```

Creating and accessing shared memory (shareMem1.c)

```
#include <stdio.h>
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>

int main(int argc, char **argv){
    int id=0, err=0;
    int *mem;

    id = shmget(IPC_PRIVATE,10,0666); /* Make shared memory segment */
    if (id == -1) perror ("Creation");
    else printf("Allocated. %d\n", (int)id);

    mem = (int *) shmat(id, (void*)0, 0); /* Attach the segment */
    if (*(int *) mem == -1) perror("Attachment.");
    else printf("Attached. Mem contents %d\n", *mem);

    *mem=1; /* Give it initial value */
    printf("Start other process. >"); getchar();

    printf("mem is now %d\n", *mem); /* Print out new value */

    err = shmctl(id, IPC_RMID, 0); /* Remove segment */
    if (err == -1) perror ("Removal.");
    else printf("Removed. %d\n", (int)(err));
    return 0;
}
```

Creating and accessing shared memory (shareMem2.c)

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>

int main(int argc, char **argv) {
    int id, err;
    int *mem;

    if (argc <= 1) { printf("Need shared memory id. \n"); exit(1); }

    sscanf(argv[1], "%d", &id); /* Get id from command line. */
    printf("Id is %d\n", id);

    mem = (int *) shmat(id, (void*) 0,0); /* Attach the segment */
    if ((int) mem == -1) perror("Attachment.");
    else printf("Attached. Mem contents %d\n",*mem);

    *mem=2; /* Give it a different value */
    printf("Changed mem is now %d\n", *mem);

    err = shmdt((void *) mem); /* Detach segment */
    if (err == -1) perror ("Detachment.");
    else printf("Detachment %d\n", err);
    return 0;
}
```

Running the two programs:

- Starting off with executing "shareMem1":

```
ad@haiku:~/SharedSegments$ ./shareMem1
Allocated. 1769489
Attached. Mem contents 0
Start other process. >
```

- Executing "shareMem2":

```
ad@haiku:~/SharedSegments$ ./shareMem2 1769489
Id is 1769489
Attached. Mem contents 1
Changed mem is now 2
Detachment 0
ad@haiku:~/SharedSegments$
```

- Providing the final input to "shareMem1":

```
Start other process. >s
mem is now 2
Removed. 0
ad@haiku:~/SharedSegments$
```

Semaphores

- ▶ **Fundamental mechanism** that facilitates **synchronization and coordinated accessing** of resources placed in shared memory.
- ▶ A semaphore is an integer whose value is **never allowed** to fall below zero.
- ▶ *Two operations* can be atomically performed on a semaphore:
 - **increment** the semaphore value by one (UP or V() ala Dijkstra).
 - **decrement** a semaphore value by one (DOWN or P() ala Dijkstra).
If the value of semaphore is currently zero, then the invoking process will block until the value becomes greater than zero.

POSIX Semaphores

```
#include <semaphore.h>
```

- ▶ `sem_init`, `sem_destroy`, `sem_post`, `sem_wait`, `sem_trywait`

```
int sem_init(sem_t *sem, int pshared, unsigned int value);
```

- ▶ The above initializes a semaphore.
- ▶ Compile either with `-lrt` or `-lpthread`
- ▶ `pshared` indicates whether this semaphore is to be shared between the threads of a process, or between processes:
 - **zero**: semaphore is shared between the **threads of a process**; should be located at an address visible to **all threads**.
 - **non-zero**: semaphore is shared **among processes**.

POSIX Semaphore Operations

- ▶ `sem_wait()`, `sem_trywait()`

- ▶ `int sem_wait(sem_t *sem);`

- `int sem_trywait(sem_t *sem);`

- ▶ Perform $P(s)$ operation.

- ▶ `sem_wait` blocks; `sem_trywait` will fail rather than block.

- ▶ `sem_post()`

- ▶ `int sem_post(sem_t *sem)`

- ▶ Performs $V(s)$ operation.

- ▶ `sem_destroy()`

- ▶ `int sem_destroy(sem_t *sem);`

- ▶ Destroys a semaphore.

Creating and using a POSIX Semaphore

```
#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include <sys/types.h>
#include <sys/ipc.h>

extern int errno;

int main(int argc, char **argv)
{
    sem_t sp; int retval;

    /* Initialize the semaphore. */
    retval = sem_init(&sp,1,2);
    if (retval != 0) {
        perror("Couldn't initialize."); exit(3); }

    retval = sem_trywait(&sp);
    printf("Did trywait. Returned %d >\n",retval); getchar();

    retval = sem_trywait(&sp);
    printf("Did trywait. Returned %d >\n",retval); getchar();

    retval = sem_trywait(&sp);
    printf("Did trywait. Returned %d >\n",retval); getchar();

    sem_destroy(&sp);
    return 0;
}
```

Executing the Program

```
ad@ad-desktop:~/src/PosixSems$ ./semtest
Did trywait. Returned 0 >

Did trywait. Returned 0 >

Did trywait. Returned -1 >

ad@ad-desktop:~/src/PosixSems$
```

Example of Shared Memory & Semaphore: semtest3.c

```
/* semtest3.c: POSIX Semaphore test example using shared memory */
#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>

#define SEGMENTSZIE sizeof(sem_t)
#define SEGMENTPERM 0666

int main(int argc, char **argv)
{
    sem_t *sp;
    int retval;
    int id, err;

    /* Make shared memory segment. */
    id = shmget(IPC_PRIVATE, SEGMENTSZIE, SEGMENTPERM);
    if (id == (void *) -1) perror("Creation");
    else printf("Allocated %d\n", id);

    /* Attach the segment. */
    sp = (sem_t *) shmat(id, (void*) 0, 0);
    if ( sp == (void *) -1) { perror("Attachment."); exit(2);}
}
```

Example: semtest3.c

```
/* Initialize the semaphore. */
retval = sem_init(sp,1,2);
if (retval != 0) {
    perror("Couldn't initialize.");
    exit(3);
}
retval = sem_trywait(sp);
printf("Did trywait. Returned %d >\n", retval); getchar();

retval = sem_trywait(sp);
printf("Did trywait. Returned %d >\n", retval); getchar();

retval = sem_trywait(sp);
printf("Did trywait. Returned %d >\n", retval); getchar();

sem_destroy(sp);

/* Remove segment. */
err = shmctl(id, IPC_RMID, 0);
if (err == -1) perror("Removal.");
else printf("Removed. %d\n",err);
return 0;
}
```

Example: semtest3a.c

```
/* semtest3a.c POSIX Semaphore test example using shared memory */
#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include <sys/types.h>
#include <sys/ipc.h>
#include <sys/shm.h>
#define SEGMENTSIZE sizeof(sem_t)
#define SEGMENTPERM 0666

extern int errno;

int main(int argc, char **argv)
{
    sem_t *sp; int retval; int id, err;

    if (argc <= 1) { printf("Need shmem id. \n"); exit(1); }

    /* Get id from command line. */
    sscanf(argv[1], "%d", &id);
    printf("Allocated %d\n", id);

    /* Attach the segment. */
    sp = (sem_t *) shmat(id, (void*) 0, 0);
    if (sp == (void *) -1) { perror("Attachment."); exit(2); }

    /* Initialize the semaphore. */
    retval = sem_init(sp, 1, 1);
    if (retval != 0) { perror("Couldn't initialize."); exit(3); }
```

Example: semtest3.c

```
    retval = sem_trywait(sp);
    printf("Did trywait. Returned %d >\n", retval); getchar();

    retval = sem_trywait(sp);
    printf("Did trywait. Returned %d >\n", retval); getchar();

    retval = sem_trywait(sp);
    printf("Did trywait. Returned %d >\n", retval); getchar();

    /* Remove segment. */
    err = shmdt((void *) sp);
    if (err == -1) perror ("Detachment.");
    return 0;
}
```

Running the two programs: semtest and semtest3a

- Starting off with executing "semtest":

```
ad@serifos:~/Recitation3/src$ ./semtest3  
Allocated 14549024  
Did trywait. Returned 0 >
```

- Executing "semtest3a" in another tty:

```
ad@serifos:~/Recitation3/src$ ./semtest3a 14549024  
Allocated 14549024  
Did trywait. Returned 0 >  
  
Did trywait. Returned -1 >
```

- Continue with "semtest3":

```
Did trywait. Returned -1 >  
  
Did trywait. Returned -1 >
```


Running the two programs: semtest and semtest3a

- Continue with "semtest3a":

```
Did trywait. Returned -1 >
```

- Follow up with "semtest3":

```
Removed. 0  
ad@serifos:~/Recitation3/src$
```

- Finish with "semtest3a":

```
ad@serifos:~/Recitation3/src$
```

Initialize and Open a **named Semaphore**

```
sem_t *sem_open(const char *name, int oflag);  
sem_t *sem_open(const char *name, int oflag,  
                mode_t mode, unsigned int value);
```

- ▶ creates a new POSIX semaphore OR opens an existing semaphore whose name is `name`.
- ▶ `oflag` specifies flags that control the operation of the call
 - `O_CREAT` creates the semaphore;
 - provided that both `O_CREAT` and `O_EXCL` are specified, an error is returned if a semaphore with `name` already exists.
- ▶ if `oflag` is `O_CREAT` then **2 more arguments** have to be used:
 - `mode` specifies the permissions to be placed on the new semaphore.
 - `value` specifies the initial value for the new semaphore.

More on Named POSIX Semaphores

- ▶ A named semaphore is identified by a (persistent) name that has the form `/this_is_a_sample_named_semaphore`.
 - consists of an initial slash followed by a (large) number of character (but no slashes).
- ▶ If you want to “see” (list) all **named semaphores** in your (Linux) system look at directory `/dev/shm`

More on Named POSIX Semaphores

```
int sem_close(sem_t *sem)
```

- closes the named semaphore referred to by *sem* freeing the system resources the invoking process has used.

```
int sem_unlink(const char *name)
```

- removes the named semaphore in question.

```
int sem_getvalue(sem_t *sem, int *sval)
```

- obtains the current value of semaphore..
- the **cheater** API-call!

Named POSIX Semaphore

```
#include      <stdio.h>
...
#include      <sys/stat.h>
#include      <semaphore.h>

int main(int argc, char *argv[]){
const char *semname;
int op=0; int val=0;

if (argc==3) {
    semname=argv[1]; op=atoi(argv[2]);
}
else {
    printf("usage: nameSem nameOfSem Operation\n"); exit(1);
}

sem_t *sem=sem_open(semname, O_CREAT|O_EXCL, S_IRUSR|S_IWUSR, 0);

if (sem!= SEM_FAILED)
    printf("created new semaphore!\n");
else if (errno== EEXIST ) {
    printf("semaphore appears to exist already!\n");
    sem = sem_open(semname, 0);
}
else ;

assert(sem != SEM_FAILED);
sem_getvalue(sem, &val);
printf("semaphore's before action value is %d\n",val);
```

Named Posix Semaphore

```
if ( op == 1 ) {
    printf("incrementing semaphore\n");
    sem_post(sem);
}
else if ( op == -1 ) {
    printf("decrementing semaphore\n");
    sem_wait(sem);
}
else if ( op == 2 ){
    printf("clearing up named semaphore\n");
    sem_close(sem); // close the sem
    sem_unlink(semname); // remove it from system
    exit(1);
}
else
    printf("not defined operation! \n");

sem_getvalue(sem, &val);
printf("semaphore's current value is %d\n",val);
sem_close(sem);
return(0);
}
```

Execution Outcome

```
ad@serifos:~/PosixSems$ ls /dev/shm/
pulse-shm-1024070233 pulse-shm-1294442337 pulse-shm-2927836935
pulse-shm-1274848112 pulse-shm-2305588894 pulse-shm-3888866544
ad@serifos:~/PosixSems$ ./namedSem /delis 1
created new semaphore!
semaphore's before action value is 0
incrementing semaphore
semaphore's current value is 1
ad@serifos:~/PosixSems$ ls /dev/shm/
pulse-shm-1024070233 pulse-shm-1294442337 pulse-shm-2927836935 sem.delis
pulse-shm-1274848112 pulse-shm-2305588894 pulse-shm-3888866544
ad@serifos:~/PosixSems$ ./namedSem /delis -1
semaphore appears to exist already!
semaphore's before action value is 1
decrementing semaphore
semaphore's current value is 0
ad@serifos:~/PosixSems$ ./namedSem /delis 2
semaphore appears to exist already!
semaphore's before action value is 0
clearing up named semaphore
ad@serifos:~/PosixSems$ ls /dev/shm/
pulse-shm-1024070233 pulse-shm-1294442337 pulse-shm-2927836935
pulse-shm-1274848112 pulse-shm-2305588894 pulse-shm-3888866544
ad@serifos:~/PosixSems$ ./namedSem /delis 1
created new semaphore!
semaphore's before action value is 0
incrementing semaphore
semaphore's current value is 1
```

Execution Outcome

```
ad@serifos:~/PosixSems$ ./namedSem /delis 1
semaphore appears to exist already!
semaphore's before action value is 1
incrementing semaphore
semaphore's current value is 2
ad@serifos:~/PosixSems$ ls /dev/shm/
pulse-shm-1024070233  pulse-shm-1294442337  pulse-shm-2927836935  sem.delis
pulse-shm-1274848112  pulse-shm-2305588894  pulse-shm-3888866544
ad@serifos:~/PosixSems$ ./namedSem /delis -1
semaphore appears to exist already!
semaphore's before action value is 2
decrementing semaphore
semaphore's current value is 1
ad@serifos:~/PosixSems$ ./namedSem /delis -1
semaphore appears to exist already!
semaphore's before action value is 1
decrementing semaphore
semaphore's current value is 0
ad@serifos:~/PosixSems$ ./namedSem /delis 2
semaphore appears to exist already!
semaphore's before action value is 0
clearing up named semaphore
ad@serifos:~/PosixSems$ ls /dev/shm/
pulse-shm-1024070233  pulse-shm-1294442337  pulse-shm-2927836935
pulse-shm-1274848112  pulse-shm-2305588894  pulse-shm-3888866544
ad@serifos:~/PosixSems$
```