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# Shared Memory & Semaphores

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# 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

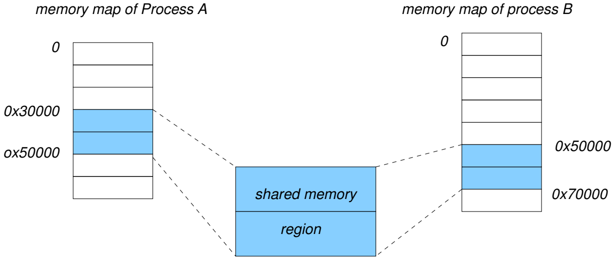
- converts a pathname and a project identifier to a (System V) IPC-key
- `key_t ftok(const char *pathname, int proj_id)`
- Calling the ftok():

```
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:

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

- Every (interested) process attaches the segment:

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

- Every process detaches the segment:

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

- Only one process has to remove the segment:

```c
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

```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 SEGMENTSIZE 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, SEGMENTSIZE, 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

```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

```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 sempahores 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$␣ls␣/dev/shm/
pulse-shm-1024070233␣␣pulse-shm-1294442337␣␣pulse-shm-2927836935
pulse-shm-1274848112␣␣pulse-shm-2305588894␣␣pulse-shm-3888866544
ad@serifos:~/PosixSems$
```