5. Synchronization (4)

Messages (1)

- Message transport through two system calls
  - `send (destination, &message);`
  - `receive (source, &message);`
- Synchronous communication:
  threads block when *send* or *receive* cannot be executed immediately, e.g. because
  - the other part has not issued the corresponding call,
  - a buffer for the messages is full or empty.

Messages (2)

- Advantage: also works on system without shared memory (distributed systems, client server computing)
- Disadvantages:
  - duplication of data is overhead
  - necessary to remember names of source and target
  - something must be done about possible loss of messages
- Implementation uses pipes, mailslots (Windows) or RPCs.

Messages (3)

- **synchronous** vs. **asynchronous**
  - synchronous: *send* / *receive* block until correspon-ding operation on the other side has finished
  - asynchronous: *send* call returns immediately; success of sending might be checkable, e.g.:
    - other side sends an explicit ACK (new message)
    - messaging system sends signal on message delivery
- **connection oriented** vs. **not conn. oriented**
  - connection oriented: permanent connection (TCP)
  - connectionless (cf. UDP)

Examples for messages (1)

Two processes toggle access rights

```
void function (int id) {
  int otherid = 1 - id;
  char message[10] = "";
  // one process may first; ID 0
  if (id==0) {
    message = "go";
  }
  // non-critical block
  while message != "go" {
    receive (otherid, &message);
  }
  // critical region
  send (otherid, "go");
  message = "";
  // further non-critical block
}
```

p0 calls *function(0)*, p1 calls *function(1)*.

p0 can enter critical region first

Examples for messages (2)

Server process grants resource access

```
//--- server -------------------

int busy;  // globale state

void main () {
  initialize ();
  while TRUE {
    receive (&id, &message);
    // message and also sender ID
    // (id) is known
    switch (message) {
      "request": enter_in_queue(id);
      "release": let_next_one();
    };
  };
};
```

```
void let_next_one () {
  if queue_is_empty () { busy = FALSE; }
  else {
    id = queue_head.id;
    send (&id, "go");
    queue_head = queue_head.next;
  };
}

void enter_in_queue (int id) {
  if queue_is_empty () and busy==FALSE {
    busy = TRUE;
    send (&id, "go")
  } else {
    allocate (&newentry);
    newentry.id = id;
    newentry.next = NULL;
    queue_last.next = newentry;
    queue_last = newentry;
  }
}
```


Examples for messages (3)

Client requests access grant from the server

```
//--- client -----------------

void function (int id) {
  reply = "";
  // non-critical block
  while (reply != "go") {
    send (server, "request");
    receive (server, &reply);  // wait for grant
  };
  // critical section
  send (server, "release");    // release access
  // further non-critical block
}
```


Examples for messages (4)

Process 1		Server		Process 2

send(server,"request");	→	receive(1,"request");
		enter_in_queue(1);
		/* busy==false, queue is empty */		

receive(server,"go");	←	send(1,"go"); busy = TRUE;		

/* critical region */		receive(2,"request");
		enter_in_queue(2);
		/* busy==true */
		queue = [2];
			←	send(server,"request");

send(server,"release");
...
	→	receive(1,"release");
		let_next_one();
		id = queue_head /* 2 */
		send(2,"go");
		queue = [ ];
			→	receive(server,"go");
				/* critical region */

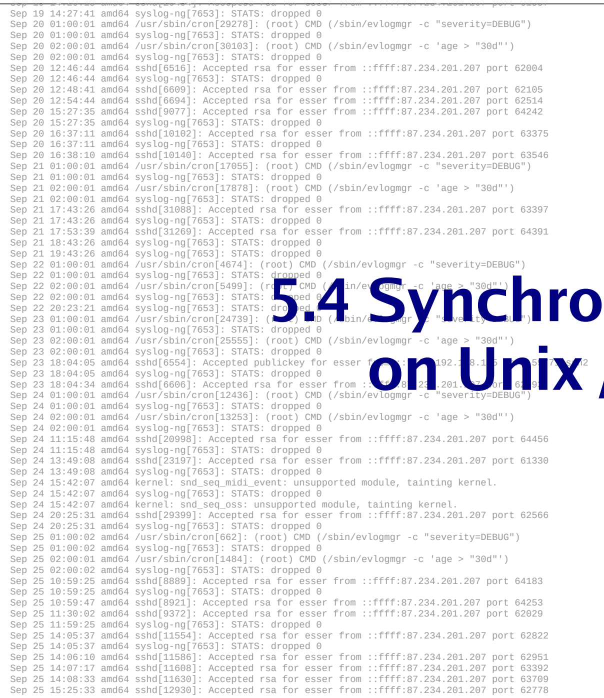
		receive(2,"release");
		let_next_one();
		/* queue is empty */
		busy = FALSE;
			←	send(server,"release");

Messages

- broadcast to several (all) processes possible
- distributed systems: Voting algorithms (using broadcast) for drawing decisions

more about messages:

Chapter 6: **IPC (Inter Process Communication)**



5.4 Synchronization on Unix / Linux

Content overview

5.4.1 Synchronitation in applications

- POSIX Threads
- Synchroniz. between processes

5.4.2 Synchronization in the Linux kernel

POSIX Threads

POSIX threads can use several standard synchronization primitives:

- Mutexes
- Semaphores
- Condition Variables

POSIX Mutexes (1)

pthread_mutex_init

```
int pthread_mutex_init (pthread_mutex_t *mutex,
                        const pthread_mutexattr_t *attr);
```

- initializes a new mutex with specific attributes (attr can also be NULL)
- Initialization in the main program before the threads start and use the mutex
- „abbreviation“:
  `pthread_mutex_t fastmutex = PTHREAD_MUTEX_INITIALIZER;`

POSIX Mutexes (2)

pthread_mutex_lock

```
int pthread_mutex_lock (pthread_mutex_t *mutex);
int pthread_mutex_trylock (pthread_mutex_t *mutex);
```

- pthread_mutex_lock
  - tries to gain the lock
  - blocks if lock is already held by a different thread
- pthread_mutex_trylock
  - also tries to gain the lock
  - call returns even if lock could not be gained (with error code **EBUSY**)

POSIX Mutexes (3)

pthread_mutex_unlock

```
int pthread_mutex_unlock (pthread_mutex_t *mutex);
```

- remove lock

pthread_mutex_destroy

```
int pthread_mutex_destroy (pthread_mutex_t *mutex);
```

- discontinue using this mutex

POSIX Mutexes (4)

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>

void *functionC();
pthread_mutex_t mutex1 =
  PTHREAD_MUTEX_INITIALIZER;
int counter = 0;
#define NO_THREADS 2

main() {
   int rc[NO_THREADS];
   int i;
   pthread_t thread[NO_THREADS];

   /* create two threads which execute functionC() */
   for (i=0; i<NO_THREADS; i++) {
     if( (rc[i]=pthread_create( &thread[i], NULL, &functionC, NULL)) ) {
       printf("Thread creation failed: %d\n", rc[i]);
     };
   };
   /* wait for the two threads */
   for (i=0; i<NO_THREADS; i++) pthread_join( thread[i], NULL);
   printf("final result: %d\n",counter);
   exit(0);
}
```

```
void *functionC()
{
   pthread_mutex_lock( &mutex1 );
   counter++;
   printf("Counter value: %d\n",counter);
   pthread_mutex_unlock( &mutex1 );
}
```

POSIX Mutexes (5)

- ... and in *broken_threads.c* a version withoud mutexes (i.e. critical region is unprotected):

```
void *functionC()
{
   // pthread_mutex_lock( &mutex1 );
   int tmp=counter;                 // read shared variable
   for (i=0; i<999999; i++) {};     // spend some time ...
   tmp++;
   counter=tmp;                     // write shared variable
   printf("Counter value: %d\n",counter);
   // pthread_mutex_unlock( &mutex1 );
}
```


POSIX Mutexes (6)

Test with 20 threads

```
$ gcc -lpthread -o threads threads.c
$ gcc -lpthread -o broken_threads broken_threads.c
```

```
$ ./pthread
Counter value: 1
Counter value: 2
Counter value: 3
Counter value: 4
Counter value: 5
Counter value: 6
Counter value: 7
Counter value: 8
Counter value: 9
Counter value: 10
Counter value: 11
Counter value: 12
Counter value: 13
Counter value: 14
Counter value: 15
Counter value: 16
Counter value: 17
Counter value: 18
Counter value: 19
Counter value: 20
final result: 20
```

```
$ ./broken_threads
Counter value: 1
Counter value: 2
Counter value: 3
Counter value: 3
Counter value: 3
Counter value: 4
Counter value: 5
Counter value: 6
Counter value: 7
Counter value: 3
Counter value: 4
Counter value: 5
Counter value: 6
Counter value: 8
Counter value: 7
Counter value: 7
Counter value: 8
Counter value: 8
Counter value: 7
Counter value: 7
final result: 7
```


POSIX Mutexes (7)

Mutexes can be „recursive“:

normal

```
pthread_mutex_lock (mutex);
/* Code  */
pthread_mutex_lock (mutex);
 /* call blocks since mutex is
    already lockjed */
pthread_mutex_unlock (mutex);
pthread_mutex_unlock (mutex);
```

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```
pthread_mutex_lock (mutex);
/* Code  */
pthread_mutex_lock (mutex);
  /* successful because the same
     thread holds this lock */
pthread_mutex_unlock (mutex);
pthread_mutex_unlock (mutex);
```

shortcut for initializing a recursive mutex:

```
pthread_mutex_t recmutex = PTHREAD_RECURSIVE_MUTEX_INITIALIZER_NP;
```


POSIX Semaphores (1)

sem_init

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

- initializes a semaphore with initial value *value*
- Initialization in main program before the threads start and use the semaphore
- *pshared*: for shared usage by several processes (not possible on Linux systems)

POSIX Semaphores (2)

sem_wait, sem_trywait

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

- sem_wait implements wait() operation
  - decrements counter c in the semaphore if c>0
  - otherwise blocks thread until c>0
- sem_trywait
  - decrements counter c in the semaphore if c>0
  - return error value EAGAIN if c<=0

POSIX Semaphores (3)

sem_post

```
int sem_post(sem_t * sem);
```

- sem_post implements signal() operation
  - increments counter c in the semaphore
  - never blocks

sem_destroy

```
int sem_destroy(sem_t * sem);
```

- stop using the semaphore

POSIX Semaphores (4)

sem_getvalue

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

- sem_getvalue reads the value of a semaphore and writes it into the given variable

POSIX Semaphores (5)

```
#include <stdio.h>
#include <stdlib.h>
#include <semaphore.h>
#include <pthread.h>

static sem_t sem;
void *functionC();
int counter = 0;
#define NO_THREADS 2

main() {
   int rc[NO_THREADS]; int i;
   pthread_t thread[NO_THREADS];
   /* initialize semaphore to 1 */
   sem_init(&sem, 0, 1);
   /* create two threads which execute functionC() */
   for (i=0; i<NO_THREADS; i++) {
     if( (rc[i]=pthread_create( &thread[i], NULL, &functionC, NULL)) ) {
       printf("Thread creation failed: %d\n", rc[i]);
     };
   };
   /* wait for the threads */
   for (i=0; i<NO_THREADS; i++) pthread_join( thread[i], NULL);
   printf("final result: %d\n",counter);
   exit(0);
}
```

```
void *functionC() {
   int i;
   sem_wait( &sem );
   int tmp=counter; // read shared variable
   for (i=0; i<999999; i++) {};
      // spend some time ...
   tmp++;
   counter=tmp;
      // write shared variable
   printf("Counter value: %d\n",counter);
   sem_post( &sem );
}
```

POSIX Condition Variables (1)

- Idea: threads wait for a specific condition to be satisfied and meanwhile sleep (cf. *monitors*)
- two base functions:
  - **pthread_cond_signal** & **thread_cond_broadcast**
    signal (satisfaction of) condition
    ➡ wakes up one thread / all threads which wait for the condition
    (non-sleeping threads are not signalled)
  - **pthread_cond_wait**
    wait until the condition is satisfied
- always protect condition variables with a mutex

POSIX Condition Variables (2)

pthread_cond_init

```
int pthread_cond_init(pthread_cond_t *cond,
  pthread_condattr_t *cond_attr);
```

- initializes a condition variable
- initialization happens in main program before the threads start and use the cond. variable
- „abbreviation“:
  `pthread_cond_t cond = PTHREAD_COND_INITIALIZER;`

POSIX Condition Variables (3)

pthread_cond_wait

```
int pthread_cond_wait ( pthread_cond_t *cond,
                        pthread_mutex_t *mutex );
```

- pthread_cond_wait unlocks the mutex and waits for the condition *cond* to be signalled (thread sleeps)
- when the condition is signalled, the function locks the mutex before transfering control back to the calling thread

POSIX Condition Variables (4)

pthread_cond_signal & pthread_cond_broadcast

```
int pthread_cond_signal(pthread_cond_t *cond);
int pthread_cond_broadcast(pthread_cond_t *cond);
```

- pthread_cond_*signal* wakes up ***one of*** the threads which wait for condition *cond*.
  (If no thread waits, nothing happens.)
- pthread_cond_*broadcast* wakes up ***all*** threads which wait for condition *cond*.
  (If no thread waits, nothing happens.)

POSIX Condition Variables (5)

```
int x,y;
pthread_mutex_t mut = PTHREAD_MUTEX_INITIALIZER;
  // mutex protects accesses to x, y
pthread_cond_t cond = PTHREAD_COND_INITIALIZER;
  // condition: x > y

thread_one () {
  /* wait for x > y */
  pthread_mutex_lock(&mut);
  while (x <= y) {
    pthread_cond_wait(&cond, &mut);
  }
  // use x and y
  pthread_mutex_unlock(&mut);
}

thread_two () {
  pthread_mutex_lock(&mut);
  // modify x and y
  if (x > y) pthread_cond_broadcast(&cond);
  pthread_mutex_unlock(&mut);
}
```


Overview of POSIX functions

	Mutexes	Semaphores	Condition Variables
wait or block	pthread_mutex_lock, pthread_mutex_trylock	sem_wait, sem_trywait	pthread_cond_wait
signal	pthread_mutex_unlock	sem_post	pthread_cond_signal, pthread_cond_broadcast
create	pthread_mutex_init	sem_init	pthread_cond_init
destroy	pthread_mutex_destroy	sem_destroy	pthread_cond_destroy