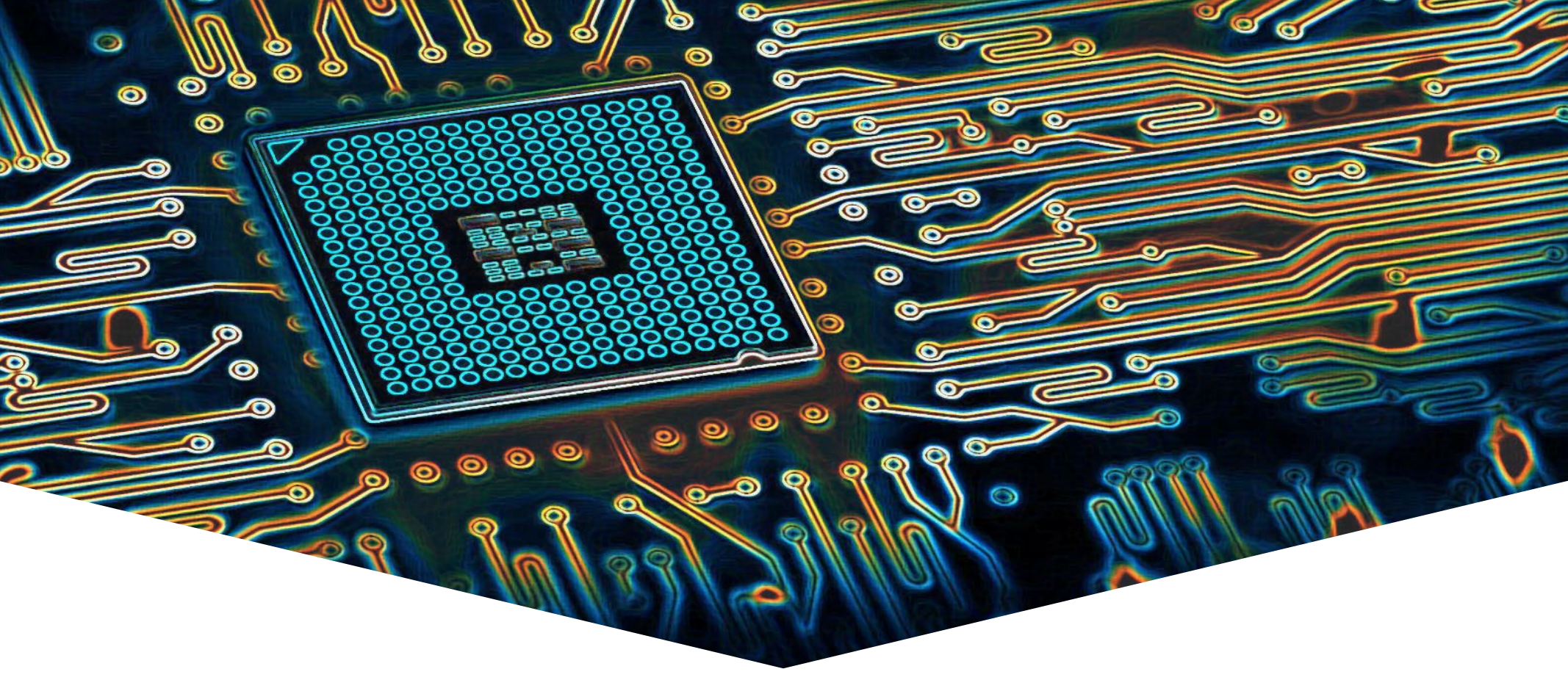


RTS10 Week 5

Overview

- Tasks
  - Creation / Deletion
  - Parameter passing
- Multitasking problems
  - Situation / Problem
  - Solution

Multitasking

"An environment where program execution can be interrupted and continued at any time in any location"

Questions

- How to design such a system and promise timing?
- How to prevent data corruption?
- How to communicate between tasks?

POSIX

POSIX

- Portable Operating System Interface (POSIX) is a standard API for Operating Systems.
  - Many OS partially comply with this standard. For example: Linux, Android, OSX, VxWorks, QNX Neutrino, free-RTOS etc.
- Tasks (threads) are dynamically created by using API calls.
- Semaphores and mutexes can be used to synchronize tasks.
- Message Queues can be used to communicate between tasks.

Pthread Example (1 of 2)


```
void *print1(void *par) {
    for (int i = 0; i < 10; i++) {
        usleep(100000);
        printf("print1\n");
    }
    return NULL;
}

void *print2(void *par) {
    for (int i = 0; i < 10; i++) {
        usleep(200000);
        printf("print2\n");
    }
    return NULL;
}
```

Pthread Example (2 of 2)


```
void *main_thread(void *arg) {
    pthread_attr_t pta;
    pthread_attr_init(&pta);
    pthread_attr_setstacksize(&pta, 1024);

    pthread_t t1, t2;
    pthread_create(&t1, &pta, &print1, NULL);
    pthread_create(&t2, &pta, &print2, NULL);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);

    pthread_attr_destroy(&pta);

    return NULL;
}
```

Uitvoer:

```
print1
print2
print1
print1
print2
print1
print1
print2
print1
print1
print2
print1
print1
print2
print1
print2
print2
print2
print2
print2
```

Source: pthread.c

Pthread with Parameter Example (1 of 2)


```
typedef struct {
    char *msg;
    useconds_t us;
} par_t;

void *print(void *par) {
    par_t* p = par;
    for (int i = 0; i < 10; i++) {
        usleep(p->us);
        printf(p->msg);
    }
    return NULL;
}
```

Pthread with Parameter Example (2 of 2)


```
void *main_thread(void *arg) {
    pthread_attr_t pta;
    pthread_attr_init(&pta);
    pthread_attr_setstacksize(&pta, 1024);

    pthread_t t1, t2;
    par_t p1 = {"print1\n", 100000};
    par_t p2 = {"print2\n", 200000};
    pthread_create(&t1, &pta, &print, &p1);
    pthread_create(&t2, &pta, &print, &p2);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);
    pthread_attr_destroy(&pta);

    return NULL;
}
```

Uitvoer:

```
print1
print2
print1
print1
print2
print1
print1
print2
print1
print1
print2
print1
print1
print2
print1
print2
print2
print2
print2
print2
```

Source: pthread_par.c

Problem with Shared Memory


```
volatile int aantal = 0;

void *teller(void *par) {
    for (int i = 0; i < 100000; i++) {
        aantal++;
    }
    return NULL;
}

//…

    pthread_create(&t1, &pta, &teller, NULL);
    pthread_create(&t2, &pta, &teller, NULL);
    pthread_create(&t3, &pta, &teller, NULL);
```

Source: pthread_shared.c

What is the final value of aantal?

Problem with Shared Memory

- The operation `aantal++` is **not atomic** (in machine code).
  - For example, R4 contains the address of `aantal`:

```
LDR.N R0, [R4, #0]
ADD.N R0, R0, #1
STR.N R0, [R4, #0]
```

What happens when a task switch occurs at this moment?

- What is the minimal and the maximal final value of aantal?
  - Minimum = 1000000
  - Maximum = 3000000

Data Corruption

Situations: Task A and B use a shared global variable
(just demonstrated)

Task C and D are both using the same peripheral
(e.g., UART port)

Goal: Preventing concurrent use of a resource by multiple tasks

Solution: Using tokens to represent resources. Allow a limited number of tasks to get the same token at the same time.

Solution?

- There are solutions which use shared variables (2 flags and 1 turn variable) and **busy waiting**.
  - Dekker's algorithm: http://en.wikipedia.org/wiki/Dekker's_algorithm
  - Peterson's algorithm: http://en.wikipedia.org/wiki/Peterson's_algorithm

- Busy waiting **costs** clock cycles!

- OSes offer solutions **without** busy waiting.

IPC Inter Process (Task) Communication

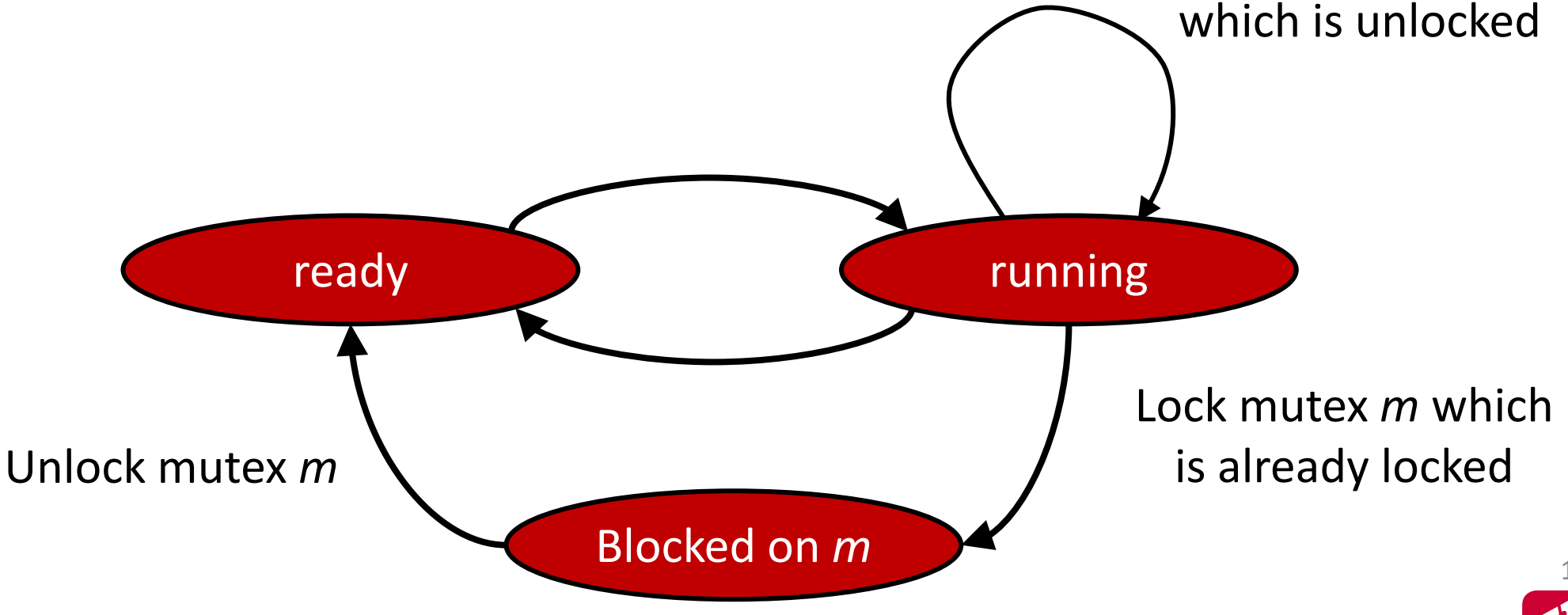
- Shared variable based
  - Dekker's or Peterson's algorithm
    - Busy waiting (inefficient)
  - Spinlock
    - Busy waiting (inefficient)
  - Mutex
  - Semaphore
  - Monitor
    - Mutex combined with Conditional variables
  - Barrier
  - Read Write Lock
  - Event Groups
- Message based
  - Message Queue

Mutex

- Simple way to create a **mut**ual **ex**clusive so-called critical section.
  - Only **one** task can be in the critical section.

- Mutex has a **lock** (take) and a **unlock** (give) function.
  - OS ensures that these functions are **atomic**!
  - At the start of the critical section the mutex must be locked (taken) and at the end of the critical section the mutex must be unlocked (given).

Task States



Mutex

- When a task *t* tries to lock mutex *m* which is already locked by another task, task *t* is blocked on *m*.
  We also say:
  - Task *t* waits for mutex *m*.
  - Task *t* sleeps until mutex *m* is unlocked.

- Order of unblocking (waking up):
  - general purpose OS: FIFO
  - real-time OS: highest priority

Mutex with Shared Memory


```
int aantal = 0;
pthread_mutex_t m;

void *teller(void *par) {
    for (int i = 0; i < 100000; i++) {
        pthread_mutex_lock(&m);
        aantal++;
        pthread_mutex_unlock(&m);
    }
    return NULL;
}
```

Source: mutex.c

Data Corruption

DANGER

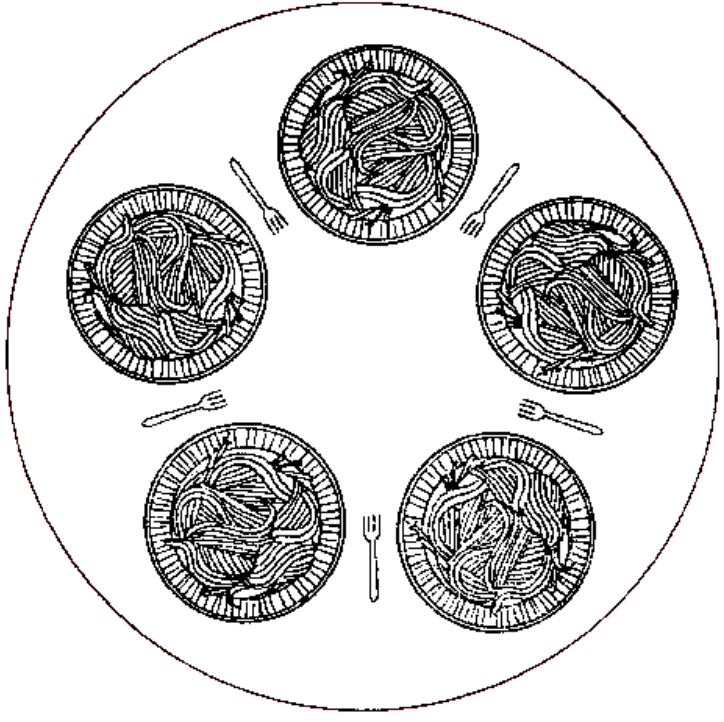
- Priority inversion
  - Low priority task has mutex locked
  - High priority task is blocked due to mutex
  - Solution: priority inheritance

Will be discussed in week 6!

- Deadlock
  - Task A has resource 1 locked and wants to lock resource 2
  - Task B has resource 2 locked and wants to lock resource 1

Deadlock (Example)

- There are 5 philosophers.
- The life of a philosopher consists of:
  - Thinking;
  - Eating.
- Each philosopher has one plate and one fork.
  - To eat a philosopher needs two forks.



Dining Philosophers


```
pthread_mutex_t dinner_fork[5];
void *philosopher(void *par) {
    int i = *(int*)par;
    while (1) {
        printf("philosopher %d is sleeping\n", i);
        usleep(100000 * (rand() % 5 + 1));
        printf("philosopher %d (tries to) picks up left fork\n", i);
        pthread_mutex_lock(&dinner_fork[i]);
        printf("philosopher %d (tries to) picks up right fork\n", i);
        pthread_mutex_lock(&dinner_fork[(i + 1) % 5]);
        printf("philosopher %d is eating\n", i);
        usleep(100000 * (rand() % 5 + 1));
        pthread_mutex_unlock(&dinner_fork[i]);
        printf("philosopher %d lies down left fork\n", i);
        pthread_mutex_unlock(&dinner_fork[(i + 1) % 5]);
        printf("philosopher %d lies down right fork\n", i);
    }
    return NULL;
}
```

Dining Philosophers


```
pthread_t t[5];
int tid[5];
for (int i = 0; i < 5; i++)
{
    tid[i] = i;
    pthread_create(&t[i], &pta, &philosopher, &tid[i]);
}
```

This program can come to a hold (deadlock)! How?

Solution? See homework assignment hereafter.

Source: pthread_philosophers.c

Counting Semaphore

- Operations:
  - Psem (prolaag (probeer te verlagen), take, wait):
    wait (block, sleep) if `count == 0` else decrement `count`.
  - Vsem (verhoog, signal, give, post):
    unblock a waiting task if `count == 0` else increment count.

- Order of unblocking (wake up):
  - general purpose OS: FIFO
  - real-time OS: highest priority

Edsger Dijkstra

Homework

- Solve the problem of the dining philosophers by using a semaphore to ensure that no more than 4 philosophers will be able to sit at the table at the same time.

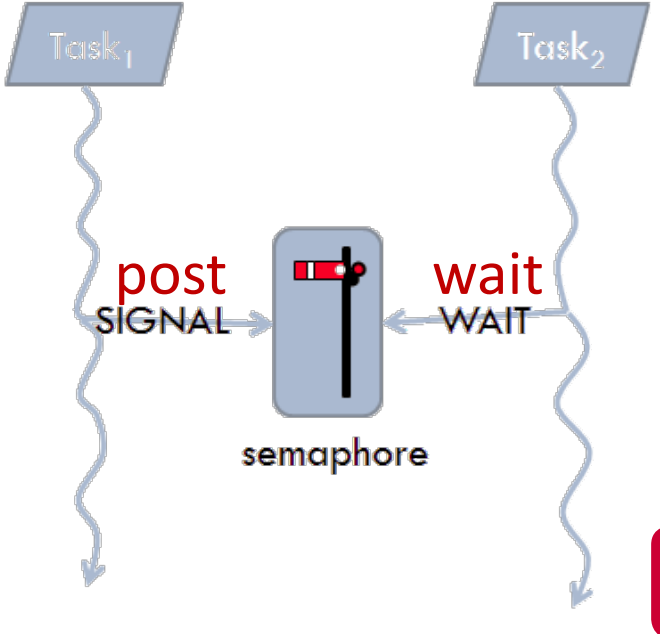
Solution: Create semaphore with initial count of 4 in main. Now each philosopher must take a semaphore after sleeping and must give the semaphore before sleeping again.

The semaphore counts the number of available chairs at the table and a philosopher requires a chair to sit at the table.

Semaphore versus Mutex

- Mutex can only be used for mutual exclusion (task which takes the mutex should also give the mutex (back)).
- Semaphore can also be used for other synchronization purposes.

- Homework:
  - Task a consists of two sequential parts a1 and a2.
  - Task b consists of two sequential parts b1 and b2.
  - Task c consists of two sequential parts c1 and c2.
  - Make sure (using a semaphore) that the parts b2 and c2 are always executed after part a1 has been executed.



IPC Inter Process (Task) Communication

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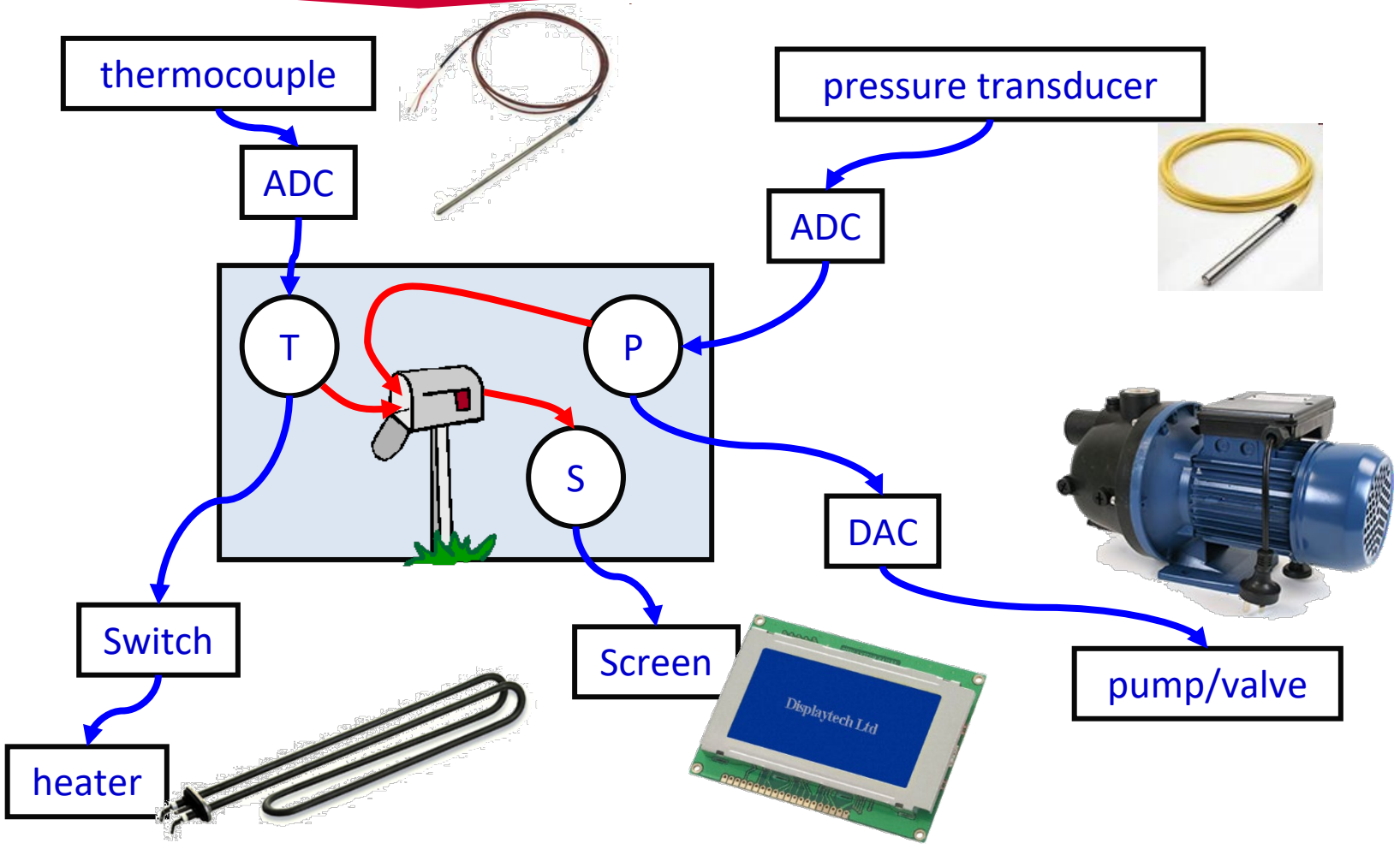
Communication between Threads



Message Queue Example (1 of 2)


```
void *main_thread(void *arg) {
    mqd_t mqdes;
    struct mq_attr mqAttrs;
    mqAttrs.mq_maxmsg = 3;
    mqAttrs.mq_msgsize = sizeof(intb;
    mqAttrs.mq_flags = 0;
    mqdes = mq_open("/ints", O_RDWR | O_CREAT, 0666, &mqAttrs);

    pthread_t tp, tc;
    pthread_attr_t attr;
    pthread_attr_init(&attr);
    pthread_attr_setstacksize(&attr, 1024);
    pthread_create(&tp, &attr, &producer, &mqdes);
    pthread_create(&tc, &attr, &consumer, &mqdes);
```

Message Queue Example (2 of 2)


```c
void *producer(void *p) {
    mqd_t mq = *(mqd_t *)p;
    for (int i = 0; i < 10; i++) {
        mq_send(mq, (char *)&i, sizeof(i), 0);
    }
    return NULL;
}

void *consumer(void *p) {
    mqd_t mq = *(mqd_t *)p;
    for (int i = 0; i < 10; i++) {
        int msg;
        mq_receive(mq, (char *)&msg, sizeof(msg), NULL);
        printf("%d\n", msg);
    }
    return NULL;
}
```

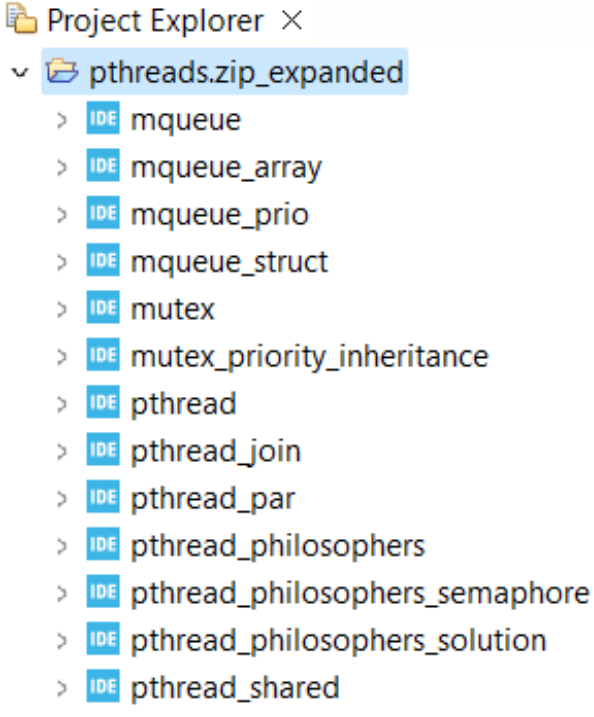
Source: mqueue.c

Kennisclips

- Er zijn kennisclips over bovenstaande onderwerpen te vinden op: https://hrelektrotechniek.bitbucket.io/pthread/
  - Daarin wordt de CC3220S van TI gebruikt i.p.v. de STM32F411E-DISCO maar dat maakt niet zo veel uit.

Example projects

All example projects can be found at:
https://bitbucket.org/HR_ELEKTRO/rts10/wiki/pthreads.md



Next week …

Schedulability en response time analyses

Aan de slag!

Aan de slag met [Opdrachten_Week_5.pdf]