

Embedded Systems Programming - PA8001

<http://goo.gl/cu800H>

Lecture 3

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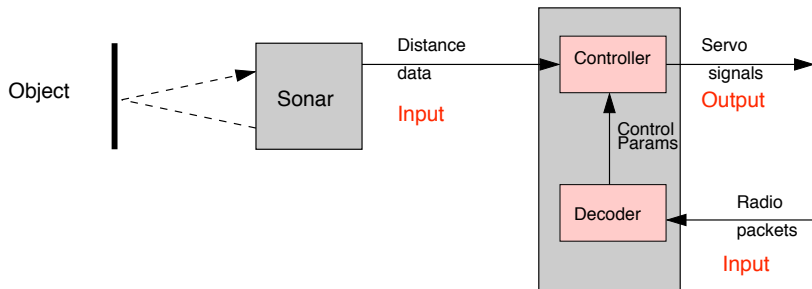
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Center for Research on Embedded Systems

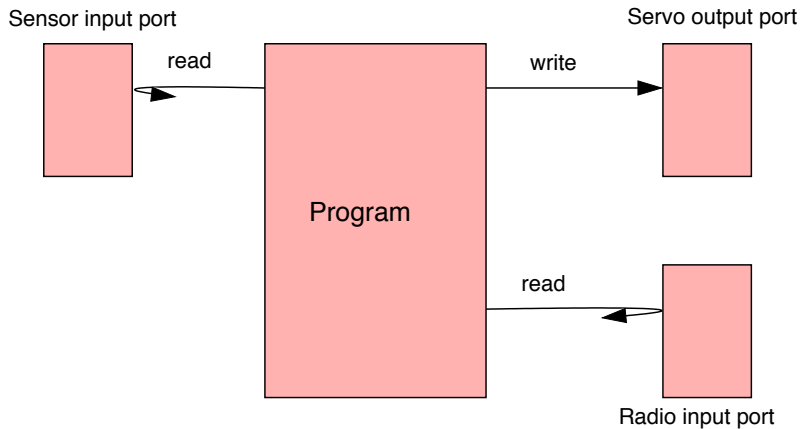
School of Information Science, Computer and Electrical Engineering

A simple embedded system

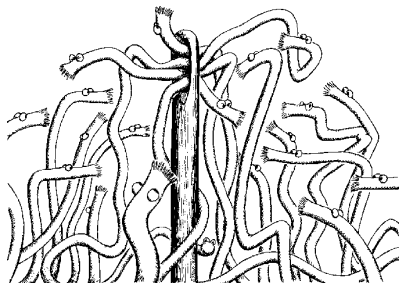
Follow an object using sonar echoes. Control parameters sent over wireless. The servo controls wheels.



The view from the processor



The program



Our order of business:
Concurrency matters!

Even with a single processor, and
more so in current **parallel**
architectures.

If time allows...
How to **implement** threads.

The program: busy waiting input

```
int sonar_read(){  
    while(SONAR_STATUS & READY == 0);  
    return SONAR_DATA;  
}
```

Functions creating an *illusion* to the rest of the program!

```
void radio_read(struct Packet *pkt){  
    while(RADIO_STATUS & READY == 0);  
    pkt->v1 = RADIO_DATA1;  
    ...  
    pkt->vn = RADIO_DATAn;  
}
```

Assuming that `status` is automatically `reset` when data is `read`.

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Functions creating an *illusion* to the rest of the program!

Assuming that **status** is automatically **reset** when data is **read**.

The program: output

```
void servo_write(int sig){  
    SERVO_DATA = sig;  
}
```

The program: algorithms

Control

```
void control(int dist, int *sig, struct Params *p);
```

Calculates the servo signal.

Decode

```
void decode(struct Packet *pkt, struct Params *p)
```

Decodes a packet and calculates new control parameters

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```
void decode(struct Packet *pkt, struct Params *p)
```

Decodes a packet and calculates new control parameters

The program: a first attempt

```
main(){
    struct Params params;
    struct Packet packet;
    int dist, signal;
    while(1){
        dist = sonar_read();
        control(dist, &signal, &params);
        servo_write(signal);

        radio_read(&packet);
        decode(&packet, &params);
    }
}
```

Problems?



Problem: **Unknown and unrelated frequencies** of events

Ignoring the other event while **busy waiting!**

Problems?



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Ignoring the other event while **busy waiting!**

The problem explained

RAM and files vs. external input

- ▶ Data is already **in place** (... radio packets are not!)
- ▶ Even if there might be reasons for waiting, sensors may provide **no (useful) content!**
- ▶ They *produce* data only because they are asked to (... remote transmitters act autonomously!)

Memory-mapped I/O may give the wrong *illusion!*

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Memory-mapped I/O may give the wrong *illusion!*

The program: a second attempt

```
while(1){  
    if(SONAR_STATUS & READY){  
        dist = SONAR_DATA;  
        control(dist,&signal,&params);  
        servo_write(signal);  
    }  
    if(RADIO_STATUS & READY){  
        packet->v1 = RADIO_DATA1;  
        ...;  
        packet->vn = RADIO_DATA $n$ ;  
        decode(&packet,&params);  
    }  
}
```

Destroy the functions for reading and have *only one* busy waiting loop!

Centralized busy waiting

Breaking **modularity**:

- ▶ Checking both events in **one big busy-waiting loop**
- ▶ Complicating the simple read operations

100% CPU usage, no matter how frequent input data arrives.

Try to make the main loop run less often!

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The program: a third attempt

The cyclic executive

```
while(1){  
    sleep_until_next_timer_interrupt();  
    if (SONAR_STATUS & READY){  
        dist = SONAR_DATA;  
        control(dist, &signal, &params);  
        servo_write(signal);  
    }  
    if (RADIO_STATUS & READY){  
        packet->v1 = RADIO_DATA1;  
        ...;  
        packet->vn = RADIO_DATAn;  
        decode(&packet, &params);  
    }  
}
```

Compromise: power consumption vs. response time

Problems?



Issue: different **duration** (processing time) of tasks

Concurrent execution

- ▶ Hitherto: a solution for different frequencies (and the waiting time)
- ▶ Challenge: concurrent execution

Possible solution

Seizing control and allowing for other tasks to take over:

interleaving task fragments

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Possible solution

Seizing control and allowing for other tasks to take over:

interleaving task fragments

Interleaving by hand

```
void decode(struct Packet *pkt, struct Params p){
    phase1(pkt,p);
    try_sonar_task();
    phase2(pkt,p);
    try_sonar_task();
    phase3(pkt,p);
}
```

```
void try_sonar_task(){
    if(SONAR_STATUS & READY){
        dist = SONAR_DATA;
        control(dist,&signal,&params);
        servo_write(signal);
    }
}
```

Again, breaking **modularity** in an ad-hoc way. How many phases of decode are sufficient?

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Again, breaking **modularity** in an ad-hoc way. How many phases of decode are sufficient?

Interleaving by hand

More fine breaking up might be needed ...

```
void phase2(struct Packet *pkt, struct Params *p){  
    while(expr){  
        try_sonar_task();  
        phase21(pkt,p);  
    }  
}
```

Interleaving by hand

More fine breaking up might be needed ...

```
void phase2(struct Packet *pkt, struct Params *p){  
    int i = 0;  
    while(expr){  
        if(i%800==0)try_sonar_task();  
        i++;  
        phase21(pkt,p);  
    }  
}
```

Unstructured and ad-hoc; any better alternative?

Interleaving by hand

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About practical 1

In lab 1 you will program 3 functions

- ▶ Test-Driven Development of a prime factorization algorithm,
- ▶ Writing prime factorization of numbers on (the HDMI) display,
- ▶ Interleaving the blinker with the prime factorizer, and
- ▶ Modify the interleaving to make the blinking period constant.

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Automatic interleaving?

There are 2 tasks, driven by independent input sources.

Handle sonar echoes running the control algorithm and updating the servo.

Handle radio packets by running the decoder.

Had we had access to 2 CPUs we could place one task in each. We can imagine some construct that allows us to **express** this in our program.

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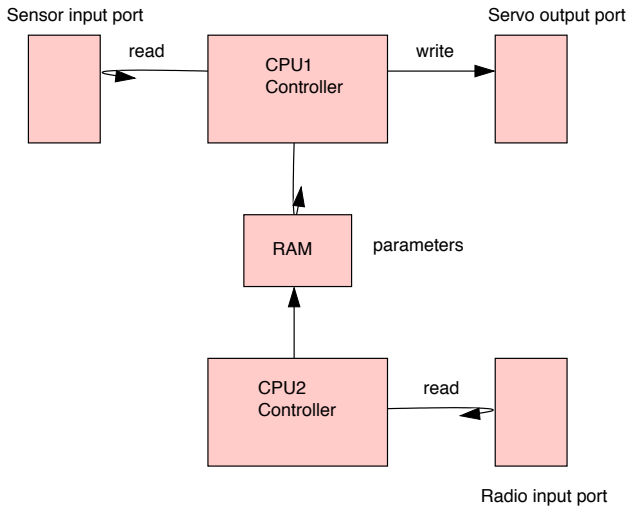
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Two CPUs



Two CPU's program

```
struct Params params;
```

```
void controller_main(){
    int dist, signal;
    while(1){
        dist = sonar_read();
        control(dist,
                &signal,
                &params);
        servo_write(signal);
    }
}
```

```
void decoder_main(){
    struct Packet packet;
    while(1){
        radio_read(&packet);
        decode(&packet, &params);
    }
}
```

We need some way of making one program of this! We will deal with it next lecture!

Concurrent Programming

Concurrent programming is the name given to programming notation and techniques for expressing potential parallelism and solving the resulting synchronization and communication problems.

A system supporting seemingly concurrent execution is called **multi-threaded**.

A **thread** is a unique execution of a sequence of machine instructions, that can be interleaved with other threads executing on the same machine.

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Where should threads belong?

A programming language?

As in Java or Ada. Programs are well organized and are independent of the OS.

Libs and OS?

Like C with POSIX threads? Good for multilanguage composition given that OS standards are followed.

This course - first part

For pedagogical purposes we choose to work with C and a small kernel.

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Our first multithreaded program

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struct Params params;
```

```
void controller_main(){  
    int dist, signal;  
    while(1){  
        dist = sonar_read();  
        control(dist,  
                &signal,  
                &params);  
        servo_write(signal);  
    }  
}
```

```
void decoder_main(){  
    struct Packet packet;  
    while(1){  
        radio_read(&packet);  
        decode(&packet, &params);  
    }  
}
```

```
main(){  
    spawn(decoder_main);  
    controller_main();  
}
```

The critical section problem

What will happen if the `params` struct is read (by the controller) **at the same time** it is written (by the decoder)?

I.e., what if the scheduler happens to insert some decoder instructions while some, but not all, of the controller's reads have been done?

This problem is central to concurrent programming where there is any amount of sharing!

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Critical sections in real life

Car dealer

Displays used car

Puts up price tag

Displays luxury car

Updates price tag

Car buyer

Becomes interested, sells her old car

Gets angry!

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Critical sections in programs

Imagine updating the same bank account from two places at approximately the same time (e.g. your employer deposits your salary at more or less the same time as you are making a small deposit).

```
int account = 0;  
account = account + 500;    account = account + 10000;
```

When this is compiled there might be several instructions for each update!

Critical sections in programs

Imagine updating the same bank account from two places at approximately the same time (e.g. your employer deposits your salary at more or less the same time as you are making a small deposit).

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int account = 0;  
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Critical sections in programs

```
load account,r1  
add 500,r1  
store r1, account
```

```
load account, r2  
add 10000, r2  
store r2, account
```

Final balance is 10500

Critical sections in programs

```
load account,r1  
add 500,r1  
store r1, account
```

```
load account, r2  
add 10000, r2  
store r2, account
```

Final balance is 10500

Critical sections in programs

```
load account,r1
```

```
add 500,r1
```

```
store r1, account
```

Final balance is 500

```
load account, r2
```

```
add 10000, r2
```

```
store r2, account
```

Critical sections in programs

Testing and setting

```
int shopper;
```

```
if(shopper == NONE)  
    shopper = HUSBAND
```

```
if(shopper==NONE)  
    shopper = WIFE
```

Possible interleaving

```
if(shopper == NONE)
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Our embedded system

Exchanging parameters

```
                struct Params p;
while(1){                while(1){
    ...                local_minD = p.minDistance;
    p.minDistance = e1;    local_maxS = p.maxSpeed;
    p.maxSpeed = e2;    ...
}                }
```

Possible interleaving

```
p.minDistance = 1;
p.maxSpeed = 1;
```

```
p.minDistance = 200;
p.maxSpeed = 150;
```

```
local_minD = 1;
```

```
local_maxS = 150
```

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}                }
```

Possible interleaving

```
p.minDistance = 1;
p.maxSpeed = 1;
```

```
p.minDistance = 200;
p.maxSpeed = 150;
```

```
local_minD = 1;
```

```
local_maxS = 150
```

The classical solution

Apply an **access protocol** to the critical sections that ensures **mutual exclusion**

Require that all parties follow the protocol

Access protocols are realized by means of a shared datastructure known as a **mutex** or a **lock**.

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Mutual exclusion

Exchanging parameters

```
struct Params p;
    mutex m;

while(1){
    ...
    lock (&m);
    p.minDistance = e1;
    p.maxSpeed = e2;
    unlock (&m);
}

while(1){
    lock (&m)
    local_minD = p.minDistance;
    local_maxS = p.maxSpeed;
    unlock (&m)
    ...
}
```

Classic Example

Bonus Question

Explain briefly the **Fischer's protocol** and describe how it achieves mutual exclusion.

Deadline

Tuesday 16/09/2014 at 17:00.