

Introduction to IoT

School Year 2023-2024

Valsalice



Course Structure

1	Introduction and Basics
2	Basic Data Types and Operators
3	Control Structures Pt. 1
4	Control Structures Pt. 2
5	Functions and Scope
6	Arrays
10	Advanced String Usage
11	Custom Data Types

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9	Timers and Concurrency
12	Basic Communication and Networking
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14	Introduction to Cooja
15	Lossy Networks
16	Reliable Data Transfer Challenge



= Core Topics



= Optional Topics

Open your Virtual Machines

1. Turn on your Laptops
2. Login to Windows using "User"
3. Open the **Virtual Box** program
4. Select the **nRF52840LAB** Virtual Machine & click **Start**
5. Log-in using credentials:

Username: **ubuntu**


Password: **ubuntu**
6. Open **Visual Studio Code** (use the App bar on the left)




Prepare the Coding Environment

- 1 From the Terminal:

```
make setup
```

- 2  valsalice-iot-23 git:(master) make setup
Enter your username:



```
✓ Repository setup complete!
```



If you see any (yellow) errors input the credentials again

- 3 Open the **week14** folder in the terminal
- 4 Right click on the left + **“Open in Integrated terminal”**

Recap: Data Types

C has a number of primitive data types:

int	42	1200	1_200	-3
float	3.14	0.00001	-2.1	
char	'A'	'@'	'\n'	
bool	true	false		

Strings are *NOT* a primitive data type, and have special syntax.

strings	"Hello"	"A"	"I am a full sentence!"
----------------	---------	-----	-------------------------

Recap: Variables

A variable is a named container that stores data or values.

```
int x = 42;  
float y = -0.12;  
char w = 'A';  
char z[50] = "Full sentence";
```

Booleans require a custom include statement:

```
#include <stdbool.h>  
bool hello = true;
```

Recap: Boolean Operators

Greater than	>
Greater or equal than	>=
Less than	<
Less or equal than	<=
Equals	==
Not equals	!=
Not	!

Recap: Chaining Comparisons

- **and** (both must be true)

```
true && false
```

```
(5 < 6) && (5 < 10)
```

- **or** (either must be true)

```
true || false
```

```
(5 < 3) || (5 < 10)
```

- **not** (negation)

```
!true
```

```
!(5 < 3)
```


Recap: If-Statement chaining

You can chain multiple conditions with **else if**.

What is the difference between these two snippets of code?

```
int num;
scanf("%d", &num);

if (num < 3) {
    printf("Small number\n");
} else if (num < 10) {
    printf("Medium number\n");
}
```

```
int num;
scanf("%d", &num);

if (num < 3) {
    printf("Small number\n");
}
if (num < 10) {
    printf("Medium number\n");
}
```

Recap: While-Loops

Repeat parts of
your code!

```
int num;  
printf("Input a number greater than 100: ");  
scanf("%d", &num);  
  
while (num <= 100) {  
    printf("Wrong number, try again: ");  
    scanf("%d", &num);  
}  
  
printf("Well done!\n");
```

Recap: For-Loops

Repeat a **specific** amount of times!

```
int x;  
  
for (x = 1; x <= 5; x++) {  
    printf("Hello %d\n", x);  
}
```

```
int x = 0;  
  
while (x < 5) {  
    x += 1;  
    printf("Hello %d\n", x);  
}
```

Recap: Arrays

Modifiable containers for data.

With **variables**:

```
int num1 = 42;
int num2 = 100;
int num3 = 10;

printf("%d\n", num1);
printf("%d\n", num2);
printf("%d\n", num3);
```

With a **list**:

```
int array[] = {42, 100,
10};

for(int i = 0; i < 3; i++)
{
    printf("%d\n",
array[i]);
}
```

Recap: Accessing Array Elements

To access array elements you can use the **[index]** operator.

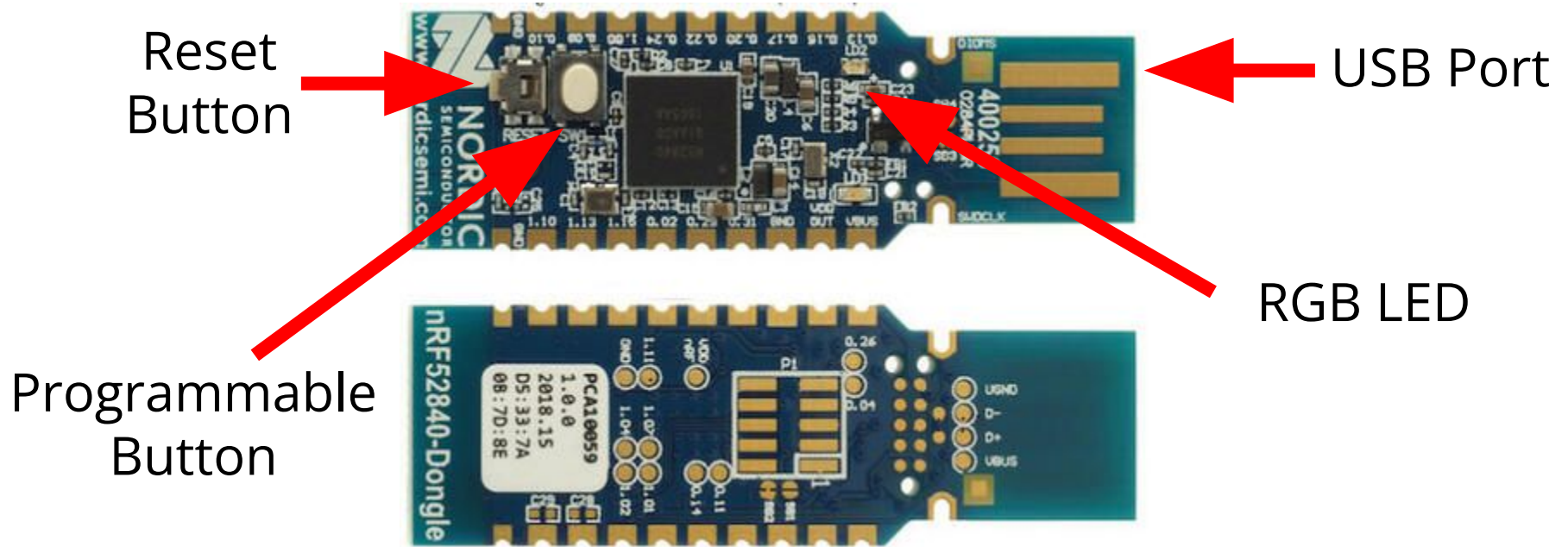
NOTE: List indices start from **0**

index:	0	1	2	3	4
<code>int array[] = {</code>	<code>17,</code>	<code>28,</code>	<code>33,</code>	<code>56,</code>	<code>6};</code>

```
printf("%d\n", array[0]);
```

```
printf("%d\n", array[3]);
```

Recap: What is the nRF52840?



Recap: The LED Library

```
#define RGB_LED_RED      1
#define RGB_LED_GREEN   2
#define RGB_LED_BLUE    4
#define RGB_LED_MAGENTA (RGB_LED_RED | RGB_LED_BLUE)
#define RGB_LED_YELLOW  (RGB_LED_RED | RGB_LED_GREEN)
#define RGB_LED_CYAN    (RGB_LED_GREEN | RGB_LED_BLUE )
#define RGB_LED_WHITE   (RGB_LED_RED | RGB_LED_GREEN | RGB_LED_BLUE)
/*-----*/
void rgb_led_off(void);
void rgb_led_set(uint8_t colour);
```

Recap: The E-Timer Library

```
/* Event generated when a timer expires */
#define PROCESS_EVENT_TIMER          0x88
/*-----*/
/* Set the amount of time on the timer. Also start the timer */
void etimer_set(struct etimer *et, clock_time_t interval);
/* Restart the timer with the previously set amount of time */
void etimer_restart(struct etimer *et);
void etimer_stop(struct etimer *et);
/*-----*/
/* Check if the timer has completed */
bool etimer_expired(struct etimer *et)
```


Recap: Using an E-Timer

```
1  #define BLINK_INTERVAL (0.2 * CLOCK_SECOND)
   static struct etimer blink_timer;

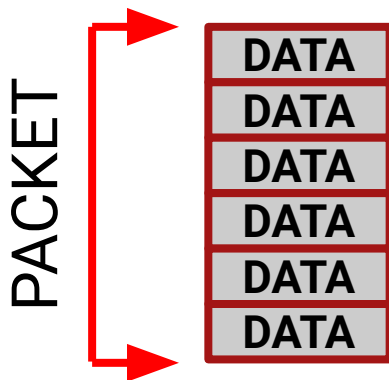
   PROCESS_THREAD(demo_process, ev, data) {
2     PROCESS_BEGIN();
   etimer_set(&blink_timer, BLINK_INTERVAL);

   while (true) {
       PROCESS_WAIT_EVENT();

3       if (etimer_expired(&blink_timer)) {
4           etimer_reset(&blink_timer);
           // Do something on timer expiry
       }
   }
   PROCESS_END();
}
```

Recap: Networking Packets

- Networking involves **transmitting data** over a medium.
- Information is transmitted in **packets**: small chunks of **data** (of arbitrary length) sent over the network.



Recap: Disambiguating Packets

To know where packets are coming from we add a **team_id** field to packets.

To use this field in the next exercise you **MUST** set the **TEAM_ID** macro at the top of the file.

```
typedef struct {  
    char team_id;  
    int command;  
    int data;  
} message_t;
```

```
// IMPORTANT!  
// Change the `TEAM_ID`!  
#define TEAM_ID 'Z'
```

Recap: Receiving Packets

We provide a helper function to simplify **receiving packets** over nullnet:

receive_nullnet_data

You can add functionality **inside the function body**.

```
/* Helper function to receive data over nullnet */
void receive_nullnet_data (
    const void *bytes,
    uint16_t len,
    const linkaddr_t *src,
    const linkaddr_t *dest)
{
    int data;
    memcpy(&data, bytes, len);

    printf("Data received: %d\n", data);
}
```

Recap: Sending Packets

We provide a helper function to simplify **sending packets** over nullnet:

send_nullnet_data

You can **call** this function but you **should NOT edit** it.

```
/* Helper function to send data over nullnet */  
void send_nullnet_data (int data) {  
    printf("Sending data: %d\n", data);  
    nullnet_buf = (uint8_t *)&data;  
    nullnet_len = sizeof(data);  
  
    NETSTACK_NETWORK.output(NULL);  
}
```

```
send_nullnet_data (200);  
  
variable = 42;  
send_nullnet_data (variable);
```

Recap: Header Files

Header files allow you to define types, structures, or **common code** once and **reuse** it in multiple source files

```
#include "config.h"
```

file.c

```
printf("Team ID: %c", TEAM_ID);
```

```
config.h

#ifndef CONFIG_H
#define CONFIG_H

/* Message Configuration */
typedef struct
{
    char team_id;
    int data;
} message_t;

#define TEAM_ID 'Z'

#endif // CONFIG_H
```

alice

Recap: Cooja

Cooja is a **Simulator** for the Contiki-NG Operating System.

It allows for Contiki-NG programs to be compiled and executed on virtual **simulated test-beds**.

The simulated motes will behave similarly to the real world.

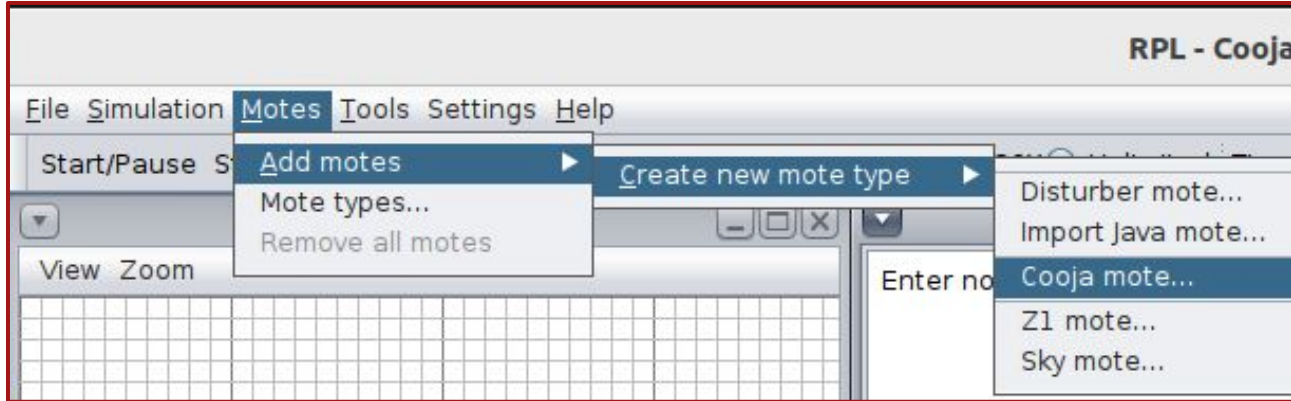
- 1 From the Terminal run the **make cooja** command:

```
make cooja
```

Recap: Adding a Cooja Mote

1 Let's add a new Mote:

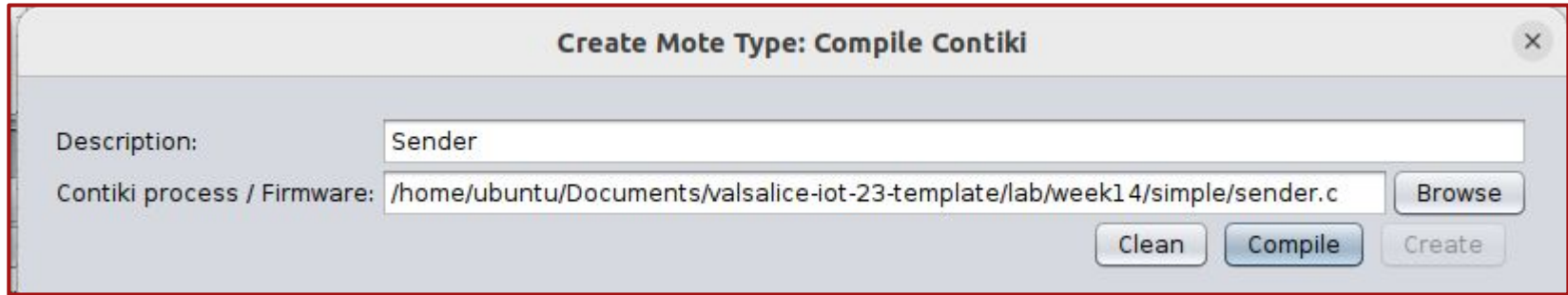
Motes > Add motes > Create new > Cooja mote



Recap: Adding a Cooja Mote

- 2 Put "**Sender**" in the description
- 3 Use the firmware under (you can also use "Browse"):

`/home/ubuntu/Documents/valsalice-iot-23/lab/week14/simple/sender.c`

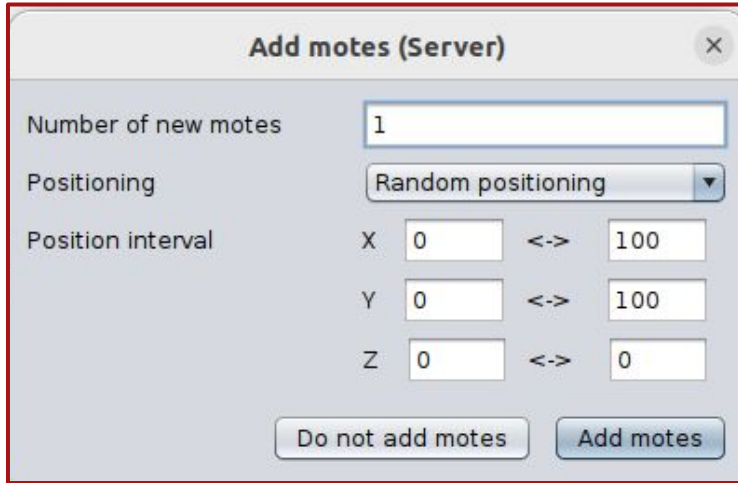


The screenshot shows a dialog box titled "Create Mote Type: Compile Contiki". It has a close button (X) in the top right corner. The "Description:" label is followed by a text input field containing "Sender". Below this, the "Contiki process / Firmware:" label is followed by a text input field containing the path "/home/ubuntu/Documents/valsalice-iot-23-template/lab/week14/simple/sender.c". To the right of this field is a "Browse" button. At the bottom right of the dialog are three buttons: "Clean", "Compile", and "Create".

- 4 Click "**Compile**"
- 5 Click "**Create**"

Recap: Adding a Cooja Mote

- 6 Put “1” in the “Number of new motes” field



Dialog box titled "Add motes (Server)".

Number of new motes: 1

Positioning: Random positioning

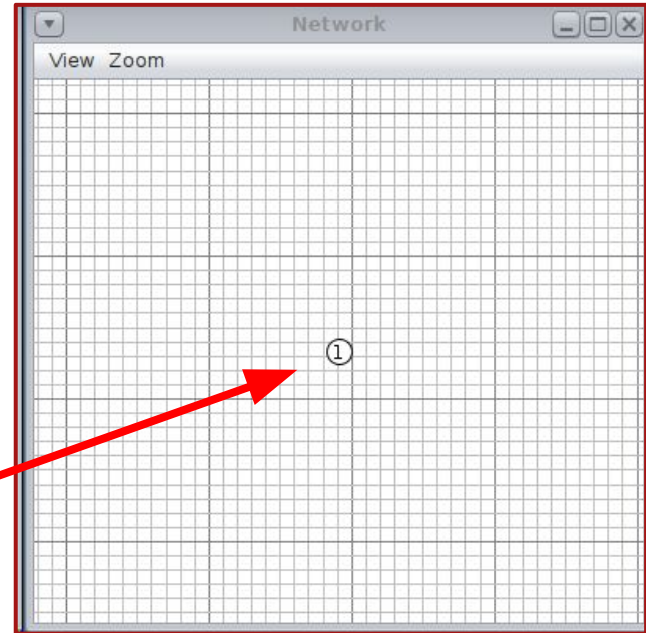
Position interval:

- X: 0 <-> 100
- Y: 0 <-> 100
- Z: 0 <-> 0

Buttons: Do not add motes, Add motes

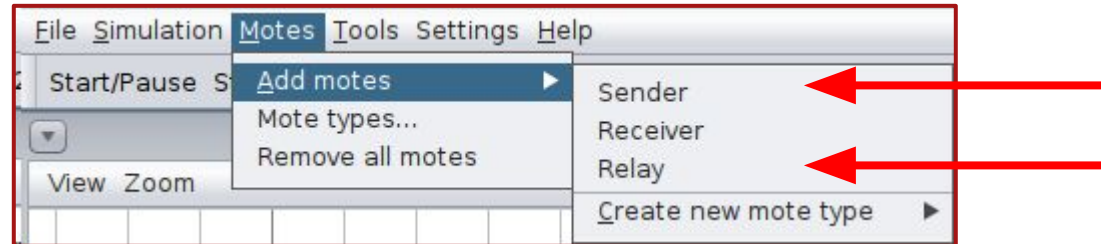
- 7 Click “**Add motes**”

- 8 You should get this



Recap: Adding a Cooja Mote

- 9 After you create the Mote it will be available for **quick access** in the simulation:

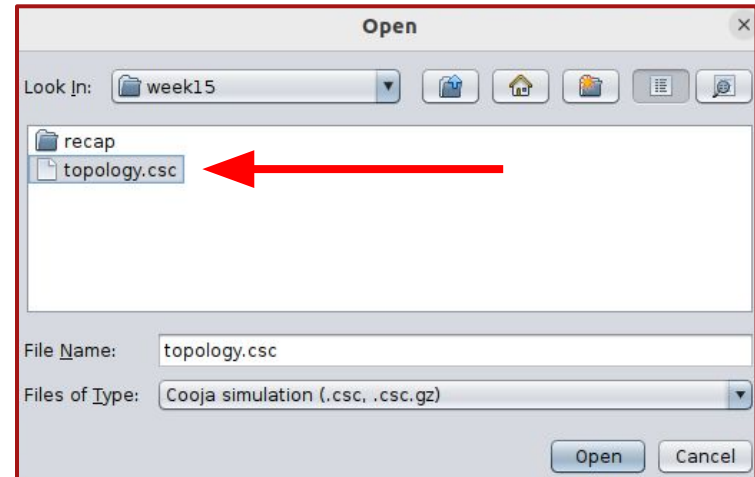
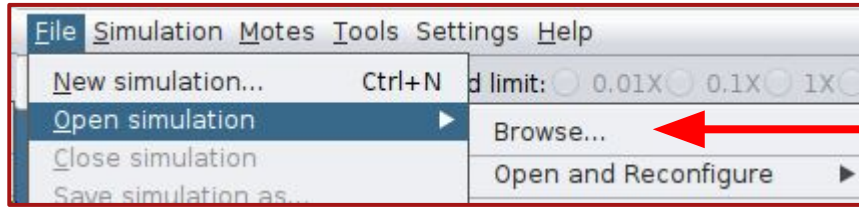


- 10 Simply click on the **Mote name** to create new motes of that type

Recap: Opening a Cooja Simulation

Open an existing Cooja Simulation

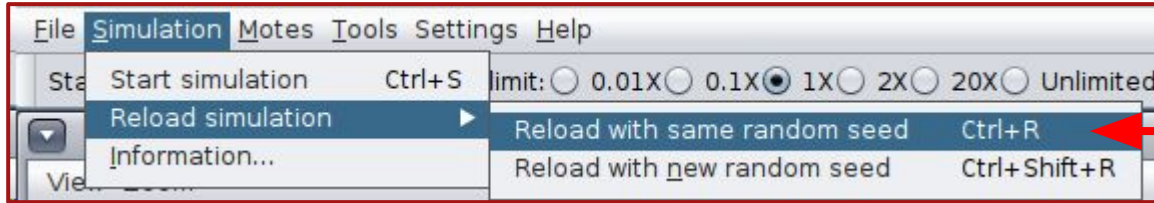
File > Open simulation > Browse...



Recap: Recompiling Mote Code

To recompile motes you simply reload the simulation

Simulation > Reload Simulation > Same seed



SHORTCUT: You can simply press **Ctrl + R**



Errors will be raised:



Node IDs

Node IDs are **unique IDs** assigned to each **physical chip**. They allow us to identify each chip when it sends or receives messages.

Cooja additionally **simulates IDs** assigning them to the nodes.

```
#include "sys/node-id.h"

printf("Node ID: %d\n", node_id);
```

Logging

Rather than using prints to **facilitate visualising** information on serial output we use a “logger”.

Fundamentally any time we would use **printf** we can now use **LOG_INFO**, there is **no other difference**.



```
#include "sys/node-id.h"

printf("Node ID: %d\n", node_id);
LOG_INFO("Node ID: %d\n", node_id);
```

Exercise



Change the **TEAM_ID** in **config.h**!

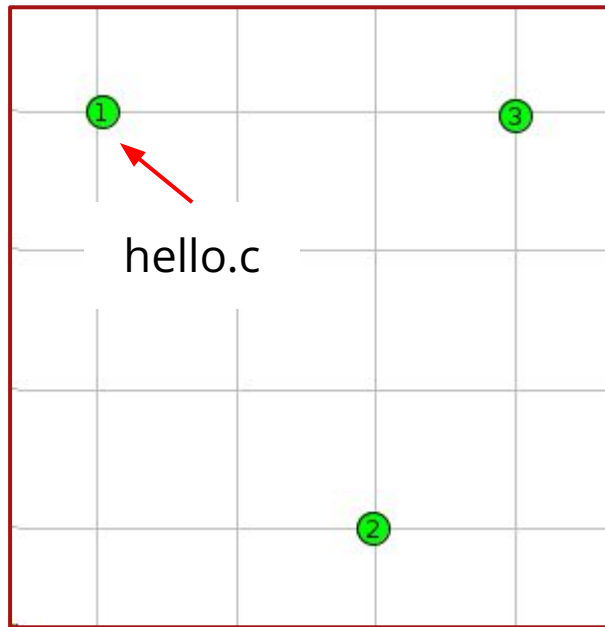
Open the following Cooja simulation:
week16/nodes/topology1.csc

Implement in **week16/nodes**:

1) **Hello (hello.c)**:

```
// TODO: Print the Node ID
```

Add multiple nodes to the simulation →



Test that it works



Open a new terminal in **week16/hello**

1) Flash the hello firmware to real hardware:

```
make hello.dfu-upload
```

2) Log into the mote, what do you see?

```
make login
```

Save remotely your Changes

1

```
make save
```

2

```
|Password
```

```
Git: https://aspina@git.spina.me (Press 'Enter' to confirm or  
'Escape' to cancel)
```

3

```
✓ Changes committed and pushed. All done!
```

Leveraging Node IDs

We will be using Node IDs to know where are coming from:

- **team_id** is for team membership
- **node_id** tracks packet origin

```
#include "config.h"

char tid = message.team_id;
int nid = message.node_id;

printf("node_id '%d', team '%c'\n", nid, tid);
```

file.c

```
config.h

#ifndef CONFIG_H
#define CONFIG_H

/* Message Configuration */
typedef struct
{
    char team_id;
    int node_id;
} message_t;

#endif // CONFIG_H
```



Exercise

⚠ Change the **TEAM_ID** in **config.h**!

Open the following Cooja simulation:
week16/chat/topology2.csc

Implement in **week16/chat**:

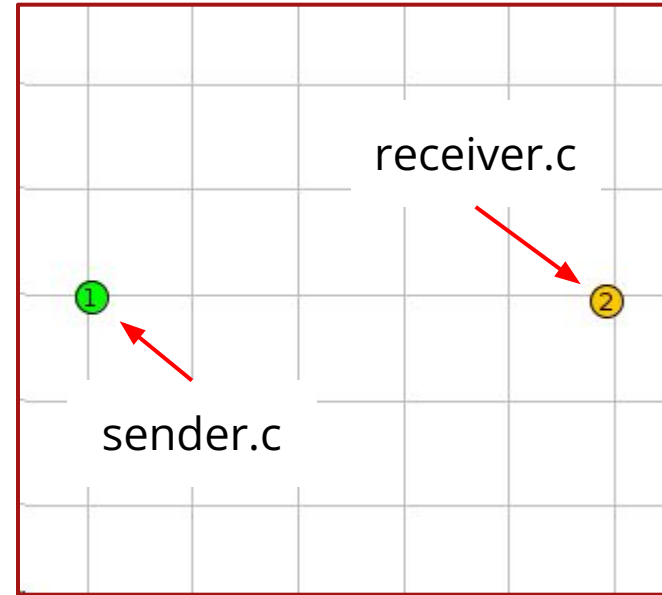
1) **Sender (sender.c):**

```
// TODO: Send an empty message
```

2) **Receiver (receiver.c):**

```
// TODO: Change `false` to check for `TEAM_ID`
```

```
// TODO: Print the node ID the message is coming from
```



Test that it works



Open a new terminal in **week16/chat**

1) Flash the sender firmware:

```
make sender.dfu-upload
```



2) Move the sender mote to a different machine!

3) Flash the receiver firmware and make login:

```
make receiver.dfu-upload
```

```
make login
```

Save remotely your Changes

1

```
make save
```

2

```
|Password
```

```
Git: https://aspina@git.spina.me (Press 'Enter' to confirm or  
'Escape' to cancel)
```

3

```
✓ Changes committed and pushed. All done!
```

Change to Message Configuration

We are changing the **message_t** struct to now also be able to disseminate data together with each packet

- **team_id** is for team membership
- **node_id** tracks packet origin
- **data** payload of each packet

```
config.h
#ifndef CONFIG_H
#define CONFIG_H

/* Message Configuration */
typedef struct
{
    char team_id;
    int node_id;
    int data;
} message_t;

#endif // CONFIG_H
```

Exercise



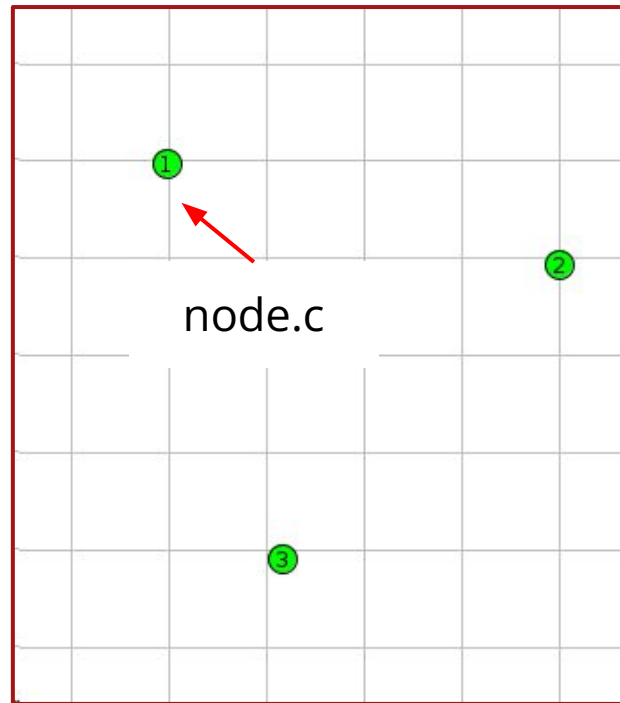
Change the **TEAM_ID** in **config.h**!

Open the following Cooja simulation:
week16/counting/topology3.csc

Implement in **week16/counting**:

1) Node (node.c):

```
// TODO: If sender is node 1 and I am node 2: reply  
// TODO: If sender is node 2 and I am node 3: reply  
// TODO: If sender is node 3 and I am node 1: reply
```



Test that it works



Open a new terminal in **week16/hello**

1) Flash the hello firmware to get the IDs of the nodes:

```
make hello.dfufu-upload
```



Open a new terminal in **week16/counting**

2) Change your **node.c** code to use the new IDs:

3) Flash the node firmware on **ALL nodes** and make login:

```
make node.dfufu-upload
```

```
make login
```

Save remotely your Changes

1

```
make save
```

2

```
|Password
```

```
Git: https://aspina@git.spina.me (Press 'Enter' to confirm or  
'Escape' to cancel)
```

3

```
✓ Changes committed and pushed. All done!
```

End of Class

See you all next week!