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
7. Introduction to Contiki-NG and nRF52840
8. Sensing and Actuating with Contiki-NG
9. Timers and Concurrency
10. Advanced String Usage
11. Custom Data Types
12. Basic Communication and Networking — JAN 16
13. Introduction to the MAC Layer — JAN 23
14. Introduction to RPL and Network Routing — JAN 30
15. Advanced Protocols: TSCH and 6TiSCH — FEB 6
16. Reliable Data Transfer Challenge — FEB 20, FEB 27, MAR 5

= 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. Add a new Virtual Machine (**Ctrl + A**)
5. Open the **VirtualBox** folder ⚠ (**NOT** the .VirtualBox)
6. Select the **nRF52840LAB** file
7. Click **Start**

Prepare the Coding Environment

1. Start the Virtual Machine **nRF52840LAB**
2. Log-in using credentials:

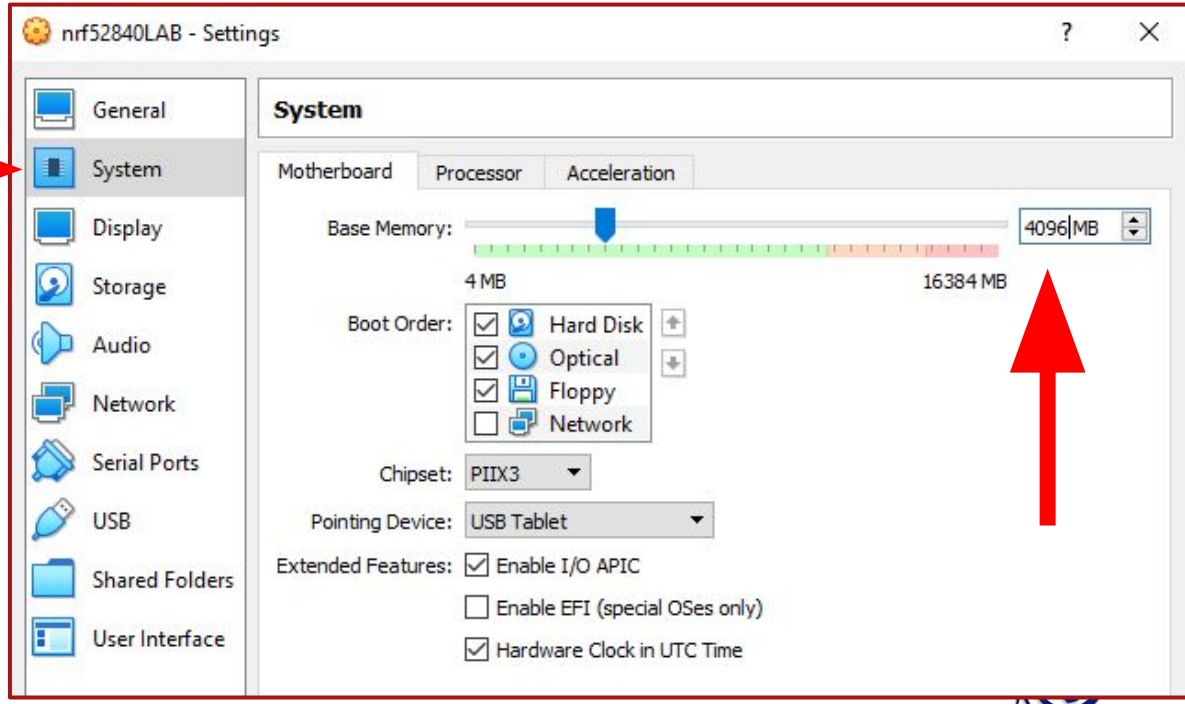
   Username: **ubuntu**

   Password: **ubuntu**

3. Open **Visual Studio Code** (use the App bar on the left)

Change the VM Memory Requirements

1. Before starting the VM go to **Settings** and then **System**
2. Change to 4096 MB!



Prepare the Coding Environment

4 From the Terminal:

```
make setup
```

5

```
○ → valsalice-iot-23 git:(master) make setup
  Enter your username:
```

6

```
Password
```

7

```
✅ Repository setup complete!
```

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

Prepare the Coding Environment

7. Open the **week12** folder in the terminal

   Right click on the left + "**Open in Integrated terminal**"

8. You should see the following in the terminal:

```
week09 git:(master)
```

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?

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

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

```c
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
`int array[] =`	`{17,`	`28,`	`33,`	`56,`	`6};`

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

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

Recap: Assigning Array Elements

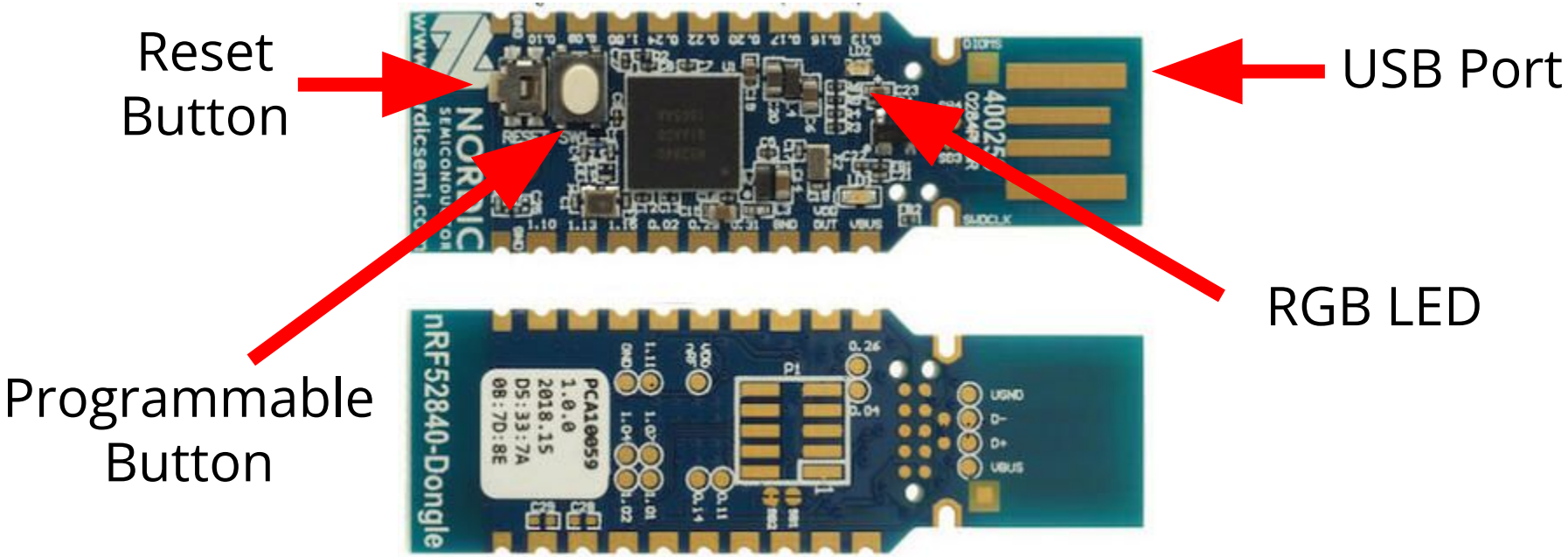
To assign array elements you can use the **[index]** operator on the left-hand-side of a statement (like a variable)

```
int array[] = {17, 28, 33, 56, 6};
array[3] = 100;
array[2] = -7;
```

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

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

Recap: What is the nRF52840?



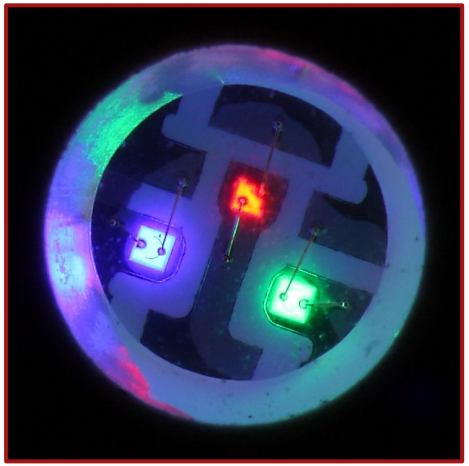
Recap: Anatomy of a Contiki-NG Program

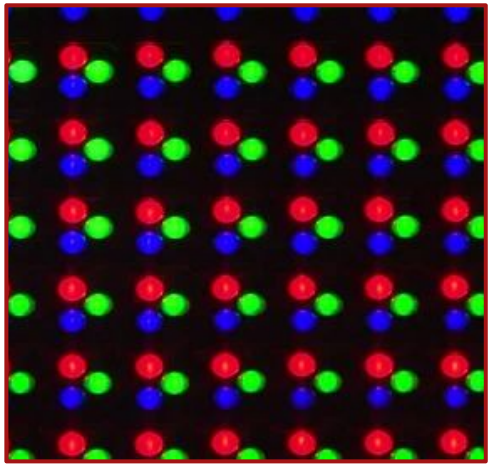
```
1 PROCESS_THREAD(button_hal_example, ev, data) {
2   PROCESS_BEGIN();
3   while (1) {
4     PROCESS_YIELD();

5     if (ev == button_hal_press_event) {
6       printf("Button pressed!\n");
      }
    }
7   PROCESS_END();
}
```

Recap: RGB LEDs

LEDs are **actuators**, they allow the device to act on the outside world. RGB LEDs have **three configurable color** channels:

1. **Red**
2. **Green**
3. **Blue**





LED displays (such as those of PCs) work the same way

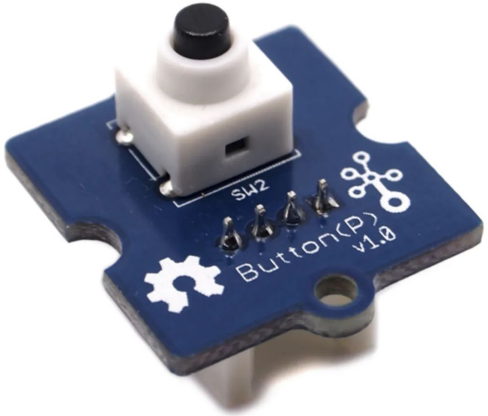
Recap: The LED Library

```
#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: Buttons

Buttons allow the device to **“sense”** the world around them.

The button allows the device to **receive input and react** to actions in the world around them.



Recap: Button Library

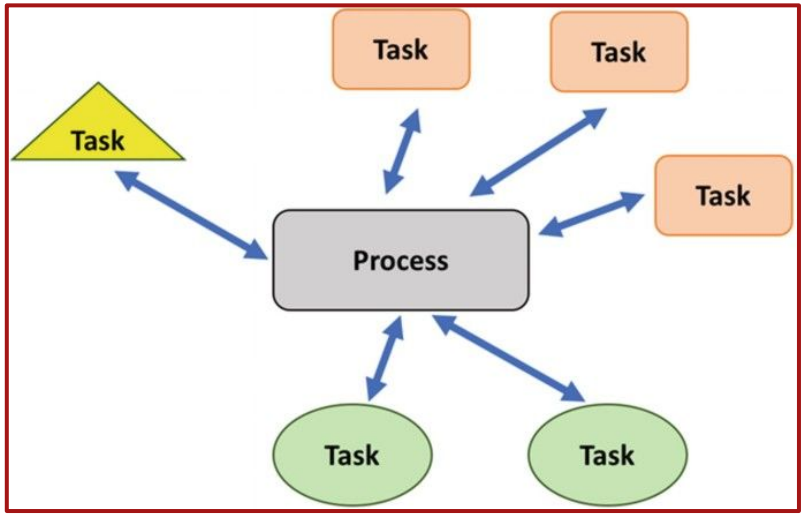
```
/* Event generated when a button gets pressed */
extern process_event_t button_hal_press_event;
/* Event generated when a button gets released */
extern process_event_t button_hal_release_event;
/* Event generated every second the button is kept pressed */
extern process_event_t button_hal_periodic_event;
/*-----------------------------------------------------------------*/
#define BUTTON_HAL_STATE_RELEASED  0
#define BUTTON_HAL_STATE_PRESSED   1
/*-----------------------------------------------------------------*/
void button_hal_init(void);
uint8_t button_hal_get_state(button_hal_button_t *button);
```

Recap: Processes

Contiki-NG **Processes** allow for the execution of **multiple tasks** at the same time (i.e. **concurrently**).

We have seen:

1. **PROCESS_BEGIN**
2. **PROCESS_END**
3. **PROCESS_YIELD**



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: Programming the nRF52840

1. Attach the **nRF52840** chip to your laptops

⚠ Ensure the device is in **bootloader mode** (blinking red light)

Reset Button

3. Program the firmware

```
make simple_timer.dfu-upload
```

Recap Exercise

Change the code in (**`simple_timer.c`**)

1) Pressing the button turns the LED Green.

2) After 2 seconds the LED is turned off

```
1  static struct etimer blink_timer;

   PROCESS_BEGIN();
   while (true) {
     PROCESS_YIELD();
     if (ev == button_hal_press_event) {
2      rgb_led_set(RGB_LED_GREEN);
3      etimer_set(&blink_timer, 2 * CLOCK_SECOND);
4    } else if (ev == PROCESS_EVENT_TIMER) {
5      if (etimer_expired(&blink_timer)) {
6        rgb_led_off();
       }
     }
   }
```

To flash: `make simple_timer.dfu-upload`

For console: `make login`

Save remotely your Changes

1. `make save`

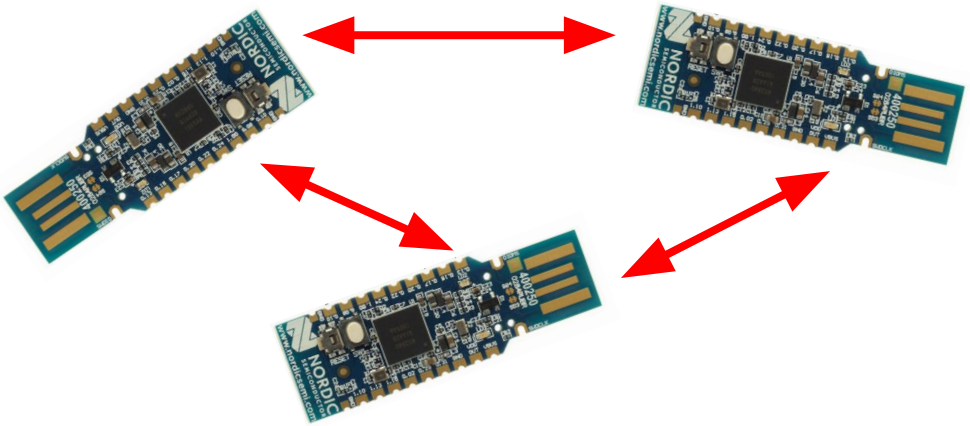
2. Password

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

3. ✅ Changes committed and pushed. All done!

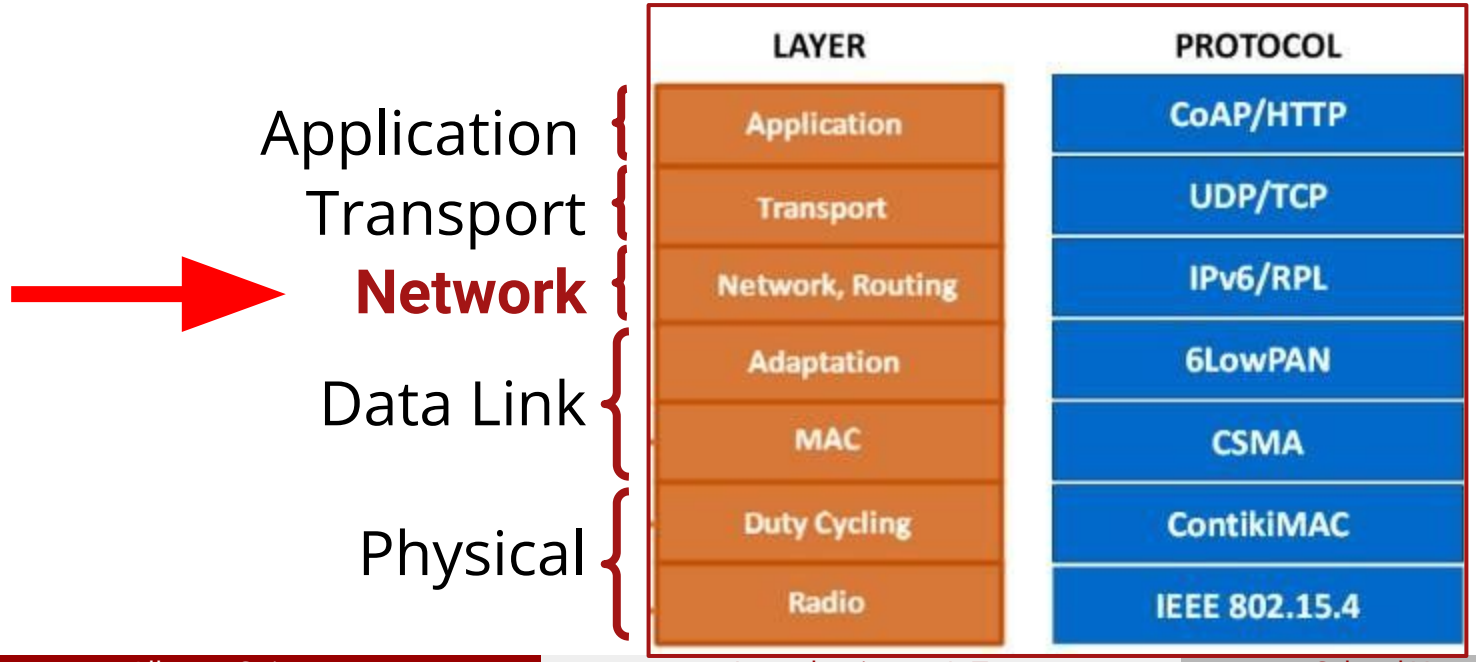
Networking

- **Networking** is the practice of connecting computers and other devices to **share information**.
- Involves **transmitting data** over various types of media, like wireless signals.



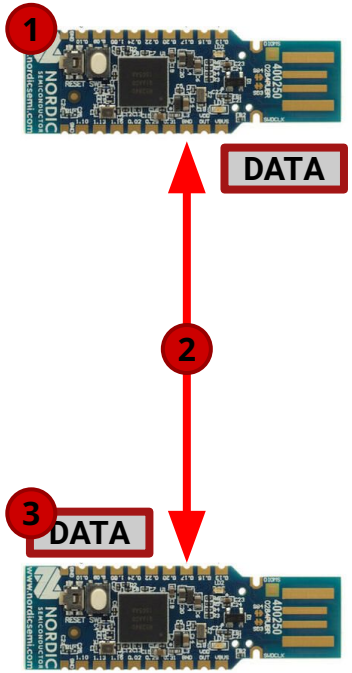
Networking

The Network layer is part of the **OSI standard**. We **disable** the Application and Transport layers in Contiki-NG using "**Nullnet**".



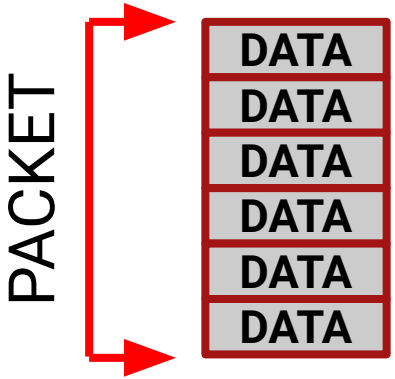
Networking Concepts

1. **Nodes**: Individual devices in a network (like computers, sensors).
2. **Links**: Connections between nodes (wired or wireless).
3. **Data Packets**: Small units of data sent over a network.



Networking Packets

- **Packets** are small chunks of **data** sent over the network.
- Packets can have **arbitrary length** (up to a maximum)



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);
}
```

Exercise

To flash: `make receiver.dfu-upload`

For console: `make login`

Change the code in (**`receiver.c`**)

1) Set your LED to the color that you receive from the network

2) Use the **blink_timer** to turn off the LED after one second of receiving the network data

HINT: Restart the timer in the **receive_nullnet_data** function

```
void receive_nullnet_data (...) {
 int data;
 memcpy(&data, bytes, len);
 printf("Color received: %d\n", data);

 // TODO (1): Set the RGB to the receiver color!

 // TODO (2a): Reset the timer to blink!
}

PROCESS_THREAD(receiver_process, ev, data) {
 PROCESS_BEGIN();
 while (true) {
   PROCESS_YIELD();

   // TODO (2b): Turn LEDs off
 }
 PROCESS_END();
}
```

1

2

2

Exercise Solution

```
void receive_nullnet_data (...)
{
 int data;
 memcpy(&data, bytes, len);

 printf("Color received: %d\n",
data);
 rgb_led_set(data);

 etimer_reset(&blink_timer);
}
```

```
while (true) {
  PROCESS_YIELD();

  if (etimer_expired(&blink_timer)) {
    etimer_reset(&blink_timer);

    rgb_led_off();
  }
}
```

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!

Sending Packets

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

send_nullnet_data

```
/* 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);
}
```

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

```
send_nullnet_data (200);

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

Exercise

To flash: `make ping.dfu-upload`

For console: `make login`

Change the code in (**`ping.c`**)

1) Set your LED to **GREEN** when you receive a message

2) Use **send_nullnet_data** to respond to network messages doubling the data value

3) Use the **blink_timer** to turn off the LED after one second of receiving the network data

```
void receive_nullnet_data (...) {
 int data;
 memcpy(&data, bytes, len);
 printf("Data received: %d\n", data);

 // TODO (1): Turn LED GREEN on message reception
 // TODO (2): Use `send_nullnet_data` to reply
 // TODO (3a): Reset the timer to blink!
}

PROCESS_THREAD(ping_process, ev, data) {
 PROCESS_BEGIN();
 while (true) {
   PROCESS_YIELD();

   // TODO (3b): Turn LEDs off
 }
 PROCESS_END();
}
```

Exercise Solution

```c
void receive_nullnet_data (...)
{
 int data;
 memcpy(&data, bytes, len);

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

 rgb_led_set(RGB_LED_GREEN);
 send_nullnet_data(data * 2);

 etimer_reset(&blink_timer);
}
```

```c
while (true) {
  PROCESS_YIELD();

  if (etimer_expired(&blink_timer)) {
    etimer_reset(&blink_timer);

    rgb_led_off();
  }
}
```

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!

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 data;
} message_t;
```

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

Exercise

To flash: `make counter.dfu-upload`

For console: `make login`

Change the code in **`counter.c`**

1) Any time you receive a **value** you should use **send_nullnet_data** to reply with **value + 1**

2) When the value you receive is above **20**, turn the LED **CYAN**

⚠ Change the **TEAM_ID** at the top!

You may use timers as you wish

```
void receive_nullnet_data (...) {
 message_t message;
 memcpy(&message, bytes, len);

 int data = message.data;
 if (message.team_id == TEAM_ID) {
   printf("Data received: %d\n", data);
   /* EDIT inside this IF-statement */
 }
}

PROCESS_THREAD(ping_process, ev, data) {
 PROCESS_BEGIN();
 while (true) {
   PROCESS_YIELD();
   // You can use timers here if you wish
 }
 PROCESS_END();
}
```

1

2

Exercise Solution

```c
if (message.team_id == TEAM_ID) {
  printf("Data received: %d\n", data);

  if (data >= 20) {
    rgb_led_set(RGB_LED_CYAN);
    etimer_stop(&blink_timer);
    etimer_stop(&retry_timer);
  } else {
    rgb_led_set(RGB_LED_GREEN);
    send_nullnet_data(data + 1);

    etimer_reset(&blink_timer);
    etimer_reset(&retry_timer);
  }
}
```

```c
while (true) {
  PROCESS_YIELD();

  if (etimer_expired(&blink_timer)) {
    etimer_reset(&blink_timer);
    rgb_led_off();
  }

  if (etimer_expired(&retry_timer)) {
    etimer_reset(&retry_timer);
    send_nullnet_data(0);
  }
}
```

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!

Quiz Time!

ahaslides.com/DN2A2

End of Class

See you all next week!