IOT

— A practical introduction with Pharo and PharoThings —

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Plan

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About this course

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Want more?

- A MOOC with more theoretical aspects: `https://www.coursera.org/learn/iot/`
- PharoThings materials: `https://github.com/SquareBracketAssociates/Booklet-APharoThingsTutorial`

Plan

What is IOT?

Internet of Things

- Objects inter-connected through the internet:
  - Objects are unique entities sharing data in a network:
    a person, a phone, a device...
  - Device:
    hardware (micro-computer, sensors, motors...) + software (*intelligence*),
  - Objects are interrelated:
    they transfer data between them through the network
  - Objects use a protocol to communicate:
    for example, an HTTP REST API through TCP/IP...
  - Objects need a power source to be autonomous

What is IOT?

Examples of IOT systems/applications

- Personal health or sport monitoring systems
- Smart homes: your fridge now tells you when you need to refill!
- Logistics: automated warehouses and production chain monitoring
- Smart grids: optimizing energy production and routing
- Etc.

Plan

Sensors

"A sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor."

– https://en.wikipedia.org/wiki/Sensor

- Transforms a physical information (*e.g.*, the temperature of the room) to an analog or digital signal
- The analog/digital signals are processed by the computer processor and interpreted and used by user-applications
- Sensors are sources of data (inputs) in IOT applications

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Examples

- Temperature sensor: measures temperature in an environment
- Camera
- Accelerometer: measures acceleration
- ...

Sensors

What do sensors measure?

- One sensor only measure one specific property of its environment
- Ideally, a sensor should not interfere with the environment (*i.e.*, not influence the measured value)
- Sensors always work in association with an electronic system (in IOT)

Sensors

What do sensors measure?

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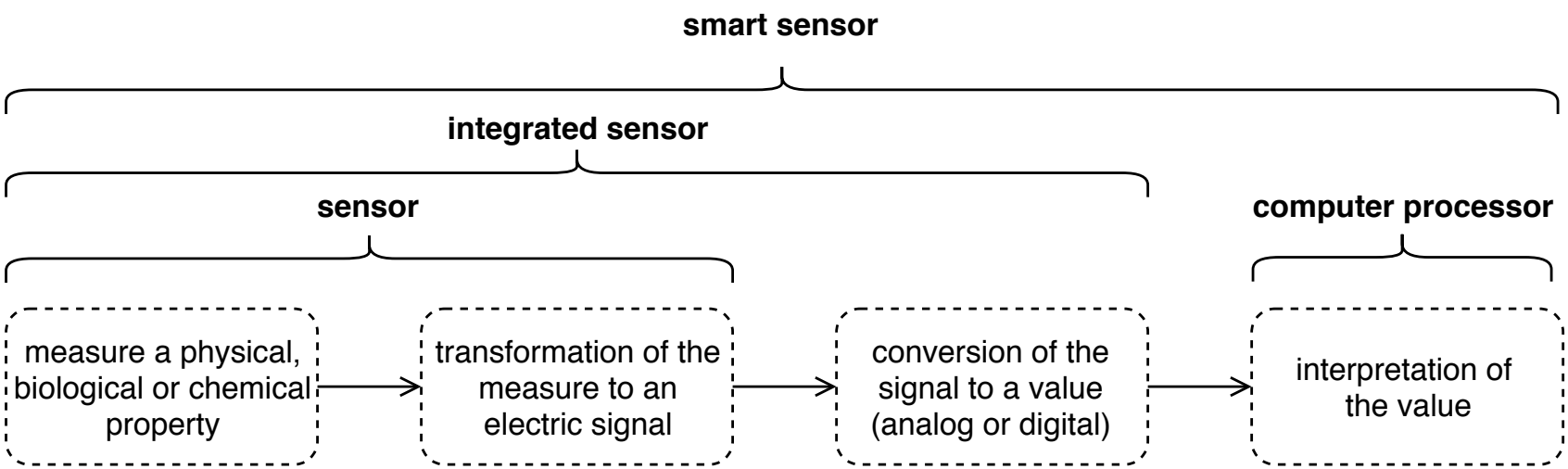
How do sensors measure?



Simplified view of sensors measurements and interpretation

Different kind of sensors

- **Basic sensor element: transforms a physical phenomenon into an electronic signal**
  Example: RTD[1]s measure the resistance of metal, that changes with temperature

- **Integrated sensor: sensor element with signal conditioning**
  Example: A sensor that transforms the resistance measured by a RTD into an analog signal (e.g., 0 to 1023)

- **Smart or intelligent sensor: integrated sensor with additional features**
  Example: A sensor that transforms the analog value transformed from an RTD resistance into a human-readable temperature in Celsius

[1] Resistance Temperature Detector

Actuators

Systems that physically interact with the environment

- Controlled by an electrical signal
  - Transforms the signal into a mechanical motion (output)
  - Requires a power source
- Has a direct impact on the environment
  - An actuator can affect sensors!

Examples

- LED: produces light
- Motor: induces movement
- Speaker: produces sound
- ...

Plan

The Raspberry-pi single-board computer

Cheap general-purpose single-board computer

- ARM processor
- Linux based distributions or Windows IOT operating systems
- 40 GPIO (general-purpose input/output) pins to control sensors/actuators

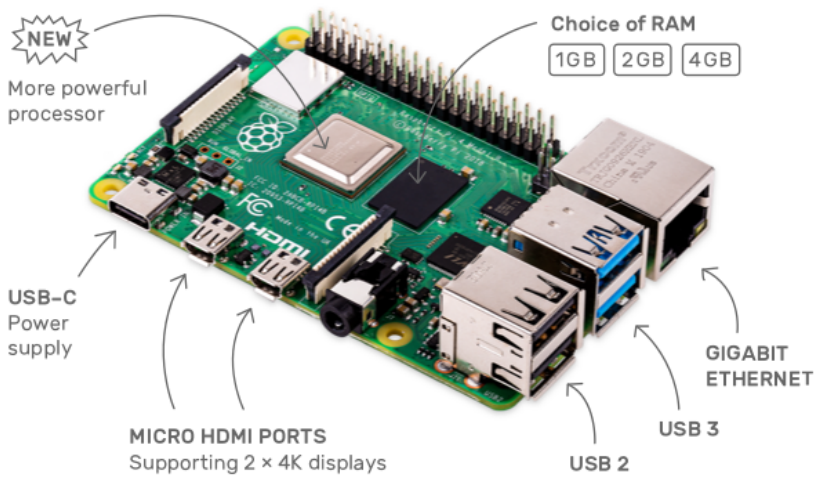


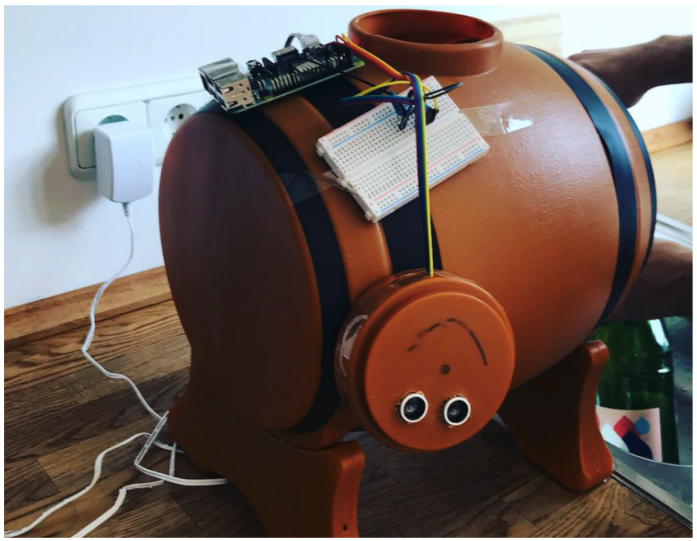
Figure: https://www.raspberrypi.org/products/raspberry-pi-4-model-b/

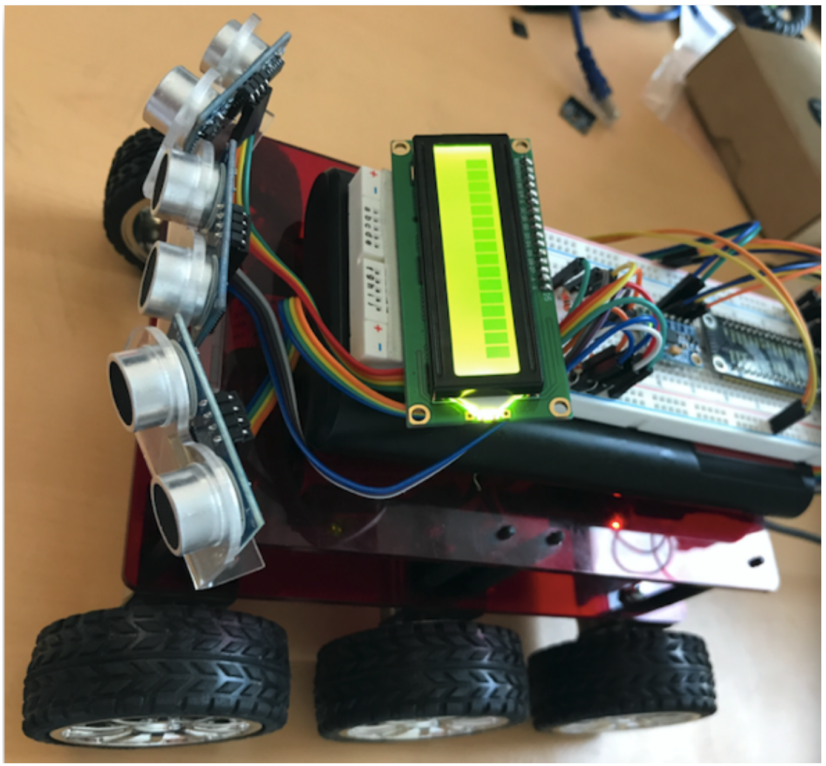
General properties of GPIO pins

- Pins can be configured as `input` (e.g., to read sensors) or as `output`
- Values set to outputs or read as input can be set to `high`, or `1` (3.3V) or `low`, or `0` (0V)
- 4 hardware PWM (Pulse-Width Modulation) pins: control of the voltage by switching power on and off at a fast rate[2]
- SPI (Serial Peripheral Interface): synchronous serial communication interface between a master and a slave[3]
- I2C (Inter-Integrated Circuit): synchronous, multi-master, multi-slave, packet switched, single-ended, serial computer bus[4]
- 2 serial pins (transmission and reception)

[2] `https://en.wikipedia.org/wiki/Pulse-width_modulation`
[3] `https://en.wikipedia.org/wiki/Serial_Peripheral_Interface`
[4] `https://en.wikipedia.org/wiki/I%C2%B2C`

Example projects based on Raspberry-pi and Pharo-Things





Plan

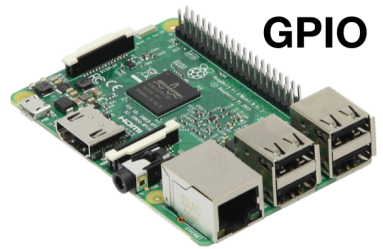
PharoThings

TelePharo
Remote
Communication

Linux

Windows

Mac OS



Raspberry-pi

Firmata

Arduino

Inspector on a PotRemoteBoard (a RpiBoard3I

a PotRemoteBoard (a RpiBoard3B in 192.168.1.14:40423)

P1 | Devices | Raw | Meta

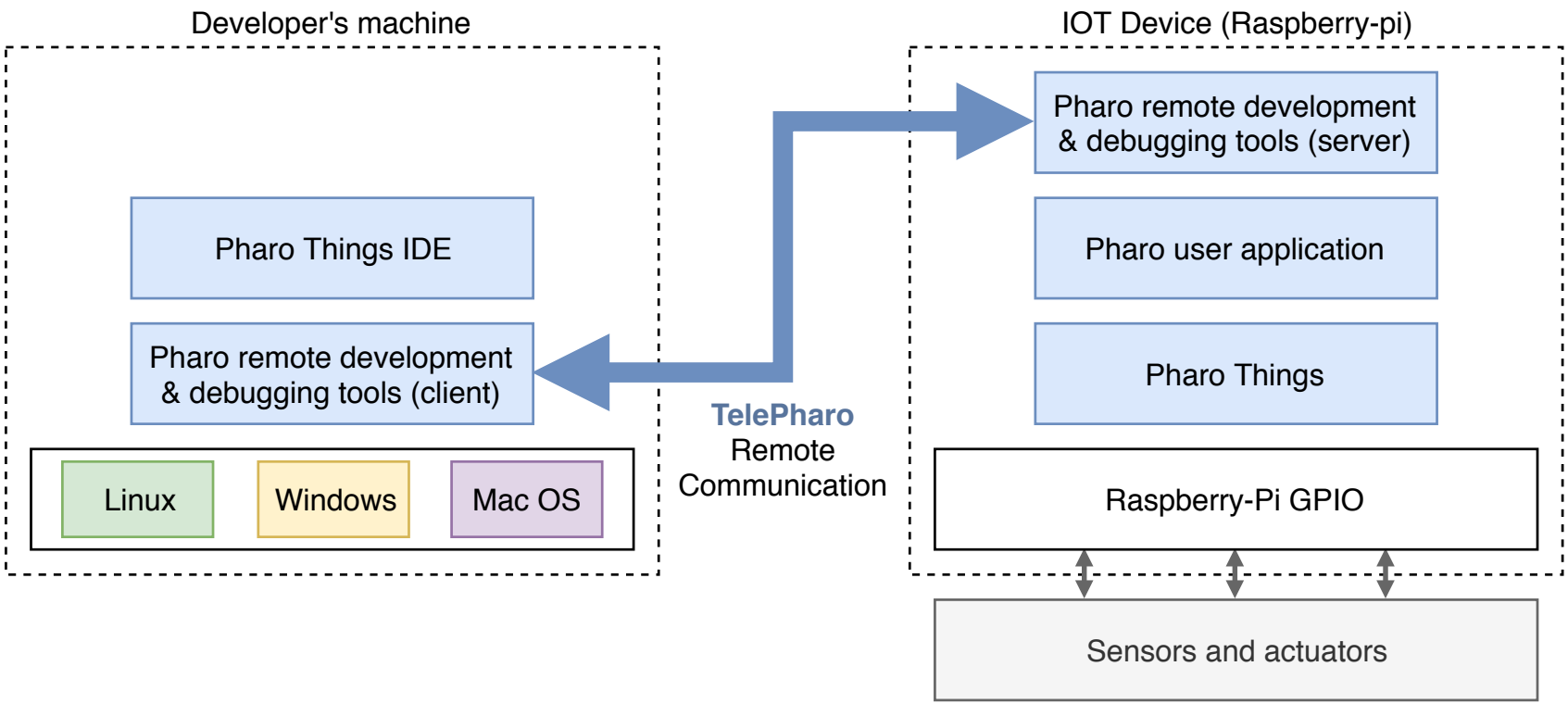
Id	Value	Name	Pin#	Pin#	Name	Value	Id
		3.3v	1	2	5v		
2		SDA (I2C)	3	4	5v		
3		SCL (I2C)	5	6	Ground (0v)		
4		GPIO7	7	8	SerialPortTXD		14
		Ground (0v)	9	10	SerialPortRXD		15
17		GPIO0	11	12	GPIO1		18
27		GPIO2	13	14	Ground (0v)		
22		GPIO3	15	16	GPIO4		23
		3.3v	17	18	GPIO5		24
10		MOSI (SPI)	19	20	Ground (0v)		
9		MISO (SPI)	21	22	GPIO6		25
11		SCLK (SPI)	23	24	CE (SPI)		8
		Ground (0v)	25	26	CE (SPI)		7
0		SDA (I2C)	27	28	SCL (I2C)		1
5		GPIO21	29	30	Ground (0v)		
6		GPIO22	31	32	GPIO26		12

```
"a PotBoardConnector(P1): gpio0..gpio27 vars are bound
to pins"
self
```

The PharoThings infrastructure

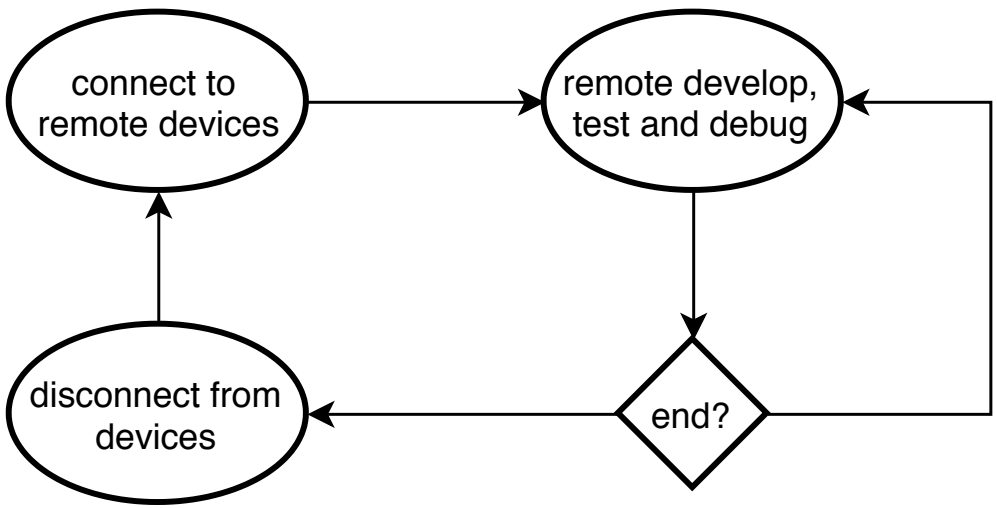
Developers (clients) connect to running IOT devices (servers)

- Developers connect to remote IOT devices running their application
- Pharo development and debugging tools are remotely usable through the TelePharo architecture
- Developers can connect to many devices at the same time from their development machine



PharoThings development process

1. Developers connect to running IOT application, deployed on IOT devices (Raspberry-pi)
2. Developers remotely and lively write, test and debug code
3. When development or debugging is finished, developers disconnect from the device
4. At any point developers can reconnect and start or continue developing their IOT app – which is still running!



Remote development and debugging tools

- Playground: write scripts and execute code
- Class browser: write classes and applications
- Inspector:
  - observe your application state
  - observe and interact with remote live objects
  - observe and control GPIO state
- Debugger: debug and fix your code (live!)
- Process browser: inspect and control running processes

Plan

Downloading and starting PharoThings on the Raspberry-pi

On a running Raspbian on your Raspberry Pi

Open a terminal window in your Raspberry Pi (local or through remote SSH) and enter the following commands:

```
wget -O - get.pharoiot.org/server | bash
```

This downloads the server side and extracts the files to the `pharoiot-server` folder. The following commands will go to that folder and run the server:

```
cd pharoiot-server
./pharo-server
```

- You should see this message: `a TlpRemoteUIManager is registered on port 40423`.
- This means that you have the TelePharo architecture running on your Raspberry on TCP port 40423 !
- Now you can use Pharo IoT on your computer to connect to your Raspberry and create IoT applications remotely.

Connecting to a remote device

On a running Raspbian on your Raspberry Pi

- First download the PharoThings IDE on your Windows/Linux/Mac computer `get.pharoiot.org/multi.zip` and run Pharo
- Open a playground in your local pharo image
- Write and `doIt` the following:

```
remotePharo := TlpRemoteIDE connectTo:
        (TCPAddress ip: #[192 168 1  200] port: 40423).
```

If you don't receive any error, this means that you are connected. The `remotePharo` object allows you to interact with the remote device.

Inspecting the physical board (1)

We can inspect the software model of the remote device

- We must select the model corresponding to physical board
  - `RpiBoardBRev1`: Raspberry Pi Model B Revision 1
  - `RpiBoardBRev2`: Raspberry Pi Model B Revision 2
  - `RpiBoard3B`: Raspberry Pi Model B+, Pi2 Model B, Pi3 Model B, Pi3 Model B+
- In the playground on your local image, evaluate the following:

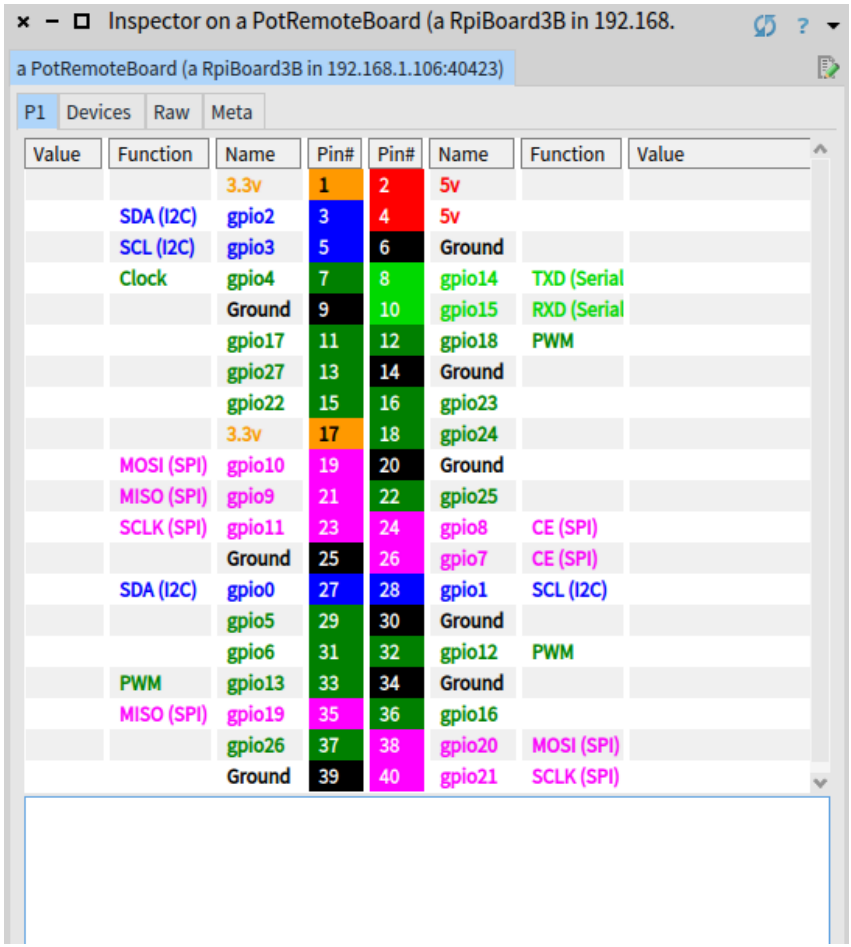
```
remoteBoard := remotePharo evaluate: [ RpiBoard3B current ].
```

- `RpiBoard3B` is a class from the remote system
- `RpiBoard3B current` returns the current instance of the board
- `evaluate:` remotely evaluates the block of code and returns the result
- `remoteBoard` stores that result, a remote instance of `RpiBoard3B`

Inspecting the physical board (2)

We can inspect the software model of the remote device

- Evaluate `remoteBoard inspect` to observe the state of the board
- The board inspector shows a layout of pins similar to Raspberry Pi docs
- This is a live tool which represents the current pins state



Value	Function	Name	Pin#	Pin#	Name	Function	Value
		3.3v	1	2	5v		
	SDA (I2C)	gpio2	3	4	5v		
	SCL (I2C)	gpio3	5	6	Ground		
	Clock	gpio4	7	8	gpio14	TXD (Serial	
		Ground	9	10	gpio15	RXD (Serial	
		gpio17	11	12	gpio18	PWM	
		gpio27	13	14	Ground		
		gpio22	15	16	gpio23		
		3.3v	17	18	gpio24		
	MOSI (SPI)	gpio10	19	20	Ground		
	MISO (SPI)	gpio9	21	22	gpio25		
	SCLK (SPI)	gpio11	23	24	gpio8	CE (SPI)	
		Ground	25	26	gpio7	CE (SPI)	
	SDA (I2C)	gpio0	27	28	gpio1	SCL (I2C)	
		gpio5	29	30	Ground		
		gpio6	31	32	gpio12	PWM	
	PWM	gpio13	33	34	Ground		
	MISO (SPI)	gpio19	35	36	gpio16		
		gpio26	37	38	gpio20	MOSI (SPI)	
		Ground	39	40	gpio21	SCLK (SPI)	

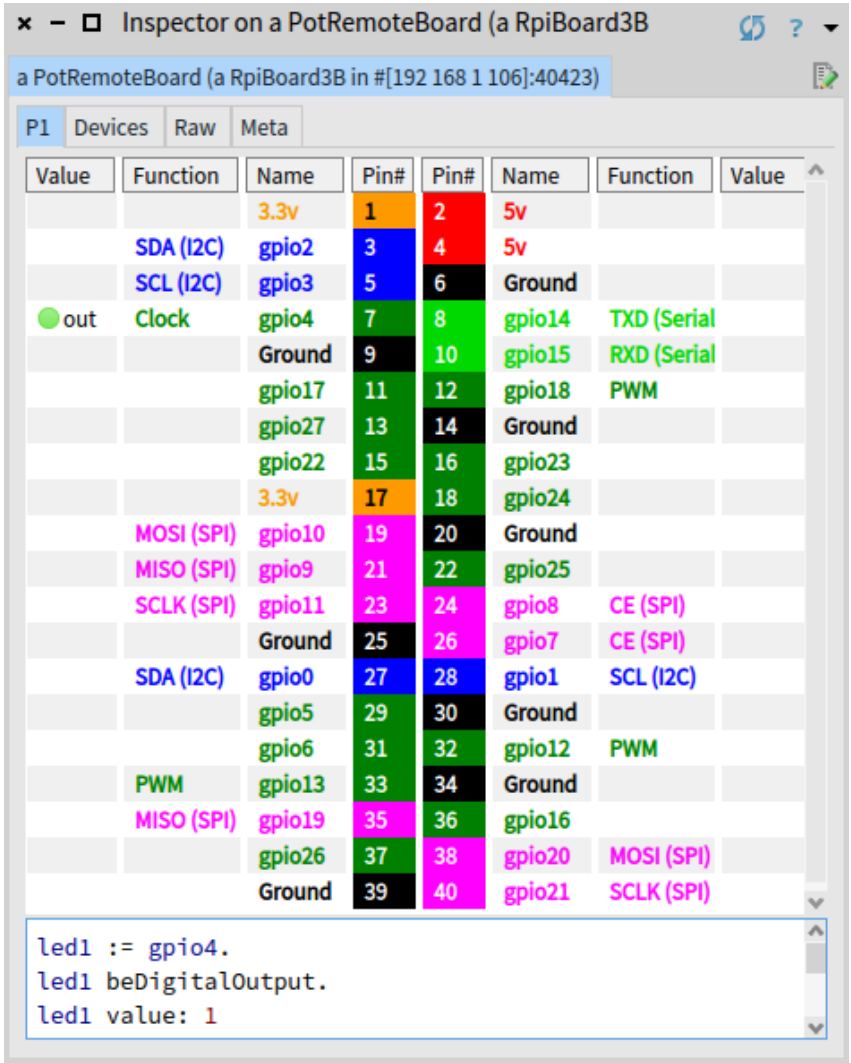
Using GPIO: set a pin state (1)

- Digital pins can be set to `HIGH` (1) or `LOW` (0)
- They are shown with green/red icons which represent `HIGH`/`LOW`
- Digital pins' values are set using the `value:` message send to a pin
- Execute the following code in the lower pane of the board inspector: icons are updated according to pin value changes

```
pin := gpio4.
pin beDigitalOutput.
pin value: 1
```

Using GPIO: set a pin state (2)

- Results are visible in the board inspector:



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	SDA (I2C)	gpio2	3	4	5v		
	SCL (I2C)	gpio3	5	6	Ground		
out	Clock	gpio4	7	8	gpio14	TXD (Serial	
		Ground	9	10	gpio15	RXD (Serial	
		gpio17	11	12	gpio18	PWM	
		gpio27	13	14	Ground		
		gpio22	15	16	gpio23		
		3.3v	17	18	gpio24		
	MOSI (SPI)	gpio10	19	20	Ground		
	MISO (SPI)	gpio9	21	22	gpio25		
	SCLK (SPI)	gpio11	23	24	gpio8	CE (SPI)	
		Ground	25	26	gpio7	CE (SPI)	
	SDA (I2C)	gpio0	27	28	gpio1	SCL (I2C)	
		gpio5	29	30	Ground		
		gpio6	31	32	gpio12	PWM	
	PWM	gpio13	33	34	Ground		
	MISO (SPI)	gpio19	35	36	gpio16		
		gpio26	37	38	gpio20	MOSI (SPI)	
		Ground	39	40	gpio21	SCLK (SPI)	

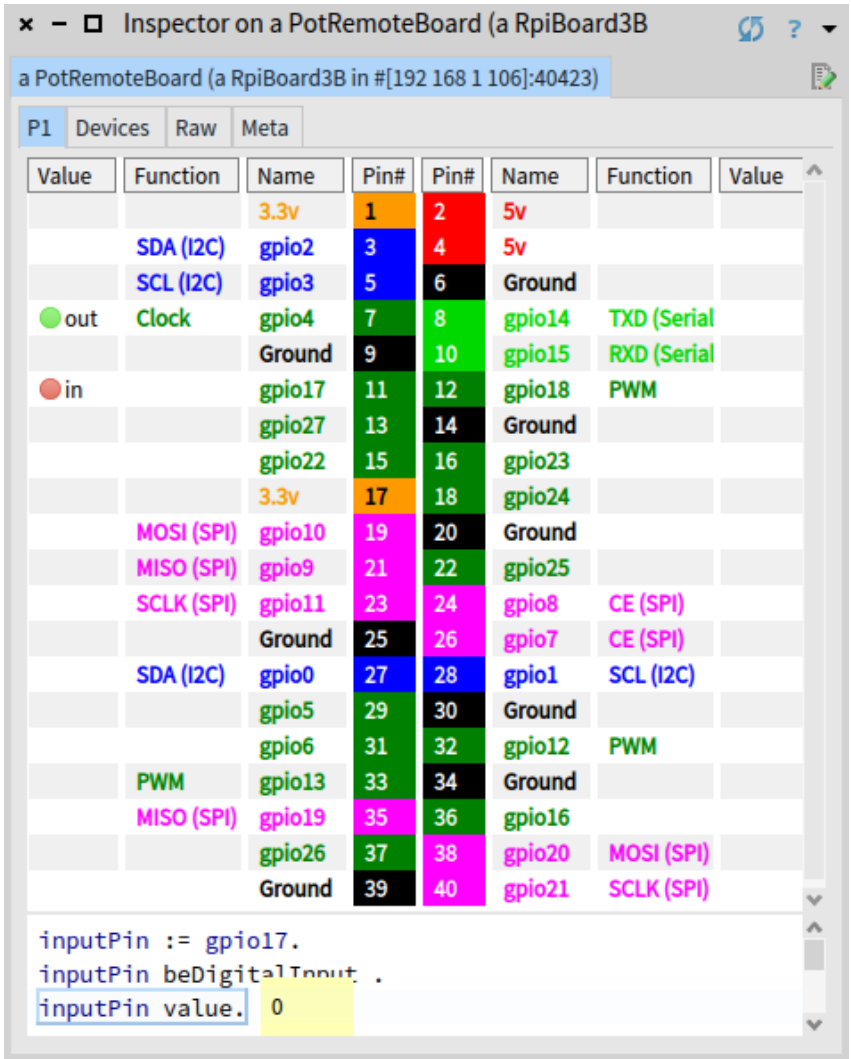
Using GPIO: read a pin state (1)

- Digital pins can be configured as inputs, possible states: `HIGH` (1)/`LOW` (0)
- Digital pins' values are read using the `value` message send to a pin
- Output pins also respond to `value`, and return the last set state
- Write the following code in the lower pane of the board inspector, and execute it:

```
inputPin := gpio17.
inputPin beDigitalInput.
inputPin value inspect
```

Using GPIO: read a pin state (2)

- Results are visible in the board inspector:



Writing and reading GPIO from the remote playground

- We can interact with the GPIO in scripts and programs
- Open locally a remote playground: `remotePharo openPlayground`
- The remote playground opens, now get the current board instance:

```
board := RpiBoard3B current.
```

- Configure a new digital pin with the current board instance :

```
pin := PotGPIO id: 7.
pin board: board.
```

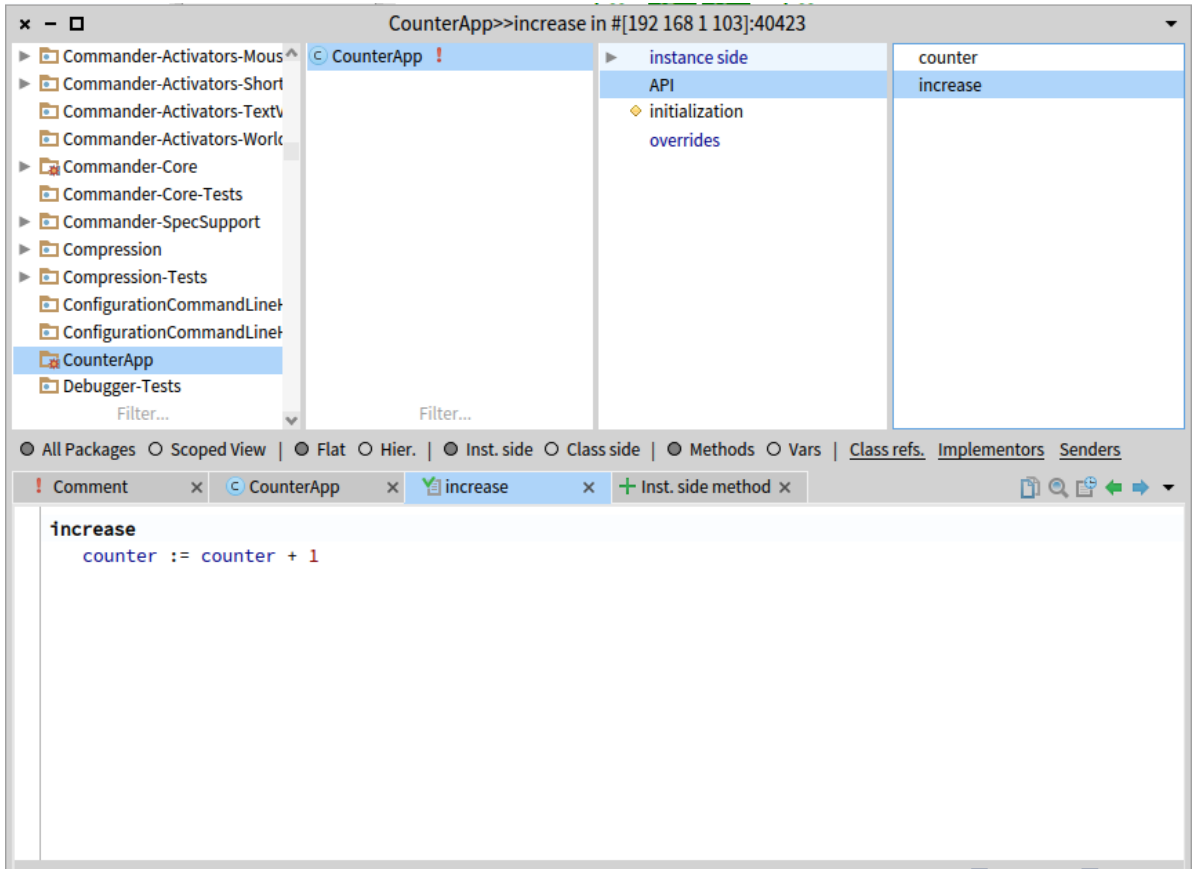
- Set the pin as output, set a `HIGH` value, inspect the state of the pin:

```
pin beDigitalOutput.
pin value: 1.
pin value inspect
```

Developing with the remote class browser

Develop your applications with the remote class browser

- Write a package
- Write a class with a method that increases a counter
- Use the remote playground to instantiate your class and play with your counter
- Save your remote code modifications: `remotePharo saveImage`



Live debugging of a remote application

- In your remote counter class, write the following method:

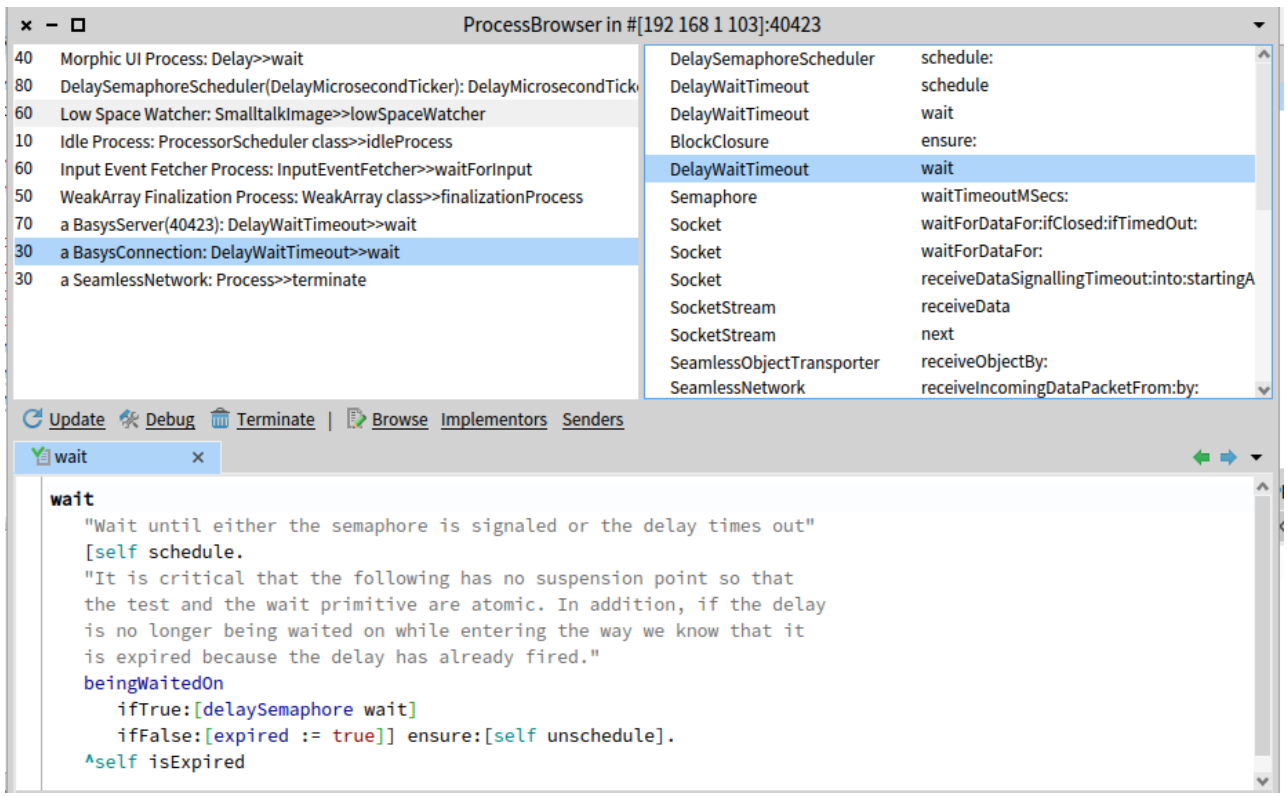
```
decrease
    counter := counter / 0
```

- Instantiate your counter in the remote playground
- Call the decrease method: there is an error because of the division by 0!
- Click "debug": a remote debugger opens
- Fix the method, then click "proceed"
- The remote code is modified and the execution continues!

The remote process browser

Inspect and control processes running on your remote Pharo application

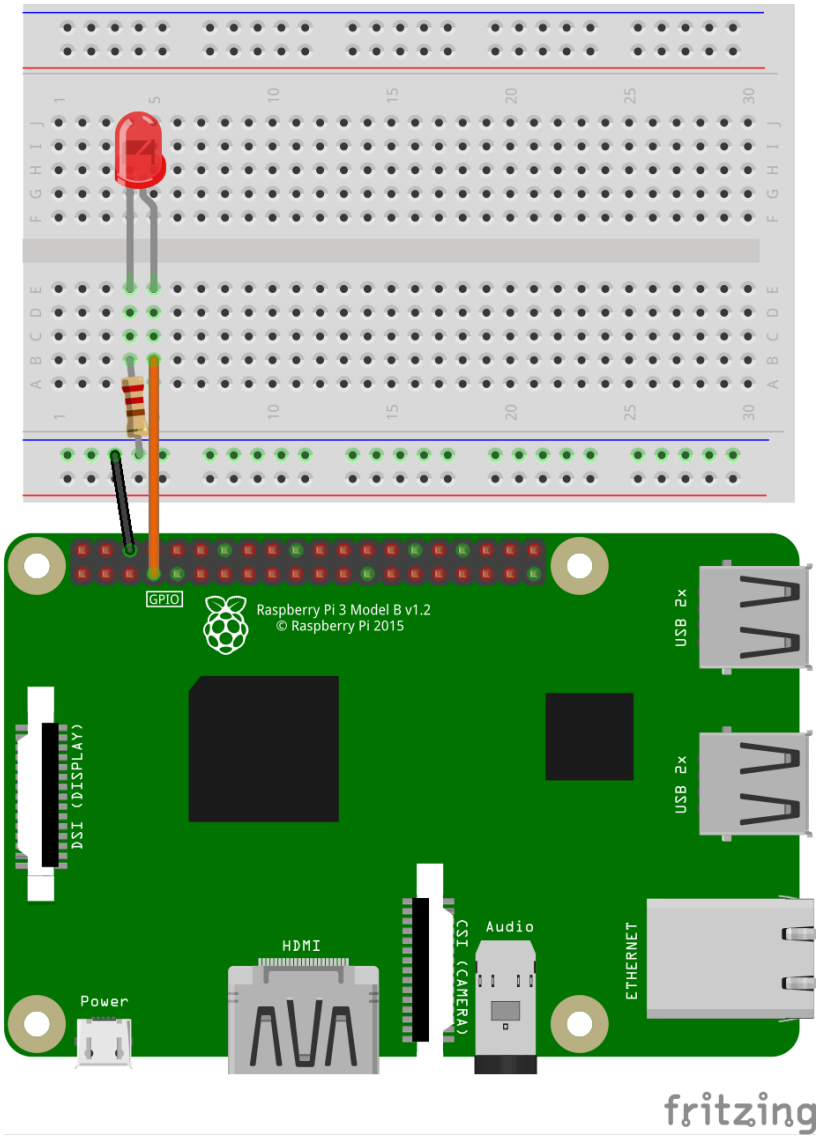
- Remotely open it using `remotePharo openProcessBrowser`
- Process priorities are on the left
- Process names are displayed in the first column
- Process stacks are on the right
- The action bar in the middle allows you to control processes



Plan

Turning LEDs on and off

Follow and adapt code from tutorial chapter 2



1. Build the LED circuit
2. Connect to the remote Pharo image
3. Open a remote Raspberry-pi board inspector
4. Set the LED pin to `HIGH`
5. Play with `toggleDigitalValue` to toggle the LED pin state

Blinking a LED

Follow and adapt code from tutorial chapter 3

1. Reuse the previous lesson to set an output pin for the LED
2. Write a loop that toogles the pin state
3. Use a delay to wait between each iteration
4. Create a process by forking the loop (and give it a name)

```
[10 timesRepeat: [
    led toggleDigitalValue.
    (Delay forSeconds: 1) wait
    ]
] forkNamed: 'BlinkerProcess'
```

Model your own LED blinker

Follow and adapt code from tutorial chapter 4

- We want a blinker object, that we can control!

1. Create a `Blinker` class in the remote browser
2. The class must have a `process` instance variable
3. The class must have a `delay` instance variable
4. The class must have a `led` instance variable
5. Create an `initialize` method to set the initial state of the blinker
6. You must be able to start and stop the blinking

```
|blinker|
blinker := Blinker new.
blinker delay: 1 second.
blinker start. "start the blinker"
blinker stop. "stop the blinker"
```

Make your LED breath using PWM

Follow and adapt code from tutorial chapter 7

- We want a to make a LED light up then fade away

```
|breathingLed|
breathingLed := BreathingLed new.
breathingLed breatheDelay: 10 milliSeconds.
breathingLed breatheFrom: 10 to: 25.
breathingLed startBreathing.
```

1. Create a `BreathingLed` class with the remote browser
2. Configure the LED pin to PWM output:

   ```
   led function: PotPWMFunction new.
   led bePWMOutput.
   ```

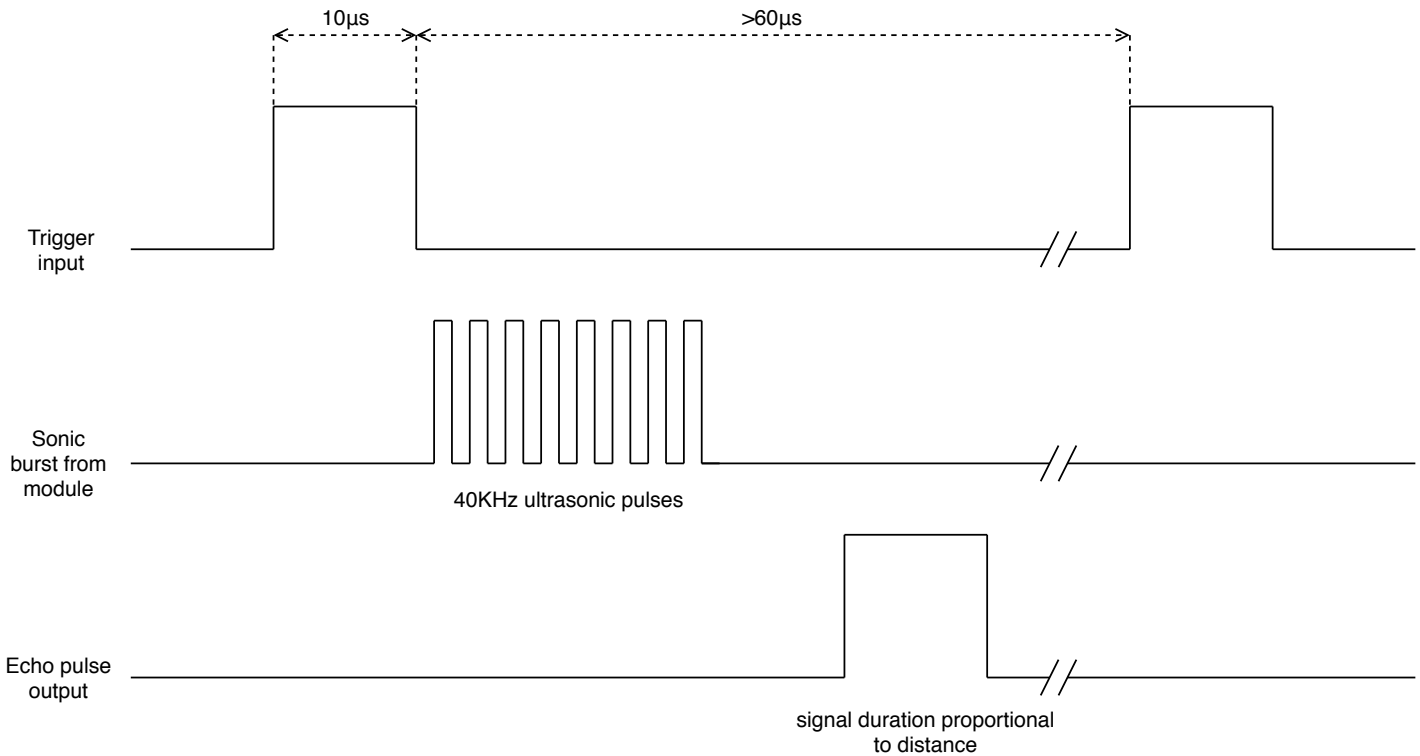
3. The PWM value must be in the interval $[0, 1023]$:

   ```
   led writePWMValue: 42.
   ```

4. To make the led breath, you must increment the PWM value by 1 from a `start` value in a loop until it reaches a `stop` value. When it does, decrease the value by 1 until it reaches the `start` value again, and so on.

Ultra-Sonic sensor: basic concepts

- The sensor sends an ultrasonic pulse, triggered by a 10 μs 5V signal on the `Trigger` pin
- Pulse waves reflect on objects in front and are reflected back to the sensor
- The sensor detects these waves and sends a 5V signal on the `Echo` pin
- The duration of the `echo` signal is proportional to the distance: we can approximate the distance using the speed of sound ($\approx 340 m.s^{-1}$)



Ultra-Sonic sensor: write your own driver!

Build the circuitry

- Follow instructions from chapter 10

Write your own driver

- Create a class with two instance variables: an `echo` and a `trigger` pins
- Create an instance creation method to initialize the pins:

```
sensor trigger: triggerPinId echo: echoPinId
```

- Write the sensor behavior:
  1. A method that sends a pulse
  2. A method that receives the pulse back signal and computes its duration
  3. A method that computes the distance from the pulse duration
  4. An interface method named `readDistance` that use all the previous method to return a distance (see next slide)
- Test your sensor!

Write your own driver: the pulse back signal reception (1/2)

Concept of a `pulseIn`[5]

- Reads a pulse (either `HIGH` or `LOW`) on a pin
- For example, if value is `HIGH`, waits for the pin to go from `LOW` to `HIGH`
- Starts a timer then waits for the pin to go `LOW` and stops timing
- Returns the length of the pulse in microseconds or gives up and returns 0 if no complete pulse was received within the timeout

In Pharo:

- We do not have the `pulseIn` mechanism in Pharo, therefore we have to simulate it!

[5] `https://www.arduino.cc/reference/en/language/functions/advanced-io/pulsein/`

Write your own driver: the pulse back signal reception (2/2)

Simulated `pulseIn` in Pharo

Function: pulseIn

Data: The Echo pin *echo* set as digital input and with pull down resister enabled[a]

Result: A duration

begin

  while *read(echo)* == *0* **do**

    startTime ← currentTime

  end

  while *read(echo)* == *1* **do**

    endTime ← currentTime

  end

  return *endTime* − *startTime*

end

[a] `send the enablePullDownResister message to the pin object`

Write your own driver: the `readDistance` interface

Beware of timeouts!

- **Use a semaphore to avoid infinite waiting on timeouts!**

```
readDistance
    | travelTime semaphore |
    semaphore := Semaphore new.
    [ ...use the sensor to find travel time... ] fork.
    semaphore
        wait: 100 milliSeconds
        onCompletion: [...return the travel time... ]
        onTimeout: [ self rebootSensor. ^ -1 ]
```

- **When the sensor times out, use the reboot trick:**

```
rebootSensor
    echoPin beDigitalOutput; value: 1.
    1 milliSeconds wait.
    echoPin value: 0.
    echoPin  beDigitalInput; enablePullDownResister.
    triggerPin beDigitalOutput; value: 0
```

Ultra-Sonic sensor: combine it with LED breathing!

Write an IOT application using an LED and an UltraSonic sensor

1. When there is nothing closer than 1 meter, the LED is off
2. When something is detected closer than 1 m, the light starts emitting light
3. The closer the obstacle, the brighter must be the LED!

I2C Sensors

LCD screen

Mini wheather station

Web server

3D gyro sensor