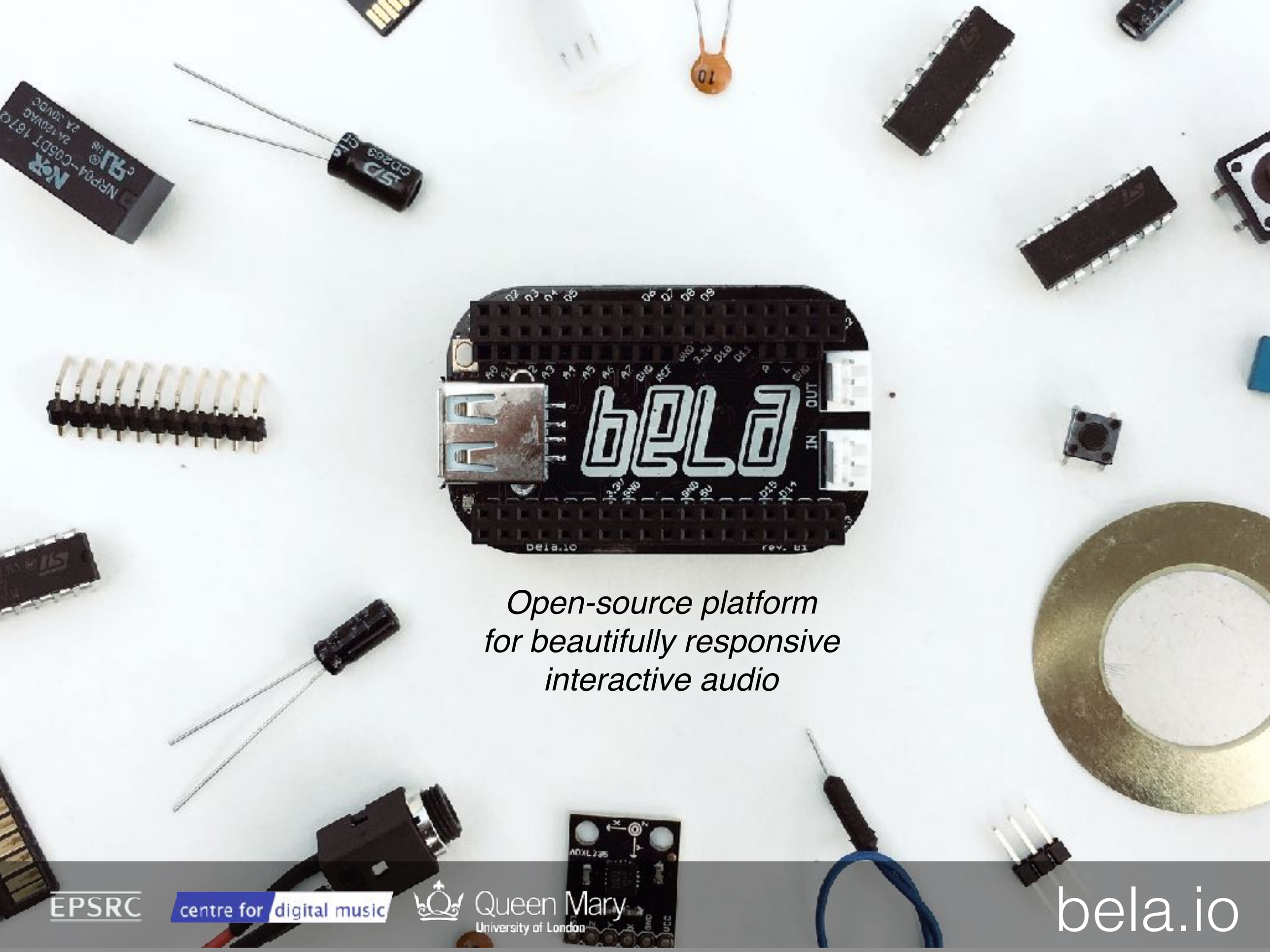


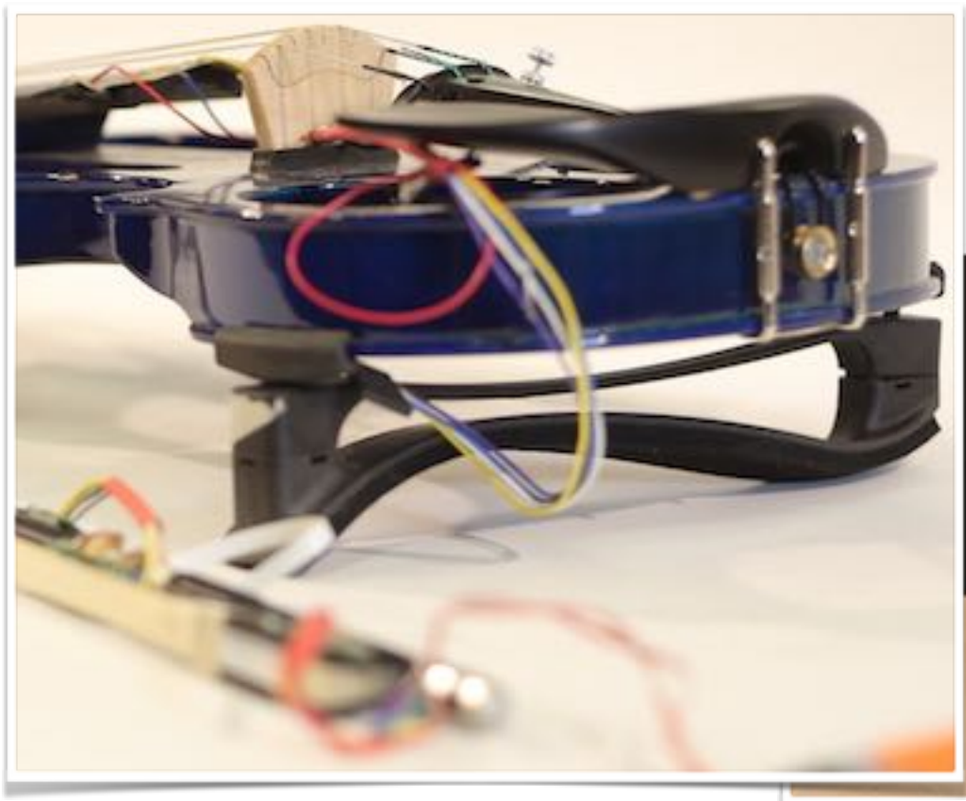

*Open-source platform*
*for beautifully responsive*
*interactive audio*

EPSRC centre for digital music Queen Mary University of London

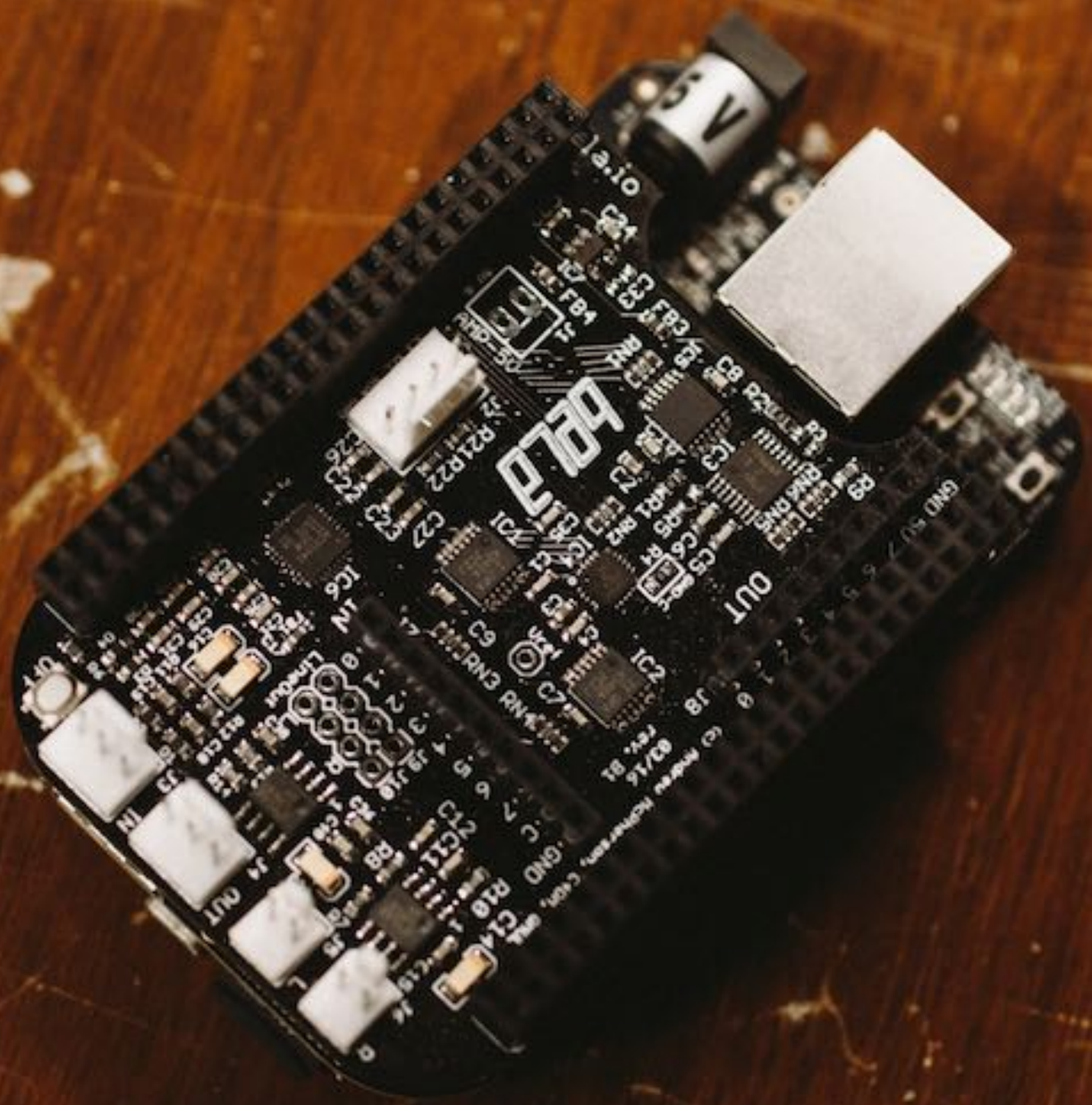
bela.io

A project of the Augmented Instruments Laboratory:

http://instrumentslab.org

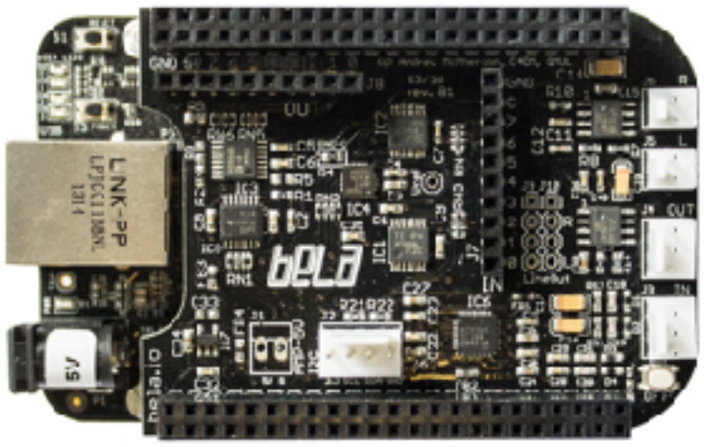


# What is Bela?



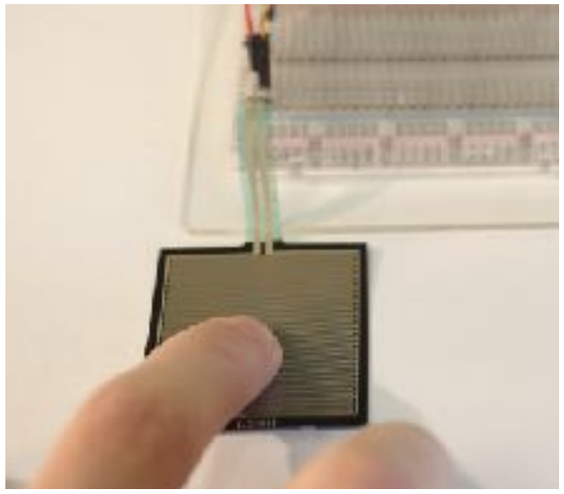
# What is Bela?

## Embedded computer designed for interactive audio



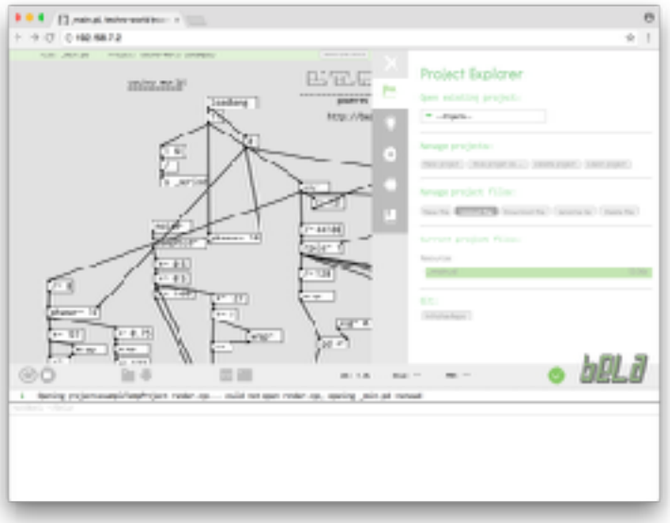
- Power of a single board computer
- Connectivity of a micro-controller
- Combines the benefits of both

## New approach to high-bandwidth sensor processing



- Analog, digital I/O sampled at audio rate
- Ultra low action-sound latency
- Jitter-free alignment between audio and sensors

## Open-source maker platform




- Open hardware and software
- Targeted at musicians, artists
- Online community resources: forum, wiki, blog.

# Latency

Delay between action and reaction,
a fundamental property of digital interactive systems

# Latency

Does it matter? Yes!

- Long latency causes an audible delay
  - But even an imperceptible delay may make an instrument feel less responsive to play
- How low is “low enough”?

  “We place the acceptable upper bound on the computer’s audible reaction to gesture at 10 milliseconds. ... Low variation of latency is critical and we argue that the range of variation should not exceed 1 ms.”

  -- David Wessel & Matthew Wright, “Problems and Prospects for Intimate Musical Control of Computers”, Computer Music Journal, **2002**.

- Surprisingly few systems for building digital musical instruments meet this threshold!

  A. McPherson, R. Jack and G. Moro. “Action-Sound Latency: Are Our Tools Fast Enough?” Proc. NIME, 2016.

# Bela hardware

8x, 16-bit Analog Out

16 digital GPIO

8x, 16-bit Analog In

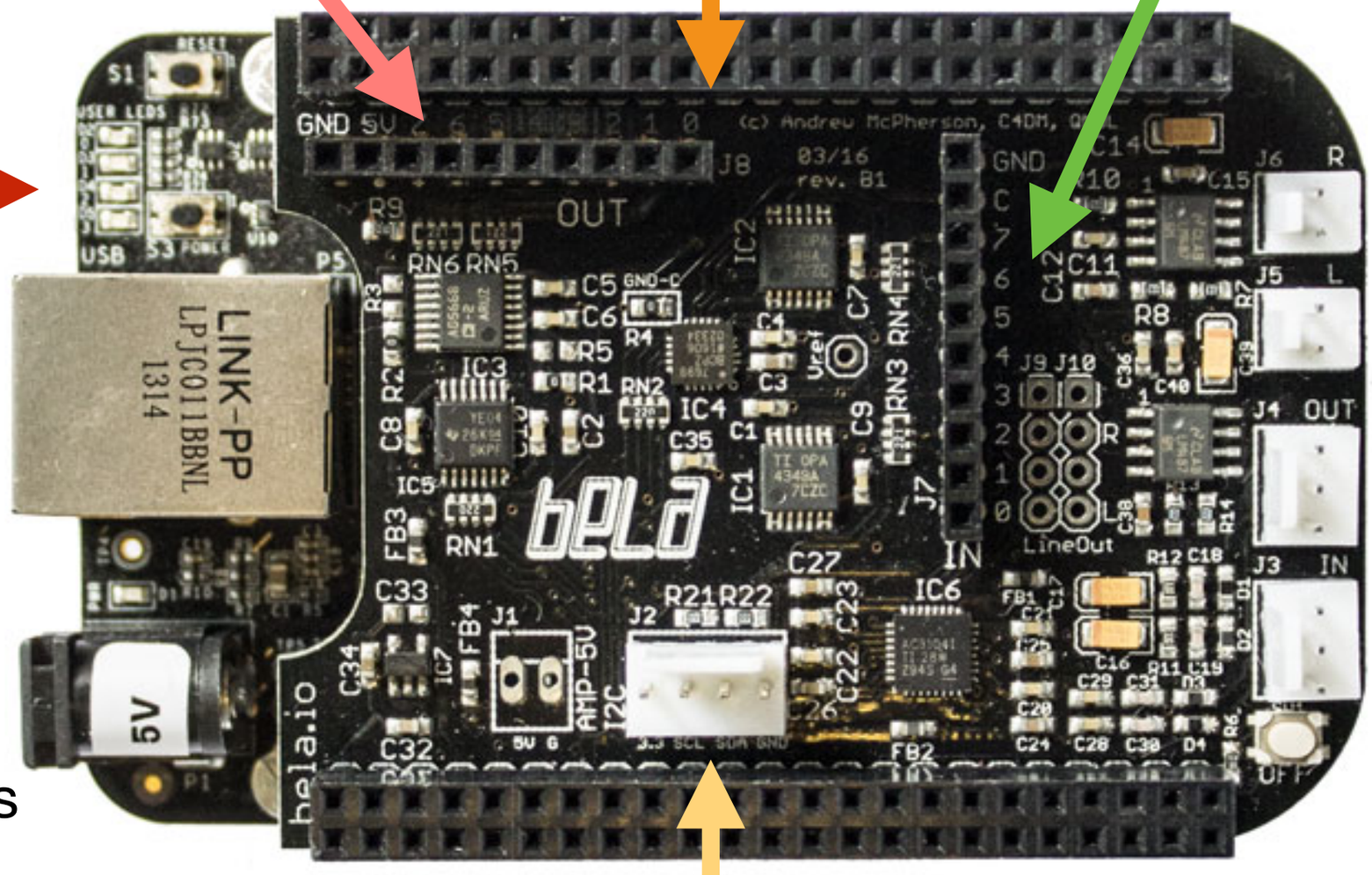
BeagleBone Black

1GHz ARM Cortex-A8

512MB RAM

NEON vector floating point

Dual PRU microcontrollers




Stereo 1.1W speaker amps

Stereo 16-bit audio out

Stereo 16-bit audio in

I2C

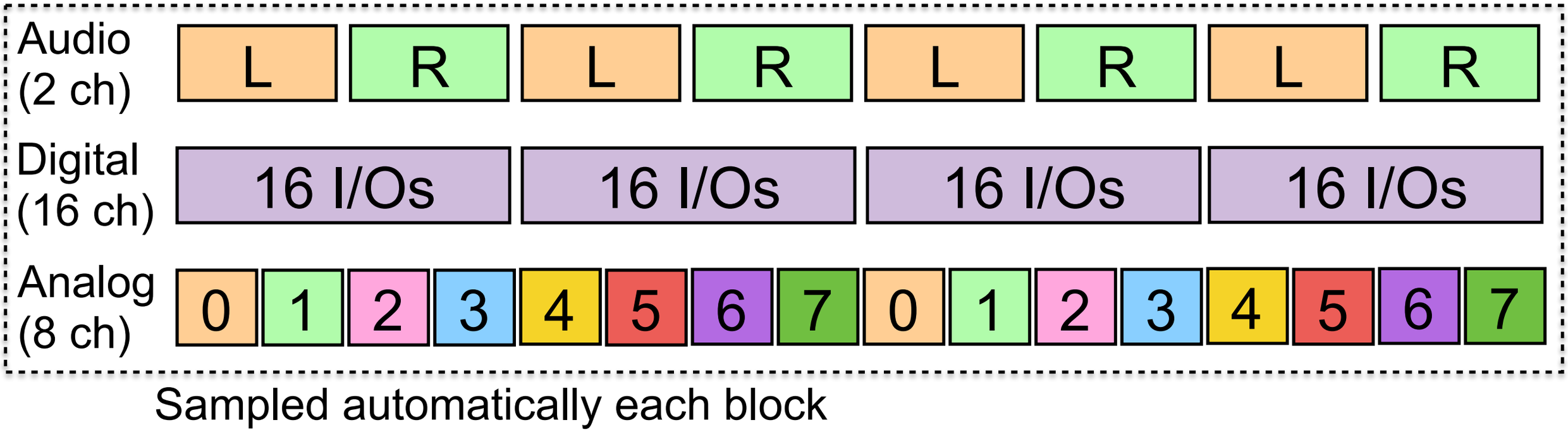
# Bela software

- Bela uses the Xenomai real-time Linux extensions to run audio code at higher priority than the entire OS

- Allows buffer sizes as small as 2 audio samples
- Digital and analog sensors sampled at audio rate, synchronously to audio clock for near-zero jitter

# Bela features

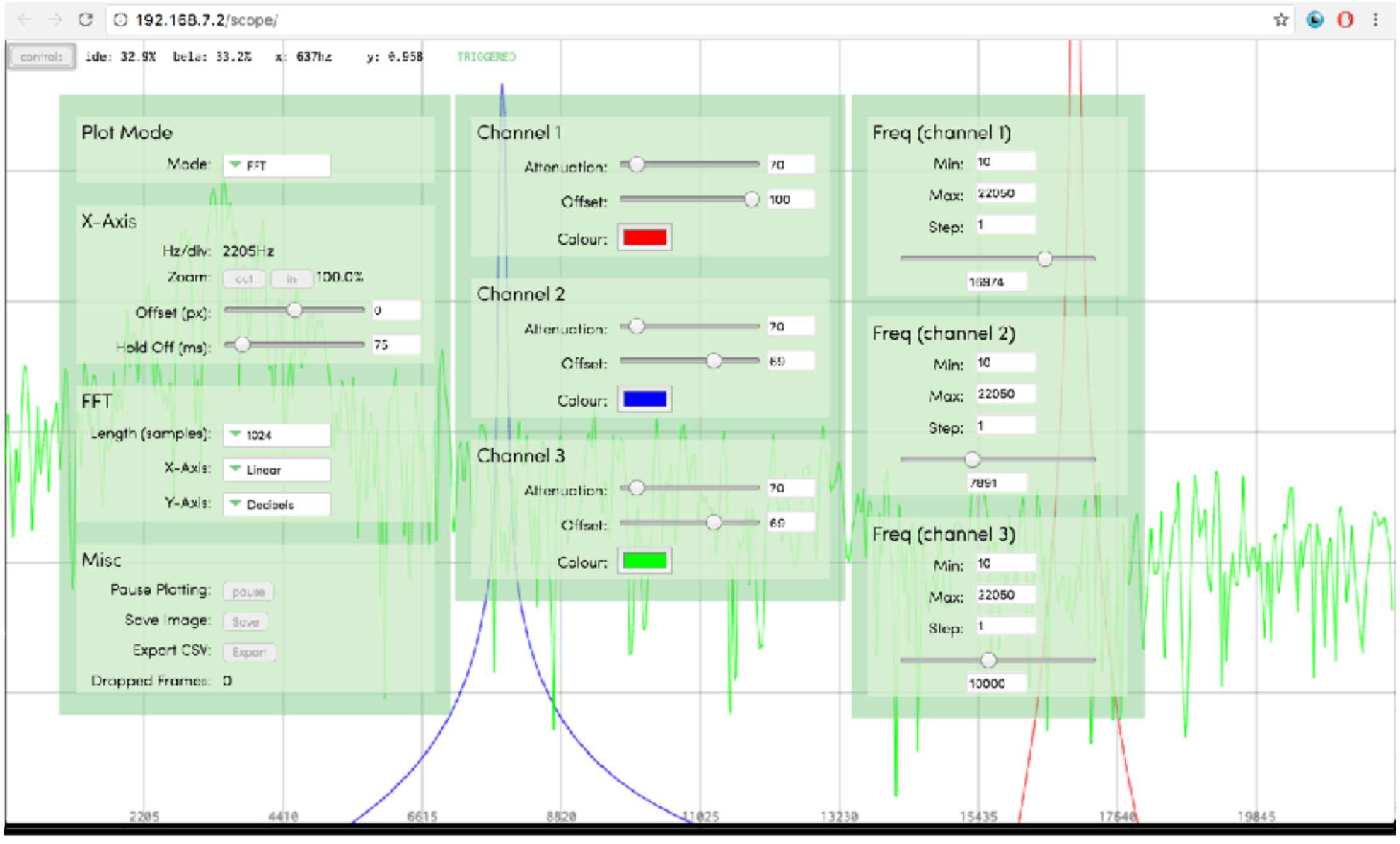
- High sensor bandwidth:
  - Digital I/Os sampled at 44.1kHz
  - Analog I/Os sampled at ≥ 22.05kHz
- Jitter-free alignment between sensors and audio
- Hard real-time audio/sensor performance but full Linux APIs still available
  - USB, network, filesystem, etc.




Sampled automatically each block

# Bela features

## Built-in, browser-based IDE with oscilloscope



# Bela features

- Programming options:
  - **C/C++** with built-in IDE (or terminal scripts)
  - **Pd** using either libpd or Heavy Audio Tools
  - **FAUST** DSP language (contributed by Stéphane Letz and Yann Orlarey)
  - **Pyo** python audio module (contributed by Olivier Bélanger)
  - **SuperCollider** (with Dan Stowell, Marije Baalman)
  - **Csound** (still in alpha; with Victor Lazzarini and Bernt Isak Wærstad)
- Open-source hardware and software
- Online repo, wiki and support forum:
  - http://github.com/BelaPlatform
  - http://forum.bela.io

# Pd on Bela

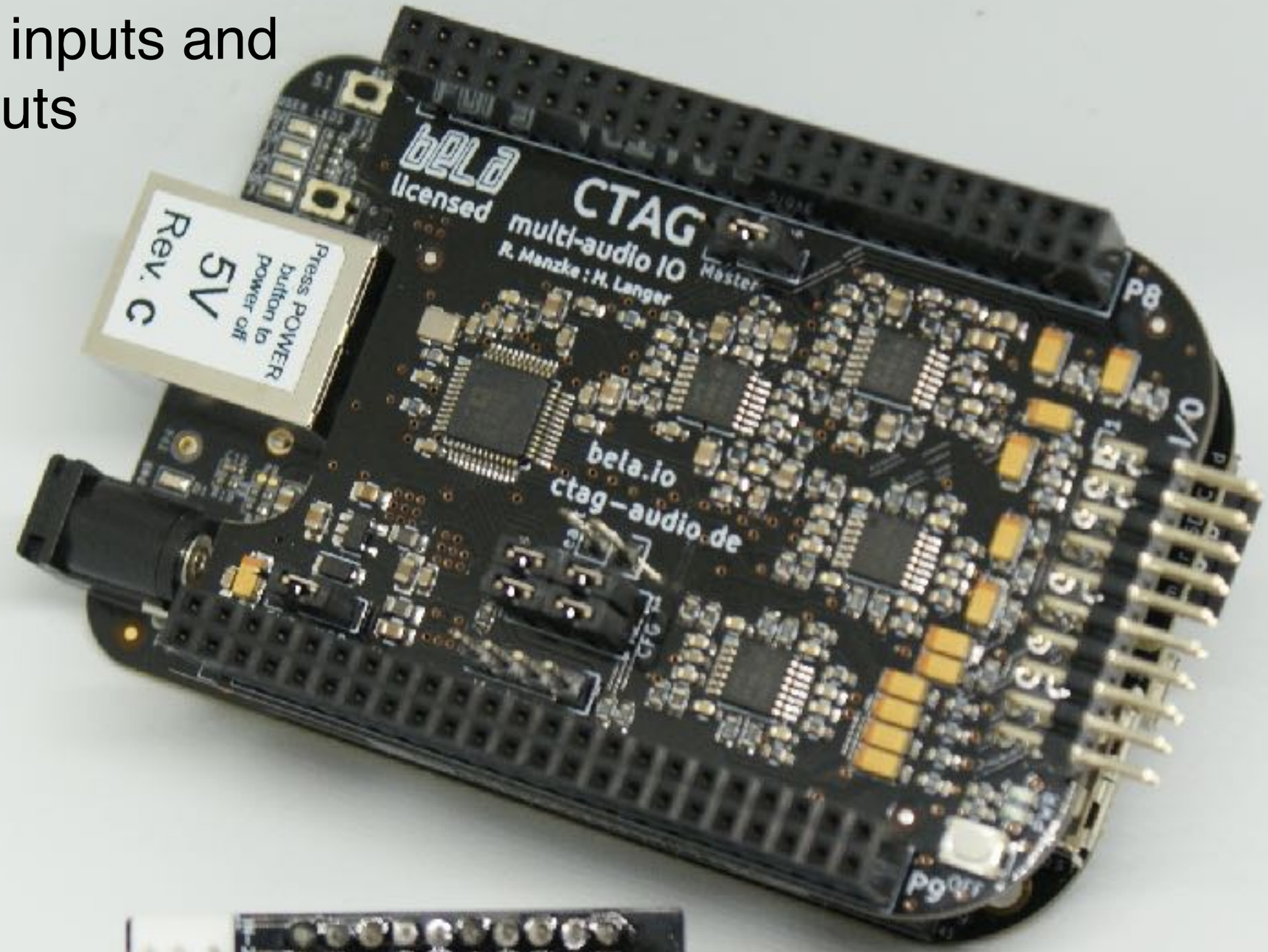

**libpd**

- Data flow computer music language
- Sketch signal and data flows
- Quickly prototype interactive audio systems
- Integrated with the browser-based IDE
- Currently no live patching in the browser

# Bela Mini

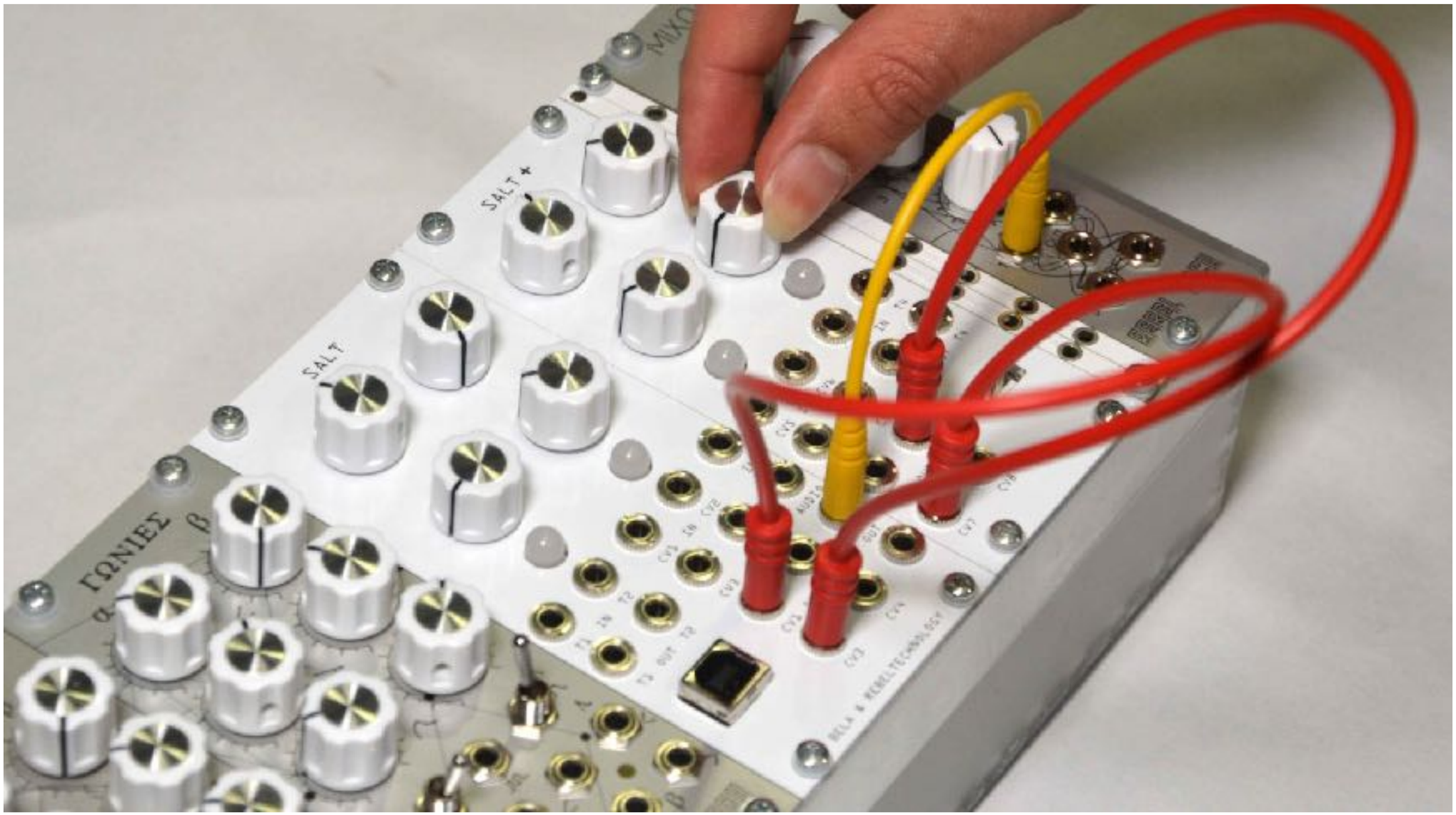
# CTAG FACE and BEAST

Up to 8 audio inputs and
16 audio outputs




# SALT: the Bela modular

a joint project with Rebel Technology (rebeltech.org)



# SALT: the Bela modular

**2 audio in**
**2 audio out**

**4 CV in**
**4 CV out**
(outputs:
-5V to 5V)

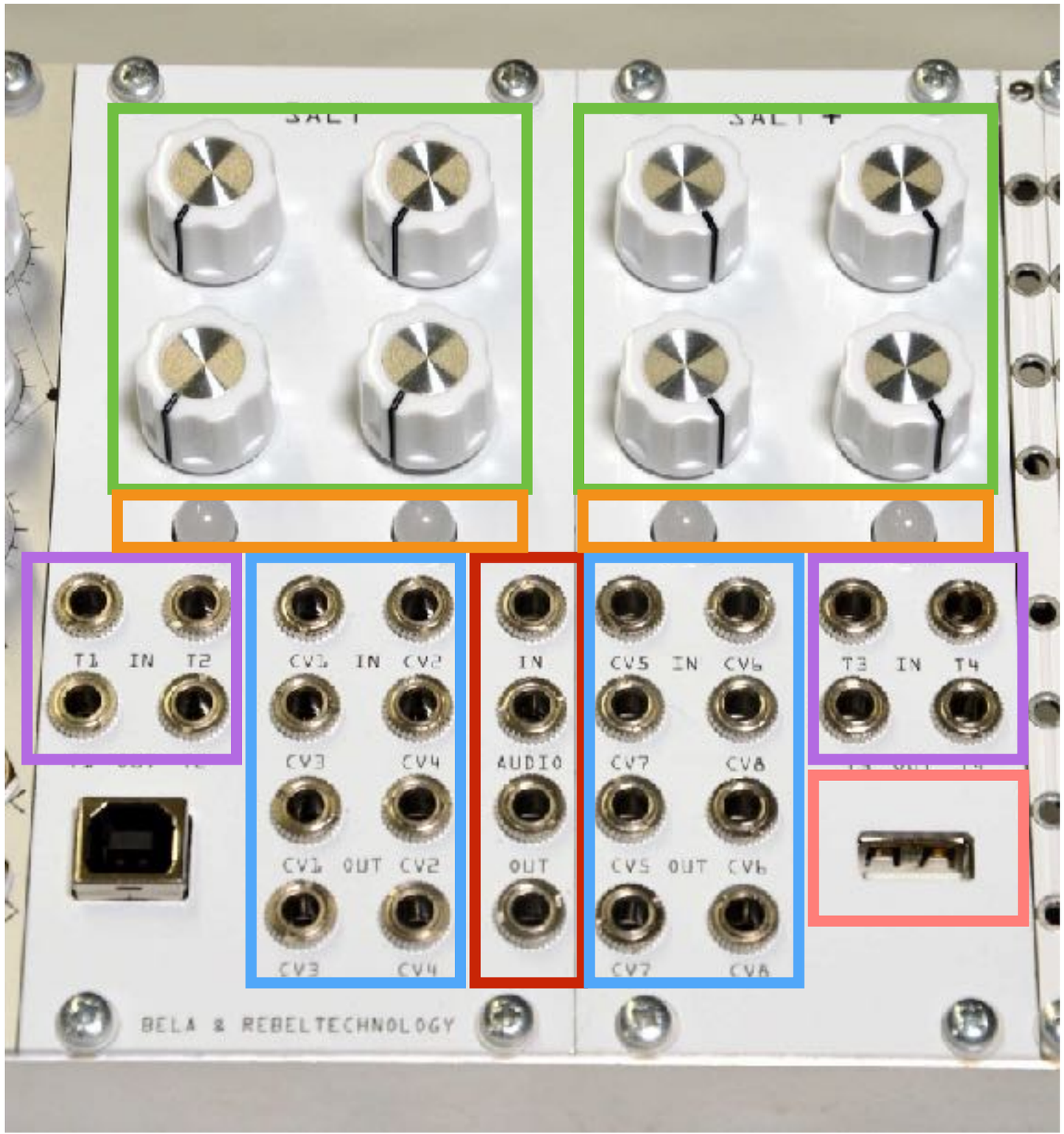
**CV input offsets**
(from -10V to 0V
to 0V to 10V)

**2 trigger in**
**2 trigger out**
(0V to 5V)

**2 buttons**
(connected
to trigger ins)

**2 LEDs**
(bi-colour)

**SALT: 12hp** **SALT+: 10hp**




**+4 CV in**
**+4 CV out**
**with input offsets**

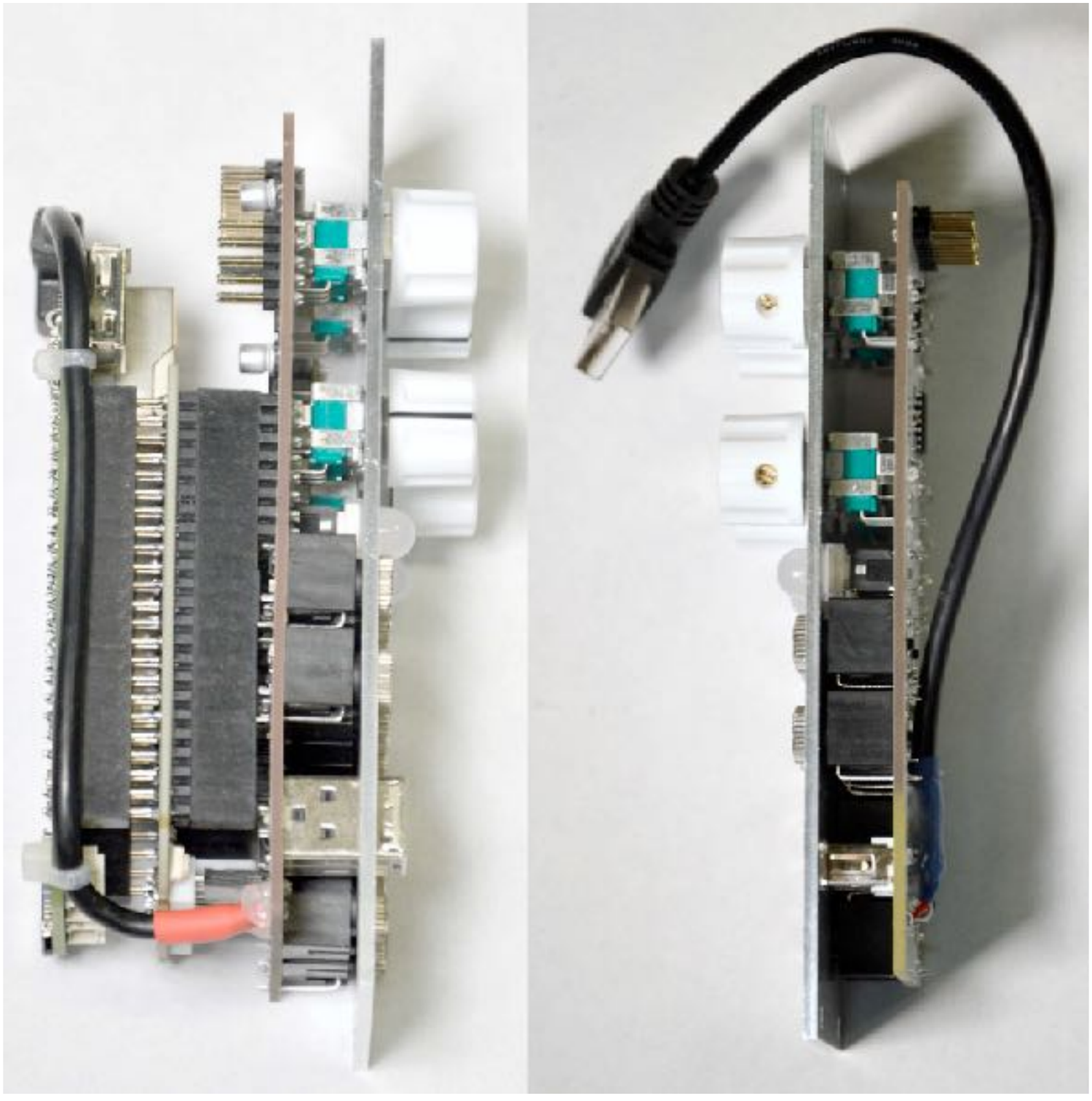
**+2 trigger in**
**+2 trigger out**

**+2 buttons**
**+2 LEDs**

**USB host**

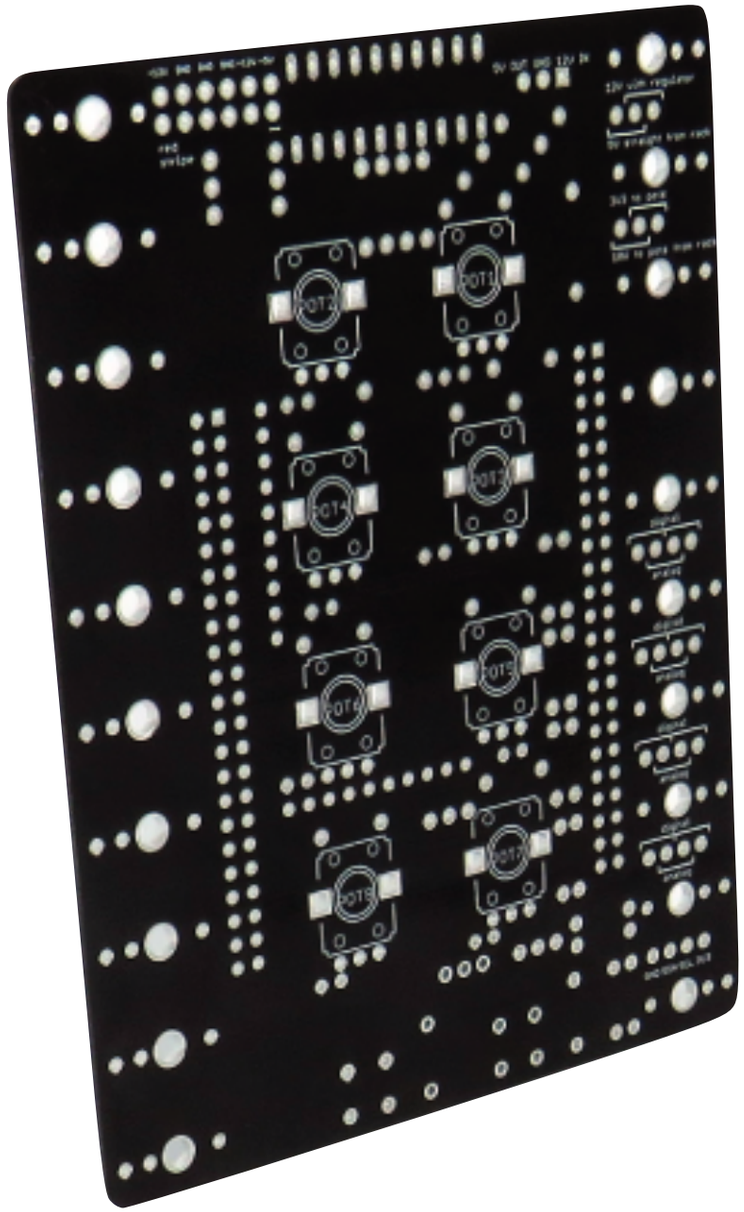
# SALT: the Bela modular

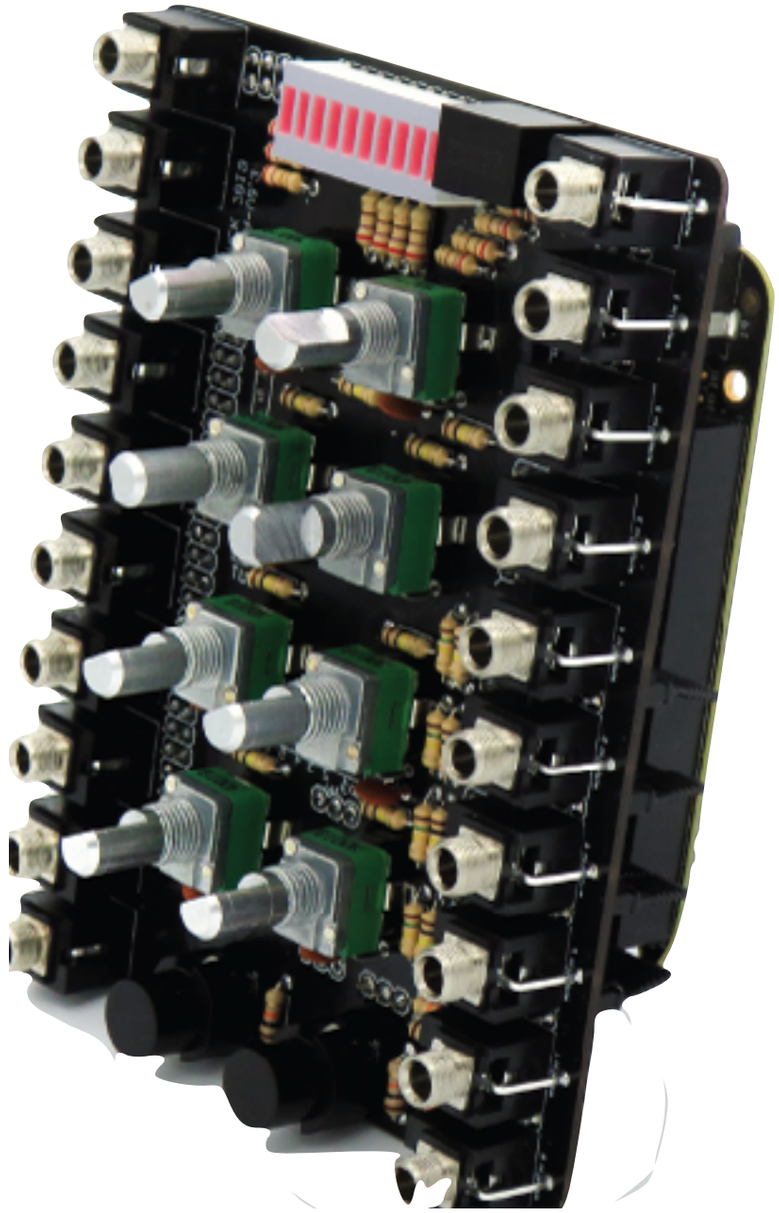
More info: **http://bela.io/salt/**



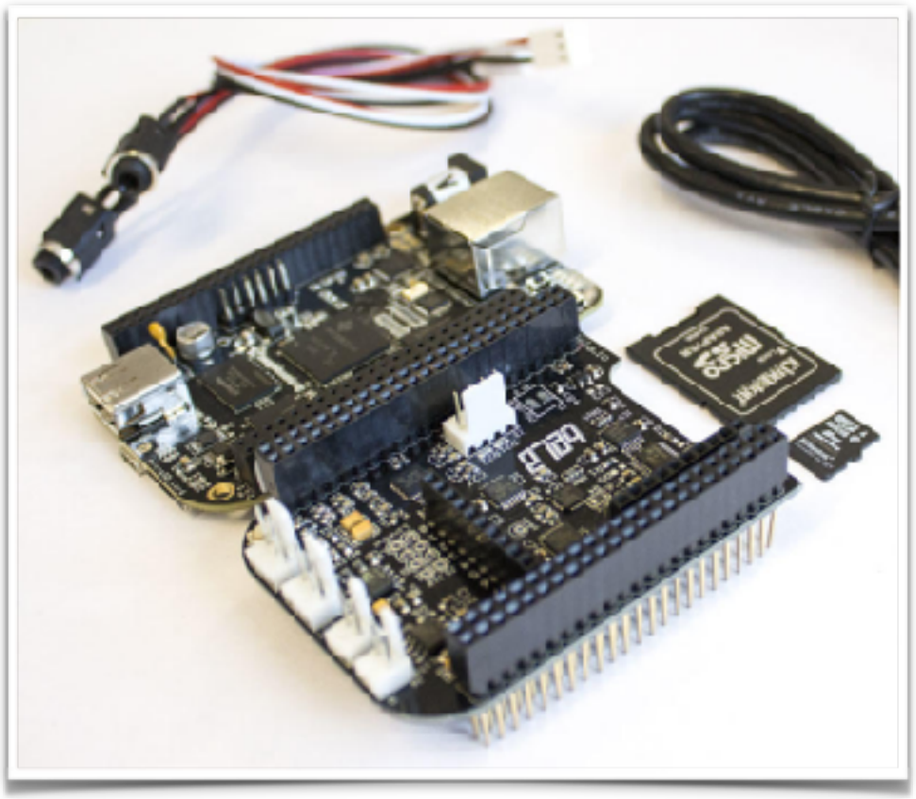
# PEPPER

passive breakout to easily connect Bela to your rack
PCB with easily sourced DIY components





# Getting started: hardware



## Bela starter kit:

- BeagleBone Black
- Bela cape
- 2 audio adapter cables
- Mini-USB cable

## Workshop extras:

- Breadboard
- Jumper wires
- Electronic components

# Getting started: software

## Chrome browser

The IDE may or may not work in other browsers


## Pd software [http://puredata.info]

Needed to edit Pd patches *(use Pd-vanilla)*

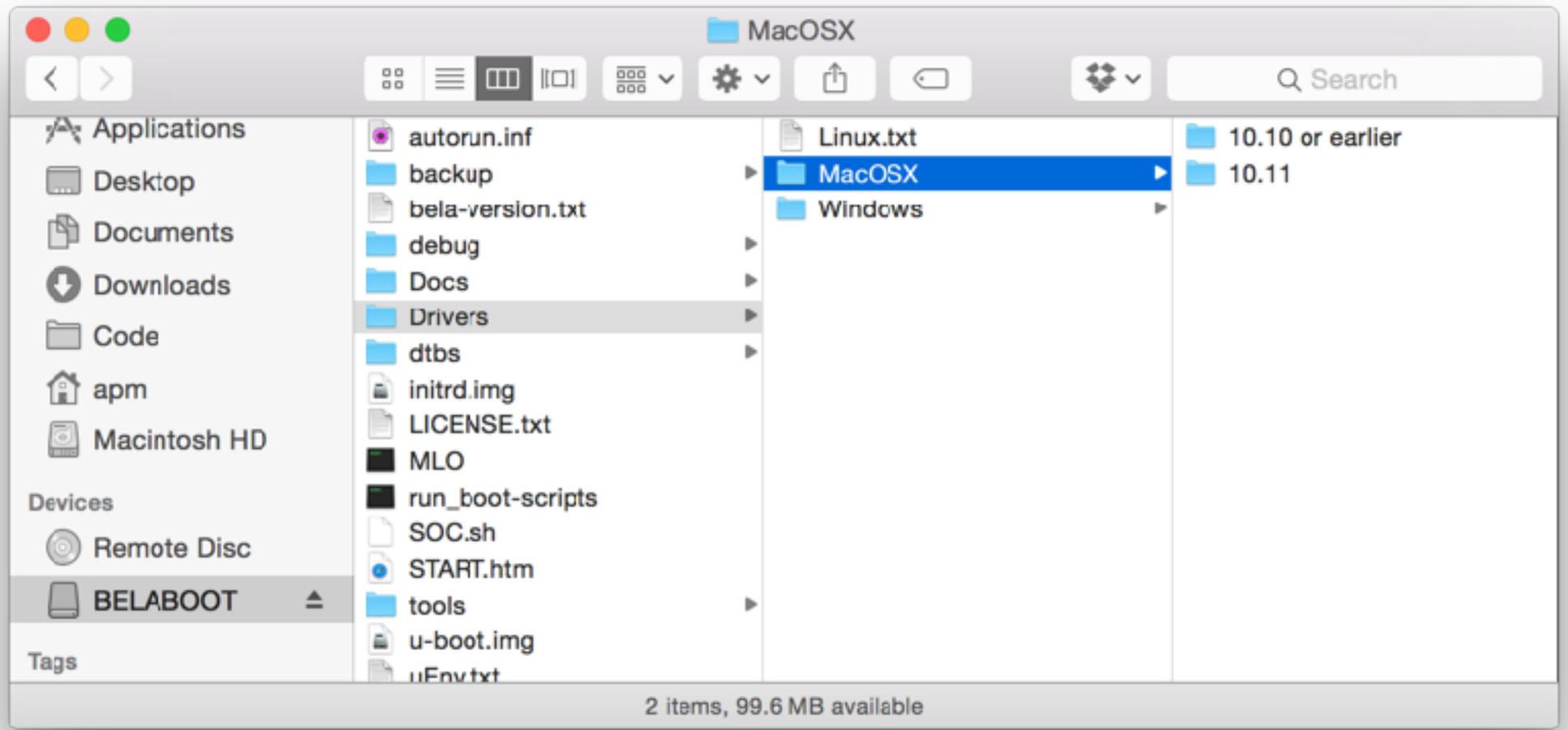

## BeagleBone Black drivers

Mac Yosemite and above, Windows Vista and above, all Linux: no drivers required.

For older operating systems the drivers can be found on the board

# Install drivers (*usually not needed)

- Step 1: Plug in Bela by USB
  - Wait for it to boot
  - You should see a drive BELABOOT come up




- Step 2: Install software from Drivers directory
- Step 3: Reboot computer

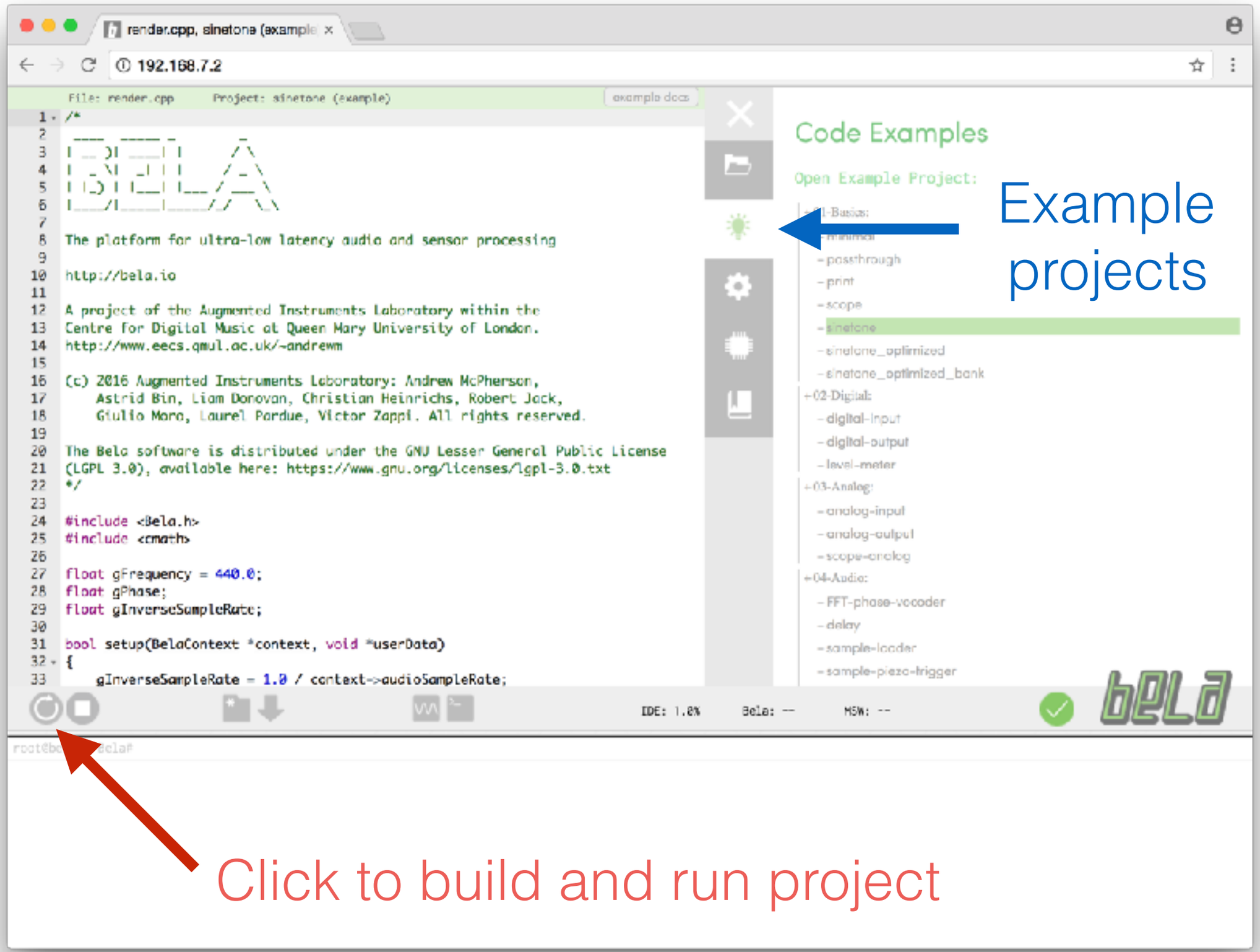
# Copy workshop examples

*As we need to edit Pd patches using Pure Data on our machine it is best to have a local copy.*

- Step 1: Copy Workshop.zip archive from circulating USB stick to computer
- Step 2: Unzip Workshop.zip

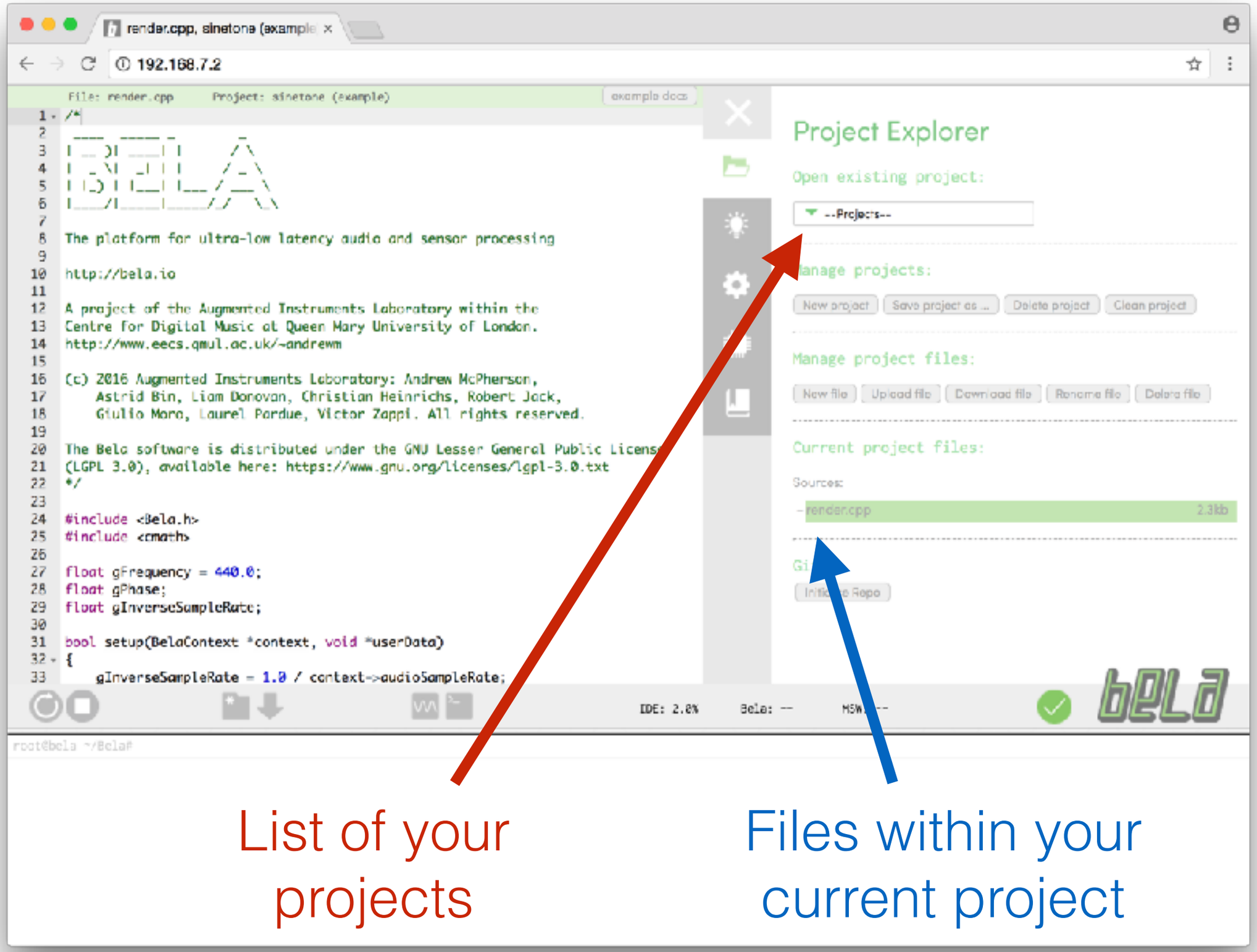
Bring up the Bela IDE:

**http://bela.local/** (or 192.168.6.2 on Windows)



Bring up the Bela IDE:

# http://bela.local/

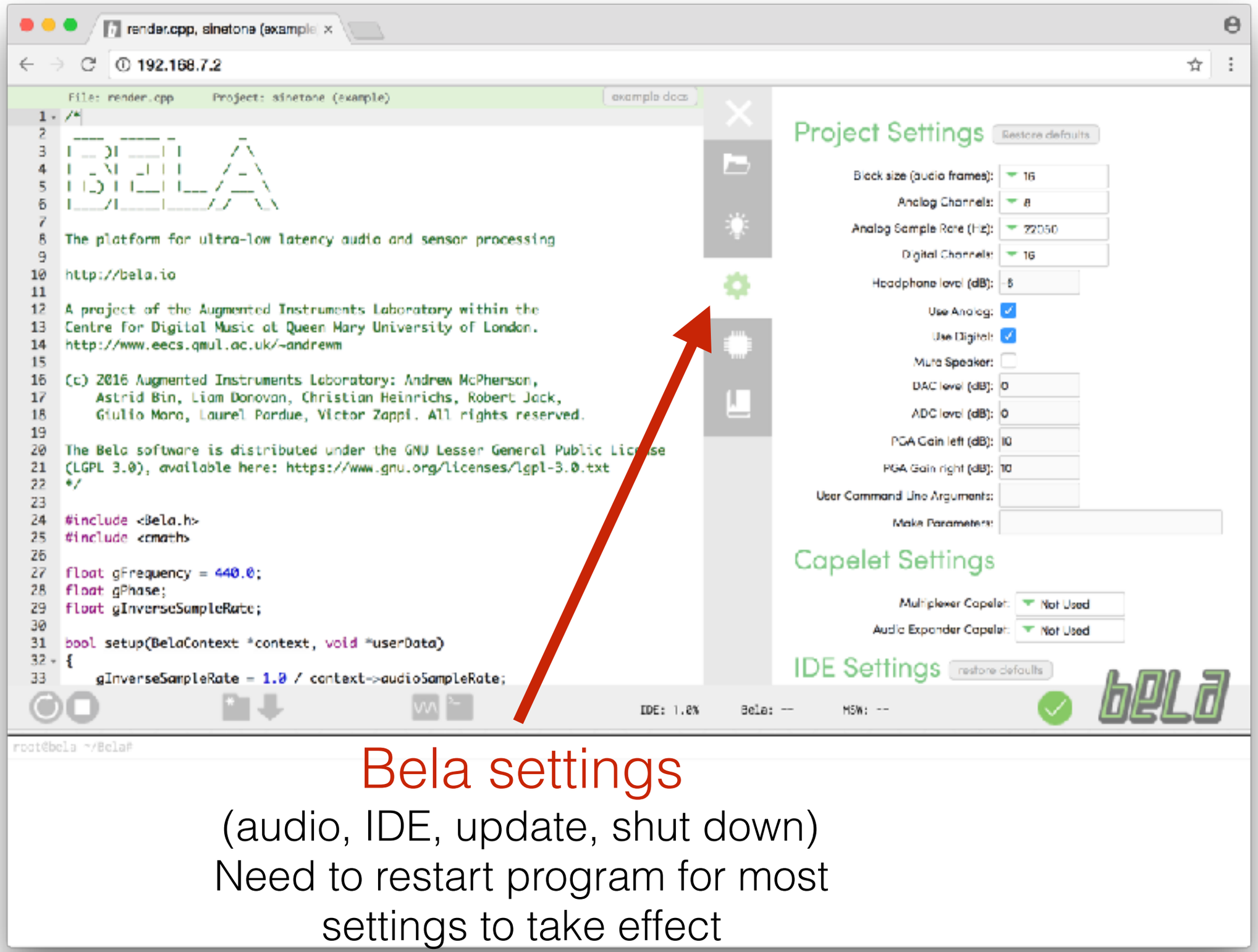



List of your projects

Files within your current project

Bring up the Bela IDE:

# http://bela.local/



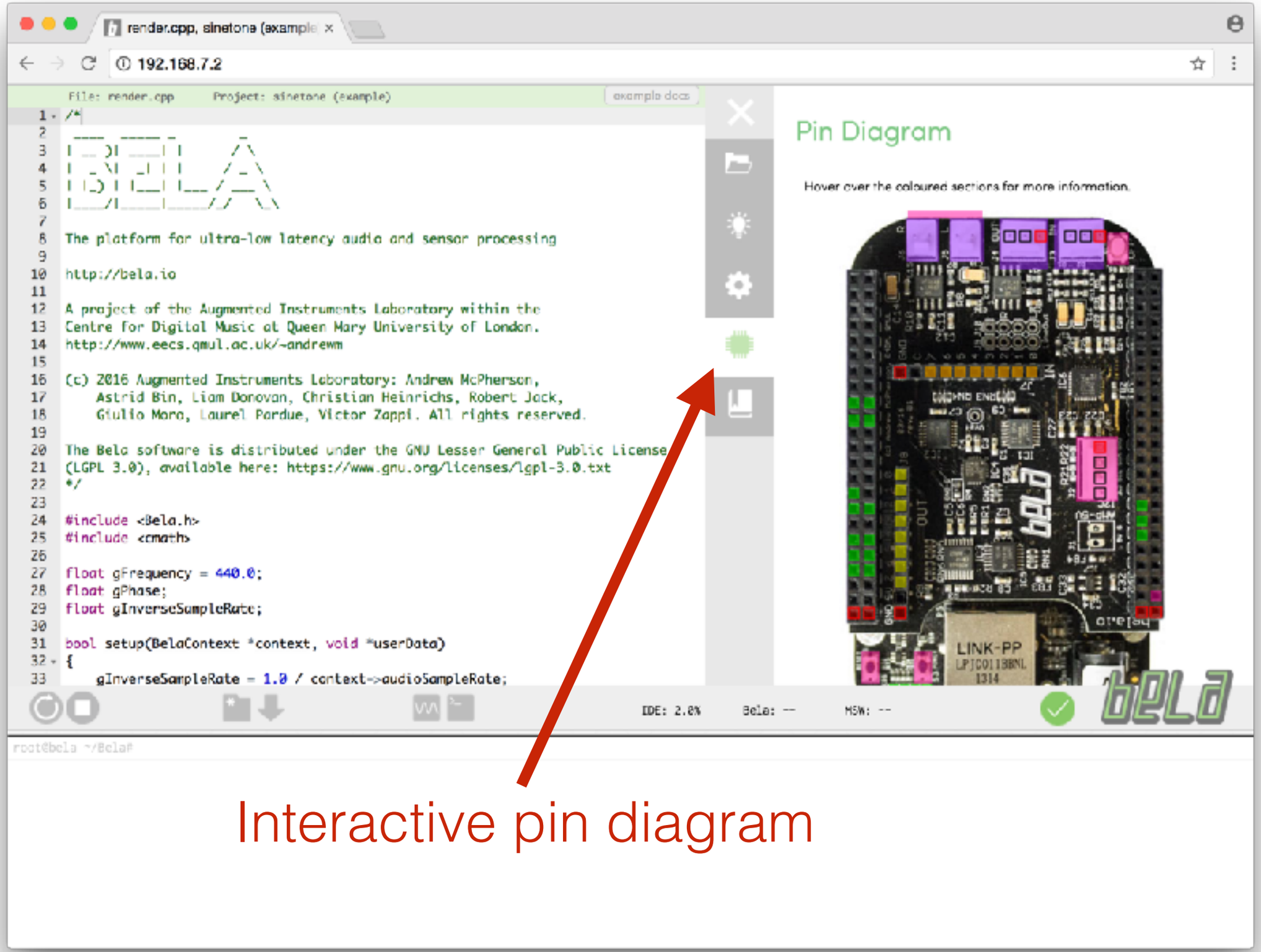

## Bela settings

(audio, IDE, update, shut down)

Need to restart program for most settings to take effect

Bring up the Bela IDE:

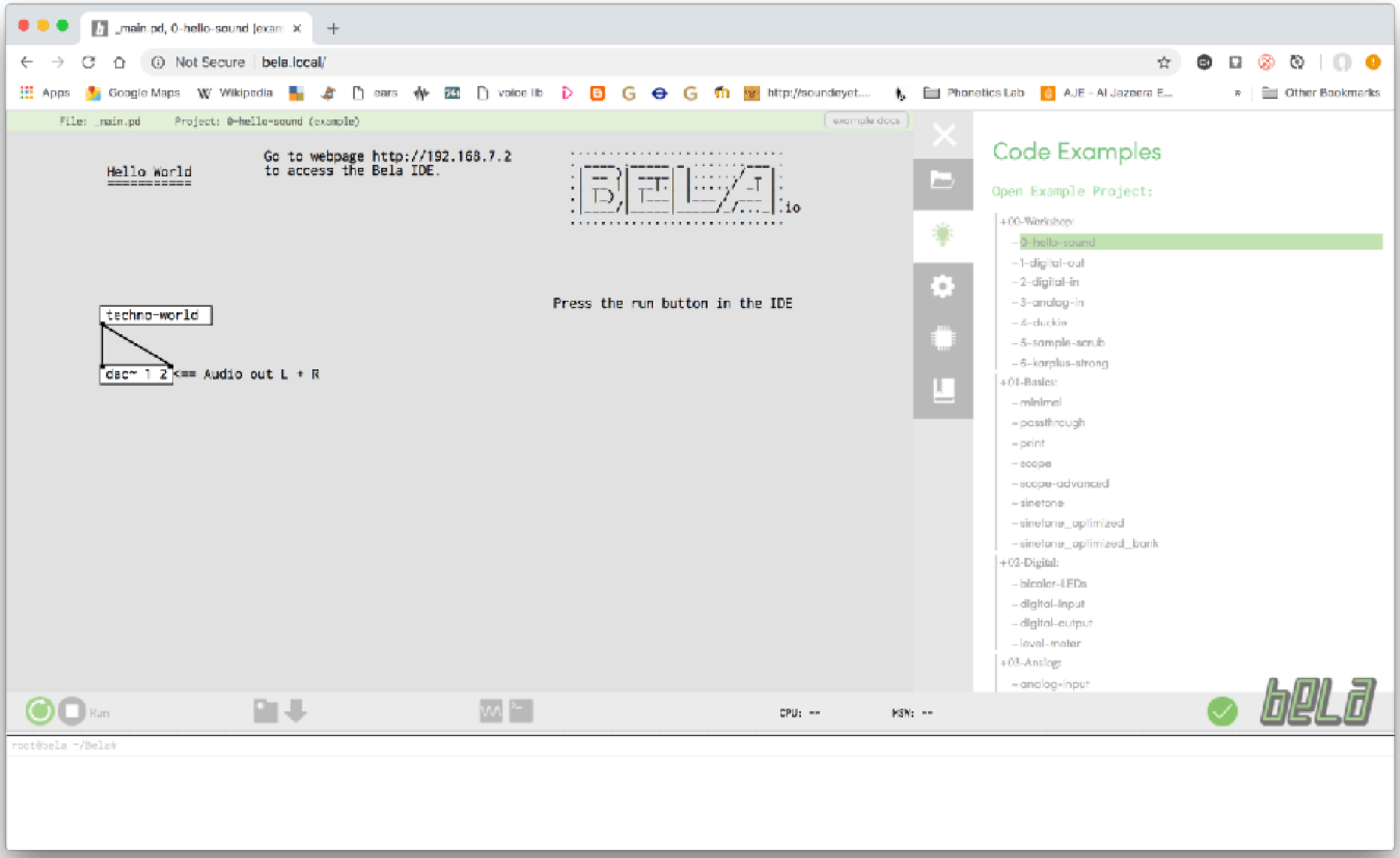
# http://bela.local/



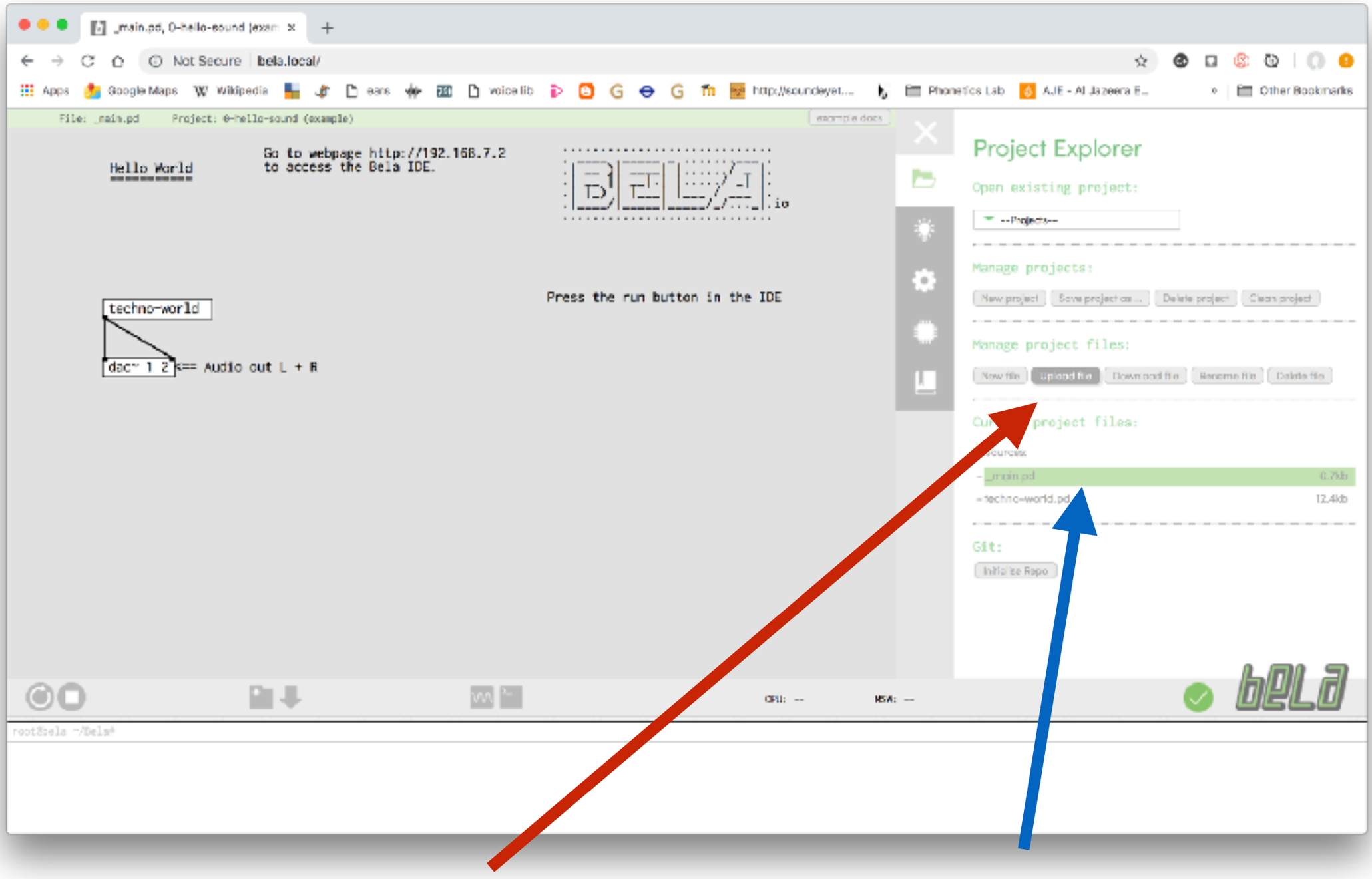

Interactive pin diagram

Open example **00-workshop/0-hello-sound**

In IDE, you can view and run but not edit Pd patches



Edit your patch in the Pd program on the computer
Save, then use Upload File button or drag file to browser window




Upload / Download File

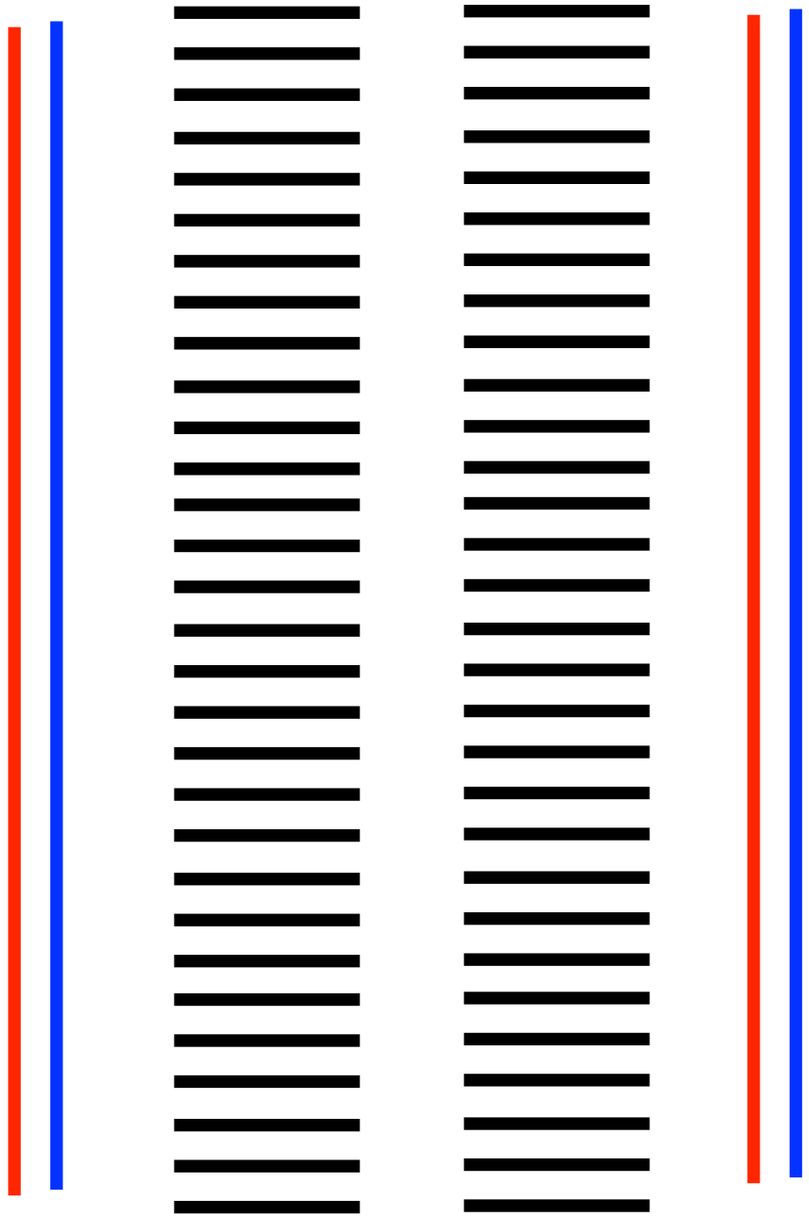
Notice: file always called _main.pd

# Using the Breadboard

Each column of 5 holes connects together

...but not across the break in the middle.

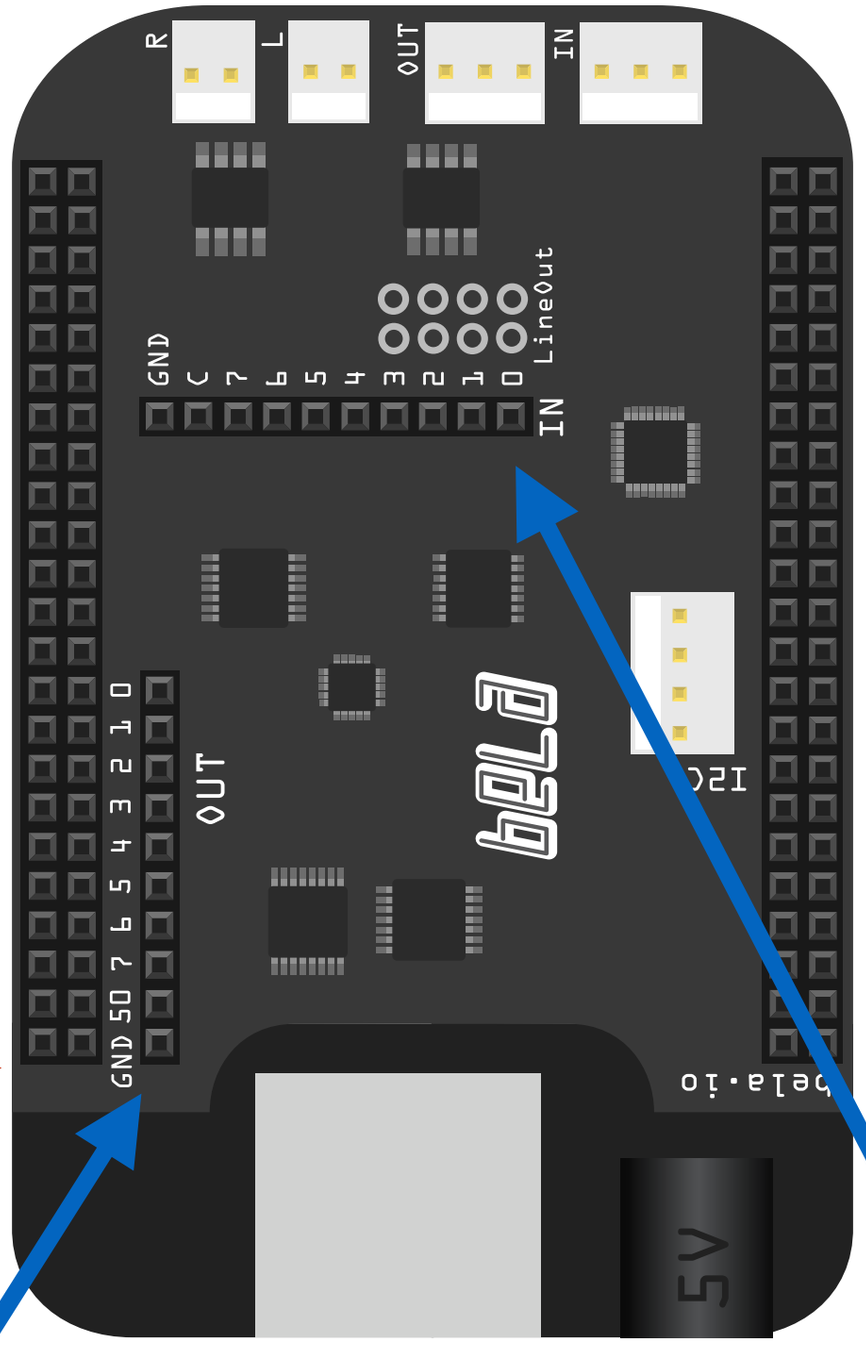
Long rows at the ends each connect together. Typically used for power and ground



# Bela pin numbering

**Important: NEVER** use 5V with digital I/Os!

| | |
|---|---|
| 14 | 13 |
| 12 | 11 |
| 10 | 9 |
| 8 | 7 |
| 6 | 5 |
| 4 | 3 |
| 2 | 1 |




| | |
|---|---|
| 14 | 13 |
| 12 | 11 |
| 10 | 9 |
| 8 | 7 |
| 6 | 5 |
| 4 | 3 |
| 2 | 1 |

P8

P9

**Analog Out**

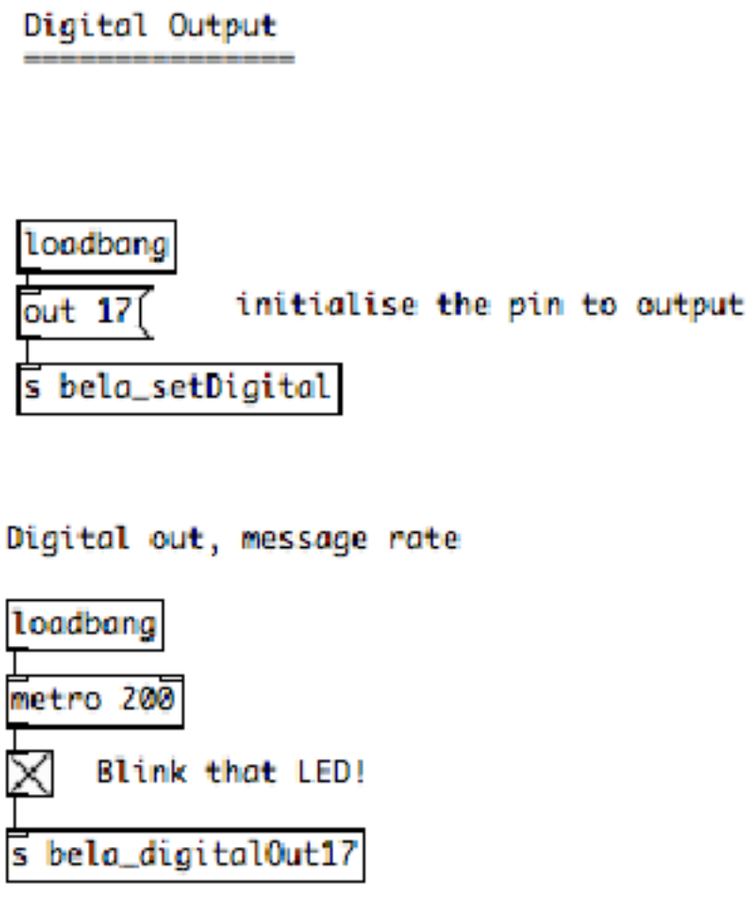
also 5V (+100Ω), ground

**Analog In**

also ground

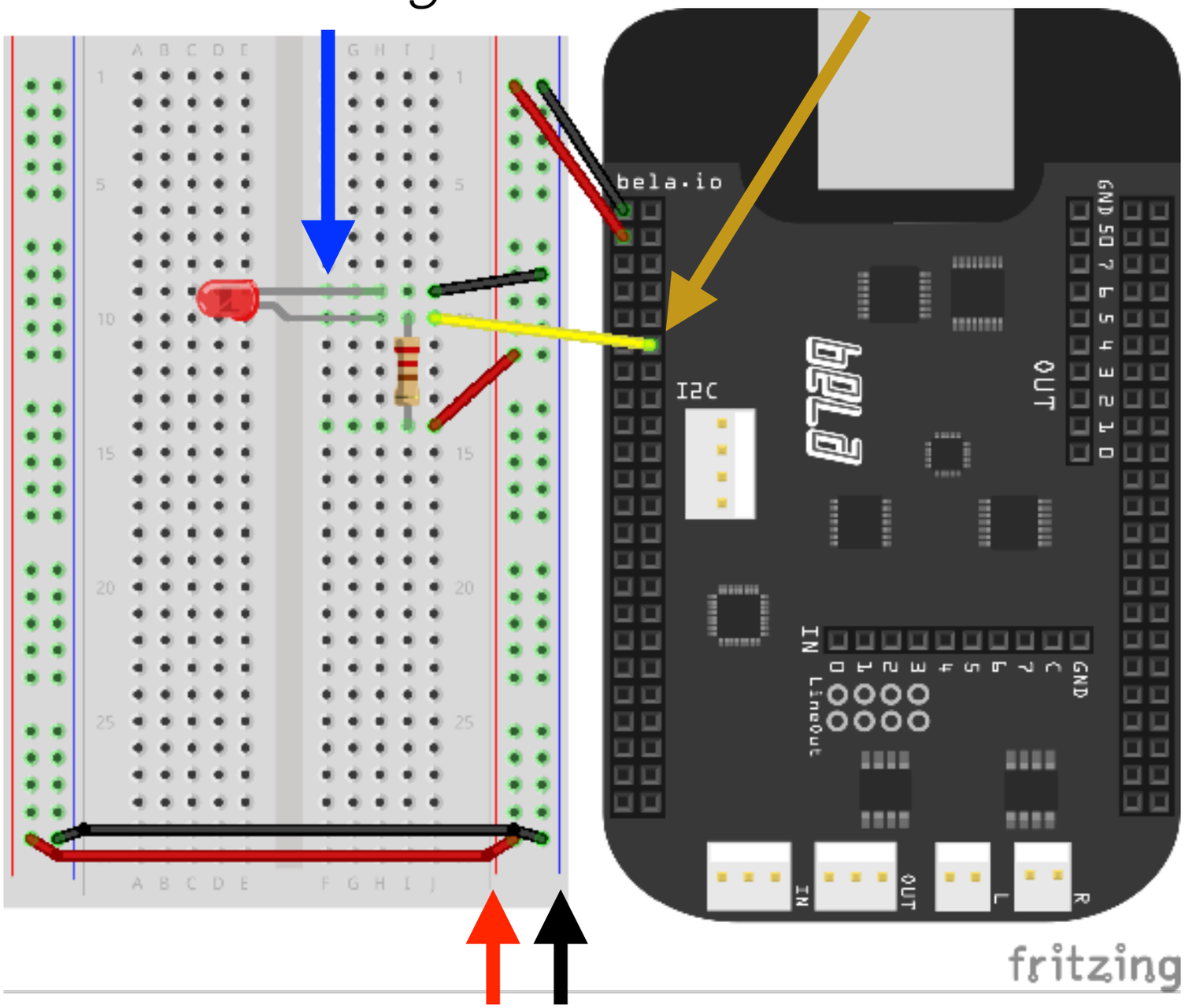
# Digital Output

examples/00-Workshop/1-digital-out




*Important:* ***short*** *lead of LED to ground*

LED on P9 pin 12




P9 pin 3: +3.3V  P9 pin 1: ground

# Digital Output

examples/13-Workshop/1-digital-out

Digital Output

loadbang

out 17 initialise the pin to output

s bela_setDigital

Digital out, message rate

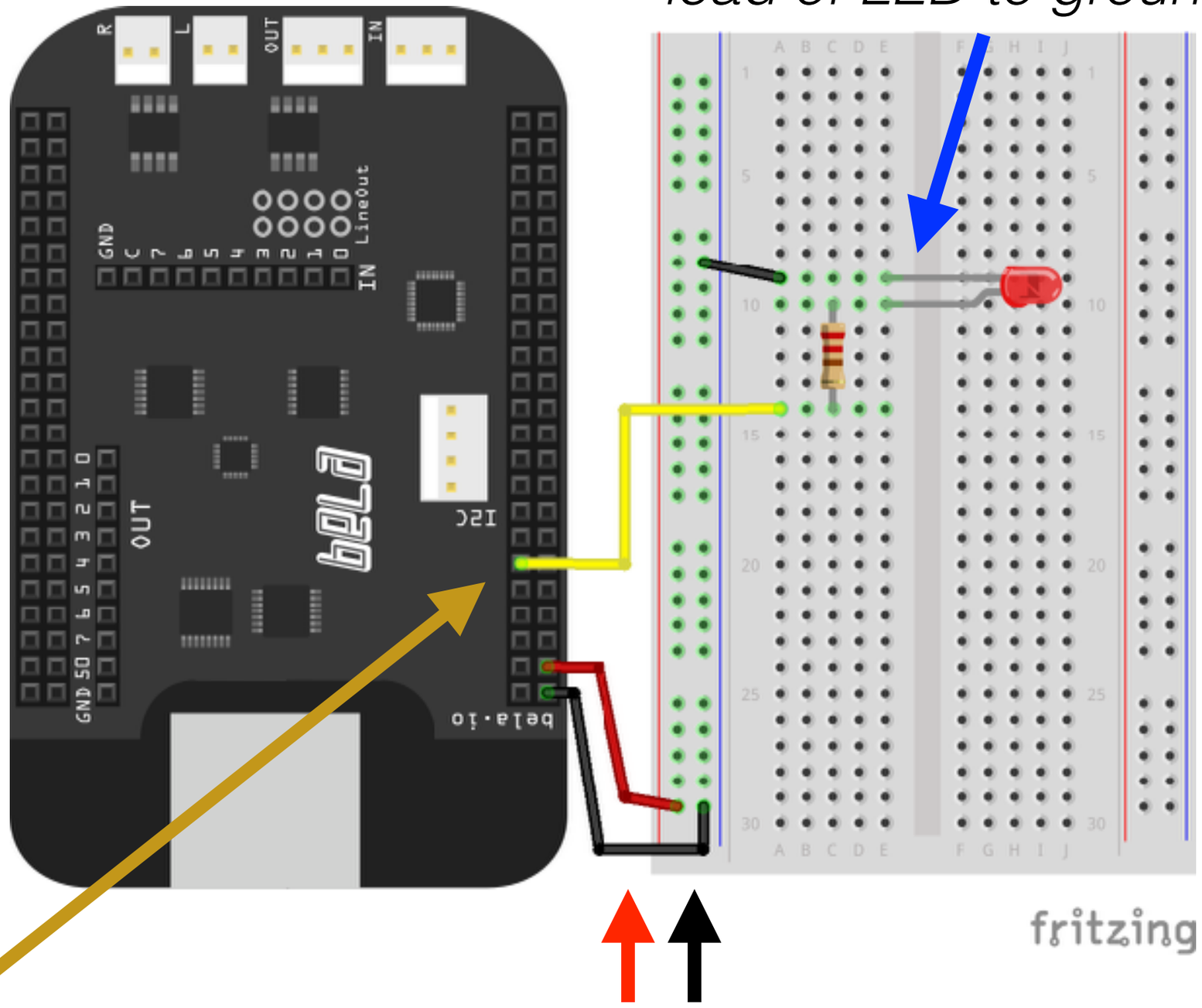
loadbang

metro 200

Blink that LED!

s bela_digitalOut17

*Important: **short** lead of LED to ground*




LED on P9 pin 12

P9 pin 3: +3.3V P9 pin 1: ground

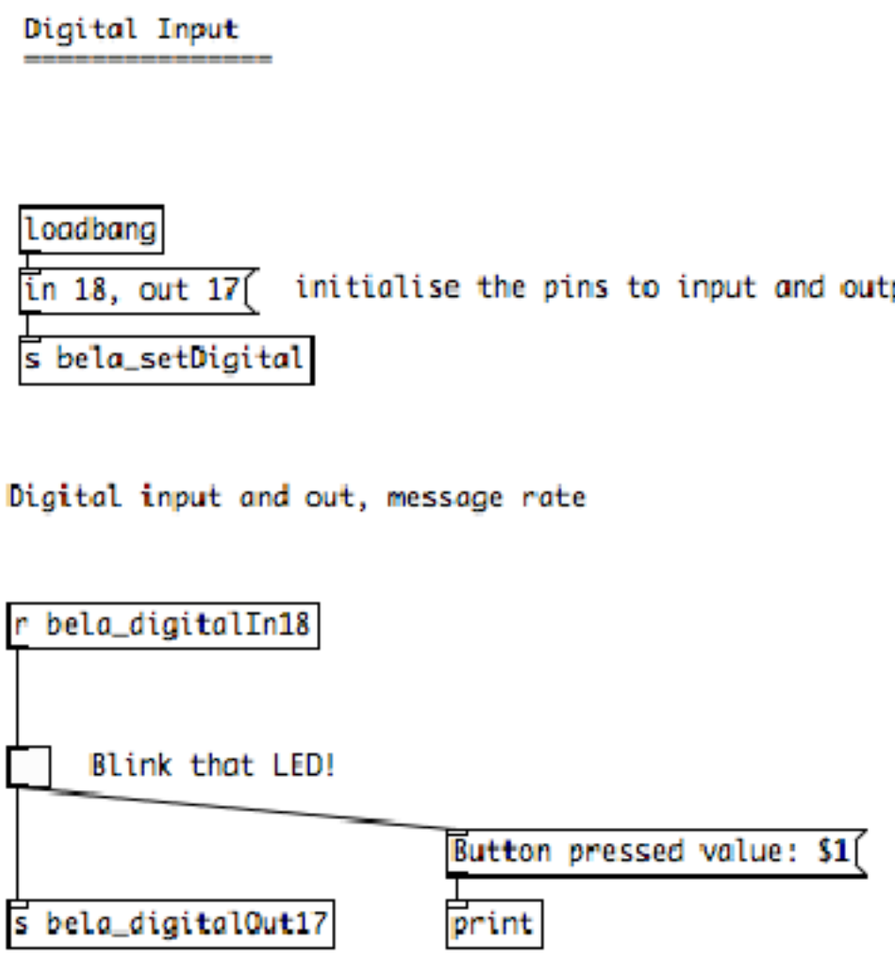
# Digital Input

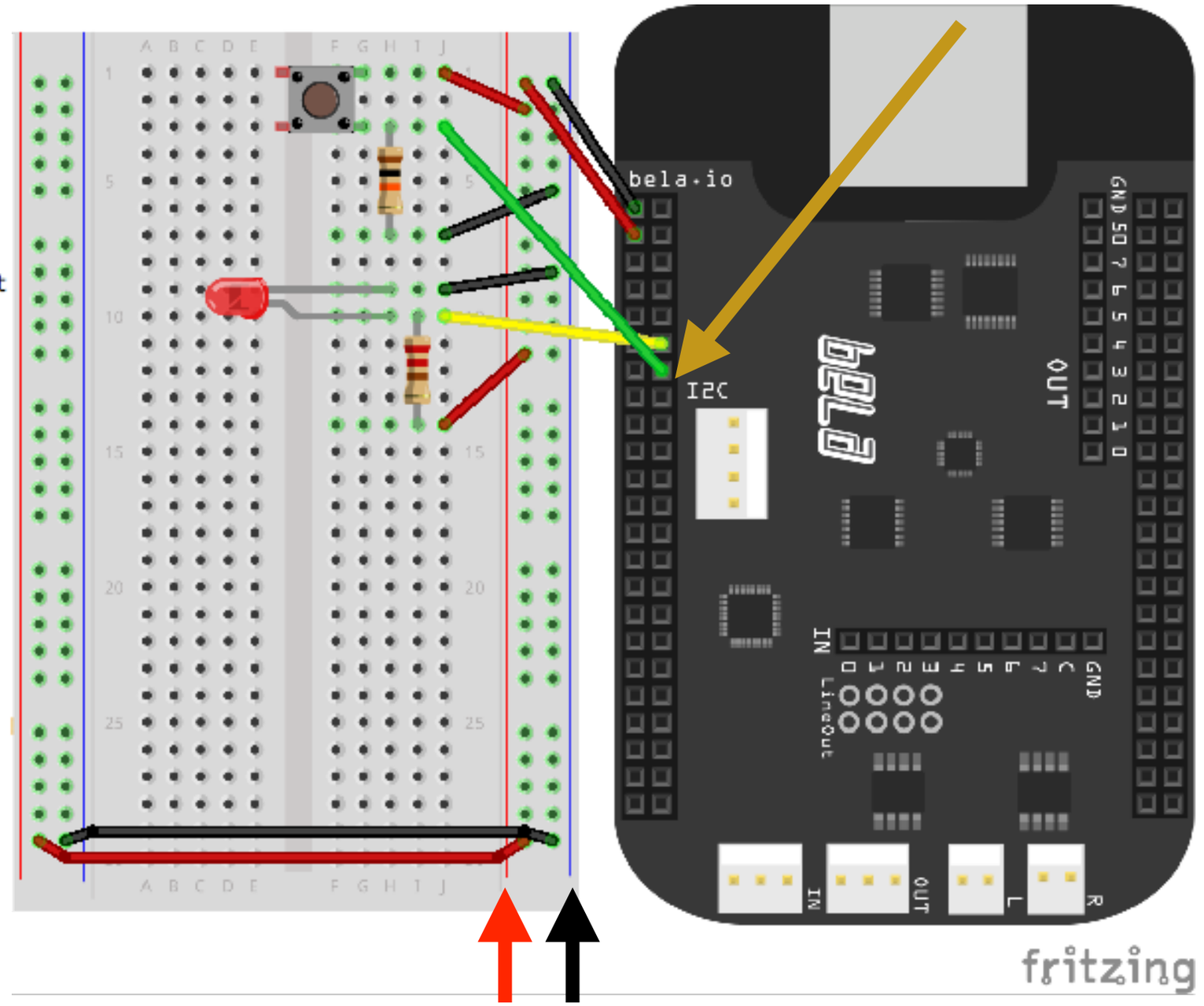
examples/00-Workshop/2-digital-in

*Button requires*

*3 wires + 10k resistor*

Button on P9 pin 14



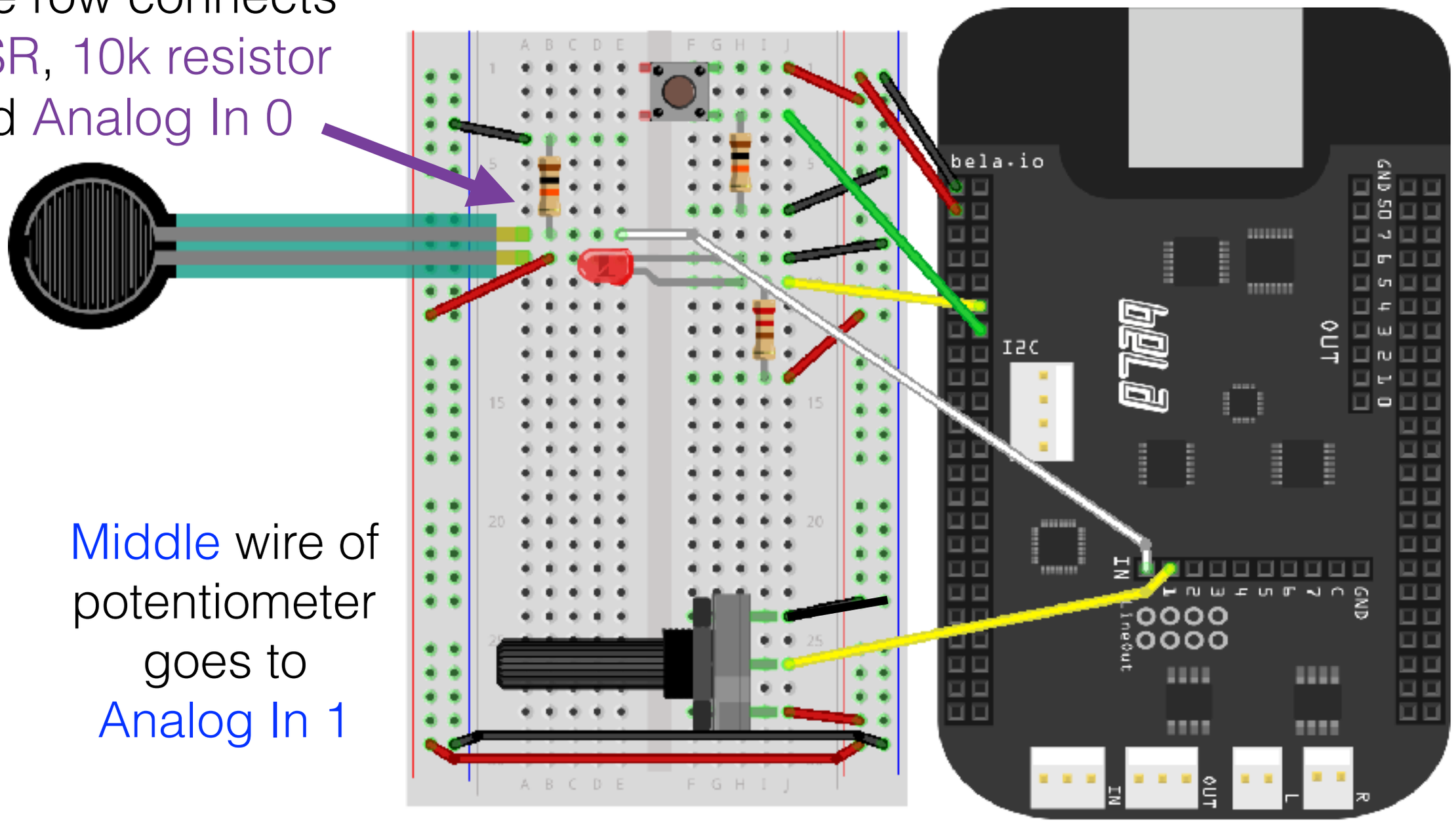

P9 pin 3: +3.3V  P9 pin 1: ground

# Analog Input

examples/00-Workshop/3-analog-in

Same row connects to FSR, 10k resistor and Analog In 0

Middle wire of potentiometer goes to Analog In 1




**Note:** in Pd, audio is on channels 1 and 2, analog on channels 3 to 10.

So here, [adc~ 3 4] → Analog In 0 and 1

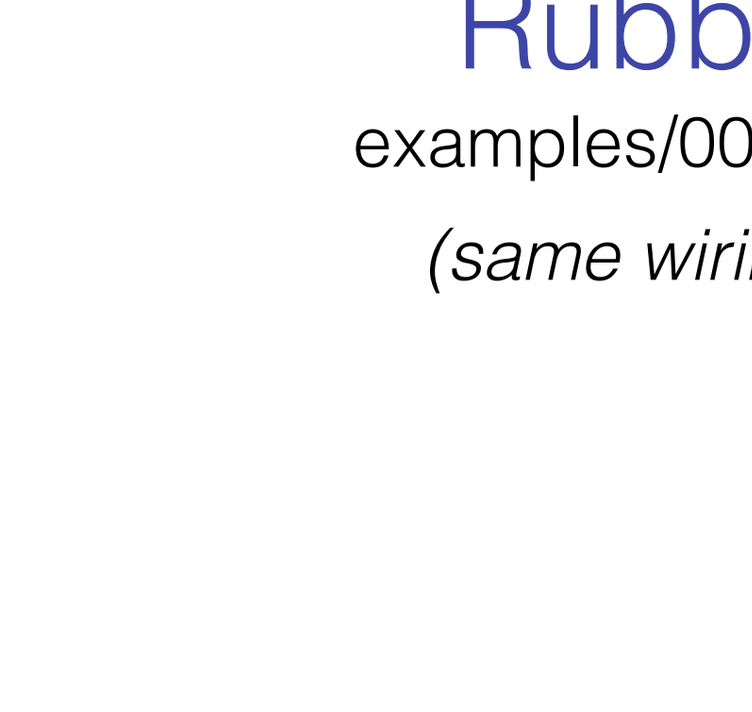
# Rubber Duckie

examples/00-Workshop/4-duckie

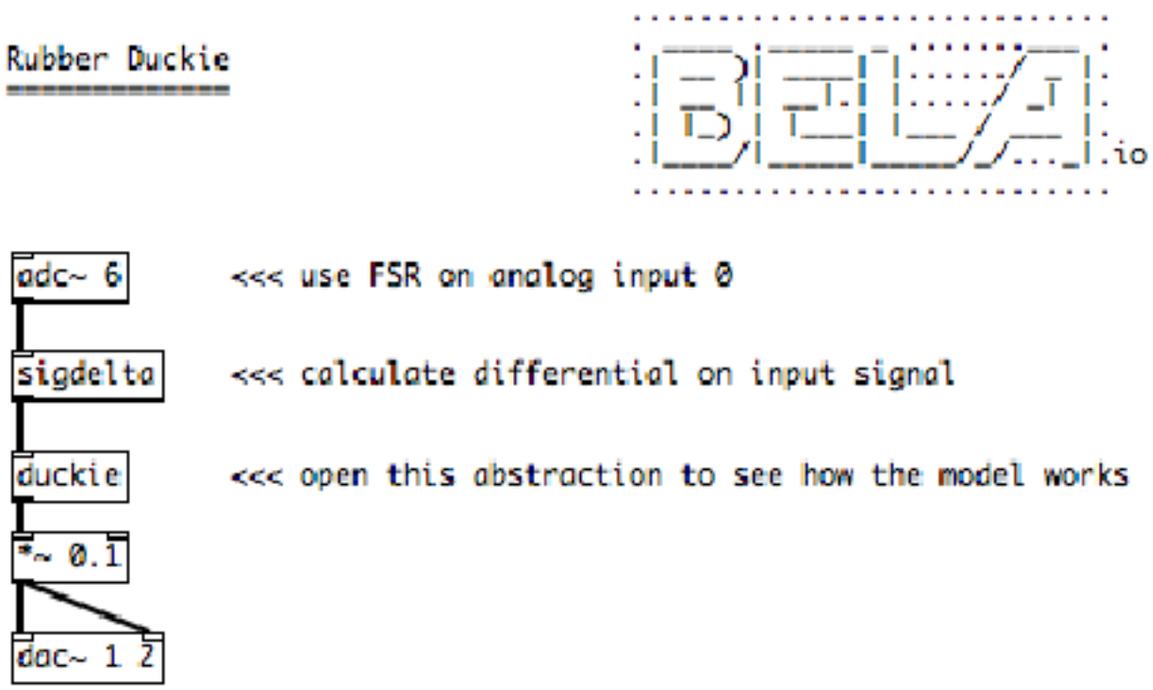
*(same wiring as 3-analog-in)*

## Abstractions:

Subsidiary Pd patches




sigdelta.pd



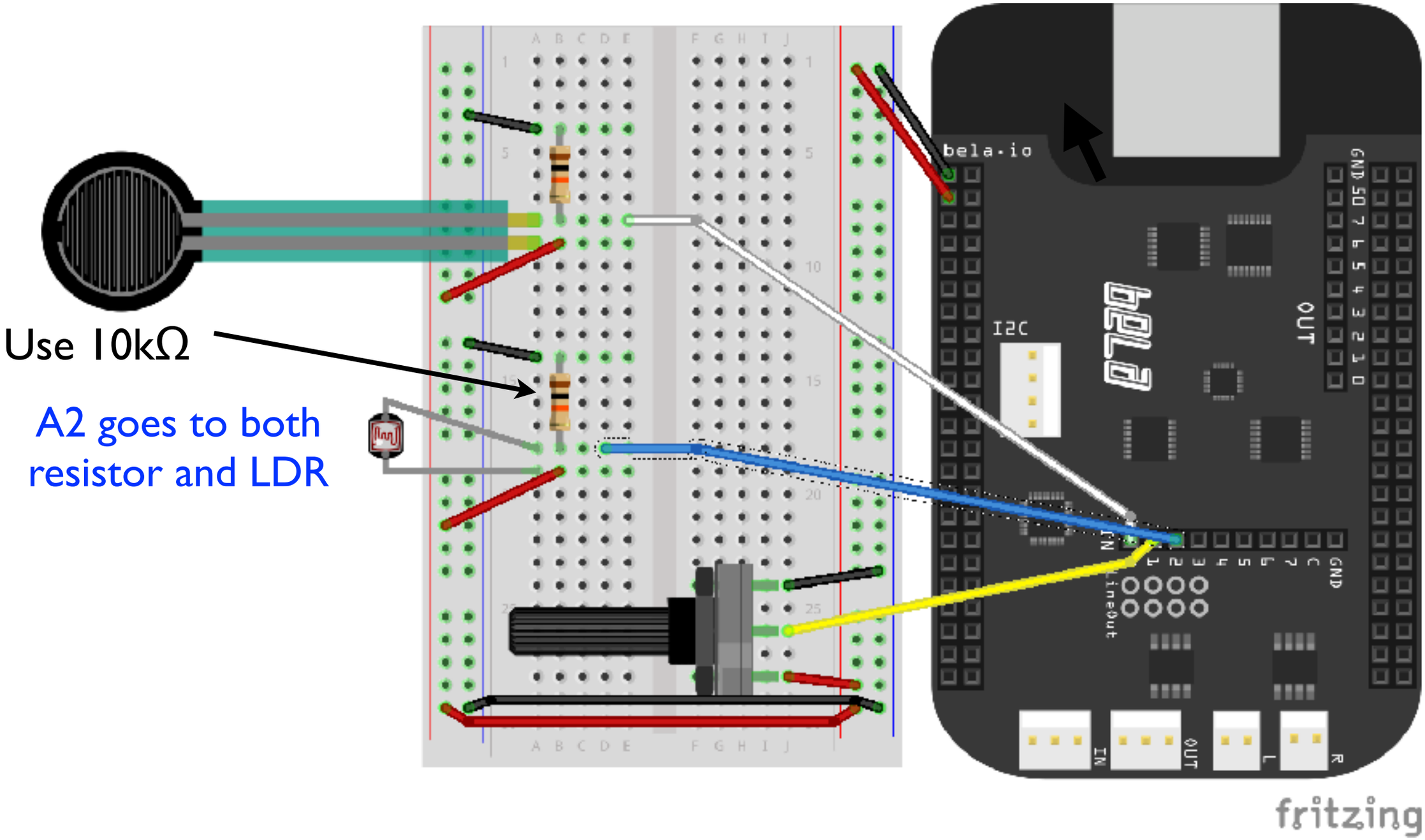

# Light sensor

examples/00-Workshop/5-fm-synth

## Add this to the existing components on the board

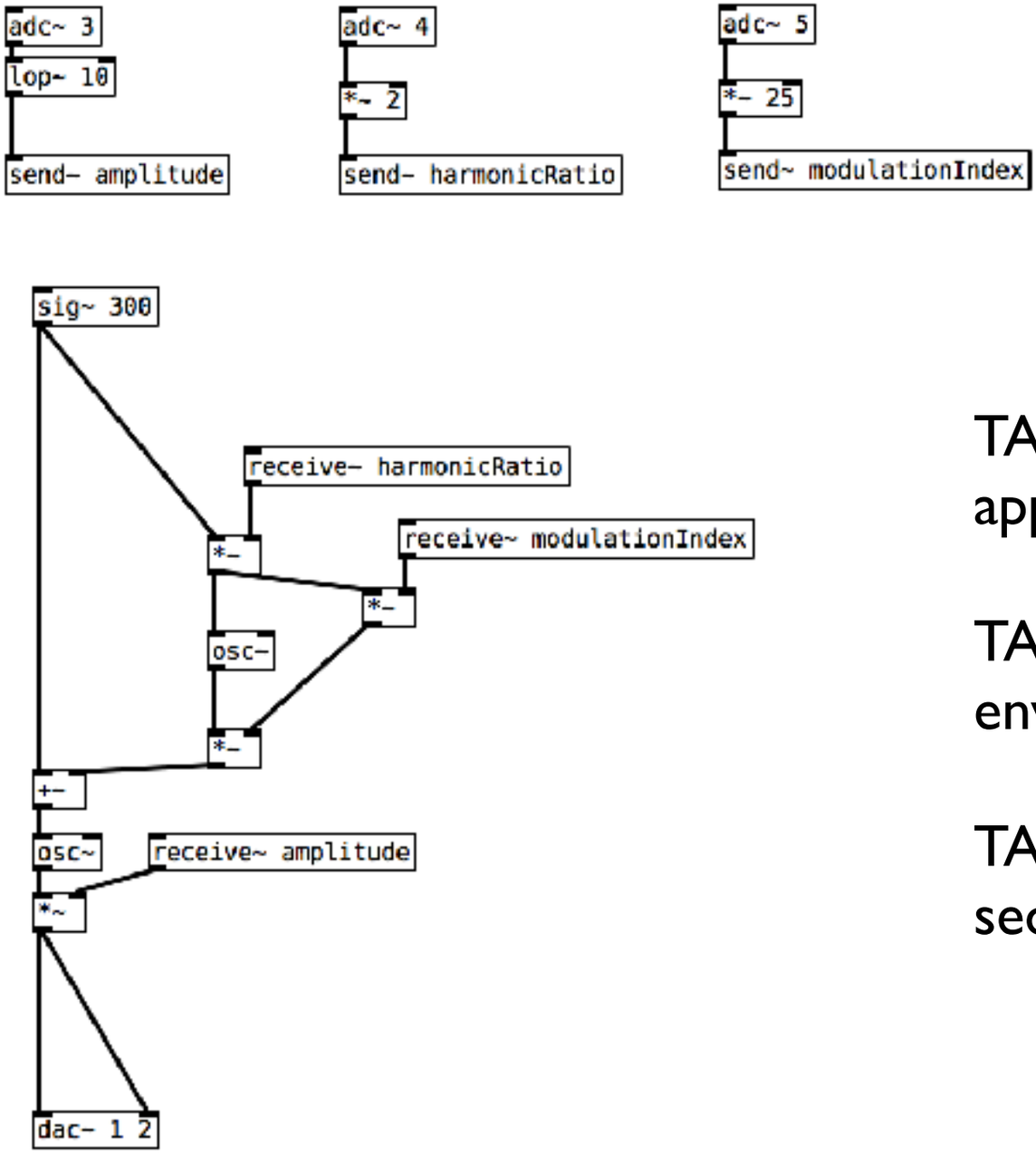
Use 10kΩ

A2 goes to both resistor and LDR



# Light sensor

examples/00-Workshop/5-fm-synth




TASK 1: map the LDR to an appropriate range by using the scope

TASK 2: use the FSR to trigger an envelope once over a threshold

TASK 3: EXTRA try to connect simple-sequencer.

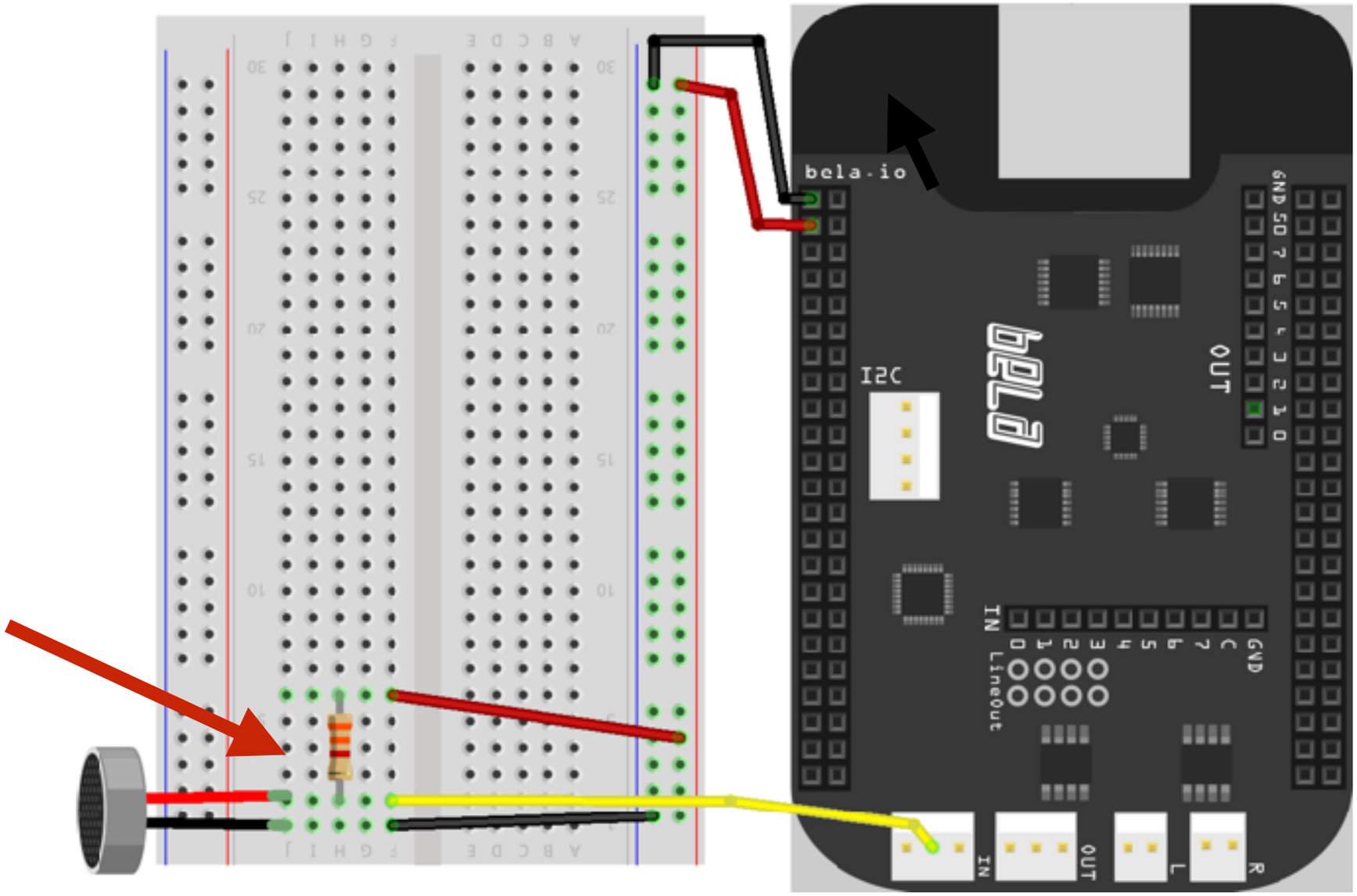
# Microphone

examples/00-Workshop/6-mic-test

## Add this to the existing components on the board

Pin attached to metal case goes to **ground**

Microphone needs resistor to +3.3V



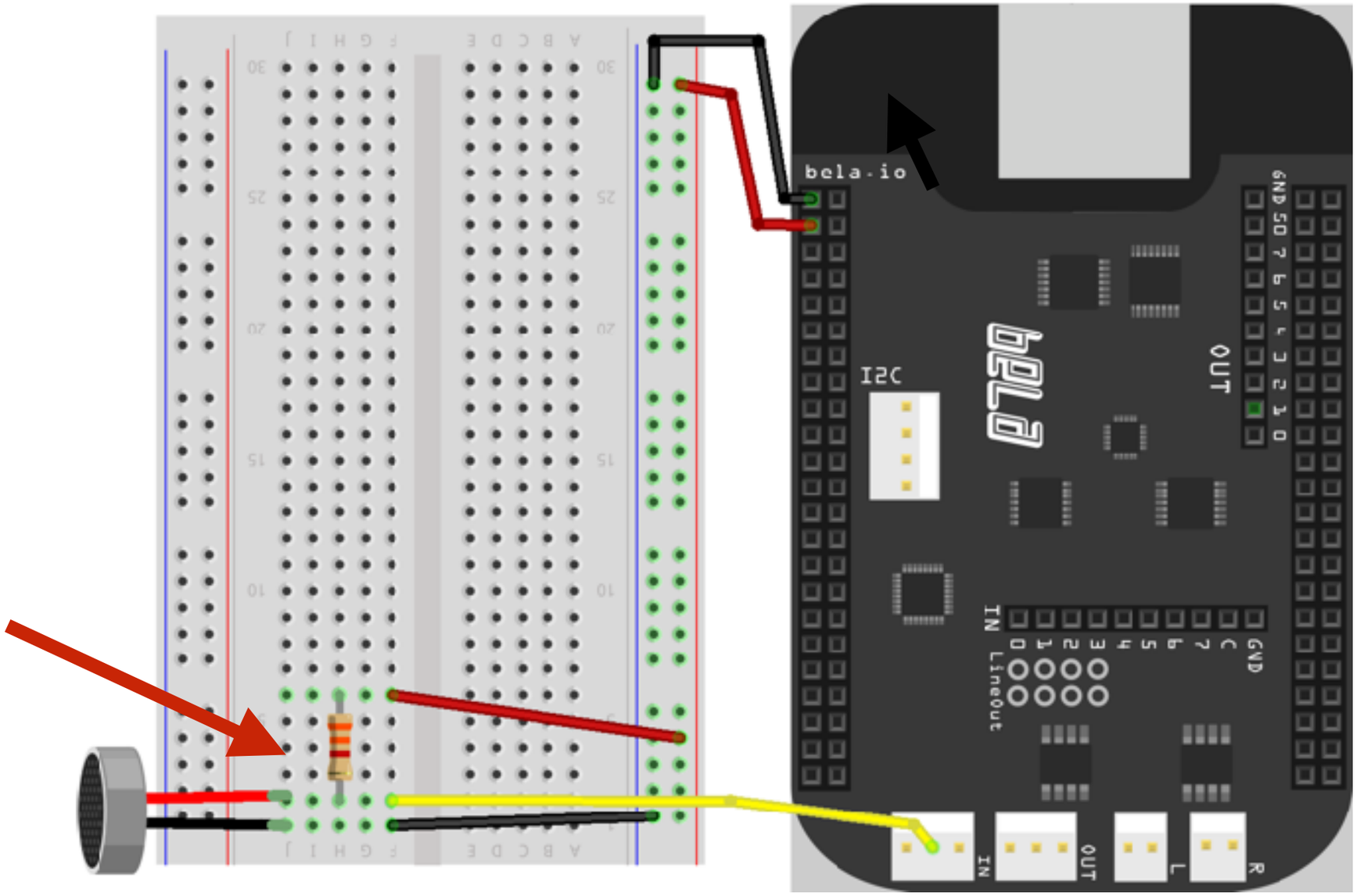
# Sampler

examples/00-Workshop/7-sample-scrub

Using the same setup as the last example (microphone plus other components)

Pin attached to metal case goes to **ground**

Microphone needs resistor to +3.3V

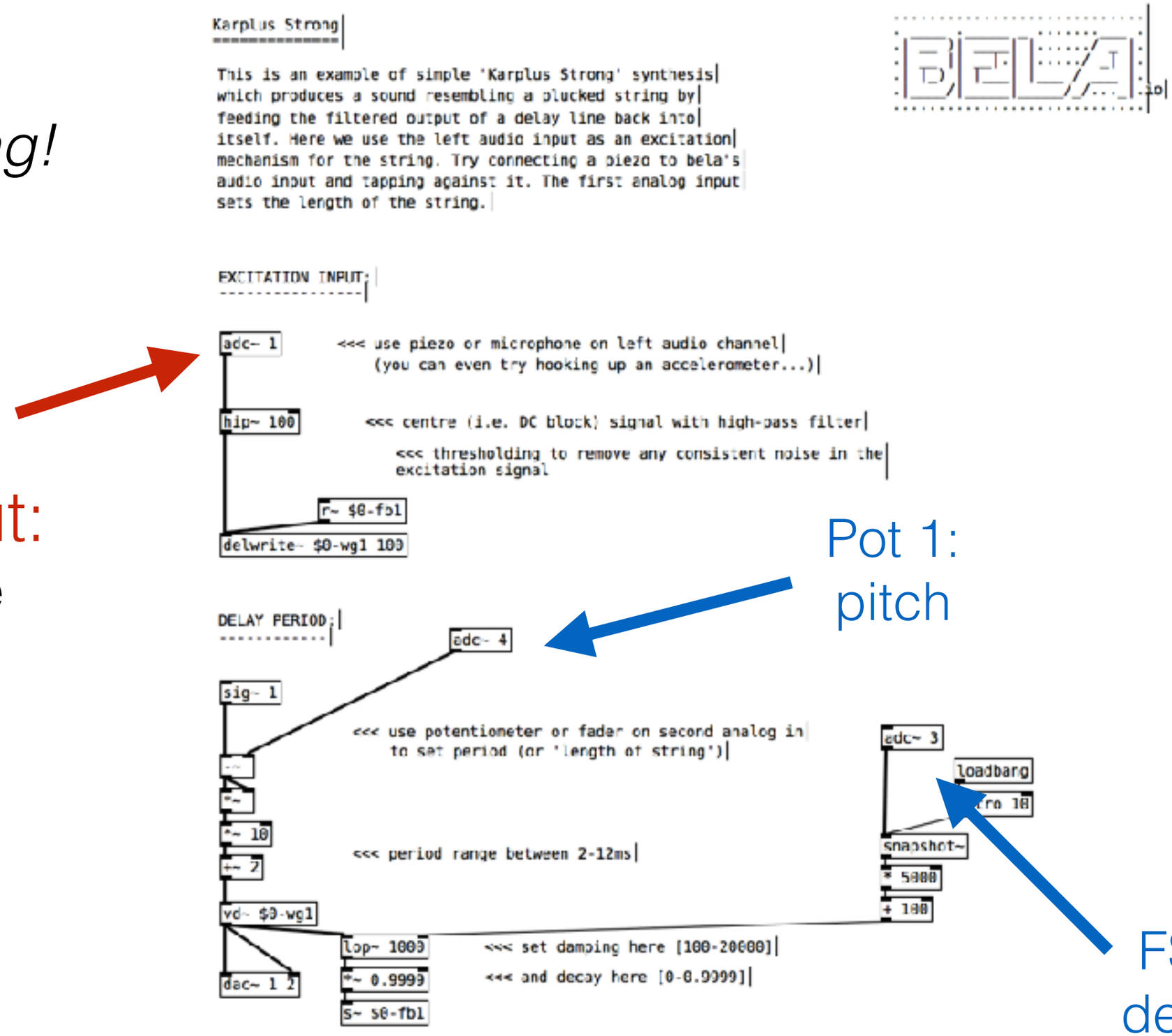


# Karplus-Strong (string synthesis)

examples/00-Workshop/8-karplus-strong

*Keep wiring!*

Audio input:
mic capsule



# Support resources: GitHub repo and wiki

## http://bela.io/code

This repository Search Pull requests Issues Gist

BelaPlatform / Bela

Unwatch 8 Star 18 Fork 0

Code Issues 11 Pull requests 0 Wiki Pulse Graphs Settings

Home

Edit New Page

roberthjack edited this page 2 days ago · 50 revisions

**NOTE:** we are currently actively updating this wiki.

Pages 28

Getting started with Bela

Bela IDE

Bela Hardware

Examples and Tutorials

Updating Bela

Clone this wiki locally

https://github.com/BelaP

Clone in Desktop

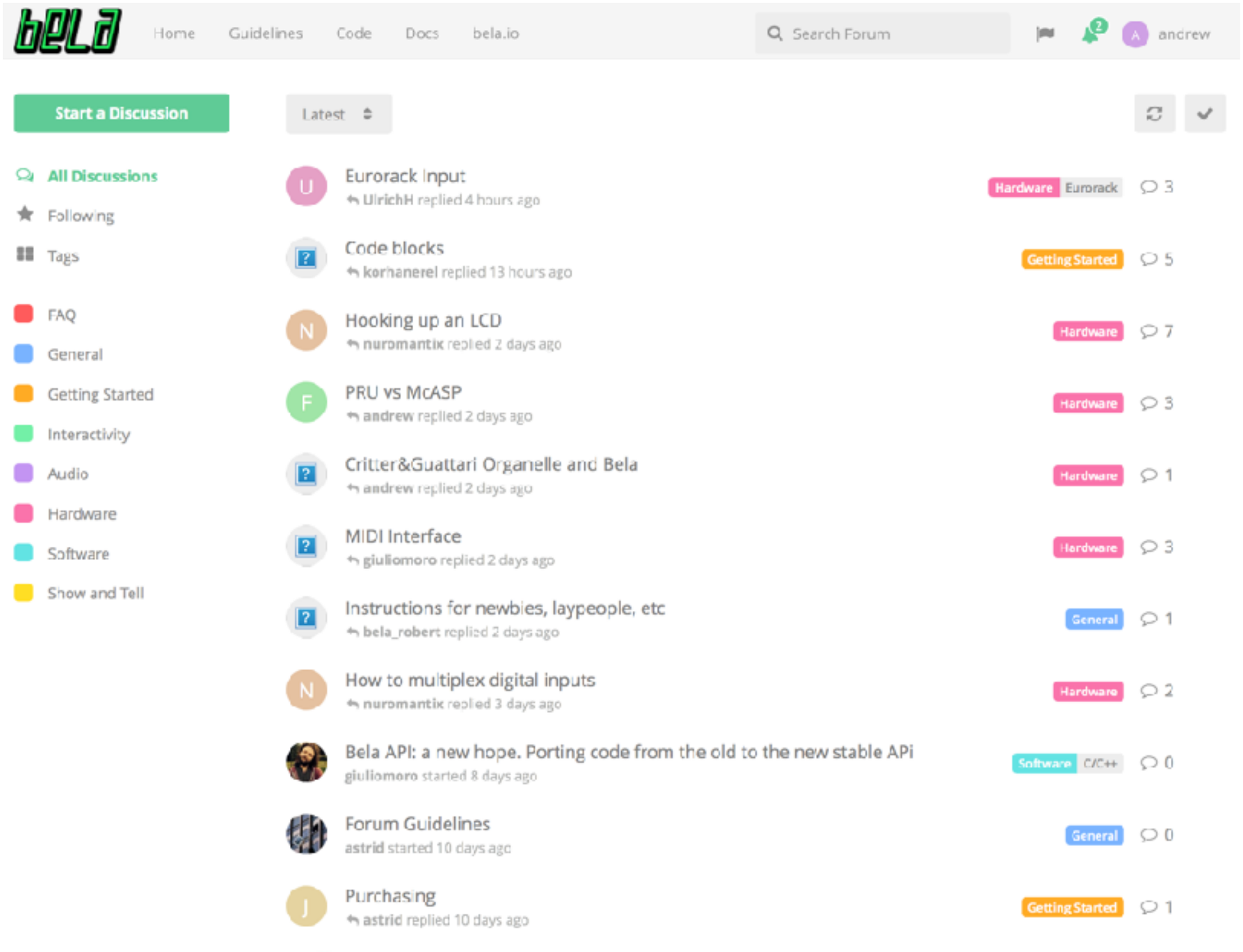
bela

# Introducing Bela

Bela is an open-source embedded system for real-time audio processing with ultra-low latency. Based on the BeagleBone Black single-board computer and featuring a custom hardware and software environment, Bela integrates audio processing and sensor connectivity in a single high-performance package. Bela has been designed to be a flexible platform for musicians, instrument designers, audio enthusiasts and interactive artists. On this Wiki you'll find all the information you'll

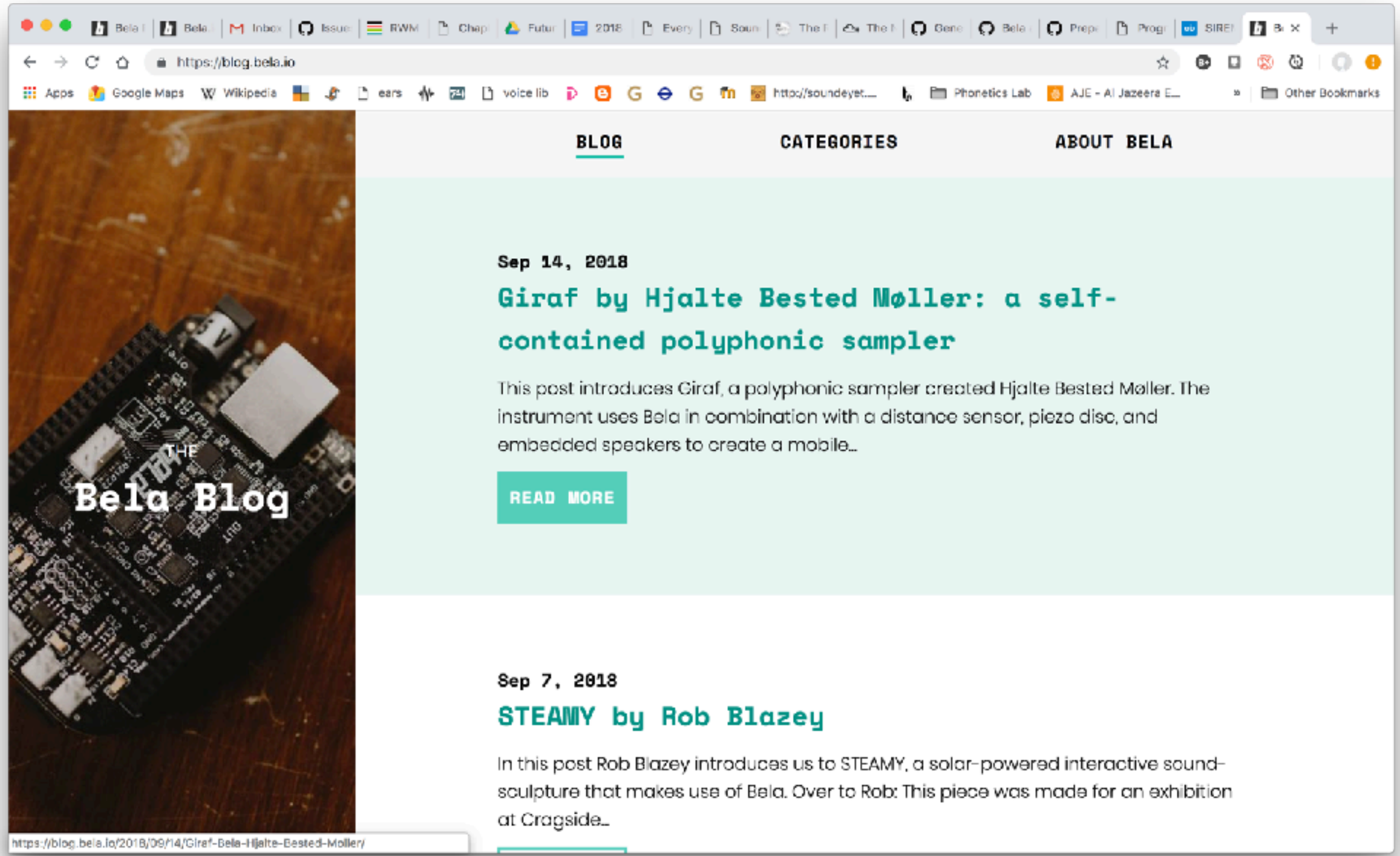
# Support resources: Bela forum

## http://forum.bela.io



# Bela blog

## http://blog.bela.io



# BELA

Stay tuned! Join the announcement list at

http://bela.io

£10 off starter kits thru 31 May using code SUPERBOOTH19

http://shop.bela.io

# C++ API

- In **`render.cpp`**....
- Three main functions:
- **`setup()`**
  *runs once at the beginning, before audio starts*
  *gives channel and sample rate info*
- **`render()`**
  *called repeatedly by Bela system ("callback")*
  *passes input and output buffers for audio and sensors*
- **`cleanup()`**
  *runs once at end*
  *release any resources you have used*
- Code docs available in sidebar of IDE, or at docs.bela.io

# Example: sinetone

```
#include <Bela.h>
#include <cmath>

float gPhase = 0.0; /* Phase of the oscillator (global variable) */

void render(BelaContext *context, void *userData)
{
    /* Iterate over the number of audio frames */
    for(unsigned int n = 0; n < context->audioFrames; n++) {
        /* Calculate the output sample based on the phase */
        float out = 0.8 * sinf(gPhase);

        /* Update the phase according to the frequency */
        gPhase += 2.0 * M_PI * gFrequency * gInverseSampleRate;
        if(gPhase > 2.0 * M_PI)
            gPhase -= 2.0 * M_PI;

        for(unsigned int channel = 0;
            channel < context->audioOutChannels; channel++) {
            /* Store the output in every audio channel */
            audioWrite(context, n, channel, out);
        }
    }
}
```

This runs once per block

This runs once per sample in the block (audioFrames gives the number)

This runs twice per frame, once for each channel

write to buffer of interleaved audio data, specifying a frame, a channel and a value

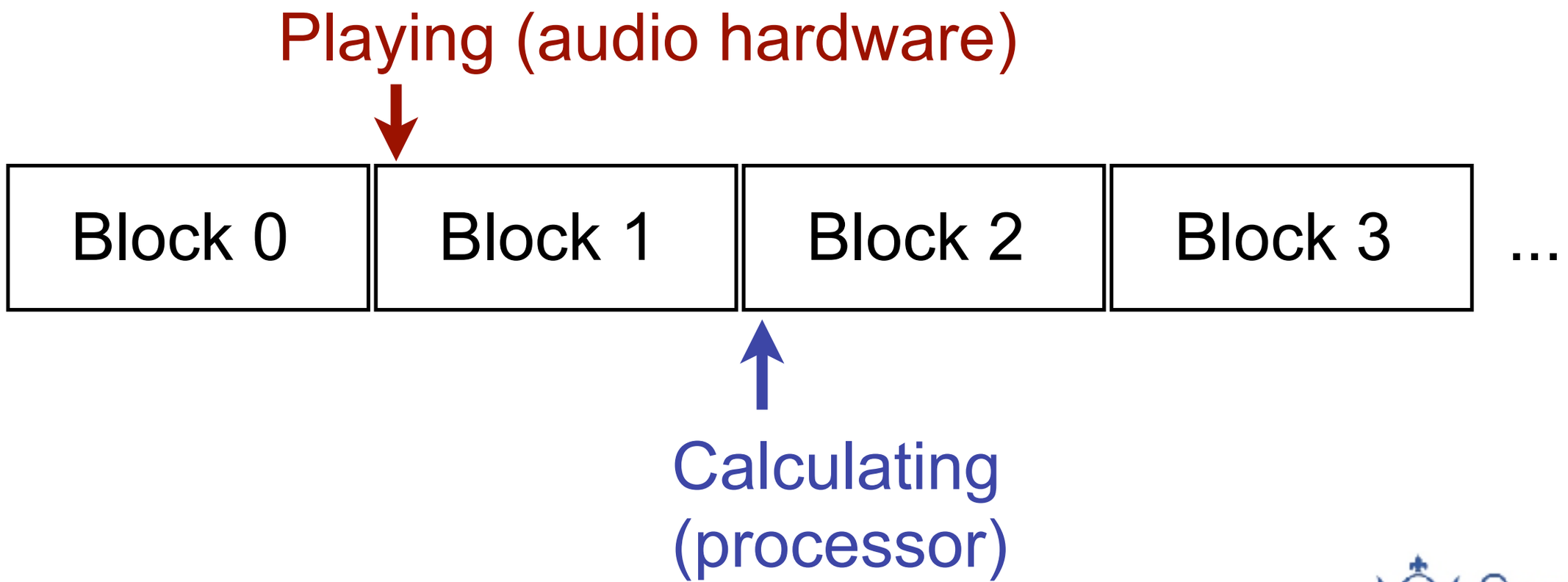
# Real-time audio

- Suppose we have code that runs offline
  - (non-real time)
- Our goal is to re-implement it online (real time)
  - Generate audio as we need it!
  - Why couldn't we just generate it all in advance, and then play it when we need it?

- Digital audio is composed of samples
  - 44100 samples per second in our example
  - That means we need a new sample every 1/44100 seconds (about every 23μs)
  - So option #1 is to run a short bit of code every sample whenever we want to know what to play next
  - What might be some drawbacks of this approach?
    - Can we guarantee we'll be ready for each new sample?

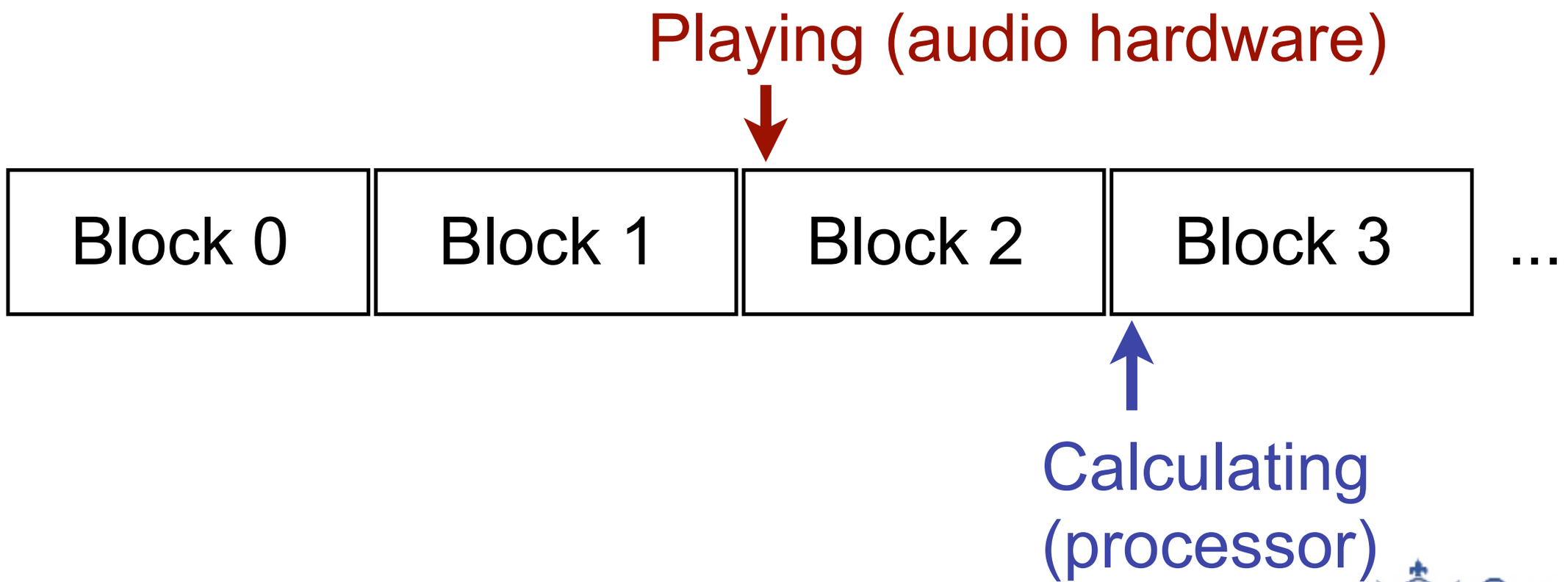
# Block-based processing

- Option #2: Process in blocks of several samples
  - Basic idea: generate enough samples to get through the next few milliseconds
  - Typical block sizes: 32 to 1024 samples
    - Usually a power of 2 for reasons having to do with hardware
  - While the audio hardware is busy playing one block, we can start calculating the next one so it's ready on time:



# Block-based processing

- Option #2: Process in blocks of several samples
  - Basic idea: generate enough samples to get through the next few milliseconds
  - Typical block sizes: 32 to 1024 samples
    - Usually a power of 2 for reasons having to do with hardware
  - While the audio hardware is busy playing one block, we can start calculating the next one so it's ready on time:



# Block-based processing

- Advantages of blocks over individual samples
  - We need to run our function less often
  - We always generate one block ahead of what is actually playing
  - Suppose one block of samples lasts 5ms, and running our code takes 1ms
  - Now, we can tolerate a delay of up to 4ms if the OS is busy with other tasks
  - Larger block size = can tolerate more variation in timing
- What is the disadvantage?
  - Latency (delay)

# Buffering illustration