# Put a Bela On Your Head

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# Disclaimer

I am not the person in this room that knows the most about Bela.

I am probably not the person in this room that knows the most about programming in Pure Data.

If either or both of these things are new to you, totally fine. Please ask questions and interrupt me whenever something doesn’t make sense.

# Today We Will Cover

1. Brief intro to programming with Pure Data

2. Introduce Bela with Pure Data

3. Some spatial audio theory

4. Interactive spatial audio on Bela

# Pure Data Basics

# Pure Data

- Working with Pd-Vanilla (not extended).
  - (This is because that’s what Bela requires.)
- Similar to Max. Kinda.
- Wiki to workshop content: http://bit.ly/soundstack2018

# Working with Bela

# Introducing Bela

- A computer without a screen, mouse, or keyboard with some extra features that make it super friendly with audio.
- Program it by connecting it to another computer with a USB cable.
- Can run from a battery, connect to external sensors, and very importantly prioritises audio over other tasks.
- See www.bela.io for documentation and tutorials.

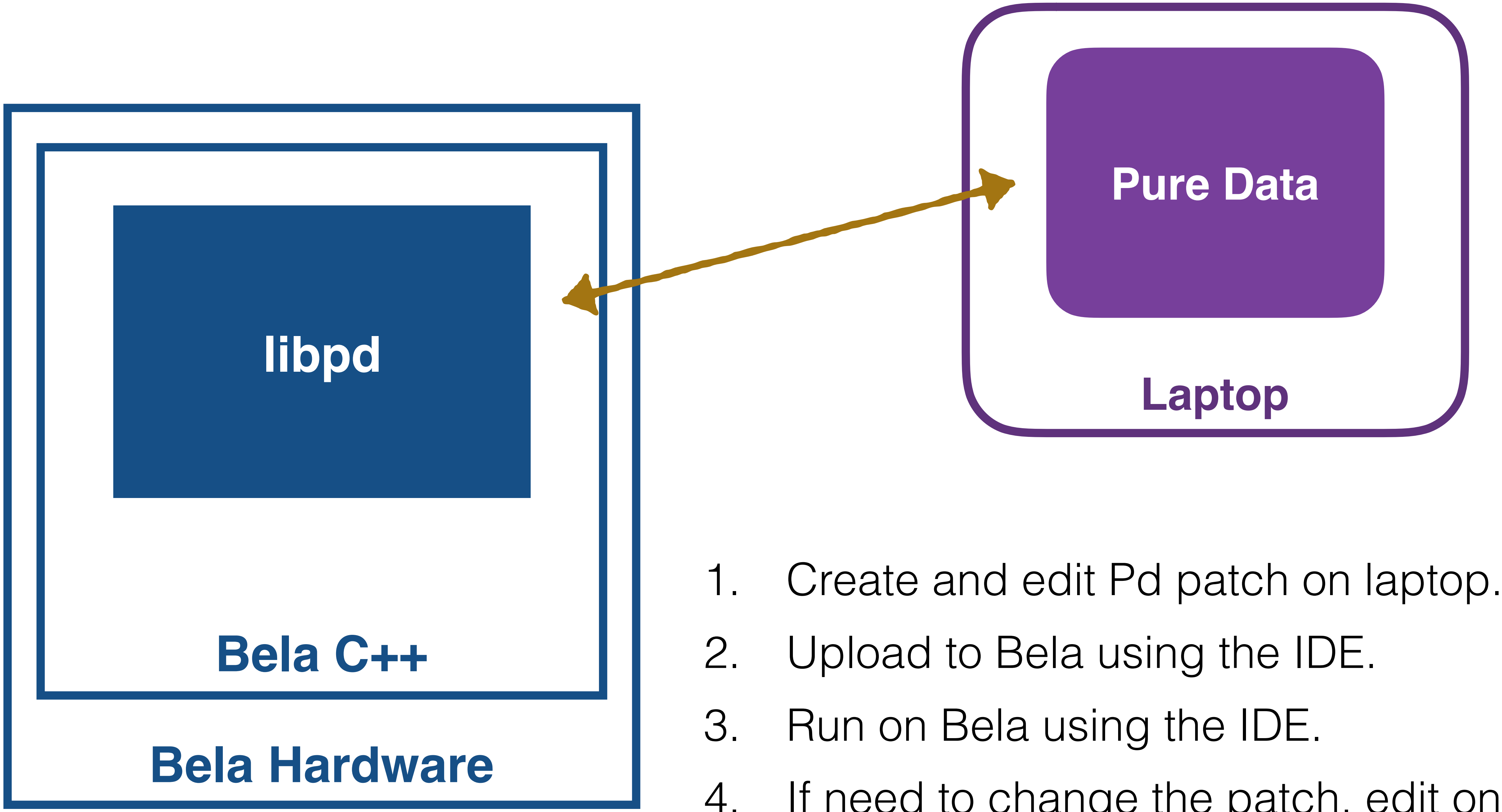
# Turning on Bela

1. Give the Bela a couple minutes to start up after you've given it power with the USB lead.

2. Open up a web browser and go to `192.168.7.2` or `bela.local` instead of a website.

3. This is the Bela IDE, which lets you program and control the Bela. Anything you see here is happening on the Bela, not on your own computer.

# Programming Bela Using Pure Data



1. Create and edit Pd patch on laptop.
2. Upload to Bela using the IDE.
3. Run on Bela using the IDE.
4. If need to change the patch, edit on laptop and repeat process.

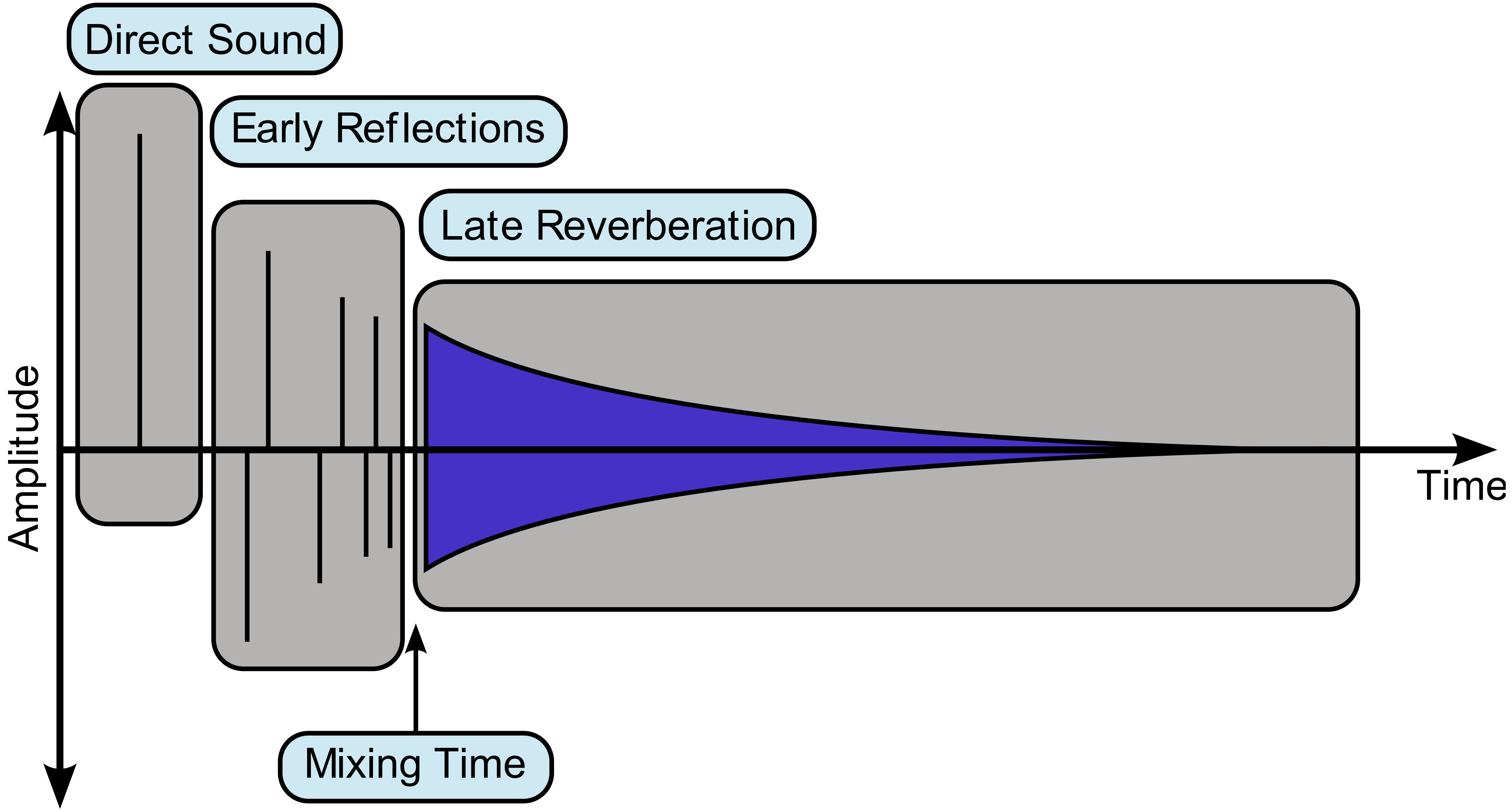
# Spatial Audio and Listening

# Spatial Audio is…

- Physical Science
- Perceptual Psychology
- Cultural Anthropology

(from ‘Spaces Speak, Are You Listening’ by Blesser and Salter)

# How do we locate a sound when we hear it?



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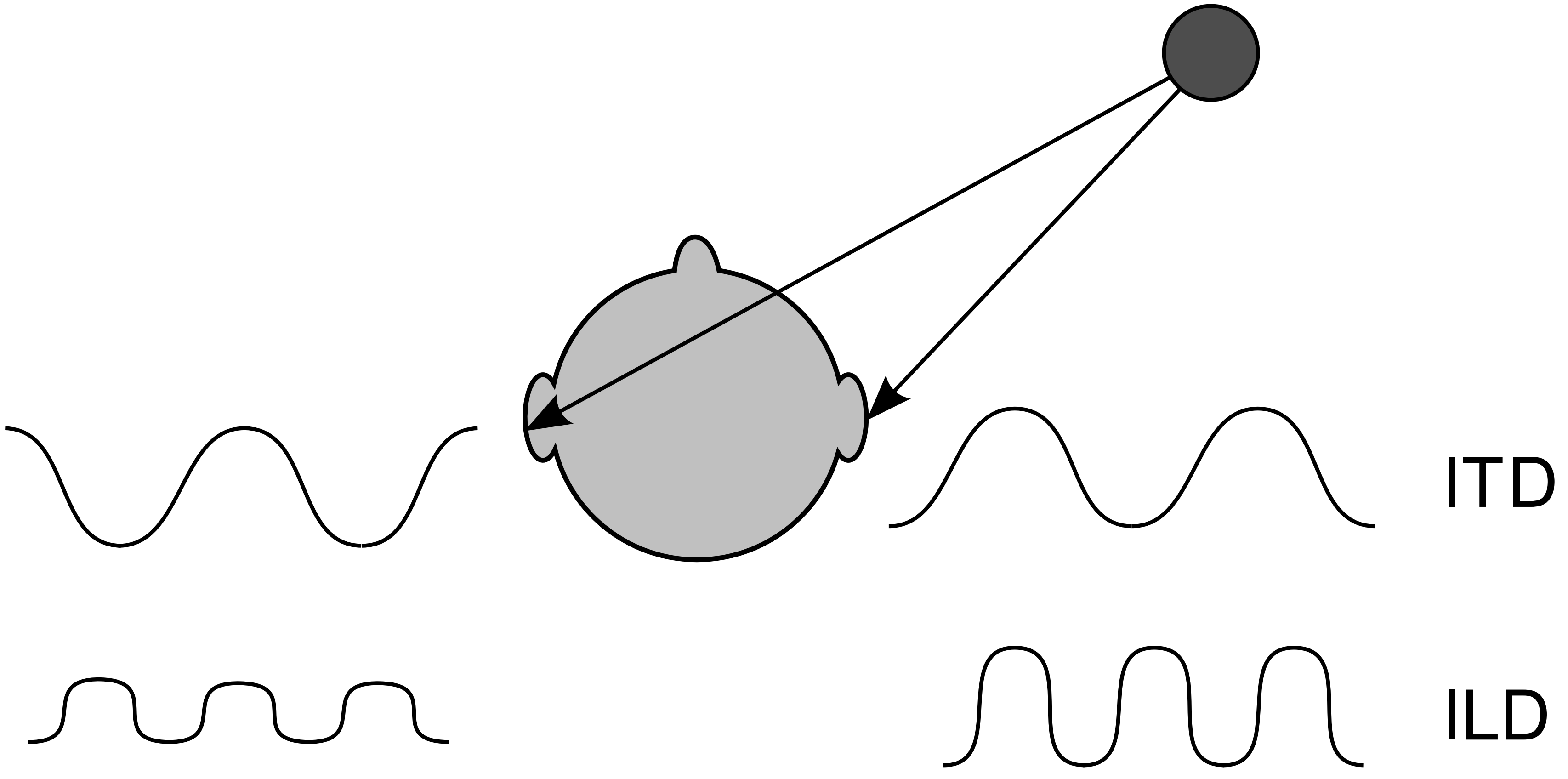
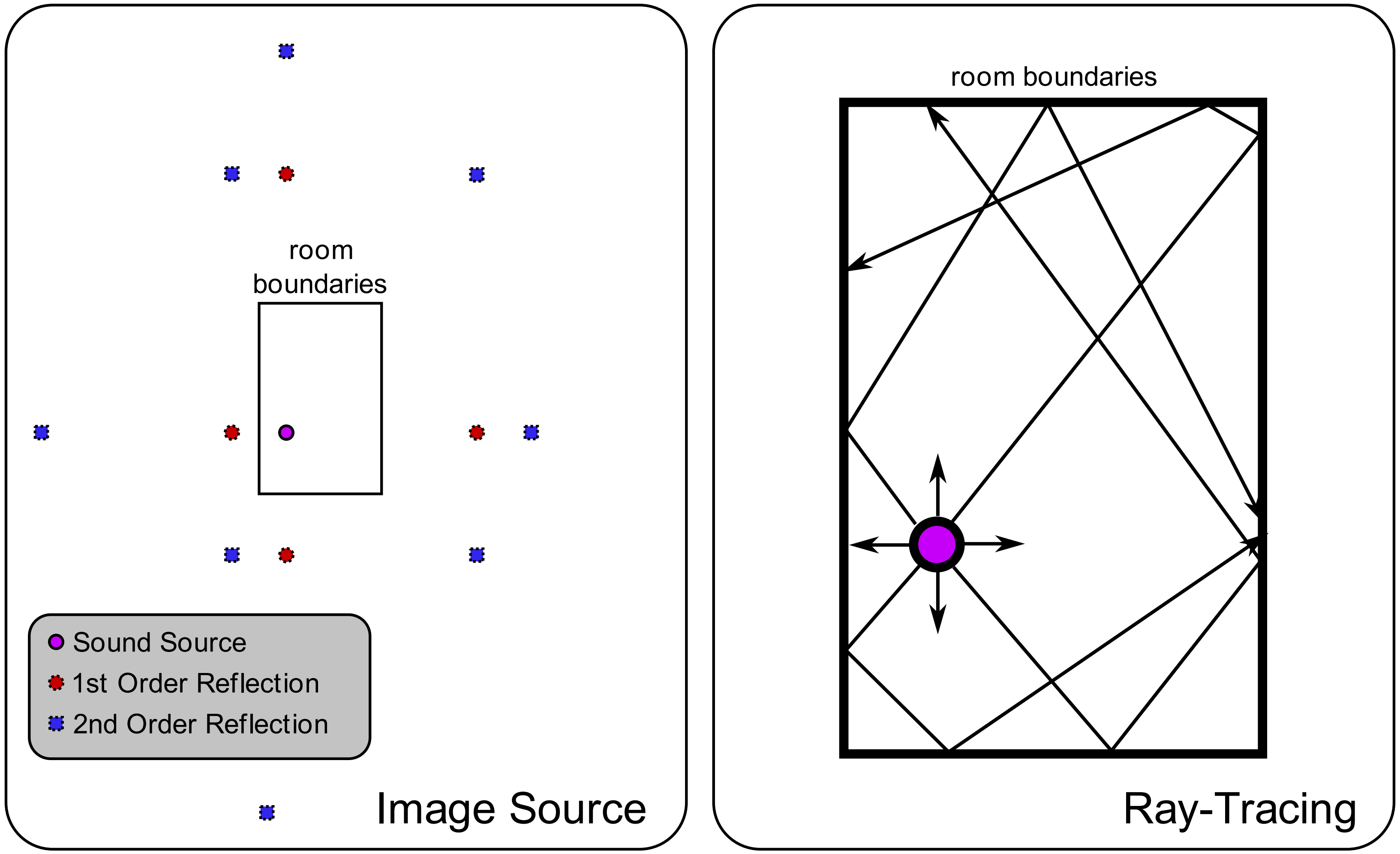


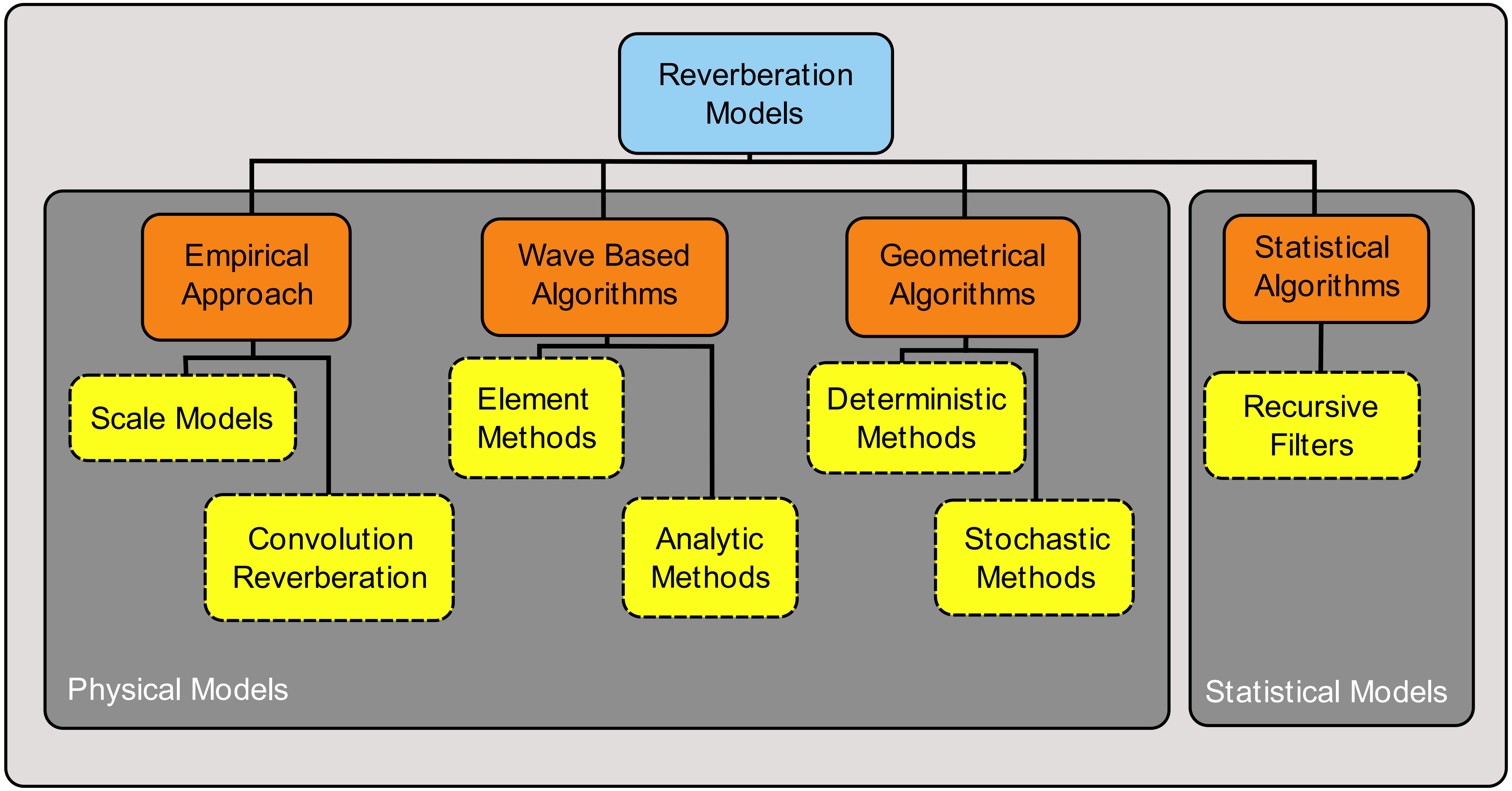
**Direct Sound**

# How do we locate a sound when we hear it?



**Early Reflections**

# How do we locate a sound when we hear it?



**Late Reverberation**

# Spatial Audio in Broadcast/ Recorded Media

- We don’t like the way ambient mics sound, especially with speech.

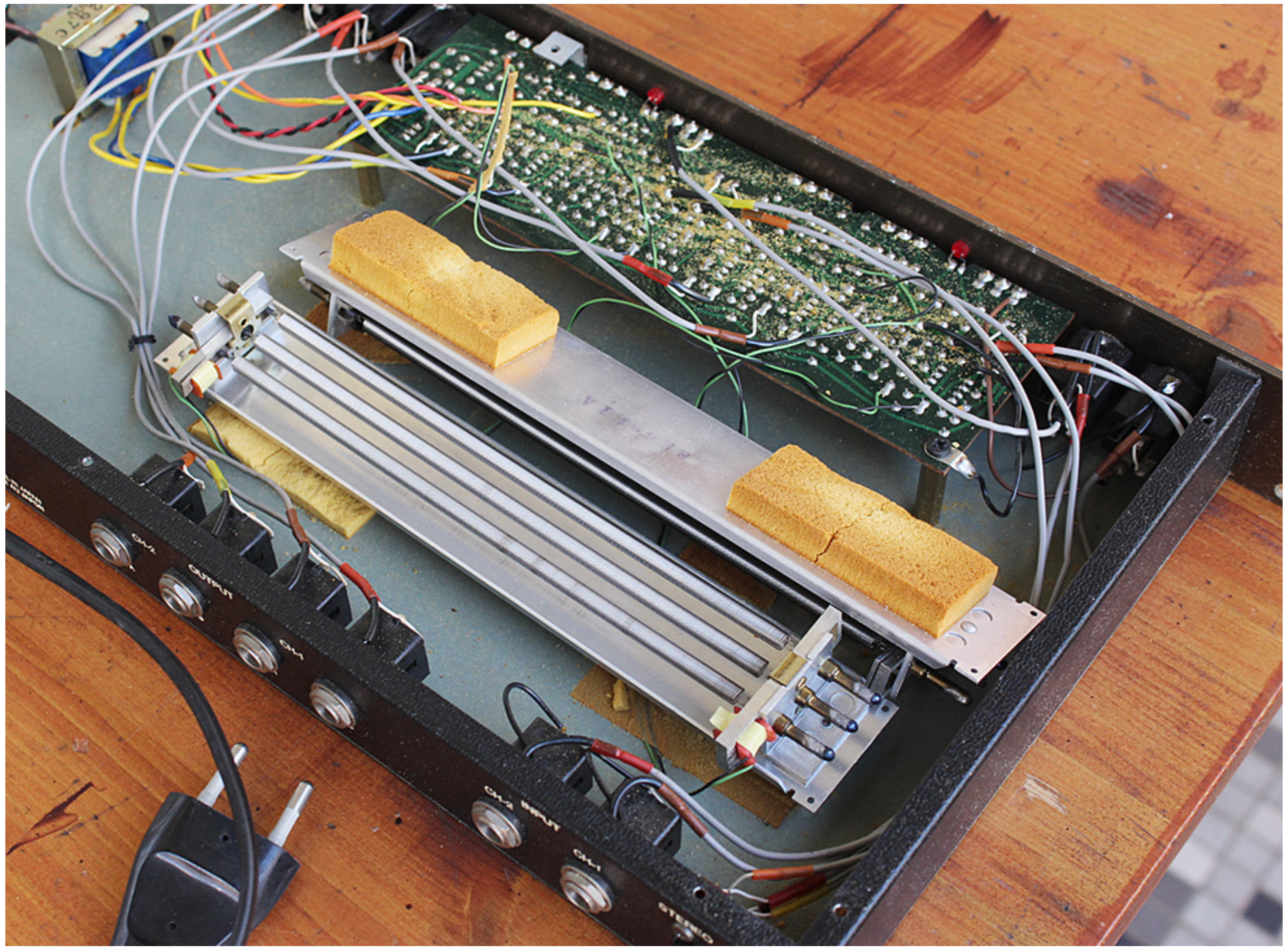
- Close miking provides the solution for removing or controlling those early reflections and late reverberation.

- We don’t like listening to (acoustic) music without room information.

- A century of engineers have worked and continue to work on how reverberation can be added to a dry sound.

# Spatial Audio in Broadcast/ Recorded Media

- A century of engineers have worked and continue to work on how reverberation can be added to a dry sound.

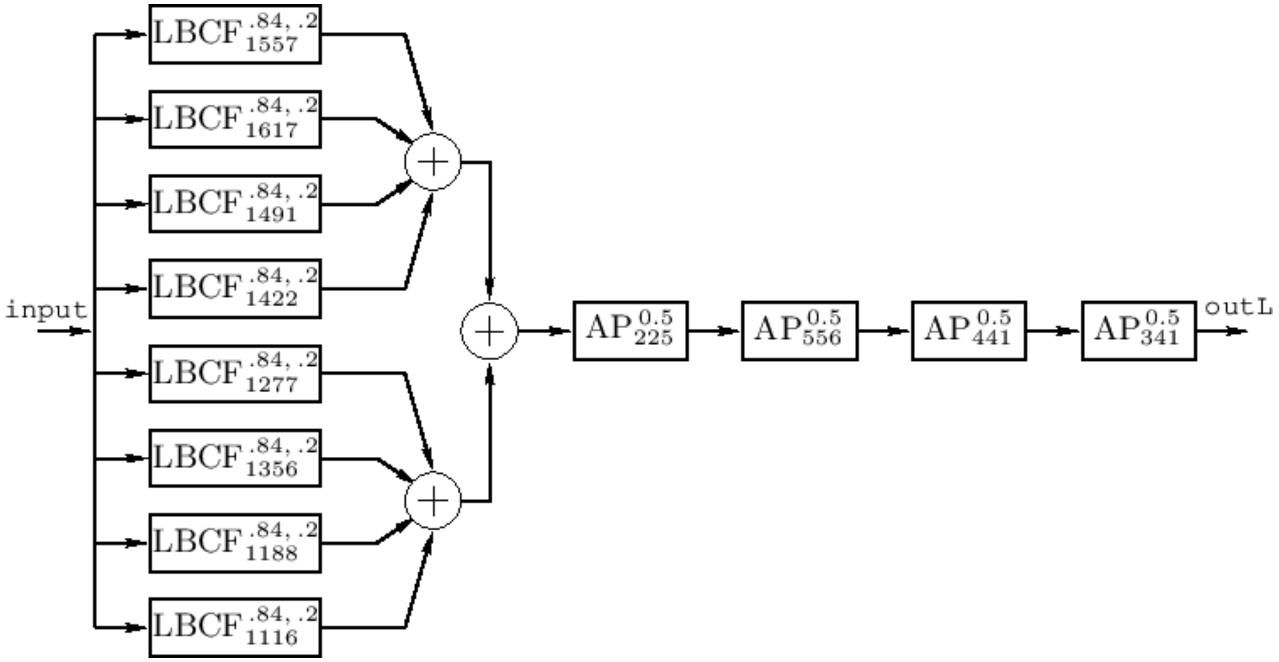


# Simple Reverb with Pure Data

# Freeverb

- Can't just use delay lines for many reasons.
- Freeverb is public domain C++ code
- vfreeverb~ is PD patch by forum user katjav and is available at

http://www.pdpatchrepo.info/hurleur/vfreeverb~alt.pd



input
$\mathrm{LBCF}^{.84,\,.2}_{1557}$
$\mathrm{LBCF}^{.84,\,.2}_{1617}$
$\mathrm{LBCF}^{.84,\,.2}_{1491}$
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+
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$\mathrm{AP}^{0.5}_{225}$
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$\mathrm{AP}^{0.5}_{441}$
$\mathrm{AP}^{0.5}_{341}$
outL

# Working with an Inertial Measurement Unit

# IMUs

- Contains multiple sensors: magnetometer; accelerometer; gyroscope.
- The data from the different sensors are combined to give some higher level information - this process is called sensor fusion.
- The sensor fusion algorithm needs to deal with drift and calibration issues. This is not easy!
- We are using the BNO055 by Bosch on a breakout board by Adafruit. The chip does all the hard work for us (though we also don't know exactly what it's doing).

# IMUs

- We are using the BNO055 by Bosch on a breakout board by Adafruit. The chip does all the hard work for us (though we also don’t know exactly what it’s doing).

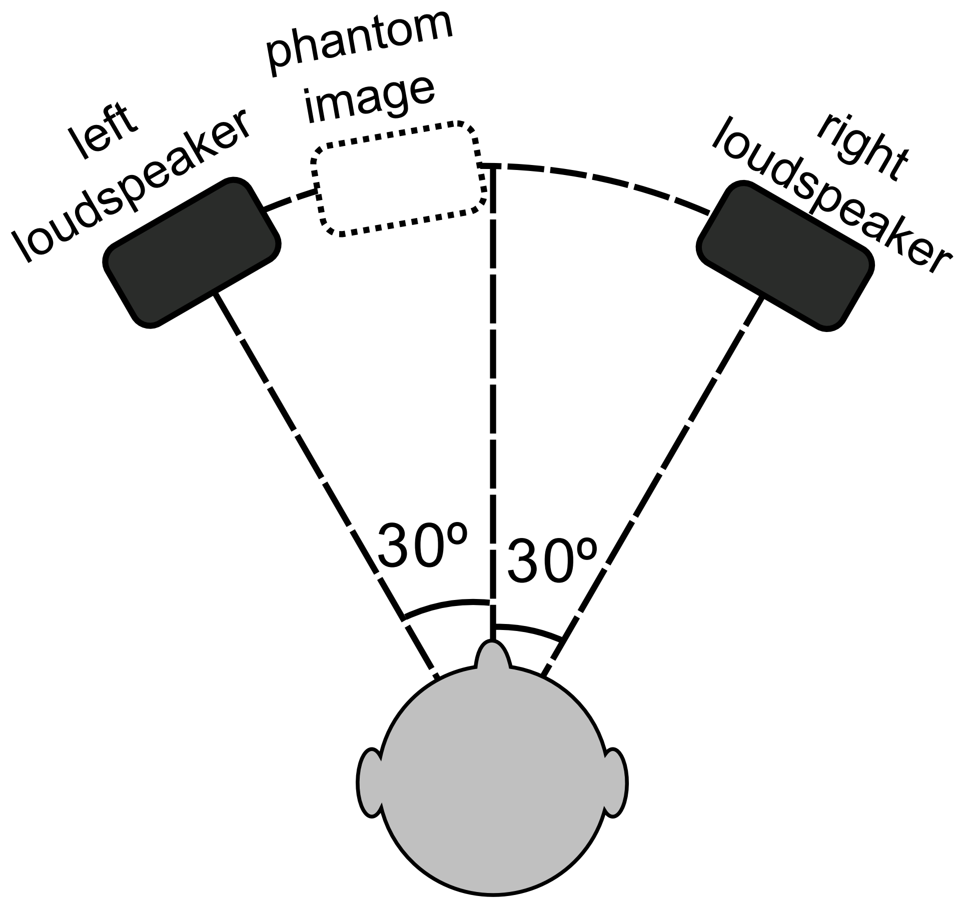
- This sensor was selected as it had good performance in a study was recently published with the AES.

    - The study’s source code available online as MrHeadTracker - https://git.iem.at/DIY/MrHeadTracker/wikis/home

# Stereo Panning with Pure Data

# Panning

- Making a sound appear to be located in between multiple speakers.
- Lots of approaches, even for only two speakers.



# Binaural Audio

# Beyond Stereo to Binaural

- Binaural means that the filtering effects of the head and maybe torso are included in the audio.

- Ideally the audio sounds like it is from outside the head, not between the ears.

- Stereo panning simulates ILD and/or ITD, it doesn’t directly change

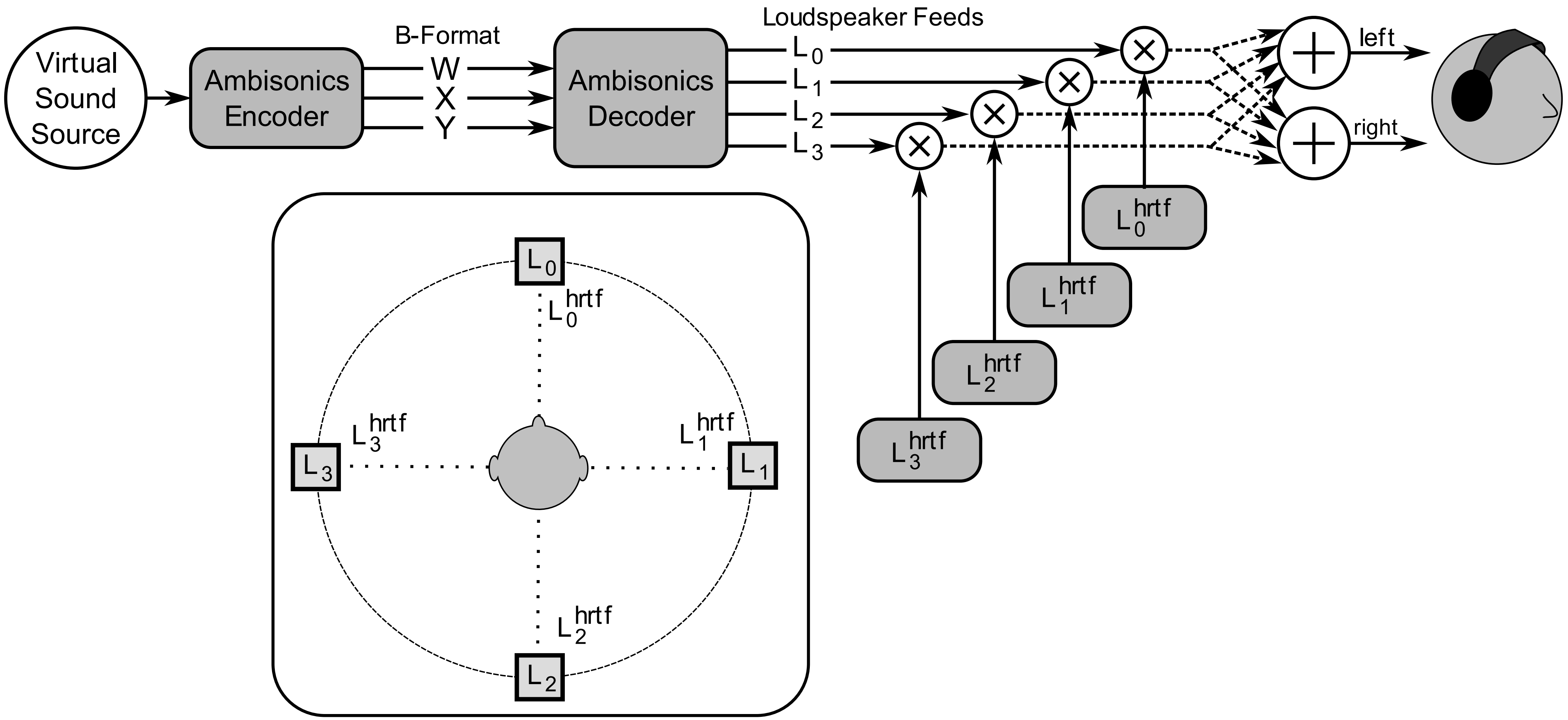
# Binaural Rendering

- Direct method is to convolve HRTF/HRIR with mono sound.
- Computational load increases with each additional source.
- Need to decide how to handle source locations where you haven’t empirically measured an HRTF.

# Binaural Rendering

- Instead of convolving a sound source with an HRTF, convolve a loudspeaker feed with an HRTF.
- (Mostly) decouples the computational load from the number of sound sources.
- Use whatever panning method you’d like to determined the audio fed to each virtual loudspeaker.

# Virtual Ambisonics



# Virtual VBAP

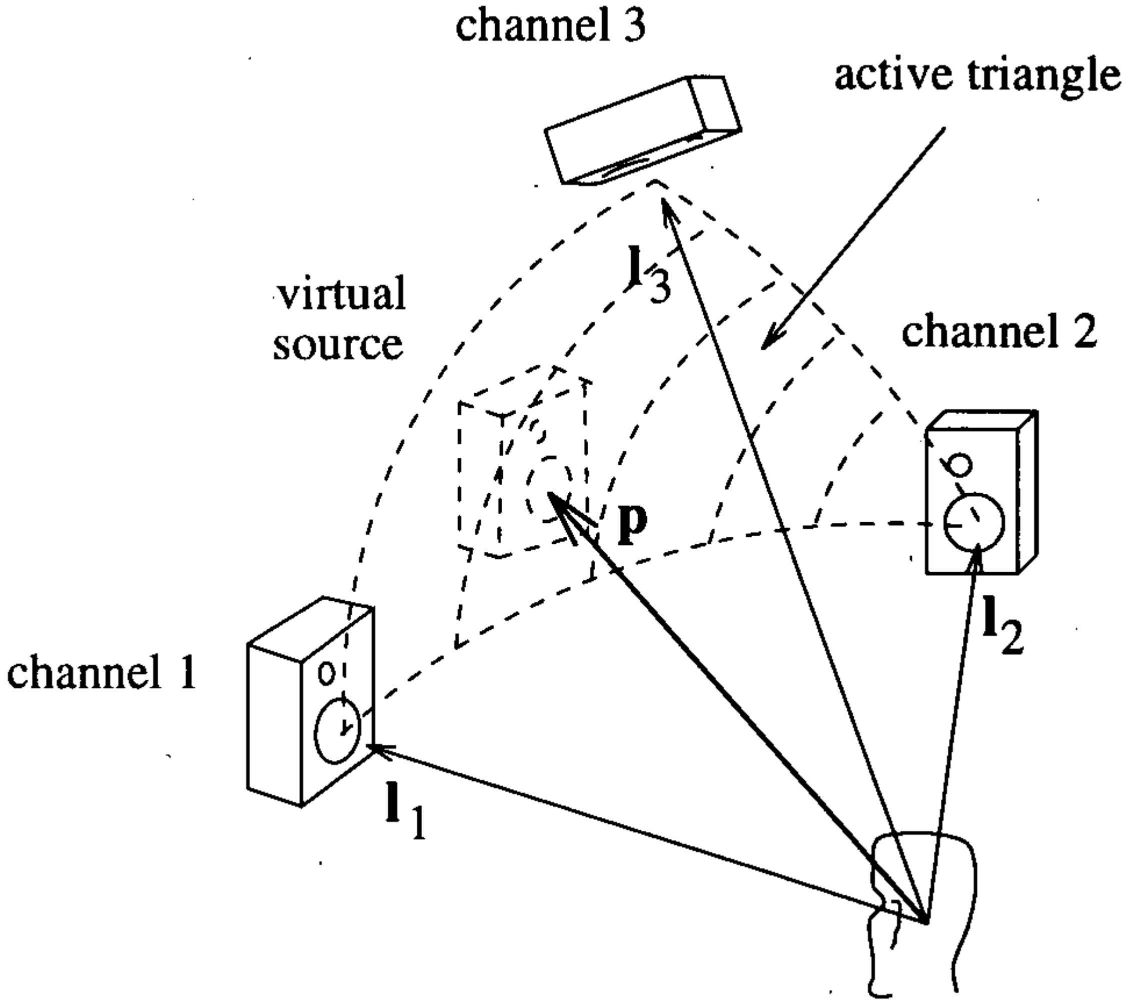
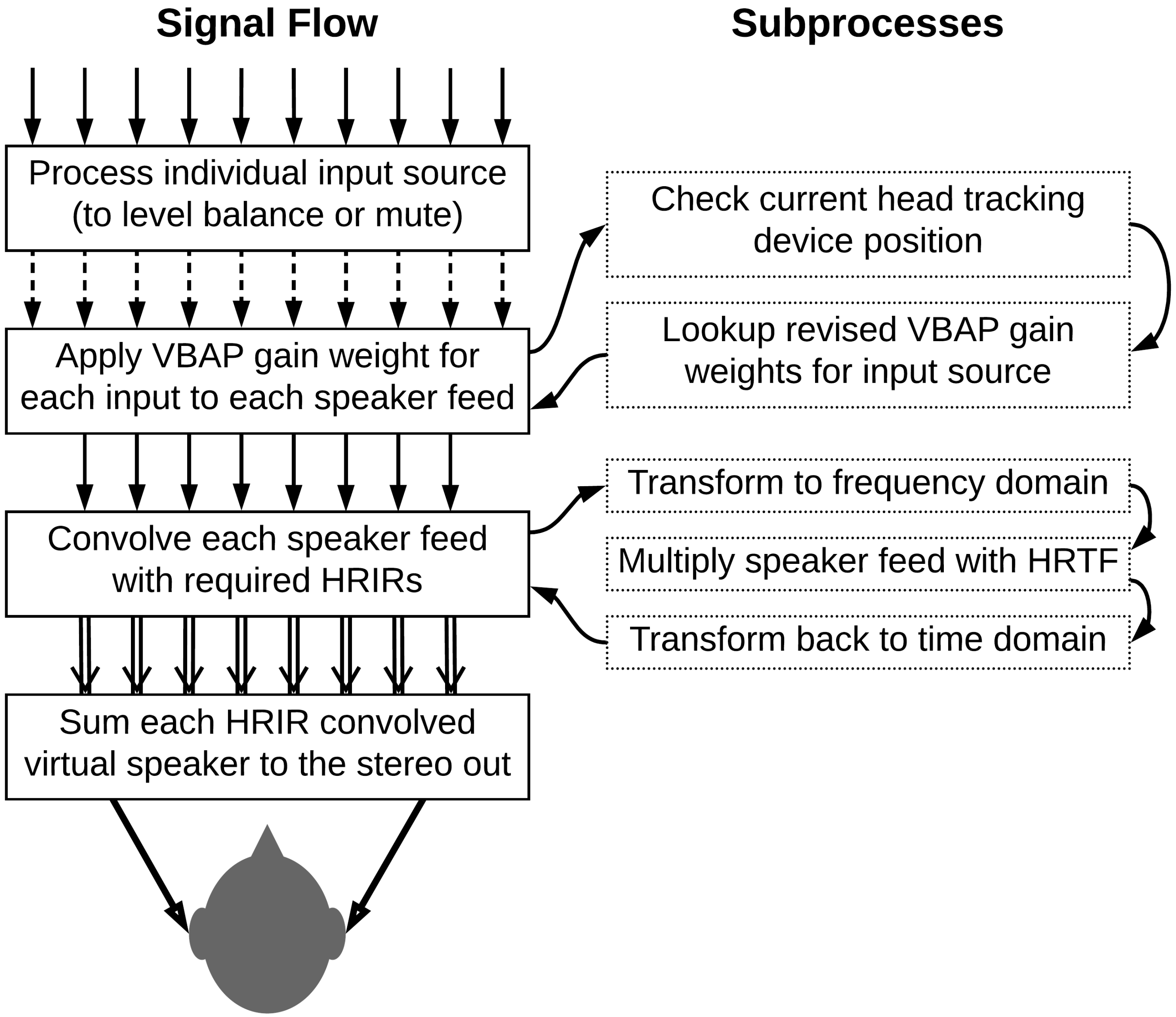


Image by Ville Pulkki



**Signal Flow**

**Subprocesses**

Process individual input source (to level balance or mute)

Apply VBAP gain weight for each input to each speaker feed

Convolve each speaker feed with required HRIRs

Sum each HRIR convolved virtual speaker to the stereo out

Check current head tracking device position

Lookup revised VBAP gain weights for input source

Transform to frequency domain

Multiply speaker feed with HRTF

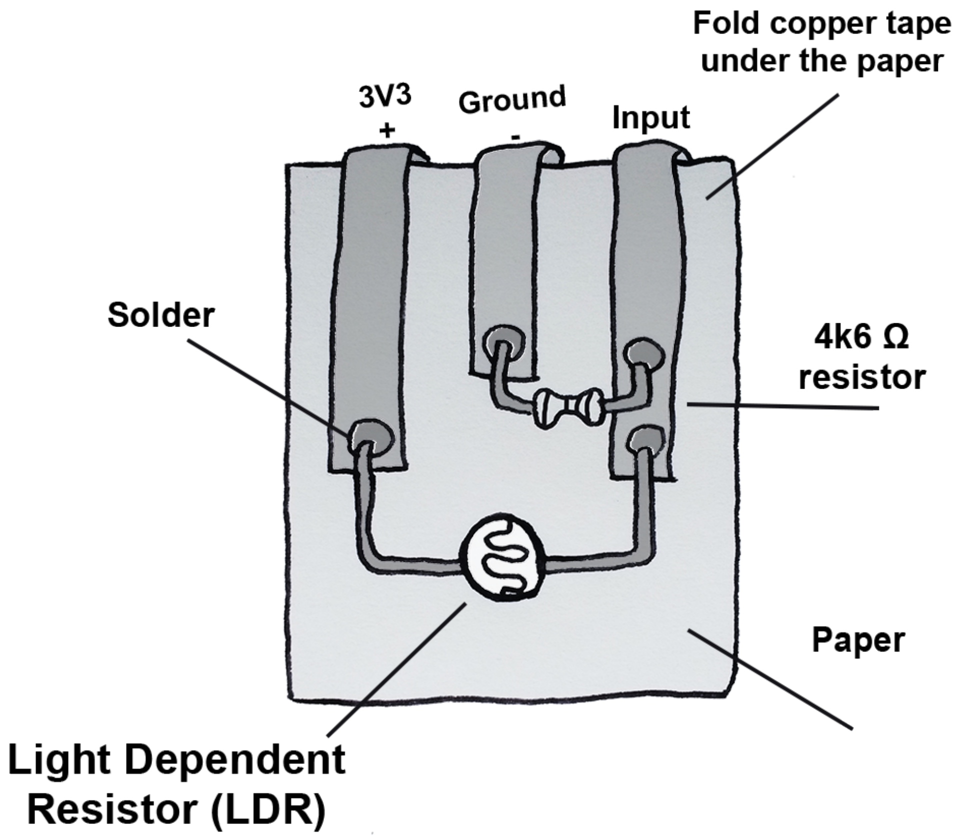
Transform back to time domain

Image by Rishi Shukla

# Sensors for Interactivity

# Selection of Paper Sensors

- Tutorials online


Fold copper tape under the paper
3V3
+
Ground
-
Input
Solder
4k6 Ω resistor
Paper
Light Dependent Resistor (LDR)