

Harvard



Yá'át'ééh 

EASI-22

Edge AI Summer  
Institute 2022

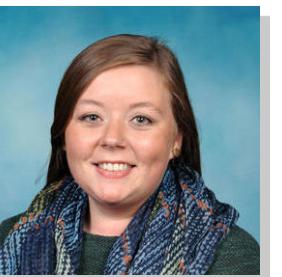
with Navajo Tech

# Hi! I'm Brian!

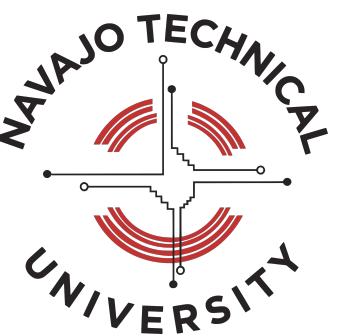
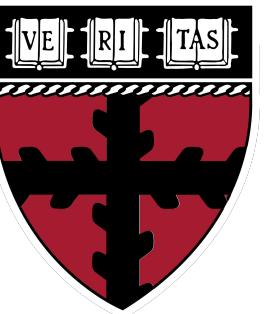
I'm an Assistant Professor of Computer Science  
at **Barnard College, Columbia University**



# Our team!



with help from **many more**



# Our website!

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[tinyMLEdu.org/EASI-22](https://tinyMLEdu.org/EASI-22)

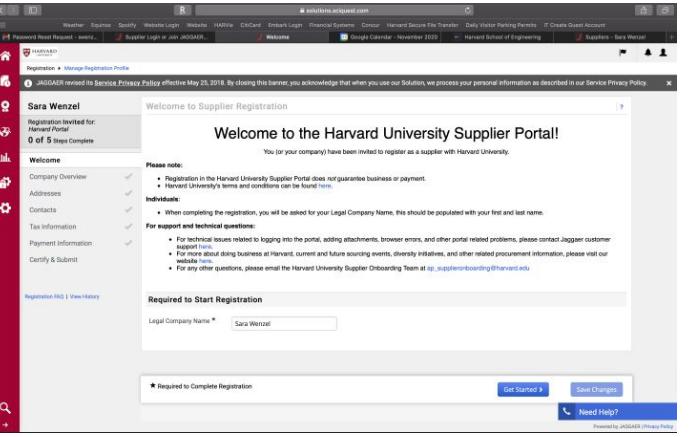
home base for **all information!**

# Make Sure to Pick Up an Arduino Kit!



Question? Contact:  
**Monsuru Ramoni**  
**[mramoni@navajotech.edu](mailto:mramoni@navajotech.edu)**

# Teachers Sign up for Buy2Pay



Question? Contact:  
**Molly Marshall**  
**mmarshall@seas.harvard.edu**

# Workshop Agenda

Day 1

Introduction to AI and (Tiny)ML

Cloud ML

Day 2

Keyword Spotting for the Navajo Language

Mobile ML

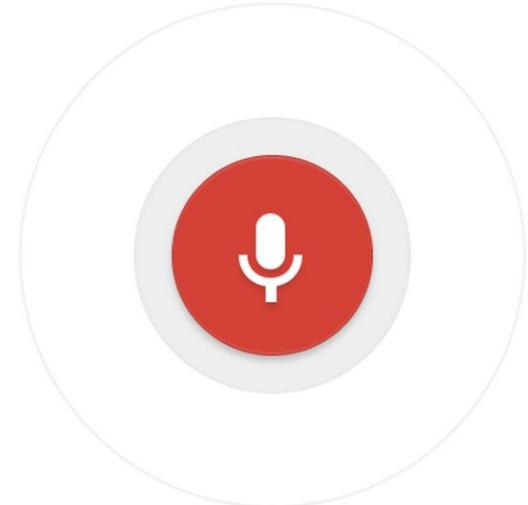
Day 3

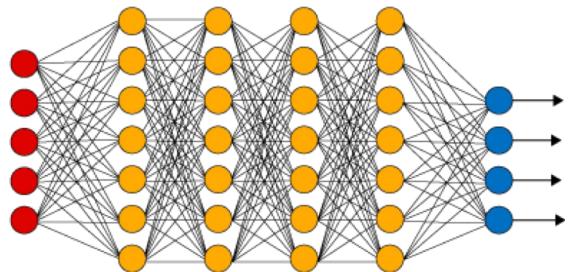
Bringing AI/ML from the Cloud to the Edge

Embedded ML

# Keyword Spotting in One Slide

If we **pick a simple task** to only identifying a **few key words** we can then use a **small model** and train it with **little data** and fit it onto an **embedded device**





# By the end of today: **Hands-on Keyword Spotting (KWS)**

We will explore the **science** behind KWS and **collect data** and **train** our own custom model to recognize “yes” vs. “no” using **Edge Impulse**

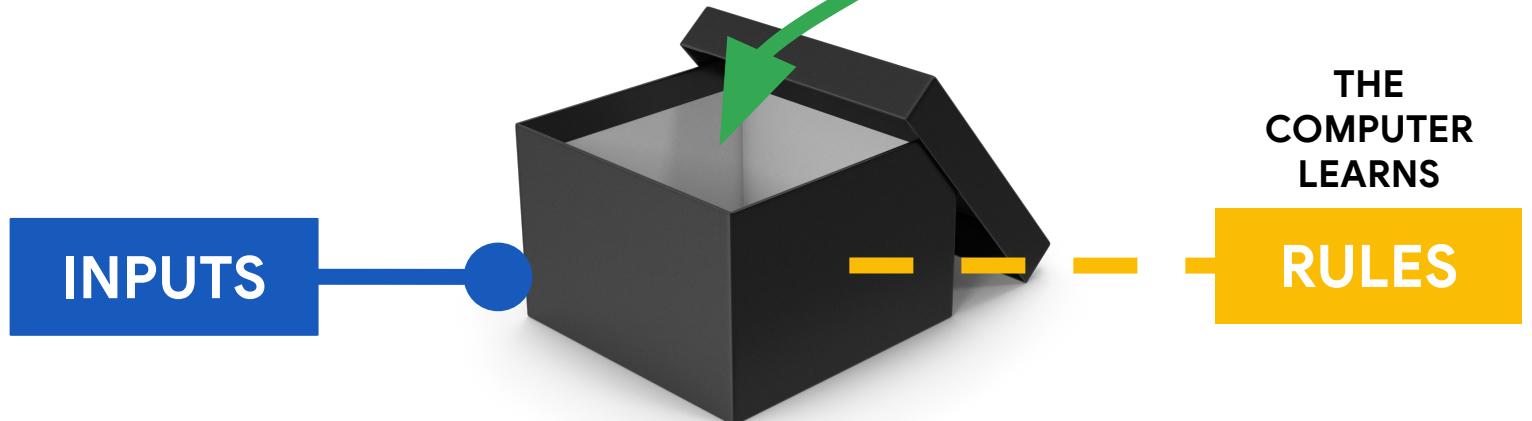
# Today's Agenda

- Preprocessing for Keyword Spotting
- Convolutional Neural Networks for Image Classification
- Hands-on: KWS Data Collection with Edge Impulse
- Hands-on: Training our Model with Edge Impulse
- Hands-on: Testing our Model in the Real World
- Summary

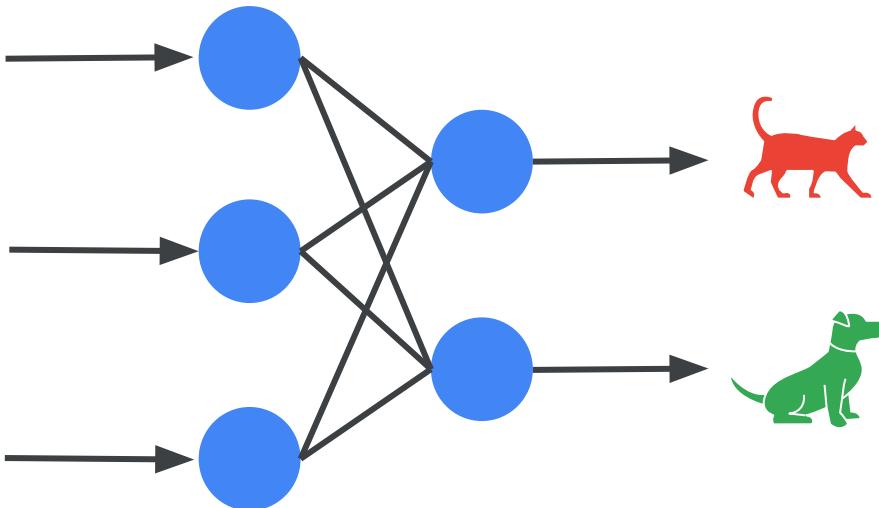


But before we  
dive into all of  
that – a little  
quick review!

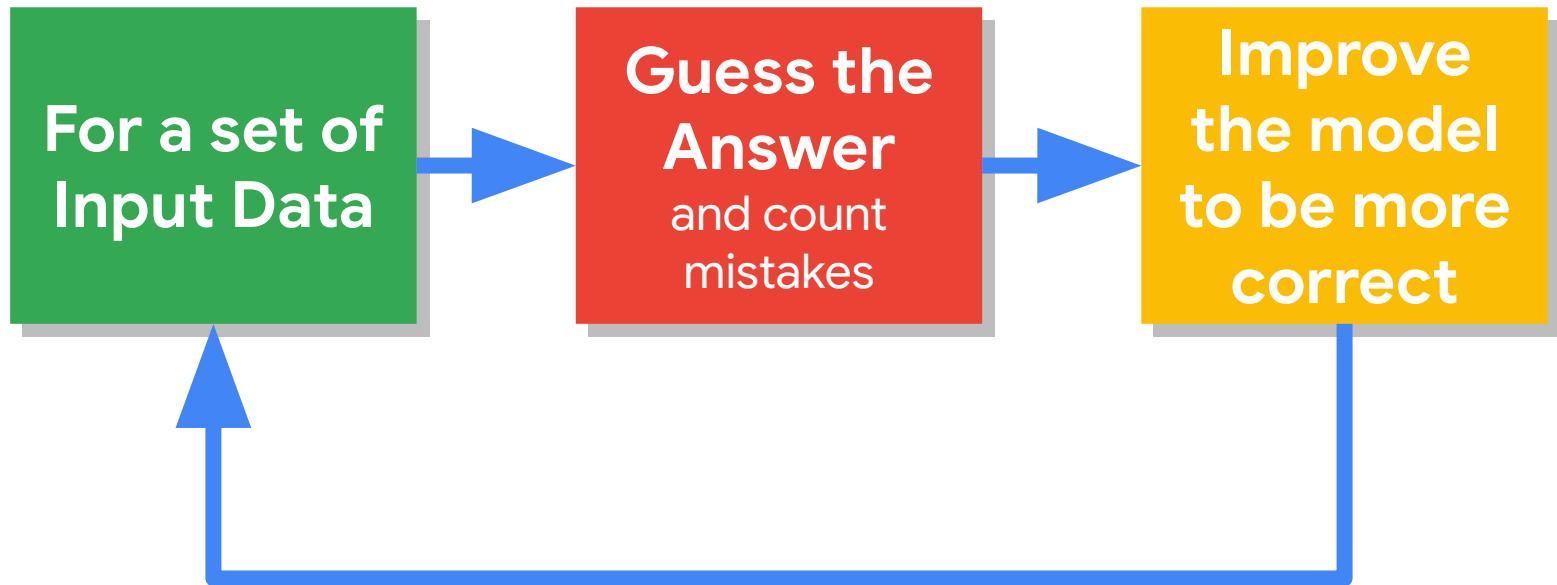
# Machine Learning



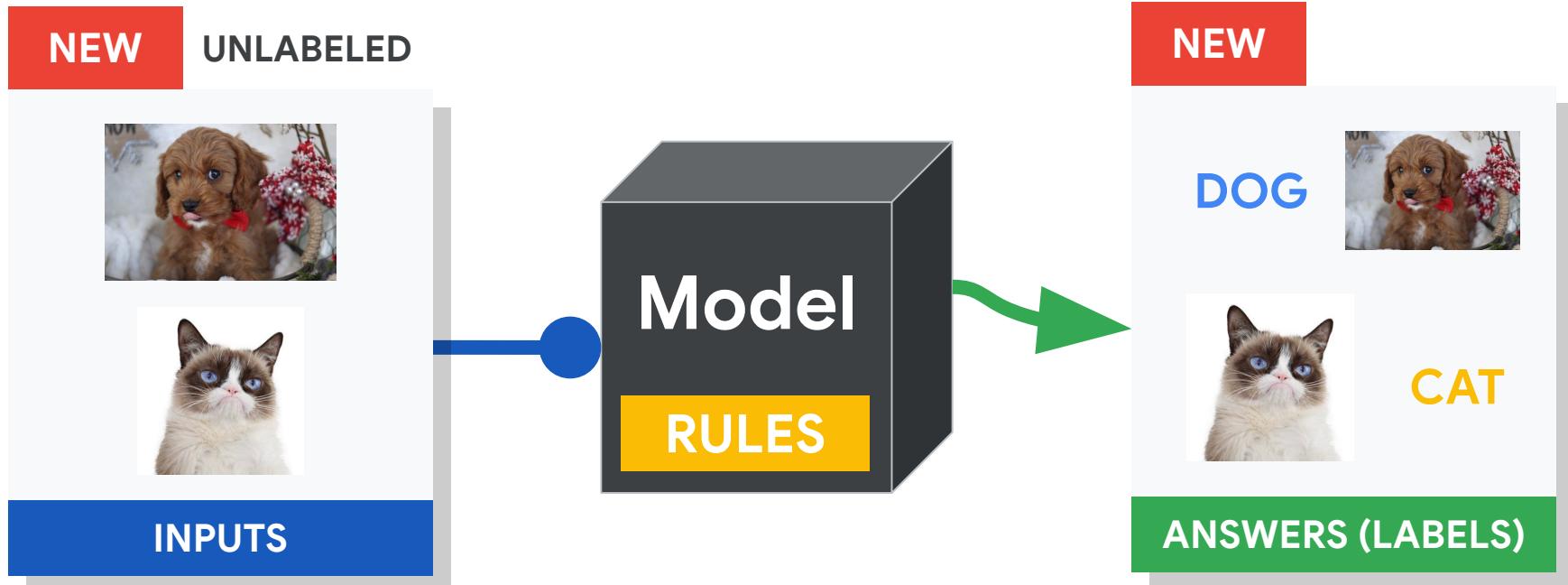
# Machine Learning with **neural networks**?



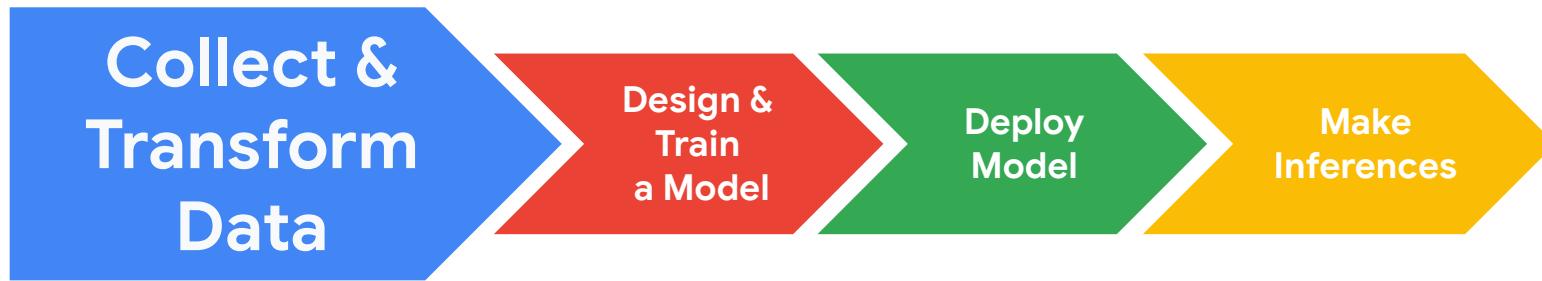
# Training the machine



# After it's learned use it for inference:



# The (Tiny) Machine Learning Workflow

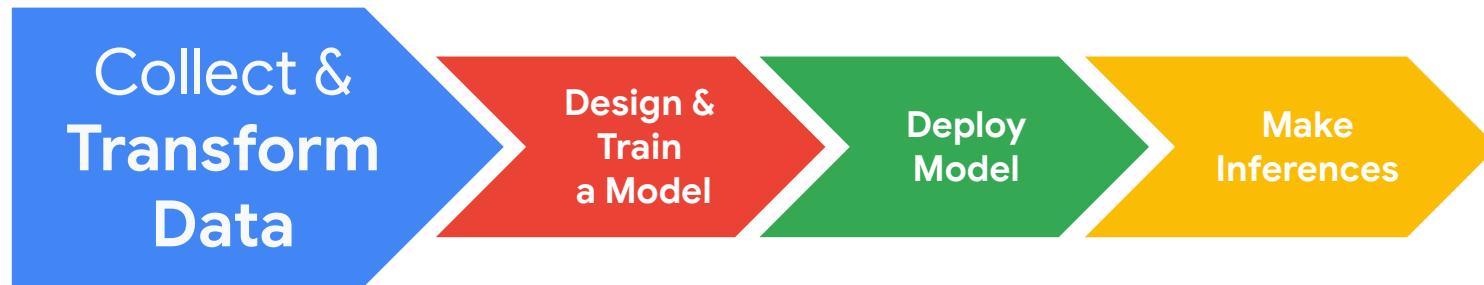


If ML is going to be everywhere  
we need to consider how to best  
collect **GOOD** data **RESPONSIBLY**

# Today's Agenda

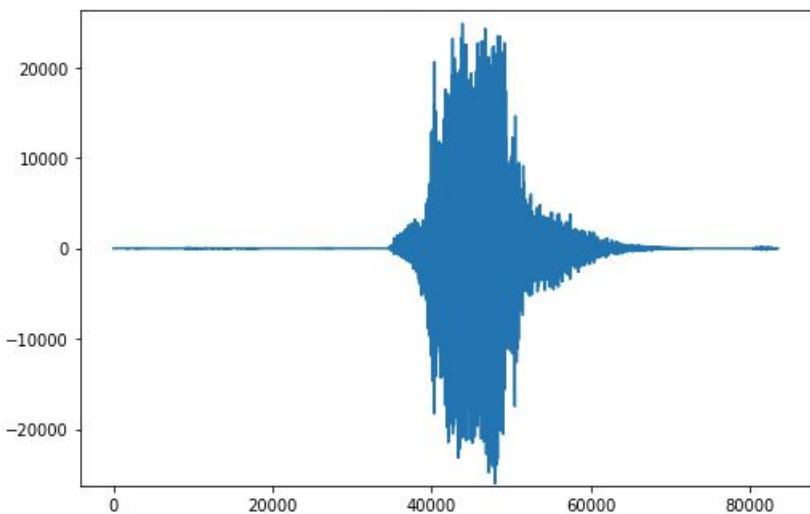
- Preprocessing for Keyword Spotting
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  - Summary

# Machine Learning Workflow



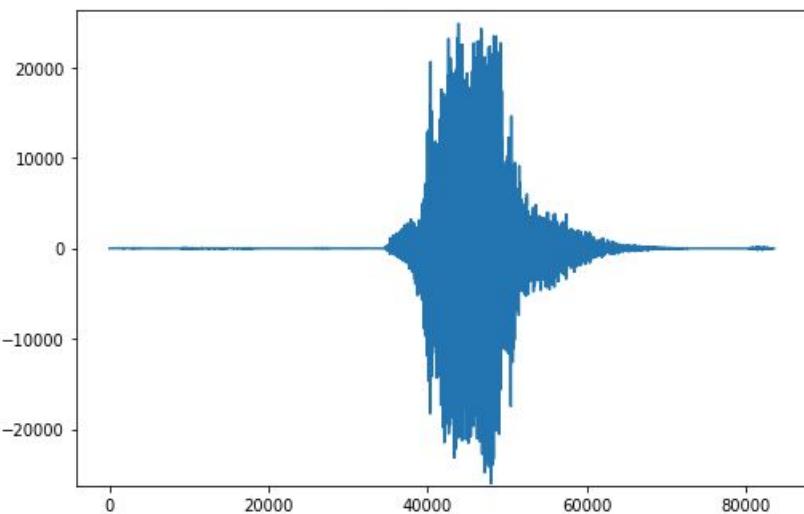
# This is an audio signal

**“Yes”** (*spoken loudly*)

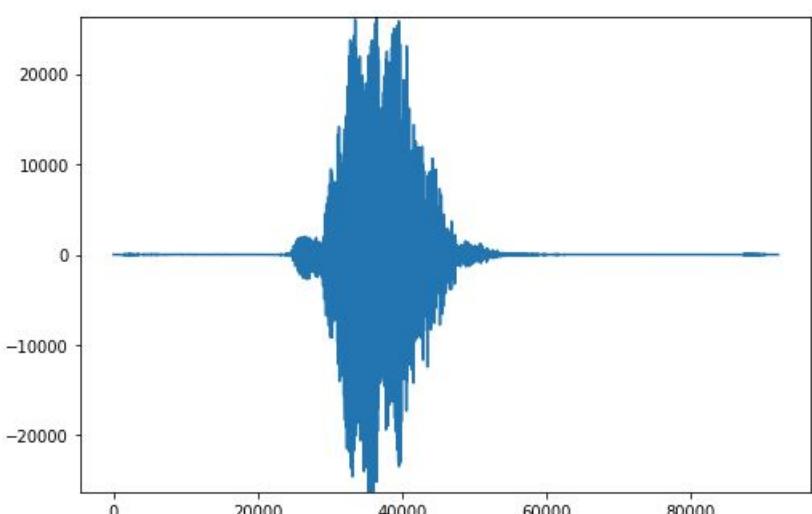


# Can you tell these two signals apart?

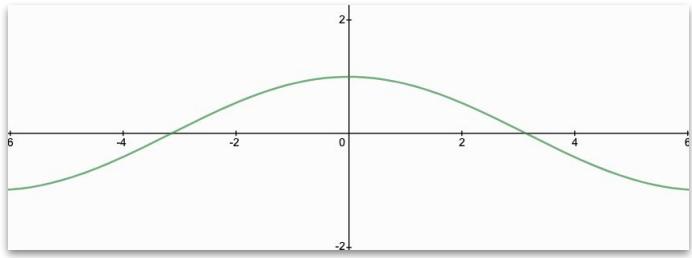
“Yes” (*spoken loudly*)



“No” (*spoken loudly*)

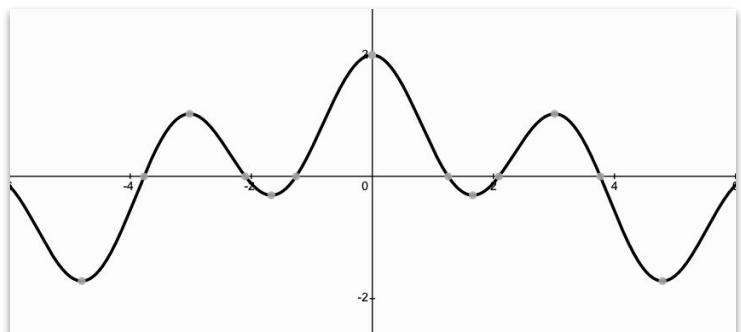
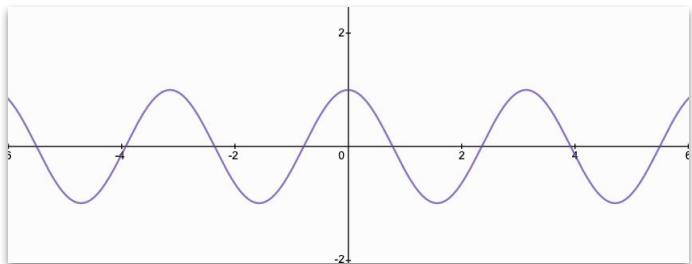


# Signal Components?



+

=



# Signal Components?

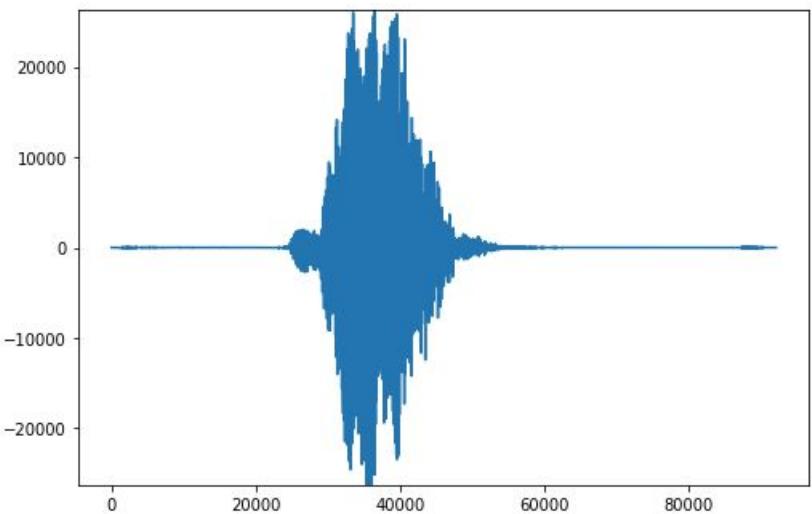
?

+

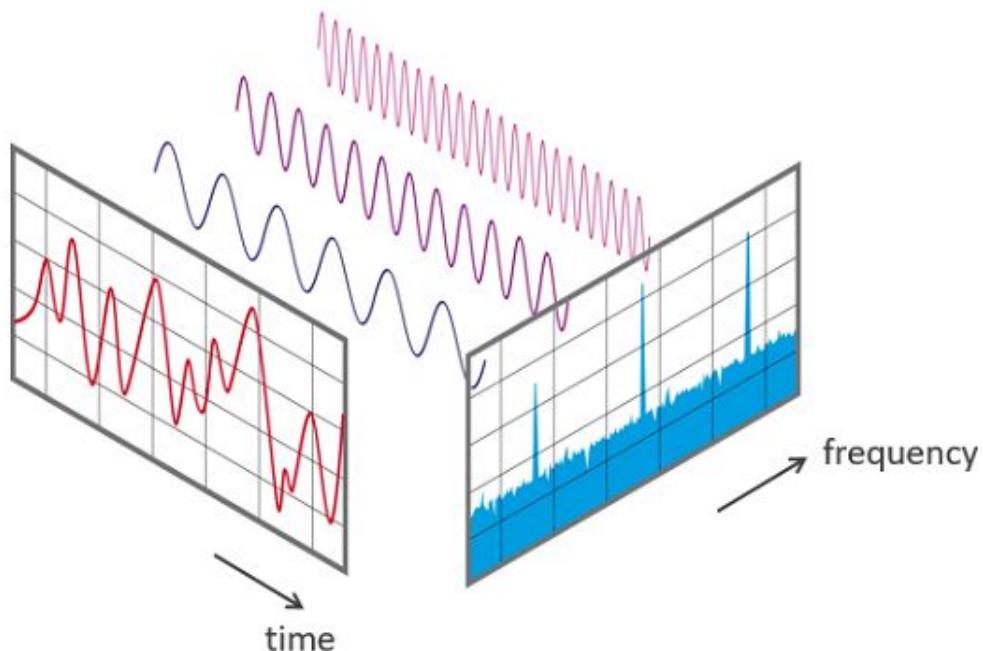
?



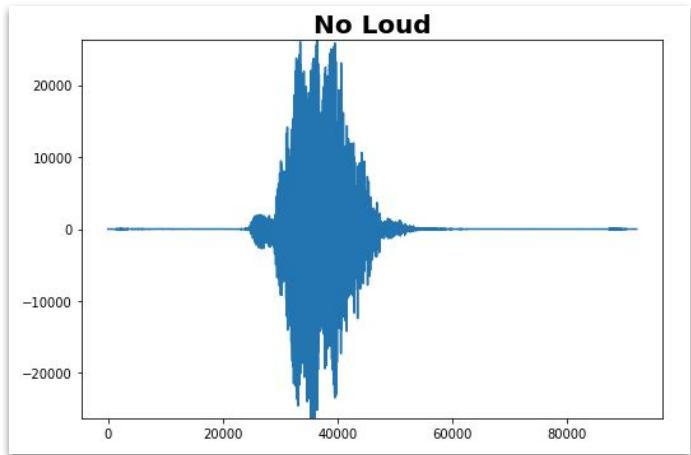
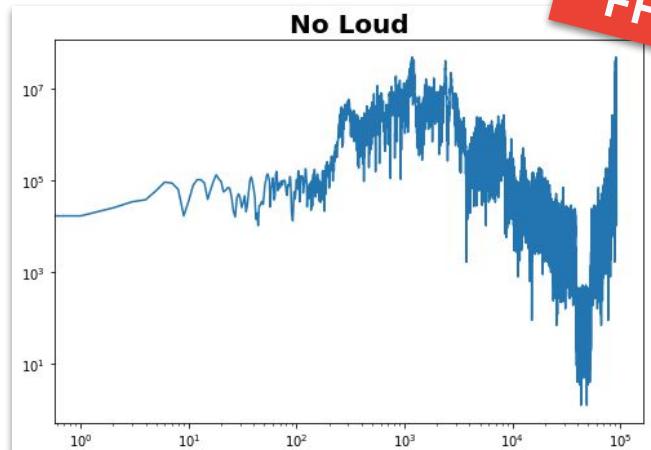
“No” (*spoken loudly*)



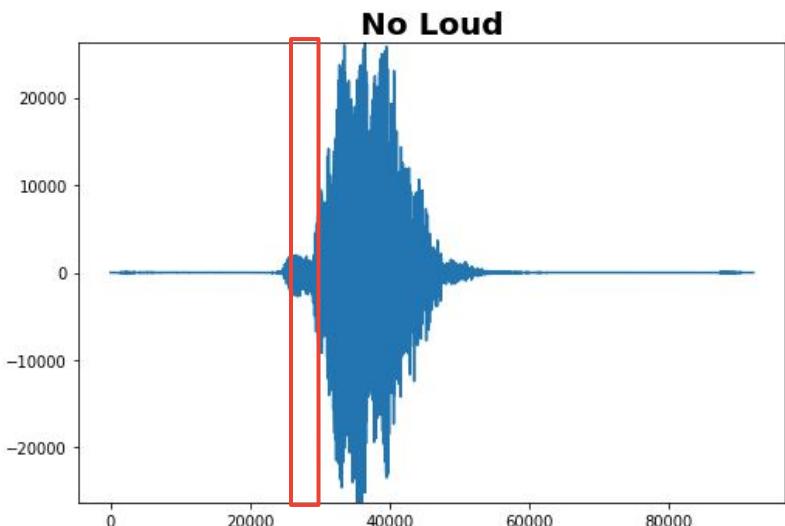
# Fast Fourier Transform: extract the frequencies from a signal



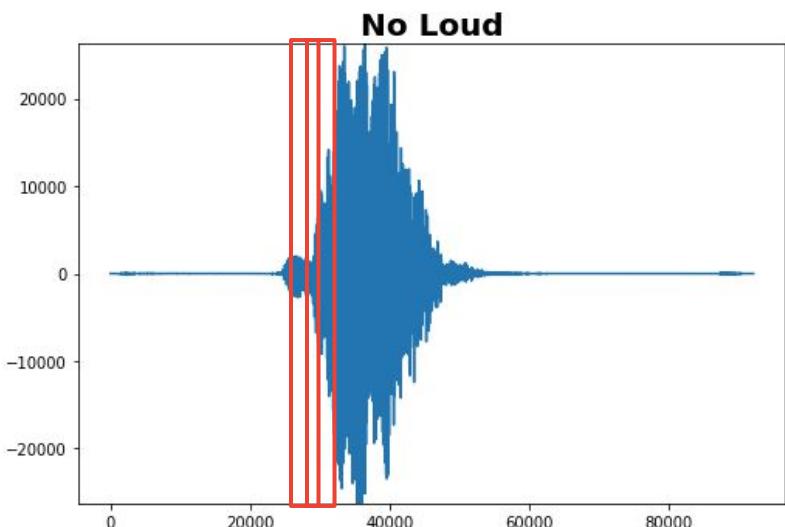
# Fast Fourier Transform



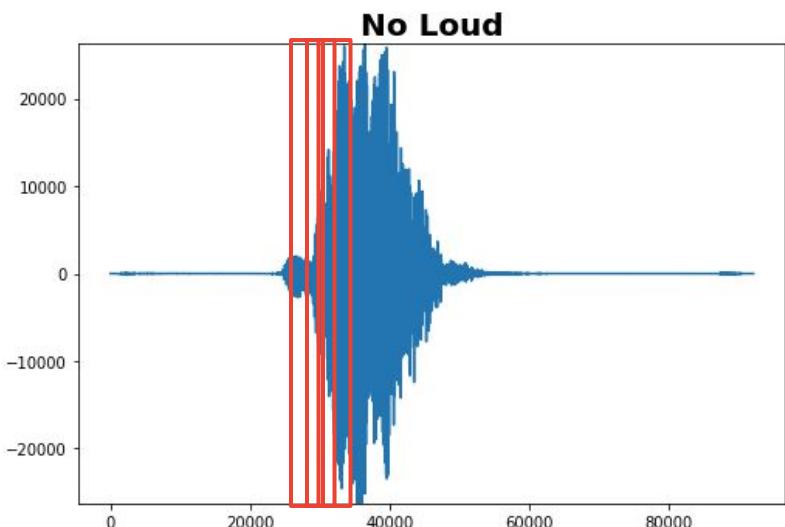
# Building a **Spectrogram** using FFTs



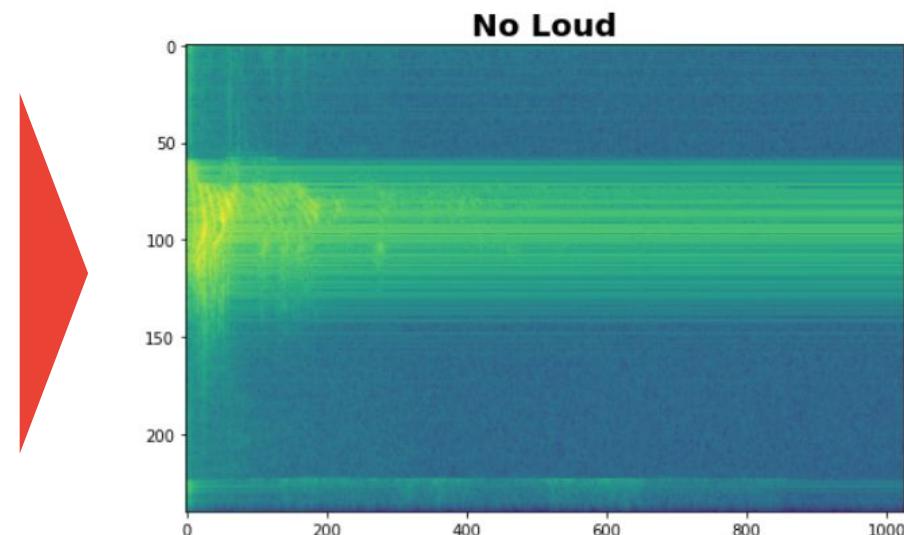
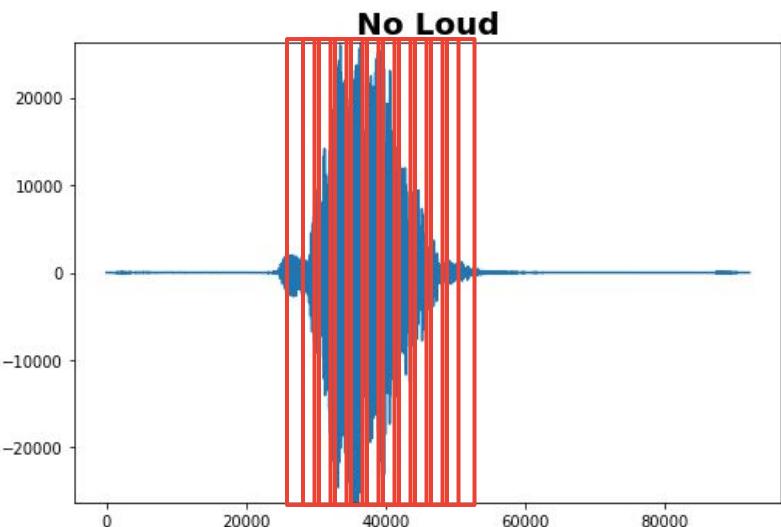
# Building a **Spectrogram** using FFTs



# Building a **Spectrogram** using FFTs

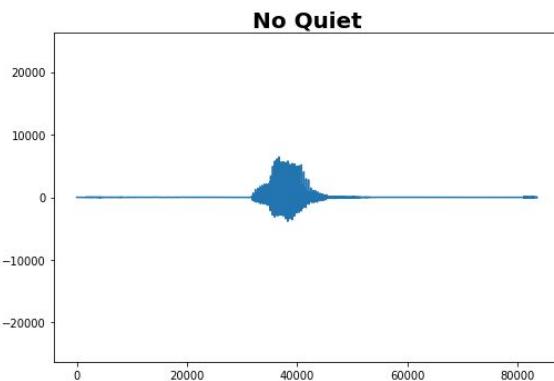
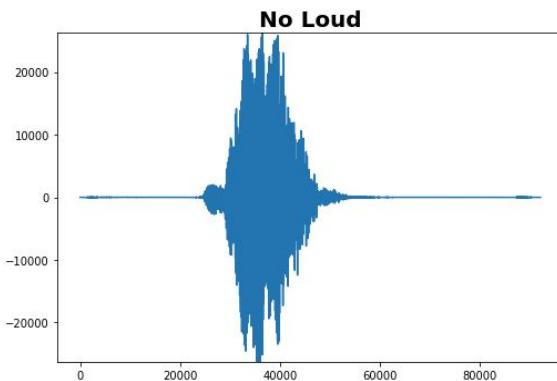
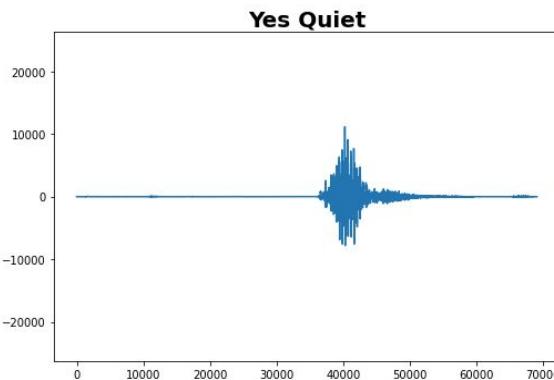
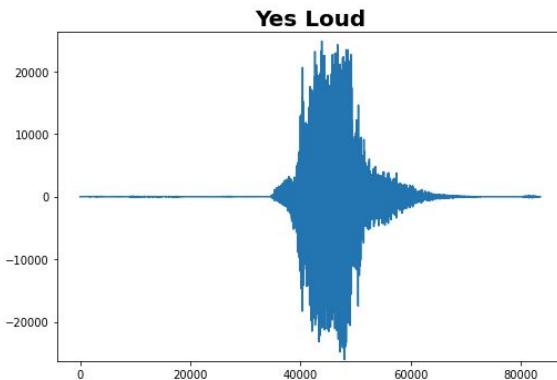


# Building a **Spectrogram** using FFTs

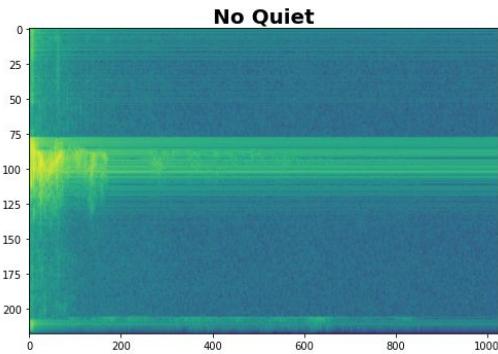
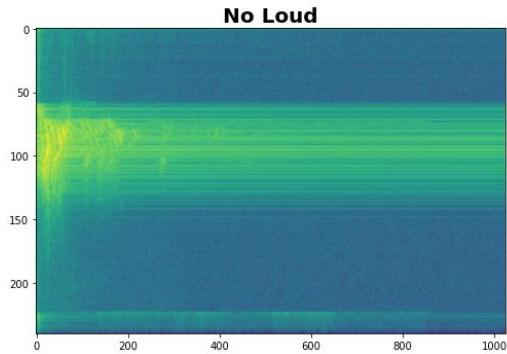
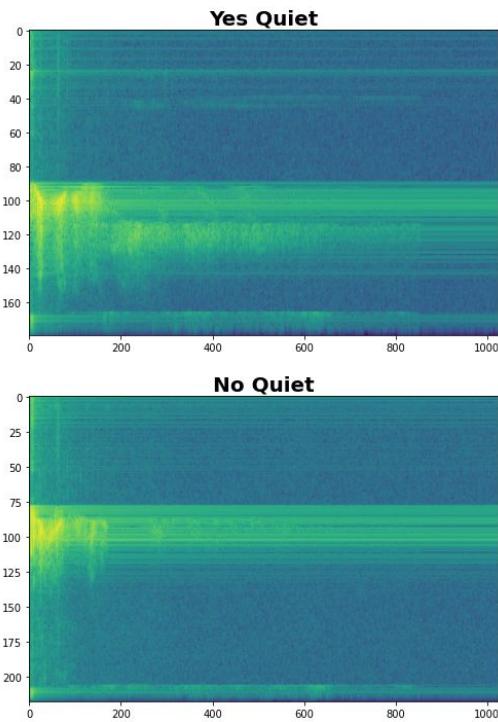
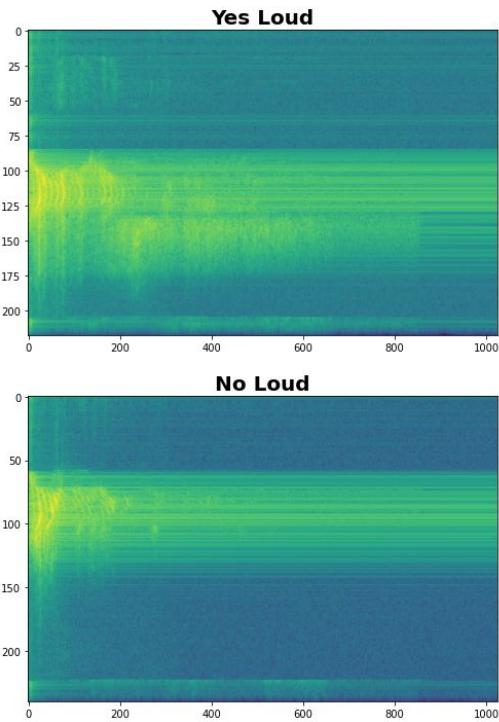


Essentially if you **stack up all the FFTs in a row** then you get the **Spectrogram** (time vs. frequency with color indicating intensity)

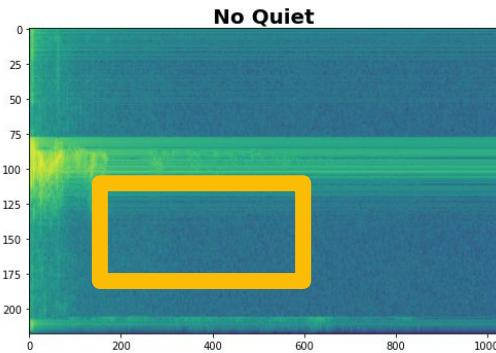
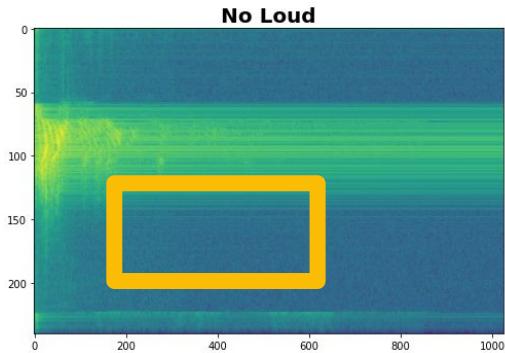
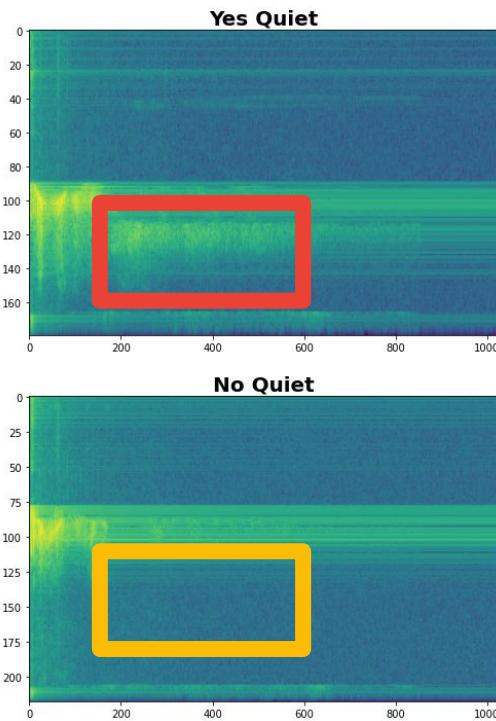
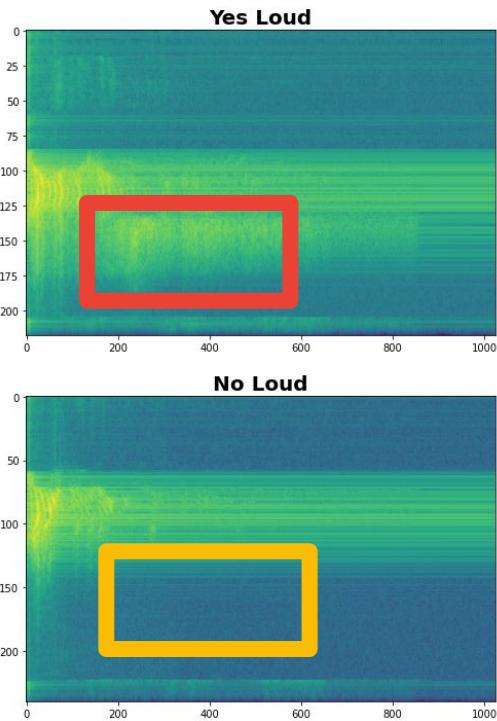
# Spectrograms help differentiate the data



# Spectrograms help differentiate the data



# Spectrograms help differentiate the data



# Data Preprocessing: Spectrograms

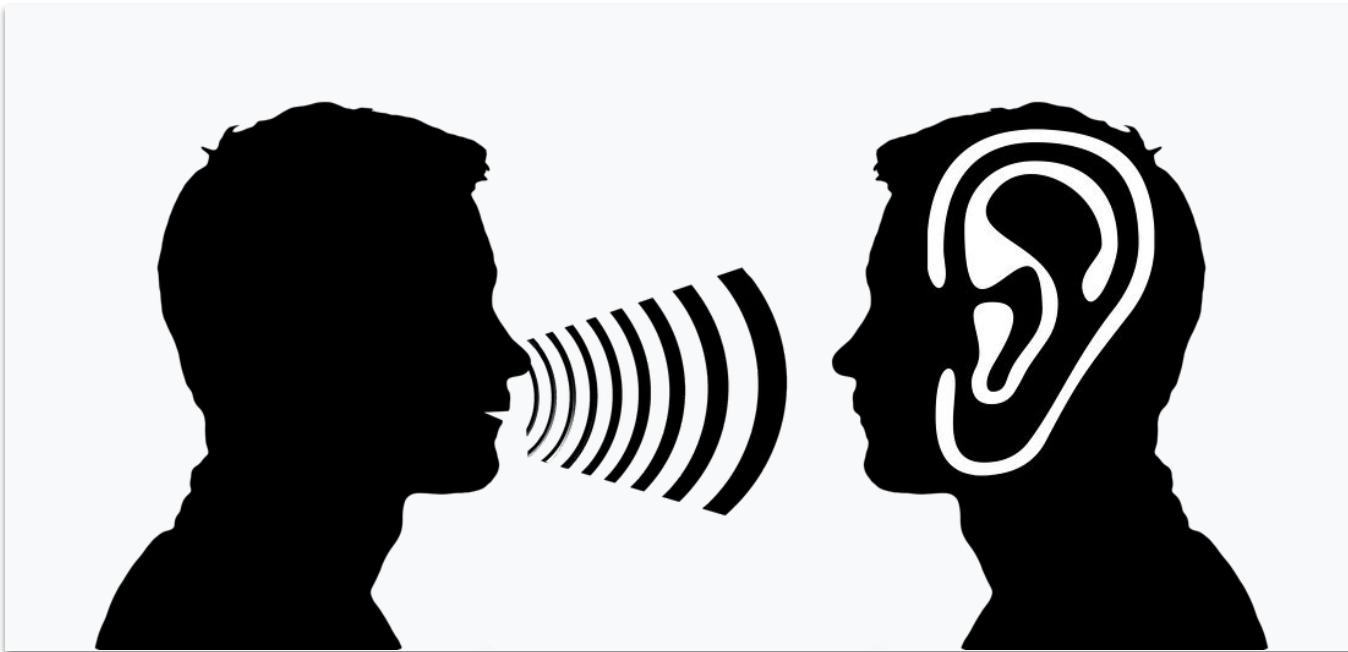


A spectrogram is also effectively an **image** that we can use as an input to a Neural Network!

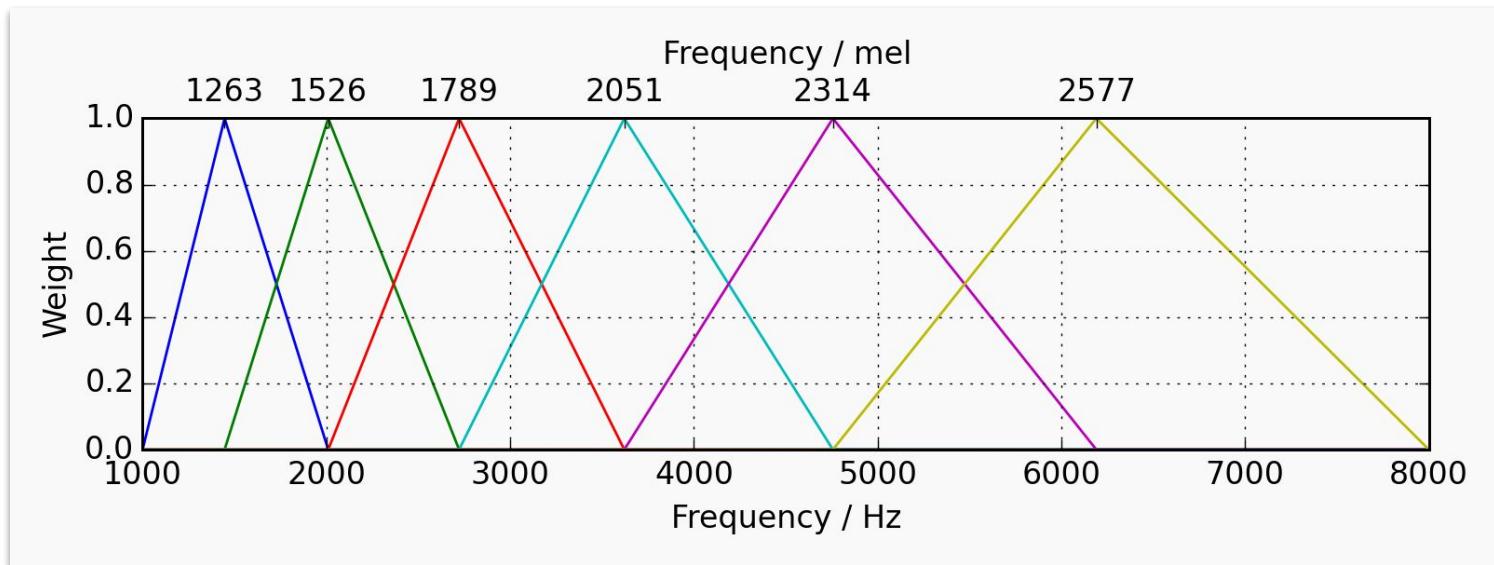


Can we do **better** than a spectrogram?

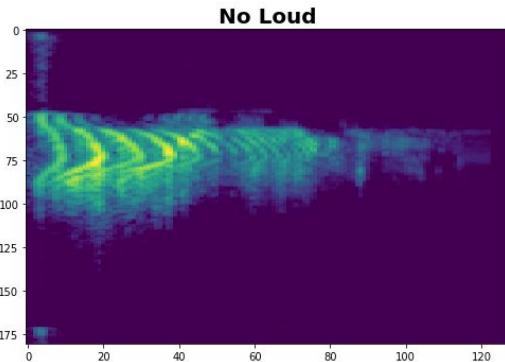
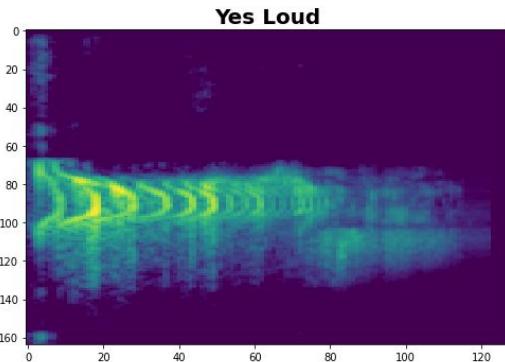
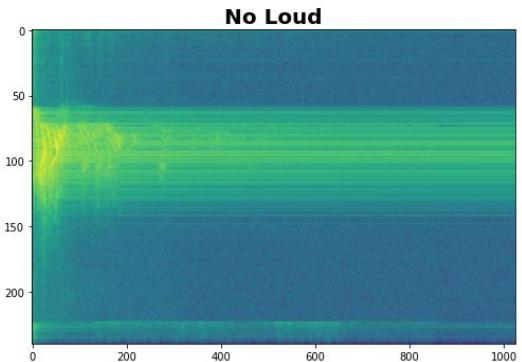
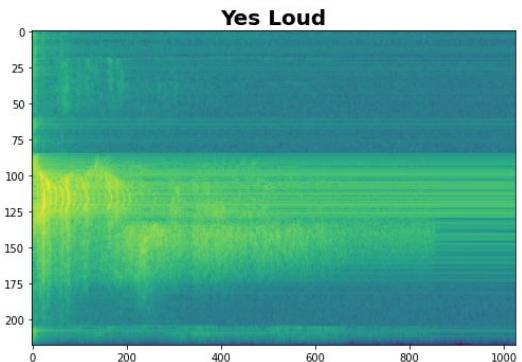
Can we take **domain knowledge** into account?



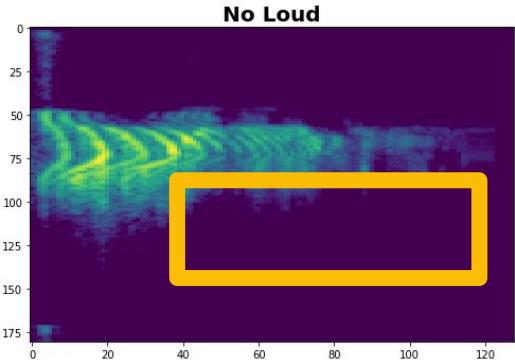
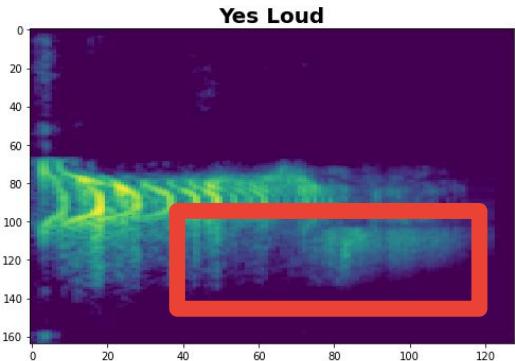
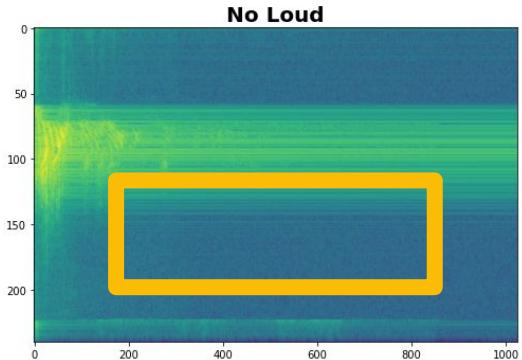
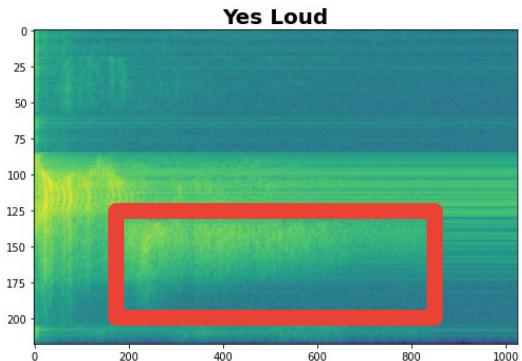
# Mel Filterbanks



# Spectrograms v. MFCCs



# Spectrograms v. MFCCs



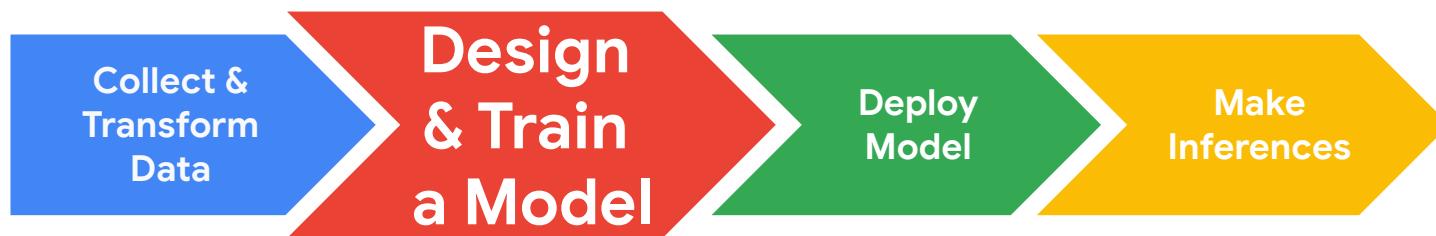
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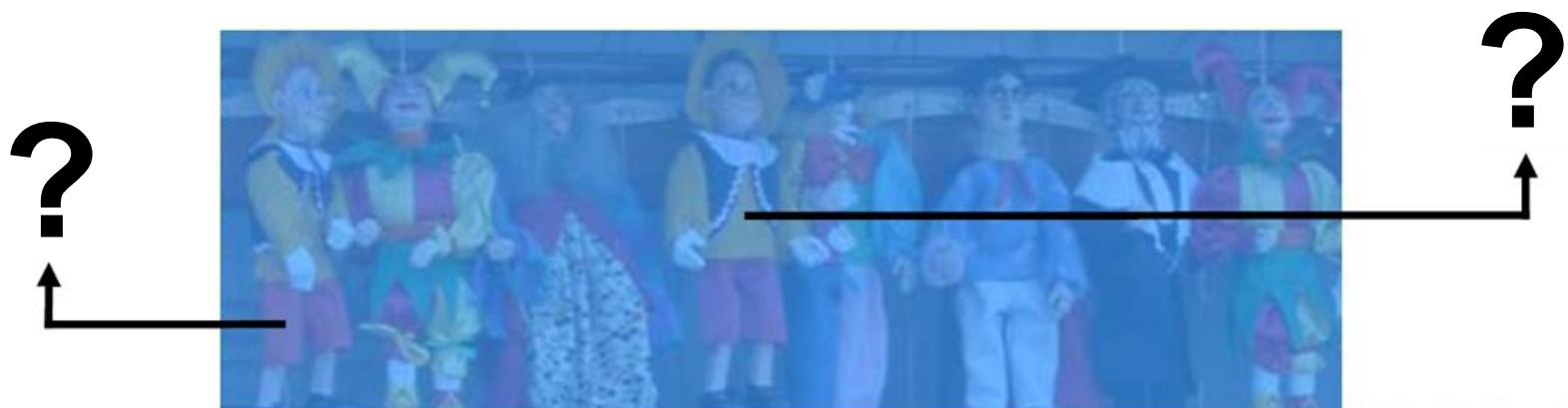
# Machine Learning Workflow



# Computer Vision is Hard

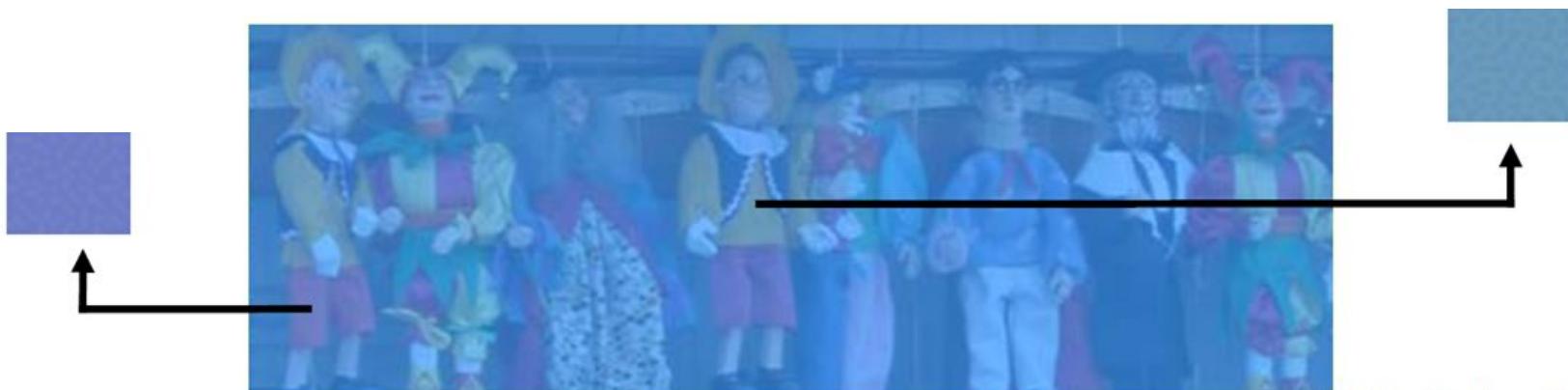
# Computer Vision is Hard

**What color are the pants and the shirt?**



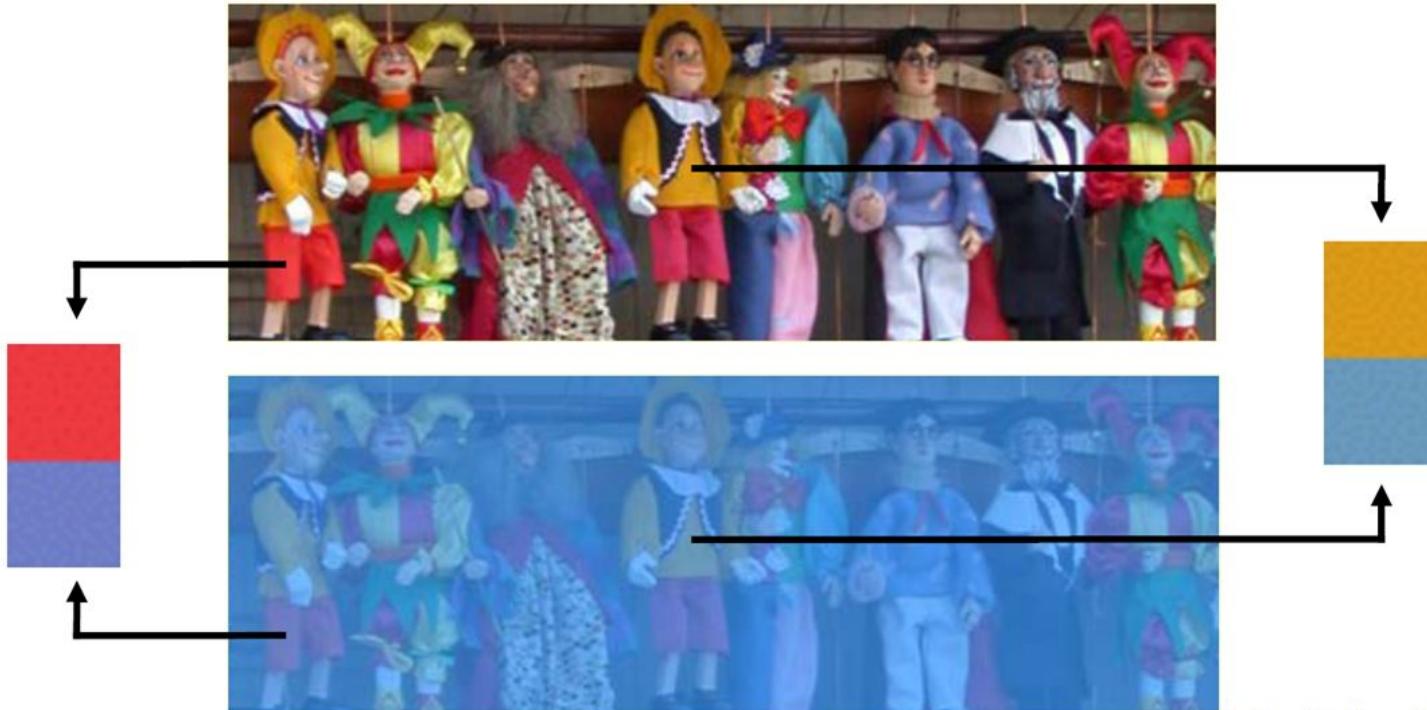
Slide Credit: Hamilton Chong

# Computer Vision is Hard



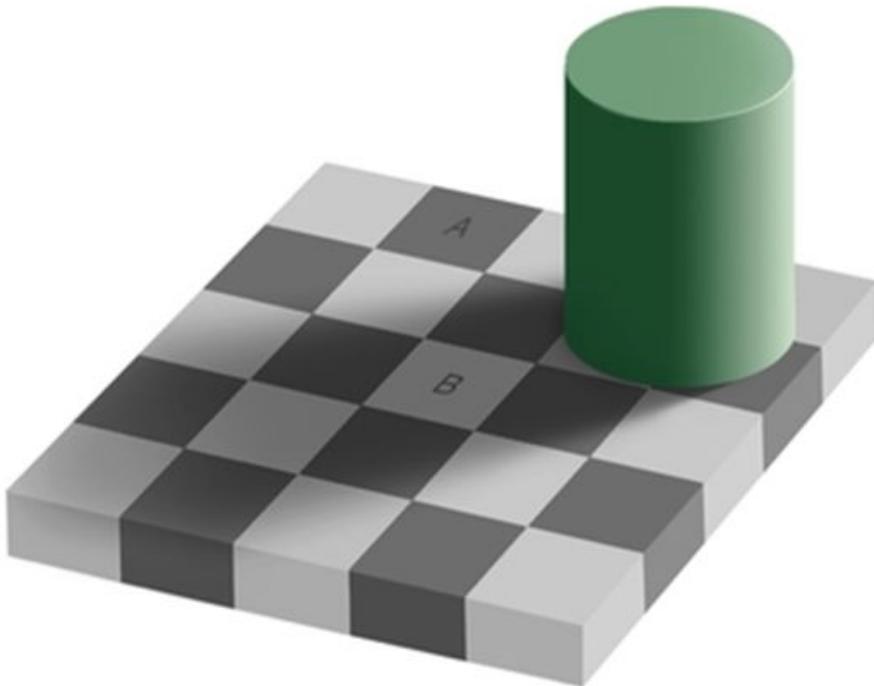
Slide Credit: Hamilton Chong

# Computer Vision is Hard



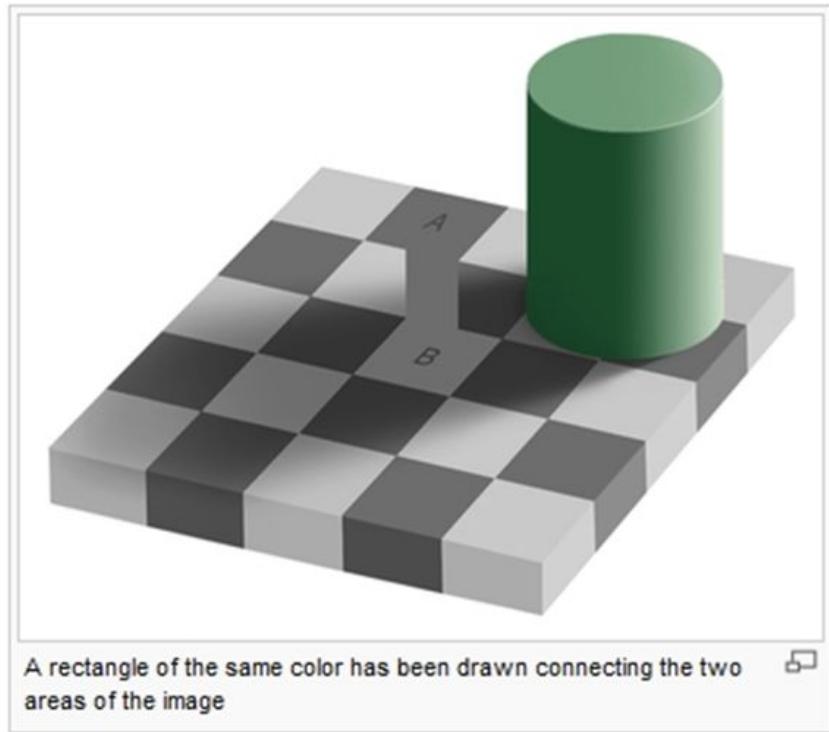
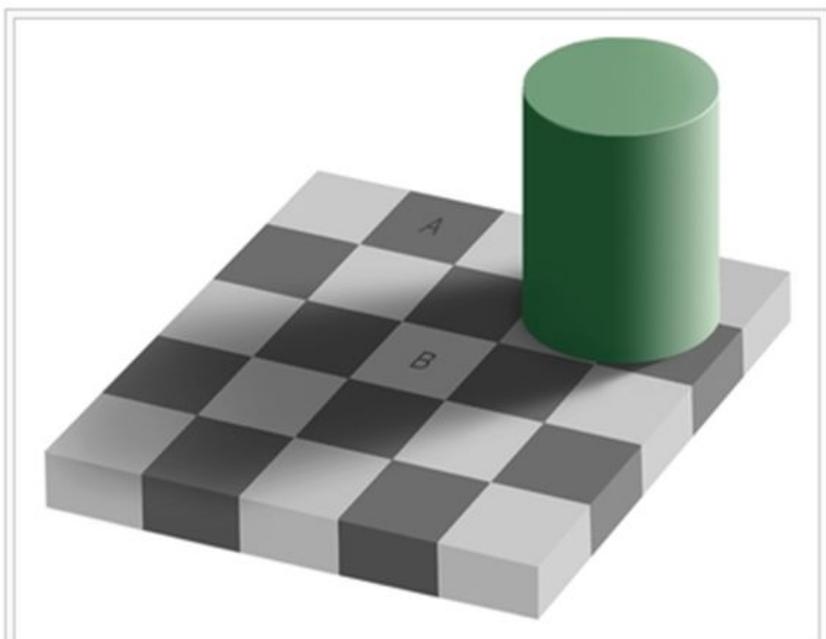
Slide Credit: Hamilton Chong

# Computer Vision is Hard



Is square  
A or B  
darker in  
color?

# Computer Vision is Hard



# What **Features** of the image might be important for self driving cars?



# What **Features** of the image might be important for self driving cars?

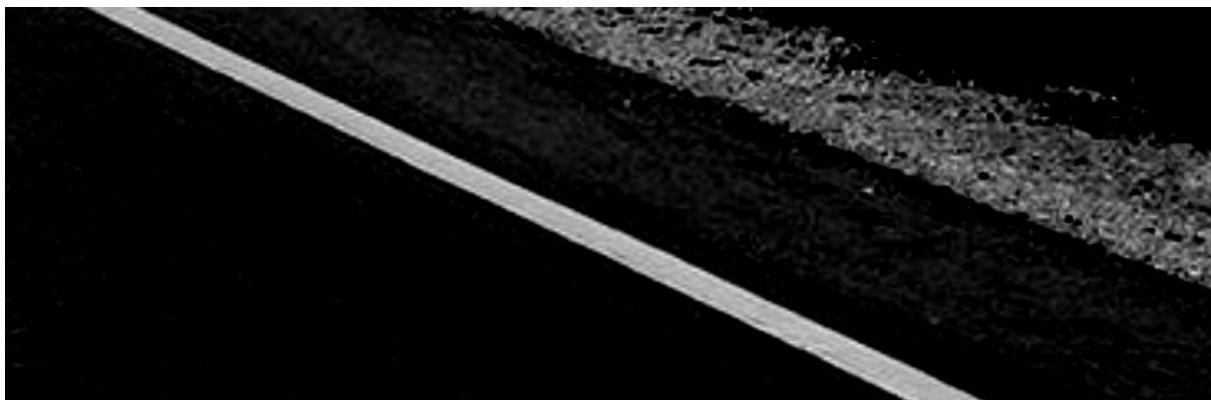


**Maybe  
straight  
lines to  
see the  
lanes  
of the  
road?**

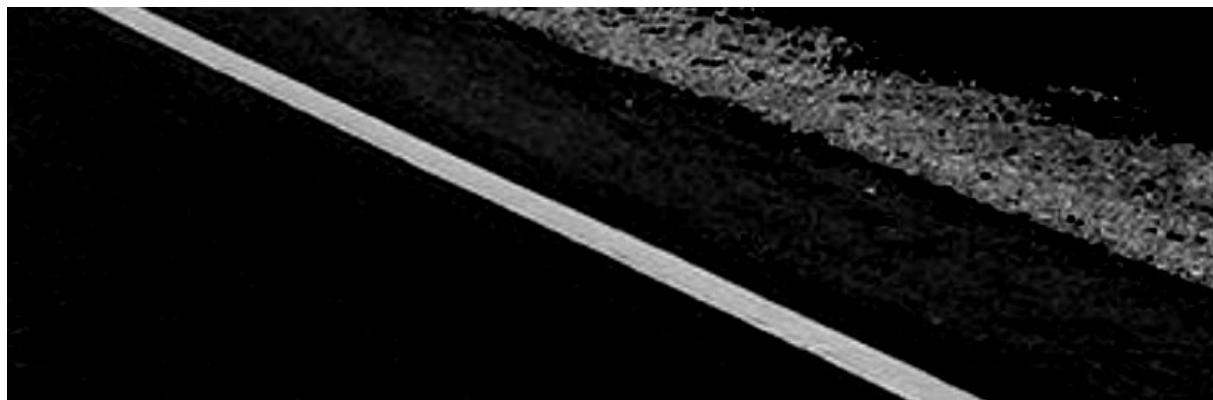
# How might we find these features?



# How might we find these features?



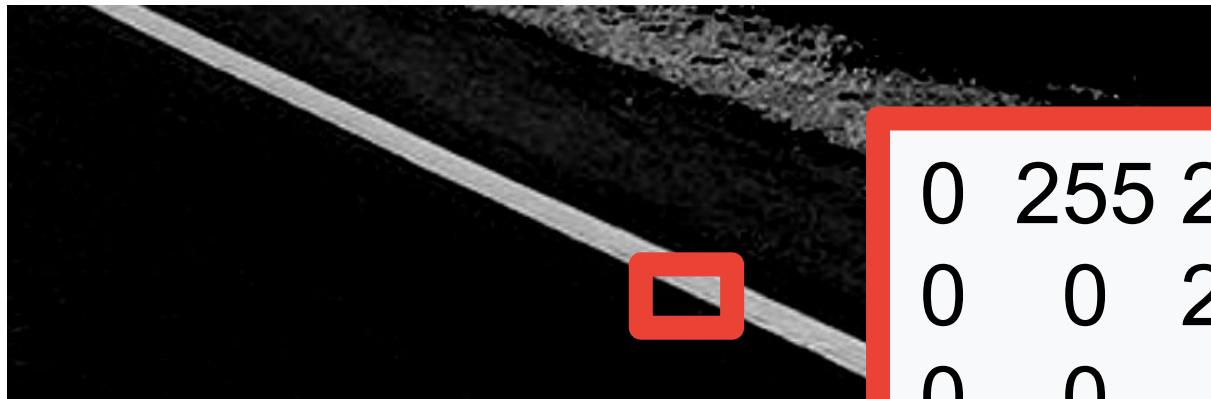
# How might we find these features?



**Black: 0**

**White: 255**

# How might we find these features?



**Black: 0**

**White: 255**

0	255	255	255	255	255
0	0	255	200	255	
0	0	0	255	255	
0	0	0	0	255	
0	0	0	0	0	0

# How might we find these features?



Look for a Big  
Change!

**Black: 0**  
**White: 255**

0	255	255	255	255	255
0	0	255	200	255	
0	0	0	255	255	
0	0	0	0	255	
0	0	0	0	0	0

How might we find these features?

**Convolutions**

# How might we find these features?

## Convolutions

Original Image

0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255

# How might we find these features?

## Convolutions

Original Image

0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255

Filter

-1	0	1
-1	0	1
-1	0	1

# How might we find these features?

## Convolutions

Original Image

0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255

Filter

-1	0	1
-1	0	1
-1	0	1

# How might we find these features?

## Convolutions

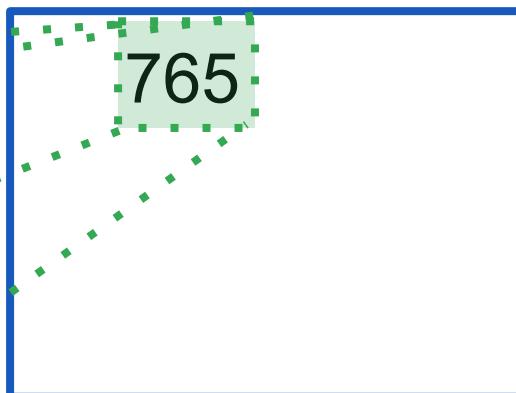
Original Image

0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255

Filter

-1	0	1
-1	0	1
-1	0	1

Output  
Feature Map



# How might we find these features?

## Convolutions

Original Image

0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255
0	0	0	255	255	255

Filter

-1	0	1
-1	0	1
-1	0	1

Output  
Feature Map

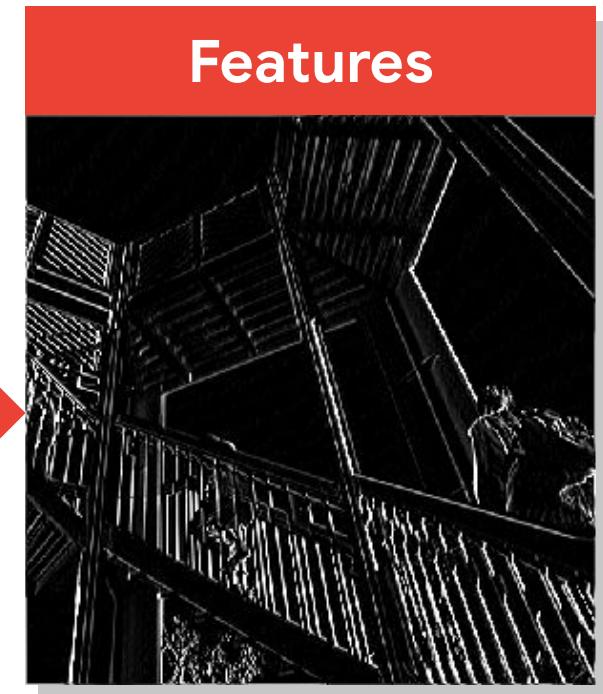
0	765	765	0
0	765	765	0
0	765	765	0
0	765	765	0

# How might we find these features?

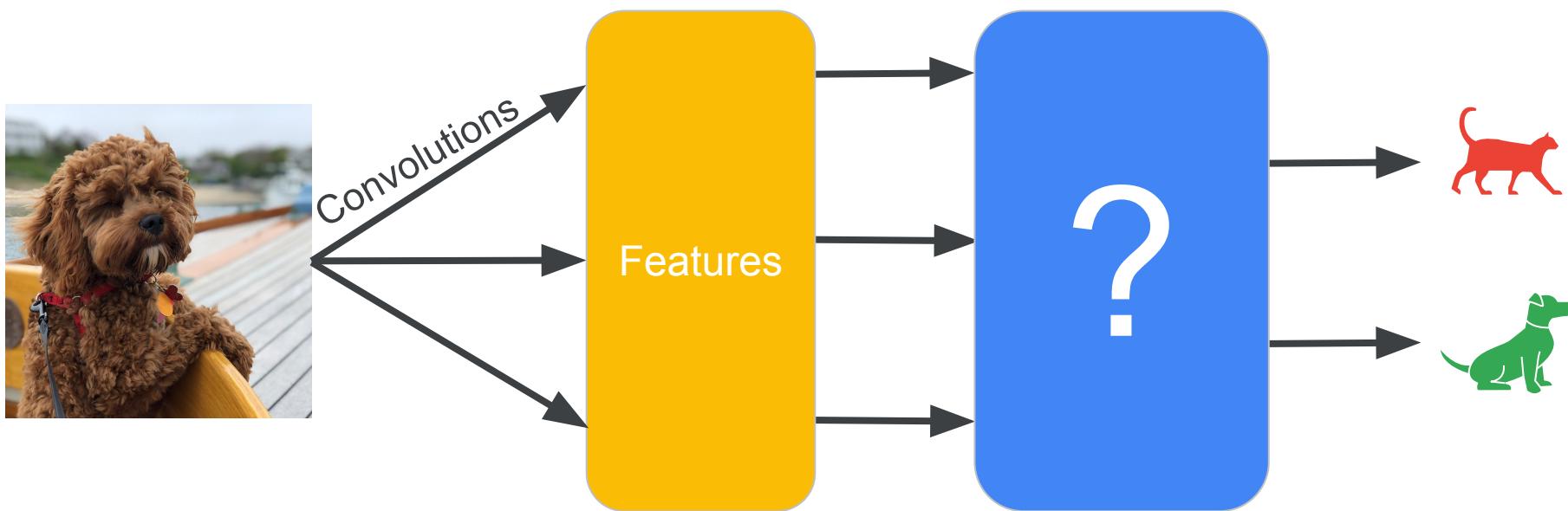
## Convolutions



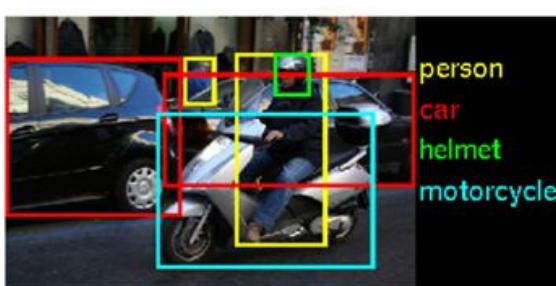
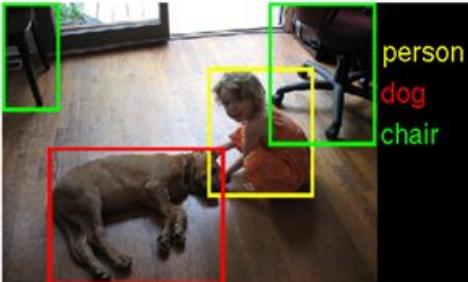
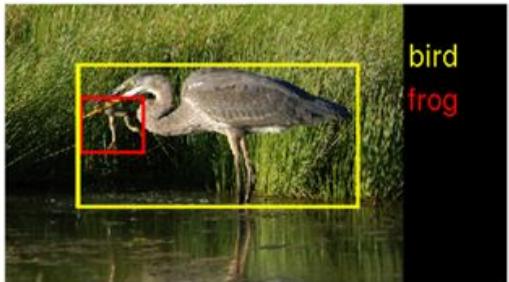
-1	0	1
-2	0	2
-1	0	1



# How might we combine these features to **classify an object?**

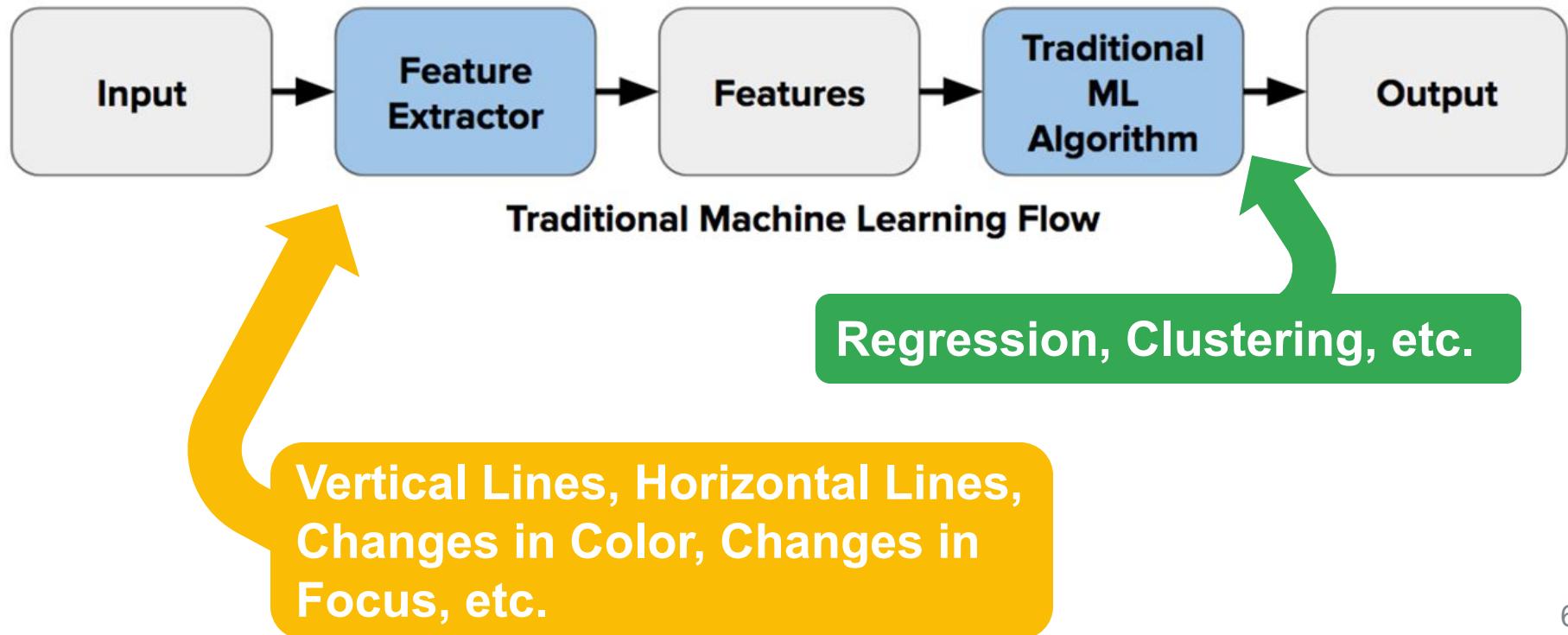


# The ImageNet Challenge and the birth of CNNs

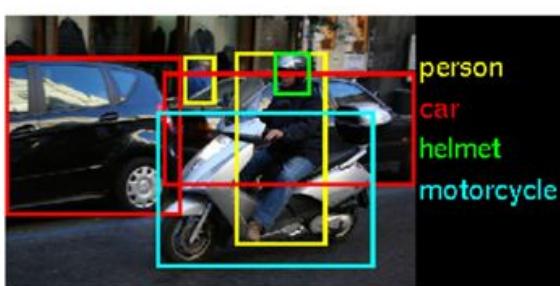
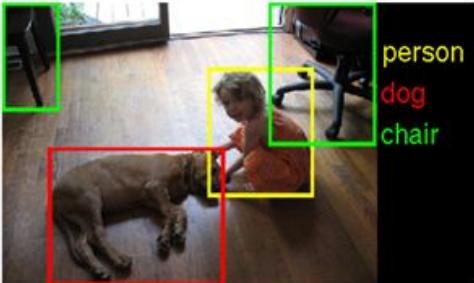
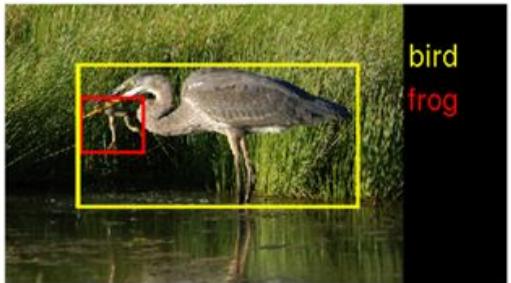


The ImageNet Challenge provided 1.2 million examples of 1,000 **labeled** items and challenged algorithms to learn from the data and then was tested on another 100,000 images

# The ImageNet Challenge and the birth of CNNs



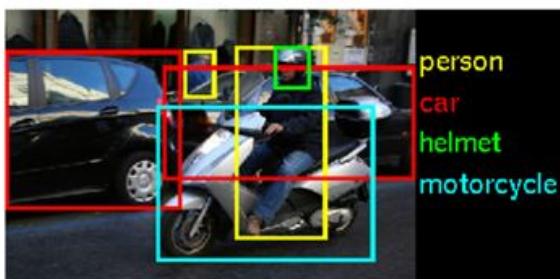
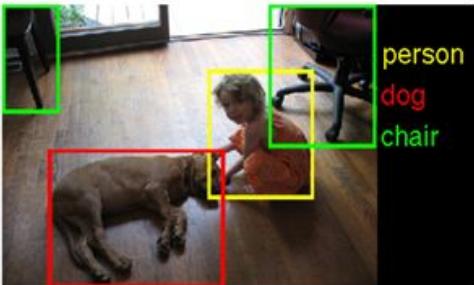
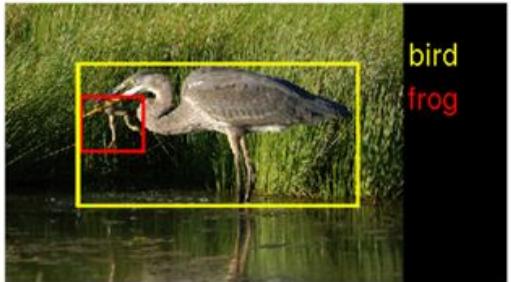
# The ImageNet Challenge and the birth of CNNs



In 2010 teams had  
**75-50%** error

In 2011 teams had  
**75-25%** error

# The ImageNet Challenge and the birth of CNNs

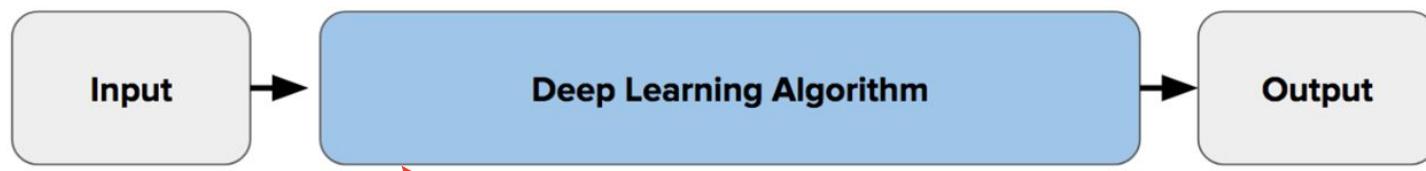


In 2012 still no team  
had less than 25%  
error barrier except  
**AlexNet at 15%**

# The ImageNet Challenge and the birth of CNNs



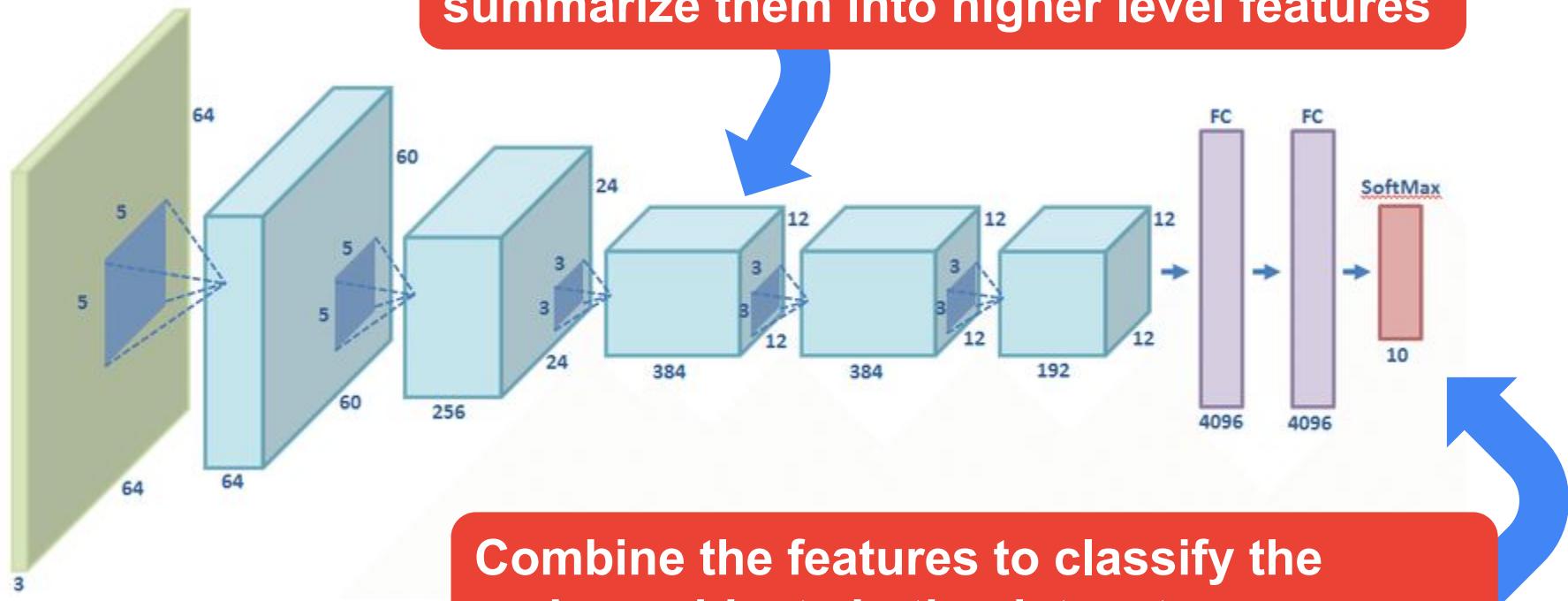
Traditional Machine Learning Flow



Deep Learning Flow

Let the computer figure out its own features  
and how to combine them!

# AlexNet

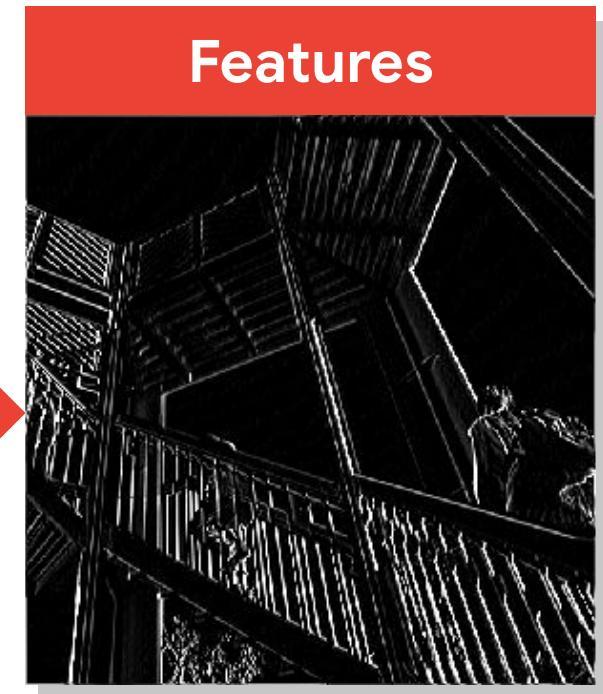


# How might we find these features?

## Convolutions



-1	0	1
-2	0	2
-1	0	1

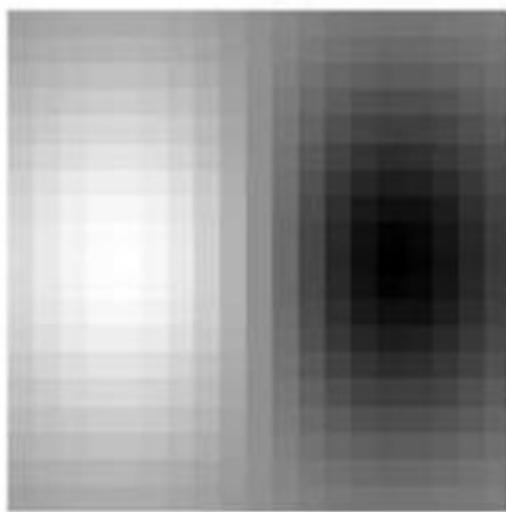


Features

# How might we find these features?

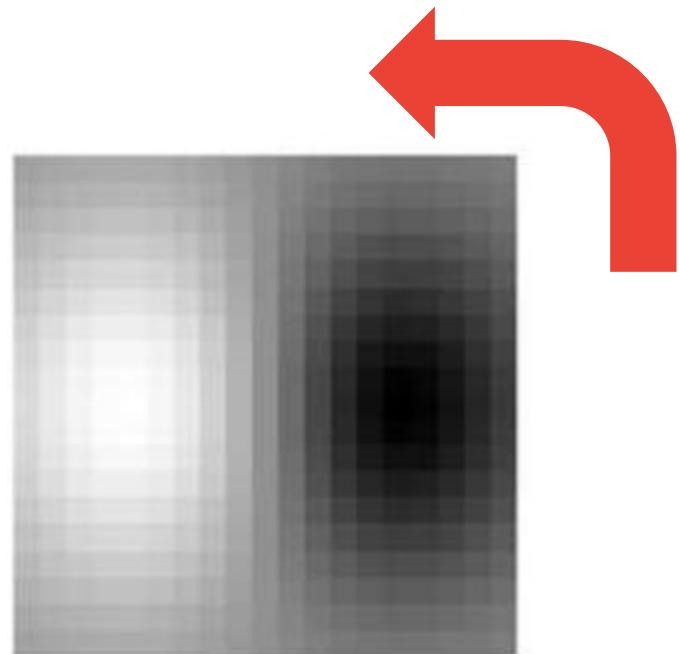
## Convolutions

-1	0	1
-2	0	2
-1	0	1



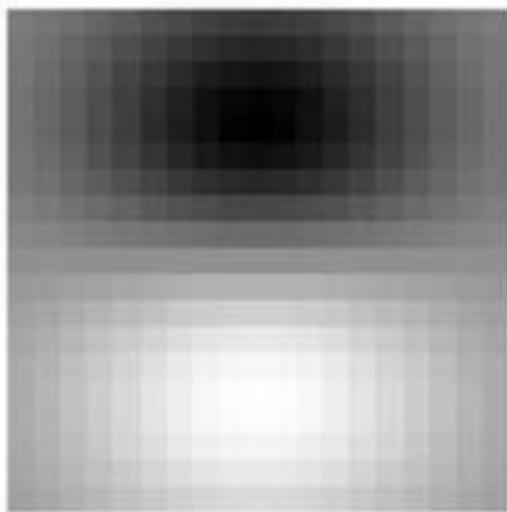
# How might we find these features?

## Convolutions

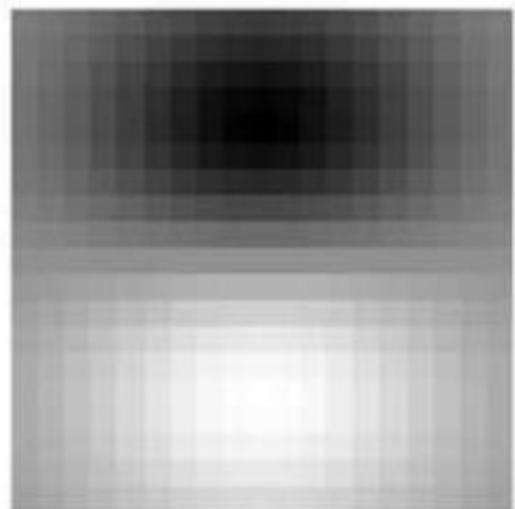
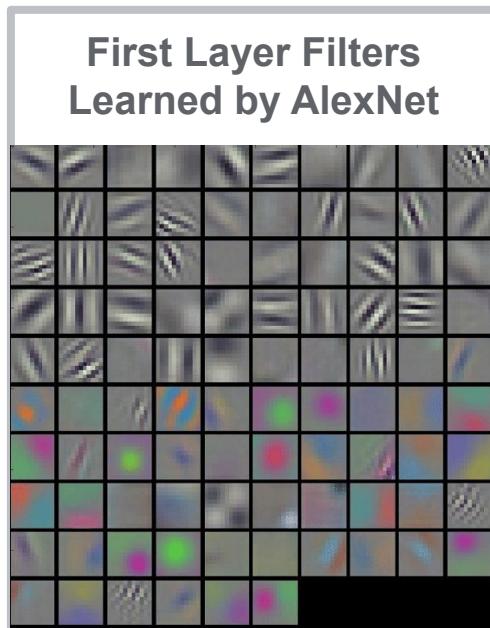


# How might we find these features?

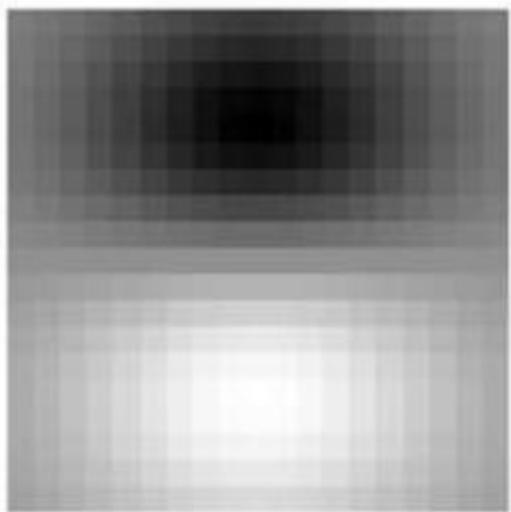
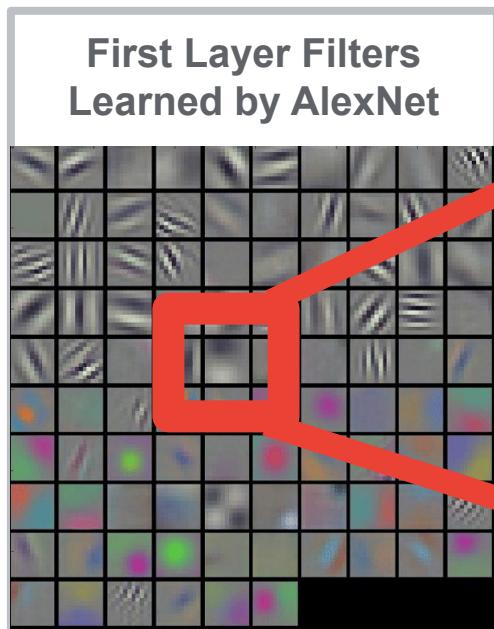
## Convolutions



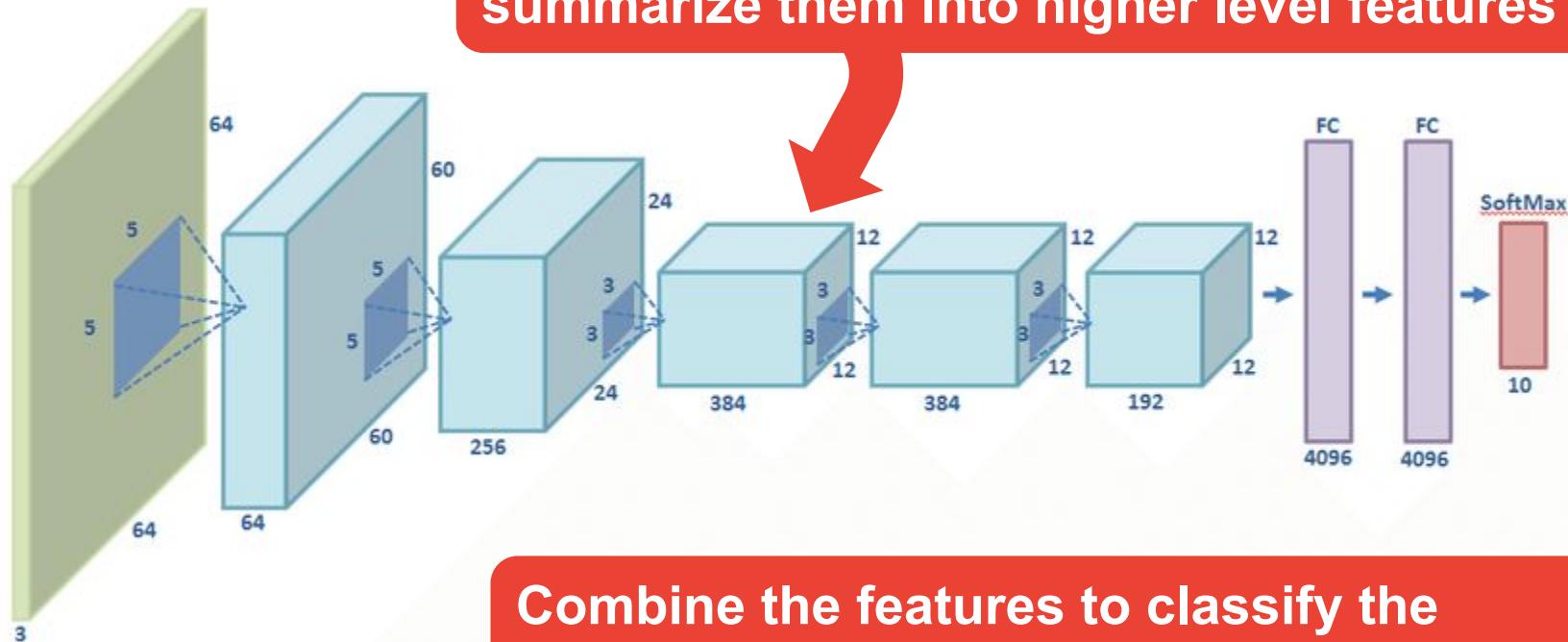
# How might we find these features? **Convolutions**



# How might we find these features? **Convolutions**



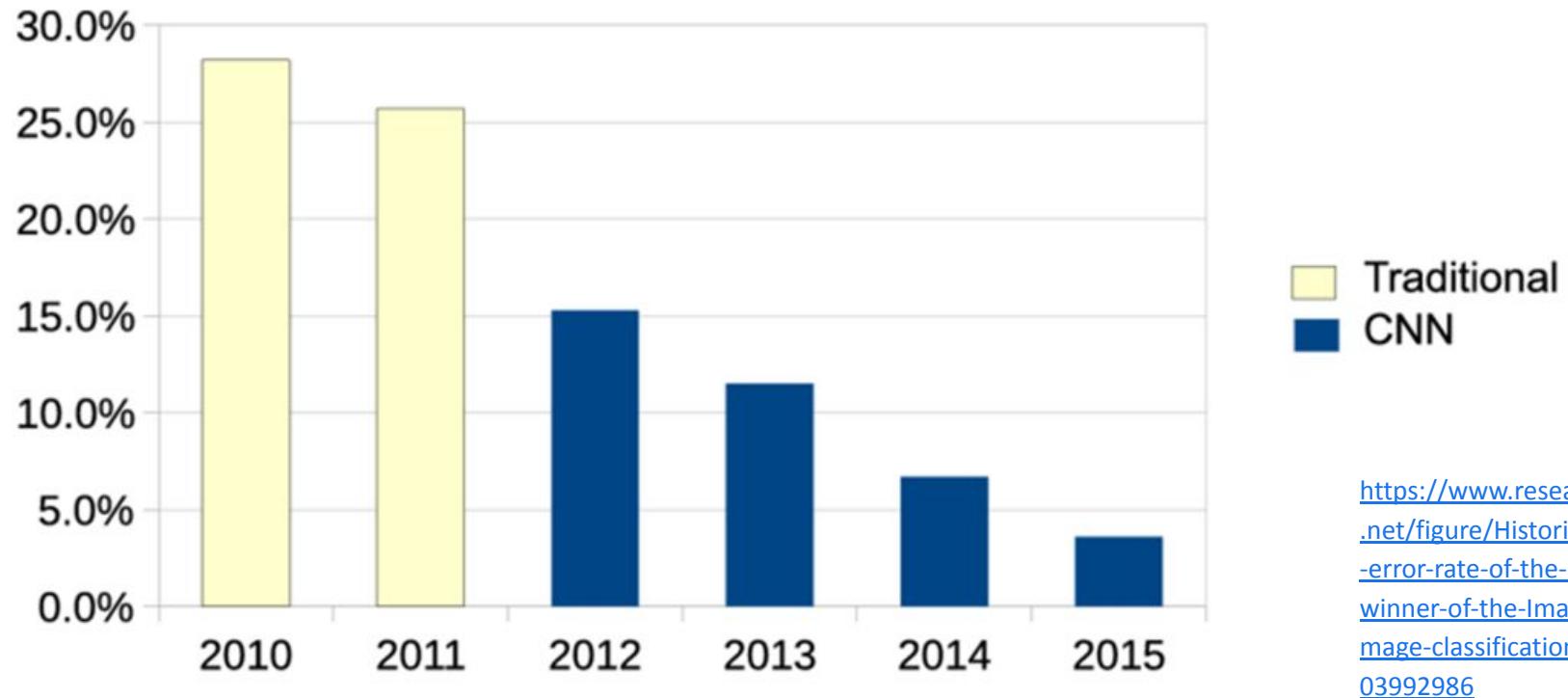
# AlexNet



Use convolutions to find features and the summarize them into higher level features

Combine the features to classify the various objects in the dataset

# The ImageNet Challenge and the birth of CNNs

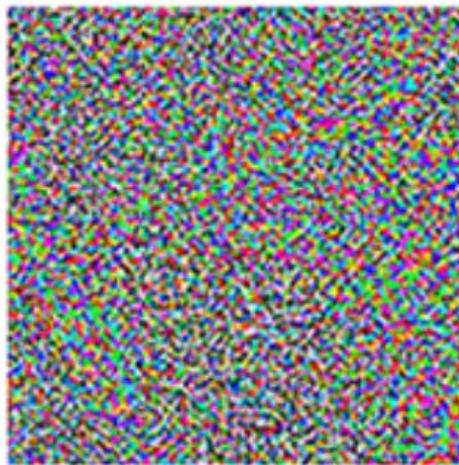


# A word of caution...

Ackerman "Hacking the Brain With Adversarial Images"



$+ \epsilon$



=



"panda"

57.7% confidence

There is **no model** of  
the world semantically  
just mathematically

"gibbon"

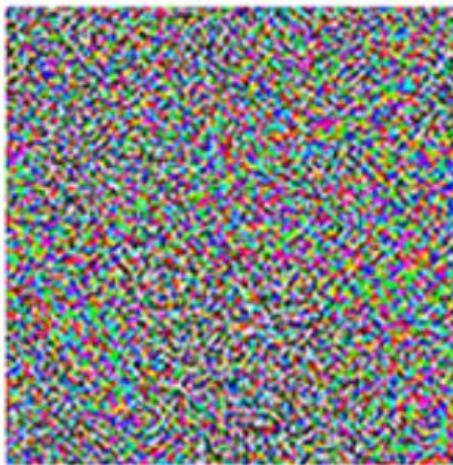
99.3% confidence

# A word of caution...

Ackerman "Hacking the Brain With Adversarial Images"



$+ \epsilon$



=



"panda"

57.7% confidence

There is **no model** of  
the world semantically  
just mathematically

"gibbon"

99.3% confidence

# Today's Agenda

- Preprocessing for Keyword Spotting
- **Convolutional Neural Networks for Image Classification**
- Hands-on: KWS Data Collection with Edge Impulse
- Hands-on: Training our Model with Edge Impulse
- Hands-on: Testing our Model in the Real World
- Summary

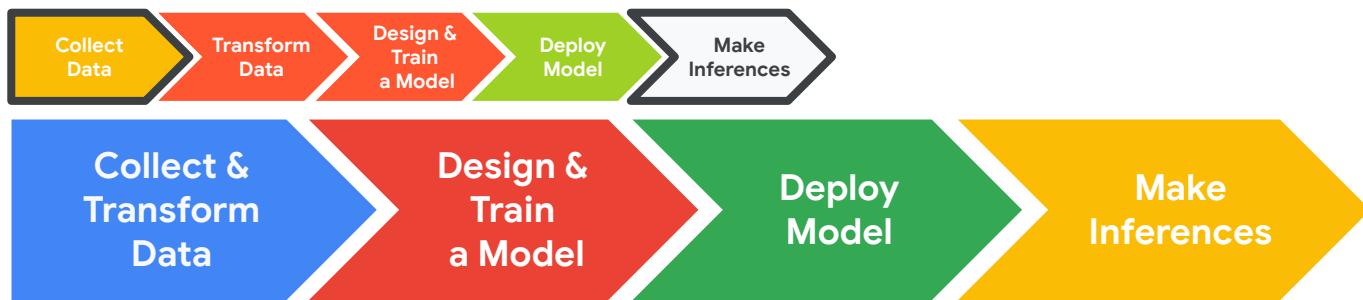
# Today's Agenda

- Preprocessing for Keyword Spotting
- Convolutional Neural Networks for Image Classification
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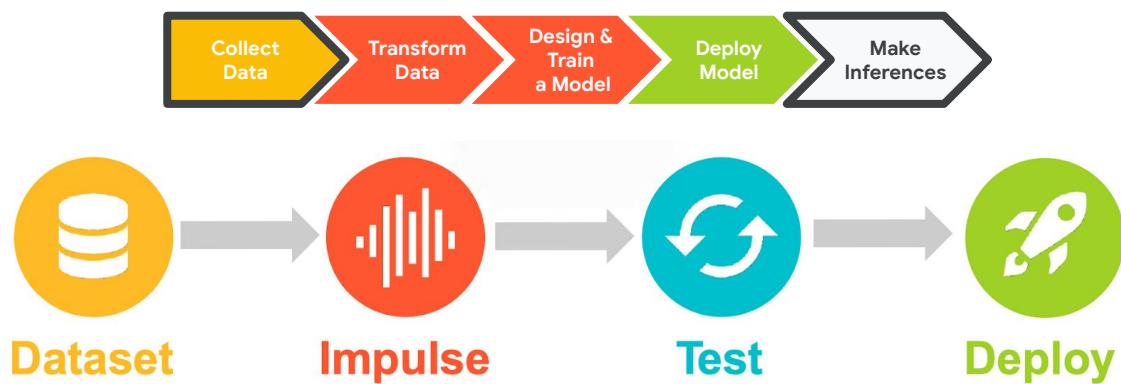
# Machine Learning Workflow



# Machine Learning Workflow



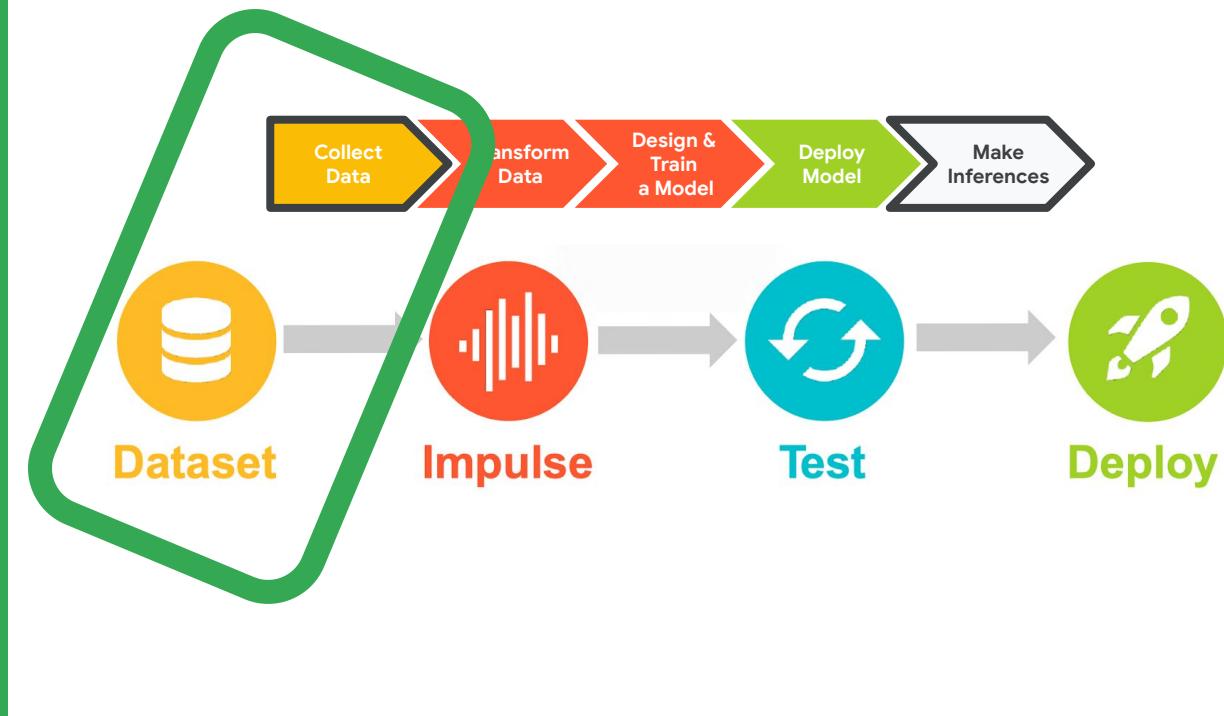
# Edge Impulse Project Dashboard



- Dashboard
- Devices
- Data acquisition
- Impulse design
- Create impulse
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment



# Edge Impulse Project Dashboard

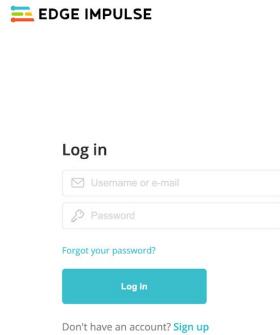


- Dashboard
- Devices
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- Live classification
- Model testing
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- Deployment

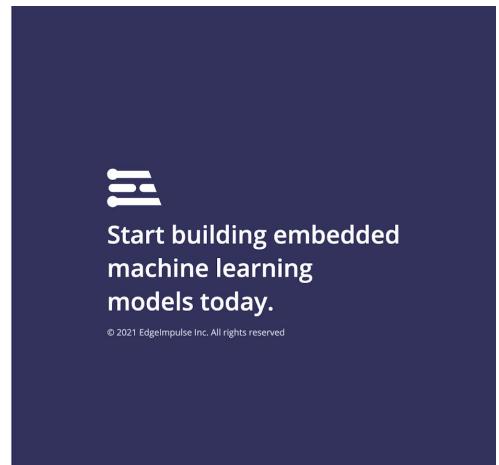
# Create an Edge Impulse Account

1. Create an Edge Impulse account:

<https://studio.edgeimpulse.com/signup>



2. Validate your email by clicking the link in the email sent to your account's email address



# Activity: Create a Keyword Spotting Dataset

Collect ~30 samples each of the following classes of data:

- **Keyword #1**  Yá'át'ééh
- **Keyword #2**  hágooñee'
- **“Unknown” words** that are not the keyword and background noise

# Activity: Create a Keyword Spotting Dataset

Collect ~30 samples each of the following classes of data:

- **Keyword #1** Yá'át'ééh 
- **Keyword #2** hágooñee' 
- ~~"Unknown" words that are not the  
and background noise~~

I've pre-loaded  
in a bunch of  
background  
noise and  
unknown  
words!

<https://www.edgeimpulse.com/blog/public-projects-launch>

# Clone my starter KWS project: <https://bit.ly/EASI22-KWS>

The screenshot shows a public Edge Impulse project page for "Harvard UNIVERSITY". A modal dialog box titled "Clone this project" is open in the center. It contains fields for "Enter a name for the cloned project" (with "EASI22-KWS" typed in), "Choose your project type" (with "Developer" selected), and "Create under organization" (set to "Harvard University"). At the bottom of the modal is a green "Clone project" button. In the top right corner of the main project page, there is a "Clone this project" button, which is also highlighted with a green rounded rectangle. The background shows the project's summary and project info sections.

You are viewing a public Edge Impulse project. Clone this project to add data or make changes.

Project info Keys Export

HARVARD UNIVERSITY

Dashboard Devices Data sources Data acquisition Impulse design EON Tuner Retrain model Live classification Model testing Versioning Deployment

Harvard This is your Edge models.

Creating your own motion recognition model

Acquire Every Motion is a developer

Design Teach your model to recognize new motions

GETTING STARTED: CONTINUOUS MOTION RECOGNITION

Clone this project

Enter a name for the cloned project:

EASI22-KWS

Choose your project type:

Developer 20 min job limit, 4GB or 4 hours of data, limited collaboration.

Enterprise No job or data size limits, higher performance, custom blocks.

Create under organization: Harvard University

Clone project

Summary

DATA COLLECTED  
50m 34s

Project info

Project ID 121232

Project version 1



- [Dashboard](#)
- [Devices](#)
- [Data acquisition](#)
- [Impulse design](#)
- [Create impulse](#)
- [EON Tuner](#)
- [Retrain model](#)
- [Live classification](#)
- [Model testing](#)
- [Versioning](#)
- [Deployment](#)

---

- [GETTING STARTED](#)
- [Documentation](#)
- [Forums](#)

## RESTORE PROJECT (SCITINYML22-KWS-TESTCLONE)



Brian\_plancher



Clone succeeded

You're now ready to build your next embedded Machine Learning project!

### Clone progress

```
[1124/3034] Restoring files...
[1246/3034] Restoring files...
[1456/3034] Restoring files...
[1578/3034] Restoring files...
[1790/3034] Restoring files...
[1980/3034] Restoring files...
[2109/3034] Restoring files...
[2279/3034] Restoring files...
[2479/3034] Restoring files...
[2602/3034] Restoring files...
[2815/3034] Restoring files...
[2938/3034] Restoring files...
[3034/3034] Restoring files...
[6/7] Restoring files OK
```

```
[7/7] Rewriting caches...
[7/7] Rewriting caches OK
```

Project has been restored!

Job completed

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DATA ACQUISITION (SCITINYML22-KWS-TESTCLONE)



Brian\_plancher

Training data

Test data

Export data



Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

DATA COLLECTED

50m 34s



TRAIN / TEST ...

100% ... ⚠



Record new data

[Connect using WebUSB](#)

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
-------------	-------	-------	--------	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

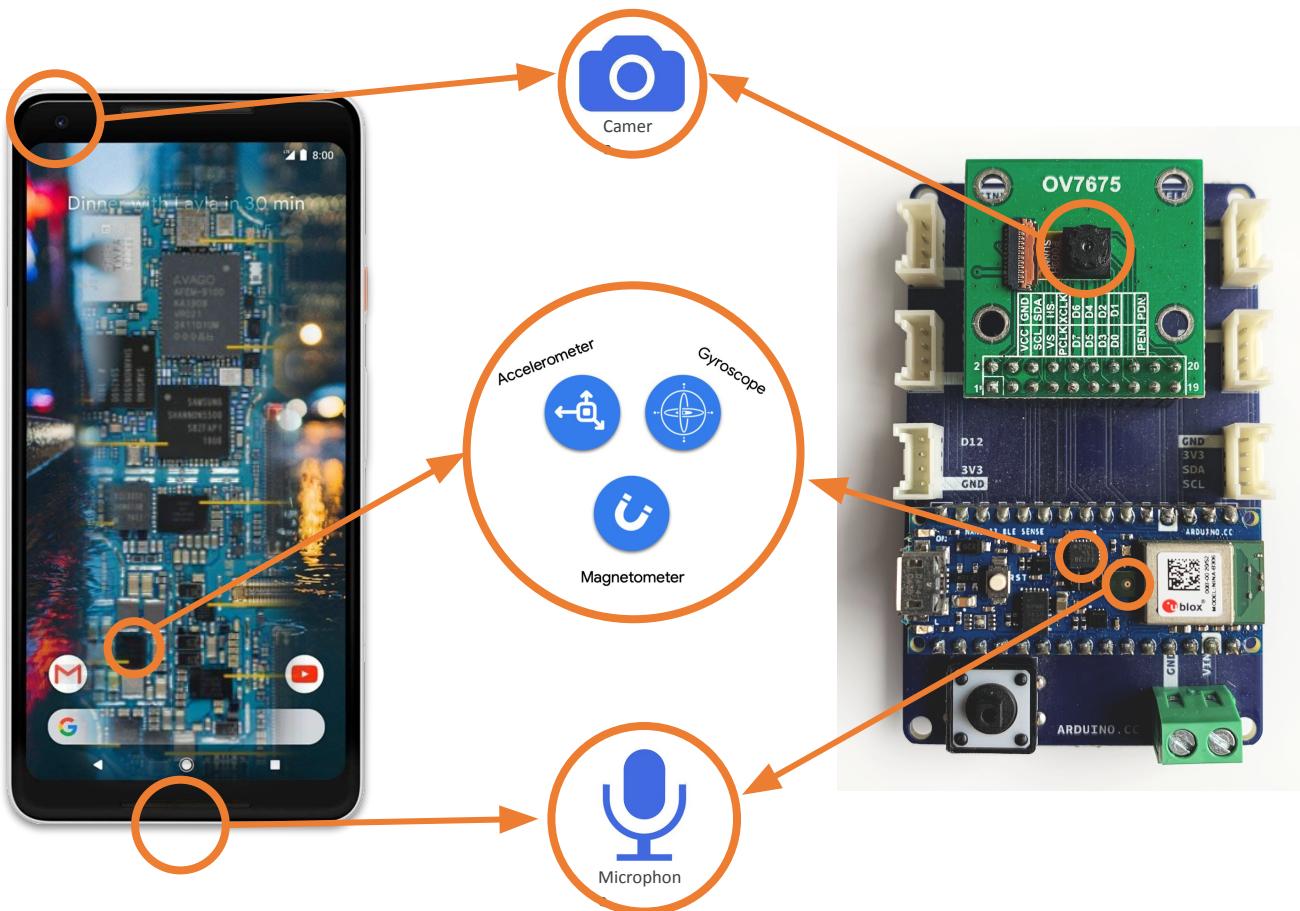
noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---

I've pre-loaded in a bunch of noise and unknown words!

noise.orig_train...	noise	Today, 11:2...	1s	⋮
---------------------	-------	----------------	----	---



Dashboard

Devices

Data acquisition

Impulse design

Create impulse

EON Tuner

Retrain model

Live classification

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Versioning

Deployment

#### GETTING STARTED

Documentation

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## DATA ACQUISITION (SCITINYML22-KWS-TESTCLONE)

Training data

Test data

Export data



Brian\_plancher



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DATA COLLECTED

50m 34s



TRAIN / TEST ...

100% ...



Record new data

Connect using WebUSB

No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

### Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮
noise.orig_test....	noise	Today, 11:2...	1s	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮
noise.running_t...	noise	Today, 11:2...	1s	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮
noise.orig_train...	noise	Today, 11:2...	1s	⋮

## Collect data

You can collect data from development boards, from your own devices, or by uploading an existing dataset.

Create



### Connect a fully supported development board

Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.

[Browse dev boards](#)



### Use your mobile phone

Use your mobile phone to capture movement, audio or images, and even run your trained model locally. No app required.



### Use your computer

Capture audio or images from your webcam or microphone, or from an external audio device.



### Data from any device with the data forwarder

Capture data from any device or development board over a serial connection, in 10 lines of code.

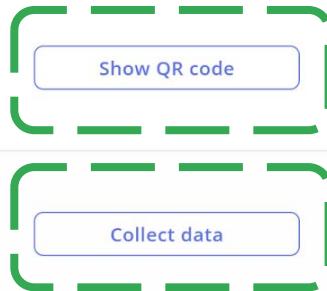
[Show docs](#)



### Upload data

Already have data? You can upload your existing datasets directly in WAV, JPG, PNG, CBOR, CSV or JSON format.

[Go to the uploader](#)



aring



llabor

## Collect data

You can collect data from development boards, from your own devices, or by uploading an existing dataset.

Create

### Connect a fully supported development board

Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.

[Browse dev boards](#)

**Point your phone camera at the QR code and open the link!**

... images, and even

[Show QR code](#)

... phone, or from an

[Collect data](#)

Capture data from any device or development board over a serial connection, in 10 lines of code.

[Show docs](#)

### Upload data

Already have data? You can upload your existing datasets directly in WAV, JPG, PNG, CBOR, CSV or JSON format.

[Go to the uploader](#)

smartphone.edgeimpulse.com 



Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images?

 Collecting audio?

 Collecting motion?

smartphone.edgeimpulse.com 



Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images?

 Collecting audio?

 Collecting video?

smartphone.edgeimpulse.com



Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images?

 Collecting audio?

 Collecting motion?

smartphone.edgeimpulse.com

 Data collection

Label: goodbye  
Length: 3s.  
Category: split

 Start recording

Audio captured with current settings: 0s

smartphone.edgeimpulse.com



Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images?

 Collecting audio?

 Collecting motion?

smartphone.edgeimpulse.com

## Data collection

 Label: goodbye Length: 3s.

 Start recording

Audio captured with current settings: 0s

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Connected as phone\_kunh8zjd

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Collecting images?

Collecting audio?

Collecting motion?

smartphone.edgeimpulse.com

## Data collection

Label: goodbye Length: 3s.  
Category: split

Start recording

Audio captured with current settings: 0s

smartphone.edgeimpulse.com

## Data collection

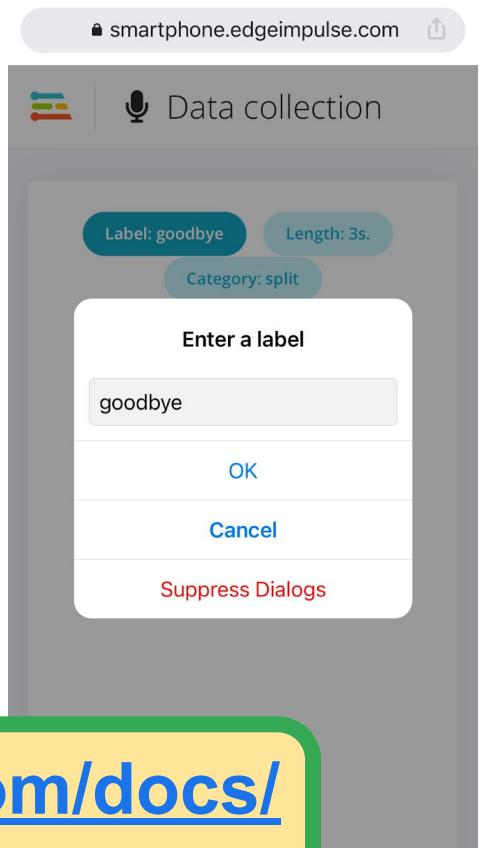
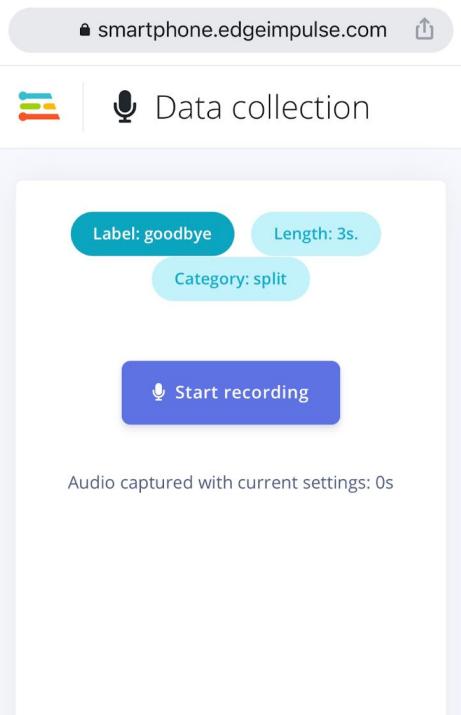
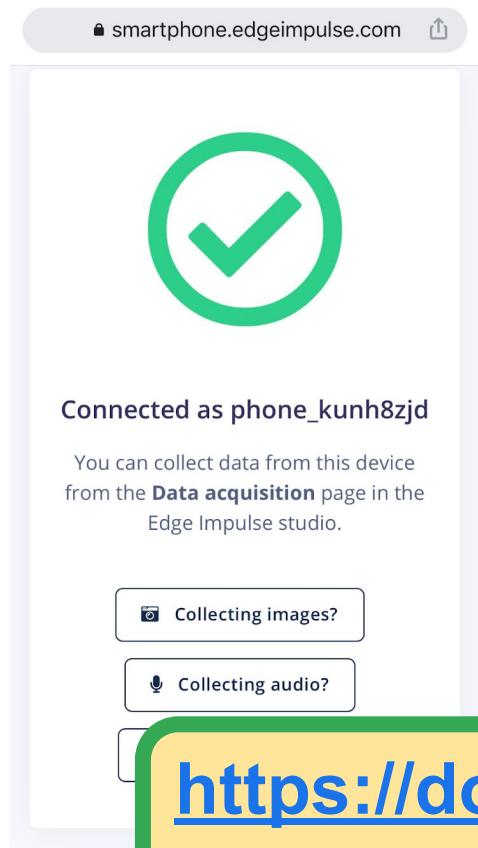
Label: goodbye Length: 3s.  
Category: split

Enter a label

OK

Cancel

Suppress Dialogs



[https://docs.edgeimpulse.com/docs/  
using-your-mobile-phone](https://docs.edgeimpulse.com/docs/using-your-mobile-phone)

DATA COLLECTED  
50m 44sTRAIN / TEST SPLIT  
100% / 0% ⚠

## Collected data

[Delete selected \(0\)](#) [Edit labels \(0\)](#) [Move to test set \(0\)](#) [Enable selected \(0\)](#) [Disable selected \(0\)](#)

<input type="checkbox"/>	SAMPLE NAME	LABEL	ADDED	LENGTH	
<input type="checkbox"/>	yes.30u5okgq	yes	Today, 14:24:58	10s	
<input type="checkbox"/>	noise.orig_train.Hallway_1.wav.7...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.Metro_1.wav.297...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.CafeTeria_1.wav....	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_test.Babble_4.wav.2000	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.running_tap.wav.29000	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.Station_1.wav.20...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirConditioner_9...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_test.Typing_1.wav.160...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.SqueakyChair_9....	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57	1s	

 [1](#)  [2](#)  [3](#)  [4](#)  [5](#)  [6](#)  [7](#) ...  [253](#) 

## Record new data

Device

6F:E3:4B:F3:11:23

Label

yes

Sample length (ms.)

10000

Sensor

Built-in microphone

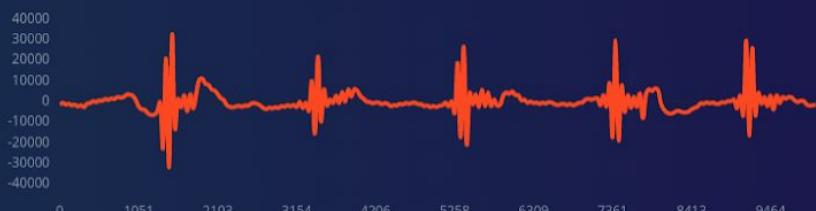
Frequency

16000Hz

[Start sampling](#)

RAW DATA

yes.30u5okgq



0:00 / 0:00

# Activity: Create a Keyword Spotting Dataset

Collect ~30 samples each of the following classes of data:

- **Keyword #1**

Yá'át'ééh 

label: yaateeh

length:

- **Keyword #2**

hágooñee' 

label: hagoonee

10 seconds

We'll resume in 10 minutes!

Label: goodbye

Length: 3s.

Category: split

Start recording

Audio captured with current settings: 0s

DATA COLLECTED  
50m 44sTRAIN / TEST SPLIT  
100% / 0% ⚠

## Collected data

[Delete selected \(0\)](#) [Edit labels \(0\)](#) [Move to test set \(0\)](#) [Enable selected \(0\)](#) [Disable selected \(0\)](#)

<input type="checkbox"/>	SAMPLE NAME	LABEL	ADDED	LENGTH	
<input type="checkbox"/>	yes.30u5okgq	yes	Today, 14:24:58	10s	
<input type="checkbox"/>	noise.orig_train.Hallway_1.wav.7...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.Metro_1.wav.297...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.CafeTeria_1.wav....	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_test.Babble_4.wav.2000	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.running_tap.wav.29000	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.Station_1.wav.20...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirConditioner_9...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_test.Typing_1.wav.160...	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.SqueakyChair_9....	noise	Today, 11:22:57	1s	
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57	1s	

 [<](#) [1](#) [2](#) [3](#) [4](#) [5](#) [6](#) [7](#) ... [253](#) [>](#) 

## Record new data

Device

6F:E3:4B:F3:11:23

Label

yes

Sample length (ms.)

10000

Sensor

Built-in microphone

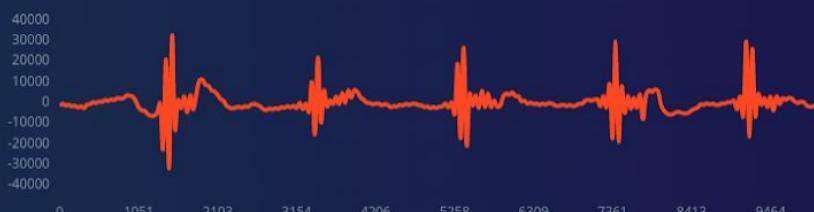
Frequency

16000Hz

[Start sampling](#)

RAW DATA

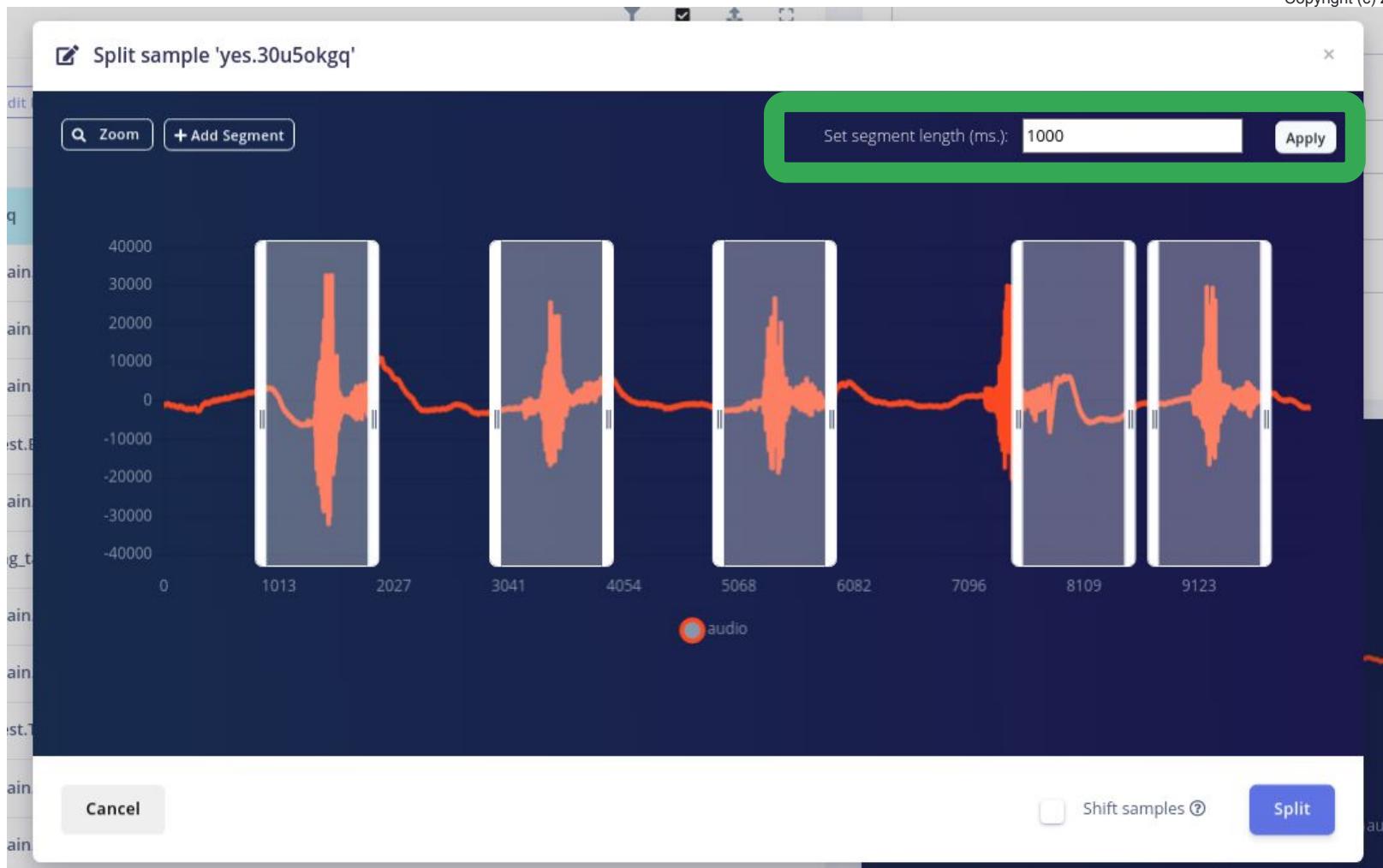
yes.30u5okgq

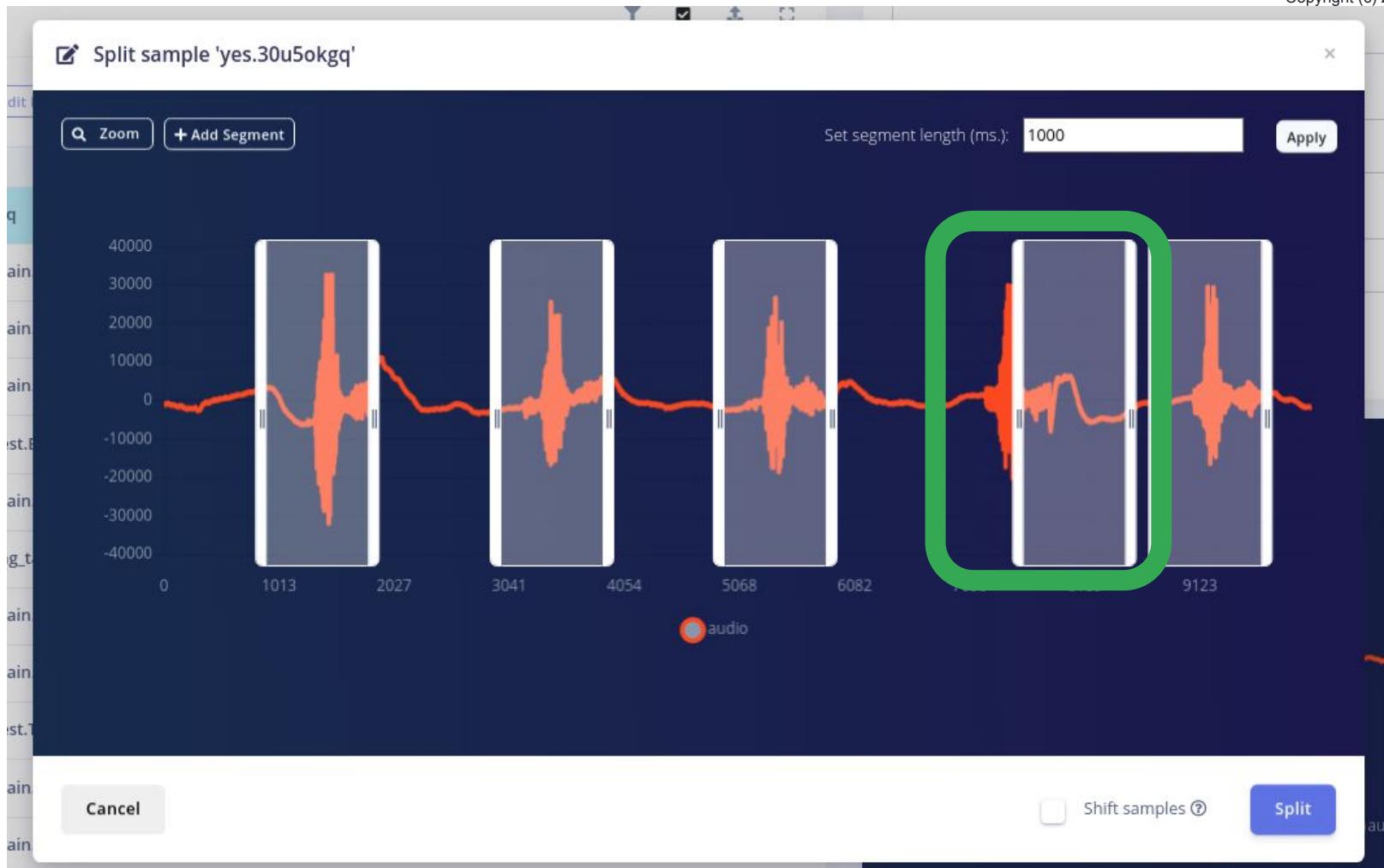


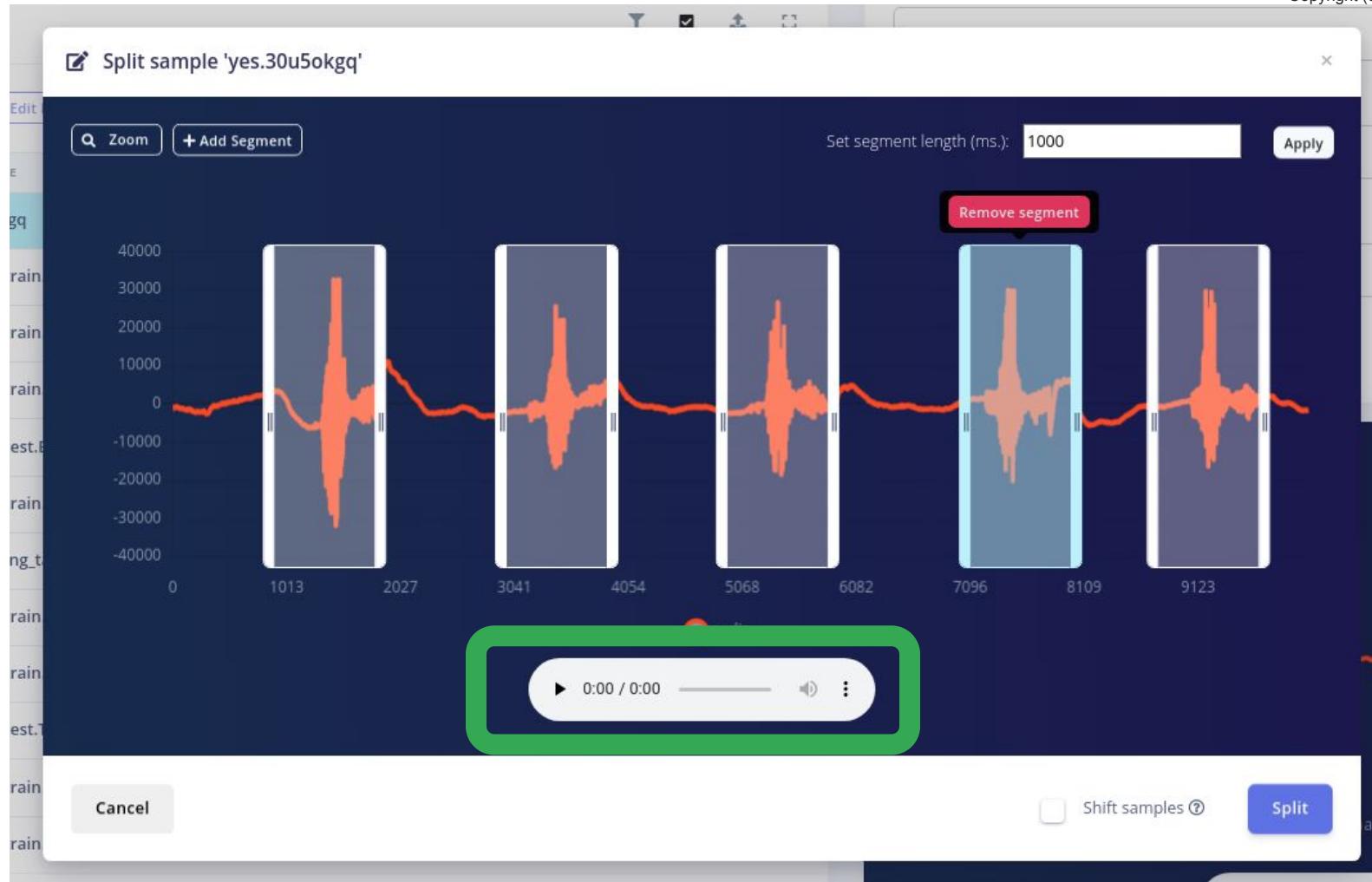
0:00 / 0:00

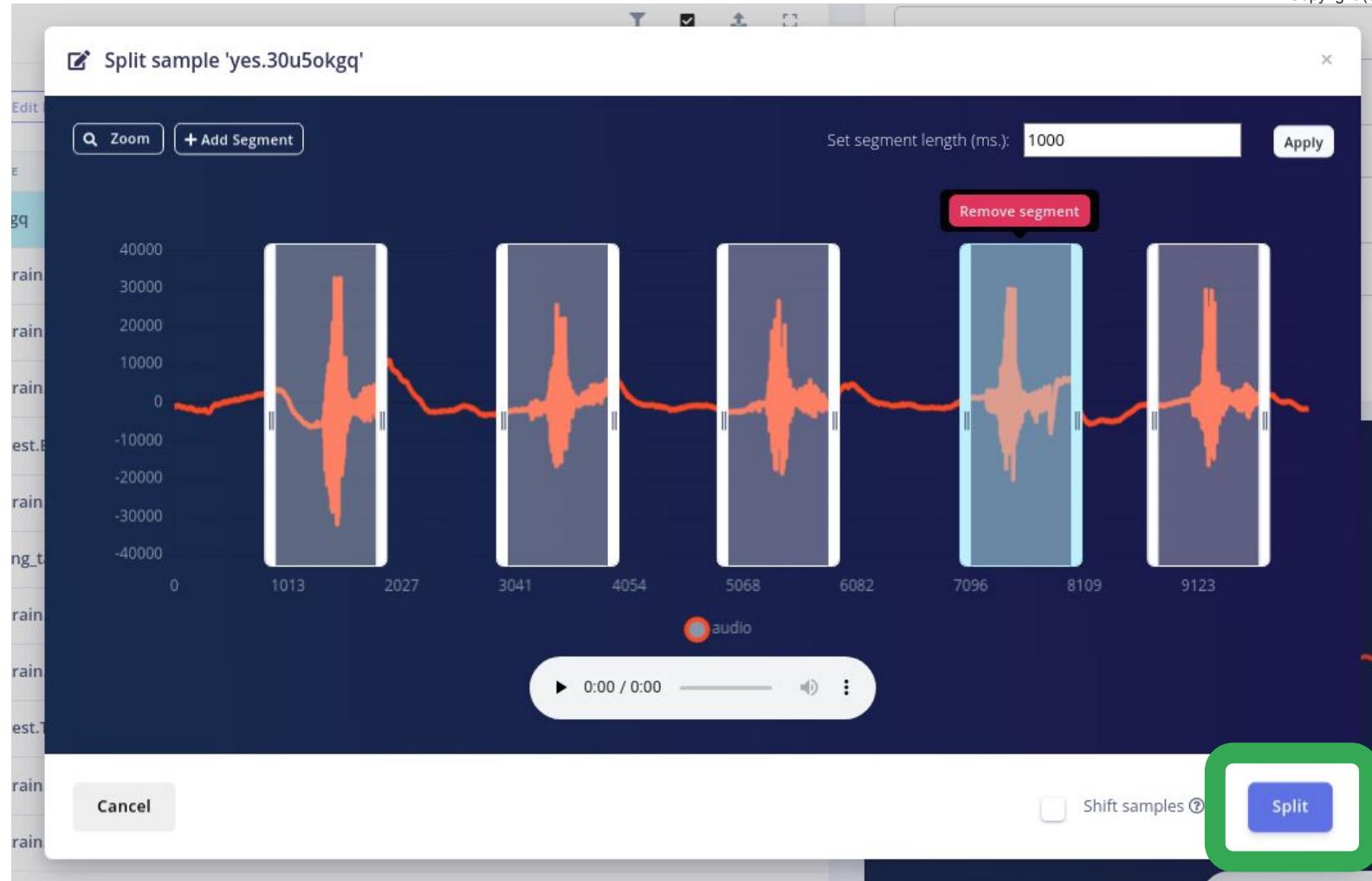
<input type="checkbox"/>	SAMPLE NAME	LABEL	ADDED	LENGTH	
<input type="checkbox"/>	yes.30u50kgq	yes	Today, 14:24:58	10s	<input type="button" value="::"/>
<input type="checkbox"/>	noise.orig_train.Hallway_1.wav.7...	noise	Today, 11:22:57		<input type="button" value="Rename"/>
<input type="checkbox"/>	noise.orig_train.Metro_1.wav.297...	noise	Today, 11:22:57		<input type="button" value="Edit label"/>
<input type="checkbox"/>	noise.orig_train.CafeTeria_1.wav....	noise	Today, 11:22:57		<input type="button" value="Move to test set"/>
<input type="checkbox"/>	noise.orig_test.Babble_4.wav.2000	noise	Today, 11:22:57		<input type="button" value="Disable"/>
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57		<input type="button" value="Crop sample"/>
<input type="checkbox"/>	noise.running_tap.wav.29000	noise	Today, 11:22:57		<input type="button" value="Split sample"/>
<input type="checkbox"/>	noise.orig_train.Station_1.wav.20...	noise	Today, 11:22:57		<input type="button" value="Download"/>
<input type="checkbox"/>					<input type="button" value="Delete"/>











DATA COLLECTED  
50m 39s

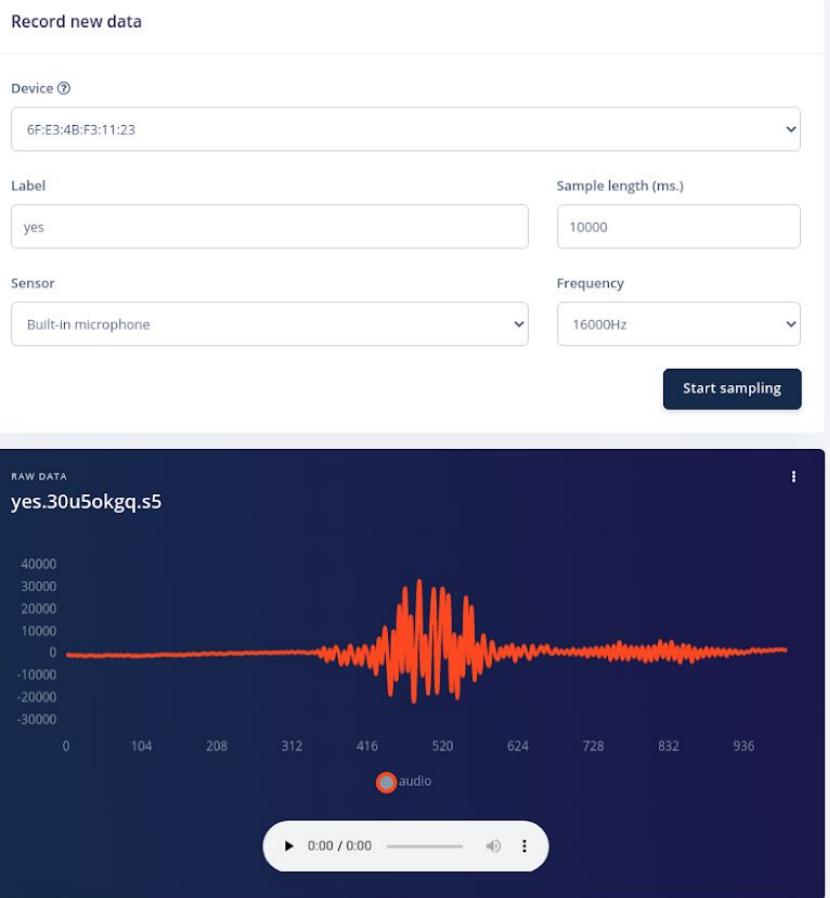
TRAIN / TEST SPLIT  
100% / 0% ⚠

Collected data

Delete selected (0) Edit labels (0) Move to test set (0) Enable selected (0) Disable selected (0)

<input type="checkbox"/>	SAMPLE NAME	LABEL	ADDED	LENGTH	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	yes.30u5okgq.s5	yes	Today, 14:31:19	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	yes.30u5okgq.s4	yes	Today, 14:31:19	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	yes.30u5okgq.s3	yes	Today, 14:31:19	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	yes.30u5okgq.s2	yes	Today, 14:31:19	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	yes.30u5okgq.s1	yes	Today, 14:31:19	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.orig_train.Metro_1.wav.297...	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.orig_train.CafeTeria_1.wav....	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.orig_test.Babble_4.wav.2000	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.running_tap.wav.29000	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>
<input type="checkbox"/>	noise.orig_train.Station_1.wav.20...	noise	Today, 11:22:57	1s	<span style="font-size: small;">⋮</span>

1 2 3 4 5 6 7 254 ... >



DATA ACQUISITION (SCITINYML22-KWS-TESTCLONE)

Training data   Test data   |   Export data



Did you know? You can capture data from any device or development board, or upload your existing datasets - [Show options](#)

DATA COLLECTED

40m 29s



TRAIN / TEST SPLIT

80% / 20% 

**Yours may say  
100% / 0%**

Collected data

SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
no.30u6lbcn.s5	no	Today, 14:40:46	1s	⋮
no.30u6lbcn.s4	no	Today, 14:40:46	1s	⋮
no.30u6lbcn.s3	no	Today, 14:40:46	1s	⋮
no.30u6lbcn.s2	no	Today, 14:40:46	1s	⋮
no.30u6lbcn.s1	no	Today, 14:40:46	1s	⋮
no.30u6k9u9.s5	no	Today, 14:40:13	1s	⋮
no.30u6k9u9.s4	no	Today, 14:40:13	1s	⋮

- Dashboard
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## DATA ACQUISITION - TESTING (SCITINYML22-KWS-TESTCLONE)

Training data

Test data

| Export data



**Did you know?** You can capture data from your device or upload your own or upload your existing dataset.

One or more of the labels in your dataset have a poor train / test split. Click to learn how to rebalance your dataset.

DATA COLLECTED

10m 20s



TRAIN

80% / 20%



### Collected data



SAMPLE NAME	LABEL	ADDED	LENGTH	⋮
noise.orig_train.Metro_1...	noise	Today, 11:22:57	1s	⋮
noise.orig_train.CafeTeri...	noise	Today, 11:22:57	1s	⋮
noise.orig_train.AirCond...	noise	Today, 11:22:57	1s	⋮

## Dataset train / test split ratio

X

**Training data** is used to train your model, and **testing data** is used to test your model's accuracy after training. We recommend an approximate 80/20 train/test split ratio for your data for every class (or label) in your dataset, although especially large datasets may require less testing data.

SUGGESTED TRAIN / TEST SPLIT

80% / 20%

### Labels in your dataset

The 'no' class has a poor train/test split ratio. To fix this, add or move samples to the training or testing data.

NO

100% / 0% (27s / 0s)

NOISE

80% / 20% (20m 22s / 5m 13s)

UNKNOWN

80% / 20% (19m 52s / 5m 7s)

YES

81% / 19% (22s / 5s)

### Perform train / test split

Use this option to rebalance your data, automatically splitting items between training and testing datasets.

**Warning: this action cannot be undone.**

Perform train / test split

## Collected data



SAMPLE NAME	LABEL	ADDED	LENGTH	
no.30u8qcvh.s1	no	Today, 15:22:58	1s	
no.30u6k9u9.s5	no	Today, 15:22:5		<a href="#">Rename</a>
no.30u6k9u9.s1	no	Today, 15:22:5		<a href="#">Edit label</a>
no.30u8qcvh.s9	no	Today, 15:22:4		<a href="#">Move to test set</a>
no.30u8qcvh.s7	no	Today, 15:22:4		<a href="#">Disable</a>
yes.30u8rq7l.s8	yes	Today, 15:20:1		<a href="#">Crop sample</a>
yes.30u8rq7l.s7	yes	Today, 15:20:1		<a href="#">Split sample</a>

[Delete](#)

## Dataset train / test split ratio



**Training data** is used to train your model, and **testing data** is used to test your model's accuracy after training. We recommend an approximate 80/20 train/test split ratio for your data for every class (or label) in your dataset, although especially large datasets may require less testing data.



### Labels in your dataset ②

The 'no' class has a poor train/test split ratio. To fix this, add or move samples to the training or testing data.



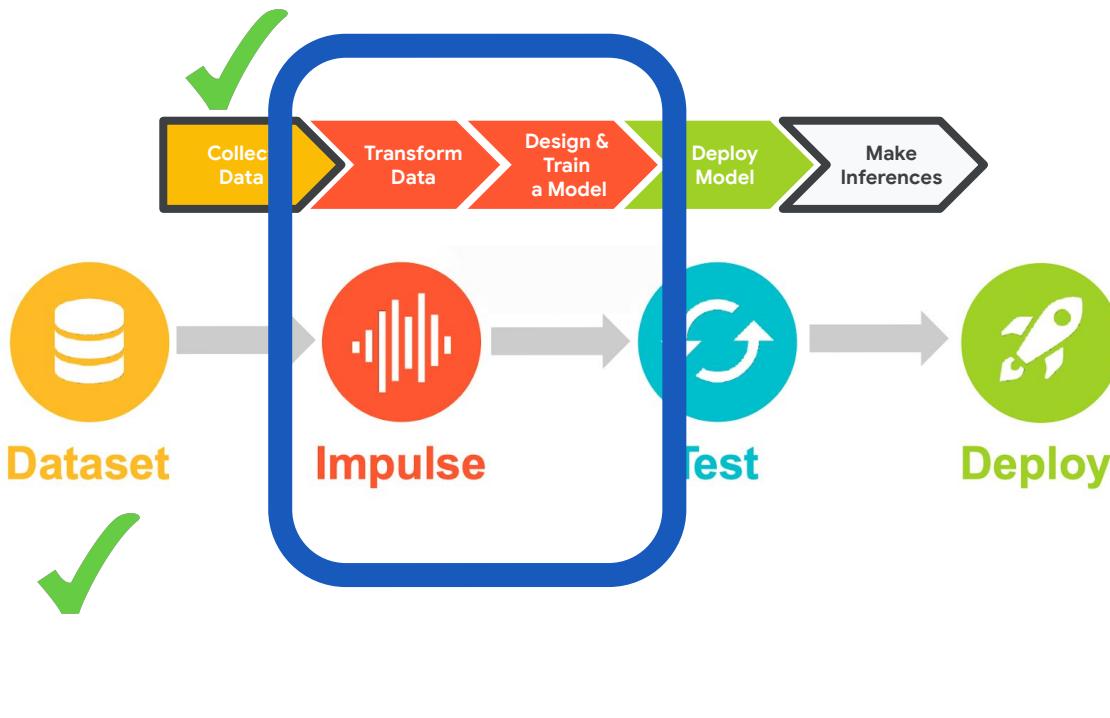
# Today's Agenda

- Preprocessing for Keyword Spotting
- Convolutional Neural Networks for Image Classification
- **Hands-on: KWS Data Collection with Edge Impulse**
- Hands-on: Training our Model with Edge Impulse
- Hands-on: Testing our Model in the Real World
- Summary

# Today's Agenda

- Preprocessing for Keyword Spotting
- Convolutional Neural Networks for Image Classification
- Hands-on: KWS Data Collection with Edge Impulse
- Hands-on: Training our Model with Edge Impulse**
- Hands-on: Testing our Model in the Real World
- Summary

# Edge Impulse Project Dashboard



- Dashboard
- Devices
- Data acquisition
- Impulse design
- Create impulse
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

## EDGE IMPULSE

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### CREATE IMPULSE (BRIAN\_PLANCHER-PROJECT-1)



Brian\_plancher



An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

#### Time series data



##### Axes

audio

##### Window size



1000 ms.

##### Window increase



500 ms.

##### Frequency (Hz)



16000



##### Zero-pad data



Add a processing block



Add a learning block



#### Output features



Save Impulse

- Dashboard
  - Devices
  - Data acquisition
  - Impulse design
  - Create impulse
  - EON Tuner
  - Retrain model
  - Live classification
  - Model testing
  - Versioning
  - Deployment
- 
- GETTING STARTED
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## CREATE IMPULSE (BRIAN\_PLANCHER-PROJECT-1)



Brian\_plancher



An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

**Time series data**

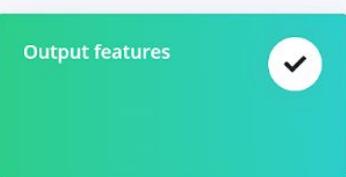
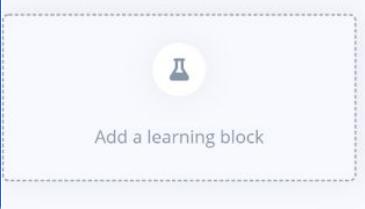
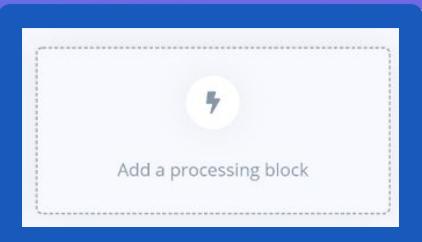
Axes  
audio

Window size ?  
1000 ms.

Window increase ?  
500 ms.

Frequency (Hz)  
16000 ?

Zero-pad data



Save Impulse

The screenshot shows the Edge Impulse web interface. On the left is a sidebar with various navigation links. The main area is titled "CREATE IMPULSE (SCITINYML22-KWS-TESTCLONE)". It includes a summary card with a waveform icon and the text "An impulse takes raw data, uses signal processing blocks to extract features, and then applies machine learning to classify it". Below this are several configuration sections:

- Time series data**: Includes "Input axes" set to "audio", "Window size" slider at 1000, "Window increase" slider at 500, "Frequency (Hz)" input field set to 16000, and a checked "Zero-pad data" checkbox.
- Output features**: A green button with a checkmark and a "Save Impulse" button.

A central modal window titled "Add a processing block" lists several processing blocks categorized by type:

- Audio (MFCC)**: Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice. Author: EdgeImpulse Inc. Add
- Audio (MFE)**: Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio. Author: EdgeImpulse Inc. Add
- Flatten**: Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks. Author: EdgeImpulse Inc. Add
- Image**: Preprocess and normalize image data, and optionally reduce the color depth. Author: EdgeImpulse Inc. Add
- Spectral Analysis**: Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time. Author: EdgeImpulse Inc. Add
- Spectrogram**: Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies. Author: EdgeImpulse Inc. Add

**⚡ Add a processing block**

Recommended based on your inputs

DESCRIPTION	AUTHOR	RECOMMENDED
Audio (MFCC) Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice.	EdgeImpulse Inc. ★	<b>Add</b>
Audio (MFE) Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.	EdgeImpulse Inc. ★	<b>Add</b>
Flatten Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	EdgeImpulse Inc.	<b>Add</b>
Image Preprocess and normalize image data, and optionally reduce the color depth.	EdgeImpulse Inc.	<b>Add</b>
Spectral Analysis Great for analyzing repetitive motion, such as data from accelerometers. Extracts the frequency and power characteristics of a signal over time.	EdgeImpulse Inc.	<b>Add</b>
Spectrogram Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	EdgeImpulse Inc.	<b>Add</b>

We'll keep things simple today and just add an MFCC but/and in future projects you can:

- **create your own blocks**
- **use multiple blocks**

<https://docs.edgeimpulse.com/docs/custom-blocks>



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#### CREATE IMPULSE (BRIAN\_PLANCHER-PROJECT-1)



Brian\_plancher



An impulse takes raw data, uses signal processing to extract features, and then uses a learning block to classify new data.

#### Time series data



##### Axes

audio

##### Window size



1000 ms.

##### Window increase



500 ms.

##### Frequency (Hz)



16000



##### Zero-pad data



#### Audio (MFCC)



##### Name

MFCC

##### Input axes

audio

Add a learning block

#### Output features



Save Impulse

Add a processing block

## 🧪 Add a learning block

Some learning blocks have been hidden based on the data in your project.

DESCRIPTION	AUTHOR	RECOMMENDED
<b>Classification (Keras)</b> Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	EdgelImpulse Inc. ★	<button>Add</button>
<b>Regression (Keras)</b> Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.	EdgelImpulse Inc.	<button>Add</button>

Cancel

Add a processing block

**Time series data**

Axes  
audio

Window size  1000 ms.

Window increase  500 ms.

Frequency (Hz)  16000

Zero-pad data 

**Audio (MFCC)**

Name

Input axes  audio

**Classification (Keras)**

Name

Input features  MFCC

Output features 3 (no, unknown, yes)

**Output features**

3 (no, unknown, yes)

**Save Impulse**

Add a processing block 

Add a learning block 

**EDGE IMPULSE**

CREATE IMPULSE (BRIAN\_PLANCHER-PROJECT-1)

✓ Successfully stored impulse. Configure the signal processing and learning blocks in the navigation bar.

**Time series data**

Axes  
audio

Window size  1000 ms.

Window increase  500 ms.

Frequency (Hz)

Zero-pad data

**Audio (MFCC)**

Name

Input axes  audio

**Classification (Keras)**

Name

Input features  MFCC

Output features  
3 (no, unknown, yes)

**Output features**

3 (no, unknown, yes)

**Save Impulse**

**Dashboard**

**Devices**

**Data acquisition**

- Impulse design
- Create impulse
- MFCC
- NN Classifier

**EON Tuner**

**Retrain model**

**Live classification**

**Model testing**

**Versioning**

**Deployment**

**GETTING STARTED**

MFCC (BRIAN\_PLANCHER-PROJECT-1)

#1 ▾ Click here to add annotations or this version

Parameters | Generate features

Generate features

Brian\_plancher

### Raw data

▶ 0:00 / 0:01 ⏸

unknown.2hvfrhdt (unknown)

Raw data visualization showing a waveform. The y-axis ranges from -20000 to 20000. The waveform is mostly flat at 0 until frame 802, then shows a burst of energy followed by a steady-state period. A red circle labeled "audio" is located on the right side of the visualization.

### Raw features

0, ...

### DSP result

#### Cepstral Coefficients

### Parameters

#### Mel Frequency Cepstral Coefficients

Number of coefficients

13

Frame length

0.02

Processed features

127

MFCC (SCITINYML22-KWS-TESTCLONE)

 Brian\_plancher

#1 ▾ Click to set a description for this version

Parameters Generate features

### Training set

Data in training set 40m 29s

Classes 4 (no, noise, unknown, yes)

Training windows 2,429

### Feature explorer

No features generated yet.

?

Generate features



MFCC (SCITINYML22-KWS-TESTCLONE)

#1 ▾ Click to set a description for this version

Parameters [Generate features](#)

Training set

Data in training set 40m 29s

Classes 4 (no, noise, unknown, yes)

Training windows 2,429

Generating features...

Feature explorer [?](#)

No features generated yet.

Feature generation output

[Cancel](#)

Creating job... OK (ID: 2596741)

Scheduling job in cluster...

Job started

Creating windows from 2429 files...

[2/3] Pre-caching files...

[3/3] Pre-caching files...

Pre-caching files OK

[ 1/2429] Creating windows from files...

## Feature explorer (2,494 samples)

?

X Axis

Y Axis

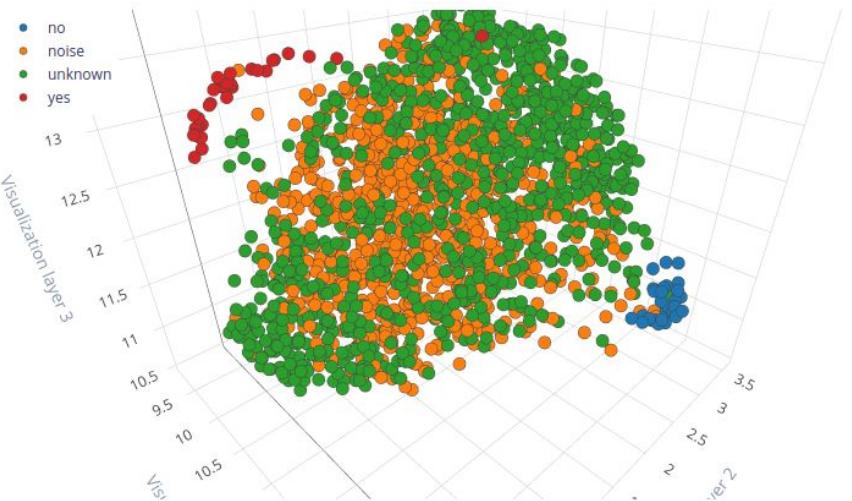
Z Axis

Visualization layer 1

Visualization layer 2

Visualization layer 3

- no
- noise
- unknown
- yes

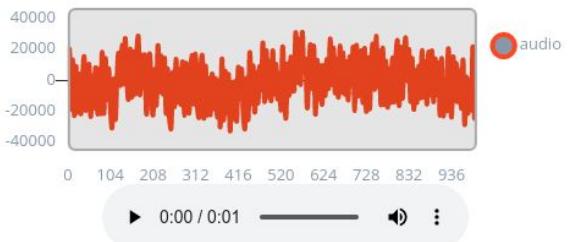


noise.pink\_noise.wav.20000

Label: noise

[View sample](#)

[View features](#)



If you can visually see the clustering of the data then it is easier for the ML model to learn!  
(But its not required and provides no guarantees)

## Feature explorer (2,494 samples)

?

X Axis

Y Axis

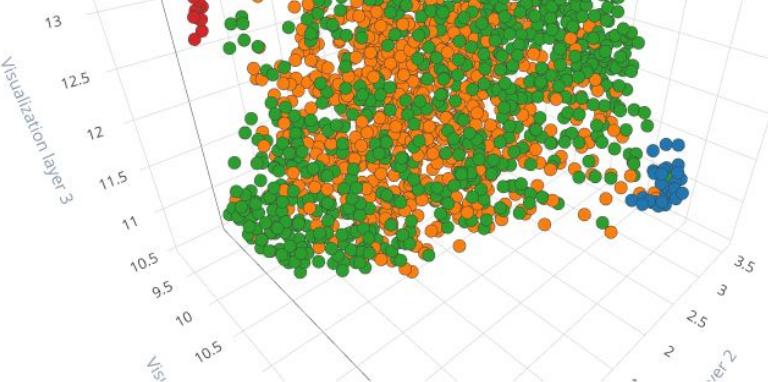
Z Axis

Visualization layer 1

Visualization layer 2

Visualization layer 3

- no
- noise
- unknown
- yes

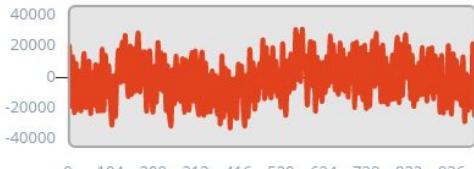


**noise.pink\_noise.wav.20000**

Label: noise

[View sample](#)

[View features](#)



▶ 0:00 / 0:01 ━━ ⏪ ⏴ ⏵

## Feature explorer (1,506 samples)

?

X Axis

Y Axis

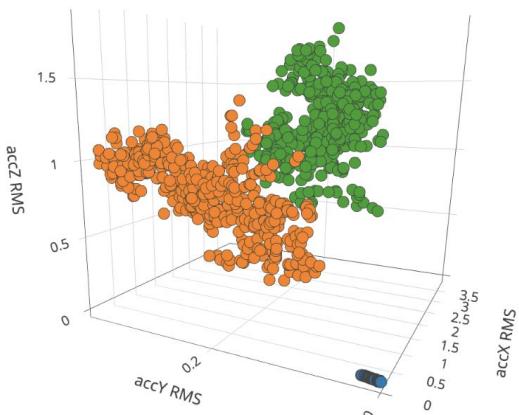
Z Axis

accX RMS

accY RMS

accZ RMS

- idle
- updown
- walk

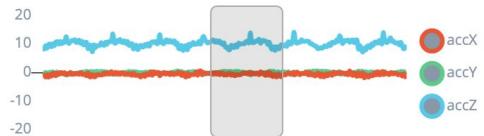


**updown.9.1cjh52qu**

Window: 4608 - 6608 ms.

Label: updown

[View features](#)



MFCC (SCITINYML22-KWS-CLONE-V2)

#1 ▾ Click to set a description for this version

Parameters [Generate features](#)

### Training set

Data in training set 41m 34s

Classes 4 (no, noise, unknown, yes)

Training windows 2,494

[Generate features](#)

### Feature generation output

```
Still running...
    completed 150 / 500 epochs
    completed 200 / 500 epochs
Still running...
    completed 250 / 500 epochs
    completed 300 / 500 epochs
Still running...
    completed 350 / 500 epochs
    completed 400 / 500 epochs
Still running...
    completed 450 / 500 epochs
Wed Apr 27 19:10:09 2022 Finished embedding
Reducing dimensions for visualizations OK
Job completed
```

### Feature explorer (2,494 samples)

X Axis

Visualization layer 1

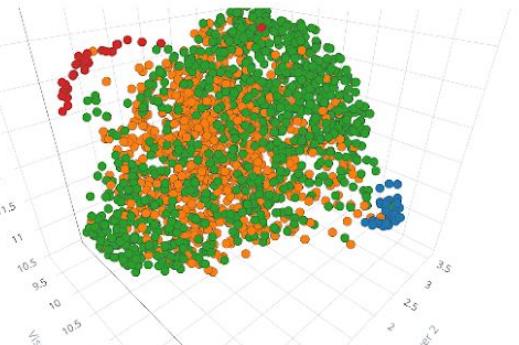
Y Axis

Visualization layer 2

Z Axis

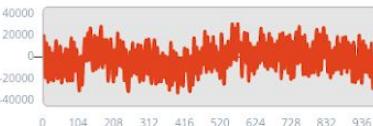
Visualization layer 3

- no
- noise
- unknown
- yes



noise.pink\_noise.wav.20000

Label: noise

[View sample](#)[View features](#)

### On-device performance

 PROCESSING TIME  
168 ms. PEAK RAM USAGE  
17 KB

NN CLASSIFIER (SCITINYML22-KWS-TESTCLONE)

#1 ▾ Click to set a description for this version

Neural Network settings

- Switch to Keras (expert) mode
- Edit as iPython notebook

Training settings

Number of training cycles

100

Learning rate

0.005

Validation set size

20

%

Auto-balance dataset



Audio training options

Data augmentation



Neural network architecture

Architecture presets 1D Convolutional (Default) 2D Convolutional

Input layer (650 features)



Reshape layer (13 columns)



1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)

# Model Design with Edge Impulse

Pre-made neural network  
“blocks” that you can add!

Neural Network settings

Training settings

Number of training cycles ② 50

Learning rate ② 0.0001

Minimum confidence rating ② 0.80

Neural network architecture

Input layer (637 features)

Reshape layer (13 columns)

1D conv / pool layer (30 neurons, 5 kernel size)

1D conv / pool layer (10 neurons, 5 kernel size)

Flatten layer

Add an extra layer

Output layer (5 features)

The screenshot shows the 'Neural Network settings' and 'Neural network architecture' sections of the Edge Impulse interface. In the training settings, the number of cycles is set to 50, learning rate to 0.0001, and minimum confidence rating to 0.80. The architecture consists of an input layer (637 features), a reshape layer (13 columns), two 1D conv/pool layers (30 and 10 neurons, 5 kernel size), a flatten layer, and an output layer (5 features). An 'Add an extra layer' button is also visible.

# Model Design with Edge Impulse

“Expert” mode to write  
your own TensorFlow code

## Neural network architecture

```
1 import tensorflow as tf
2 from tensorflow.keras.models import Sequential
3 from tensorflow.keras.layers import Dense, InputLayer,
4     Dropout, Conv1D, Conv2D, Flatten, Reshape, MaxPooling1D,
5     MaxPooling2D, BatchNormalization
6 from tensorflow.keras.optimizers import Adam
7 sys.path.append('./resources/libraries')
8 import ei_tensorflow.training
9
10 # model architecture
11 model = Sequential()
12 channels = 1
13 columns = 13
14 rows = int(input_length / (columns * channels))
15 model.add(Reshape((rows, columns, channels), input_shape
16                   =(input_length, )))
17 model.add(Conv2D(8, kernel_size=3, activation='relu',
18                 kernel_constraint=tf.keras.constraints.MaxNorm(1),
19                 padding='same'))
20 model.add(MaxPooling2D(pool_size=2, strides=2, padding
21                   ='same'))
22 model.add(Dropout(0.25))
23 model.add(Conv2D(16, kernel_size=3, activation='relu',
24                 kernel_constraint=tf.keras.constraints.MaxNorm(1),
25                 padding='same'))
26 model.add(MaxPooling2D(pool_size=2, strides=2, padding
27                   ='same'))
28 model.add(Dropout(0.25))
29 model.add(Flatten())
30 model.add(Dense(classes, activation='softmax', name='y_pred'))
```

Start training

## Neural network architecture

Architecture presets ⓘ 1D Convolutional (Default) 2D Convolutional

Input layer (650 features)

Reshape layer (13 columns)

1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

1D conv / pool layer (16 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

Flatten layer

Add an extra layer

Output layer (3 features)

Start training

## Neural network architecture

```

1 import tensorflow as tf
2 from tensorflow.keras.models import Sequential
3 from tensorflow.keras.layers import Dense, InputLayer, Dropout, Conv1D, Conv2D,
4   Flatten, Reshape, MaxPooling1D, MaxPooling2D, BatchNormalization,
5   TimeDistributed
6 from tensorflow.keras.optimizers import Adam
7
8 # model architecture
9
10 model.add(Reshape((int(input_length / 13), 13), input_shape=(input_length, )))
11 model.add(Conv1D(8, kernel_size=3, activation='relu', padding='same'))
12 model.add(MaxPooling1D(pool_size=2, strides=2, padding='same'))
13 model.add(Conv1D(16, kernel_size=3, activation='relu', padding='same'))
14 model.add(MaxPooling1D(pool_size=2, strides=2, padding='same'))
15 model.add(Dropout(0.25))
16 model.add(Flatten())
17 model.add(Dense(classes, activation='softmax', name='y_pred'))
18
19 # this controls the learning rate
20 opt = Adam(lr=0.005, beta_1=0.9, beta_2=0.999)
21 # this controls the batch size, or you can manipulate the tf.data.Dataset objects
22 # yourself
23 BATCH_SIZE = 32
24 train_dataset = train_dataset.batch(BATCH_SIZE, drop_remainder=False)
25 validation_dataset = validation_dataset.batch(BATCH_SIZE, drop_remainder=False)
26 callbacks.append(BatchLoggerCallback(BATCH_SIZE, train_sample_count))
27
28 # train the neural network
29 model.compile(loss='categorical_crossentropy', optimizer=opt, metrics=['accuracy'])
30 model.fit(train_dataset, epochs=100, validation_data=validation_dataset, verbose=2,
31           callbacks=callbacks)

```

## Neural network architecture

Architecture presets ② 1D Convolutional (Default) 2D Convolutional

Input layer (650 features)

Reshape layer (13 columns)

1D conv / pool layer (8 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

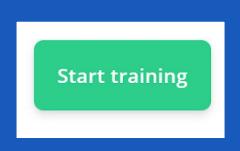
1D conv / pool layer (16 neurons, 3 kernel size, 1 layer)

Dropout (rate 0.25)

Flatten layer

Add an extra layer

Output layer (3 features)

Start training

## Neural network architecture

```
1 import tensorflow as tf
2 from tensorflow.keras.models import Sequential
3 from tensorflow.keras.layers import Dense, InputLayer, Dropout, Conv1D, Conv2D,
4     Flatten, Reshape, MaxPooling1D, MaxPooling2D, BatchNormalization,
5     TimeDistributed
6 from tensorflow.keras.optimizers import Adam
7
8 # model architecture
9 model = Sequential()
10 model.add(Reshape((int(input_length / 13), 13), input_shape=(input_length, )))
11 model.add(Conv1D(8, kernel_size=3, activation='relu', padding='same'))
12 model.add(MaxPooling1D(pool_size=2, strides=2, padding='same'))
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25 validation_dataset = validation_dataset.batch(BATCH_SIZE, drop_remainder=False)
```

For now just stick with the defaults but/and you can easily design **any model** you want and use **any optimizer** you want using **TensorFlow!**

## Training output

```
Epoch 95/100  
4/4 - 0s - loss: 0.1044 - accuracy: 0.9500 - val_loss: 0.2934 - val_accuracy: 0.9231  
Epoch 96/100  
4/4 - 0s - loss: 0.0256 - accuracy: 1.0000 - val_loss: 0.3830 - val_accuracy: 0.8846  
Epoch 97/100  
4/4 - 0s - loss: 0.0523 - accuracy: 0.9800 - val_loss: 0.4366 - val_accuracy: 0.8462  
Epoch 98/100  
4/4 - 0s - loss: 0.0451 - accuracy: 0.9800 - val_loss: 0.4265 - val_accuracy: 0.8846  
Epoch 99/100  
4/4 - 0s - loss: 0.0514 - accuracy: 0.9900 - val_loss: 0.3926 - val_accuracy: 0.8846  
Epoch 100/100  
4/4 - 0s - loss: 0.0348 - accuracy: 0.9900 - val_loss: 0.3571 - val_accuracy: 0.9231  
Finished training
```



Training Set



Validation Set

# Final Accuracy

Model

Last training performance (validation set)

ACCURACY **96.6%** LOSS **0.09**

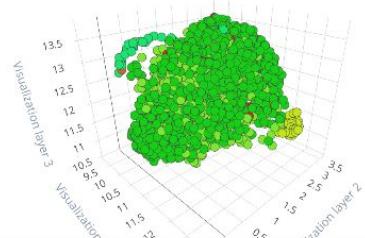
Confusion matrix (validation set)

	NO	NOISE	UNKNOWN	YES
NO	100%	0%	0%	0%
NOISE	0%	96.4%	3.6%	0%
UNKNOWN	0%	2.5%	97.1%	0.4%
YES	0%	0%	20%	80%
F1 SCORE	1.00	0.97	0.96	0.80

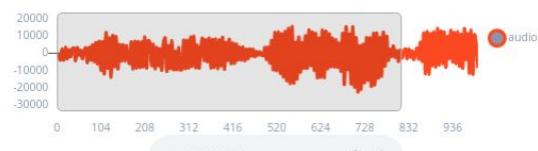
Feature explorer (full training set) ⓘ

Legend:

- no - correct
- noise - correct
- unknown - correct
- yes - correct
- noise - incorrect
- unknown - incorrect
- yes - incorrect



noise.orig\_test.Neighbor\_6.wav.8000  
Label: noise  
Predicted: noise  
[View sample](#) [View features](#)



On-device performance ⓘ

INFERENCING TIME **11 ms.** PEAK RAM USAGE **5.0K** FLASH USAGE **34.8K**

Final Accuracy

Accuracy Breakdown

Model

Last training performance (validation set)

ACCURACY 96.6% LOSS 0.09

Confusion matrix (validation set)

	NO	NOISE	UNKNOWN	YES
NO	100%	0%	0%	0%
NOISE	0%	96.4%	3.6%	0%
UNKNOWN	0%	2.5%	97.1%	0.4%
YES	0%	0%	20%	80%
F1 SCORE	1.00	0.97	0.96	0.80

Feature explorer (full training set) ⑦

Legend:

- no - correct
- noise - correct
- unknown - correct
- yes - correct
- noise - incorrect
- unknown - incorrect
- yes - incorrect

3D scatter plot showing feature distributions across three layers of the model.

noise.orig\_test.Neighbor\_6.wav.8000

Label: noise  
Predicted: noise  
[View sample](#) [View features](#)

On-device performance ⑦

INFERENCING TIME 11 ms. PEAK RAM USAGE 5.0K FLASH USAGE 34.8K

2D audio waveform visualization.

# Confusion Matrix

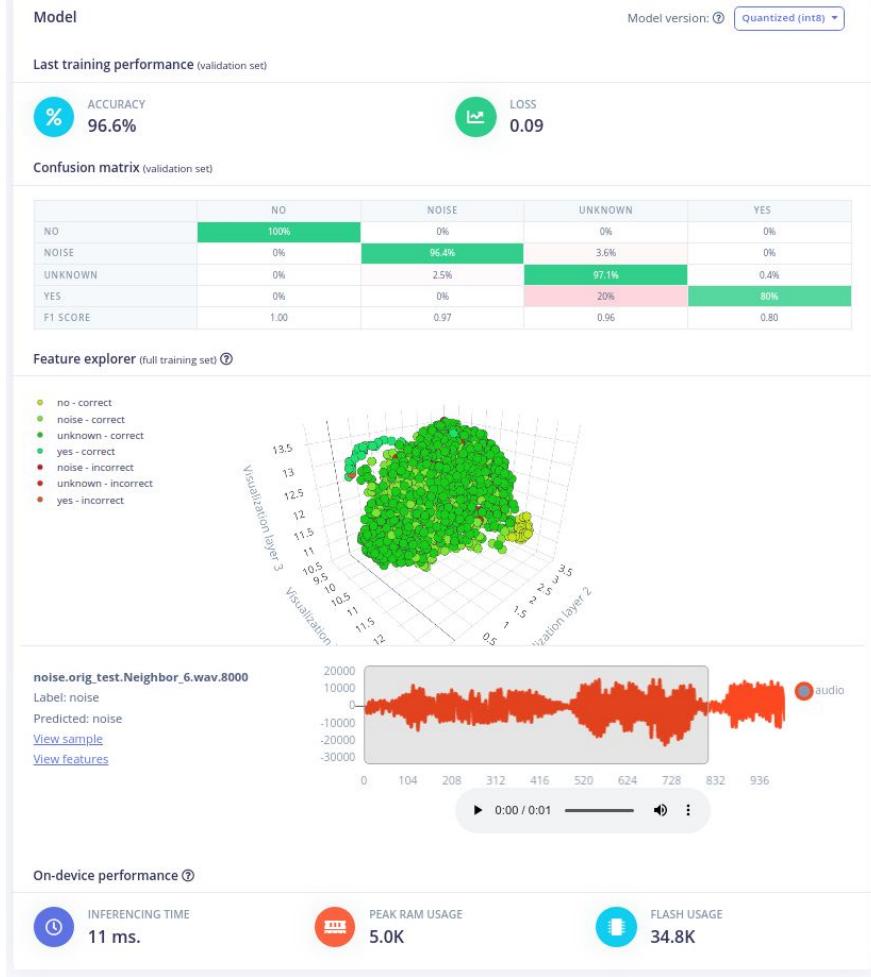
	Actual Output = Yes	Actual Output = No
Predicted Output = Yes	<b># of True Positive</b>	<b># of False Positive <i>Type 1 Error</i></b>
Predicted Output = No	<b># of False Negative <i>Type 2 Error</i></b>	<b># of True Negative</b>

Final Accuracy

Accuracy Breakdown

Feature Explorer

Individual Data Points



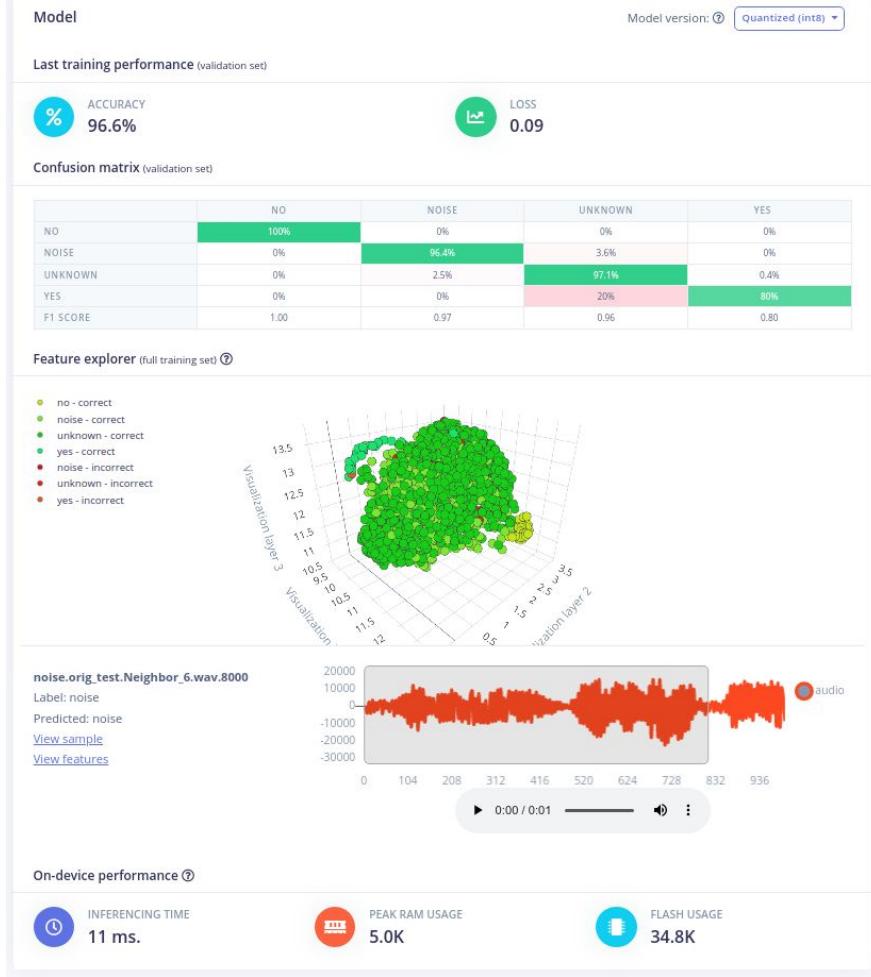
Final Accuracy

Accuracy Breakdown

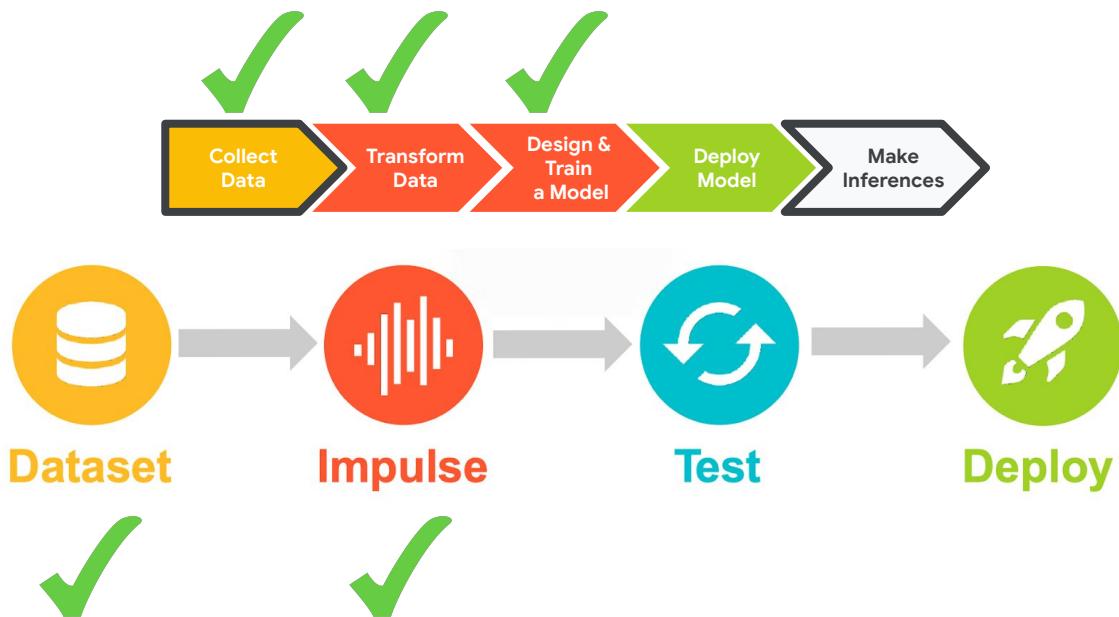
Feature Explorer

Individual Data Points

Expected runtime/memory



# Edge Impulse Project Dashboard



- Dashboard
- Devices
- Data acquisition
- Impulse design
- Create impulse
- MFCC
- NN Classifier
- EON Tuner
- Retrain model
- Live classification
- Model testing
- Versioning
- Deployment

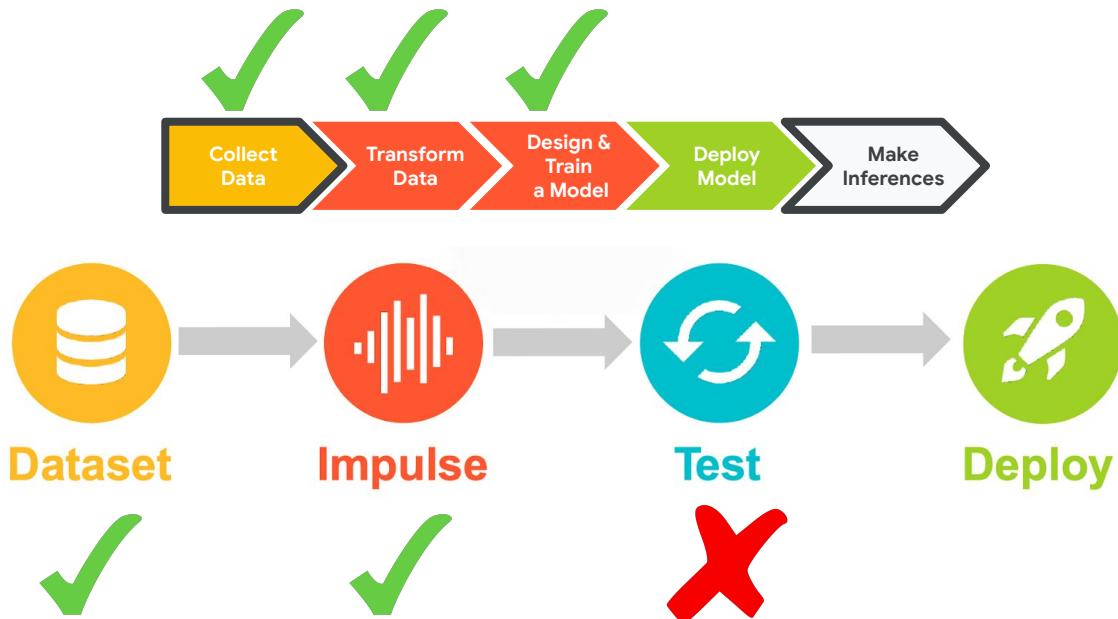
# Today's Agenda

- Preprocessing for Keyword Spotting
- Convolutional Neural Networks for Image Classification
- Hands-on: KWS Data Collection with Edge Impulse
- Hands-on: Training our Model with Edge Impulse**
- Hands-on: Testing our Model in the Real World
- Summary

# Today's Agenda

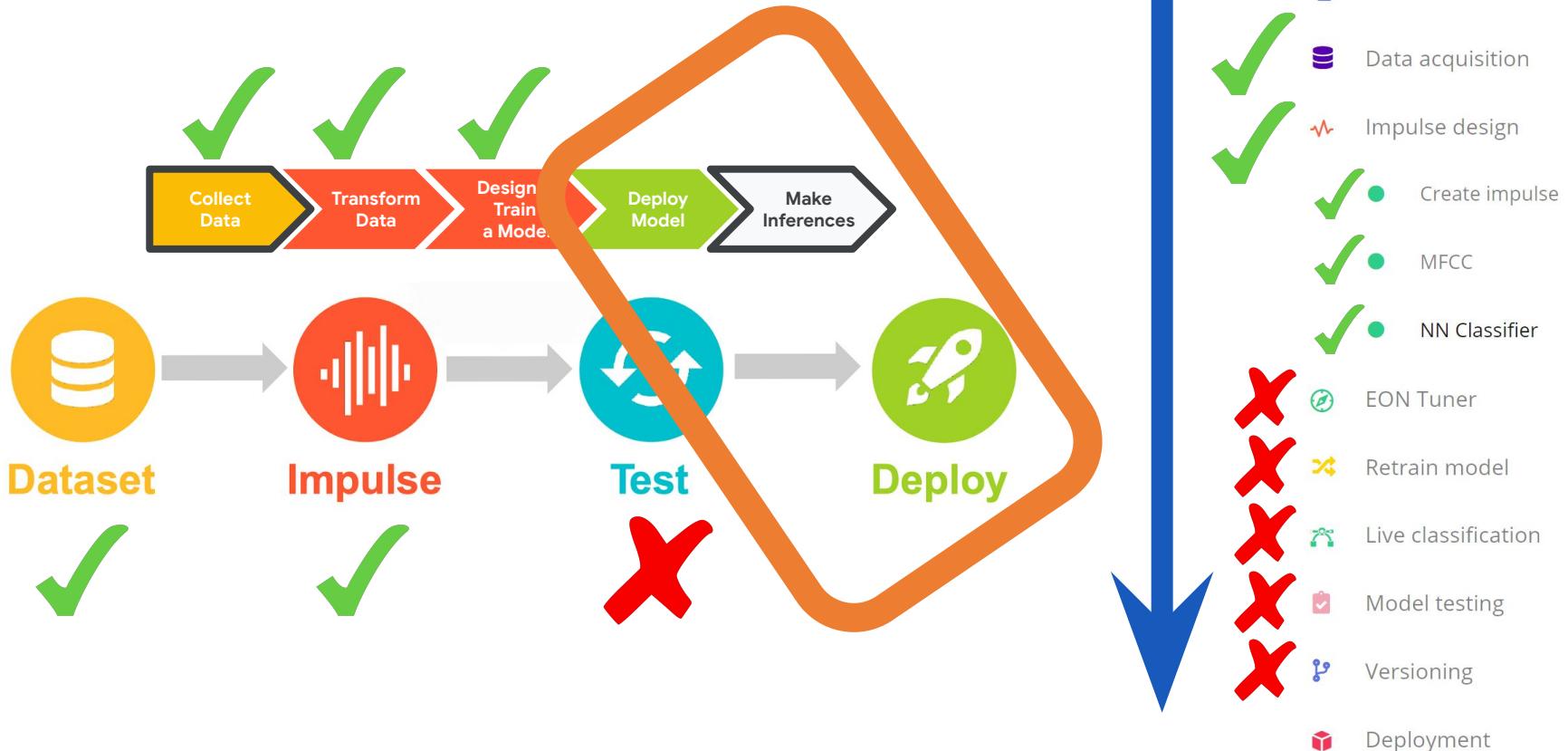
- Preprocessing for Keyword Spotting
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# Edge Impulse Project Dashboard



- Dashboard
  - Devices
  - Data acquisition
  - Impulse design
  - Create impulse
  - MFCC
  - NN Classifier
  - EON Tuner
  - Retrain model
  - Live classification
  - Model testing
  - Versioning
  - Deployment
- A large blue downward-pointing arrow is positioned to the left of the legend, pointing from the bottom of the dashboard area towards the list of features.

# Edge Impulse Project Dashboard



## Your devices

Devices

Impulse design

Create impulse

MFCC

NN Classifier

 Collect data

X

You can collect data from development boards, from your own devices, or by uploading an existing dataset.

**Connect a fully supported development board**

Get started with real hardware from a wide range of silicon vendors - fully supported by Edge Impulse.

[Browse dev boards](#)

REMOTE ... LAST SEEN



NAME

phone\_kunh8zjd

camera, ... Today, 16:24:48

**Use your mobile phone**

Use your mobile phone to capture movement, audio or images, and even run your trained model locally. No app required.

[Show QR code](#)

camera, ... Jun 21 2021, 18:41:37

[+ Connect a new device](#)

## Your devices

These are devices that are connected to the Edge Impulse studio.

## NAME

 phone\_kunh8zjd computer\_kq77e063

REMOTE ... LAST SEEN

camera, ... Today, 16:24:48

Jun 21 2021, 18:41:37

Devices

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Show QR code



## Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images? Collecting audio? Collecting motion?

Switch to classification mode

</> This client is [open source](#).

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 Collecting images? Collecting audio? Collecting motion?[Switch to classification mode](#)</> This client is [open source](#). Classifier

## Building project...

Job started

[Switch to data collection mode](#)</> This client is [open source](#).

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[Browse dev boards](#)

REMOTE ... LAST SEEN

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camera, ... Today, 16:24:48

Jun 21 2021, 18:41:37



## Connected as phone\_kunh8zjd

You can collect data from this device from the **Data acquisition** page in the Edge Impulse studio.

 Collecting images? Collecting audio? Collecting motion?[Switch to classification mode](#)</> This client is [open source](#).

## Classifier



## Building project...

Job started

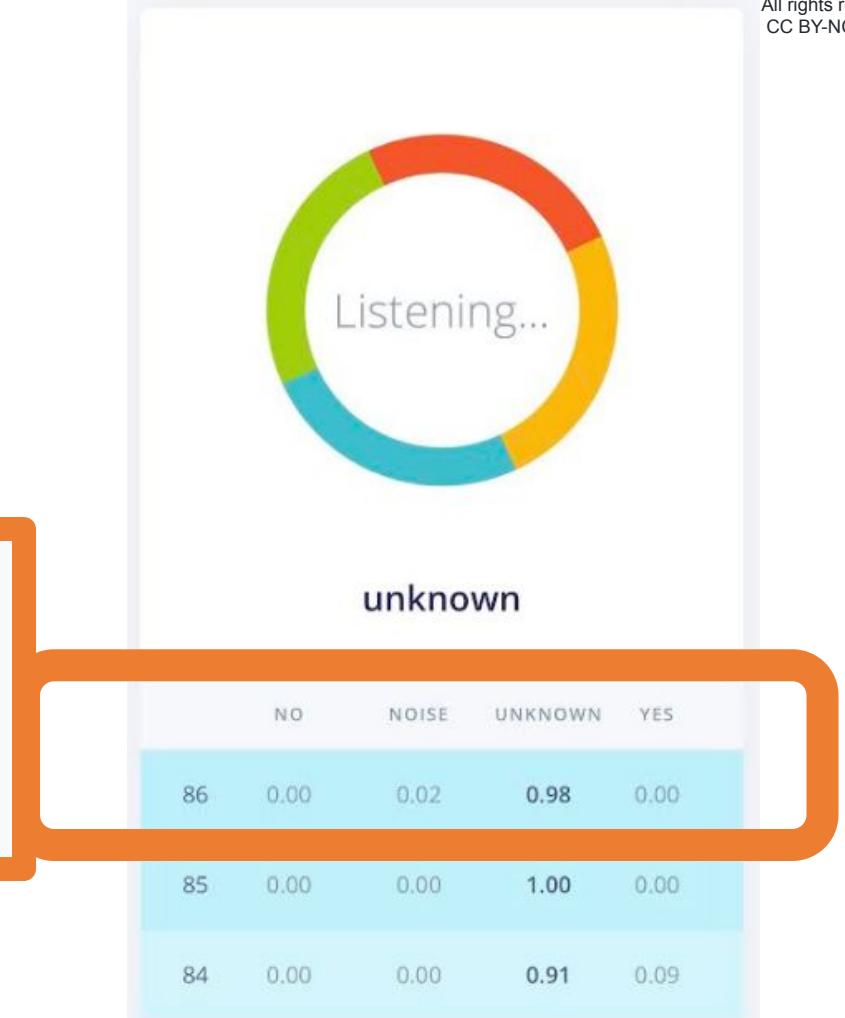
[Switch to data collection mode](#)</> This client is [open source](#).

unknown

NO	NOISE	UNKNOWN	YES
86	0.00	0.02	<b>0.98</b>
85	0.00	0.00	<b>1.00</b>
84	0.00	0.00	<b>0.91</b>

# Deploy and Test your Model

Shows the **score** for **(confidence that the current sounds is)** each of the various keywords and unknown and bolds the highest score.



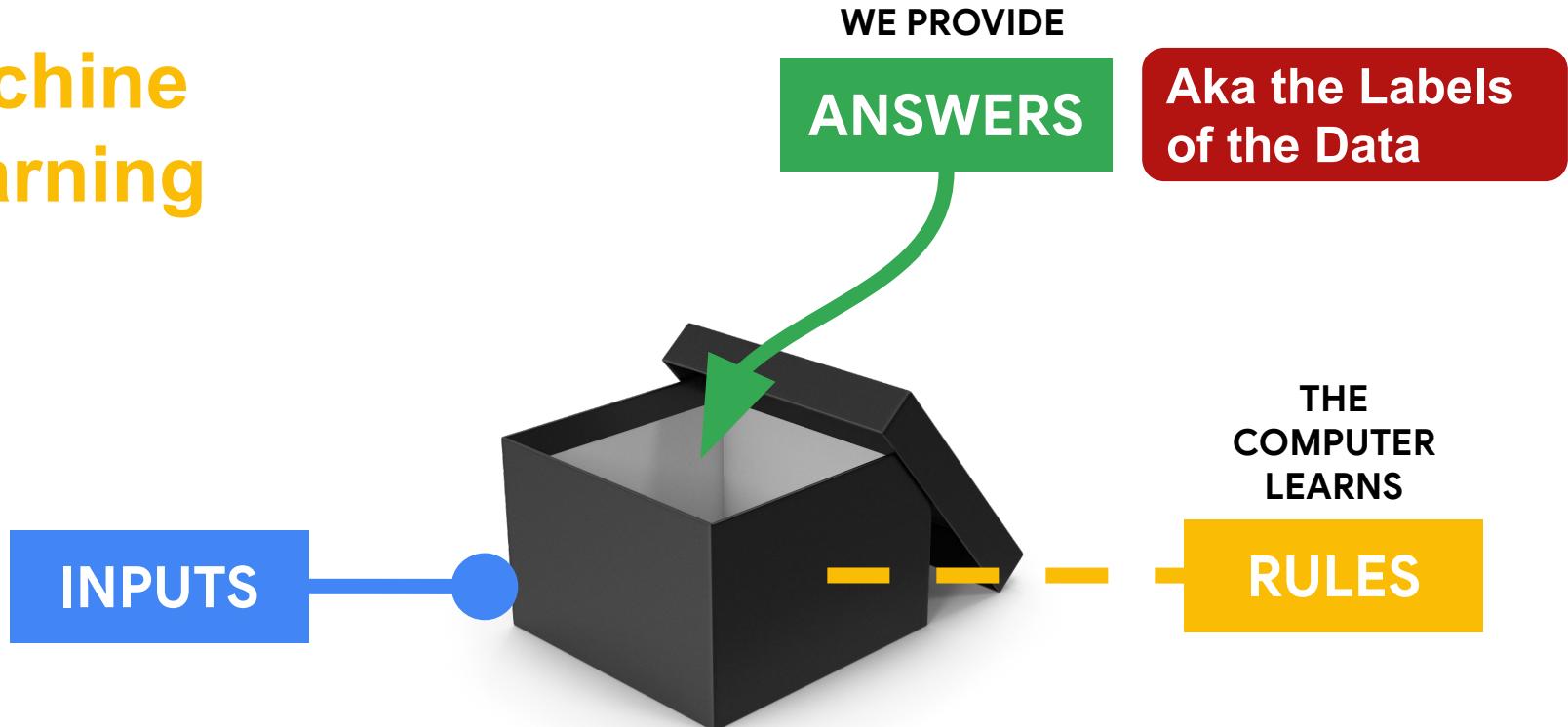
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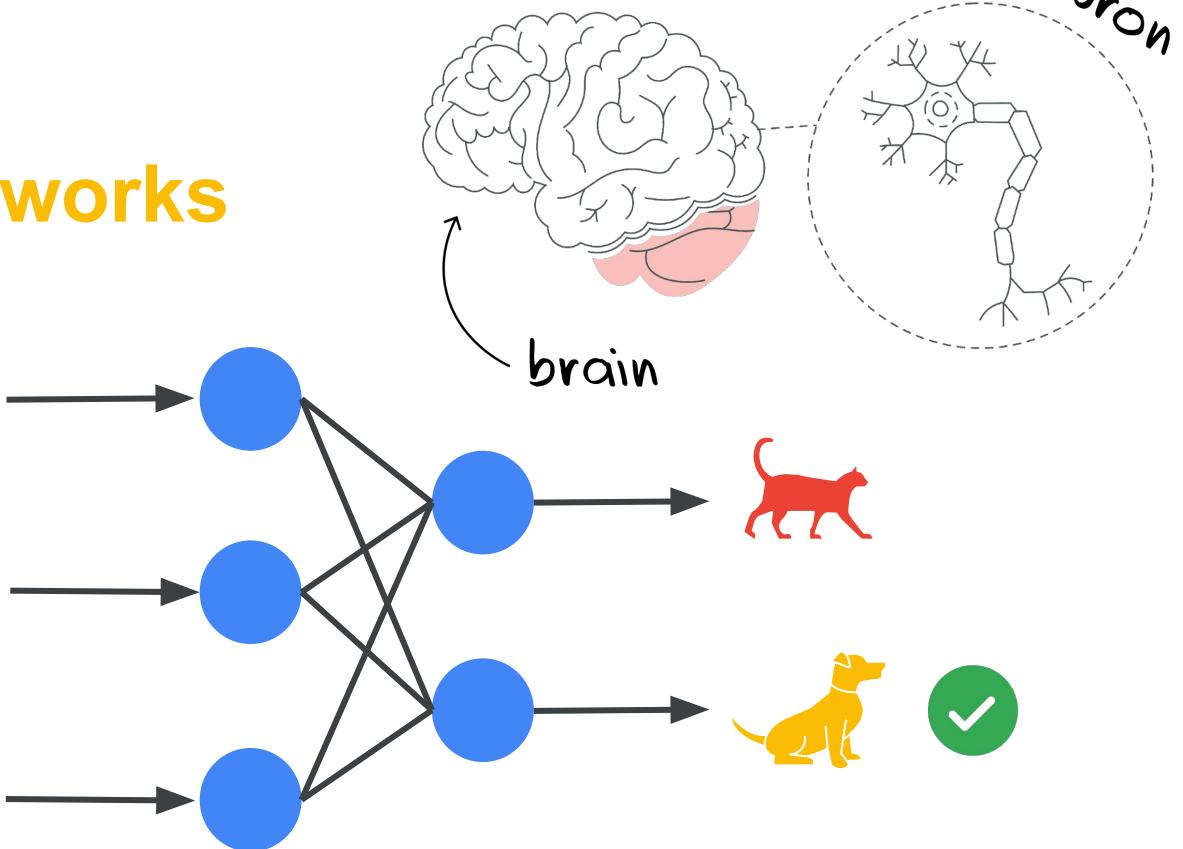
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# Machine Learning



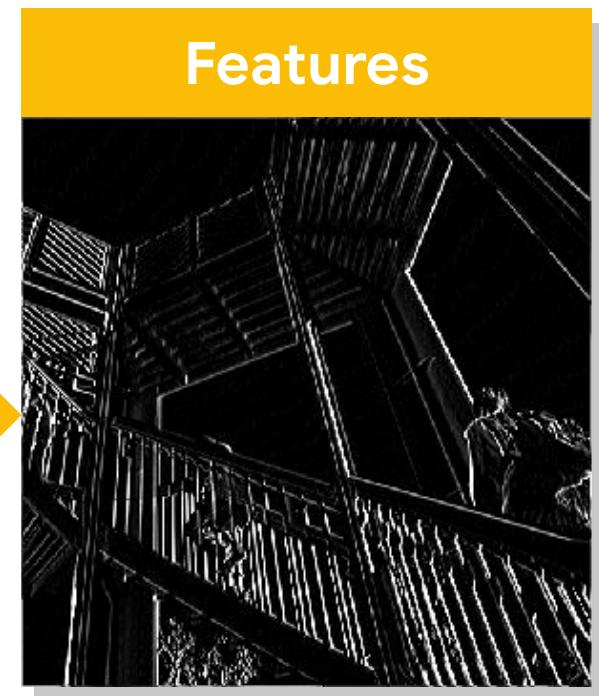
# Deep Learning with Neural Networks



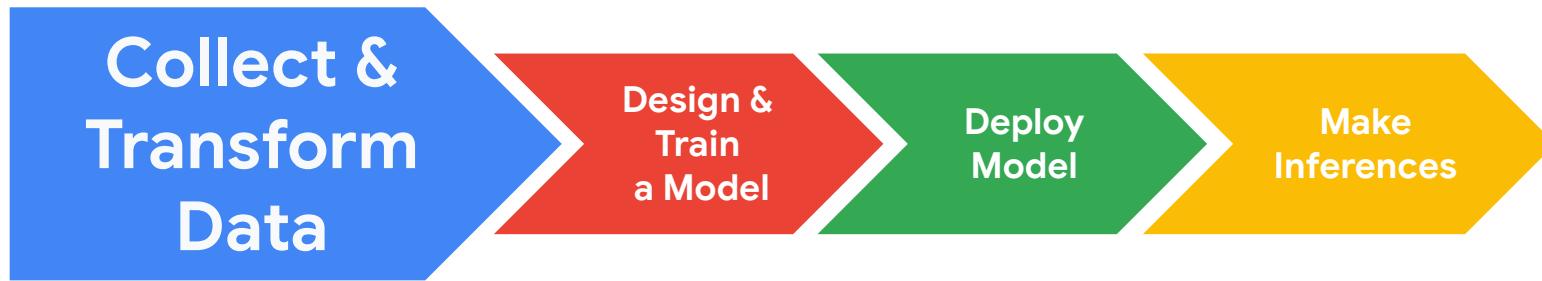
# Features can be found with **Convolutions**



-1	0	1
-2	0	2
-1	0	1

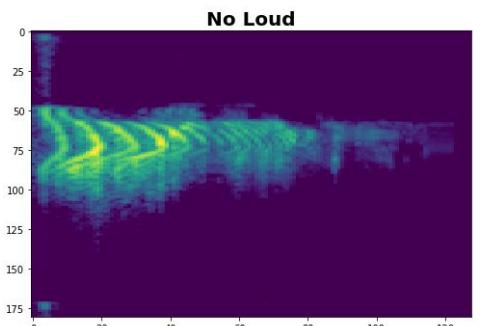
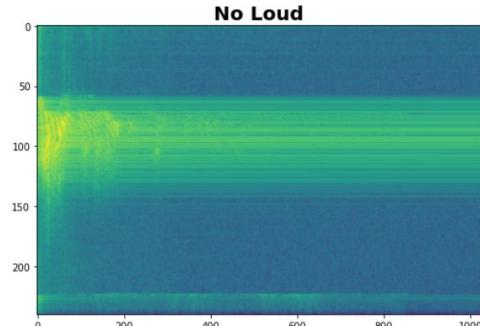
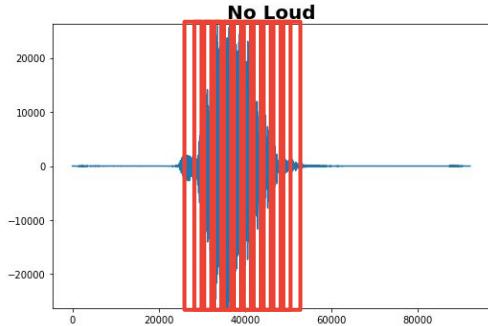
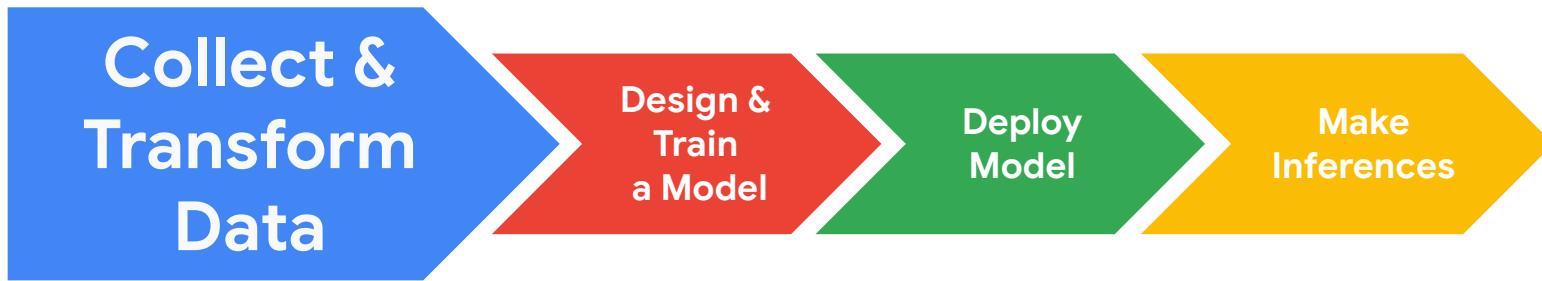


# The (Tiny) Machine Learning Workflow

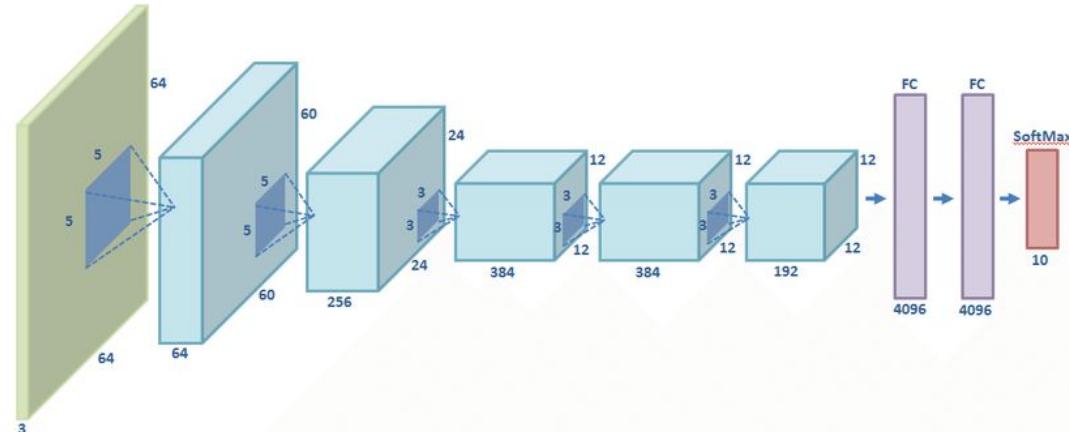
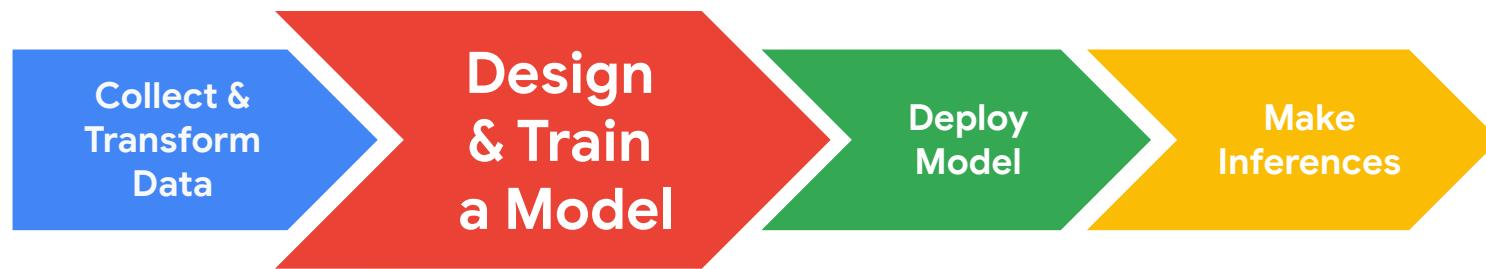


If ML is going to be everywhere  
we need to consider how to best  
collect **GOOD** data **RESPONSIBLY**

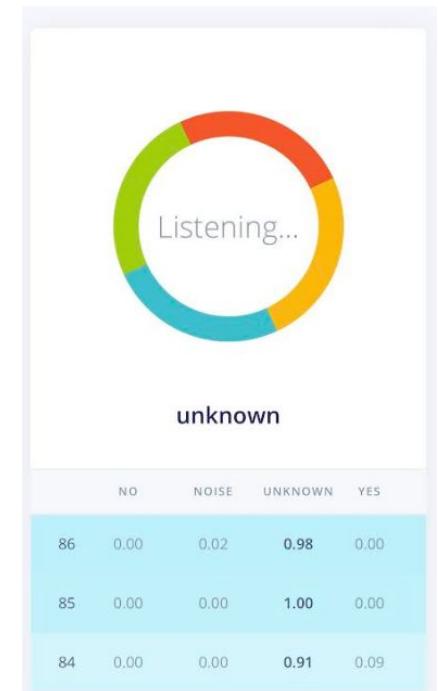
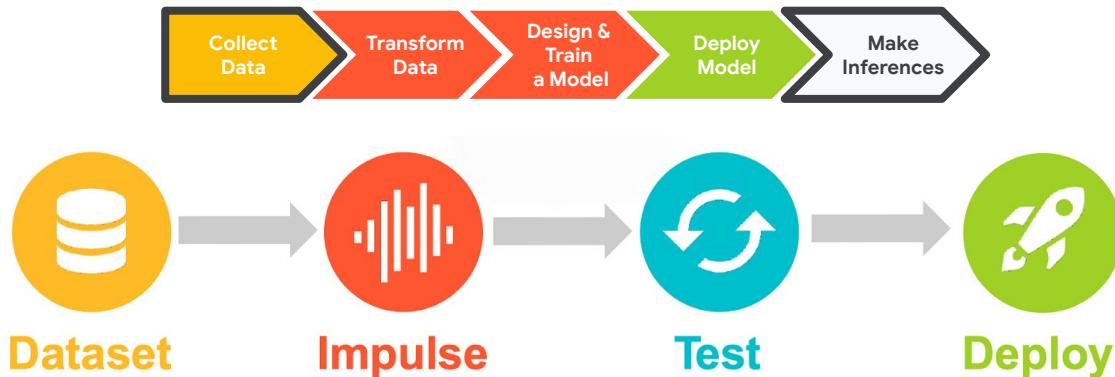
# The (Tiny) Machine Learning Workflow



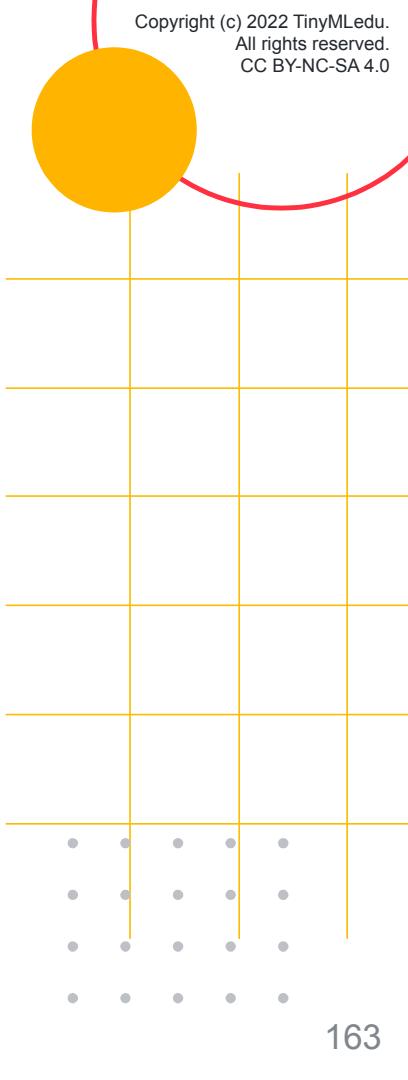
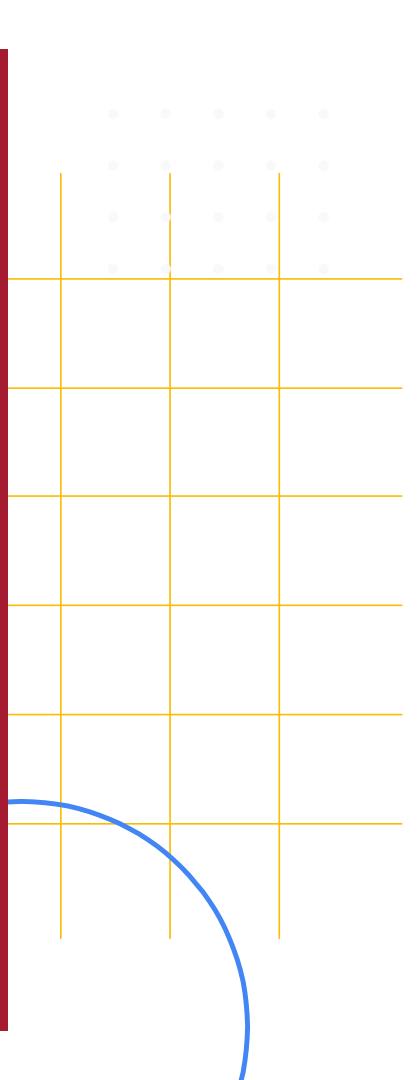
# The (Tiny) Machine Learning Workflow



# The (Tiny) Machine Learning Workflow



Edge Impulse Simplifies  
Training and Deployment



# Better Data = Better Models!



hágoónee' 🙌

see you again at 12pm (Mountain Time)