

Harvard



Yá'át'ééh 🖐️

EASI-22

Edge AI Summer
Institute 2022

with Navajo Tech

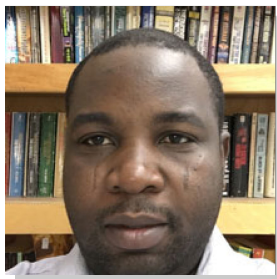


Hi! I'm Brian!

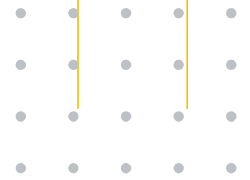
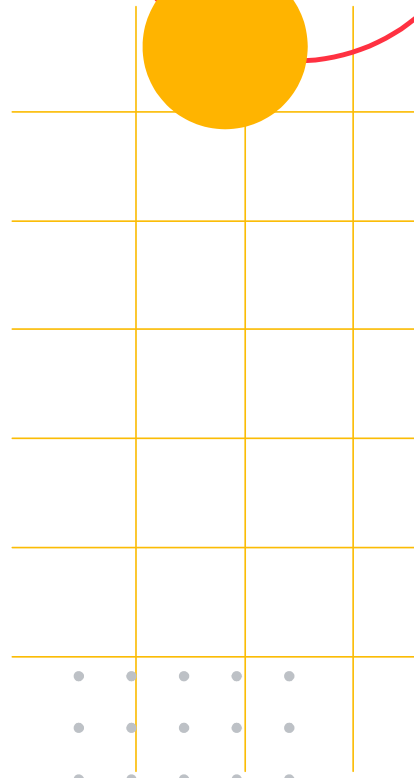
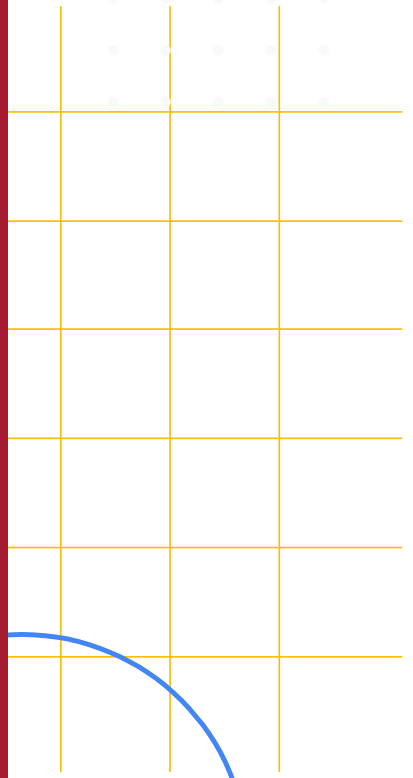
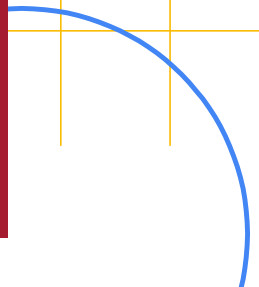
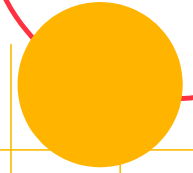
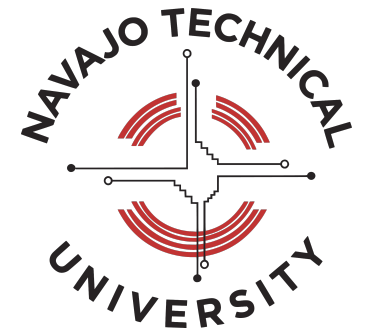
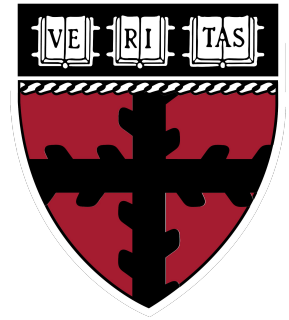
I'm an Assistant Professor of Computer Science
at **Barnard College, Columbia University**



Our team!



with help from **many more**



Our website!

tinyMLedu.org/EASI-22

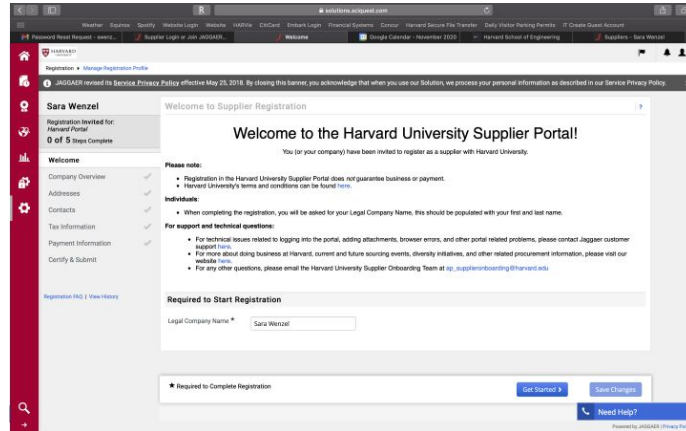
home base for **all information!**

Make Sure to Pick Up an Arduino Kit!



**Question? Contact:
Monsuru Ramoni
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

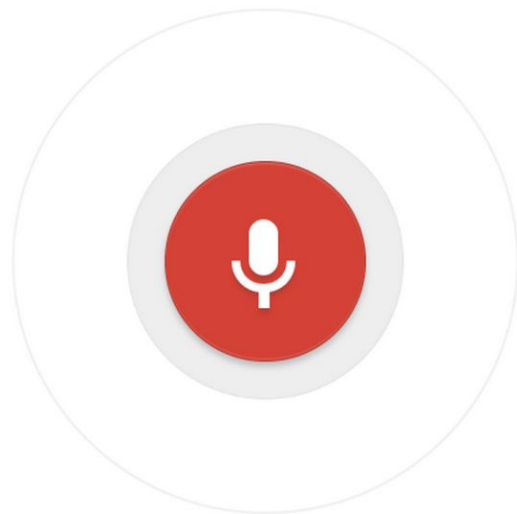
Day 3

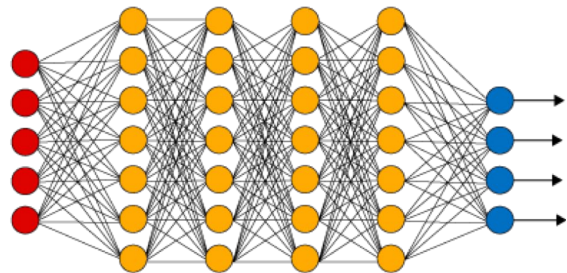
Bringing AI/ML from the Cloud to the Edge

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**



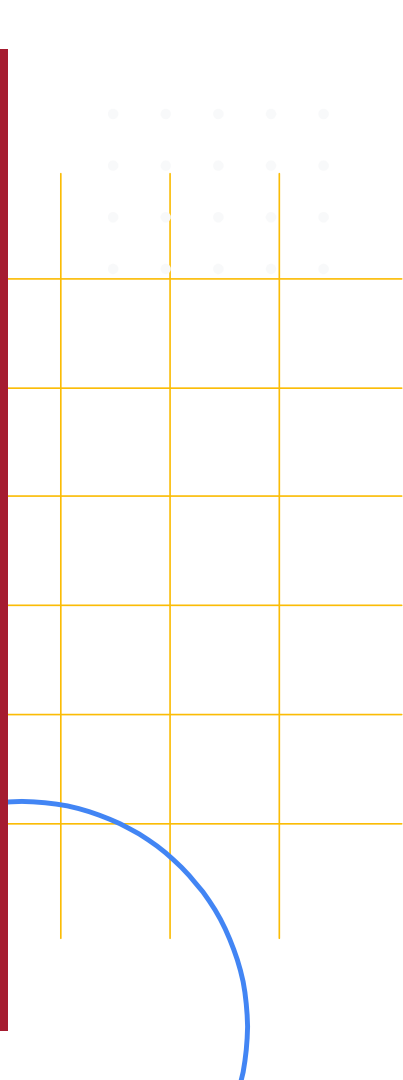


By the end of today: Hands-on Keyword Spotting (KWS)

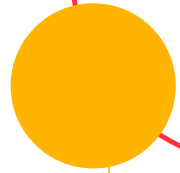
We will explore the **science** behind KWS and **collect data** and **train** our own custom model to recognize “yes” vs. “no” using **Edge Impulse**

Today's Agenda

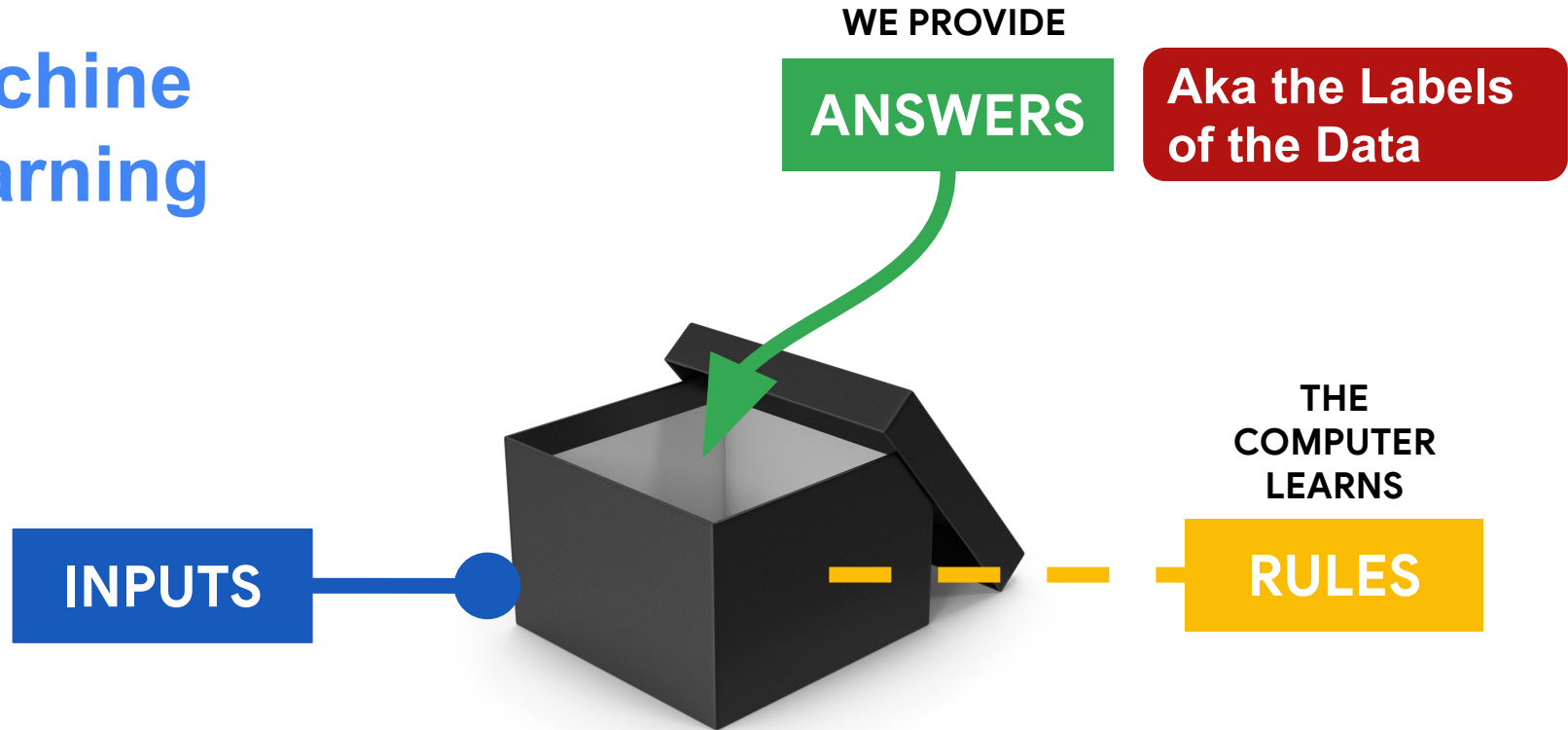
- Preprocessing for Keyword Spotting
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- Summary



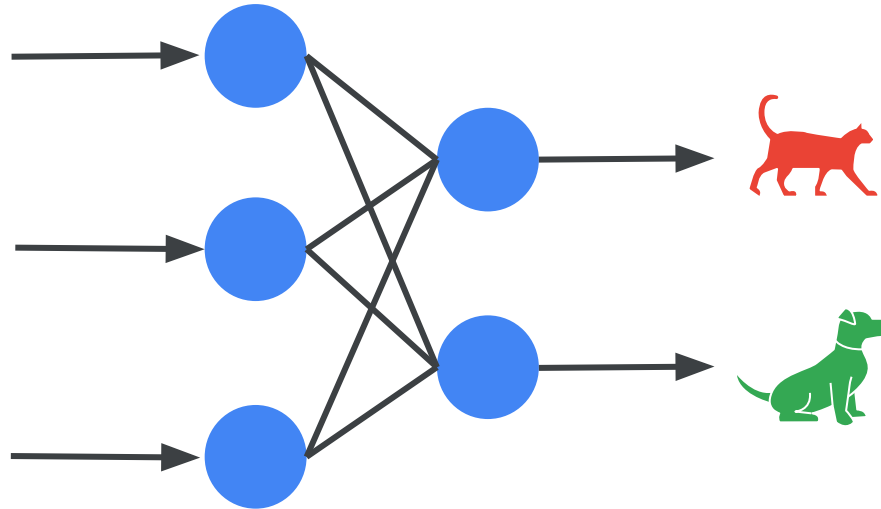
But before we
dive into all of
that – a little
quick review!



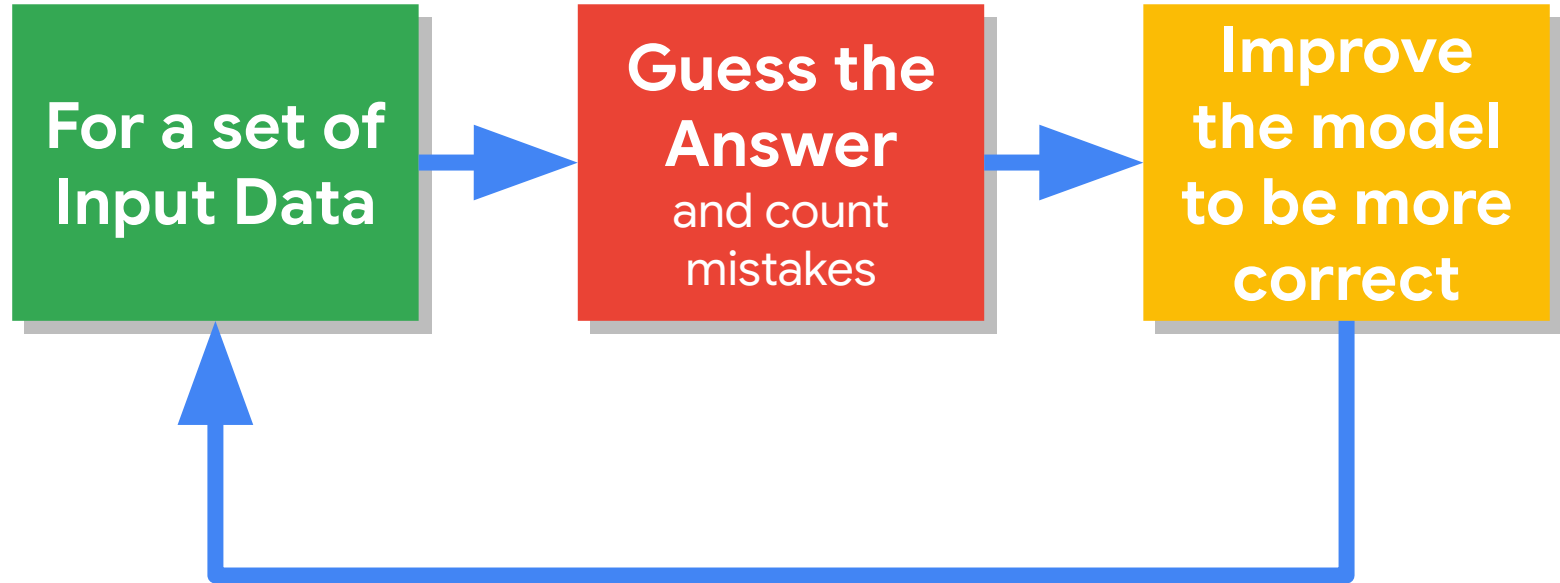
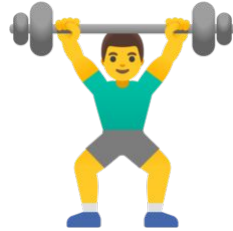
Machine Learning



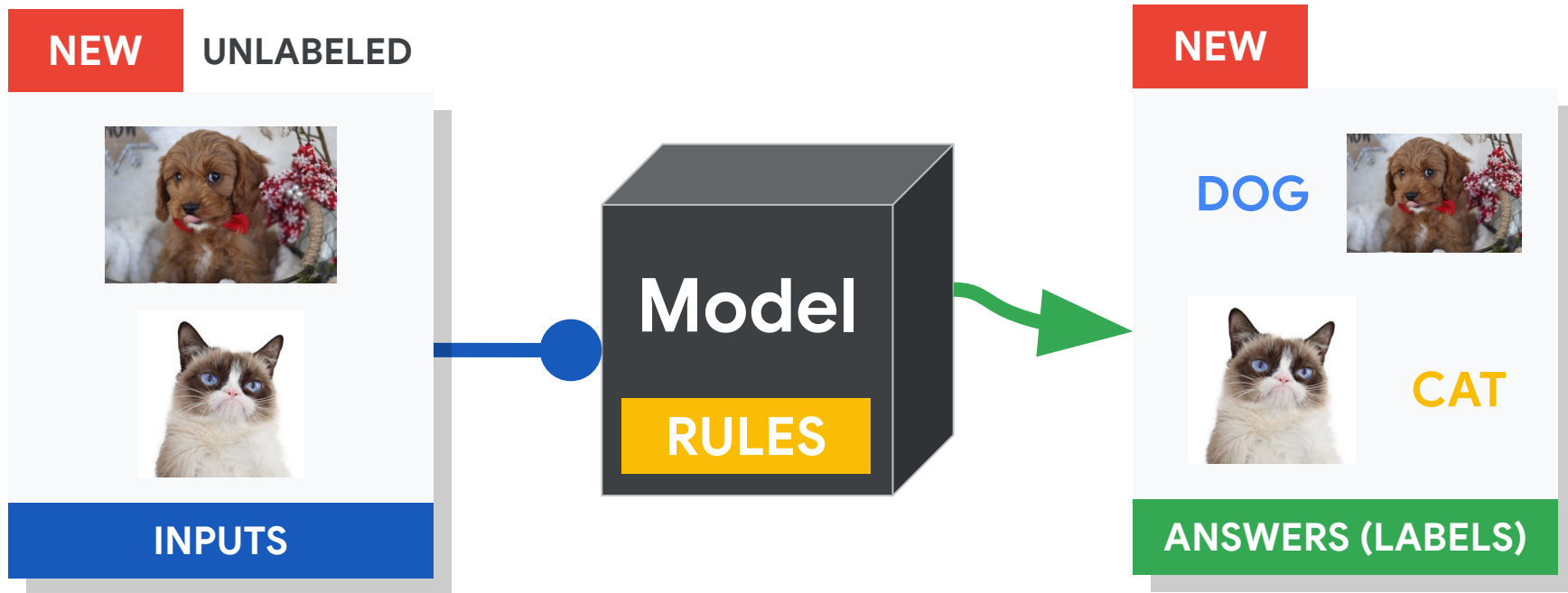
Machine Learning with **neural networks**?



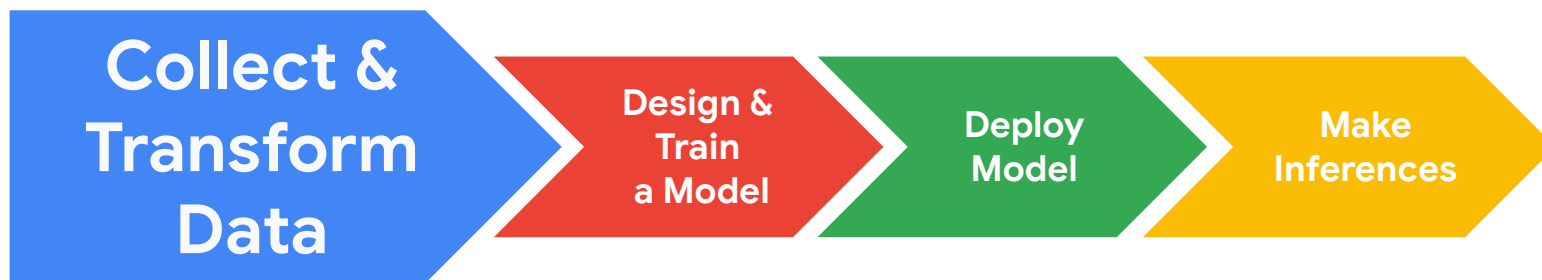
Training the machine



After it's **learned** use it for **inference**:



The (Tiny) Machine Learning **Workflow**

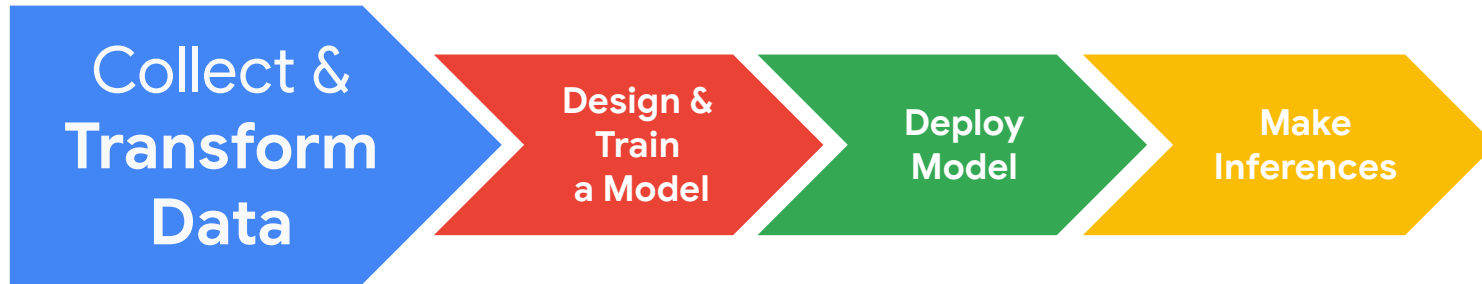


**If ML is going to be everywhere
we need to consider how to best
collect **GOOD** data **RESPONSIBLY****

Today's Agenda

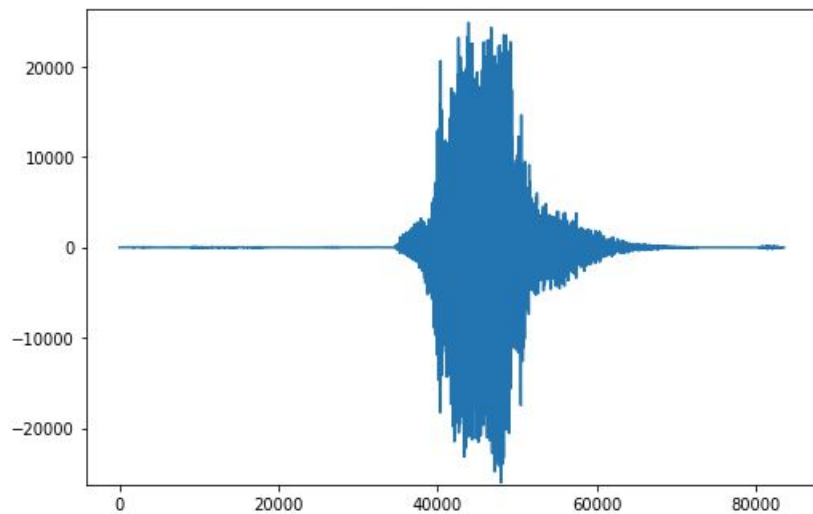
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Machine Learning **Workflow**



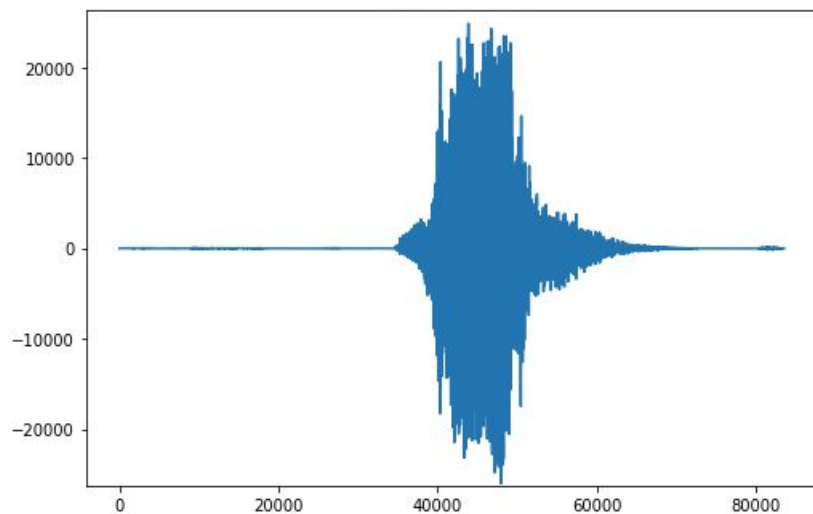
This is an audio signal

“Yes” (*spoken loudly*)

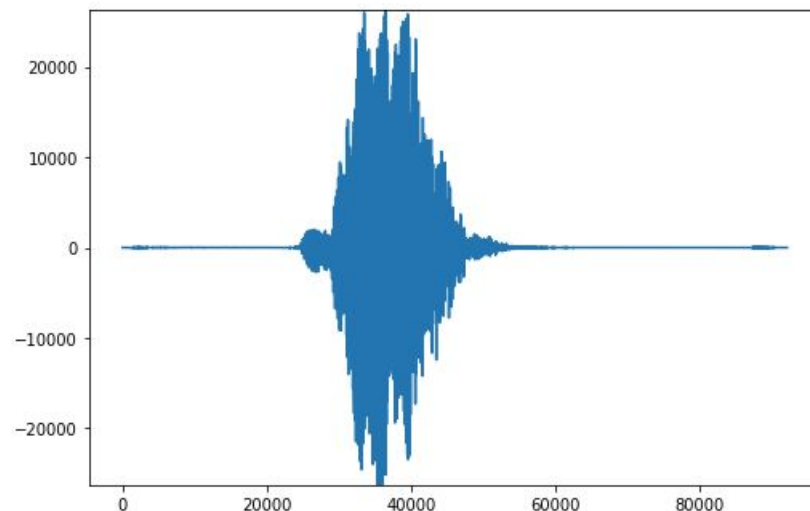


Can you tell these two signals apart?

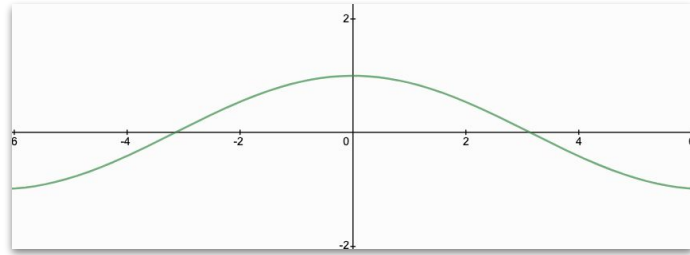
“Yes” (*spoken loudly*)



“No” (*spoken loudly*)

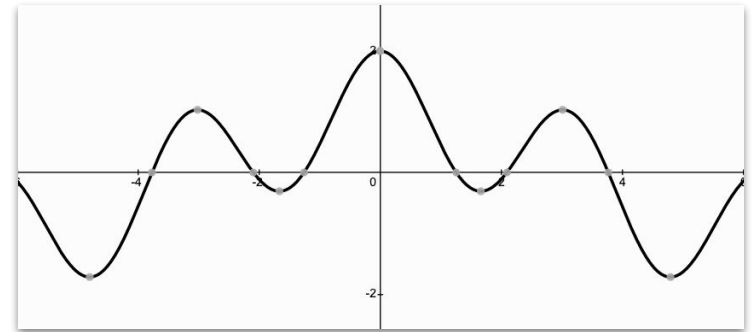
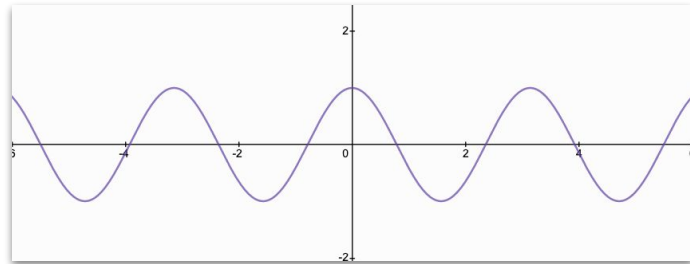


Signal Components?



+

=



Signal Components?

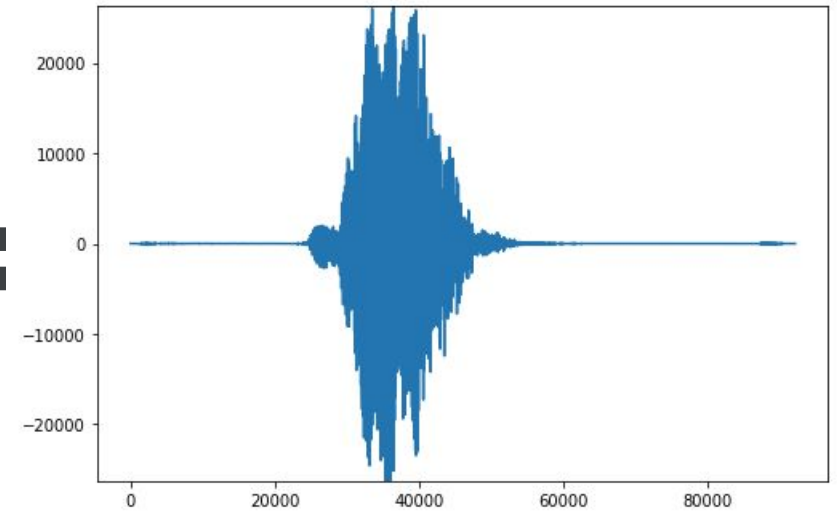
?

+

=

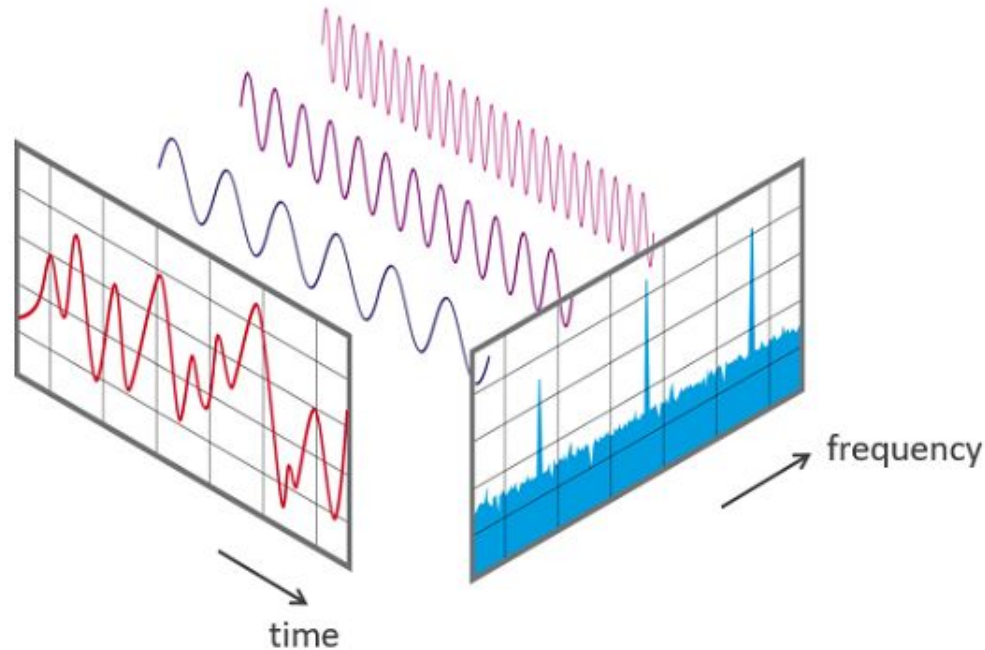
?

“No” (*spoken loudly*)



Fast Fourier Transform:

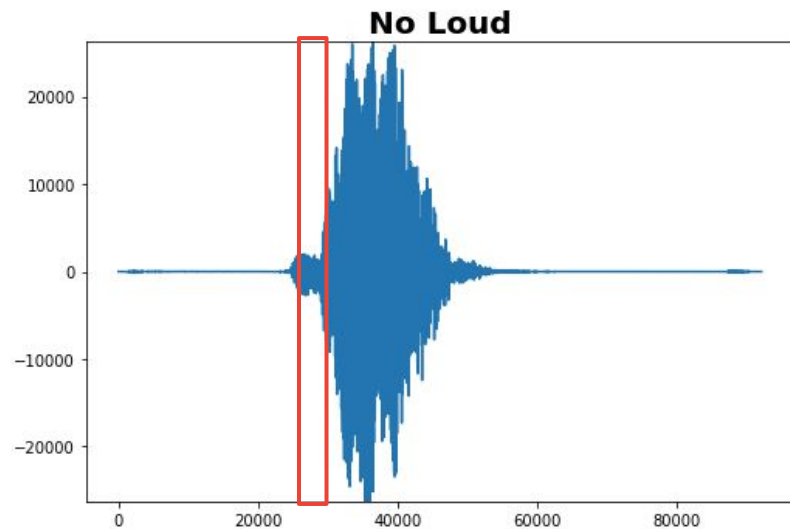
extract the frequencies from a signal



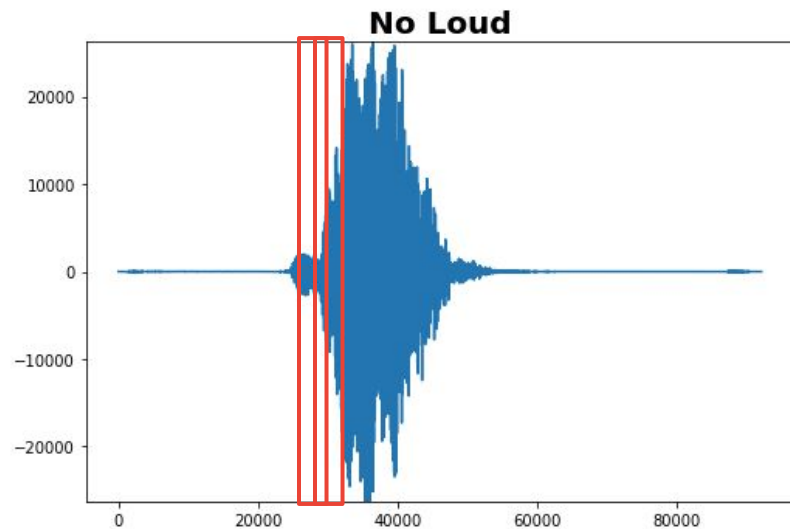
Fast Fourier Transform



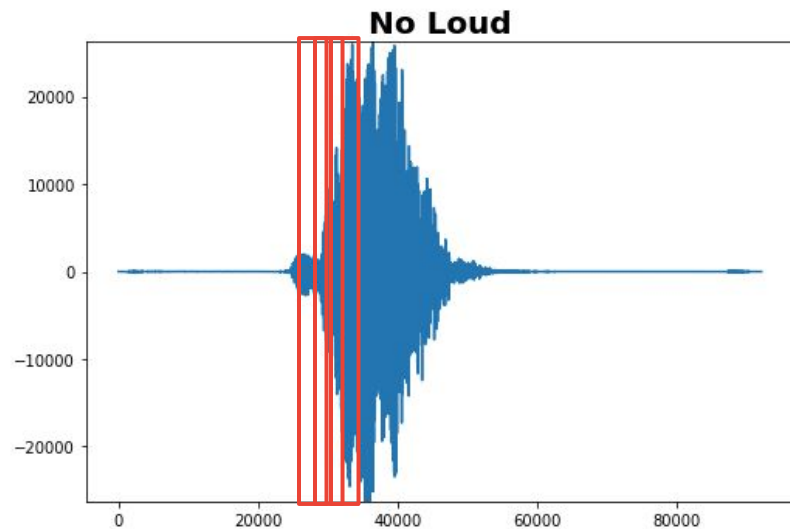
Building a Spectrogram using FFTs



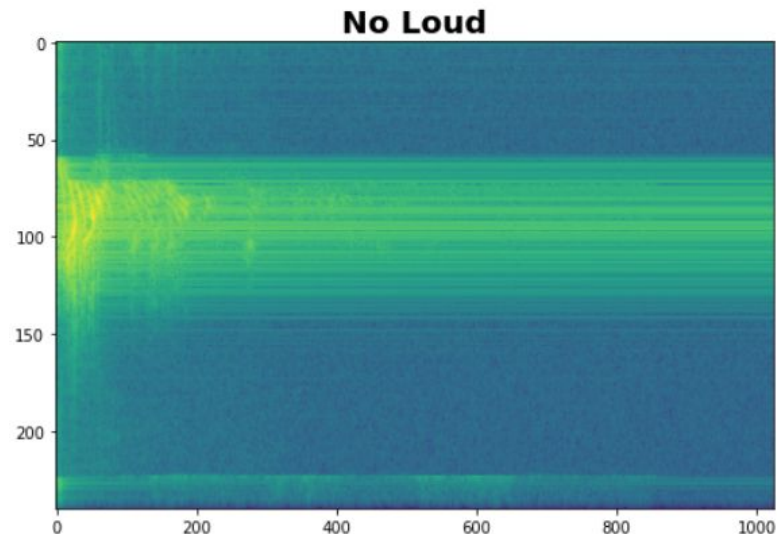
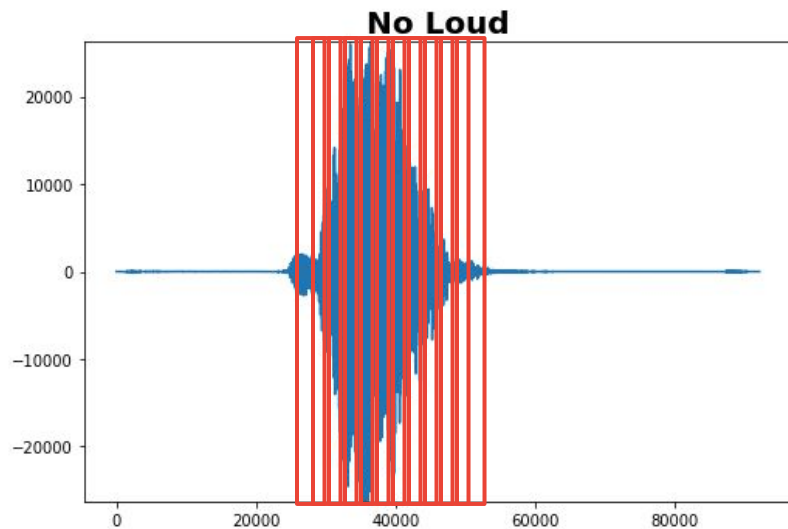
Building a Spectrogram using FFTs



Building a Spectrogram using FFTs

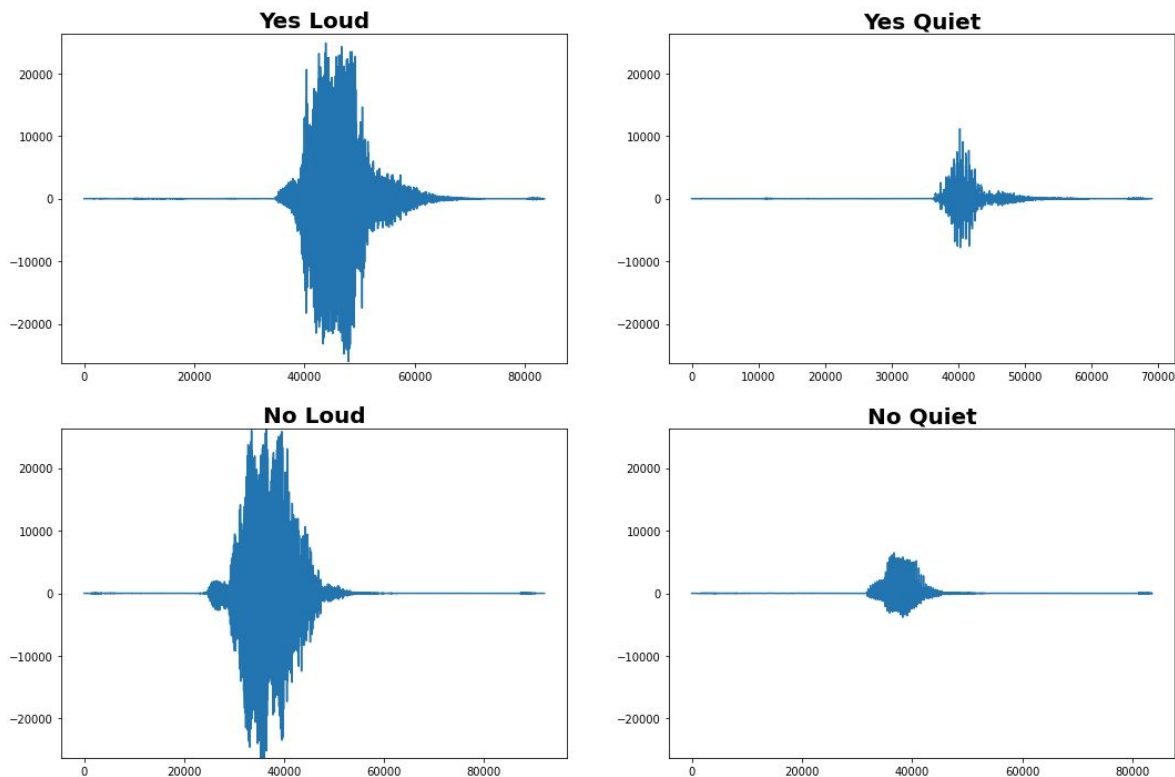


Building a **Spectrogram** using FFTs

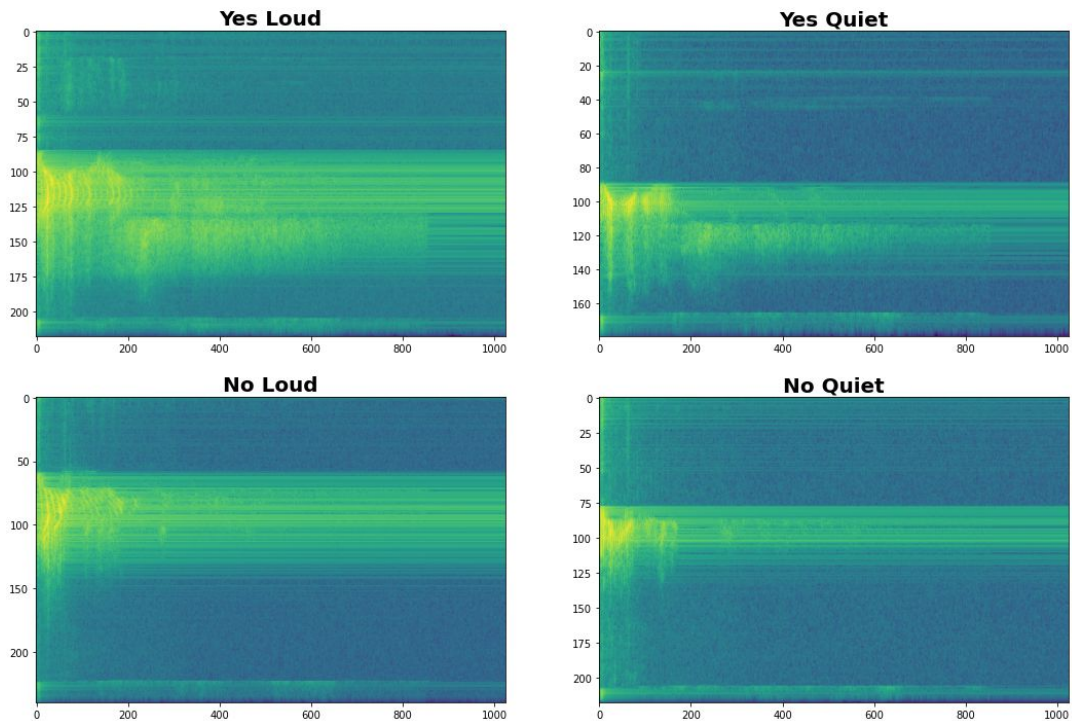


Essentially if you **stack up all the FFTs in a row** then you get the **Spectrogram** (time vs. frequency with color indicating intensity)

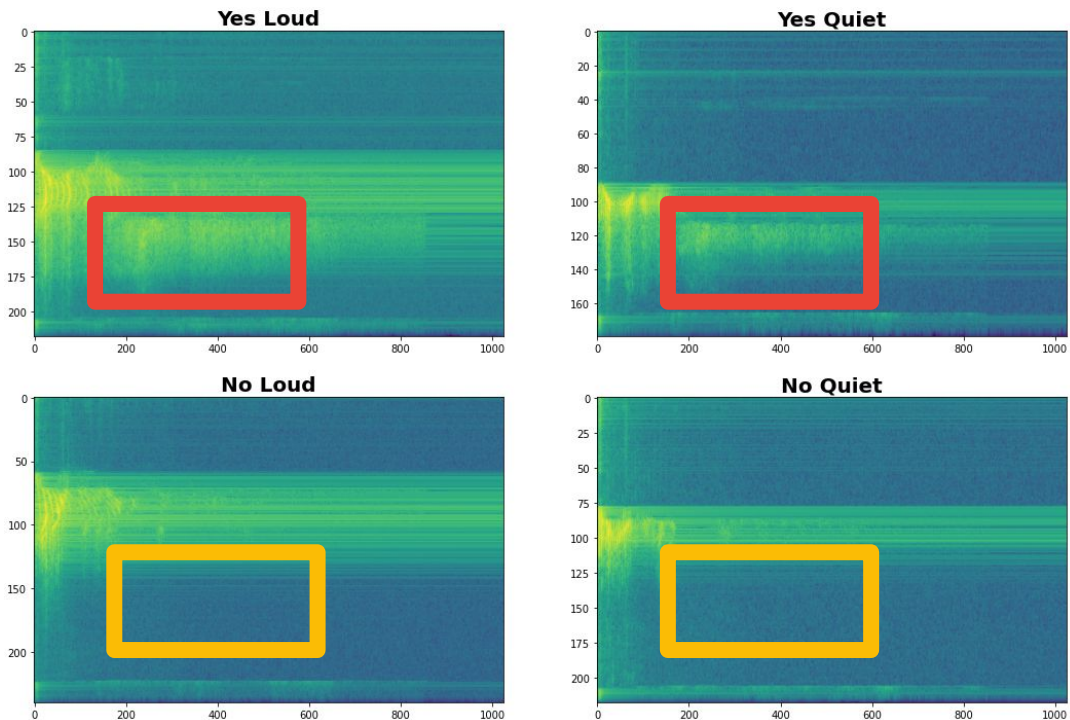
Spectrograms help differentiate the data



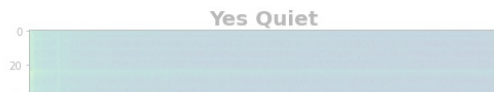
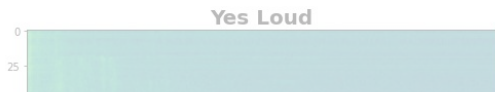
Spectrograms help differentiate the data



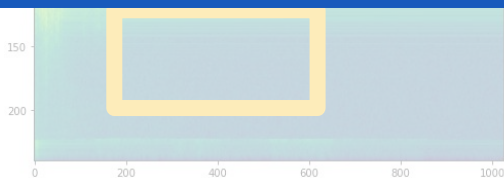
Spectrograms help differentiate the data



Data Preprocessing: Spectrograms

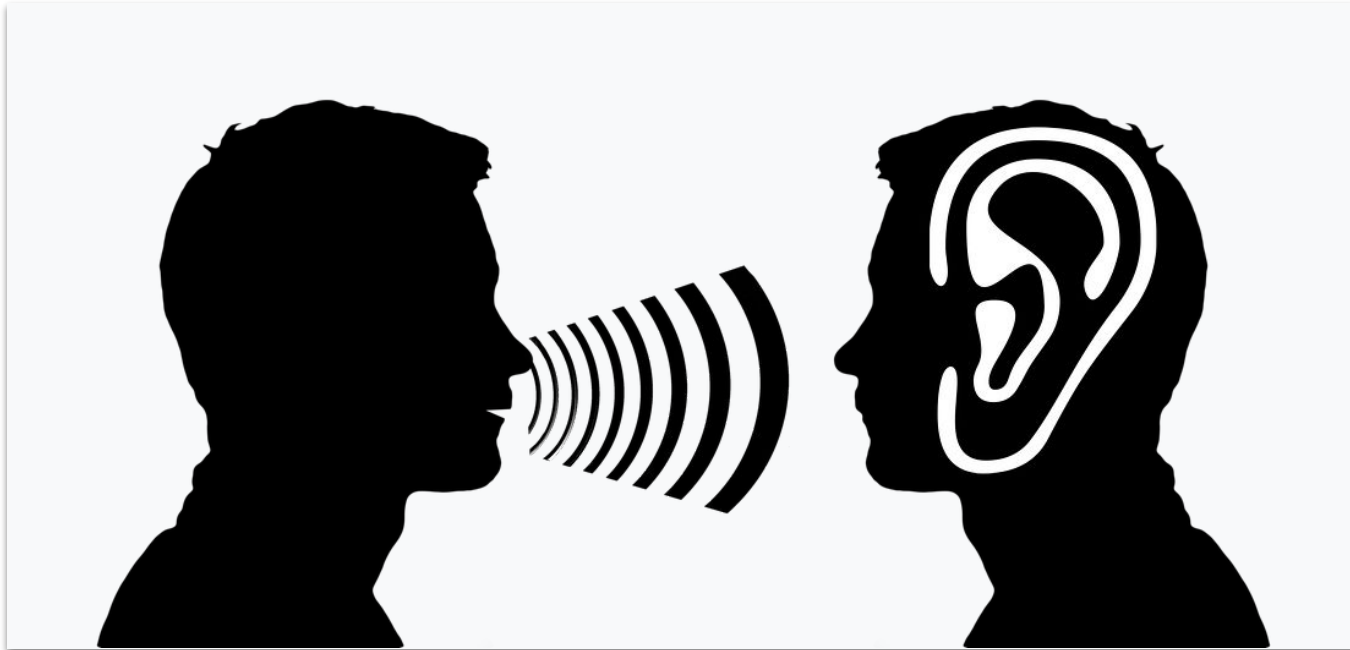


A spectrogram is also effectively an **image** that we can use as an input to a Neural Network!

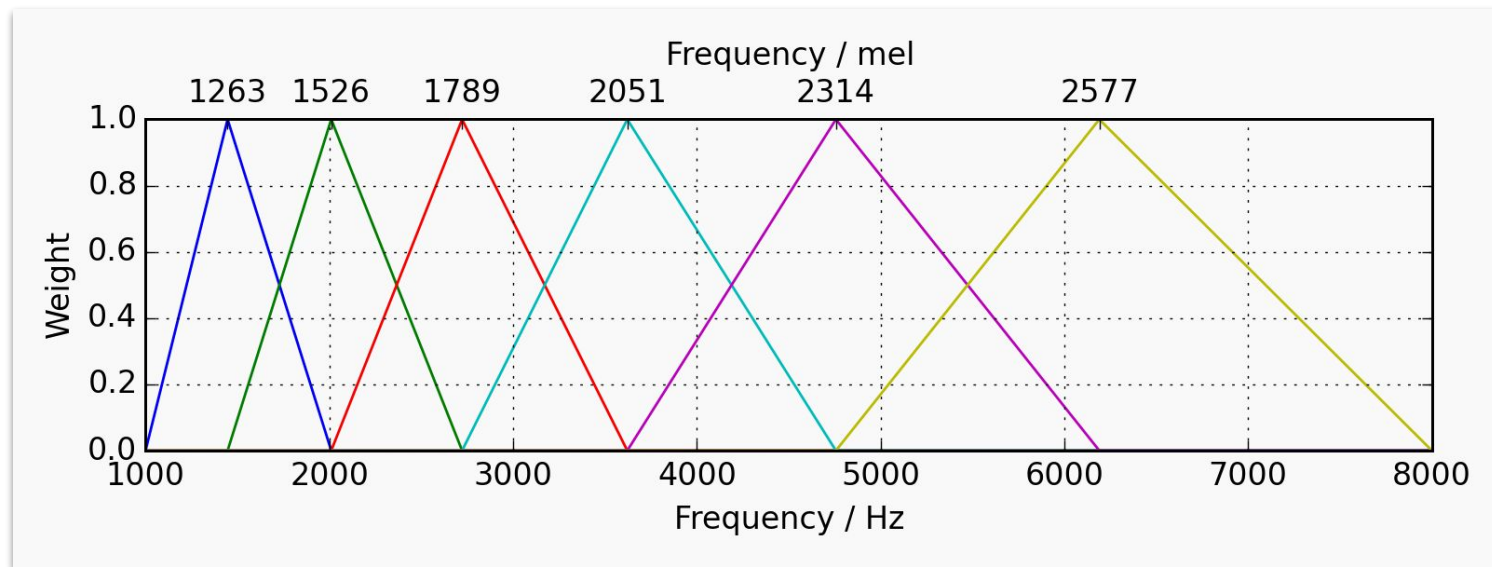


Can we do **better** than a spectrogram?

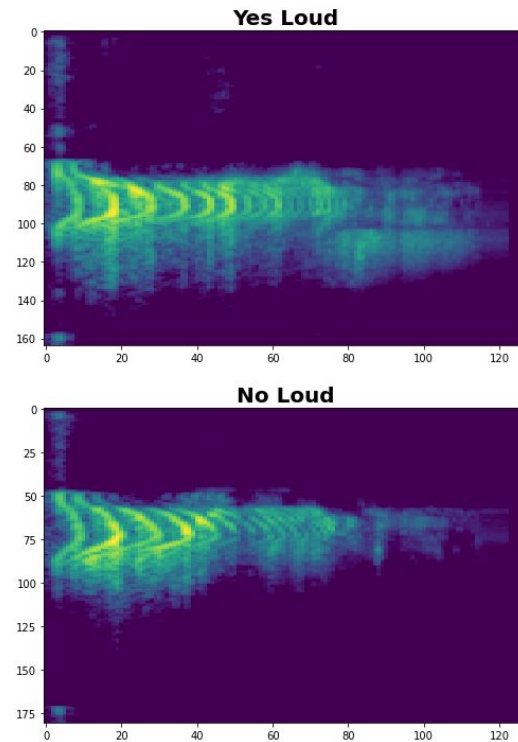
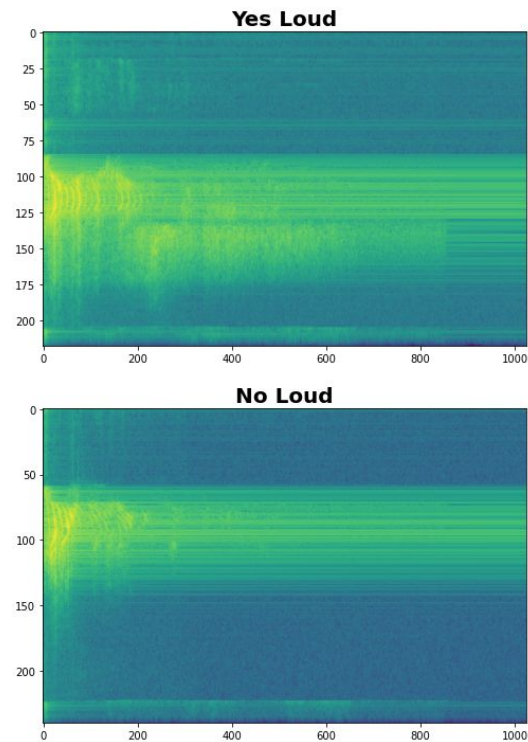
Can we take **domain knowledge** into account?



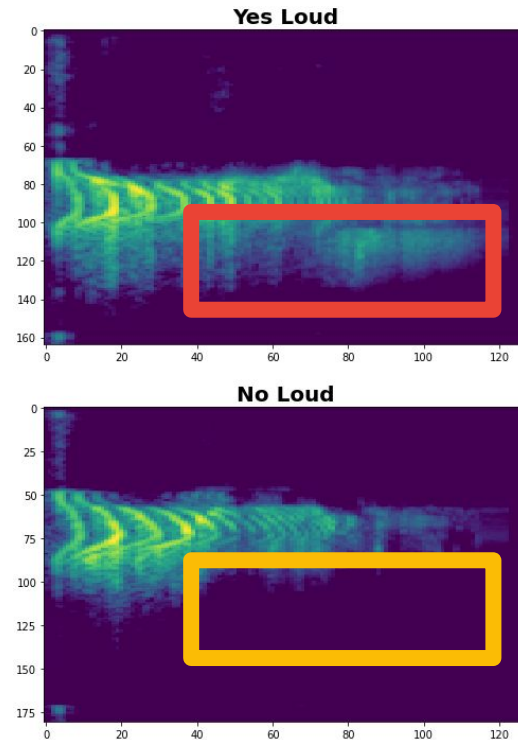
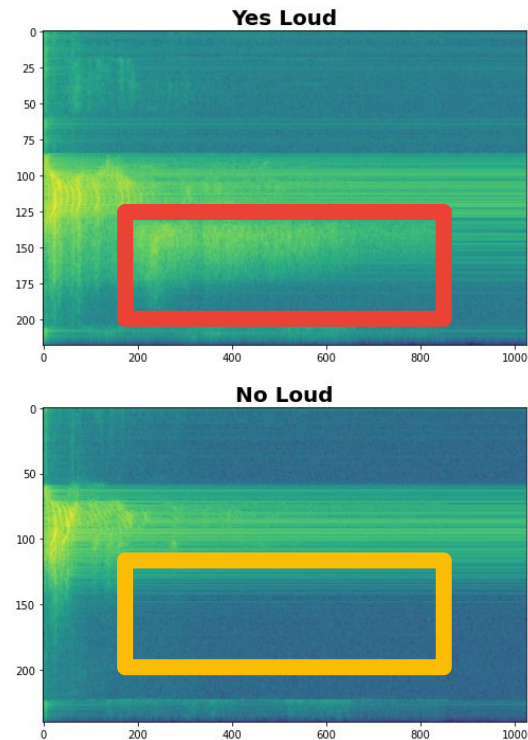
Mel Filterbanks



Spectrograms v. MFCCs



Spectrograms v. MFCCs



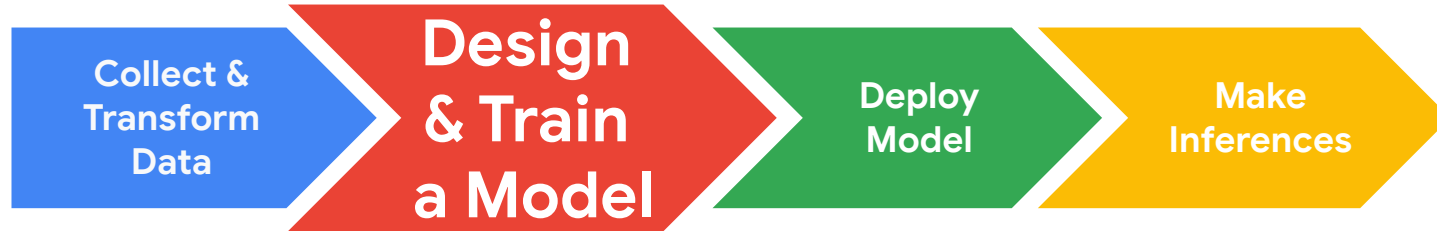
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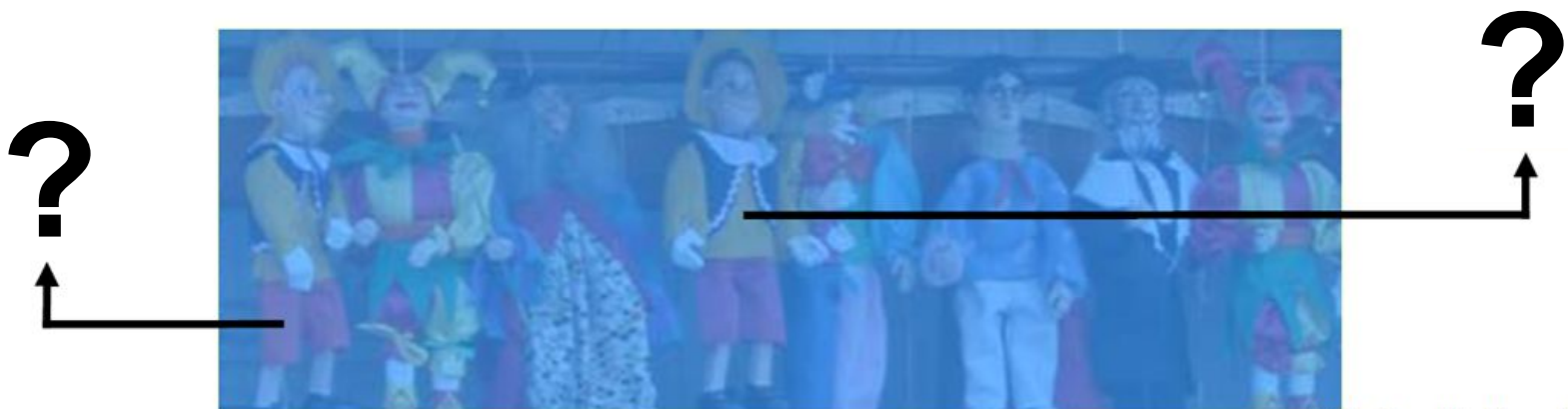
Machine Learning **Workflow**



Computer Vision is Hard

Computer Vision is Hard

What color are the pants and the shirt?



Slide Credit: Hamilton Chong

Computer Vision is Hard



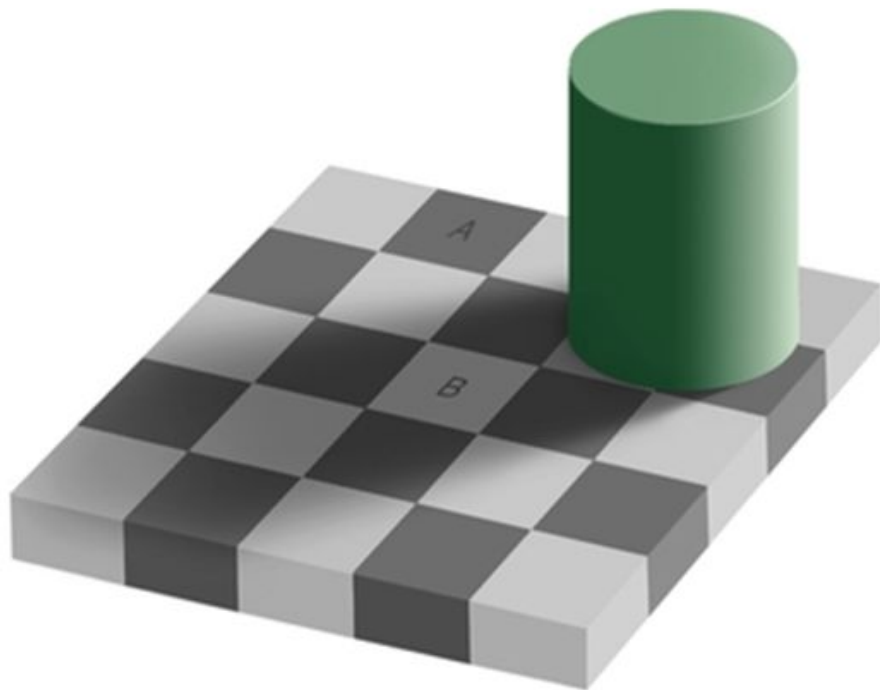
Slide Credit: Hamilton Chong

Computer Vision is Hard



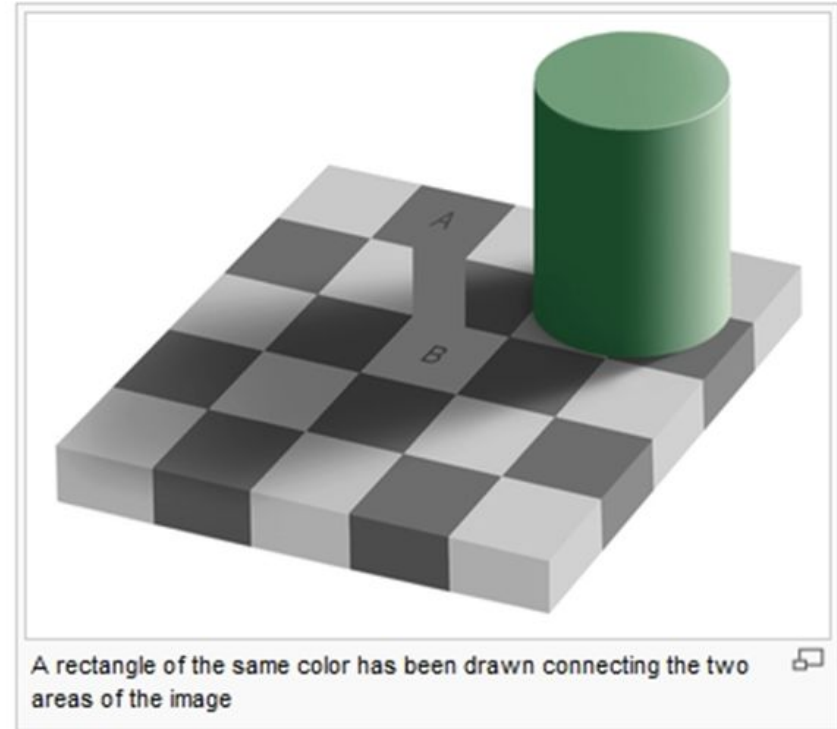
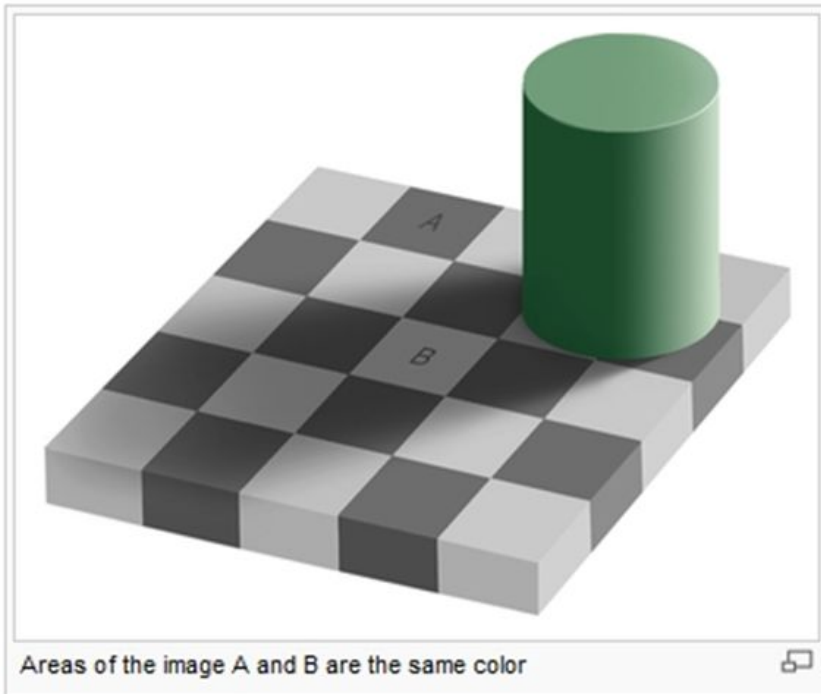
Slide Credit: Hamilton Chong

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?

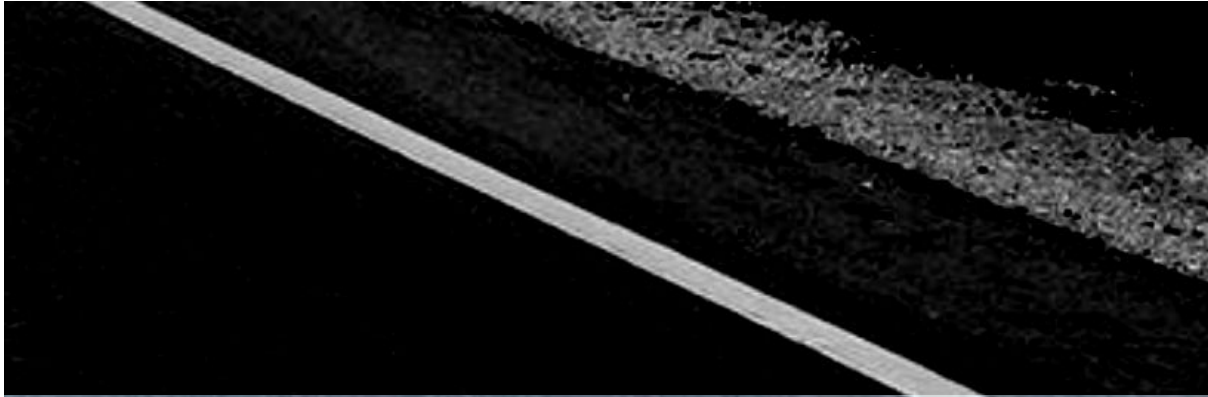


**Maybe
straight
lines to
see the
lanes
of the
road?**

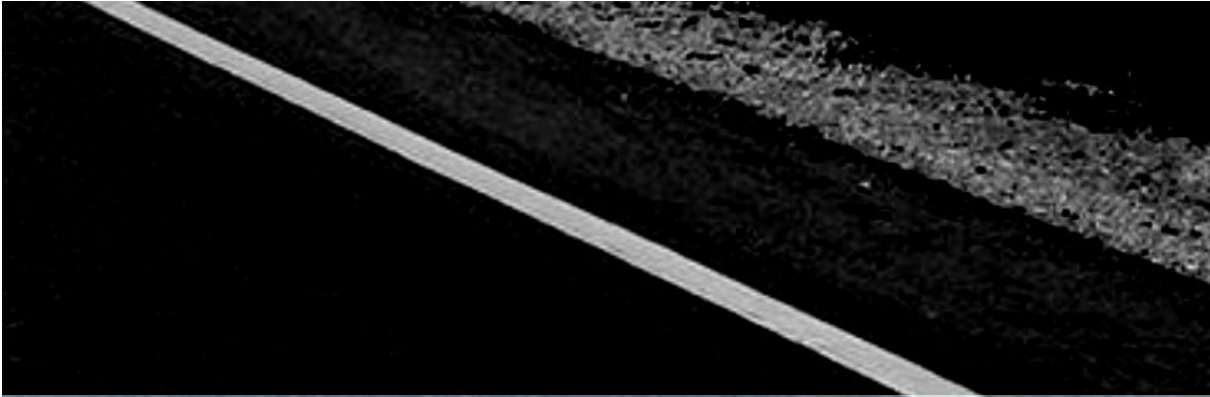
How might we find these features?



How might we find these features?



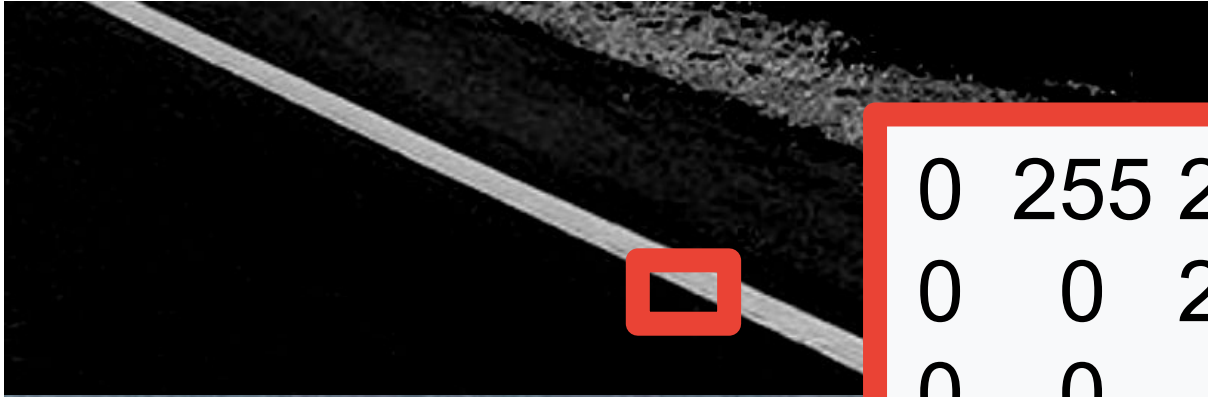
How might we find these features?



Black: 0

White: 255

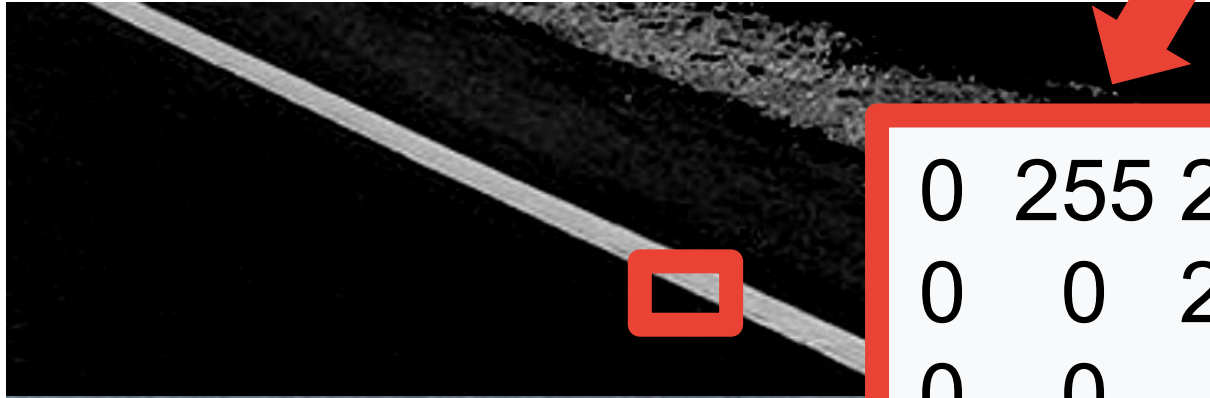
How might we find these features?



Black: 0
White: 255

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

How might we find these features?



Look for a Big Change!

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

Black: 0
White: 255

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

765

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

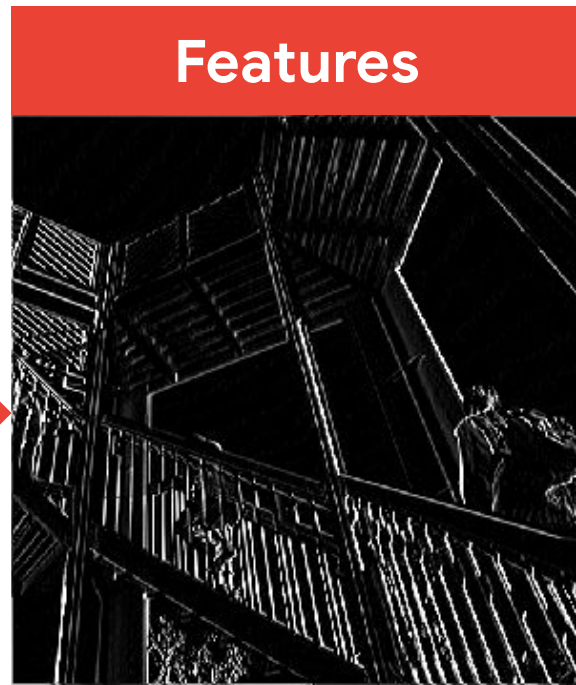
0	765	765	0
0	765	765	0
0	765	765	0
0	765	765	0

How might we find these features?

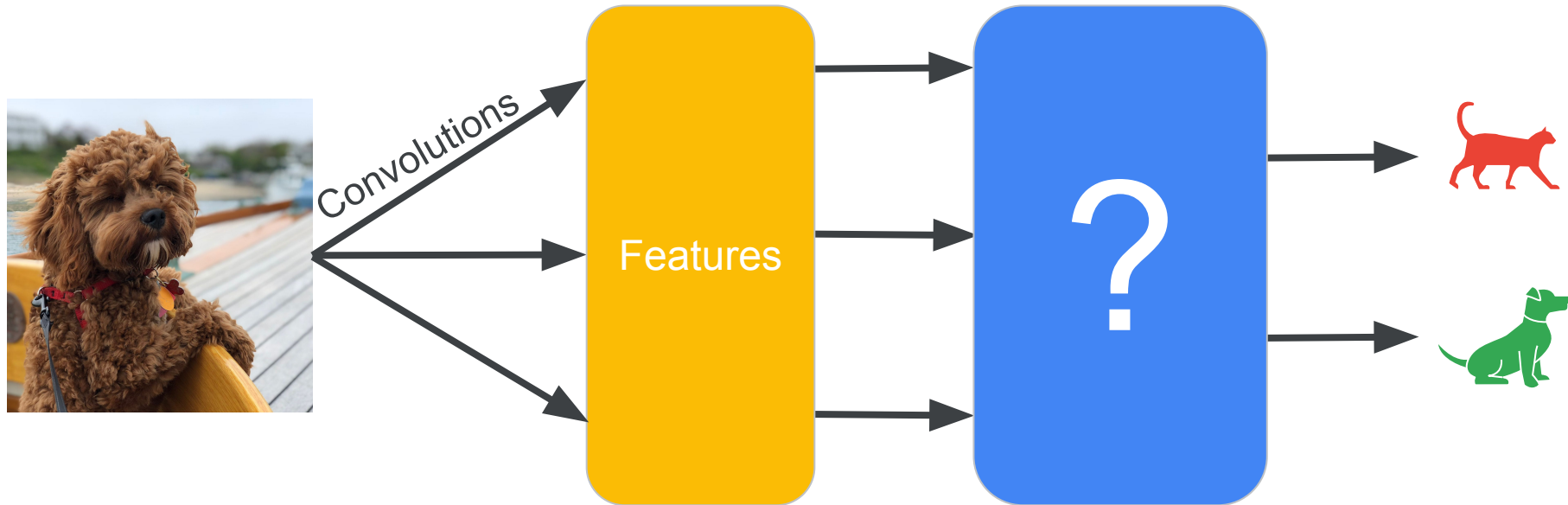
Convolutions



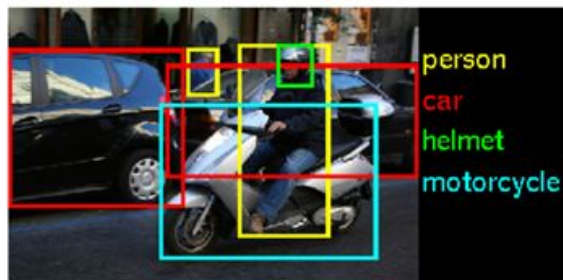
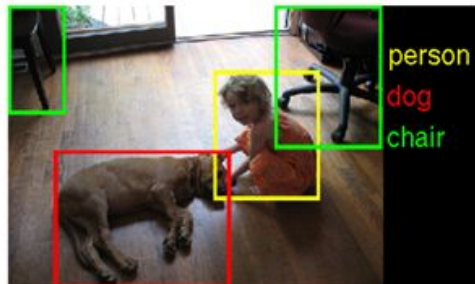
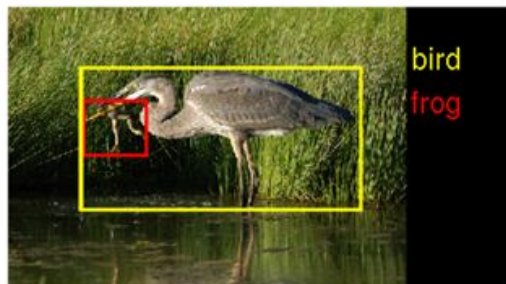
-1	0	1
-2	0	2
-1	0	1



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

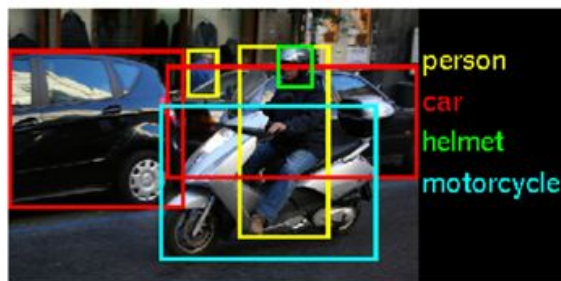
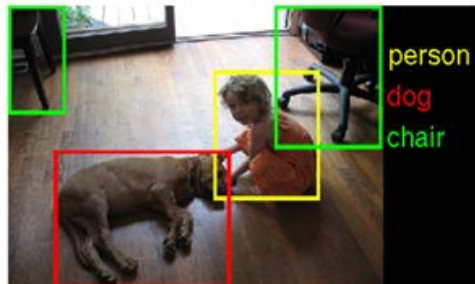
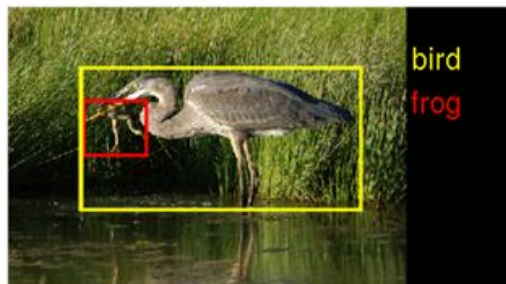


Traditional Machine Learning Flow

Regression, Clustering, etc.

**Vertical Lines, Horizontal Lines,
Changes in Color, Changes in
Focus, etc.**

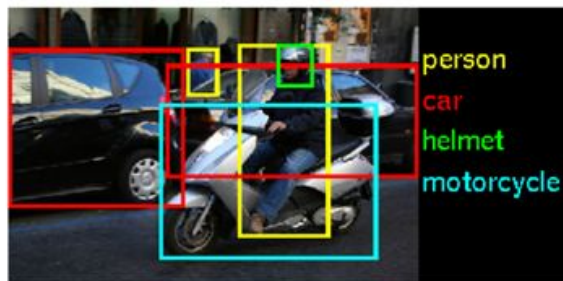
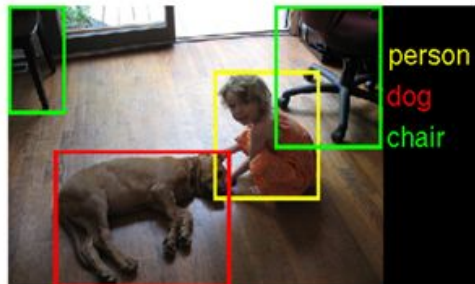
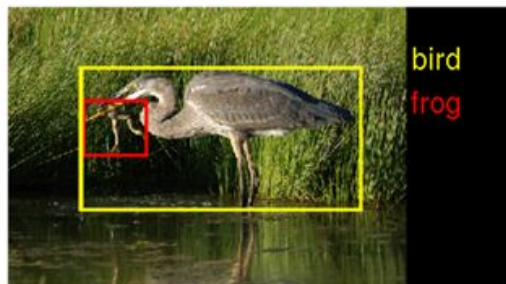
The ImageNet Challenge and the birth of CNNs



In 2010 teams had
75-50% error

In 2011 teams had
75-25% error

The ImageNet Challenge and the birth of CNNs

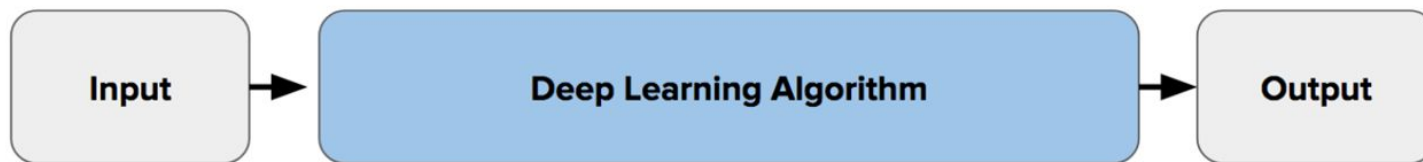


In 2012 still no team
had less than 25%
error barrier except
AlexNet at 15%

The ImageNet Challenge and the birth of CNNs



Traditional Machine Learning Flow

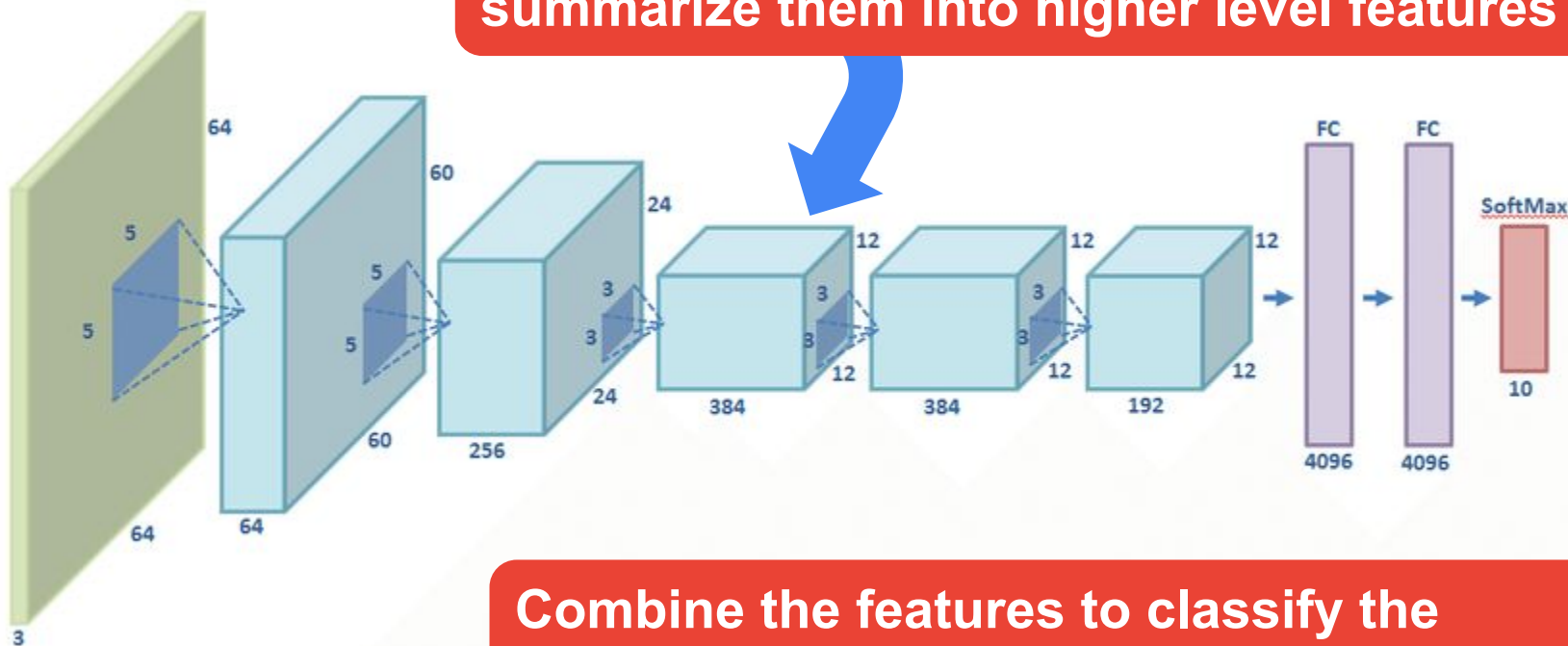


Deep Learning Flow

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

AlexNet

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



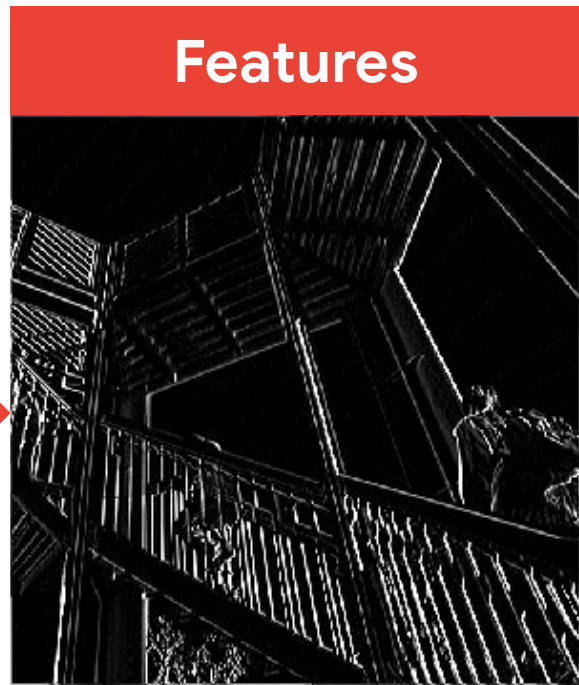
Combine the features to classify the various objects in the dataset

How might we find these features?

Convolutions



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

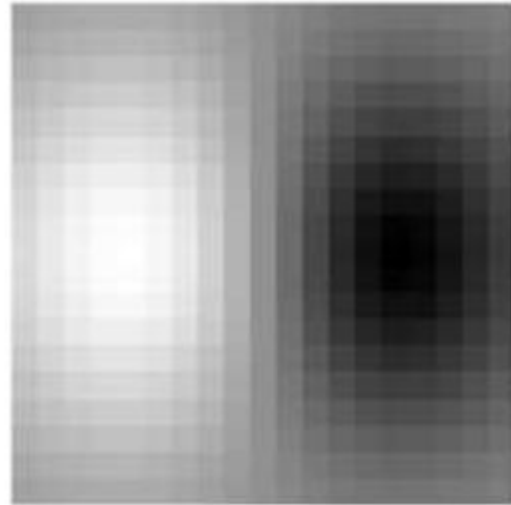


Features

How might we find these features?

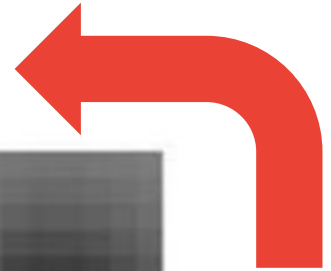
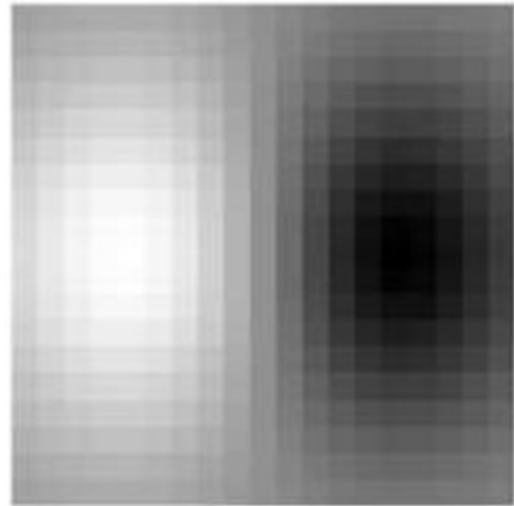
Convolutions

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



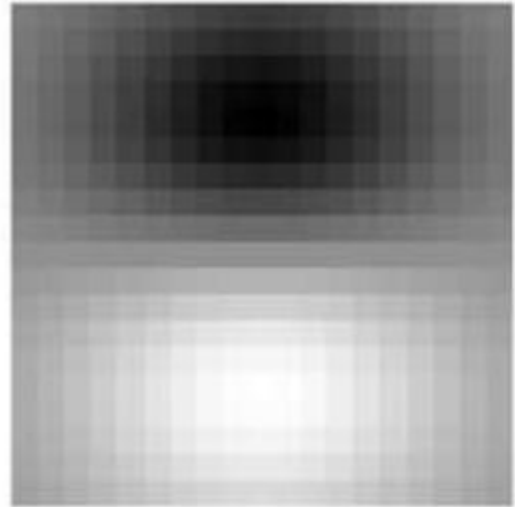
How might we find these features?

Convolutions



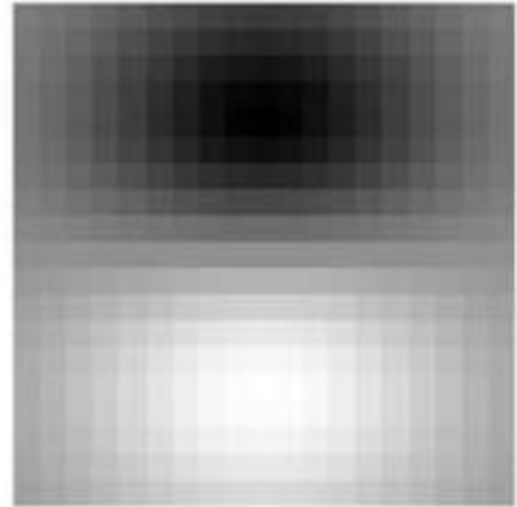
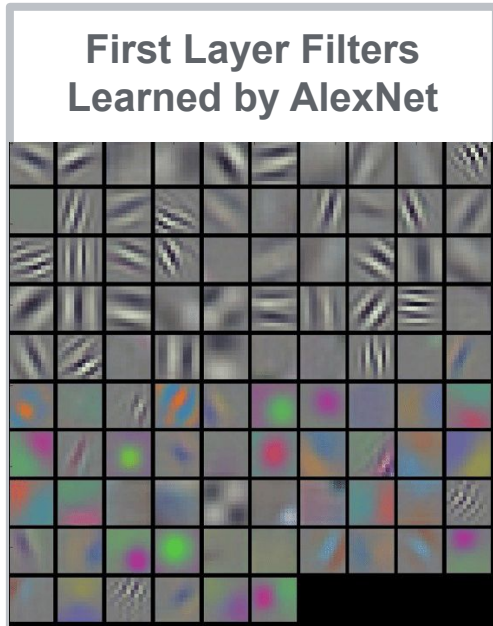
How might we find these features?

Convolutions



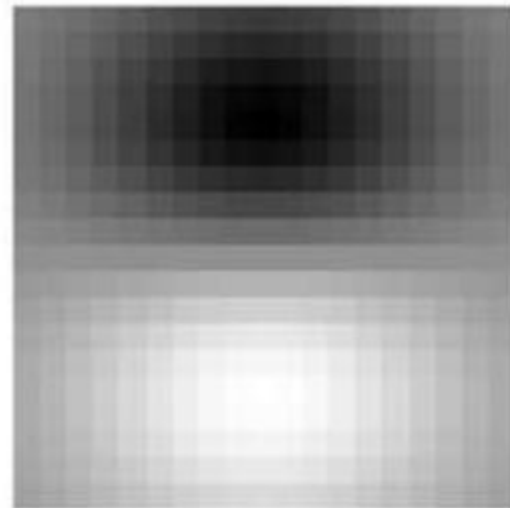
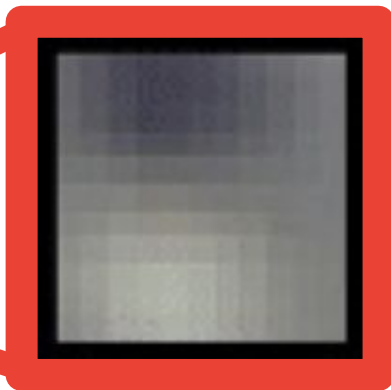
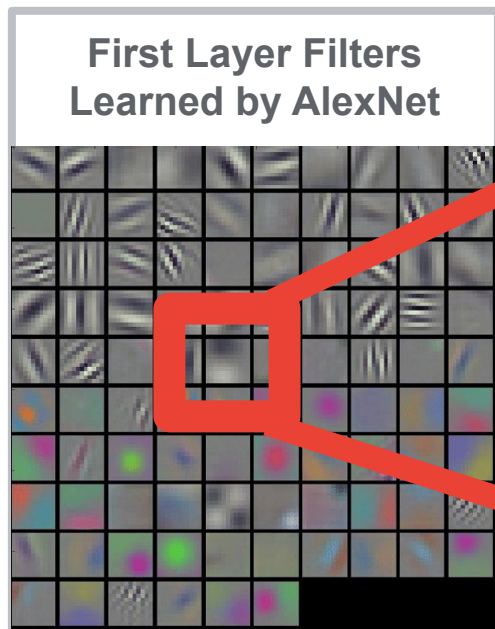
How might we find these features?

Convolutions



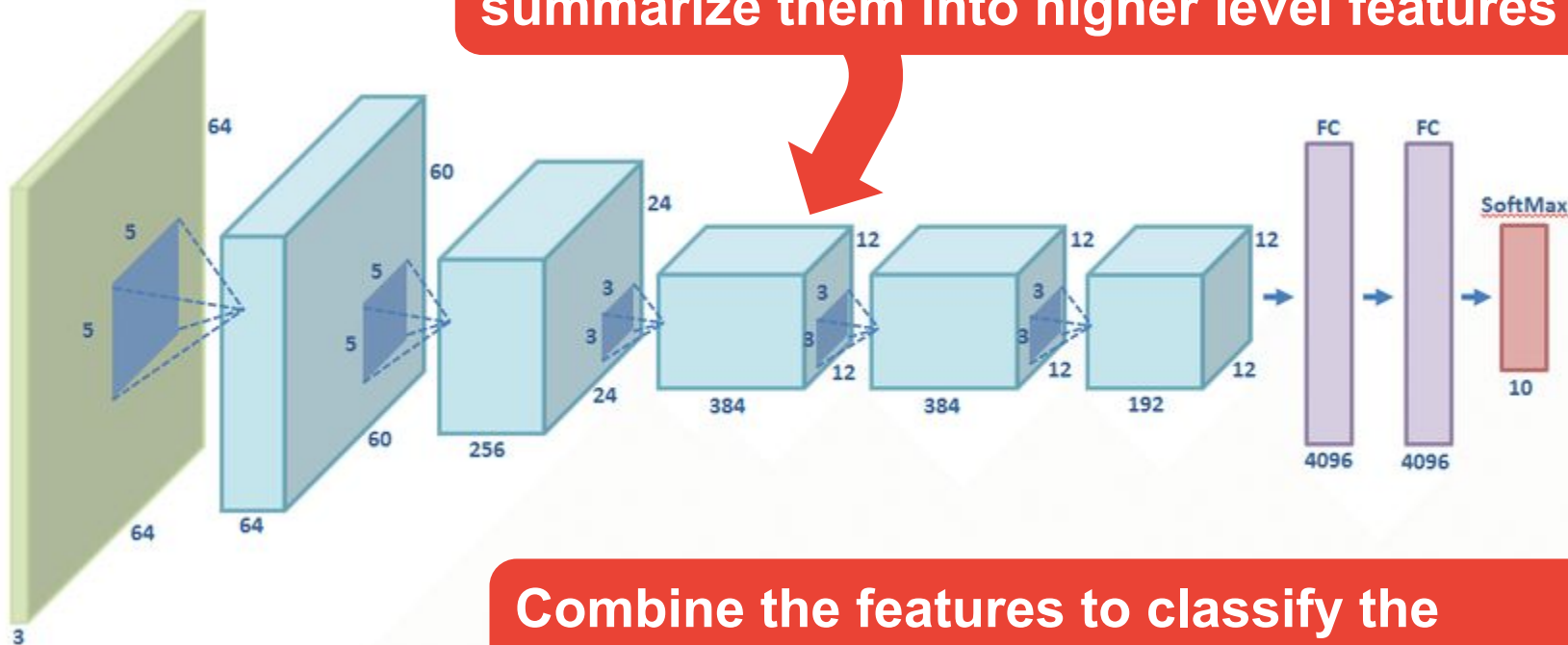
How might we find these features?

Convolutions



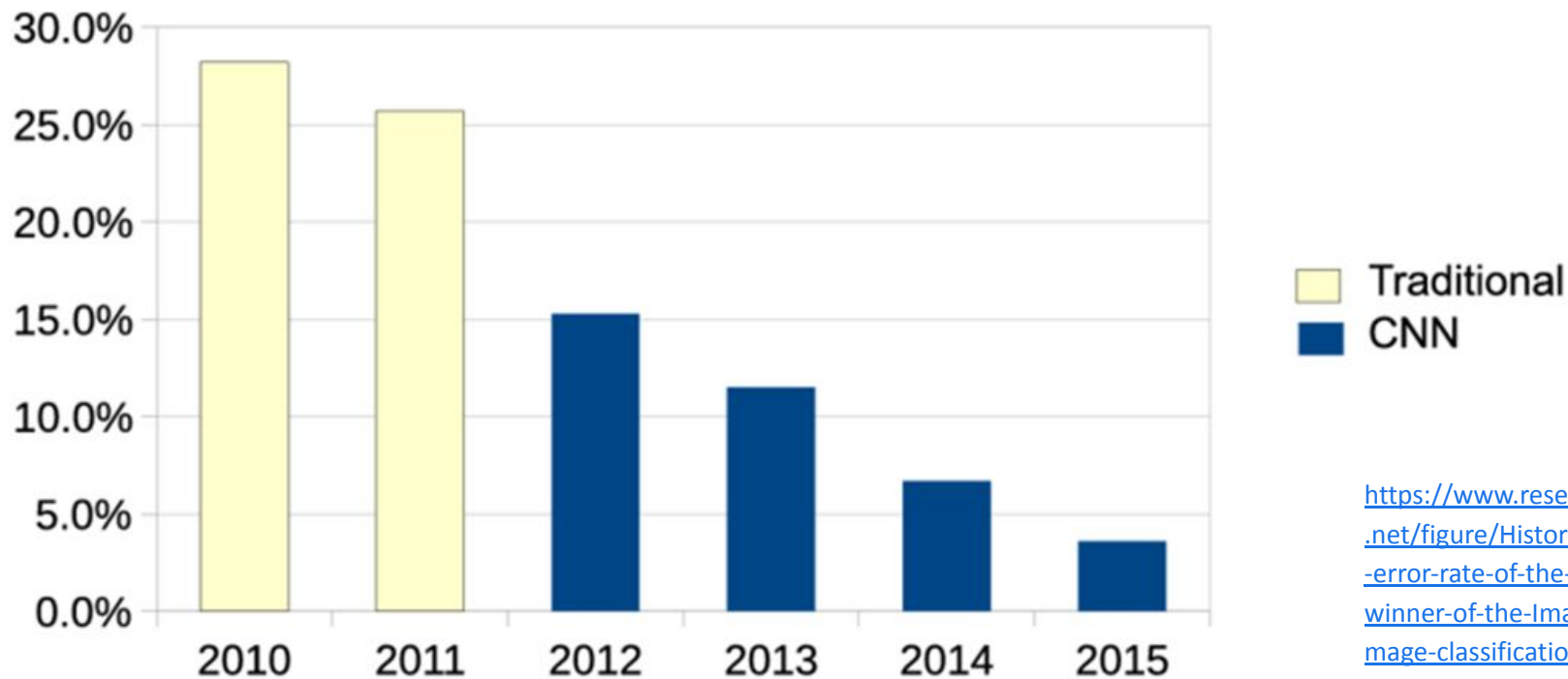
AlexNet

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



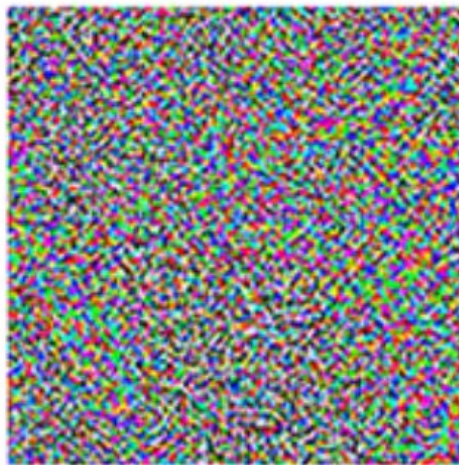
https://www.researchgate.net/figure/Historical-top5-error-rate-of-the-annual-winner-of-the-ImageNet-image-classification_fig7_303992986

A word of caution...

Ackerman "Hacking the Brain With Adversarial Images"



+ ϵ



=



"panda"

57.7% confidence

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

"gibbon"

99.3% confidence

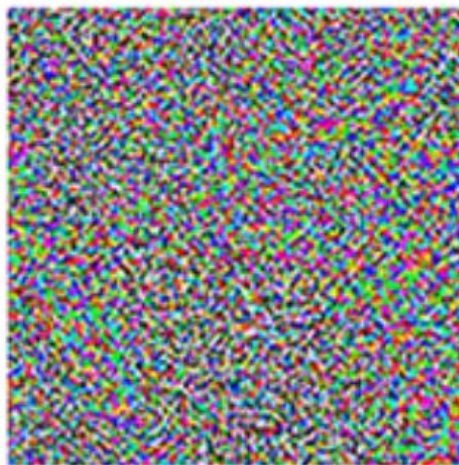
<https://www.vox.com/future-perfect/2019/4/8/18297410/ai-tesla-self-driving-cars-adversarial-machine-learning>

A word of caution...

Ackerman "Hacking the Brain With Adversarial Images"



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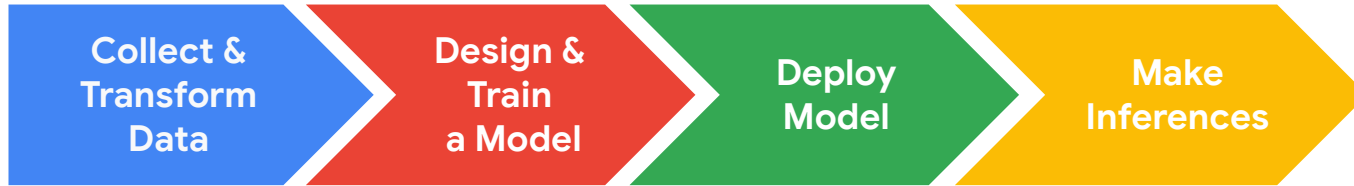
Today's Agenda

- 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

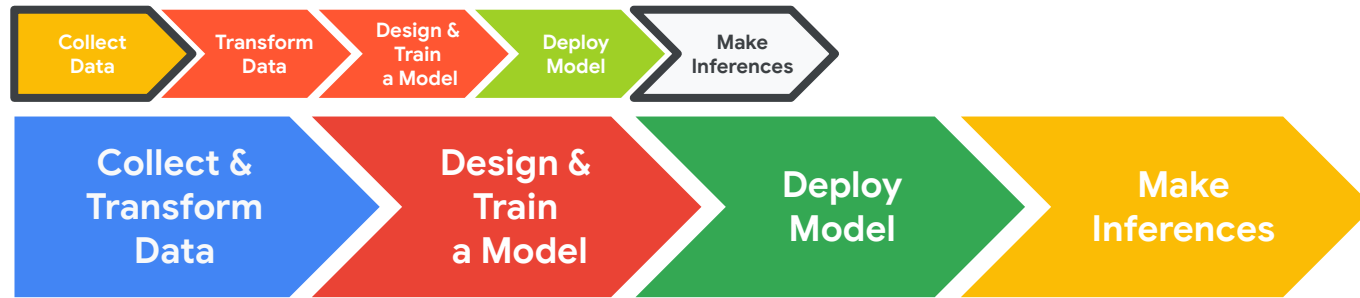
Today's Agenda

- Preprocessing for Keyword Spotting
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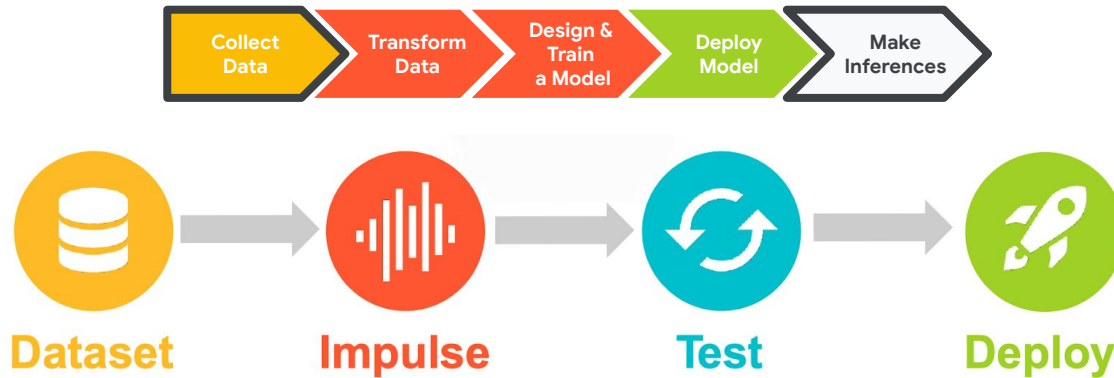
Machine Learning **Workflow**




Machine Learning Workflow

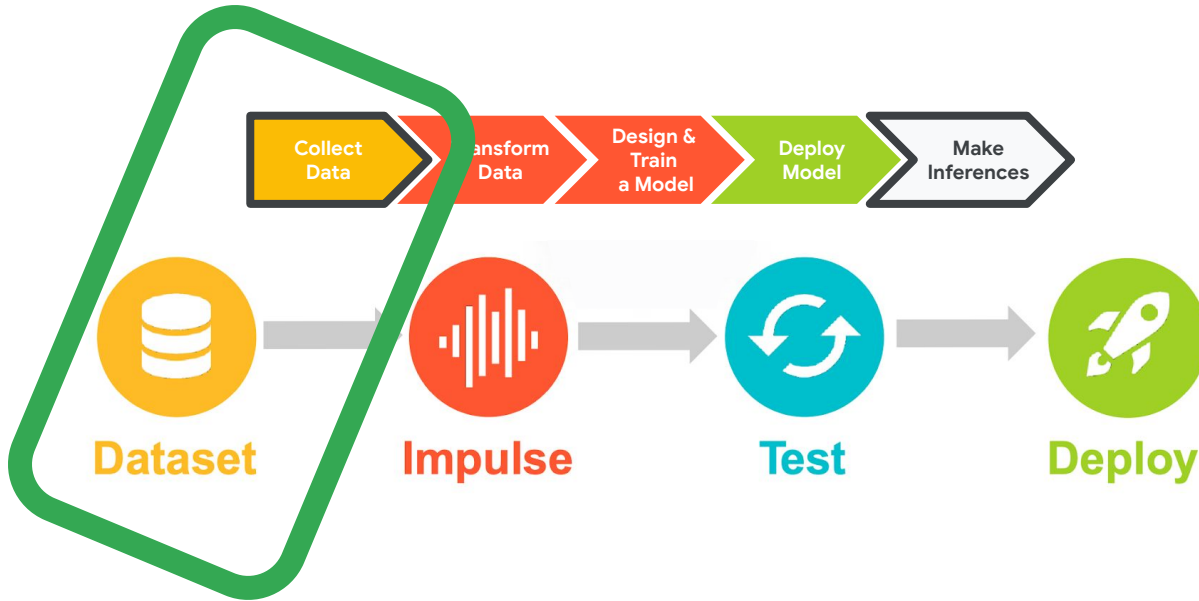


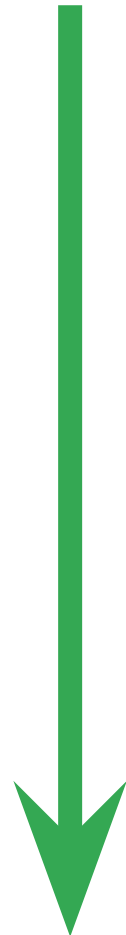











Edge Impulse Project Dashboard



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

Edge Impulse Project Dashboard



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

 EDGE IMPULSE

Log in

[Forgot your password?](#)

[Log in](#)

Don't have an account? [Sign up](#)



Start building embedded
machine learning
models today.

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Activity: Create a Keyword Spotting Dataset

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

- **Keyword #1** **Yá'át'ééh** 🖐️
- **Keyword #2** **hágoónee'** 🖐️
- **“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** **hágoónee'** 🖐️
- ~~“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>

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

HARVARD UNIVERSITY

Project info Keys Export

Brian_plancher

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

GETTING STARTED: CONTINUOUS MOTION RECOGNITION

 Dashboard

 Devices

 Data acquisition

 Impulse design

 Create impulse

 EON Tuner

 Retrain model

 Live classification

 Model testing

 Versioning

 Deployment

GETTING STARTED

 Documentation

 Forums



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

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.

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...				
noise.or				
noise.ru				
noise.orig				
noise.orig_train...	noise	Today, 11:2...	1s	

RAW DATA

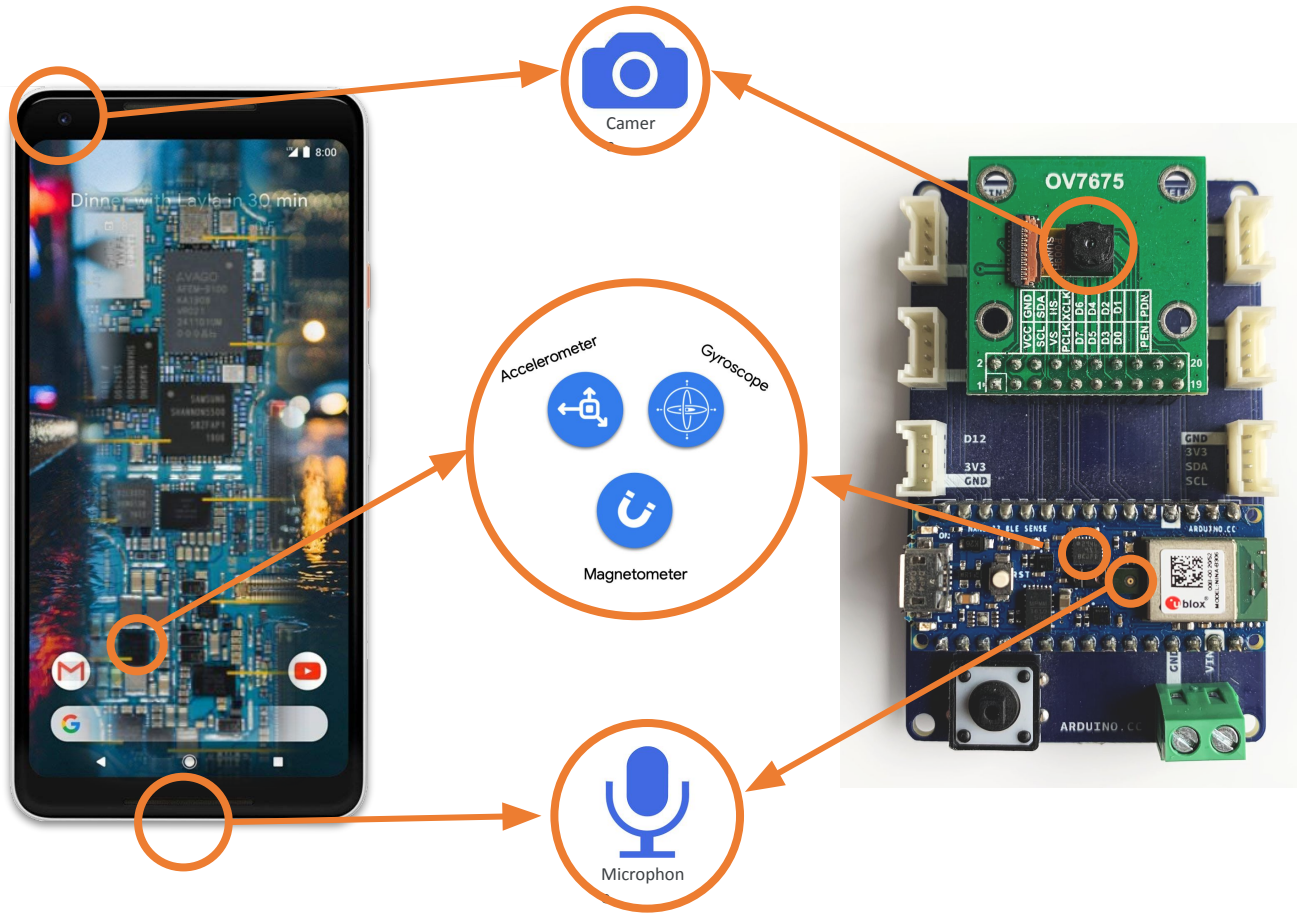
Click on a sample to load...

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

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












GETTING STARTED

- Documentation
- Forums





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](#) 

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

GETTING STARTED

-  Documentation
-  Forums

DATA COLLECTED
50m 34s



TRAIN / TEST ...
100% ...



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	⋮

Record new data

 Connect using WebUSB

 No devices connected to the remote management API.

RAW DATA

Click on a sample to load...

Collect data ✕

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](#)



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](#)



Use your computer

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

[Collect data](#)



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](#)

Collect data ✕

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](#)
-  **Point your phone camera at the QR code and open the link!**
... images, and even [Show QR code](#)
-  **Point your phone camera at the QR code and open the link!**
... 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 📄



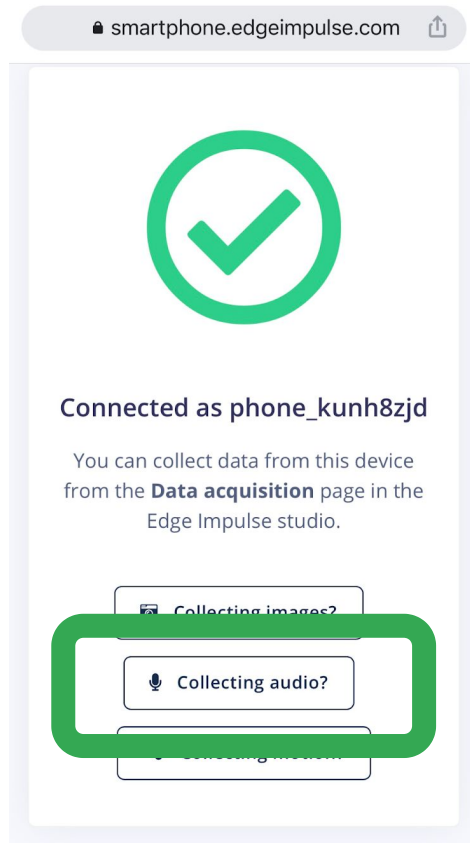
Connected as phone_kunh8zjd

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 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.

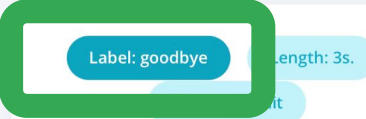
 Collecting images?

 Collecting audio?


 Collecting motion?

smartphone.edgeimpulse.com

 Data collection




Label: goodbye length: 3s.

 Start recording


Audio captured with current settings: 0s


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

  Data collection

Label: goodbye Length: 3s.
Category: split

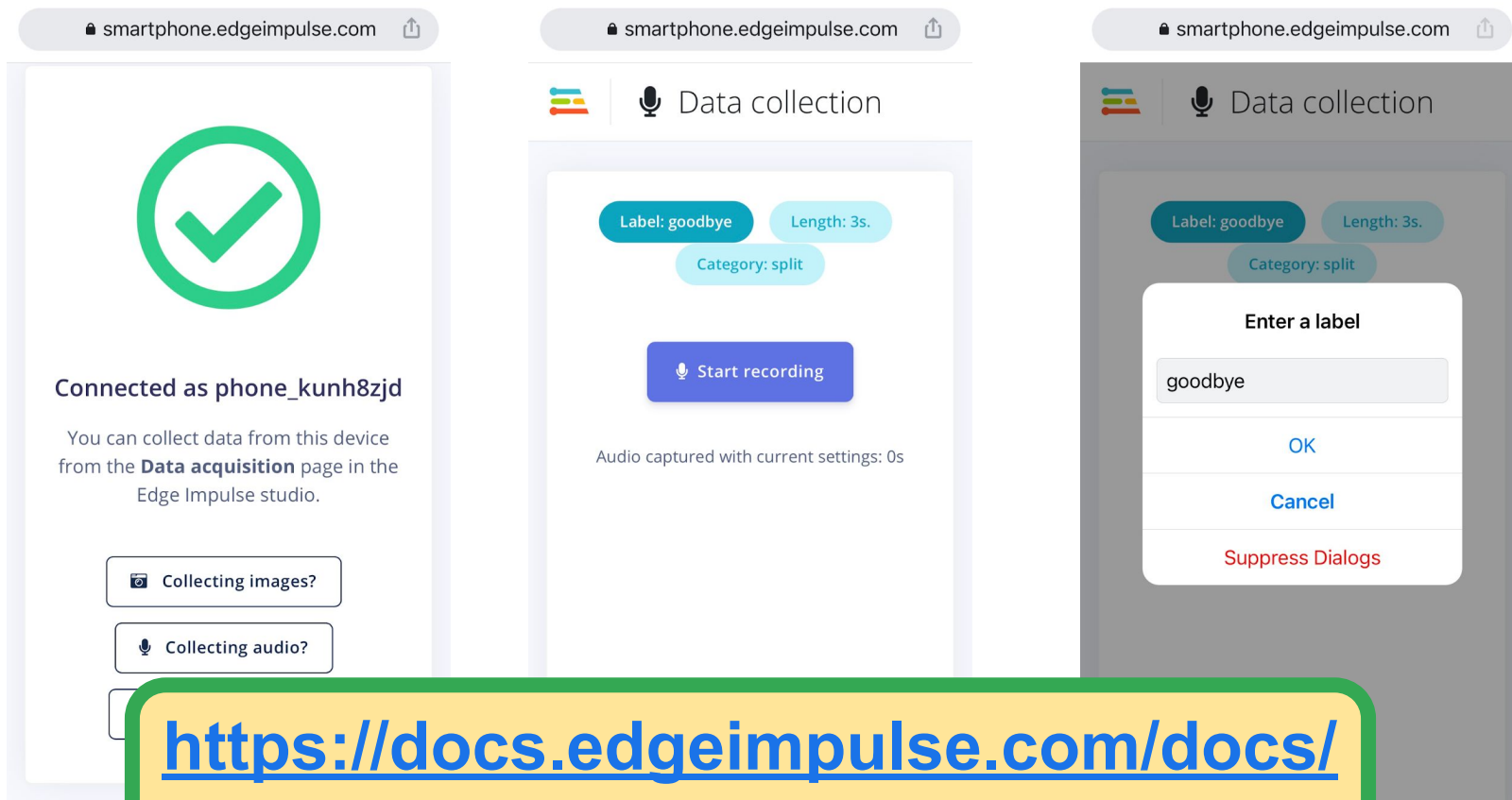
Enter a label

goodbye

OK

Cancel

Suppress Dialogs



<https://docs.edgeimpulse.com/docs/using-your-mobile-phone>

DATA COLLECTED
50m 44s



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	
<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

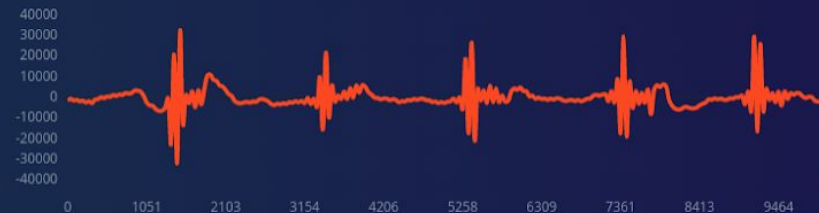
Frequency

16000Hz

Start sampling

RAW DATA

yes.30u5okgq



audio

▶ 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:



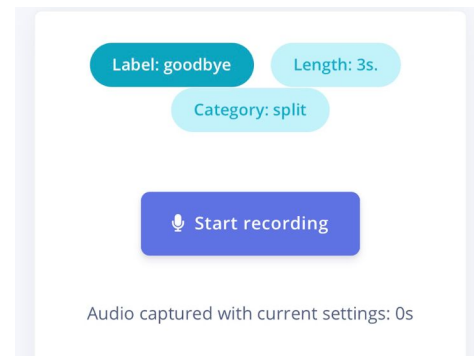
• **Keyword #2**

hágoónee' 🖐️

label: hagoonee

10 seconds

We'll resume in 10 minutes!



DATA COLLECTED
50m 44s



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	
<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

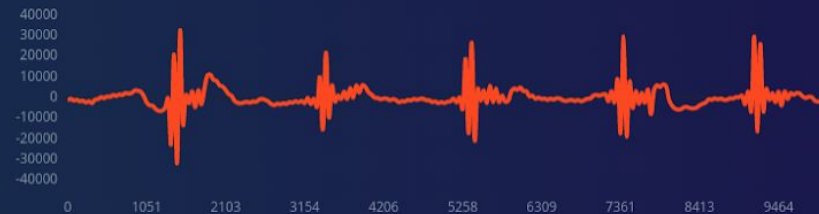
Frequency

16000Hz

Start sampling


RAW DATA

yes.30u5okgq



audio

▶ 0:00 / 0:00

<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		
<input type="checkbox"/>	noise.orig_train.Metro_1.wav.297...	noise	Today, 11:22:57		
<input type="checkbox"/>	noise.orig_train.CafeTeria_1.wav....	noise	Today, 11:22:57		
<input type="checkbox"/>	noise.orig_test.Babble_4.wav.2000	noise	Today, 11:22:57		
<input type="checkbox"/>	noise.orig_train.AirportAnnounc...	noise	Today, 11:22:57		
<input type="checkbox"/>	noise.running_tap.wav.29000	noise	Today, 11:22:57		
<input type="checkbox"/>	noise.orig_train.Station_1.wav.20...	noise	Today, 11:22:57		

- Rename
- Edit label
- Move to test set
- Disable
- Crop sample
- Split sample**
- Download
- Delete

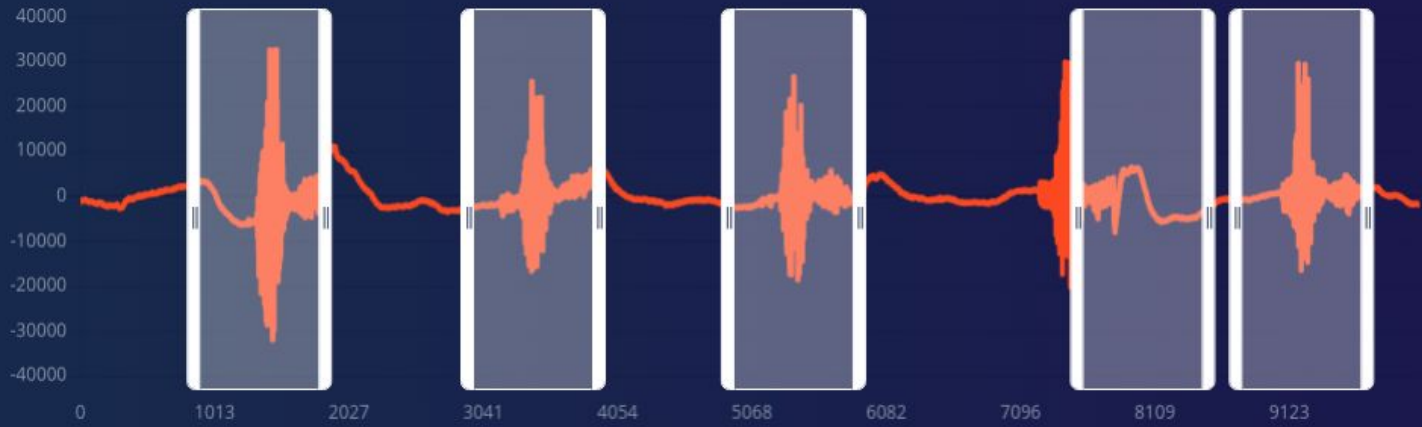
Split sample 'yes.30u5okgq'

Zoom

+ Add Segment

Set segment length (ms.):

Apply



audio

Cancel

Shift samples ?

Split

Split sample 'yes.30u5okgq'

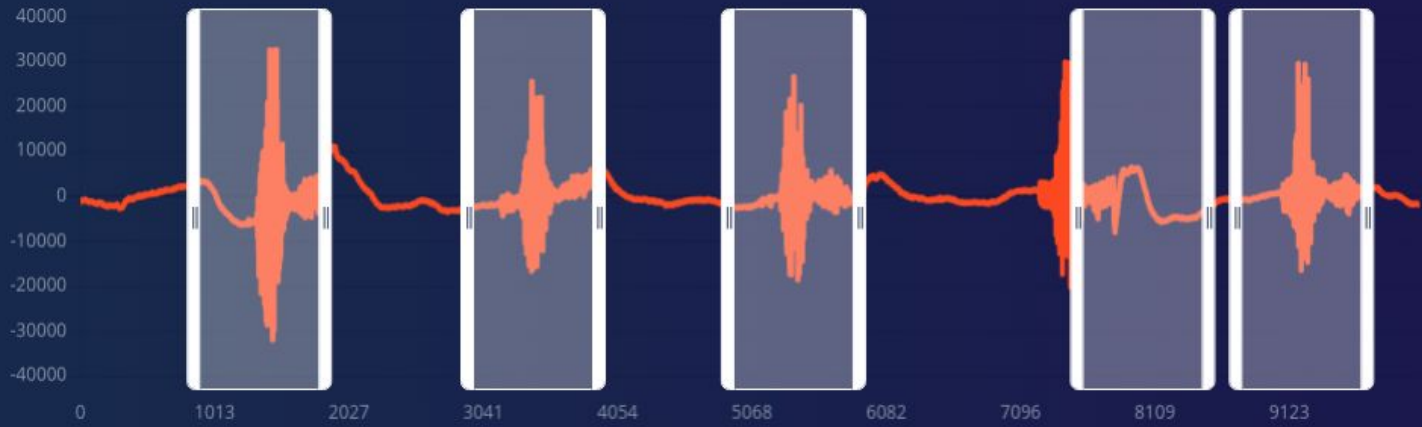
Zoom

+ Add Segment

Set segment length (ms.):

1000

Apply



audio

Cancel

Shift samples ?

Split

Split sample 'yes.30u5okgq'

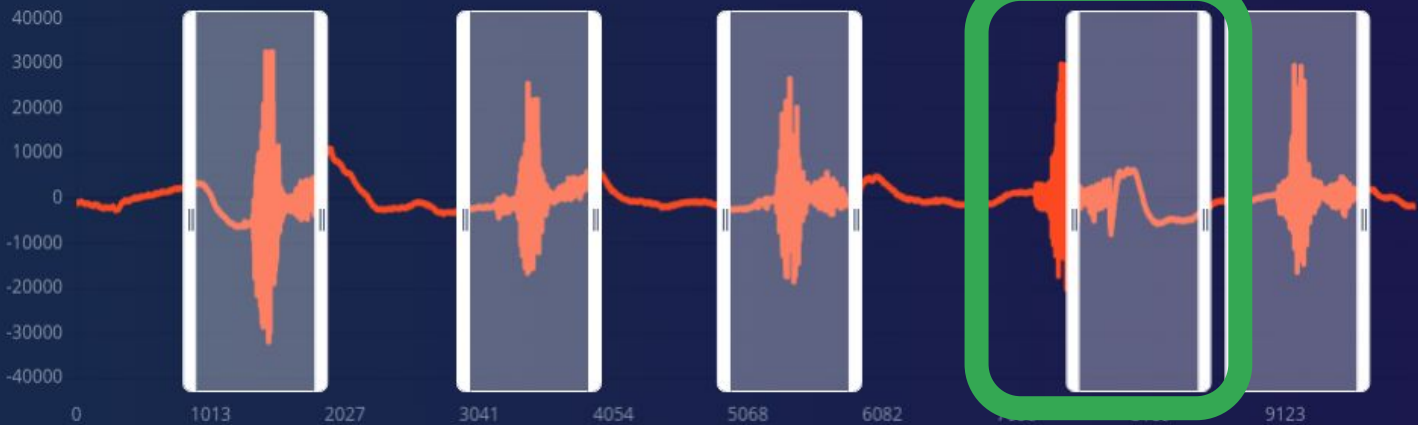
Zoom

+ Add Segment

Set segment length (ms.):

1000

Apply



audio

Cancel

Shift samples ?

Split

Split sample 'yes.30u5okgq'

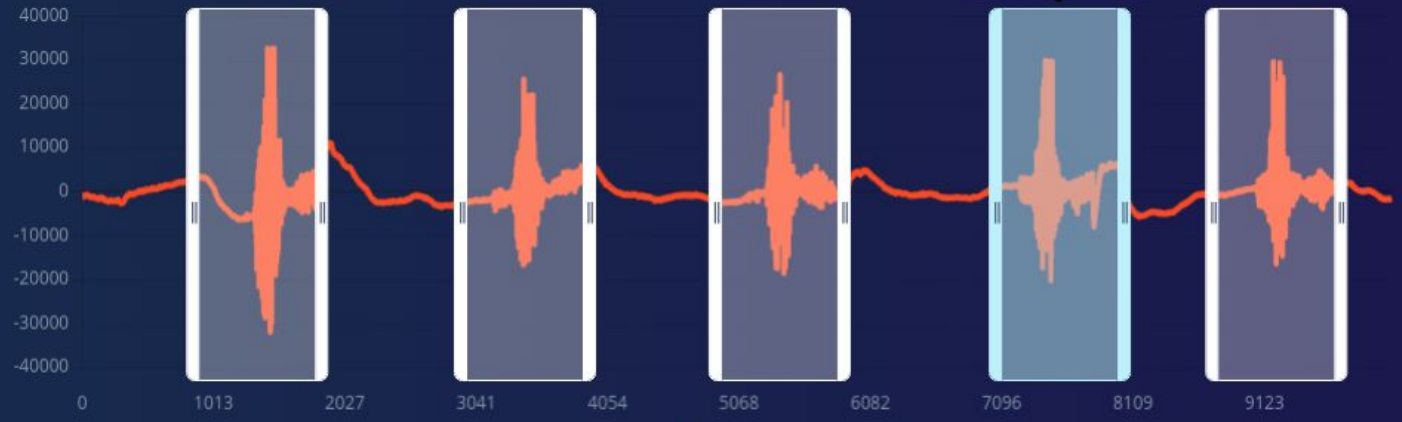
Zoom

+ Add Segment

Set segment length (ms.):

Apply

Remove segment



0:00 / 0:00

Cancel

Shift samples ⓘ

Split

Split sample 'yes.30u5okgq'

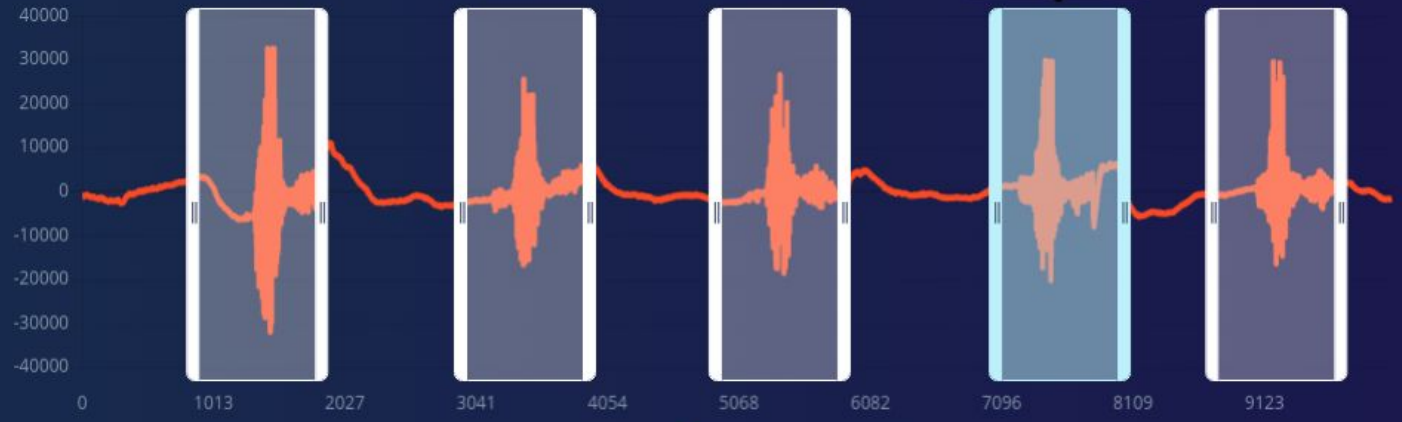
Zoom

+ Add Segment

Set segment length (ms.):

Apply

Remove segment



audio

0:00 / 0:00 [Progress bar] [Speaker icon] [Menu icon]

Cancel

Shift samples ?

Split

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	
<input type="checkbox"/>	yes.30u5okgq.s5	yes	Today, 14:31:19	1s	⋮
<input type="checkbox"/>	yes.30u5okgq.s4	yes	Today, 14:31:19	1s	⋮
<input type="checkbox"/>	yes.30u5okgq.s3	yes	Today, 14:31:19	1s	⋮
<input type="checkbox"/>	yes.30u5okgq.s2	yes	Today, 14:31:19	1s	⋮
<input type="checkbox"/>	yes.30u5okgq.s1	yes	Today, 14:31:19	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	⋮

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

Record new data

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

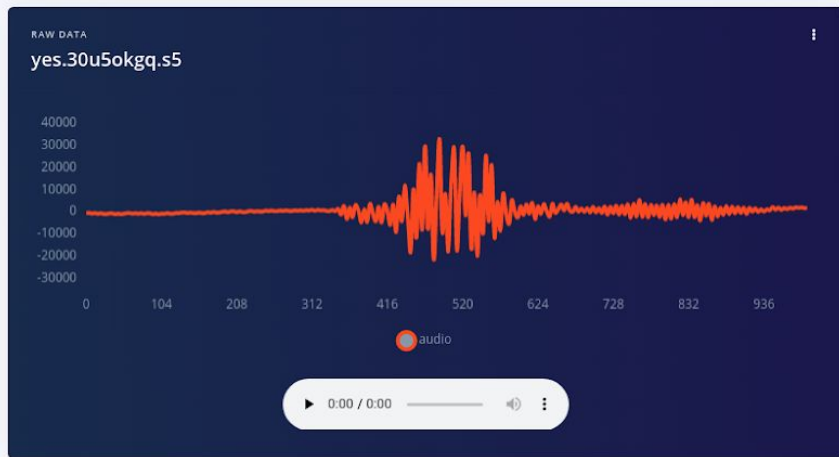
Label
yes

Sample length (ms.)
10000

Sensor
Built-in microphone

Frequency
16000Hz

Start sampling



- Dashboard
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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	⋮
no.30u6k9u9.s3	no	Today, 14:40:13	1s	⋮

DATA ACQUISITION - TESTING (SCITINYML22-KWS-TESTCLONE)

Training data

Test data

Export data



Did you know? You can capture data from any device or upload your existing data.

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

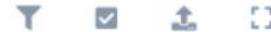


TR

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



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		
no.30u6k9u9.s1	no	Today, 15:22:5		
no.30u8qcvh.s9	no	Today, 15:22:4		
no.30u8qcvh.s7	no	Today, 15:22:4		
yes.30u8rq7l.s8	yes	Today, 15:20:1		
yes.30u8rq7l.s7	yes	Today, 15:20:1		

- Rename
- Edit label
- Move to test set
- Disable
- Crop sample
- Split sample
- Download
- 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.

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

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



NOISE

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



UNKNOWN

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



YES

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



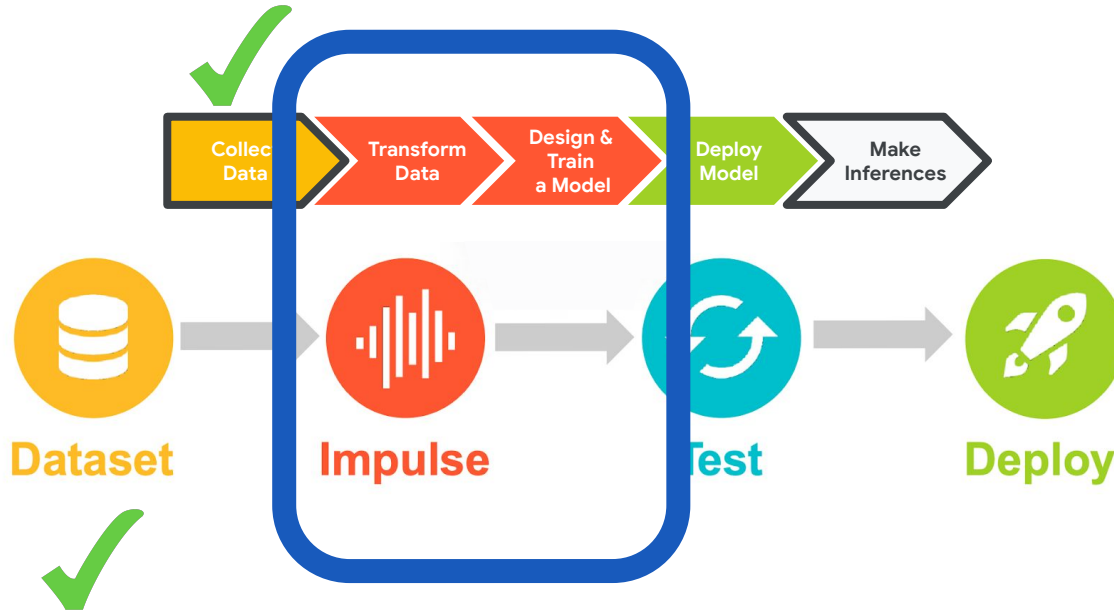
Today's Agenda

- 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



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



- Dashboard
- Devices
- Data acquisition
- Impulse design**
 - Create impulse**
 - EQN Tuner
- Retrain model
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- GETTING STARTED
 - Documentation
 - Forums


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


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

- Dashboard
- Devices
- Data acquisition
- Impulse design
 - Create impulse
- EON Tuner
- Retrain model
- Live classification
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- Versioning
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- GETTING STARTED
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Time series data 


Axes
audio


Window size 


1000 ms.


Window Increase 


500 ms.

Frequency (Hz) 




Zero-pad data 






Add a processing block



Add a learning block

Output features 

Save Impulse

The screenshot displays the Edge Impulse web interface. On the left is a navigation sidebar with options: Dashboard, Devices, Data acquisition, Impulse design (with 'Create impulse' selected), EON Tuner, Retrain model, Live classification, Model testing, Versioning, and Deployment. Below this is a 'GETTING STARTED' section with links to Documentation and Forums. The main workspace is titled 'CREATE IMPULSE (SCTINYML22-KWS-TESTCLONE)'. A red configuration panel for 'Time series data' is visible, with settings for 'Input axes' (audio), 'Window size' (slider), 'Window increase' (slider), 'Frequency (Hz)' (16000), and 'Zero-pad data' (checked). A modal window titled 'Add a processing block' is open, listing several processing blocks with their descriptions, authors, and 'Add' buttons. The background workspace shows a 'block' placeholder and a green 'Output features' panel with a checkmark and a 'Save Impulse' button. The user's profile 'Brian_plancher' is in the top right corner. The footer contains the copyright notice: '© 2022, EdgeImpulse Inc. All rights reserved.'

DESCRIPTION	AUTHOR	RECOMMENDED	
Audio (MFCC) Extracts features from audio signals using Mel Frequency Cepstral Coefficients, great for human voice.	EdgeImpulse Inc.	★	Add
Audio (MFE) Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.	EdgeImpulse Inc.	★	Add
Flatten Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	EdgeImpulse Inc.		Add
Image Preprocess and normalize image data, and optionally reduce the color depth.	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.	EdgeImpulse Inc.		Add
Spectrogram Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	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. ★	<input type="button" value="Add"/>
Audio (MFE) Extracts a spectrogram from audio signals using Mel-filterbank energy features, great for non-voice audio.	EdgeImpulse Inc. ★	<input type="button" value="Add"/>
Flatten Flatten an axis into a single value, useful for slow-moving averages like temperature data, in combination with other blocks.	EdgeImpulse Inc.	<input type="button" value="Add"/>
Image Preprocess and normalize image data, and optionally reduce the color depth.	EdgeImpulse Inc.	<input type="button" value="Add"/>
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.	<input type="button" value="Add"/>
Spectrogram Extracts a spectrogram from audio or sensor data, great for non-voice audio or data with continuous frequencies.	EdgeImpulse Inc.	<input type="button" value="Add"/>

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>

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

- Dashboard
- Devices
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- Impulse design
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- GETTING STARTED
- Documentation
- Forums

Time series data


Axes
audio

Window size ?

1000 ms.

Window increase ?

500 ms.

Frequency (Hz) ?
 


Zero-pad data ?

Audio (MFCC)

Name

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
Classification (Keras) Learns patterns from data, and can apply these to new data. Great for categorizing movement or recognizing audio.	EdgeImpulse Inc.	★ <input type="button" value="Add"/>
Regression (Keras) Learns patterns from data, and can apply these to new data. Great for predicting numeric continuous values.	EdgeImpulse Inc.	<input type="button" value="Add"/>

Add a processing block

The image shows a machine learning workflow builder interface with four main blocks and two action buttons:

- Time series data (Red block):** Contains settings for 'Axes' (audio), 'Window size' (1000 ms), 'Window increase' (500 ms), 'Frequency (Hz)' (16000), and 'Zero-pad data' (checked).
- Audio (MFCC) (White block):** Name: MFCC; Input axes: audio (checked).
- Classification (Keras) (Purple block):** Name: NN Classifier; Input features: MFCC (checked); Output features: 3 (no, unknown, yes).
- Output features (Green block):** 3 (no, unknown, yes).

At the bottom, there are two dashed boxes for adding blocks:

- Add a processing block:** Represented by a lightning bolt icon.
- Add a learning block:** Represented by a flask icon.

A blue-bordered box highlights a green 'Save Impulse' button on the right side of the interface.

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

Dashboard

Devices

Data acquisition

Impulse design

Create impulse

MFCC

NN Classifier

EON Tuner

Retrain model

Live classification

Model testing

Versioning

Deployment

GETTING STARTED

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

Classification (Keras)

Name

NN Classifier

Input features

MFCC

Output features

3 (no, unknown, yes)

Output features

3 (no, unknown, yes)

Save Impulse

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

[Generate features](#)

Feature explorer ?

No features generated yet.



#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 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

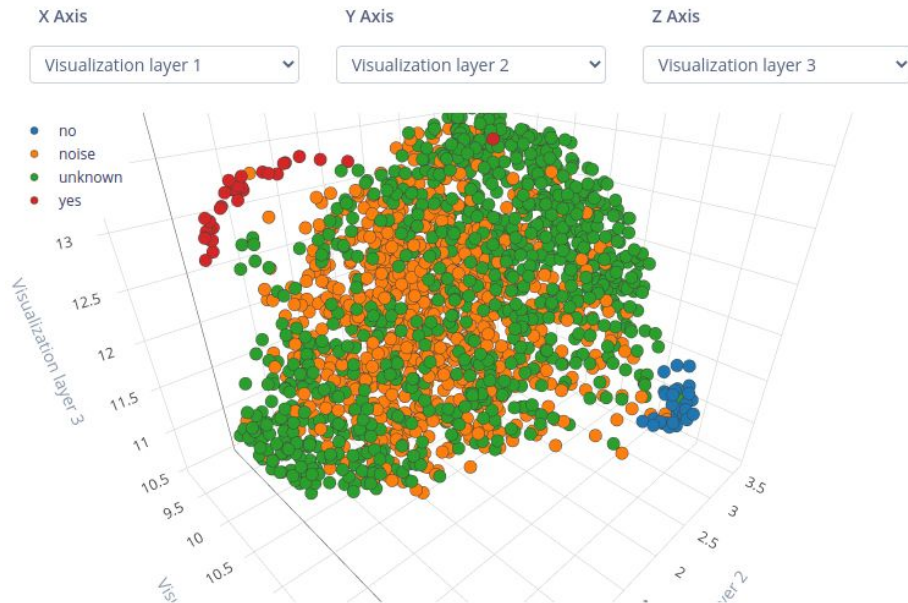
[ 1/2429] Creating windows from files...
```

Feature explorer



No features generated yet.

Feature explorer (2,494 samples)



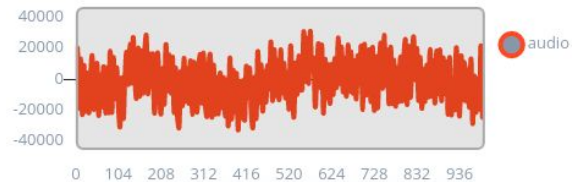
If you can visually see the clustering of the data then it is easier for the ML model to learn!
(But its not required and provides no guarantees)

noise.pink_noise.wav.20000

Label: noise

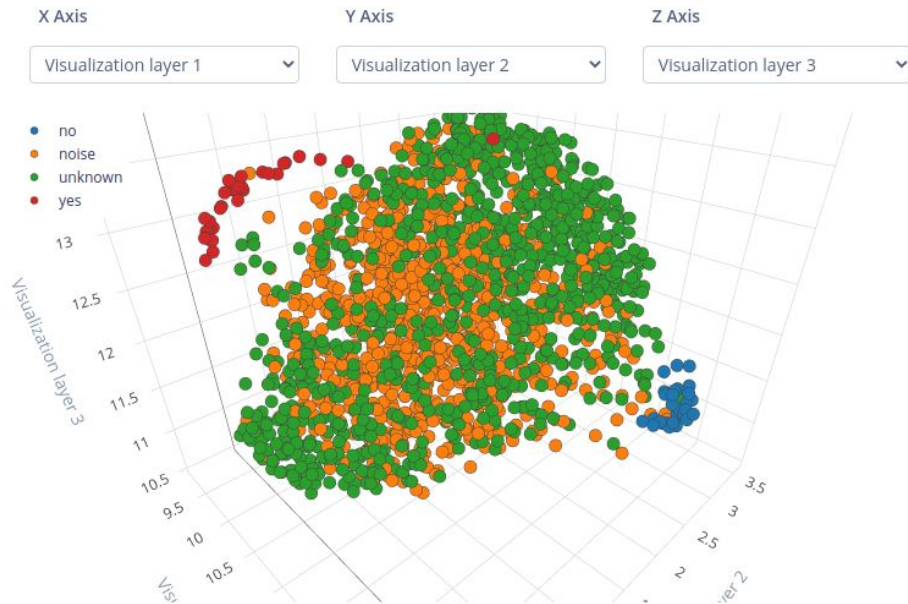
[View sample](#)

[View features](#)



▶ 0:00 / 0:01

Feature explorer (2,494 samples)

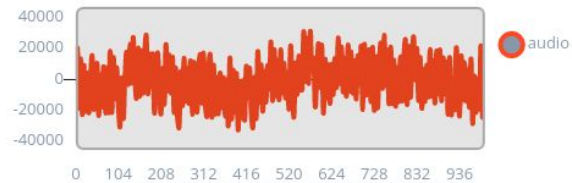


noise.pink_noise.wav.20000

Label: noise

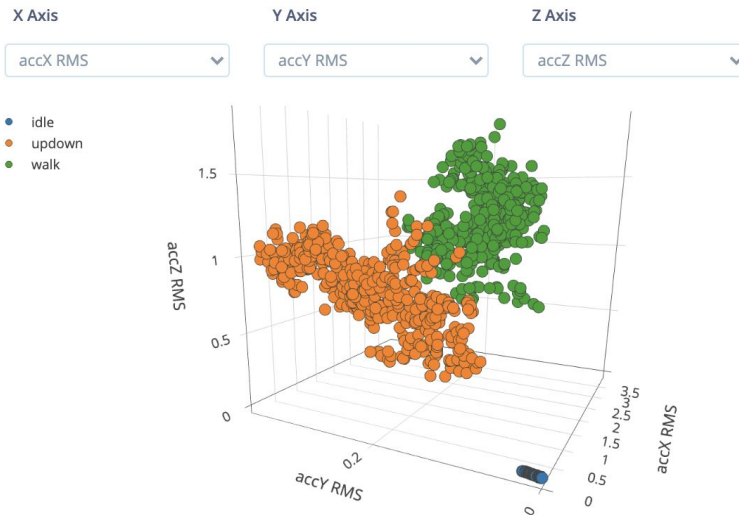
[View sample](#)

[View features](#)



▶ 0:00 / 0:01

Feature explorer (1,506 samples)

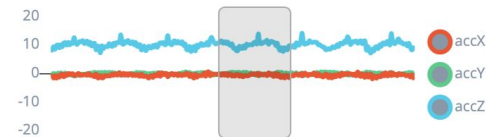


updown.9.1cjh52qu

Window: 4608 - 6608 ms.

Label: updown

[View features](#)



#1 ▼ Click to set a description for this versionParameters 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

```

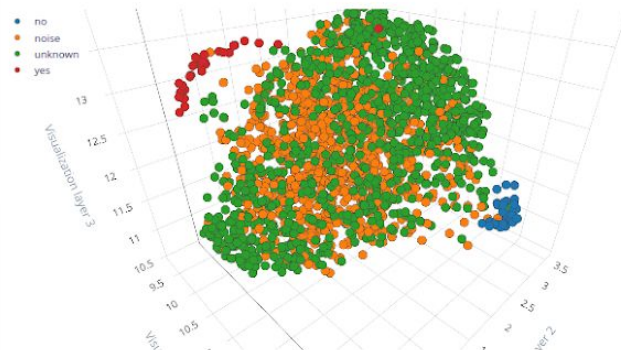
Still running...
  completed 150 / 500 epochs
  completed 200 / 500 epochs
Still running...
  completed 250 / 500 epochs
  completed 300 / 500 epochs
Still running...
  completed 350 / 500 epochs
  completed 400 / 500 epochs
Still running...
  completed 450 / 500 epochs
Wed Apr 27 19:18:09 2022 Finished embedding
Reducing dimensions for visualizations OK

Job completed

```

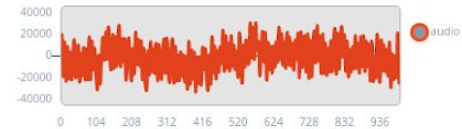
Feature explorer (2,494 samples)

X Axis Visualization layer 1 ▼ Y Axis Visualization layer 2 ▼ Z Axis Visualization layer 3 ▼



noise.pink_noise.wav.20000

Label: noise

[View sample](#)[View features](#)On-device performance ?
 PROCESSING TIME
168 ms.

 PEAK RAM USAGE
17 KB

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NN CLASSIFIER (SCITINYML22-KWS-TESTCLONE)

#1 [Click to set a description for this version](#)

Neural Network settings

Training settings

Number of training cycles [?](#)

Learning rate [?](#)

Validation set size [?](#)

%

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)



Switch to Keras (expert mode)



Edit as IPython notebook

Model Design with Edge Impulse

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

Neural Network settings

Training settings

Number of training cycles ⓘ

Learning rate ⓘ

Minimum confidence rating ⓘ

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)

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

```

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,
  Flatten, Reshape, MaxPooling1D, MaxPooling2D, BatchNormalization,
  TimeDistributed
4 from tensorflow.keras.optimizers import Adam
5
6 # model architecture
7 model = Sequential()
8 model.add(Reshape((int(input_length / 13), 13), input_shape=(input_length, )))
9 model.add(Conv1D(8, kernel_size=3, activation='relu', padding='same'))
10 model.add(MaxPooling1D(pool_size=2, strides=2, padding='same'))
11 model.add(Dropout(0.25))
12 model.add(Conv1D(16, kernel_size=3, activation='relu', padding='same'))
13 model.add(MaxPooling1D(pool_size=2, strides=2, padding='same'))
14 model.add(Dropout(0.25))
15 model.add(Flatten())
16 model.add(Dense(classes, activation='softmax', name='y_pred'))
17
18 # this controls the learning rate
19 opt = Adam(lr=0.005, beta_1=0.9, beta_2=0.999)
20 # this controls the batch size, or you can manipulate the tf.data.Dataset objects
  yourself
21 BATCH_SIZE = 32
22 train_dataset = train_dataset.batch(BATCH_SIZE, drop_remainder=False)
23 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 Model version: Quantized (int8)

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)

- 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

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

Final Accuracy

Accuracy Breakdown

Model

Model version: Quantized (int8)

Last training performance (validation set)

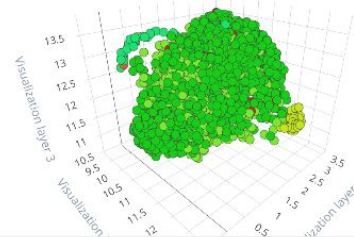
ACCURACY 96.6% LOSS 0.09

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

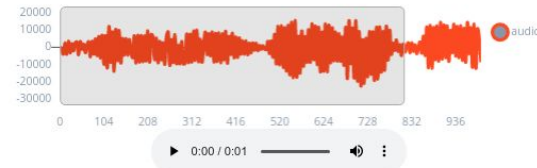
Feature explorer (full training set)

- 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

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

Confusion Matrix

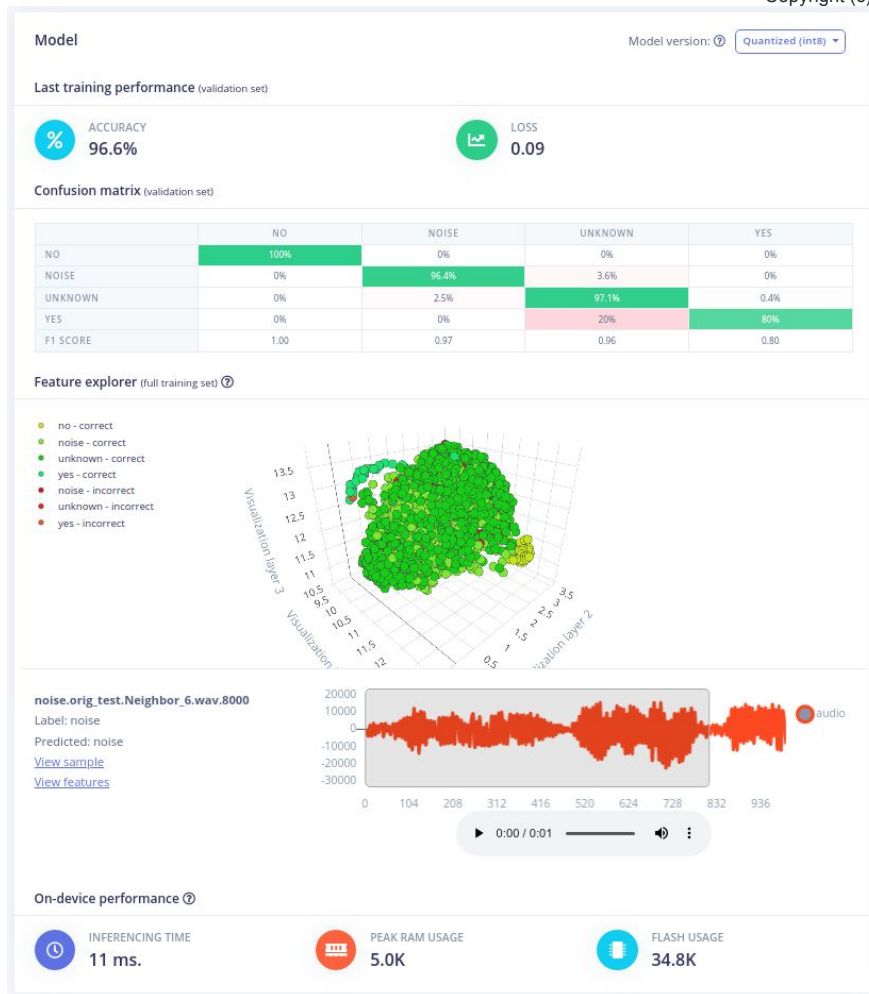
	Actual Output = Yes	Actual Output = No
Predicted Output = Yes	# of True Positive	# of False Positive <i>Type 1 Error</i>
Predicted Output = No	# of False Negative <i>Type 2 Error</i>	# of True Negative

Final Accuracy

Accuracy Breakdown

Feature Explorer

Individual Data Points



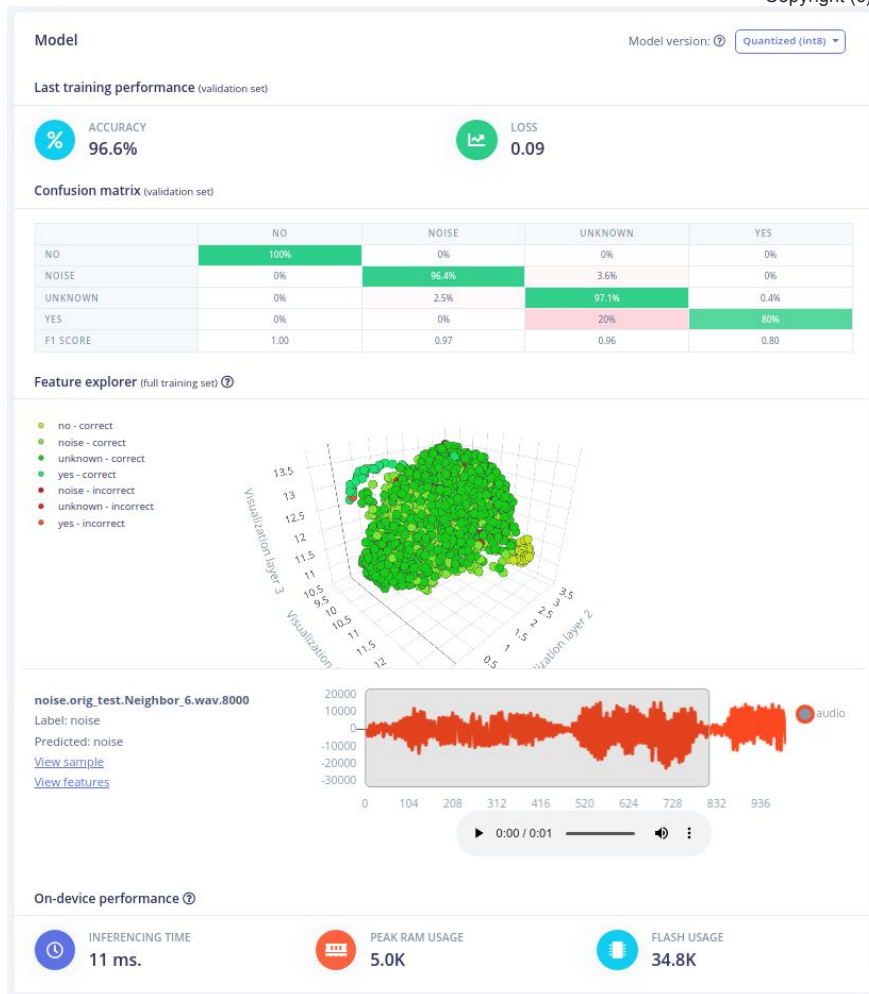
Final Accuracy

Accuracy Breakdown

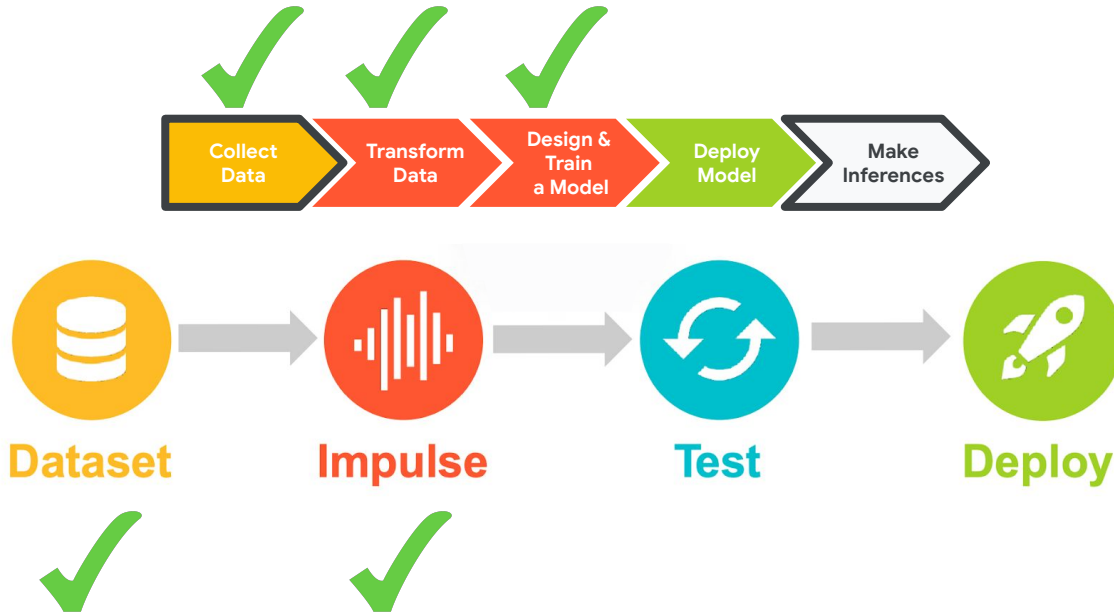
Feature Explorer

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

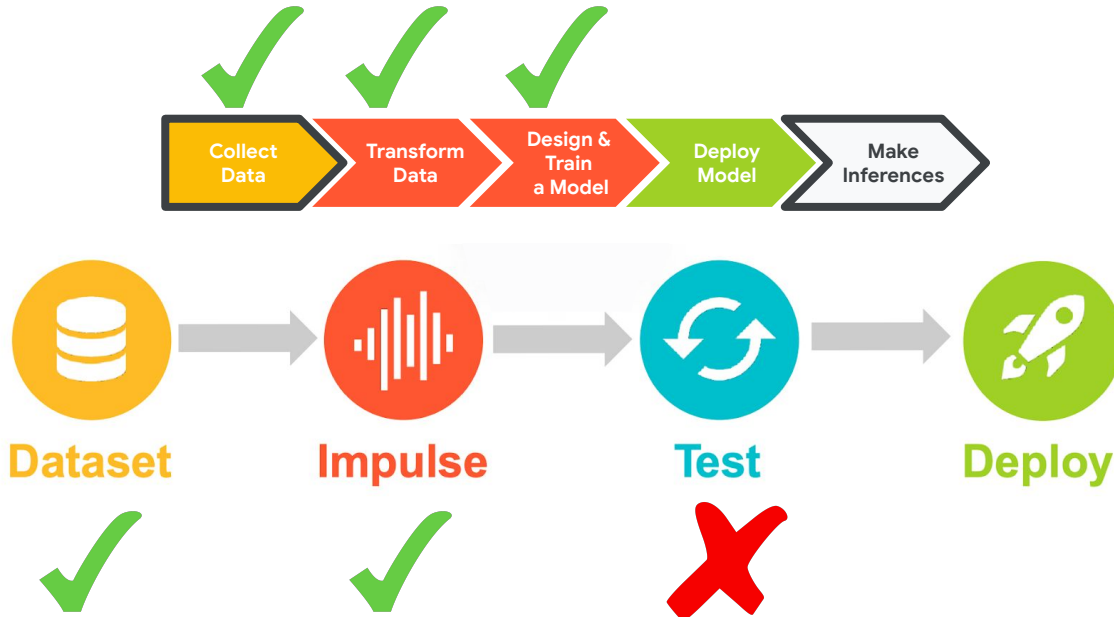
Today's Agenda

- 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

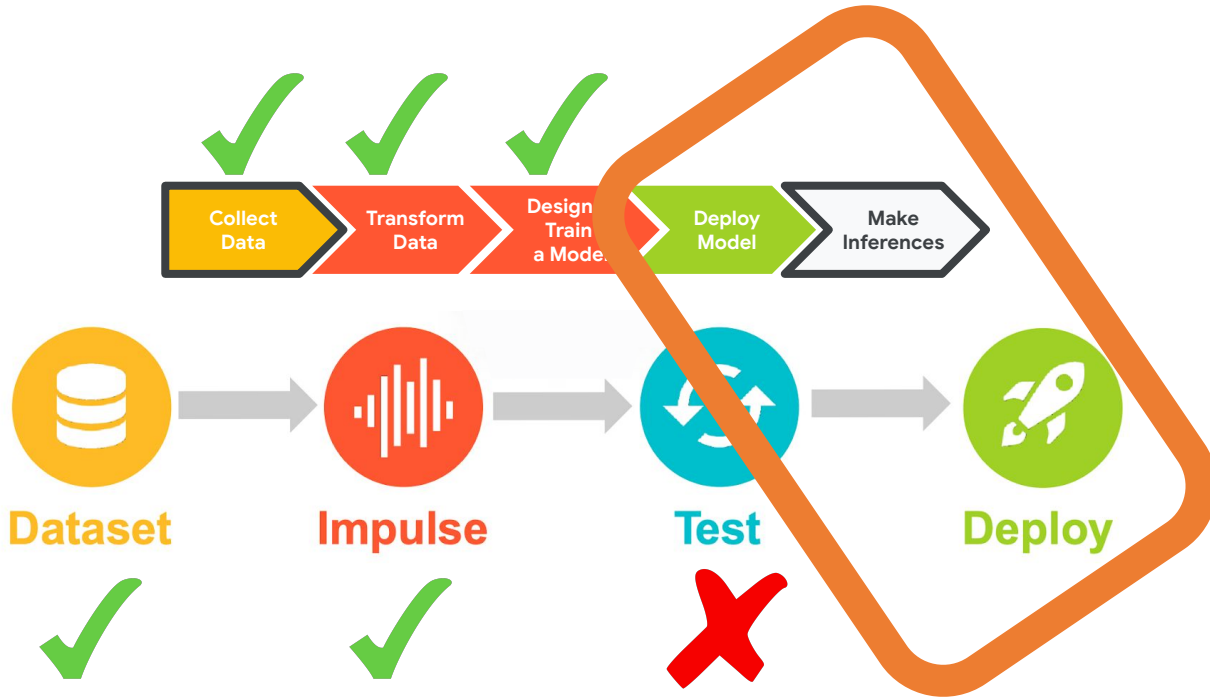
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Edge Impulse Project Dashboard

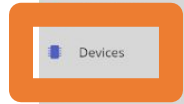


- Dashboard
- Devices
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Edge Impulse Project Dashboard



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



Devices

- Impulse design
- Create impulse
- MFCC
- NN Classifier

Your devices

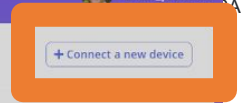
These are devices that are connected to the Edge Impulse

NAME
phone_kunh8zjd
computer_kq77e063

Collect data

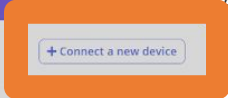
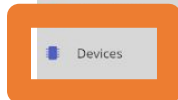
You can collect data from development boards, from your own devices, or by uploading an existing dataset.

- 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](#)
- 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](#)



+ Connect a new device

REMOTE ...	LAST SEEN
camera, ...	Today, 16:24:48
camera	Jun 21 2021, 18:41:37



- Impulse design
- Create impulse
- MFCC
- NN Classifier

Your devices

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

NAME	REMOTE ...	LAST SEEN
phone_kunh8zjd	camera, ...	Today, 16:24:48
computer_kq77e063	camera	Jun 21 2021, 18:41:37

Collect data

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

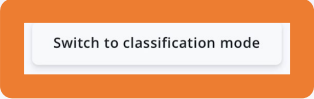
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Connected as phone_kunh8zjd

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

- Collecting images?
- Collecting audio?
- Collecting motion?



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

Devices

Your devices

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

NAME

phone_kunh8zjd

computer_kq77e063

Collect data

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Show QR code

+ Connect a new device



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

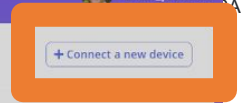
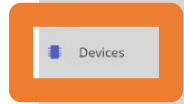


Building project...

Job started

Switch to data collection mode

This client is open source.

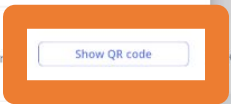


Collect data

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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](#).



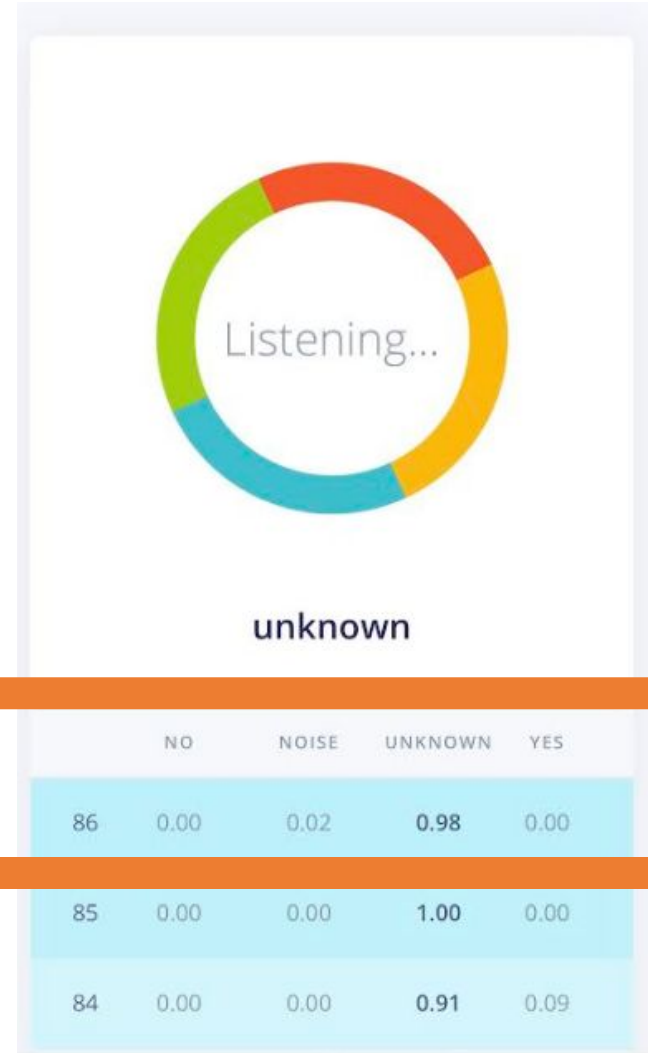
Listening...

unknown

	NO	NOISE	UNKNOWN	YES
86	0.00	0.02	0.98	0.00
85	0.00	0.00	1.00	0.00
84	0.00	0.00	0.91	0.09

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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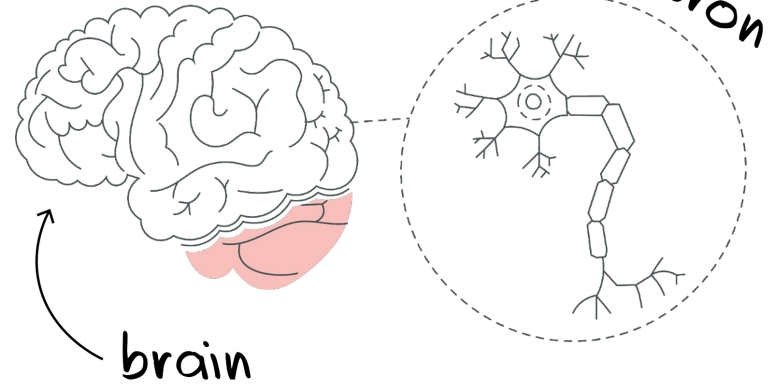
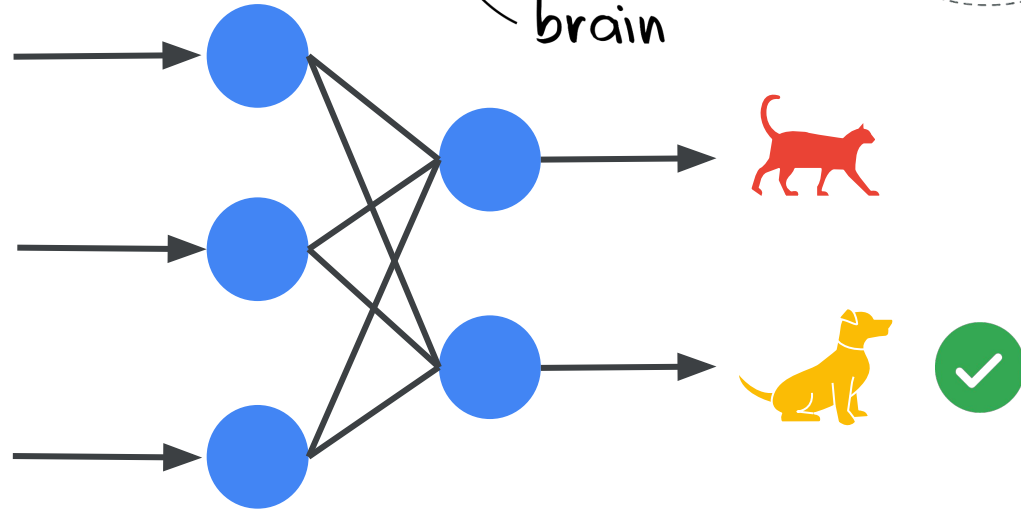
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● Summary

Machine Learning



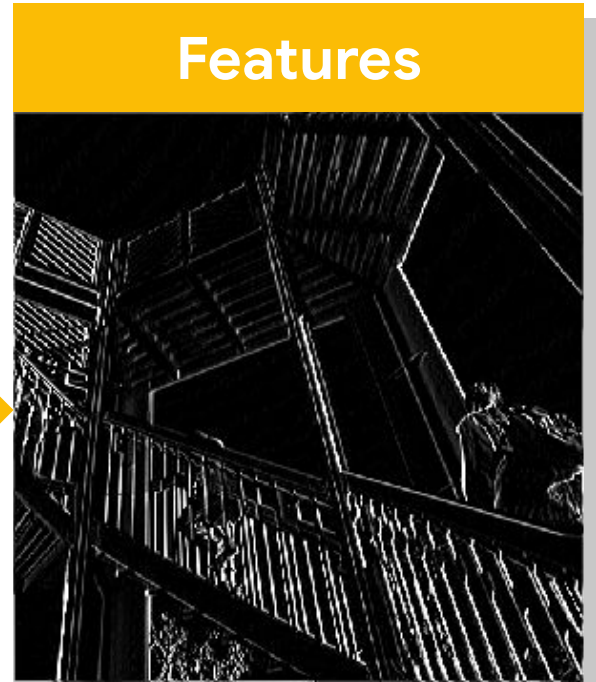
Deep Learning with **Neural Networks**



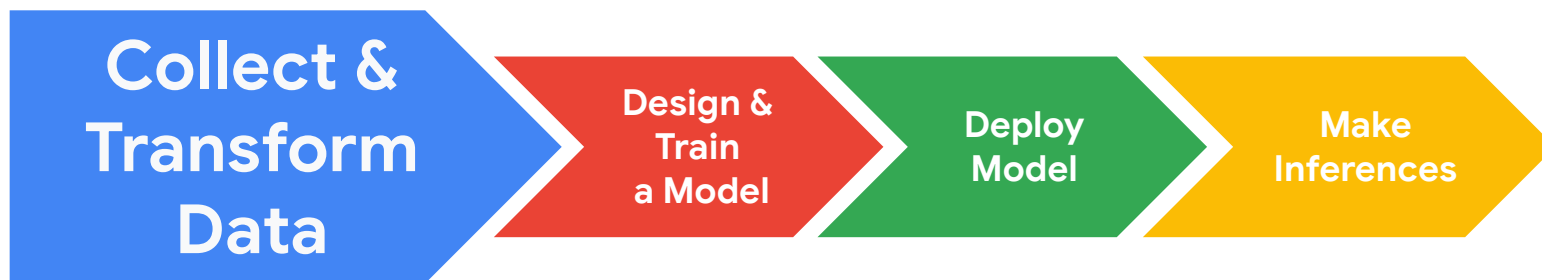
Features can be found with **Convolutions**



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

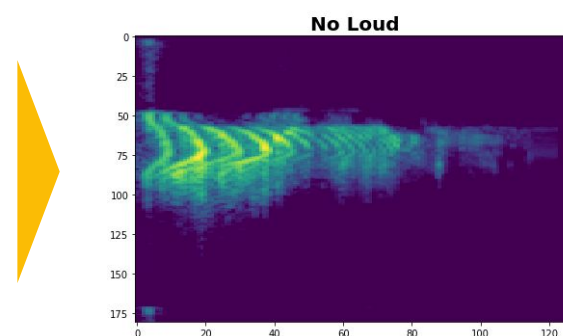
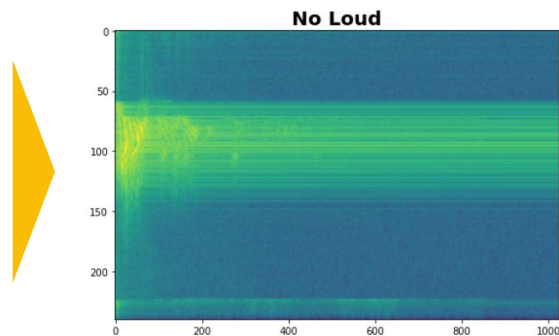
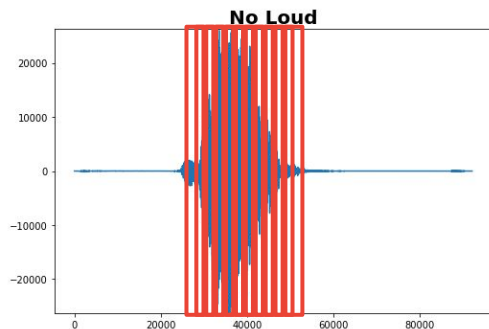
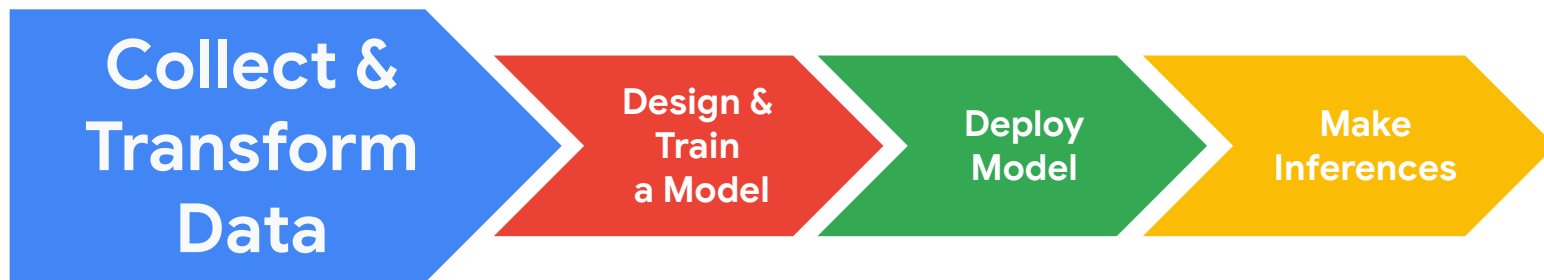


The (Tiny) Machine Learning **Workflow**

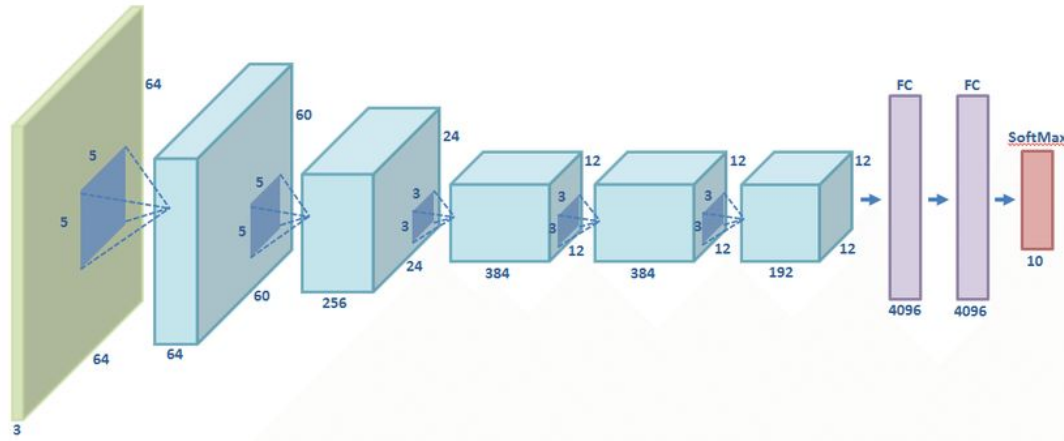
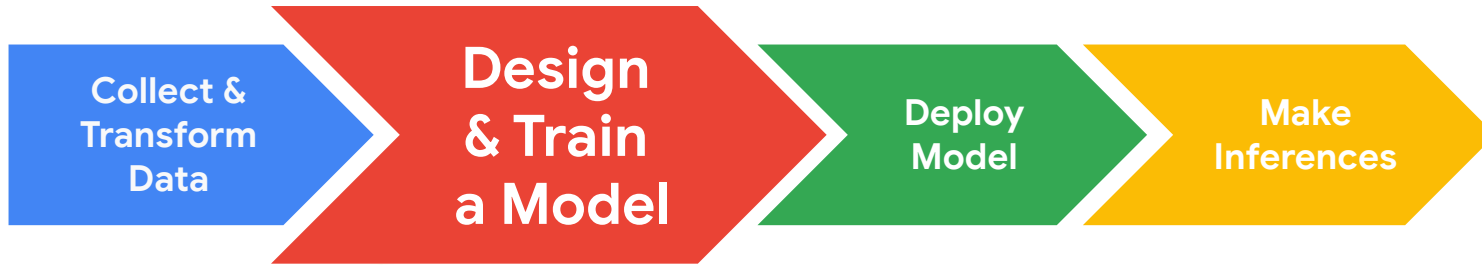


**If ML is going to be everywhere
we need to consider how to best
collect **GOOD** data **RESPONSIBLY****

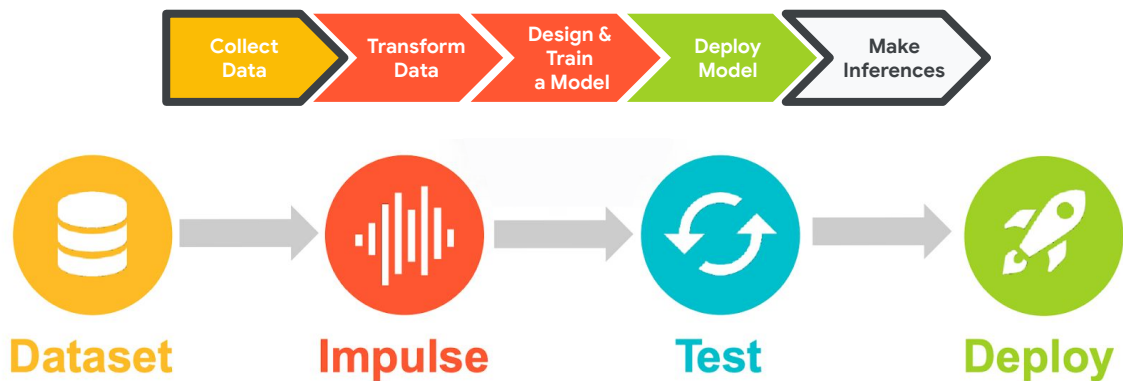
The (Tiny) Machine Learning **Workflow**



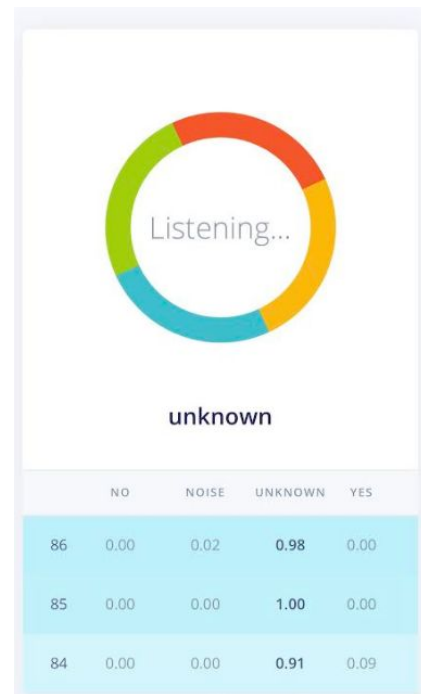
The (Tiny) Machine Learning Workflow



The (Tiny) Machine Learning Workflow



Edge Impulse Simplifies
Training and Deployment





Better Data =
Better Models!



hágoónee' 🖐️

see you again at 12pm (Mountain Time)