



Tiny machine learning

Arduino Education

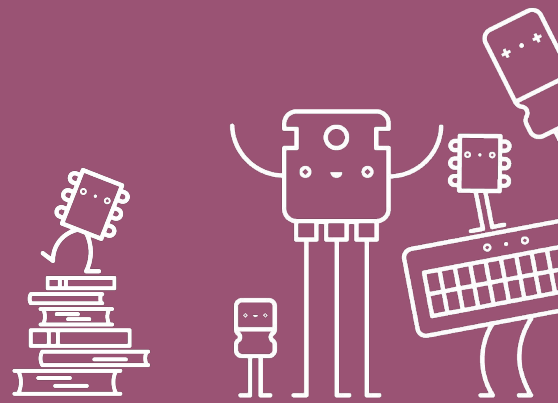
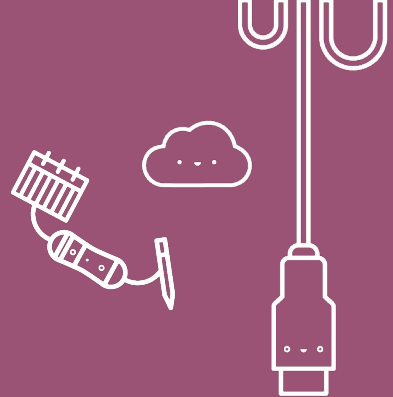
June 23rd 2021





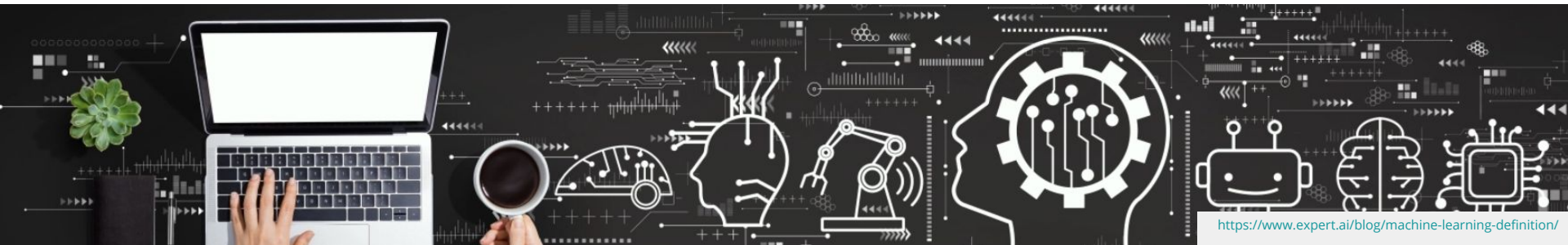
Agenda

- What is Machine Learning
- Applications
- Tiny Machine learning
- Tiny Machine learning kit
- Examples



Machine Learning

- Day to day tasks like scrolling through social media, taking a picture, checking the weather, all depend on machine learning models.
- **Machine learning** is a subset of AI.
- Machines take data and 'learn' for themselves.
- Machine learning systems can quickly apply knowledge and **training** from large datasets to excel at **facial recognition, speech recognition, object recognition, translation, and many other tasks.**
- Machine learning allows a system to **learn to recognize patterns on its own and make predictions,** contrary to hand-coding a software program with specific instructions to complete a task.



Machine Learning

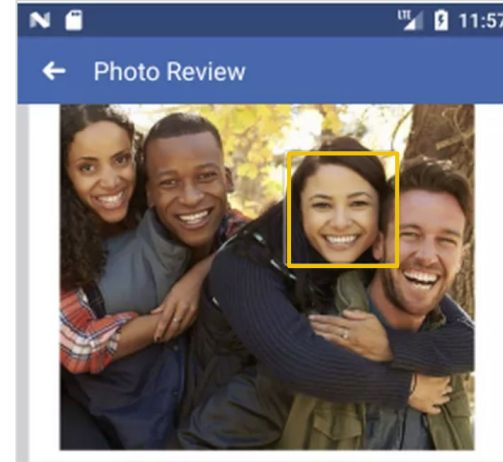
- It started from games.
- Computers were trained to play games for example checkers with humans.
- The term *machine learning* was coined in 1959 by Arthur Samuel, pioneer in the field of computer gaming and artificial intelligence.
- Blue an IBM computer beat world chess champion Garry Kasparov in 1996.



Photograph: Stan Honda/AFP/Getty Images

Machine Learning applications for everyday life

- Fraud detection
- Online recommender systems
- Google search algorithms
- The self-driving cars
- Face recognition



<https://www.cnet.com/news/>



Why to learn ML?

- Predictive inventory planning
- Recommendation engines
- Market segmentation & targeting

Retail



- Alerts & diagnosis from real time patient data
- Disease identification
- Proactive health management

Healthcare



- Aircraft scheduling
- Customer complaint resolution
- Traffic patterns
- Safety monitoring
- Dynamic pricing

Travel & transportation



- Risk analytics
- Sales & marketing campaign management
- Customer segmentation
- Fraud detection

Financial services



- Power usage analytics
- Energy demand & supply administration
- Smart grid management

Energy



- Predictive maintenance
- Propensity to buy
- Demand forecasting
- Process optimization

Manufacturing



Challenges of Machine Learning

Machine Learning allows a computer to internalize concepts found in data to form predictions for new situations.

Training these models are computationally expensive.

Running inference on these models are computationally expensive as well.

We need computing systems that are fast enough to handle it.

Most of these models run on huge data centres with clusters of CPUs and GPUs

To reach reliable levels of accuracy, models require large datasets to 'learn' from.

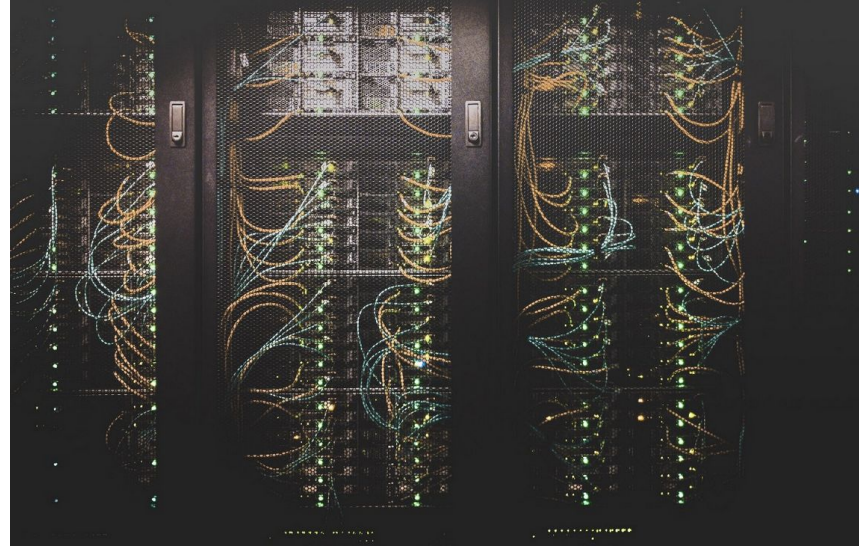
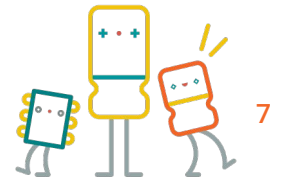


Photo by Taylor Vick on Unsplash

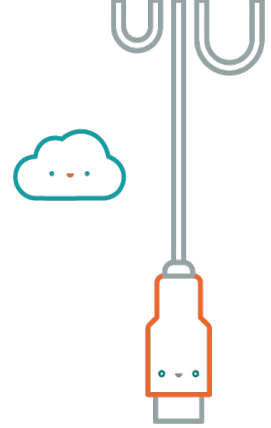


Challenges of Machine Learning

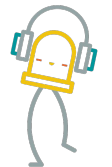
When you take a picture, you want the machine learning magic to happen instantly.

In this case, you would want the machine learning model to run locally.

When you say “Alexa” or “Ok, Google”, you want your devices **to respond to instantly.**

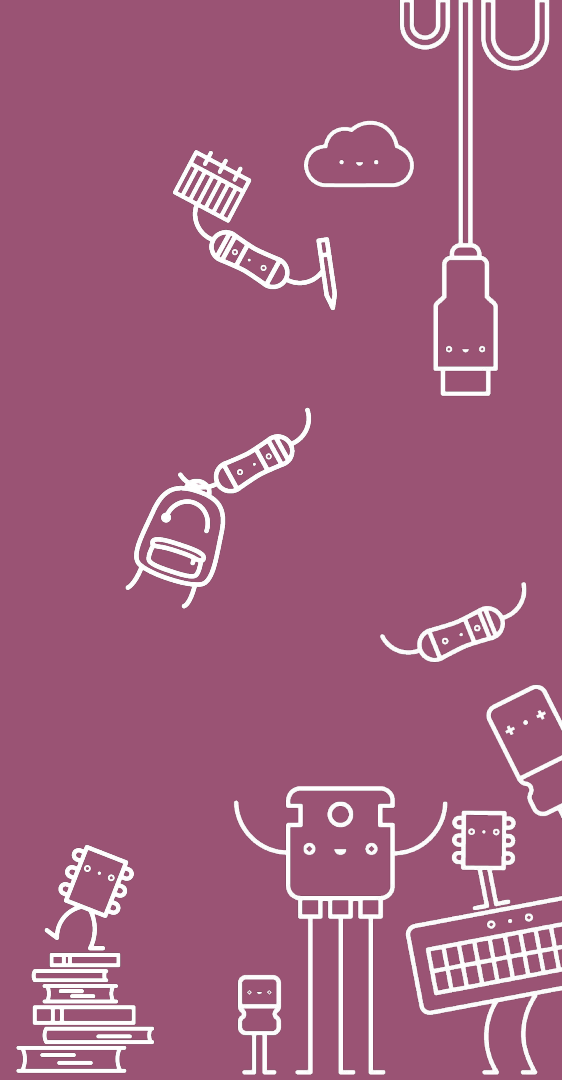


1. **Energy:** Efficiency issues / large data centers of computers
2. **Privacy & data acquisition:** Machine Learning requires massive data sets to train on, and these should be inclusive/unbiased, and of good quality
3. **Latency:** Send the data up and down takes time
4. **Reliability:** What happen if the network is down





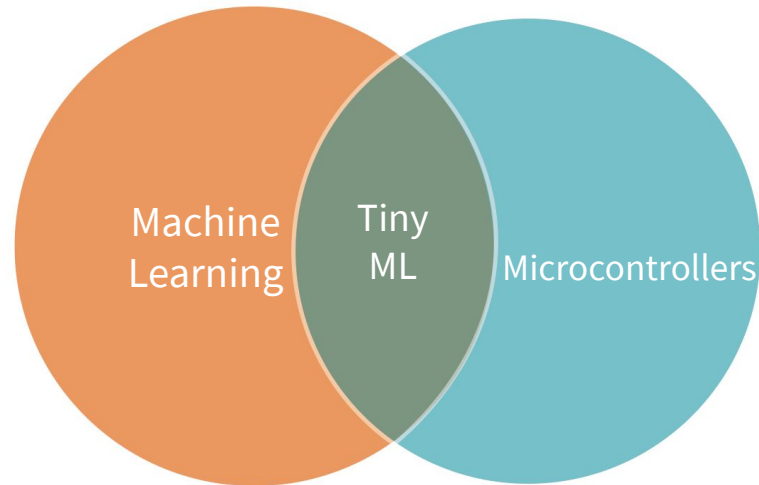
Tiny machine learning



Tiny Machine Learning

Collaboration of machine learning and embedded ultra-low power internet of things devices that explores the types of models you can run on small, low-powered devices like microcontrollers.

The philosophy of TinyML is **doing more** on the device with **less resources** – in **smaller form-factors, less energy** and **lower cost**.



Advantages of Tiny Machine Learning

1. **Low Power Consumption:** Microcontrollers consume very little power. This enables them to run without being charged for a really long time.
2. **Low Latency:** Since the model runs on the edge, the data doesn't have to be sent to a server to run inference. This reduces the latency of the output.
3. **Low Bandwidth:** As the data doesn't have to be sent to the server constantly, less internet bandwidth is used.
4. **Privacy:** Since the model is running on the edge, your data is not stored in any servers (privacy by design)



Tiny machine learning

Tiny ML started with Ok google.

Ok google it is a machine learning model that runs on all of our phones, does not run on a big data centre. It runs in the single processing little chip that is always on.

How they do that?

TinyML is focused on **inference**, we want a response to an event coming in.

The training of this model, the million of voices and keywords to distinguish between the phrases, happens somewhere in the cloud, but the final inference can happen on this small devices.



What do we need?

1. Hardware:

Arduino Nano 33 BLE Sense

It provides enough power to run TinyML models. It has a colour, brightness, proximity, gesture, motion, vibration, orientation, temperature, humidity, and pressure sensors. It also contains a digital microphone and a Bluetooth low energy(BLE) module.

2. Software - Framework

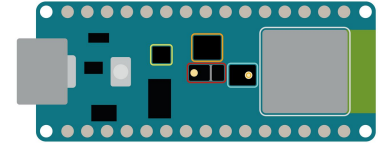
TensorFlow Lite is the most popular and has the most community support. Using TensorFlow Lite Micro, we can deploy models on microcontrollers.

Arduino IDE: There is an arduino library available for TensorFlow Lite, on the Nano 33 BLE Sense

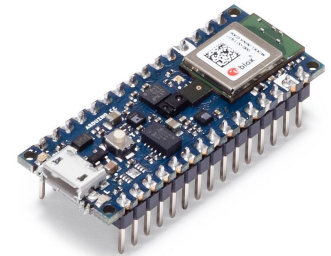
It comes with 4 examples showing how to run speech, accelerometer and image machine learning on a microcontroller.

3. Resources

Since TinyML is an emerging field, there aren't many learning materials as of today. Harvard University's Course on TinyML by Vijay Janapa Reddi



- ◆ Color, brightness, proximity and gesture sensor
- ◆ Digital microphone
- ◆ Motion, vibration and orientation sensor
- ◆ Temperature, humidity and pressure sensor
- ◆ Arm Cortex-M4 microcontroller and BLE module



TensorFlow

Arduino content NOT included

TINY Machine Learning KIT



- Arduino Nano 33 BLE Sense that sense movement, acceleration, rotation, temperature, humidity, barometric pressure, sounds, gestures, proximity, color, and light intensity.
- A camera module (OV7675)
- Custom Arduino shield to attach your components and create unique TinyML projects.
- University students can use the kit to explore practical ML use cases using classical algorithms as well as deep neural networks powered by TensorFlow Lite Micro.

TINY Machine Learning KIT

Arduino content NOT included

COURSE 1

- Understand what machine learning (ML) is
- Deep learning and embedded machine learning
- Understand neural networks
- Background responsibilities and Real Examples

COURSE 2

- Train your device using your own datasets
- Using external training models for your project
- Basics of AI, real user cases and scenarios
- Know and play with some of the most used technics
- Real world industry applications

COURSE 3

- Hardware basics
- Code your own projects with TinyML
- Train your TinyML device
- Deploy, test, and correct your TinyML projects

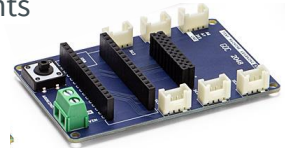


Arduino Nano 33 BLE Sense

- Senses: movement, acceleration, rotation, temperature, humidity, barometric pressure, sounds, gestures, proximity, color, and light intensity.



Custom Arduino shield to attach your components



Camera module (OV7675)




External content:


- There is **NO Arduino content** for this kit
- Use the freely available content & courses from [Harvard University at EdX](#)

Arduino IDE
Tensor Flow
Google Colab

edX: Tiny machine learning course

Courses Programs Discover New Help r_escobedo

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Deploying TinyML


HarvardX - TinyML3
Started - Mar 15, 2021

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Fundamentals of TinyML

HarvardX - TinyML1
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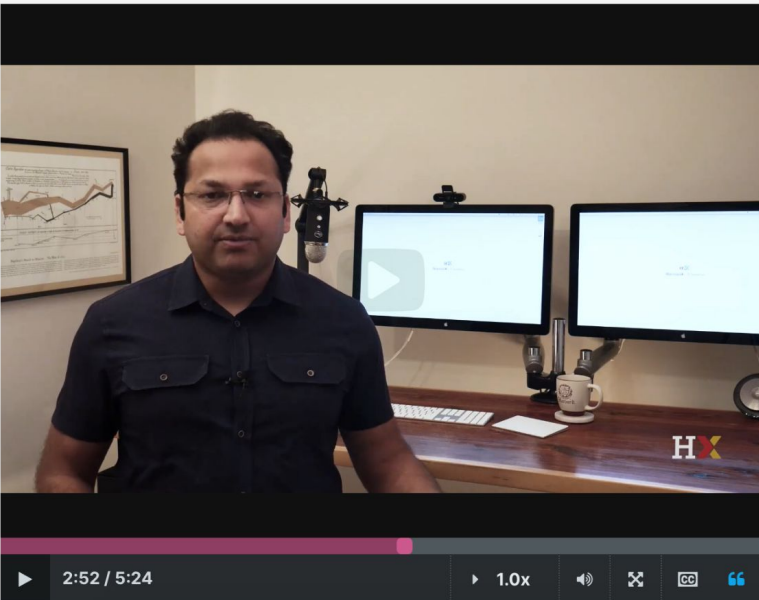
edX: Tiny machine learning course

< Previous            Next >

TinyML Application Deployment Preview

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TinyML Application Deployment Preview



And hey, in course 2, I did train a small, nice with spotting model.

So hey, what more do I need to know?

I'm going to tell you that there is much more than just getting the model right.

I hinted at this in course 2.

But when it comes to actually deploying the model on device,

you really have to think about where is the audio stream coming from.

It's not a file on your computer.

It literally streams in from the input sensor.

And how do you couple that input sensor with your neural network

and make sure all of these things run in a timely fashion?



And there's also the aspect of post processing.

If some of these things seem new or a little complicated,



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Please find below all other winners:

Best AI Product in Cyber Security

Axiado Corporation

Best Innovation in Creative Arts

Oxia Palus

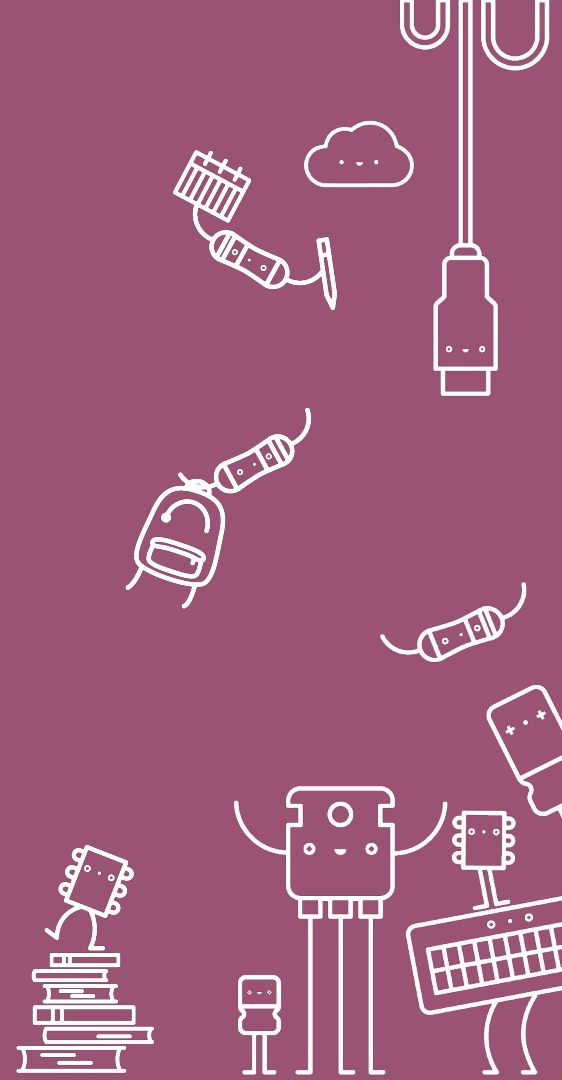
Outstanding Research Contribution in AI – Best Course In AI

edX: The Future of ML is Tiny and Bright



Tiny machine learning

Examples with Arduino



Tiny machine learning examples



Fruit identification using Arduino and TensorFlow

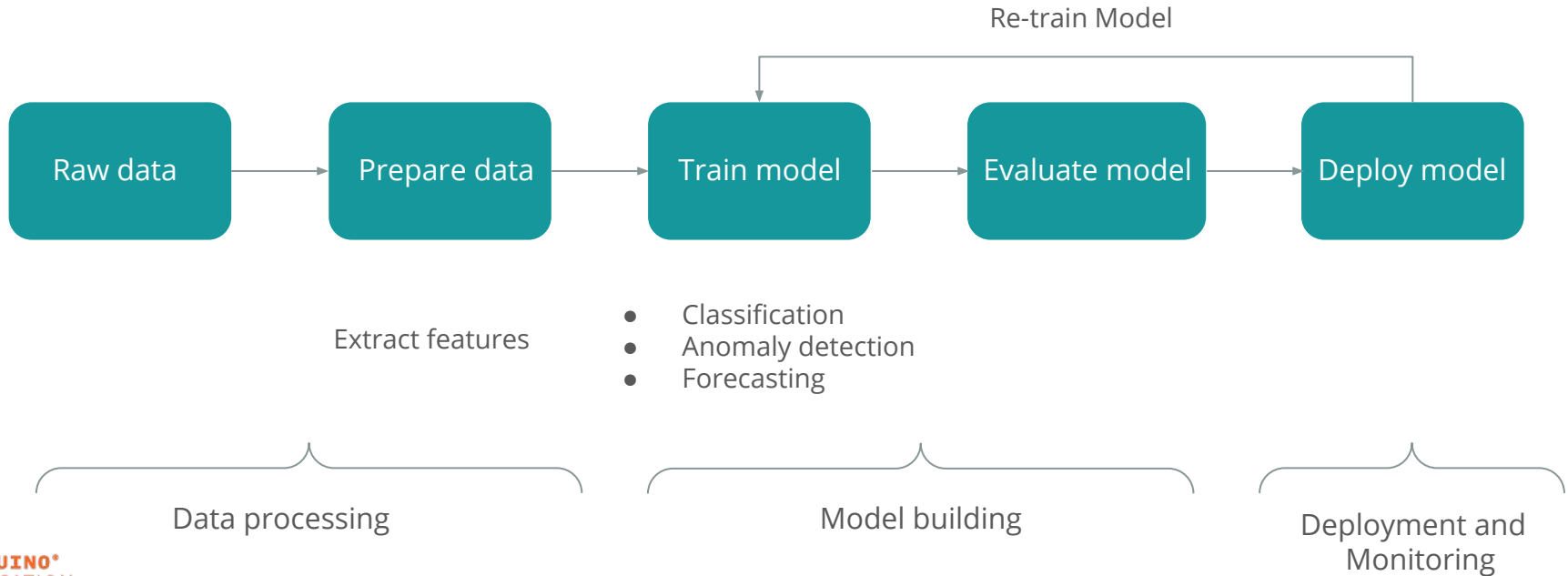
TensorFlow Lite Micro library and the Arduino Nano 33 BLE Sense's colorimeter and proximity sensor to classify objects



Gesture classification

Training your own gesture classification model, output as emojis

Tiny machine workflow

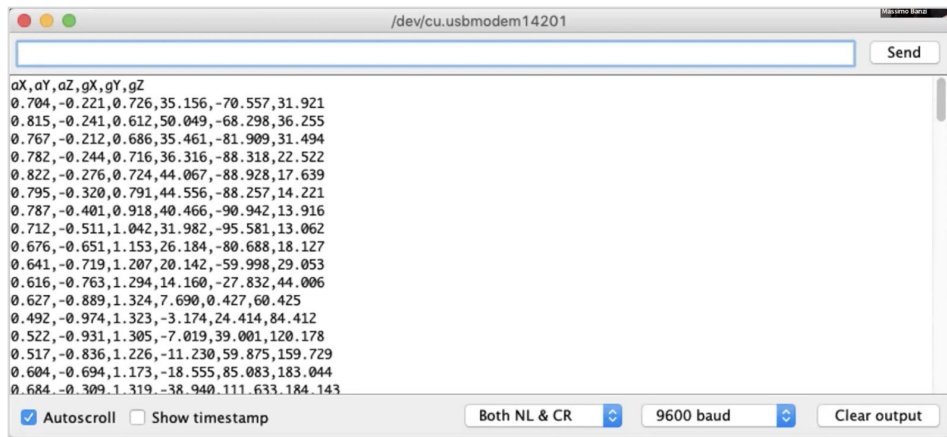


Gesture classification

The objective of the project is to **create a virtual keyboard** that turns a **gesture into an emoji**.

What you need: Nano Ble 33 sense, Arduino IDE, Tensorflow and Jupiter notebook.

- Open the Arduino IDE
- Go to Sketches/IMU_Capture/IMU_Capture.ino
- We will get data from the gyroscope
- Compile the sketch and upload to the board
- Open the serial monitor



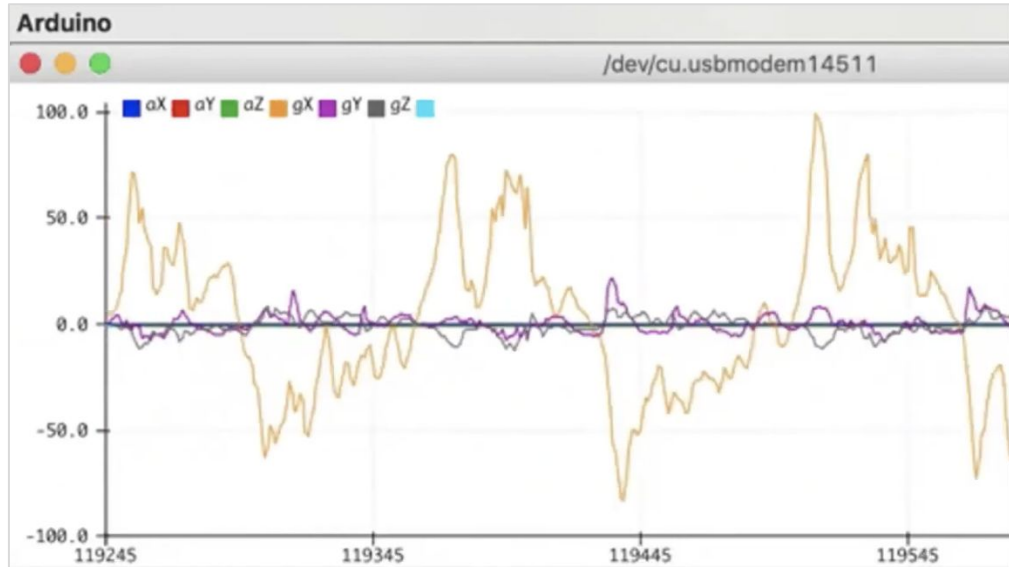
The screenshot shows the serial monitor window for a device at /dev/cu.usbmodem14201. The data being received is a series of gyroscope readings in the format: `aX,aY,aZ,gX,gY,gZ`. The data is displayed as a list of 16 rows of floating-point numbers, representing the acceleration and angular velocity along the X, Y, and Z axes.

```
aX,aY,aZ,gX,gY,gZ
0.704,-0.221,0.726,35.156,-70.557,31.921
0.815,-0.241,0.612,50.049,-68.298,36.255
0.767,-0.212,0.686,35.461,-81.909,31.494
0.782,-0.244,0.716,36.316,-88.318,22.522
0.822,-0.276,0.724,44.067,-88.928,17.639
0.795,-0.320,0.791,44.556,-88.257,14.221
0.787,-0.401,0.918,40.466,-90.942,13.916
0.712,-0.511,1.042,31.982,-95.581,13.062
0.676,-0.651,1.153,26.184,-80.688,18.127
0.641,-0.719,1.207,20.142,-59.998,29.053
0.616,-0.763,1.294,14.160,-27.832,44.006
0.627,-0.889,1.324,7.690,0.427,60.425
0.492,-0.974,1.323,-3.174,24.414,84.412
0.522,-0.931,1.305,-7.019,39.001,120.178
0.517,-0.836,1.226,-11.230,59.875,159.729
0.604,-0.694,1.173,-18.555,85.083,183.044
0.684,-0.309,1.319,-38.940,111.633,184.143
```

Gesture classification

-We can also get the data in from of a graph in real time

- if we use the serial plotter on the Arduino IDE



Gesture classification



With the board in our hand we do the punch and flex gesture 10 times

We copy that info and create 2 csv files: one for punch and other for flex

Go to a Jupyter notebook, hosted on google colab

You can go through the code that does all the training and also the snippet of code that takes the model generated by tensorflow and gets the file converted into a “.h” file for Arduino.

There is a section on the notebook where you can drag your two files. And then you get the model.h

The screenshot shows a Jupyter notebook interface with the following content:

- Table of contents:**
 - Tiny ML on Arduino
 - Setup Python Environment
 - Upload Data
 - Graph Data (optional)
 - Train Neural Network
 - Parse and prepare the data**
 - Randomize and split the input and output pairs for training
 - Build & Train the Model
 - Verify
 - Graph the loss
 - Graph the loss again, skipping a bit of the start
 - Graph the mean absolute error
 - Run with Test Data
 - Convert the Trained Model to Tensor Flow Lite
 - Encode the Model in an Arduino Header File
 - Classifying IMU Data

- Tiny ML on Arduino**
- Gesture recognition tutorial**
 - Sandeep Mistry - Arduino
 - Don Coleman - Chariot Solutions
- <https://github.com/arduino/ArduinoTensorFlowLiteTutorials/>
- Setup Python Environment**

The next cell sets up the dependencies in required for the notebook, run it.

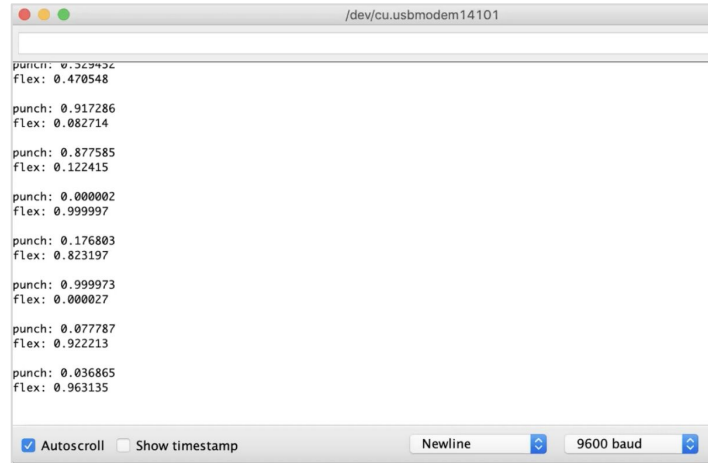
```
[ ] # Setup environment
!apt-get --qq install xxd
!pip install pandas numpy matplotlib
!pip install tensorflow==2.0.0-rc1
```
- Upload Data**
- Open the panel on the left side of Colab by clicking on the >
- Select the files tab

Gesture classification

You go to the IDE, there is another example called IMU classifier paste the model.h files from google and you will see this on the serial monitor which the level of confidence of each gesture.

Practical use of this example:

Someone with disability could operate an equipment with gestures

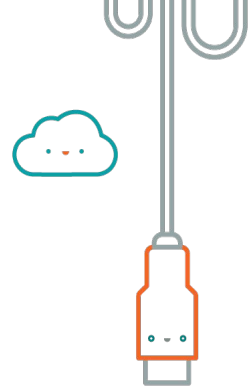
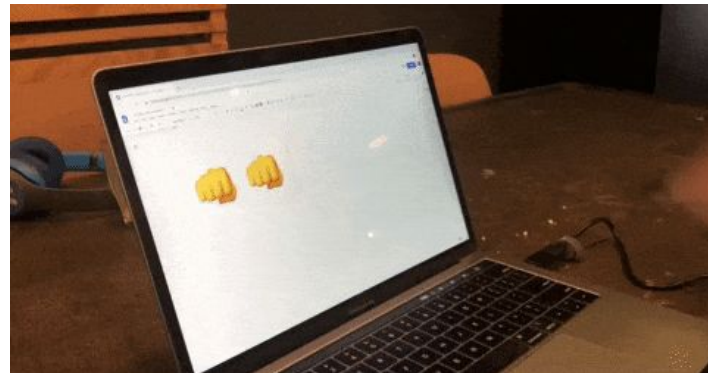


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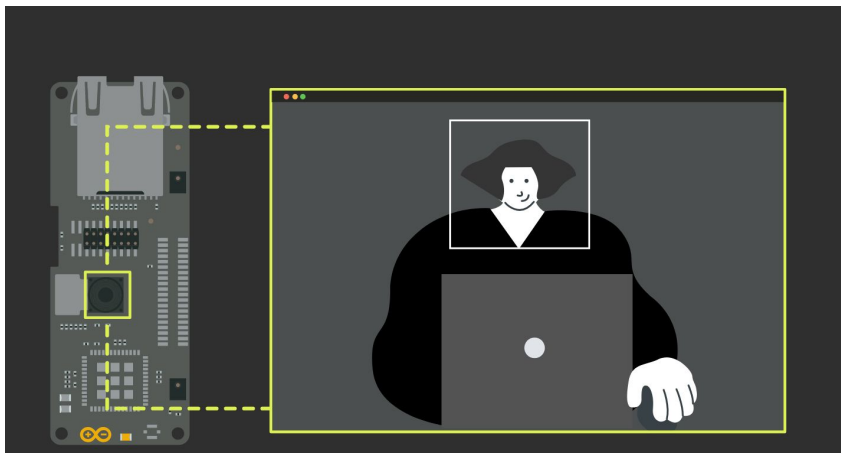
/dev/cu.usbmodem14101
punch: 0.529432
fLex: 0.470548
punch: 0.917286
fLex: 0.082714
punch: 0.877585
fLex: 0.122415
punch: 0.000002
fLex: 0.999997
punch: 0.176803
fLex: 0.823197
punch: 0.999973
fLex: 0.000027
punch: 0.077787
fLex: 0.922213
punch: 0.036865
fLex: 0.963135

```

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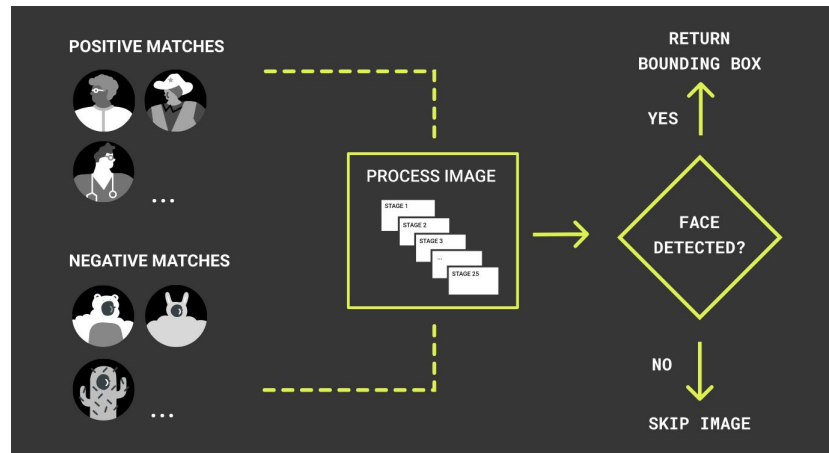


Tiny machine Learning example - Portenta



Creating a Basic Face Filter With OpenMV editor

In this tutorial you will build a MicroPython application with OpenMV that uses the Portenta Vision Shield to detect faces and overlay them with a custom bitmap image.



The Haar Cascade Algorithm

Algorithms can be trained to detect the desired type of object.



Tiny Machine Learning applications

Epilet

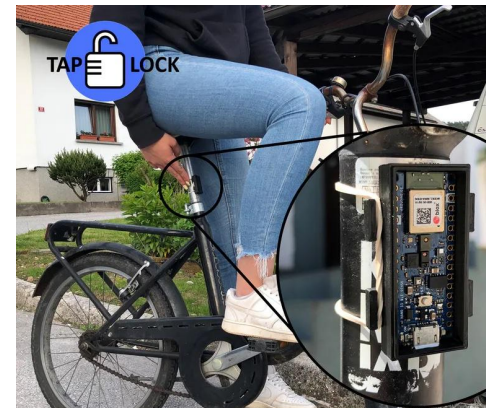
TinyML-powered bracelet for detecting epileptic seizures

TapLock

Uses tinyML on Arduino to protect your bike from thieves

PUPPI

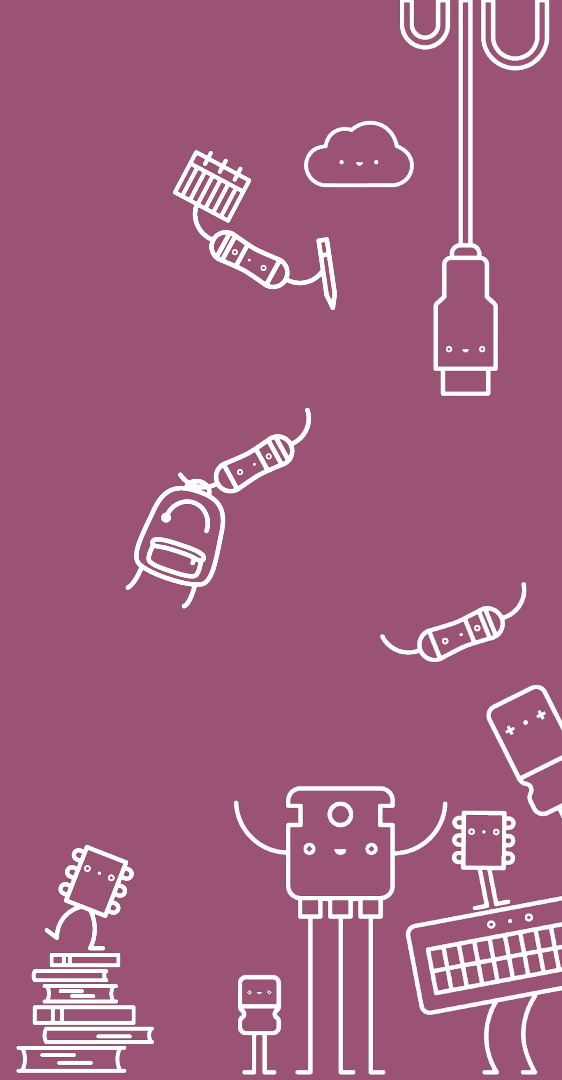
A tiny, portable, edge ML device ready to interpret a dog's mood based on vocal signals.



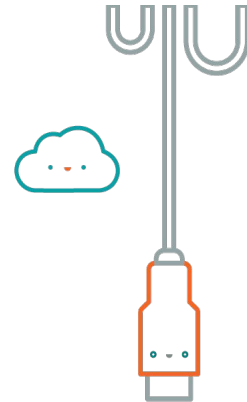


Arduino Tiny machine learning

Coming soon

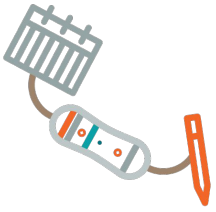


What do you need to get started?



- **ML theory:** Knowing the basics of ML theory will give you a foundation to build on, and help you troubleshoot when something goes wrong.
- **Coding skills:** Building ML requires coding in order to do the data management, parameter tuning, and parsing results needed to test and optimize your model.
- **Math and stats:** ML is a math heavy discipline, so if you plan to modify ML models or build new ones from scratch, familiarity with the underlying math concepts is crucial to the process.

Build your own projects: Getting hands on experience with ML is the best way to put the concepts learned to the test.



Arduino Education

Enabling anyone to innovate by making
complex technologies simple
to use.

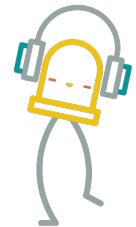


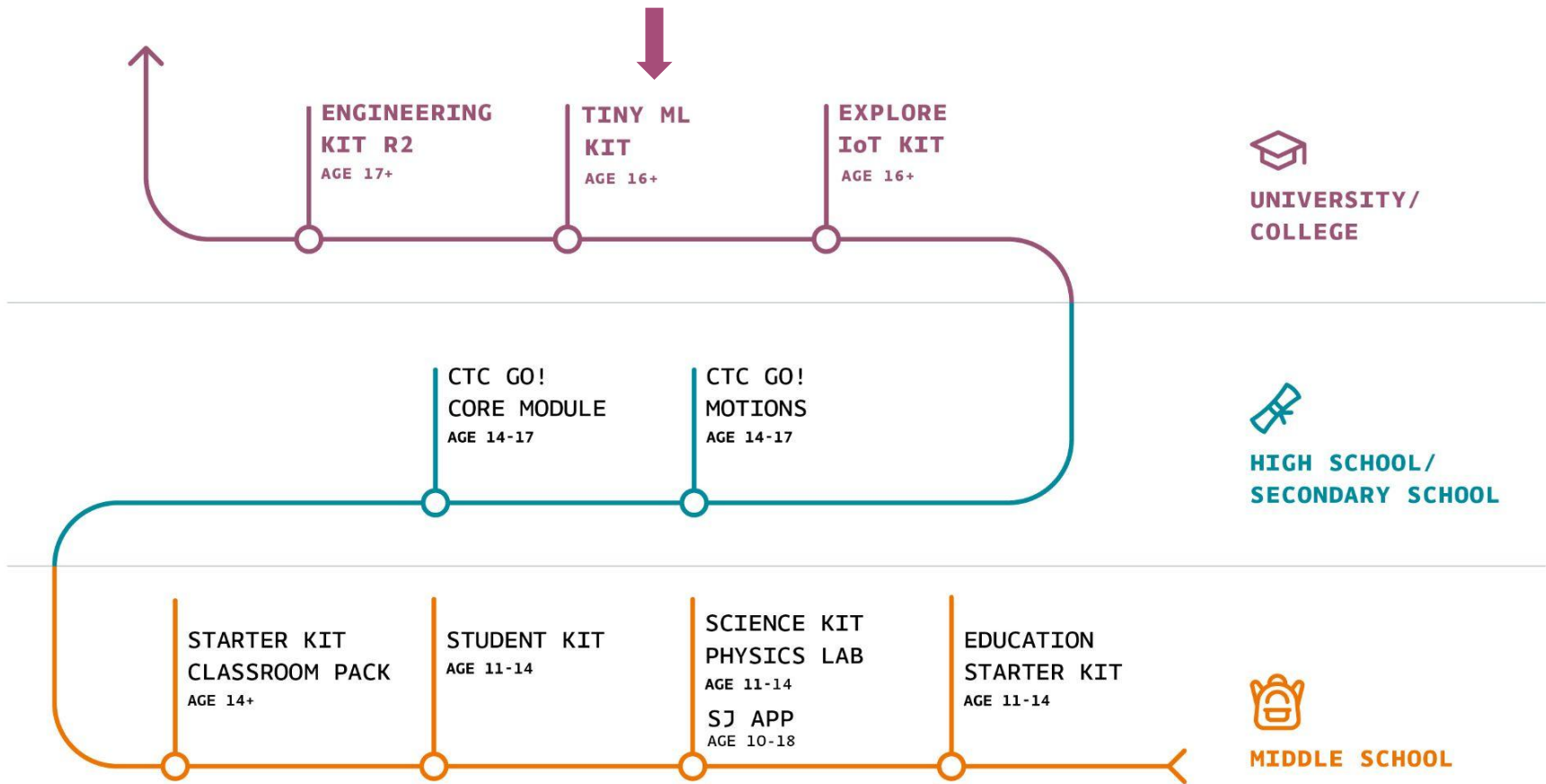
Arduino Tiny Machine Learning Kit

Research:

- Interview with teachers, experts on the field.
- Needs, content, learning approach.

- University students / High School 17+
- Arduino Content & libraries to learn the core concepts of machine learning
- Software
- Hardware
- Step by step activities and projects







Thank you!

