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ECML PKDD 2021 Tutorial

Machine Learning Meets Internet of Things: From Theory to Practice

Part IV: Efficient Execution of ML Classifiers on IoT Devices

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ML Classifiers on IoT Devices

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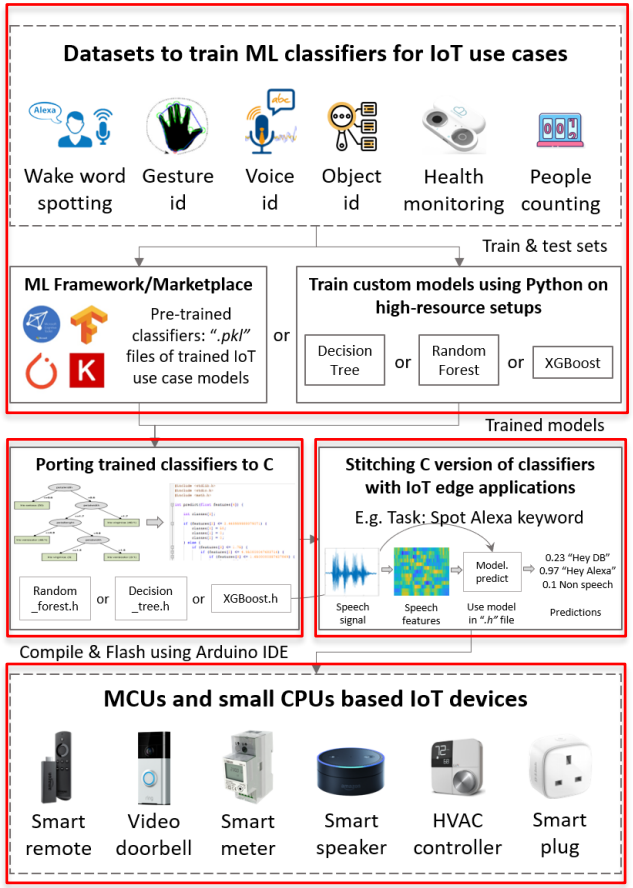

- Generic end-to-end design flow: porting and execution method for IoT devices
  - ✓ **Step1:** Take a pre-trained or train own custom classifier model - DT, RF, SVM, others
  - ✓ **Step2:** Port classifiers to its MCU executable C version using any libraries: micromlgen, sklearn-porter, m2cgen
  - ✓ **Step3:** Stitch the generated C classifier with the IoT use-case application. Passing data to trained classifier
  - ✓ **Step4:** Flash using Arduino IDE. Execute models on MCUs, small CPUs of IoT devices

Porting to Plain C

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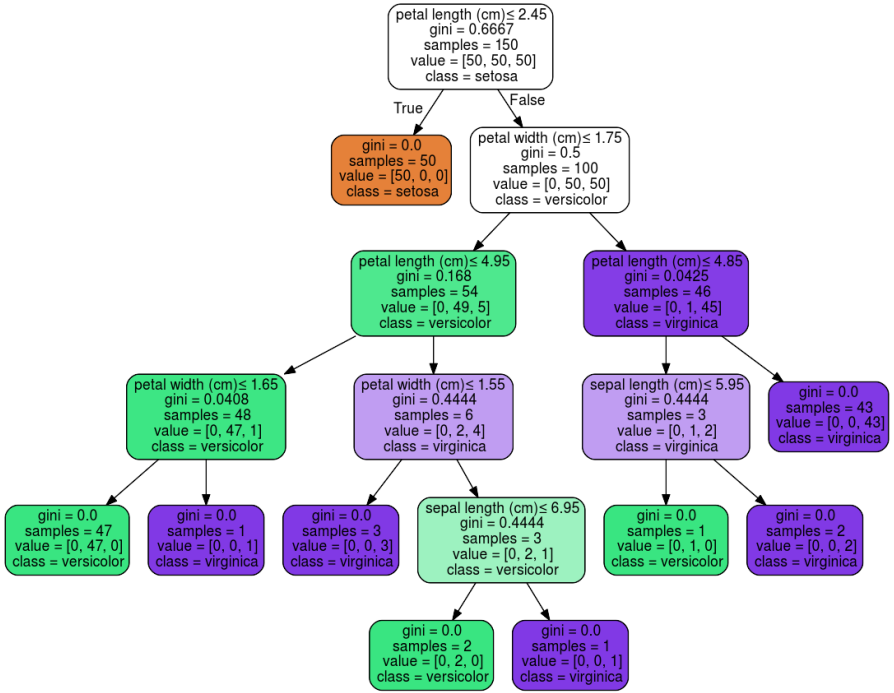
- Trained DT classifier in textual format (left)
  - ✓ Graphviz tool: visually representing structural information



- MicromIgen Ported C version (right). Exported to a *.h* file
  - ✓ During inference on MCUs we pass data to this *predict* function

```
#pragma once
#include <cstdarg>
namespace Eloquent {
    namespace ML {
        namespace Port {
            class DecisionTree {
                public:
                    /**
                    * Predict class for features vector
                    */
                    int predict(float *x) {
                        if (x[3] <= 0.800000011920929) {
                            return 0;
                        }

                        else {
                            if (x[3] <= 1.75) {
                                if (x[2] <= 5.049999952316284) {
                                    return 1;
                                }
```

Inference on MCUs

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- .h dataset file (e.g. *Iris_flowers_test.h*) to supply data during to Ported model during onboard inference

```
#pragma once
#define FEATURES_DIM 4
#define DATASET_SIZE 100

float X[DATASET_SIZE][FEATURES_DIM] = {
        {   6.3   ,   2.5   ,   4.9   ,   1.5   },
        {   5.0   ,   3.4   ,   1.5   ,   0.2   },
        {   5.4   ,   3.7   ,   1.5   ,   0.2   },
        {   5.7   ,   4.4   ,   1.5   ,   0.4   },
        {   6.6   ,   3.0   ,   4.4   ,   1.4   },
```

Data rows

Labels

```
int y[DATASET_SIZE] = {   1   ,   0   ,   0   ,   0   ,   1
```

✓ The Iris Flowers dataset in .h file: Rows with its labels are written

```
#include "RF_Iris.h"
#include "Iris_flowers_test.h"
```

- Load the .h model and the .h dataset file into the main program (IoT use-case application)
- We then pass data to *predict* function inside the .h model file to obtain inference results

✓ Data can be from real-world sensors - inference for edge analytics use-cases when apt model is used (instead of Iris dataset trained model)

```
Serial.print("The Predicted values are: ");
 int startl = millis();

 for (int i = 0; i < DATASET_SIZE; i++)
 {
     Serial.print(clf.predict(X[i]));
     }
```

Demo

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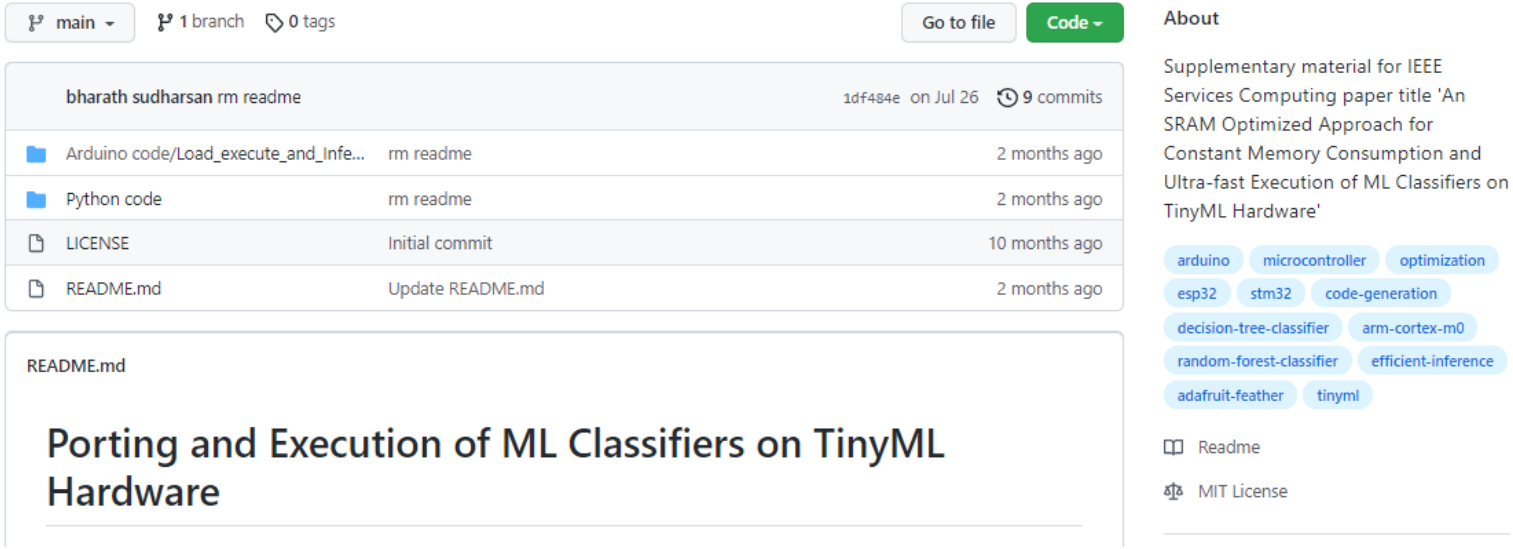
- Repo: https://github.com/bharathsudharsan/ML-Classifiers-on-MCUs

  ✓ Python folder covers: DT and RF training + Porting to plain C - generate *x_model.h* file

  ✓ Arduino IDE folder covers: Load + Execute + Infer using ported DT and RF classifier models



Conclusion

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- Generic, end-to-end design flow for ML classifier porting, stitching, and efficient execution
- Researchers and Engineers can apply this flow to port and execute any use-case ML models on their IoT devices/products
- Same flow applies for other code generation libraries: sklearn-porter, m2cgen, emlearn
- Same flow to port other ML algorithms like LGBM, XGB, AdaGrad, LogisticRegressionCV, etc.

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