

Laporan Praktikum Internet of Things (IoT)

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Abstrak

Praktikum ini bertujuan untuk mengimplementasikan proses dalam model machine learning menggunakan pendekatan Tiny Machine Learning (TinyML). Model yang digunakan dilatih terlebih dahulu

menggunakan TensorFlow di Google Colab dengan dataset Iris, yang memuat tiga jenis bunga yaitu Setosa,

Versicolor, dan Virginica dengan berdasarkan panjang dan lebar sepal serta panjang dan lebar petal. Setelah proses

pelatihan, model dikonversi ke format TensorFlow Lite (.tflite) selanjutnya diubah menjadi file C++

(iris_model.h), sehingga dapat digunakan langsung dalam lingkungan pengembangan non-Python. Pengerjaan

dilakukan secara virtual di Visual Studio Code (VSC) dengan menggunakan PlatformIO, yang mensimulasikan

pengembangan pada perangkat ESP32. File utama (main.cpp) bertanggung jawab untuk inisialisasi model,

penyusunan input manual, eksekusi inferensi, dan pencetakan hasil klasifikasi ke terminal. Meskipun tidak

menggunakan library TensorFlow Lite Micro, pendekatan ini tetap merepresentasikan prinsip TinyML, yaitu

menjalankan inferensi model machine learning secara lokal dengan efisien di sistem tertanam. Hasil pengujian

menunjukkan bahwa model mampu melakukan klasifikasi jenis bunga dengan akurasi yang baik. Praktikum ini

memberikan pemahaman dan pengimplementasian mengenai alur kerja TinyML, mulai dari pelatihan model di

cloud dalam lingkungan pemrograman C++ yang ringan, serta membuka wawasan terhadap pengembangan sistem

kecerdasan buatan secara dasar terkait dengan *Internet of Things (IoT)* dan *Machine Learning*.

Kata Kunci—*Internet of Things, Wokwi, Iris, Pemelajaran mesin, TinyML*

Abstract

This practicum aims to implement the process in a machine learning model using the Tiny Machine Learning

(TinyML) approach. The model used is first trained using TensorFlow in Google Colab with the Iris dataset, which

contains three types of flowers namely Setosa, Versicolor, and Virginica based on the length and width of the

sepals and the length and width of the petals. After the training process, the model is converted to TensorFlow

Lite (.tflite) format and then converted into a C++ file (iris_model.h), so that it can be used directly in non-Python

development environments. The work was done virtually in Visual Studio Code (VSC) using PlatformIO, which

simulates development on an ESP32 device. The main file (main.cpp) is responsible for model initialization,

manual input generation, inference execution, and printing classification results to the terminal. Although it does

not use the TensorFlow Lite Micro library, this approach still represents the TinyML principle, which is to run

machine learning model inference locally efficiently on the embedded system. The test results show that the model

is able to perform flower type classification with good accuracy. This practicum provides an understanding and

implementation of the TinyML workflow, starting from model training in the cloud in a lightweight C++

programming environment, and opens up insights into the development of basic artificial intelligence systems

related to the Internet of Things (IoT) and Machine Learning.

Keywords—*Internet of Things, Wokwi, Iris, Machine learning, TinyML***1. Introduction (Pendahuluan)**

Praktikum ini bertujuan untuk mempelajari dan mengimplementasikan proses klasifikasi berbasis

machine learning dengan menggunakan pendekatan TinyML. Model machine learning dilatih

menggunakan TensorFlow di Google Colab dengan dataset Iris, lalu dikonversi ke format TensorFlow

Lite (.tflite), dan akhirnya diubah menjadi file header C++ agar dapat dijalankan pada sistem selain

menggunakan program bahasa Python. Proses implementasi dilakukan secara virtual melalui Visual

Studio Code (VSC) dengan PlatformIO yang mensimulasikan lingkungan mikrokontroler seperti ESP32.

Program utama (main.cpp) bertanggung jawab atas proses inferensi, dimulai dari inisialisasi model,

penyusunan input secara manual, hingga pencetakan hasil prediksi ke terminal. Walaupun tidak menggunakan library TensorFlow Lite Micro, pendekatan ini tetap selaras dengan prinsip TinyML, yakni menjalankan model secara lokal dan efisien. Praktikum ini memberikan pemahaman terkait alur kerja TinyML, dari pelatihan hingga deployment, sekaligus menumbuhkan wawasan praktis terhadap pengembangan sistem AI yang mudah dan dasar.

1.1 Latar Belakang

Saat ini adalah era yang dikenal dengan era kecerdasan buatan (*Artificial Intelligence/AI*), yang berbanding lurus dengan seiring berkembangnya teknologi. Banyak muncul kebutuhan untuk mengimplementasikan model ke dalam perangkat yang lebih kecil dan hemat daya dengan salah satu pendekatan yang muncul sebagai solusi adalah Tiny Machine Learning (TinyML), yaitu penerapan machine learning pada perangkat dengan sumber daya terbatas seperti mikrokontroler. TinyML memungkinkan proses inferensi dilakukan secara lokal, tanpa ketergantungan terhadap server eksternal atau konektivitas internet, sehingga sangat relevan untuk diterapkan dalam sistem berbasis Internet of Things (IoT).

Sebagai dasar pembelajaran dan sebagai awal pembelajaran antara IoT dan ML, dataset Iris digunakan karena kesederhanaan dan kejelasan strukturnya. Dataset ini memuat informasi tentang tiga spesies bunga yaitu Setosa, Versicolor, dan Virginica dengan berdasarkan empat fitur utama yaitu panjang dan lebar sepal serta panjang dan lebar petal. Dataset ini sering dijadikan acuan dalam praktik supervised learning, terutama dalam klasifikasi. Dengan menggabungkan konsep dasar machine learning dan implementasi model ke dalam sistem tertanam, praktikum ini menjadi media yang efektif untuk memperkenalkan penerapan TinyML secara praktis dan mudah dimengerti.

1.2 Tujuan Eksperimen

Eksperimen ini bertujuan untuk:

-

Memahami alur kerja Tiny Machine Learning (TinyML) secara mendasar dengan praktik yang sederhana.

-

Menguji kemampuan model klasifikasi berbasis dataset Iris dalam mengenali jenis bunga iris.

-

Memberikan pemahaman terkait penerapan kecerdasan buatan (AI).

2. Methodology (Metodologi)

2.1 Tools & Materials (Alat dan Bahan)

Untuk menjalankan eksperimen ini, beberapa alat dan bahan yang digunakan adalah:

-

Platform simulasi Wokwi: Digunakan untuk melakukan simulasi sistem secara digital.

-

Visual Studio Code dengan ekstensi PlatformIO dengan library

-

Kode program berbasis C/C++: Digunakan untuk mengontrol urutan nyala-mati LED virtual dalam simulasi.

-

Mikrokontroler ESP32 (virtual pada Wokwi dan PlatformIO): Sebagai unit pemrosesan utama dan sebagai pengendali yang dilengkapi dengan Wi-Fi dan Bluetooth.

-

Google Colab : untuk proses pelatihan model machine learning menggunakan TensorFlow berbasis Python dengan dataset Iris.

-

TensorFlow & TensorFlow Lite : Library machine learning yang digunakan untuk membangun dan mengonversi model ke format .tflite.

-

Iris Dataset : Dataset yang berisi tiga jenis bunga iris yaitu Setosa, Versicolor, Virginica berdasarkan panjang dan lebar sepal serta petal.

-

Pelatihan Model (Model Training) menggunakan Google Colab dan library TensorFlow.

Dataset Iris digunakan untuk melatih model klasifikasi berdasarkan panjang dan lebar sepal, serta panjang dan lebar petal.

Google Collab : <https://colab.research.google.com/drive/1GpV46E9Thaaf7BmtK4aRPBqZ7X4Js77?usp=sharing>

-

Menambahkan library : `tflm_esp32` melalui VSC dan EloquentTinyML melalui github :

<https://github.com/eloquentarduino/EloquentTinyML>

-

Menambahkan kode program dari Wokwi ke VSC berupa halaman : `main.cpp` (kode program utama), `diagram.json` (simulator komponen iot), `iris_model.h` (hasil training dari google collab)

-

Build program lalu lalu tambahkan `wokwi.toml`

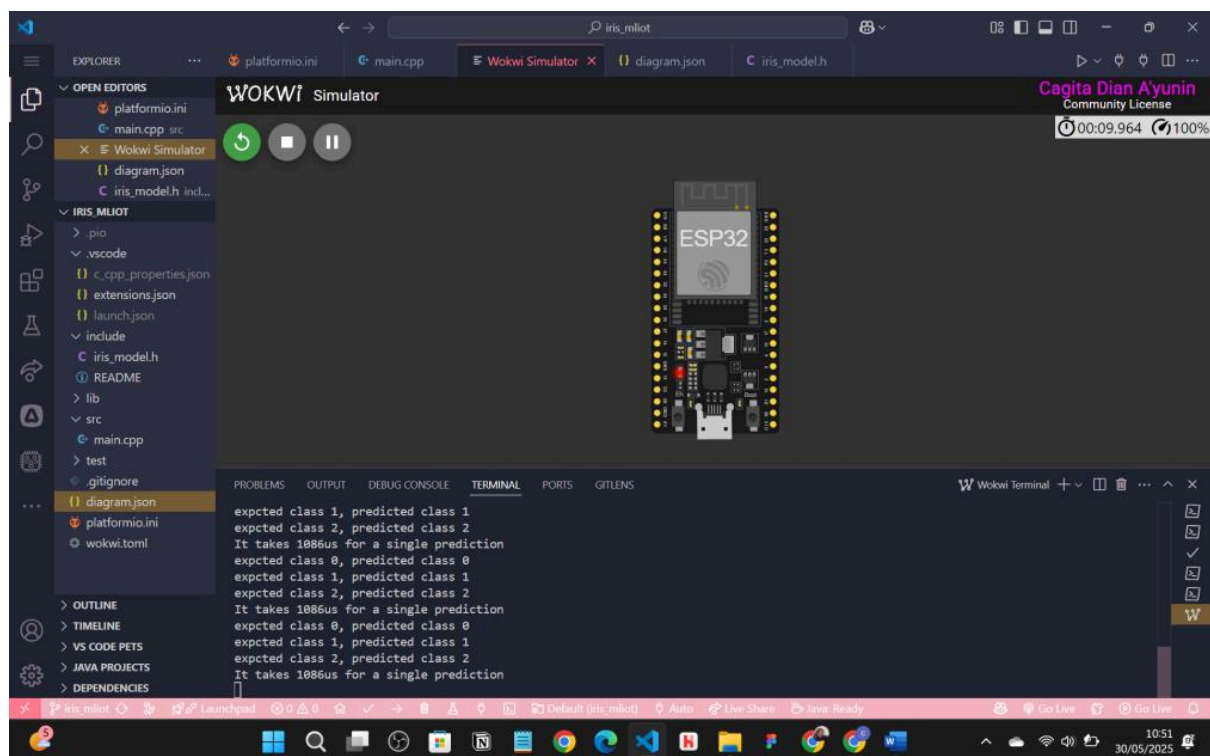
-

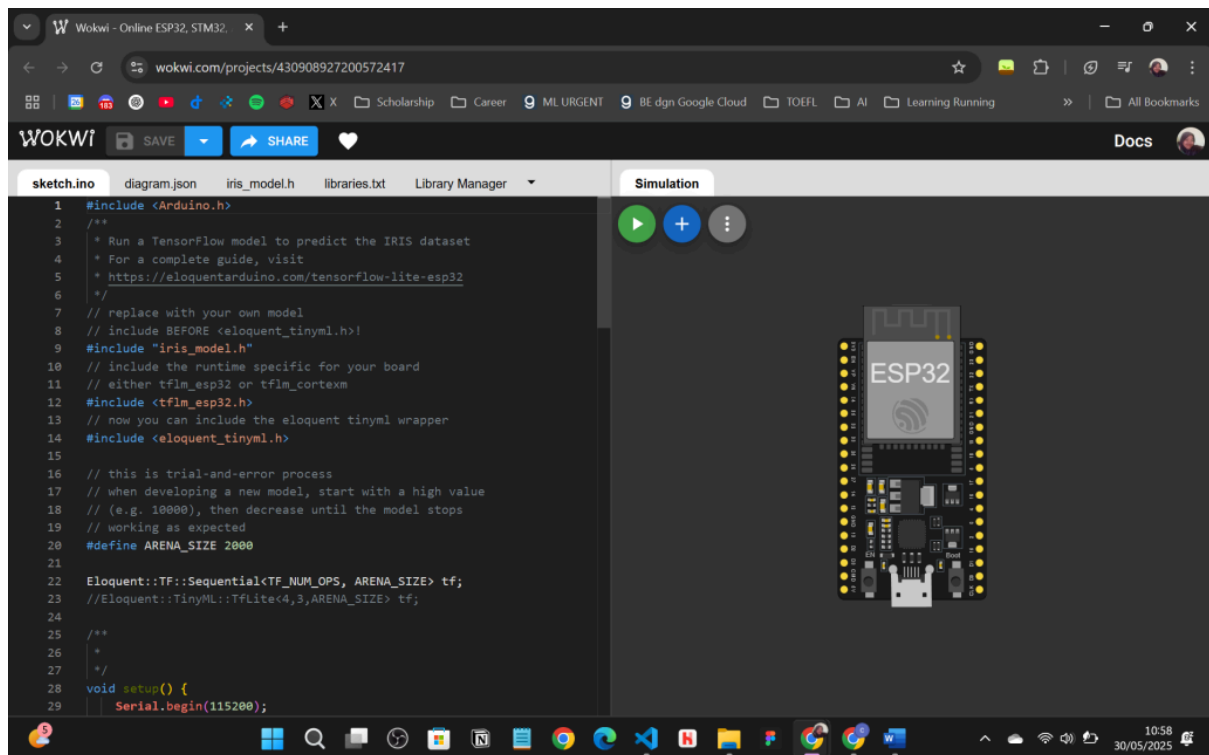
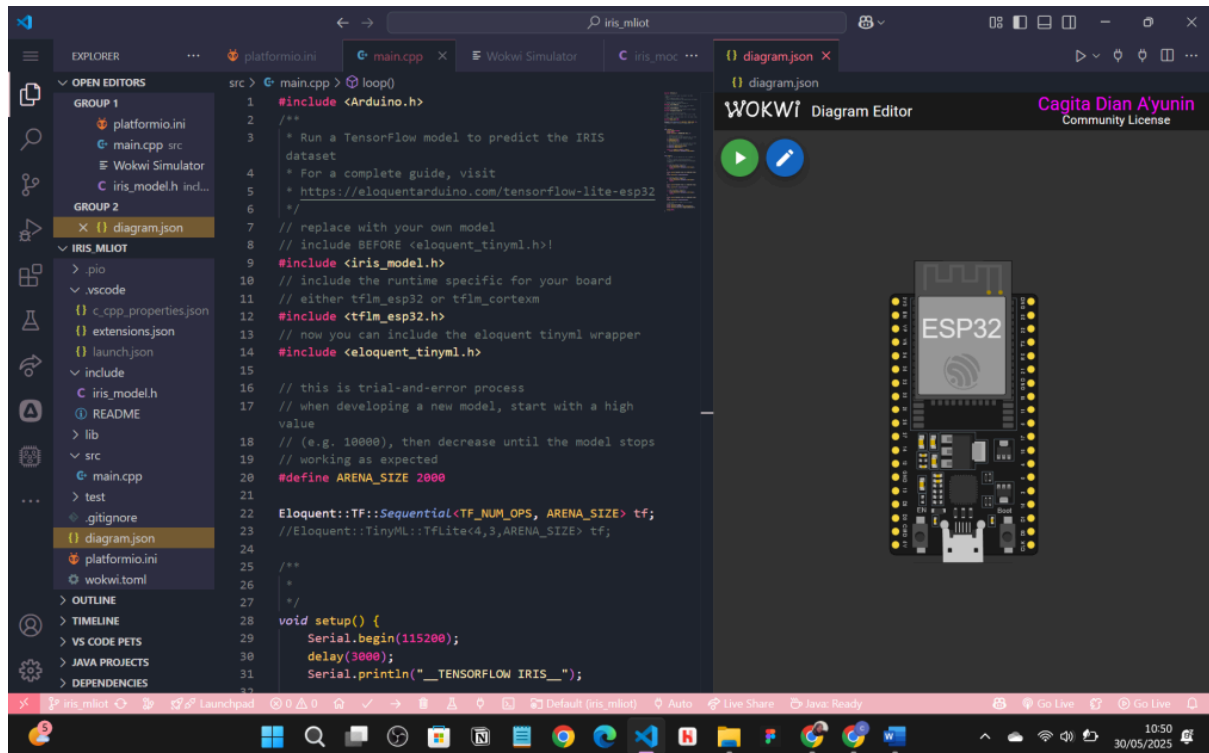
Jalankan program

3. Result and Discussion (Hasil dan Pembahasan)

3.1 Experimental Result (Hasil Eksperimen)

Berikut adalah screenshot hasil simulasi pada Visual Studio Code dan Wokwi





Hasil praktikum menunjukkan bahwa model machine learning dalam bentuk TinyML dapat berjalan secara efisien di mikrokontroler seperti ESP32. Melalui simulasi virtual menggunakan Wokwi lalu di pindah ke VSC ini membuktikan bahwa meskipun terdapat keterbatasan sumber daya, perangkat tetap mampu menjalankan proses klasifikasi berbasis AI secara real-time. Model yang digunakan adalah hasil pelatihan pada dataset Iris, yang terdiri tiga jenis bunga. Dataset ini dipilih karena strukturnya yang sederhana sehingga ideal untuk demonstrasi model klasifikasi. Praktikum ini berhasil memperlihatkan bagaimana TinyML memungkinkan AI dijalankan secara mandiri di sistem tertanam, tanpa perlu bergantung pada cloud atau perangkat eksternal.

4. Appendix (Lampiran)

4.1 Kode Program (Main.cpp)

```
#include <Arduino.h>
/**
 * Run a TensorFlow model to predict the IRIS dataset
 * For a complete guide, visit
 * https://eloquentarduino.com/tensorflow-lite-esp32
 */
// replace with your own model
// include BEFORE <eloquent_tinymml.h>!
#include <iris_model.h>
// include the runtime specific for your board
// either tflm_esp32 or tflm_cortexm
#include <tflm_esp32.h>
// now you can include the eloquent tinymml wrapper
#include <eloquent_tinymml.h>
// this is trial-and-error process
// when developing a new model, start with a high value
// (e.g. 10000), then decrease until the model stops
// working as expected
#define ARENA_SIZE 2000
Eloquent::TF::Sequential<TF_NUM_OPS, ARENA_SIZE> tf;
//Eloquent::TinyML::TfLite<4,3,ARENA_SIZE> tf;/**
*
*/
void setup() {
  Serial.begin(115200);
  delay(3000);
  Serial.println("__TENSORFLOW IRIS__");
  // configure input/output
  // (not mandatory if you generated the .h model
  // using the everywhereml Python package)
  tf.setNumInputs(4);
  tf.setNumOutputs(3);
  // add required ops
  // (not mandatory if you generated the .h model
  // using the everywhereml Python package)
  tf.resolver.AddFullyConnected();
  tf.resolver.AddSoftmax();
  while (!tf.begin(irisModel).isOk())
    Serial.println(tf.exception.toString());
}
void loop() {
  // x0, x1, x2 are defined in the irisModel.h file
  //
  https://github.com/eloquentarduino/EloquentTinyML/tree/main/examples/IrisExample/irisModel.h
  // classify sample from class 0
  if (!tf.predict(x0).isOk()) {
    Serial.println(tf.exception.toString());
    return;
  }
  Serial.print("expcted class 0, predicted class ");
```

```

Serial.println(tf.classification);
// classify sample from class 1
if (!tf.predict(x1).isOk()) {
Serial.println(tf.exception.toString());
return;
}
Serial.print("expted class 1, predicted class ");
Serial.println(tf.classification);
// classify sample from class 2
if (!tf.predict(x2).isOk()) {
Serial.println(tf.exception.toString());
return;
}
Serial.print("expted class 2, predicted class ");
Serial.println(tf.classification);
// how long does it take to run a single prediction?
Serial.print("It takes ");
Serial.print(tf.benchmark.microseconds());
Serial.println("us for a single prediction");
delay(1000);
}

```

4.2 Kode Program (diagram.json)

```

{
"version": 1,
"author": "subairi",
"editor": "wokwi",
"parts": [ { "type": "board-esp32-devkit-c-v4", "id": "esp", "top": 0, "left": 0, "attrs": {} } ],
"connections": [ [ "esp:TX", "$serialMonitor:RX", "", [] ], [ "esp:RX", "$serialMonitor:TX", "",
[] ] ],
"dependencies": {}
}

```

4.3 Kode Program (iris_model.h)

```

#pragma once
#ifdef __has_attribute
#define HAVE_ATTRIBUTE(x) __has_attribute(x)
#else
#define HAVE_ATTRIBUTE(x) 0
#endif
#if HAVE_ATTRIBUTE(aligned) || (defined(__GNUC__) && !defined(__clang__))
#define DATA_ALIGN_ATTRIBUTE __attribute__((aligned(4)))
#else
#define DATA_ALIGN_ATTRIBUTE
#endif
// automatically configure network
#define TF_NUM_INPUTS 4
#define TF_NUM_OUTPUTS 3
#define TF_NUM_OPS 2
#define TF_OP_SOFTMAX
#define TF_OP_FULLYCONNECTED
// sample data
float x0[4] = {0.2222222222f, 0.6250000000f, 0.06779661017f, 0.04166666667f};
float x1[4] = {0.7500000000f, 0.5000000000f, 0.62711864407f, 0.54166666667f};

```



```
float x2[4] = {0.5555555555555555f, 0.5416666666666667f, 0.84745762712f, 1.0000000000000000f};
```

```
/** model size = 5048 bytes */
```

```
const unsigned char irisModel[] DATA_ALIGN_ATTRIBUTE = { 0x1c, 0x00, 0x00, 0x00, 0x54,  
0x46, 0x4c, 0x33, 0x14, 0x00, 0x20, 0x00, 0x1c, 0x00, 0x18, 0x00, 0x14, 0x00, 0x10, 0x00, 0x0c,  
0x00, 0x00, 0x00, 0x08, 0x00, 0x04, 0x00, 0x14, 0x00, 0x00, 0x00, 0x1c, 0x00, 0x00, 0x00, 0x90,  
0x00, 0x00, 0x00, 0xe8, 0x00, 0x00, 0x00, 0x88, 0x0d, 0x00, 0x00, 0x98, 0x0d, 0x00, 0x00, 0x54,  
0x13, 0x00, 0x00, 0x03, 0x00, 0x00, 0x00, 0x01, 0x00, 0x00, 0x00, 0x10, 0x00, 0x00, 0x00, 0x00, 0x0a,  
0x00, 0x10, 0x00, 0x0c, 0x00, 0x08, 0x00, 0x04, 0x00, 0x0a, 0x00, 0x00, 0x00,  
0x0c, 0x00, 0x00, 0x00, 0x1c, 0x00, 0x00, 0x00, 0x38, 0x00, 0x00, 0x00, 0x0f, 0x00, 0x00, 0x00,  
0x73, 0x65, 0x72, 0x76, 0x69, 0x6e, 0x67, 0x5f, 0x64, 0x65, 0x66, 0x61, 0x75, 0x6c, 0x74, 0x00,  
0x01, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x98, 0xff, 0xff, 0xff, 0x0a, 0x00, 0x00, 0x00,  
0x04, 0x00, 0x00, 0x00, 0x07, 0x00, 0x00, 0x00, 0x64, 0x65, 0x6e, 0x73, 0x65, 0x5f, 0x32, 0x00,  
0x01, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x5a, 0xf2, 0xff, 0xff, 0x04, 0x00, 0x00, 0x00,  
0x0b, 0x00, 0x00, 0x00, 0x64, 0x65, 0x6e, 0x73, 0x65, 0x5f, 0x69, 0x6e, 0x70, 0x75, 0x74, 0x00,  
0x02, 0x00, 0x00, 0x00, 0x34, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0xdc, 0xff, 0xff, 0xff,  
0x0d, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x13, 0x00, 0x00, 0x00, 0x43, 0x4f, 0x4e, 0x56,  
0x45, 0x52, 0x53, 0x49, 0x4f, 0x4e, 0x5f, 0x4d, 0x45, 0x54, 0x41, 0x44, 0x41, 0x54, 0x41, 0x00,  
0x08, 0x00, 0x0c, 0x00, 0x08, 0x00, 0x04, 0x00, 0x08, 0x00, 0x00, 0x00, 0x0c, 0x00, 0x00, 0x00,  
0x04, 0x00, 0x00, 0x00, 0x13, 0x00, 0x00, 0x00, 0x6d, 0x69, 0x6e, 0x5f, 0x72, 0x75, 0x6e, 0x74,  
0x69, 0x6d, 0x65, 0x5f, 0x76, 0x65, 0x72, 0x73, 0x69, 0x6f, 0x6e, 0x00, 0x0e, 0x00, 0x00, 0x00,  
0x9c, 0x0c, 0x00, 0x00, 0x94, 0x0c, 0x00, 0x00, 0x44, 0x0c, 0x00, 0x00, 0x28, 0x0c, 0x00, 0x00,  
0x98, 0x0b, 0x00, 0x00, 0x88, 0x09, 0x00, 0x00, 0x78, 0x01, 0x00, 0x00, 0xa8, 0x00, 0x00, 0x00,  
0xa0, 0x00, 0x00, 0x00, 0x98, 0x00, 0x00, 0x00, 0x90, 0x00, 0x00, 0x00, 0x88, 0x00, 0x00, 0x00,  
0x68, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x0a, 0xf3, 0xff, 0xff, 0x04, 0x00, 0x00, 0x00,  
0x54, 0x00, 0x00, 0x00, 0x0c, 0x00, 0x00, 0x00, 0x08, 0x00, 0x0e, 0x00, 0x08, 0x00, 0x04, 0x00,  
0x08, 0x00, 0x00, 0x00, 0x10, 0x00, 0x00, 0x00, 0x24, 0x00, 0x00, 0x00, 0x00, 0x00, 0x06,  
0x00, 0x08, 0x00, 0x04, 0x00, 0x06, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x00, 0x00,  
0x00, 0x00, 0x00, 0x00, 0x0a, 0x00, 0x10, 0x00, 0x0c, 0x00, 0x08, 0x00, 0x04, 0x00, 0x0a, 0x00,  
0x00, 0x00, 0x02, 0x00, 0x00, 0x00, 0x02, 0x00, 0x00, 0x00, 0x04, 0x00, 0x00, 0x00, 0x06,  
0x00, 0x00, 0x00, 0x32, 0x2e, 0x31, 0x35, 0x2e, 0x30, 0x00, 0x00, 0x6a, 0xf3, 0xff, 0xff, 0x04,  
0x00, 0x00, 0x00, 0x10, 0x00, 0x00, 0x00, 0x31, 0x2e, 0x35, 0x2e, 0x30, 0x00, 0x00, 0x00, 0x00,  
0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x78, 0xee, 0xff, 0xff, 0x7c, 0xee, 0xff, 0xff, 0x80,  
0xee, 0xff, 0xff, 0x84, 0xee, 0xff, 0xff, 0x96, 0xf3, 0xff, 0xff, 0x04, 0x00, 0x00, 0x00, 0xc0, 0x00,  
0x00, 0x00, 0xce, 0xe2, 0x15, 0xbf, 0xf8, 0xa5, 0x36, 0xbe, 0x3e, 0xea, 0xdb, 0xbe, 0x8f, 0x17,  
0x36, 0xbe, 0xf5, 0xab, 0x05, 0xbf, 0xfc, 0xd5, 0xd4, 0x3e, 0xe0, 0xd2, 0x94, 0xbe, 0x98, 0xb6,  
0xaa, 0xbe, 0x7d, 0x36, 0x66, 0xbe, 0x32, 0x06, 0x99, 0x3e, 0x87, 0xee, 0x2e, 0xbf, 0xe3, 0xcf,  
0xac, 0x3e, 0x80, 0x10, 0x35, 0x3f, 0x58, 0x20, 0x21, 0x3f, 0x6f, 0xac, 0xfd, 0x3e, 0x2c, 0xa9,  
0x9e, 0x3e, 0x5c, 0xcb, 0x15, 0x3e, 0x68, 0xd6, 0x90, 0xbe, 0x9d, 0x13, 0x83, 0xbe, 0x42, 0x9b,  
0xbe, 0x3e, 0x78, 0x58, 0xe9, 0x3d, 0xf4, 0x62, 0x31, 0x3e, 0x9f, 0x8a, 0x66, 0xbe, 0x40, 0x86,  
0xc6, 0xbd, 0x16, 0xec, 0x0a, 0x3d, 0x44, 0x7c, 0xb9, 0xbd, 0x16, 0x21, 0x03, 0xbf, 0x5f, 0x4b,  
0x48, 0xbe, 0xc2, 0xc4, 0x07, 0x3e, 0xfb, 0x9f, 0x5f, 0xbe, 0x5f, 0x6b, 0xaa, 0xbe, 0x13, 0x07,  
0x04, 0xbf, 0xde, 0x6c, 0x57, 0xbe, 0x0c, 0xc0, 0x10, 0x3f, 0x4a, 0x10, 0xdd, 0x3e, 0x08, 0x0f,  
0xad, 0x3e, 0xd8, 0x76, 0xce, 0xbe, 0x20, 0xb8, 0xf1, 0xbc, 0xa8, 0x5e, 0xd9, 0x3e, 0xe2, 0xaa,  
0xe2, 0x3e, 0x8b, 0xb6, 0xd7, 0x3e, 0xd8, 0xb5, 0xcd, 0xbe, 0x67, 0xba, 0x9b, 0x3e, 0x98, 0xc7,  
0x37, 0xbf, 0x94, 0xef, 0x0f, 0xbf, 0x06, 0x21, 0x78, 0xbb, 0x41, 0x14, 0xfb, 0xbe, 0x8e, 0xa1,  
0xdf, 0xbe, 0x62, 0xf4, 0xff, 0xff, 0x04, 0x00, 0x00, 0x00, 0x00, 0x08, 0x00, 0x00, 0x50, 0xe2,  
0x80, 0x3d, 0xa8, 0x0f, 0x36, 0x3e, 0x33, 0x63, 0xb5, 0x3e, 0x67, 0x39, 0x58, 0xbe, 0x01, 0x13,  
0x11, 0x3e, 0x03, 0x40, 0xad, 0x3e, 0x41, 0x64, 0xd7, 0x3d, 0x00, 0x92, 0x2d, 0xba, 0x72, 0x9f,  
0xcf, 0x3e, 0x4c, 0x71, 0xb9, 0xbc, 0x74, 0xb1, 0x95, 0xbe, 0x52, 0x0d, 0xb6, 0x3e, 0xe0, 0x51,  
0x87, 0x3d, 0xec, 0x17, 0x09, 0x3e, 0xf9, 0x22, 0xea, 0xbb, 0xb0, 0x80, 0x71, 0x3d, 0xe2, 0x8e,  
0x91, 0xbe, 0x4e, 0x8b, 0x30, 0xbe, 0x31, 0xf8, 0x81, 0xbe, 0xf4, 0xa1, 0x0e, 0x3e, 0x44, 0xb6,  
0x1e, 0xbe, 0xa3, 0xe2, 0xb9, 0xbe, 0x63, 0xe9, 0x5f, 0x3e, 0xcb, 0x9c, 0xa9, 0x3e, 0xaf, 0xe1,
```

0xb6, 0x3e, 0xfd, 0x21, 0x0e, 0xbe, 0x1a, 0xc7, 0x1e, 0x3e, 0xe7, 0xf4, 0xc7, 0x3d, 0x36, 0x2c,
0x7e, 0x3e, 0x51, 0x2d, 0xb2, 0x3e, 0x28, 0xb4, 0xcd, 0x3e, 0xe3, 0xbd, 0x1f, 0xbc, 0xc9, 0x41,
0xf4, 0xbe, 0x9f, 0x19, 0x3c, 0x3e, 0x95, 0xf2, 0x87, 0x3e, 0x7c, 0x01, 0xeb, 0xbd, 0xfe, 0xb6,
0x8e, 0x3e, 0x84, 0xc8, 0xd1, 0xbd, 0x41, 0xab, 0xf2, 0xbd, 0x50, 0x23, 0x5f, 0xbe, 0x42, 0xd7,
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