LAPORAN PRAKTIKUM INTERNET OF THINGS (IOT)

IMPLEMENTASI MODEL TINYML UNTUK KLASIFIKASI DATASET IRIS MENGGUNAKAN ESP32

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ABSTRAK

Tujuan dari proyek ini adalah untuk menggunakan konsep Tiny Machine Learning (TinyML) dengan mikrokontroler ESP32. Dengan menggunakan TensorFlow Lite dan pustaka EloquentTinyML, model klasifikasi IRIS yang telah dilatih sebelumnya diintegrasikan ke dalam ESP32 untuk memprediksi jenis bunga berdasarkan parameter seperti panjang dan lebar sepal atau petal. Proses ini dilakukan secara lokal, tanpa memerlukan koneksi internet setelah pemrograman selesai; namun, selama proses simulasi dan pengembangan, koneksi diperlukan. Simulasi proyek dilakukan di Wokwi dan hasil dipantau melalui Serial Monitor di VSCode.

Kata Kunci : ESP32, Wokwi, TinyML

ABTRACT

The goal of this project is to use the Tiny Machine Learning (TinyML) concept with an ESP32 microcontroller. Using TensorFlow Lite and the EloquentTinyML library, a pre-trained IRIS classification model is integrated into the ESP32 to predict flower types based on parameters such as sepal or petal length and width. This process is done locally, without requiring an internet connection after programming is complete; however, during the simulation and development process, a connection is required. The simulation of the project is done in Wokwi and the results are monitored via the Serial Monitor in VSCode.

Keywords: ESP32, Wokwi, TinyML

1. PENDAHULUAN

1.1 Latar Belakang

Dalam beberapa tahun terakhir, teknologi kecerdasan buatan (AI) dan pengajaran mesin telah berkembang pesat. Tiny Machine Learning (TinyML) adalah area yang menarik karena menerapkan model ML pada perangkat tepi yang memiliki sumber daya terbatas, seperti mikrokontroler. TinyML memungkinkan perangkat kecil, murah, dan hemat energi untuk melakukan inferensi AI secara lokal tanpa bergantung pada internet atau cloud computing. Aplikasi Internet of Things (IoT) yang membutuhkan respons cepat, keamanan data, dan efisiensi energi membutuhkan hal ini.

ESP32, salah satu mikrokontroler yang paling populer dan kuat, menyediakan platform yang ideal untuk pengembangan TinyML. Dengan kemampuan pemrosesan yang cukup dan konektivitas yang lengkap, ESP32 memungkinkan pengoperasian model TensorFlow Lite yang dioptimalkan, yang berarti bahwa model ML yang sebelumnya hanya dapat berjalan pada perangkat dengan sumber daya yang besar sekarang dapat dijalankan pada perangkat yang tertanam.

Dataset IRIS dipilih untuk studi kasus klasifikasi karena merupakan dataset klasik dalam dunia pembelajaran mesin yang sering digunakan sebagai contoh pengenalan pola. Dataset ini mengandung fitur sederhana seperti panjang dan lebar sepal dan petal, yang dapat dikategorikan menjadi tiga jenis bunga iris. Proyek ini, dengan menggunakan model klasifikasi IRIS pada ESP32, menunjukkan bahwa TinyML dapat diterapkan dengan baik dan bahwa ESP32 dapat melakukan tugas AI dengan baik. Meskipun TinyML memungkinkan inferensi offline, pengembangan model, konversi ke TensorFlow Lite, dan simulasi kode di lingkungan seperti Wokwi semuanya membutuhkan koneksi internet. Ini adalah pertimbangan penting untuk implementasi, terutama dalam hal pengembangan dan distribusi aplikasi berbasis TinyML yang luas.

Secara keseluruhan, tujuan proyek ini adalah untuk memperluas pengetahuan dan kemampuan dalam bidang AI embedded dan IoT, serta menghasilkan solusi cerdas dan mandiri melalui penggabungan teknologi ML dengan sistem tertanam.

1.2 Tujuan

Adapun tujuan dari praktikum ini ialah :

1. Mengintegrasikan model klasifikasi IRIS, yang berbasis TensorFlow Lite, ke ESP32.
2. Mempelajari proses TinyML mulai dari pelatihan model
3. Simulasi dan pengujian model dilakukan menggunakan Wokwi dan VSCode.

2. METODOLOGI

2.1 Alat dan Bahan

Alat :

a. Laptop
b. Platform Wokwi
c. Platform Visual Studio Code (VSCode)

Bahan :

a. ESP32 (Virtual dalam platform wokwi)
b. Bahasa Pemrograman C++ Pustaka Arduino
c. Dataset IRIS
d. Library
    - EloquentTinyML
    - eloquentarduino/tflm_esp32

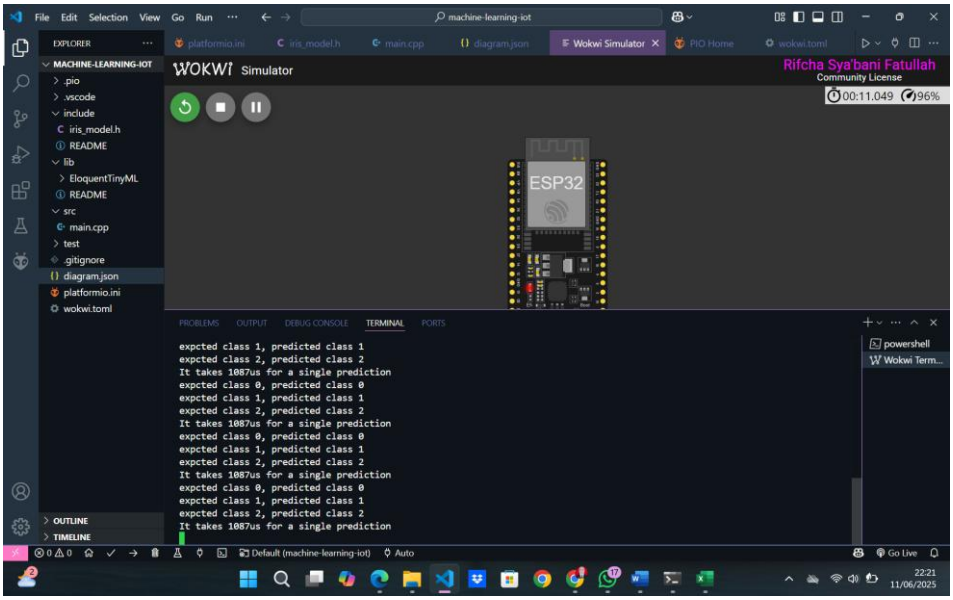
2.2 Langkah Implementasi

1. Buka platform VSCode
2. Install ekstensi PlatformIO
3. Buat proyek baru dengan board EDP32 DOIT DEVKIT V1
4. Tambahkan library tflm_esp32 dan EloquentTinyML
5. Salin file iris_model.h hasil konservasi model tensorflow lite ke folder include
6. Buat kode program main.cpp di dalam folder src
7. Jalankan Program
8. Pastikan serial monitor menampilkan hasil prediksi kelas IRIS

3. Hasil dan Pembahasan

3.1 Hasil Eksperimen

a. Hasil kelas data IRIS yang diuji



b. Dataset IRIS

sepal length (cm)	sepal width (cm)	petal length (cm)	petal width (cm)	target	species
5.1	3.5	1.4	0.2	0	setosa
4.9	3	1.4	0.2	0	setosa
4.7	3.2	1.3	0.2	0	setosa
4.6	3.1	1.5	0.2	0	setosa
5	3.6	1.4	0.2	0	setosa
5.4	3.9	1.7	0.4	0	setosa
4.6	3.4	1.4	0.3	0	setosa
5	3.4	1.5	0.2	0	setosa
4.4	2.9	1.4	0.2	0	setosa
4.9	3.1	1.5	0.1	0	setosa
5.4	3.7	1.5	0.2	0	setosa
4.8	3.4	1.6	0.2	0	setosa
4.8	3	1.4	0.1	0	setosa
4.3	3	1.1	0.1	0	setosa
5.8	4	1.2	0.2	0	setosa
5.7	4.4	1.5	0.4	0	setosa
5.4	3.9	1.3	0.4	0	setosa
5.1	3.5	1.4	0.3	0	setosa
5.7	3.8	1.7	0.3	0	setosa
5.1	3.8	1.5	0.3	0	setosa
5.4	3.4	1.7	0.2	0	setosa
5.1	3.7	1.5	0.4	0	setosa
4.6	3.6	1	0.2	0	setosa
5.1	3.3	1.7	0.5	0	setosa
4.8	3.4	1.9	0.2	0	setosa
5	3	1.6	0.2	0	setosa
5	3.4	1.6	0.4	0	setosa
5.2	3.5	1.5	0.2	0	setosa
5.2	3.4	1.4	0.2	0	setosa
4.7	3.2	1.6	0.2	0	setosa
4.8	3.1	1.6	0.2	0	setosa

7	3.2	4.7	1.4	1	versicolor			
6.4	3.2	4.5	1.5	1	versicolor			
6.9	3.1	4.9	1.5	1	versicolor			
5.5	2.3	4	1.3	1	versicolor			
6.5	2.8	4.6	1.5	1	versicolor			
5.7	2.8	4.5	1.3	1	versicolor			
6.3	3.3	4.7	1.6	1	versicolor			
4.9	2.4	3.3	1	1	versicolor			
6.6	2.9	4.6	1.3	1	versicolor			
5.2	2.7	3.9	1.4	1	versicolor			
5	2	3.5	1	1	versicolor			
5.9	3	4.2	1.5	1	versicolor			
6	2.2	4	1	1	versicolor			
6.1	2.9	4.7	1.4	1	versicolor			
5.6	2.9	3.6	1.3	1	versicolor			
6.7	3.1	4.4	1.4	1	versicolor			
5.6	3	4.5	1.5	1	versicolor			
5.8	2.7	4.1	1	1	versicolor			
6.2	2.2	4.5	1.5	1	versicolor			
5.6	2.5	3.9	1.1	1	versicolor			
5.9	3.2	4.8	1.8	1	versicolor			
6.1	2.8	4	1.3	1	versicolor			
6.3	2.5	4.9	1.5	1	versicolor			
6.1	2.8	4.7	1.2	1	versicolor			
6.4	2.9	4.3	1.3	1	versicolor			
6.6	3	4.4	1.4	1	versicolor			
6.8	2.8	4.8	1.4	1	versicolor			
6.7	3	5	1.7	1	versicolor			
6	2.9	4.5	1.5	1	versicolor			
5.7	2.6	3.5	1	1	versicolor			
5.5	2.4	3.8	1.1	1	versicolor			
5.5	2.4	3.7	1	1	versicolor			

6.3	3.3	6	2.5	2	virginica
5.8	2.7	5.1	1.9	2	virginica
7.1	3	5.9	2.1	2	virginica
6.3	2.9	5.6	1.8	2	virginica
6.5	3	5.8	2.2	2	virginica
7.6	3	6.6	2.1	2	virginica
4.9	2.5	4.5	1.7	2	virginica
7.3	2.9	6.3	1.8	2	virginica
6.7	2.5	5.8	1.8	2	virginica
7.2	3.6	6.1	2.5	2	virginica
6.5	3.2	5.1	2	2	virginica
6.4	2.7	5.3	1.9	2	virginica
6.8	3	5.5	2.1	2	virginica
5.7	2.5	5	2	2	virginica
5.8	2.8	5.1	2.4	2	virginica
6.4	3.2	5.3	2.3	2	virginica
6.5	3	5.5	1.8	2	virginica
7.7	3.8	6.7	2.2	2	virginica
7.7	2.6	6.9	2.3	2	virginica
6	2.2	5	1.5	2	virginica
6.9	3.2	5.7	2.3	2	virginica
5.6	2.8	4.9	2	2	virginica
7.7	2.8	6.7	2	2	virginica
6.3	2.7	4.9	1.8	2	virginica
6.7	3.3	5.7	2.1	2	virginica
7.2	3.2	6	1.8	2	virginica
6.2	2.8	4.8	1.8	2	virginica
6.1	3	4.9	1.8	2	virginica
6.4	2.8	5.6	2.1	2	virginica
7.2	3	5.8	1.6	2	virginica
7.4	2.8	6.1	1.9	2	virginica
7.9	3.8	6.4	2	2	virginica

3.2 Pembahasan

Dengan proses inferensi dengan waktu sekitar 1 milidetik, implementasi TinyML pada ESP32 melalui simulasi di Wokwi menunjukkan bahwa mikrokontroler kecil dapat menjalankan model AI dengan baik. Ini menunjukkan bahwa perangkat edge dapat melakukan tugas AI secara real-time dengan menggunakan sedikit daya. Model yang telah dimuat berjalan secara lokal di dalam simulasi; namun, pengembangan dan simulasi membutuhkan koneksi internet. Dengan demikian, inferensi dapat dilakukan tanpa koneksi internet. Ini menunjukkan kapasitas TinyML untuk aplikasi yang membutuhkan tingkat otonomi tinggi, seperti perangkat Internet of Things yang tersebar.

Dataset Iris, yang ditampilkan dalam bentuk tabel, berfungsi sebagai sumber data pelatihan dasar. Data ini, yang mencakup dimensi sepal dan petal dari berbagai spesies Iris, digunakan untuk mengajar model. Namun demikian, irisModel adalah model pembelajaran mesin yang berhasil dilatih (trained model). Ini ditampilkan sebagai array biner const unsigned char irisModel[]. Model ini telah menjalani tahap pembelajaran intensif menggunakan Dataset Iris. Dalam proses ini, ia mengubah parameter internalnya, termasuk bias arsitektur jaringan saraf dan bobot, untuk mengklasifikasikan spesies Iris sesuai dengan fitur inputnya. Oleh karena itu, Iris Dataset adalah basis empiris yang memungkinkan model untuk belajar dan menggeneralisasi, sedangkan Iris Model adalah produk intelektual dari proses pembelajaran tersebut, siap untuk inferensi atau prediksi data baru seperti x0, x1, dan x2 dalam aplikasi dunia nyata.

4. Lampiran

a. 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_tinyml.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 tinyml wrapper
#include <eloquent_tinyml.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("expcted 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("expcted 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);
}
```

b. Kode Program diagram.json

```
{
  "version": 1,
  "author": "rifcha sya'bani fatullah",
  "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": {}
}
```

d. Kode 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] = {0.22222222222f, 0.62500000000f, 0.06779661017f, 0.04166666667f};

float x1[4] = {0.75000000000f, 0.50000000000f, 0.62711864407f, 0.54166666667f};

float x2[4] = {0.55555555556f, 0.54166666667f, 0.84745762712f, 1.00000000000f};

/** 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, 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,
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