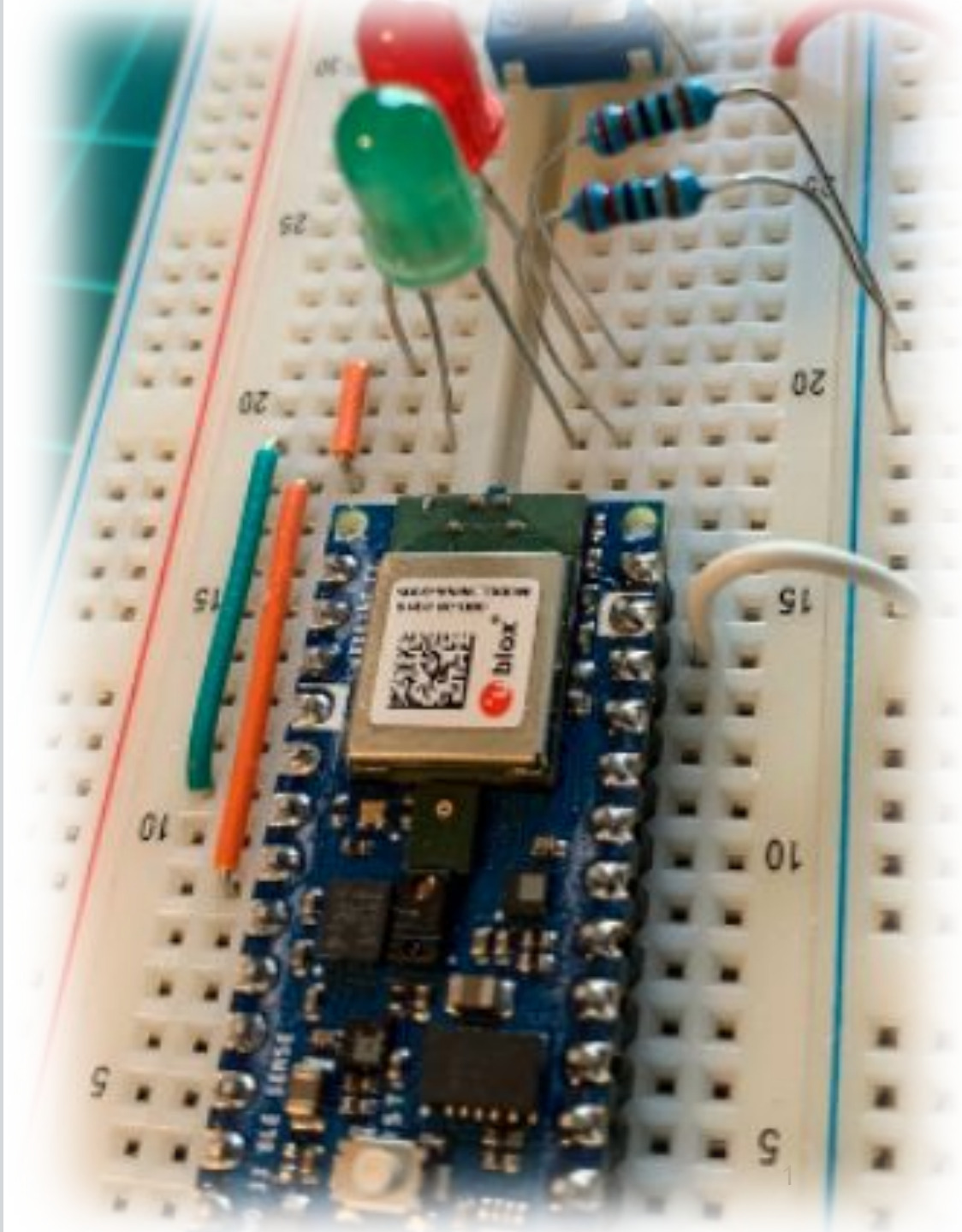
IESTI01 – TinyML

Embedded Machine Learning

26.a Person Detection (VWW) Application



Prof. Marcelo Rovai
UNIFEI

Person Detection:
Application Architecture

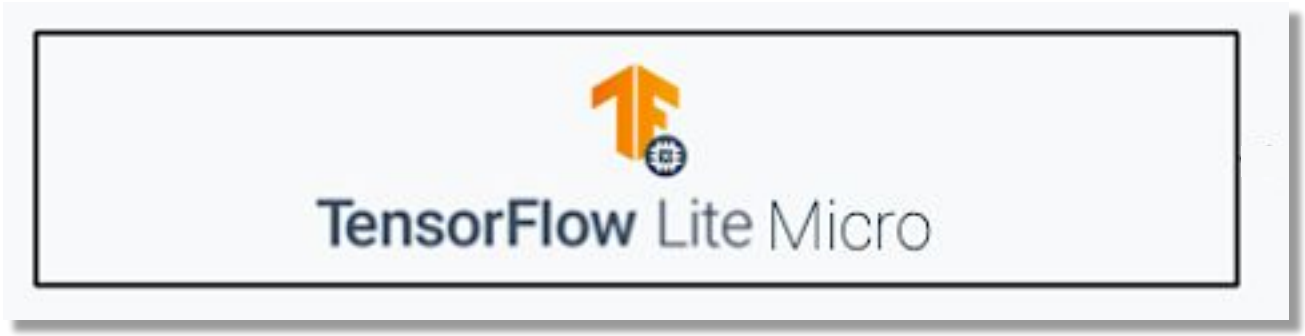
✔

X

Person Detection using Transfer Learning Model

Code Walkthrough!

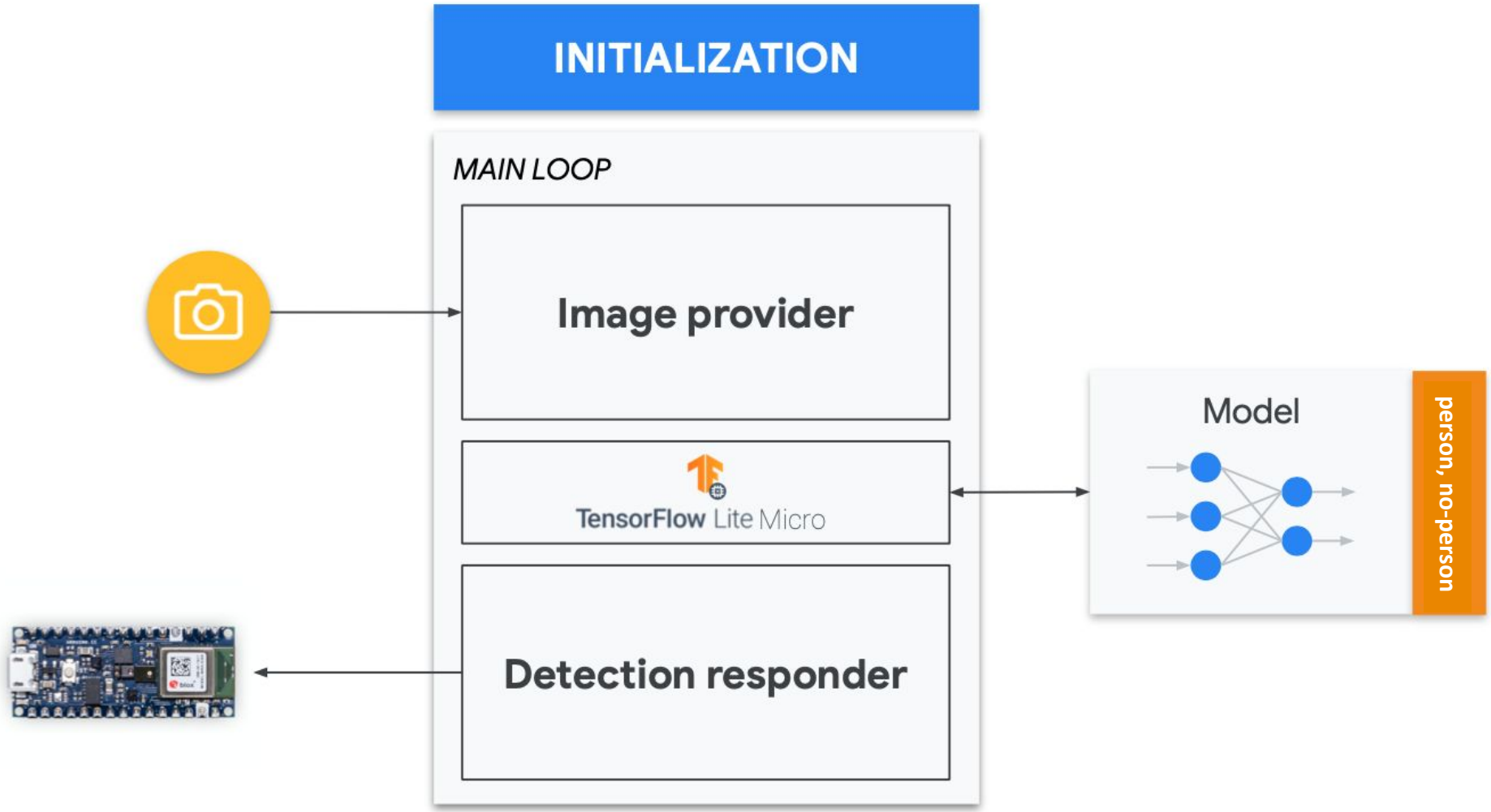
person_detection.ino (Arduino IDE TFLite Example)



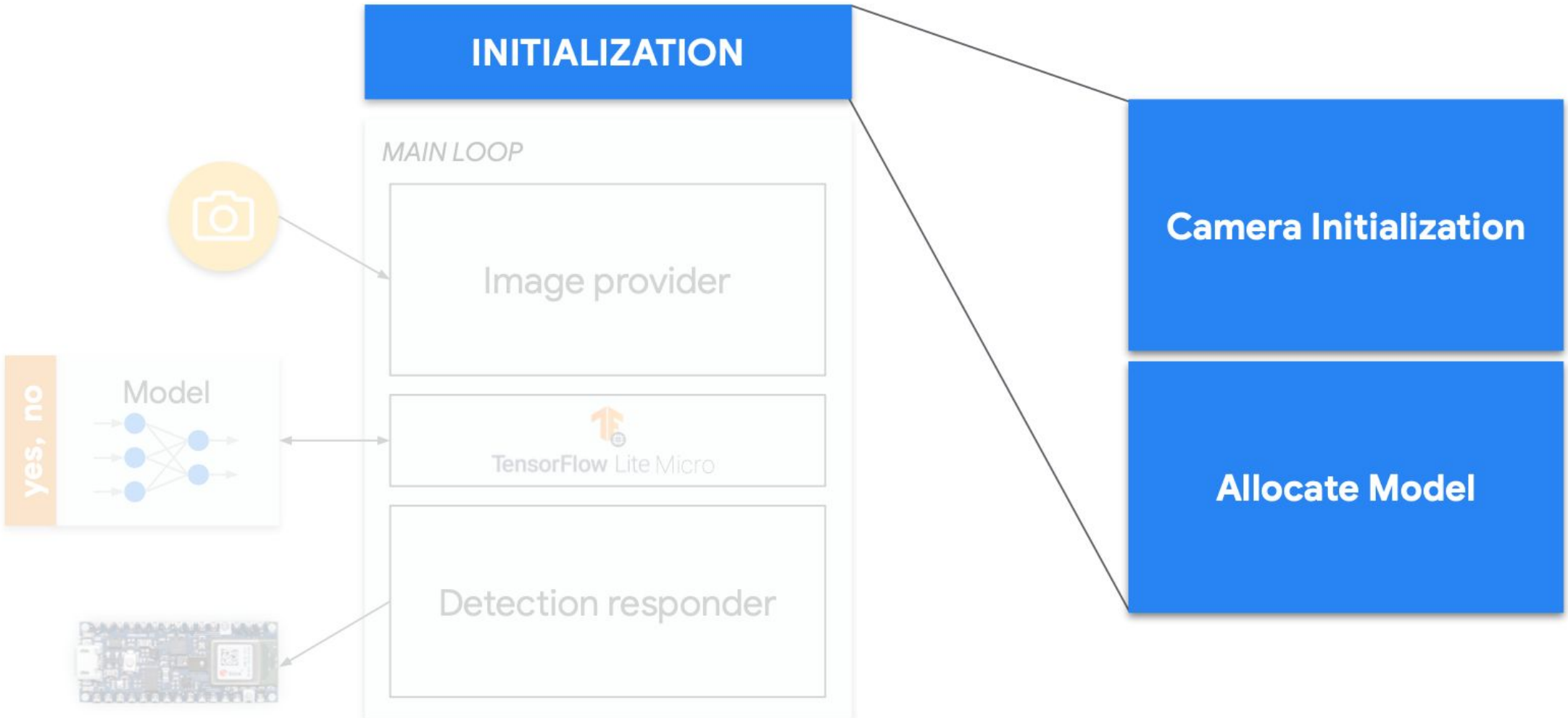
TensorFlow Lite Micro - Paper

MLSys 2021: TensorFlow Lite Micro TFLM

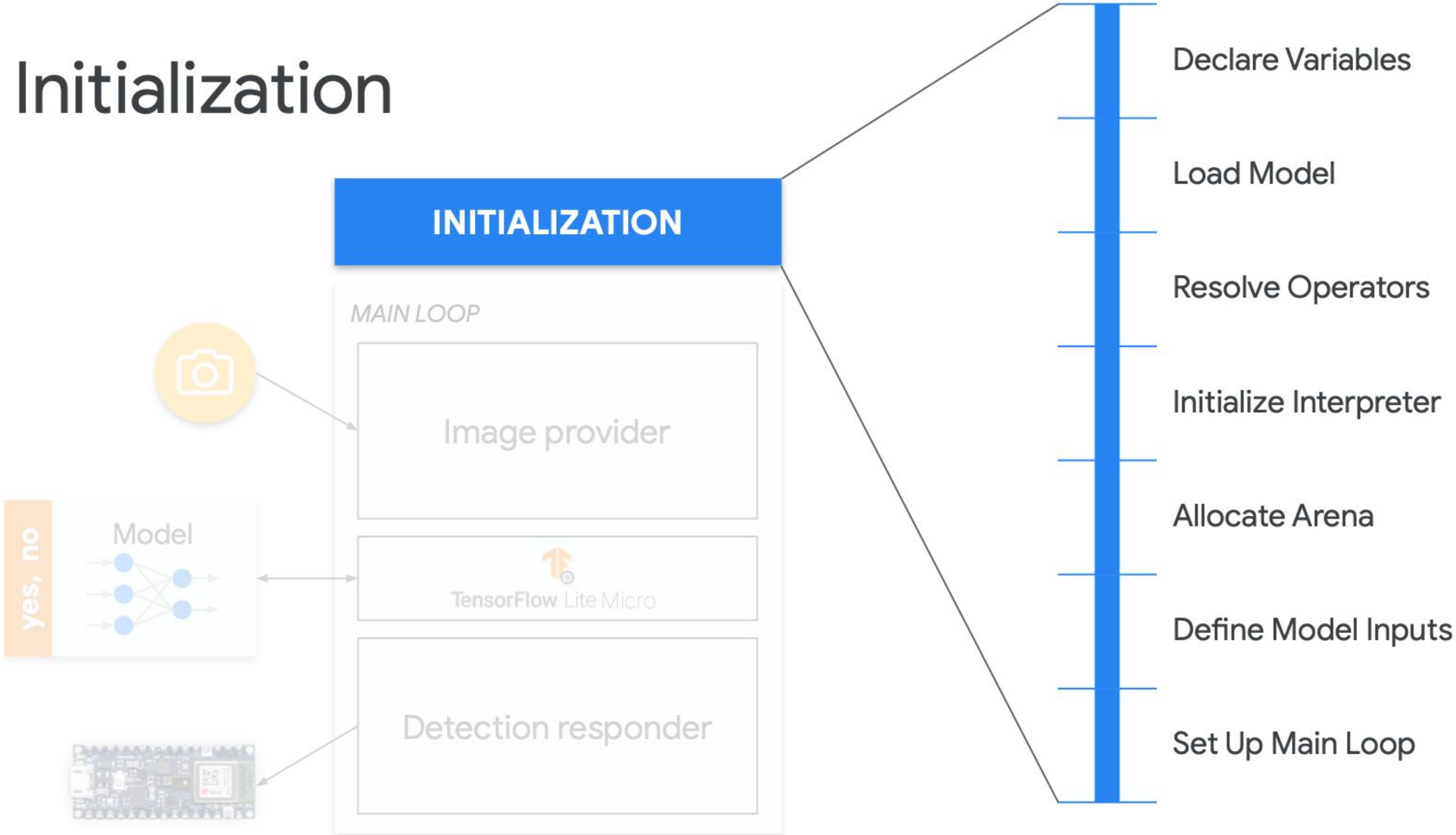
Person Detection **Components**



Initialization



Initialization

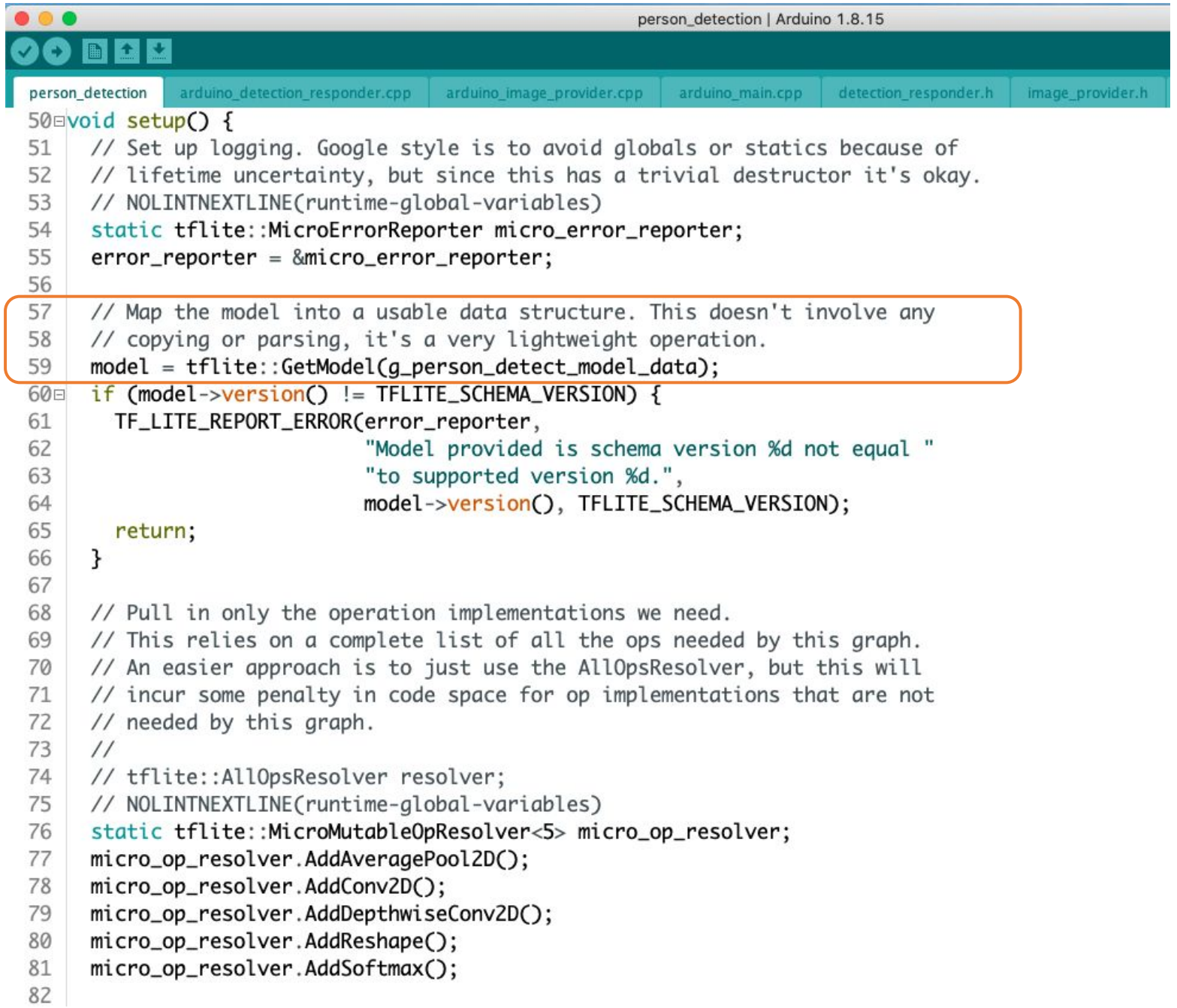


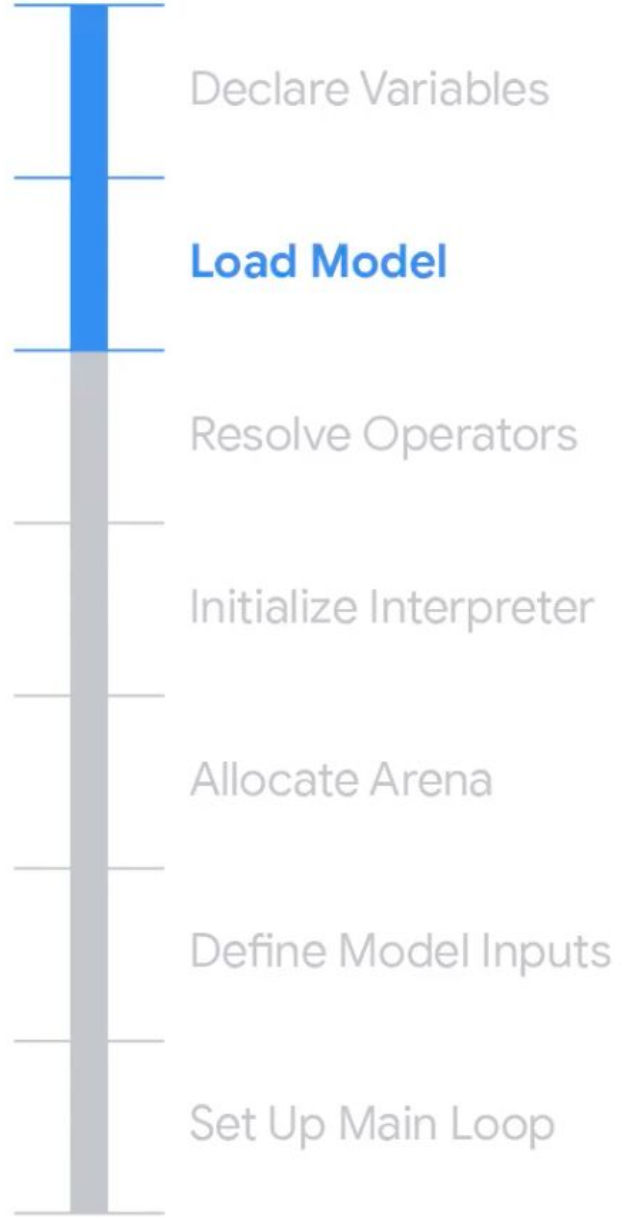
person_detection | Arduino 1.8.15

person_detection | arduino_detection_responder.cpp | arduino_image_provider.cpp | arduino_main.cpp | detection_responder.h | image_provider.h

```
15
16 #include <TensorFlowLite.h>
17
18 #include "main_functions.h"
19
20 #include "detection_responder.h"
21 #include "image_provider.h"
22 #include "model_settings.h"
23 #include "person_detect_model_data.h"
24 #include "tensorflow/lite/micro/micro_error_reporter.h"
25 #include "tensorflow/lite/micro/micro_interpreter.h"
26 #include "tensorflow/lite/micro/micro_mutable_op_resolver.h"
27 #include "tensorflow/lite/schema/schema_generated.h"
28 #include "tensorflow/lite/version.h"
29
30 // Globals, used for compatibility with Arduino-style sketches.
31 namespace {
32 tflite::ErrorReporter* error_reporter = nullptr;
33 const tflite::Model* model = nullptr;
34 tflite::MicroInterpreter* interpreter = nullptr;
35 TfLiteTensor* input = nullptr;
36
37 // In order to use optimized tensorflow lite kernels, a signed int8_t quantized
38 // model is preferred over the legacy unsigned model format. This means that
39 // throughout this project, input images must be converted from unisgned to
40 // signed format. The easiest and quickest way to convert from unsigned to
41 // signed 8-bit integers is to subtract 128 from the unsigned value to get a
42 // signed value.
43
44 // An area of memory to use for input, output, and intermediate arrays.
45 constexpr int kTensorArenaSize = 136 * 1024;
46 static uint8_t tensor_arena[kTensorArenaSize];
47 } // namespace
48
```

- **Declare Variables**
- Load Model
- Resolve Operators
- Initialize Interpreter
- Allocate Arena
- Define Model Inputs
- Set Up Main Loop


person_detection | Arduino 1.8.15
person_detection
arduino_detection_responder.cpp
arduino_image_provider.cpp
arduino_main.cpp
detection_responder.h
image_provider.h
50 void setup() {
51 // Set up logging. Google style is to avoid globals or statics because of
52 // lifetime uncertainty, but since this has a trivial destructor it's okay.
53 // NOLINTNEXTLINE(runtime-global-variables)
54 static tflite::MicroErrorReporter micro_error_reporter;
55 error_reporter = &micro_error_reporter;
56
57 // Map the model into a usable data structure. This doesn't involve any
58 // copying or parsing, it's a very lightweight operation.
59 model = tflite::GetModel(g_person_detect_model_data);
60 if (model->version() != TFLITE_SCHEMA_VERSION) {
61 TF_LITE_REPORT_ERROR(error_reporter,
62 "Model provided is schema version %d not equal "
63 "to supported version %d.",
64 model->version(), TFLITE_SCHEMA_VERSION);
65 return;
66 }
67
68 // Pull in only the operation implementations we need.
69 // This relies on a complete list of all the ops needed by this graph.
70 // An easier approach is to just use the AllOpsResolver, but this will
71 // incur some penalty in code space for op implementations that are not
72 // needed by this graph.
73 //
74 // tflite::AllOpsResolver resolver;
75 // NOLINTNEXTLINE(runtime-global-variables)
76 static tflite::MicroMutableOpResolver<5> micro_op_resolver;
77 micro_op_resolver.AddAveragePool2D();
78 micro_op_resolver.AddConv2D();
79 micro_op_resolver.AddDepthwiseConv2D();
80 micro_op_resolver.AddReshape();
81 micro_op_resolver.AddSoftmax();
82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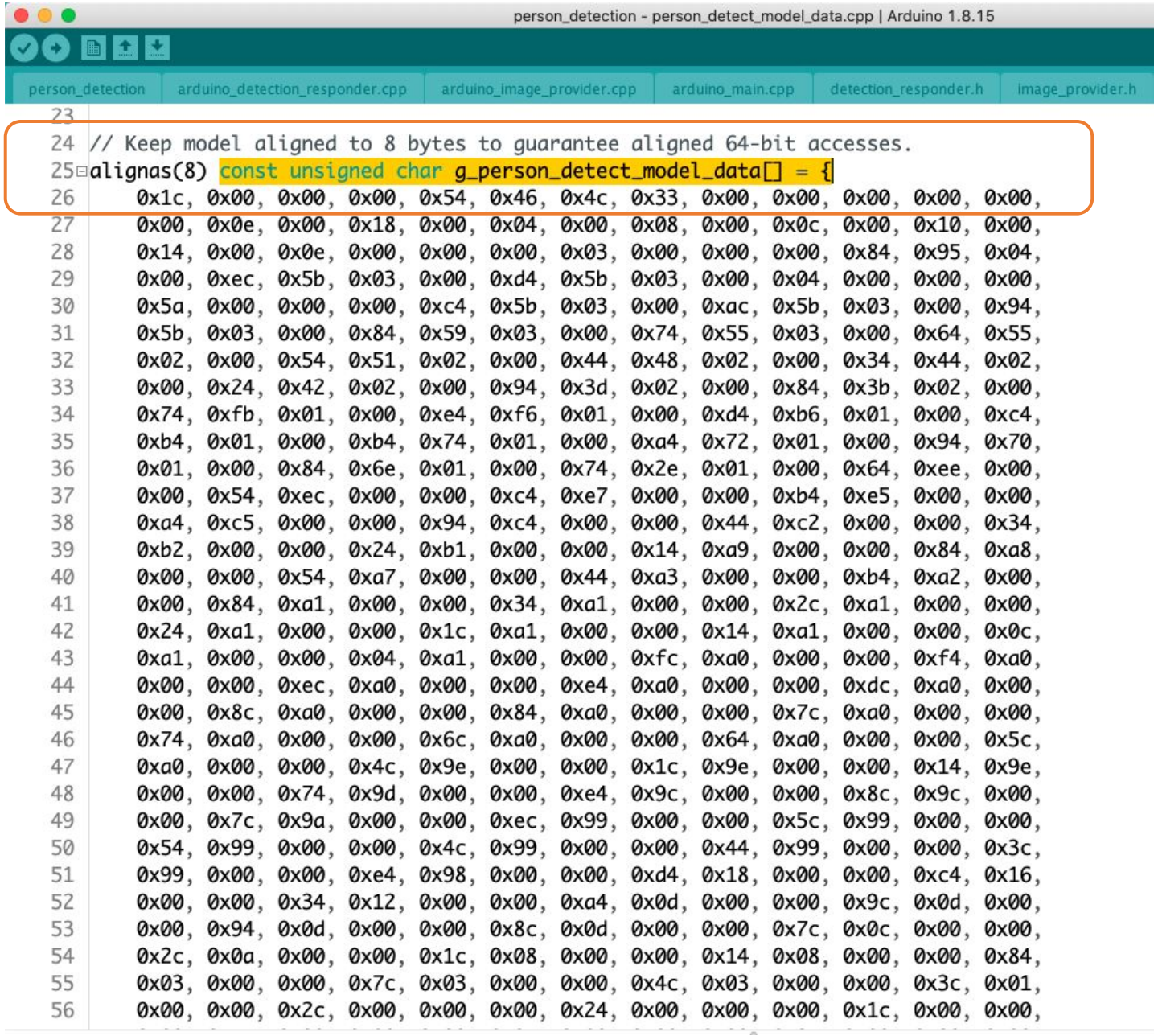
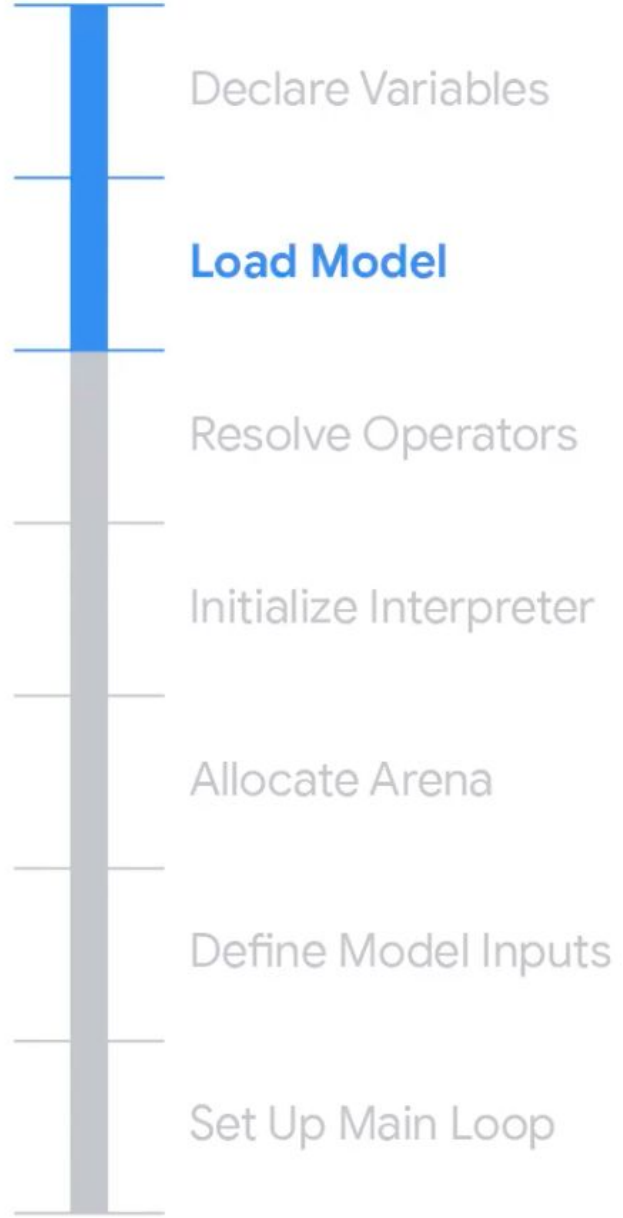

person_detection - person_detect_model_data.cpp | Arduino 1.8.15
person_detection
arduino_detection_responder.cpp
arduino_image_provider.cpp
arduino_main.cpp
detection_responder.h
image_provider.h
// Keep model aligned to 8 bytes to guarantee aligned 64-bit accesses.
alignas(8) const unsigned char g_person_detect_model_data[] = {
0x1c, 0x00, 0x00, 0x00, 0x54, 0x46, 0x4c, 0x33, 0x00, 0x00, 0x00, 0x00, 0x00,
0x00, 0x0e, 0x00, 0x18, 0x00, 0x04, 0x00, 0x08, 0x00, 0x0c, 0x00, 0x10, 0x00,
0x14, 0x00, 0x0e, 0x00, 0x00, 0x00, 0x03, 0x00, 0x00, 0x00, 0x84, 0x95, 0x04,
0x00, 0xec, 0x5b, 0x03, 0x00, 0xd4, 0x5b, 0x03, 0x00, 0x04, 0x00, 0x00, 0x00,
0x5a, 0x00, 0x00, 0x00, 0xc4, 0x5b, 0x03, 0x00, 0xac, 0x5b, 0x03, 0x00, 0x94,
0x5b, 0x03, 0x00, 0x84, 0x59, 0x03, 0x00, 0x74, 0x55, 0x03, 0x00, 0x64, 0x55,
0x02, 0x00, 0x54, 0x51, 0x02, 0x00, 0x44, 0x48, 0x02, 0x00, 0x34, 0x44, 0x02,
0x00, 0x24, 0x42, 0x02, 0x00, 0x94, 0x3d, 0x02, 0x00, 0x84, 0x3b, 0x02, 0x00,
0x74, 0xfb, 0x01, 0x00, 0xe4, 0xf6, 0x01, 0x00, 0xd4, 0xb6, 0x01, 0x00, 0xc4,
0xb4, 0x01, 0x00, 0xb4, 0x74, 0x01, 0x00, 0xa4, 0x72, 0x01, 0x00, 0x94, 0x70,
0x01, 0x00, 0x84, 0x6e, 0x01, 0x00, 0x74, 0x2e, 0x01, 0x00, 0x64, 0xee, 0x00,
0x00, 0x54, 0xec, 0x00, 0x00, 0xc4, 0xe7, 0x00, 0x00, 0xb4, 0xe5, 0x00, 0x00,
0xa4, 0xc5, 0x00, 0x00, 0x94, 0xc4, 0x00, 0x00, 0x44, 0xc2, 0x00, 0x00, 0x34,
0xb2, 0x00, 0x00, 0x24, 0xb1, 0x00, 0x00, 0x14, 0xa9, 0x00, 0x00, 0x84, 0xa8,
0x00, 0x00, 0x54, 0xa7, 0x00, 0x00, 0x44, 0xa3, 0x00, 0x00, 0xb4, 0xa2, 0x00,
0x00, 0x84, 0xa1, 0x00, 0x00, 0x34, 0xa1, 0x00, 0x00, 0x2c, 0xa1, 0x00, 0x00,
0x24, 0xa1, 0x00, 0x00, 0x1c, 0xa1, 0x00, 0x00, 0x14, 0xa1, 0x00, 0x00, 0x0c,
0xa1, 0x00, 0x00, 0x04, 0xa1, 0x00, 0x00, 0xfc, 0xa0, 0x00, 0x00, 0xf4, 0xa0,
0x00, 0x00, 0xec, 0xa0, 0x00, 0x00, 0xe4, 0xa0, 0x00, 0x00, 0xdc, 0xa0, 0x00,
0x00, 0x8c, 0xa0, 0x00, 0x00, 0x84, 0xa0, 0x00, 0x00, 0x7c, 0xa0, 0x00, 0x00,
0x74, 0xa0, 0x00, 0x00, 0x6c, 0xa0, 0x00, 0x00, 0x64, 0xa0, 0x00, 0x00, 0x5c,
0xa0, 0x00, 0x00, 0x4c, 0x9e, 0x00, 0x00, 0x1c, 0x9e, 0x00, 0x00, 0x14, 0x9e,
0x00, 0x00, 0x74, 0x9d, 0x00, 0x00, 0xe4, 0x9c, 0x00, 0x00, 0x8c, 0x9c, 0x00,
0x00, 0x7c, 0x9a, 0x00, 0x00, 0xec, 0x99, 0x00, 0x00, 0x5c, 0x99, 0x00, 0x00,
0x54, 0x99, 0x00, 0x00, 0x4c, 0x99, 0x00, 0x00, 0x44, 0x99, 0x00, 0x00, 0x3c,
0x99, 0x00, 0x00, 0xe4, 0x98, 0x00, 0x00, 0xd4, 0x18, 0x00, 0x00, 0xc4, 0x16,
0x00, 0x00, 0x34, 0x12, 0x00, 0x00, 0xa4, 0x0d, 0x00, 0x00, 0x9c, 0x0d, 0x00,
0x00, 0x94, 0x0d, 0x00, 0x00, 0x8c, 0x0d, 0x00, 0x00, 0x7c, 0x0c, 0x00, 0x00,
0x2c, 0x0a, 0x00, 0x00, 0x1c, 0x08, 0x00, 0x00, 0x14, 0x08, 0x00, 0x00, 0x84,
0x03, 0x00, 0x00, 0x7c, 0x03, 0x00, 0x00, 0x4c, 0x03, 0x00, 0x00, 0x3c, 0x01,
0x00, 0x00, 0x2c, 0x00, 0x00, 0x00, 0x24, 0x00, 0x00, 0x00, 0x1c, 0x00, 0x00,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60   if (model->version() != TFLITE_SCHEMA_VERSION) {
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62                          "Model provided is schema version %d not equal "
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64                          model->version(), TFLITE_SCHEMA_VERSION);
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82
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- Declare Variables
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82
83  // Build an interpreter to run the model with.
84  // NOLINTNEXTLINE(runtime-global-variables)
85  static tflite::MicroInterpreter static_interpreter(
86      model, micro_op_resolver, tensor_arena, kTensorArenaSize, error_reporter);
87  interpreter = &static_interpreter;
88
89  // Allocate memory from the tensor_arena for the model's tensors.
90  TfLiteStatus allocate_status = interpreter->AllocateTensors();
91  if (allocate_status != kTfLiteOk) {
92    TF_LITE_REPORT_ERROR(error_reporter, "AllocateTensors() failed");
93    return;
94  }
95
96  // Get information about the memory area to use for the model's input.
97  input = interpreter->input(0);
98 }
99
```

- Declare Variables
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91  if (allocate_status != kTfLiteOk) {
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93    return;
94  }
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96  // Get information about the memory area to use for the model's input.
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```

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Initialization

Camera Initialization

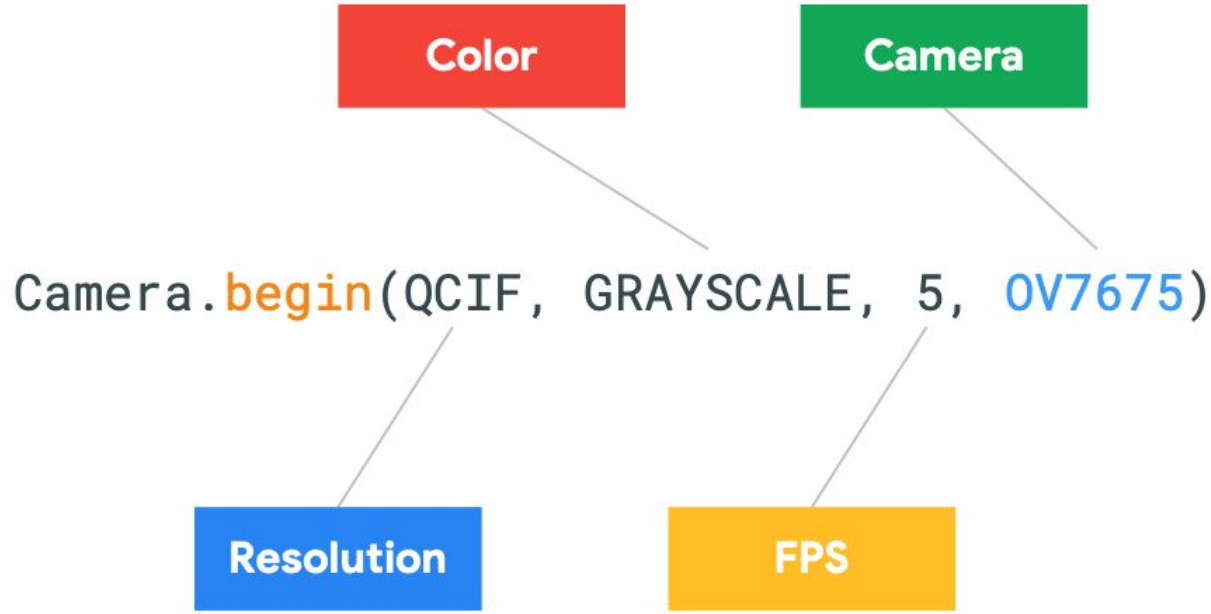
Allocate Model

```
// Initialize camera if necessary
if (!g_is_camera_initialized) {
  if (!Camera.begin(QCIF, GRAYSCALE, 5, OV7675)) {
    TF_LITE_REPORT_ERROR(error_reporter, "Failed to
                                  initialize
                                camera!");
    return kTfLiteError;
  }
  g_is_camera_initialized = true;
}
```

Initialization

Camera Initialization

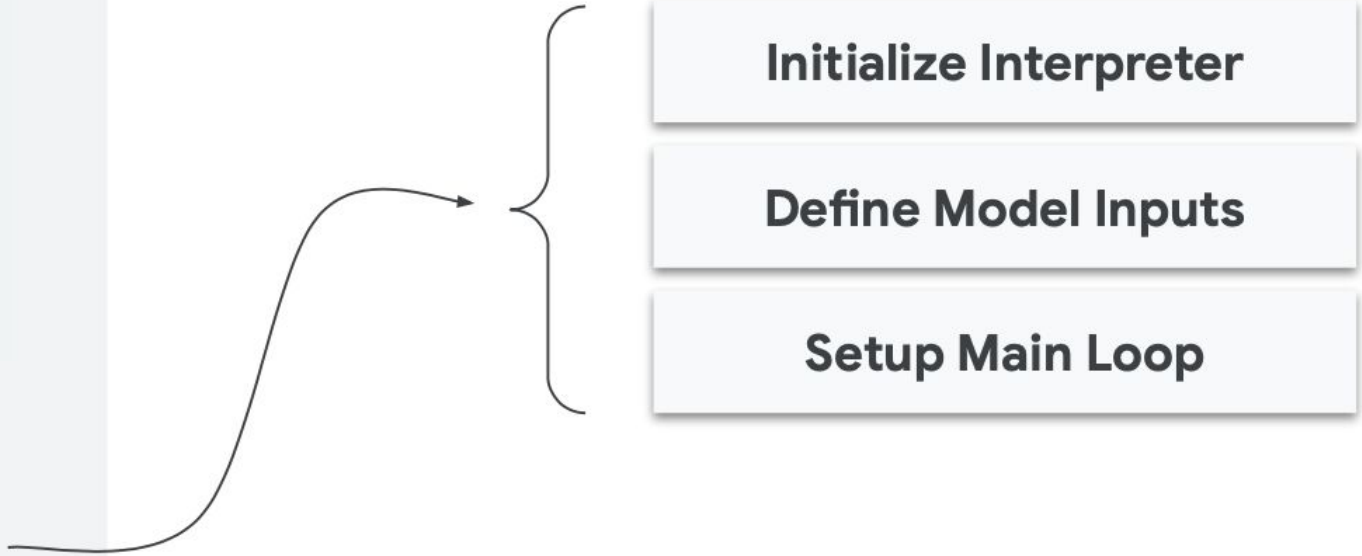
Allocate Model



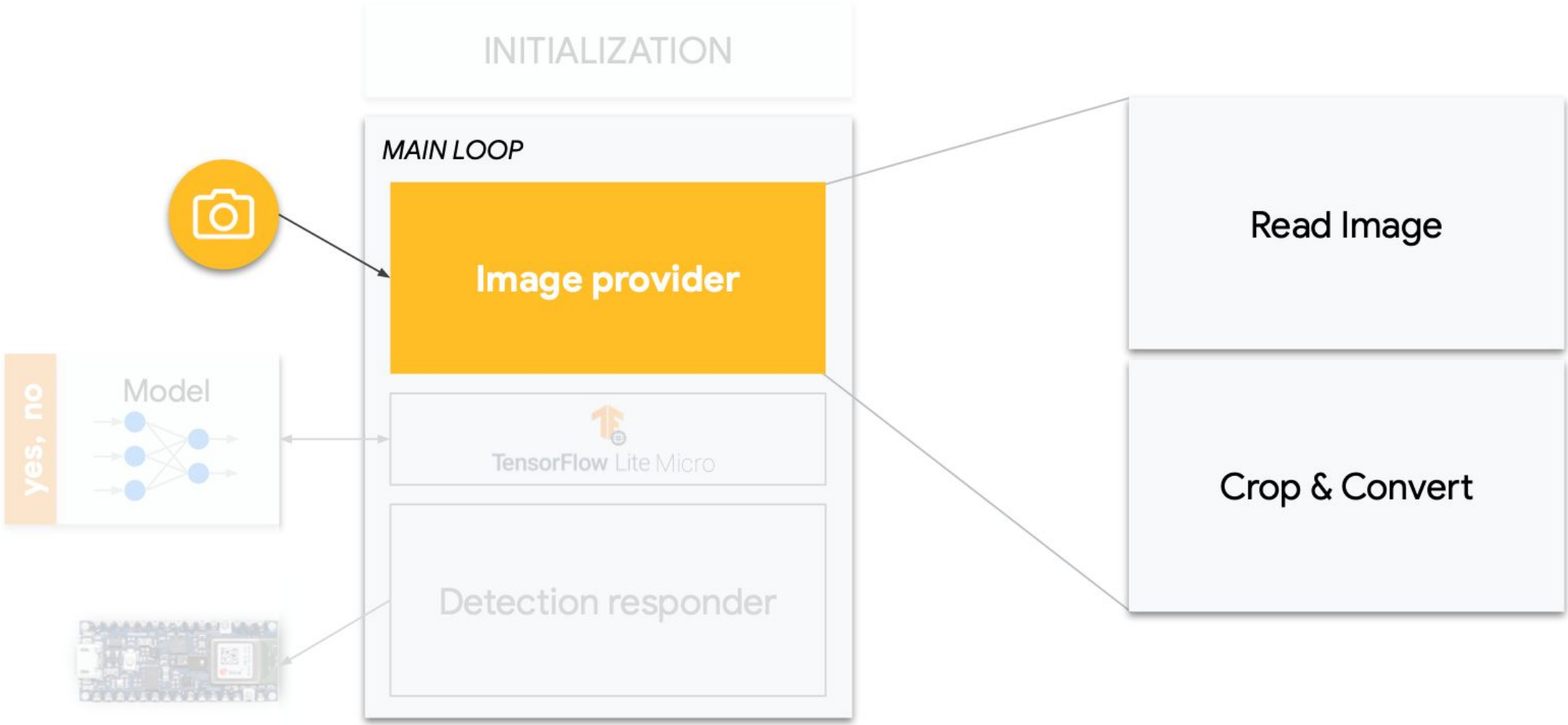
Initialization

Camera Initialization

Allocate Model



Pre-processing



Pre-processing

Read Image

Crop & Convert

```
// Get an image from the camera module
TfLiteStatus GetImage(tflite::ErrorReporter* error_reporter,
          int image_width, int image_height, int channels,
          int8_t* image_data)
```

Pre-processing

Read Image

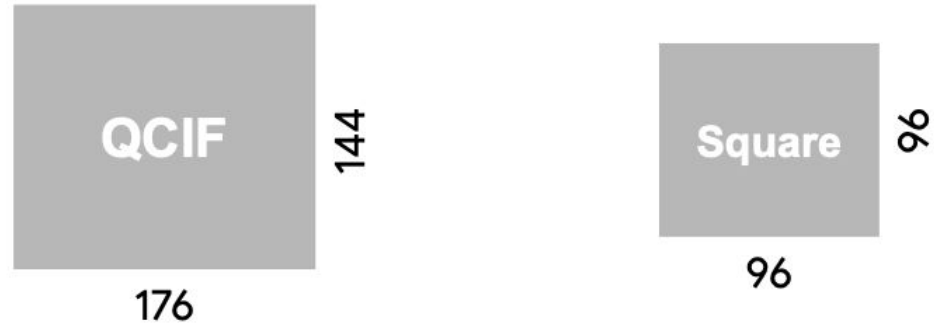
Crop & Convert

```
// Read camera data
Camera.readFrame(data);
```

Pre-processing

Read Image

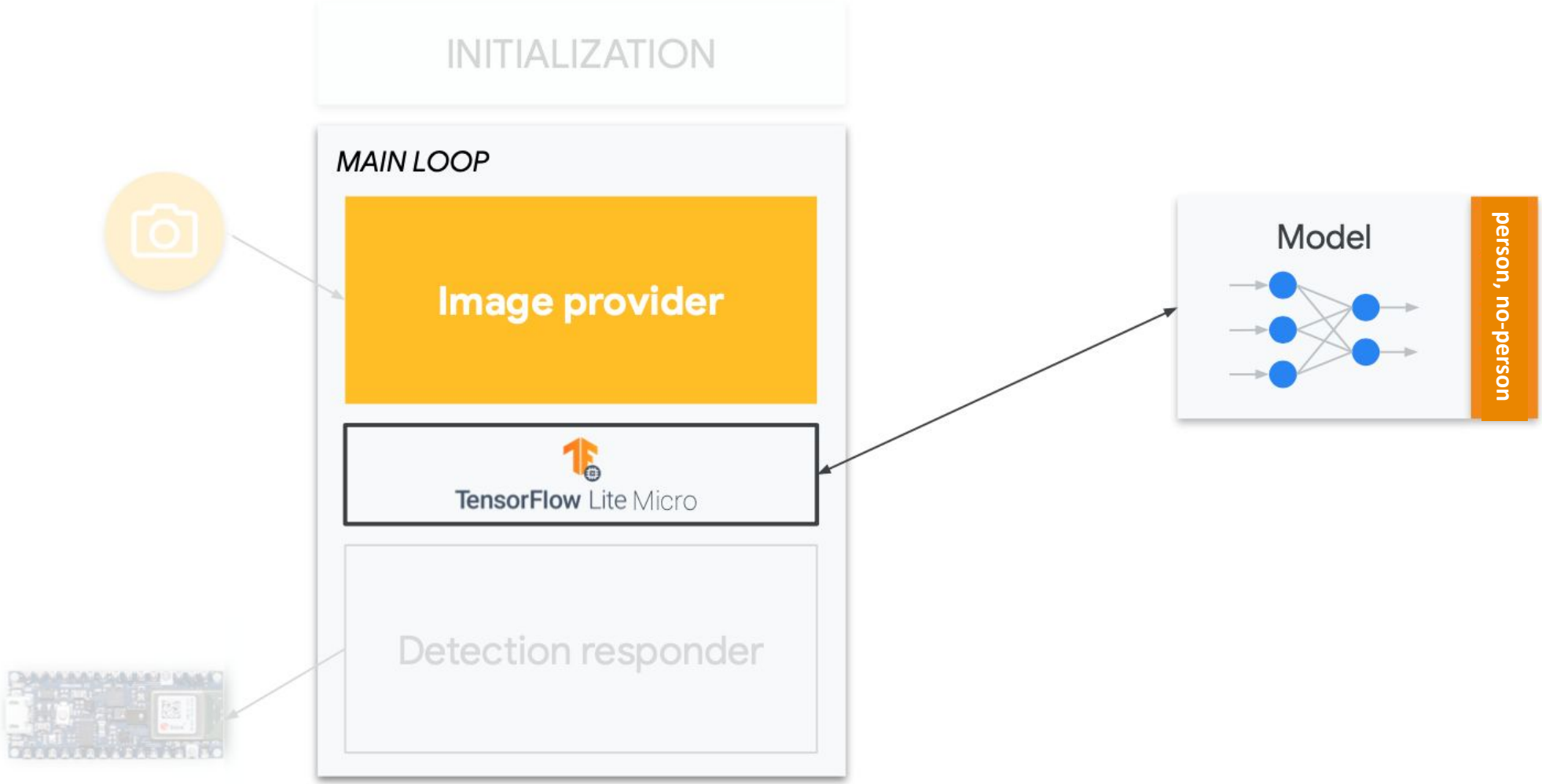
Crop & Convert



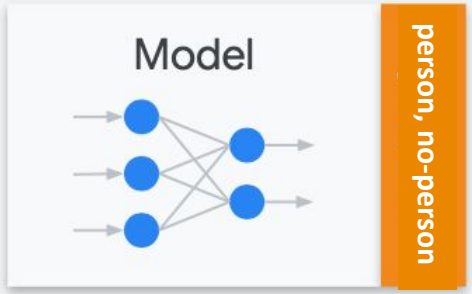

```
int min_x = (176 - 96) / 2;
int min_y = (144 - 96) / 2;
int index = 0;

// Crop 96x96 image. This lowers FOV, ideally we should downsample
for (int y = min_y; y < min_y + 96; y++) {
  for (int x = min_x; x < min_x + 96; x++) {
    image_data[index++] = static_cast<int8_t>(data[(y * 176) + x] - 128);
    // convert TF input image to signed 8-bit
  }
}
```

Interpreter + Model

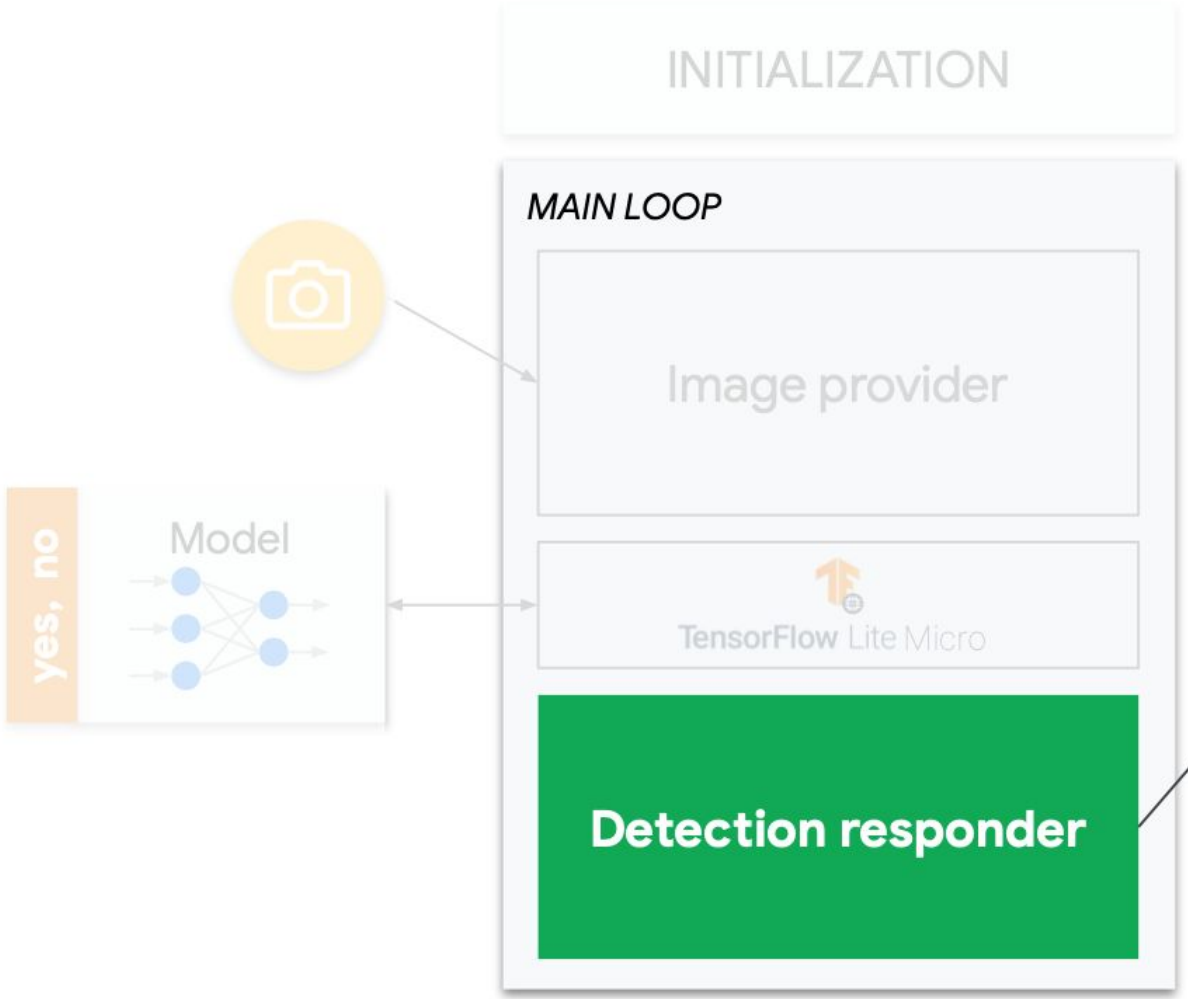


Interpreter + Model




```
kTfLiteOk != vww_interpreter->Invoke()
```

Post-processing



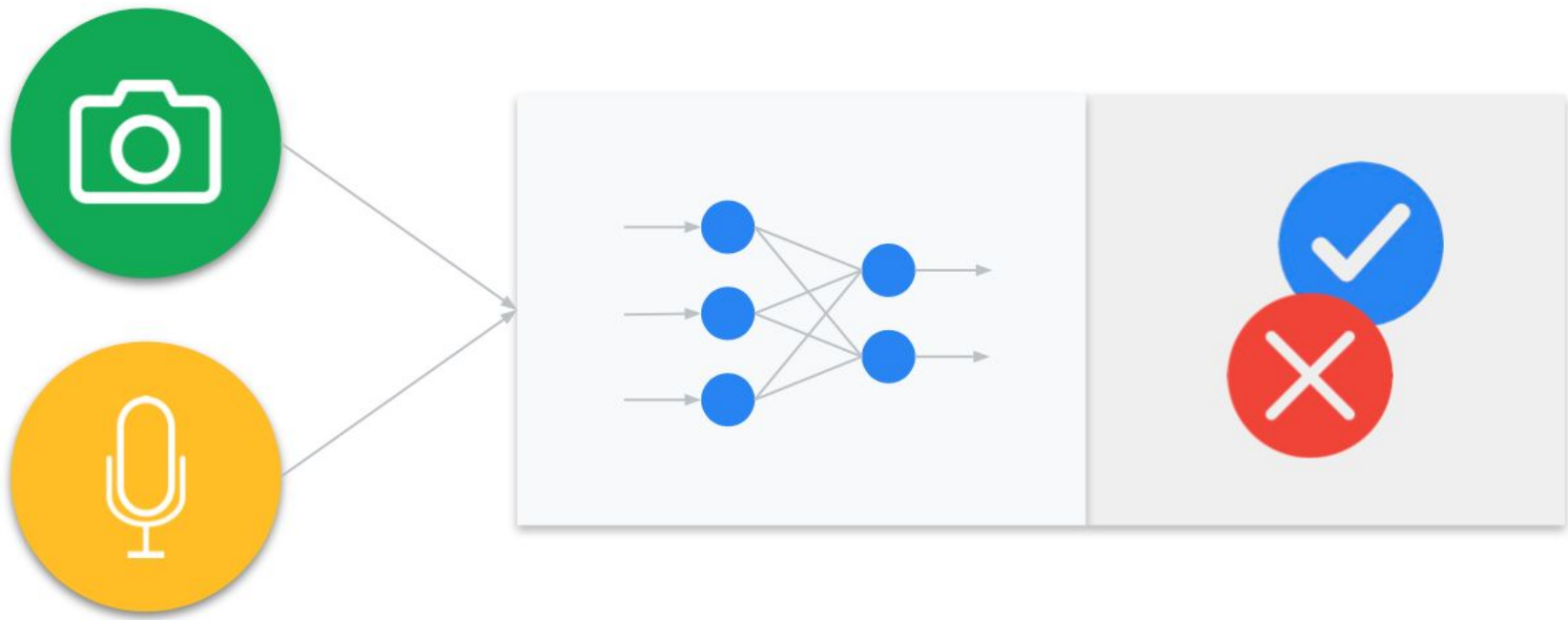

```
113  TfLiteTensor* output = interpreter->output(0);
114
115  // Process the inference results.
116  int8_t person_score = output->data.uint8[kPersonIndex];
117  int8_t no_person_score = output->data.uint8[kNotAPersonIndex];
118  RespondToDetection(error_reporter, person_score, no_person_score);
```

Detection responder

```
if (person_score > no_person_score) {
  digitalWrite(LEDG, LOW);
  digitalWrite(LEDR, HIGH);
} else {
  digitalWrite(LEDG, HIGH);
  digitalWrite(LEDR, LOW);
}
```

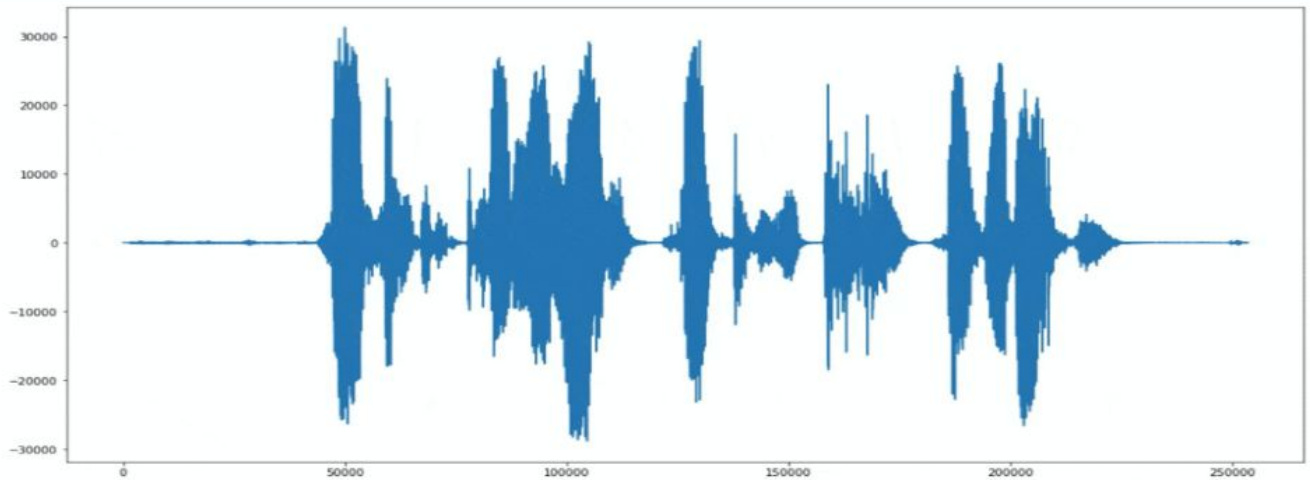
Person Detection:
Multi-Tenancy

MultiModal



MultiModal ML Workflow

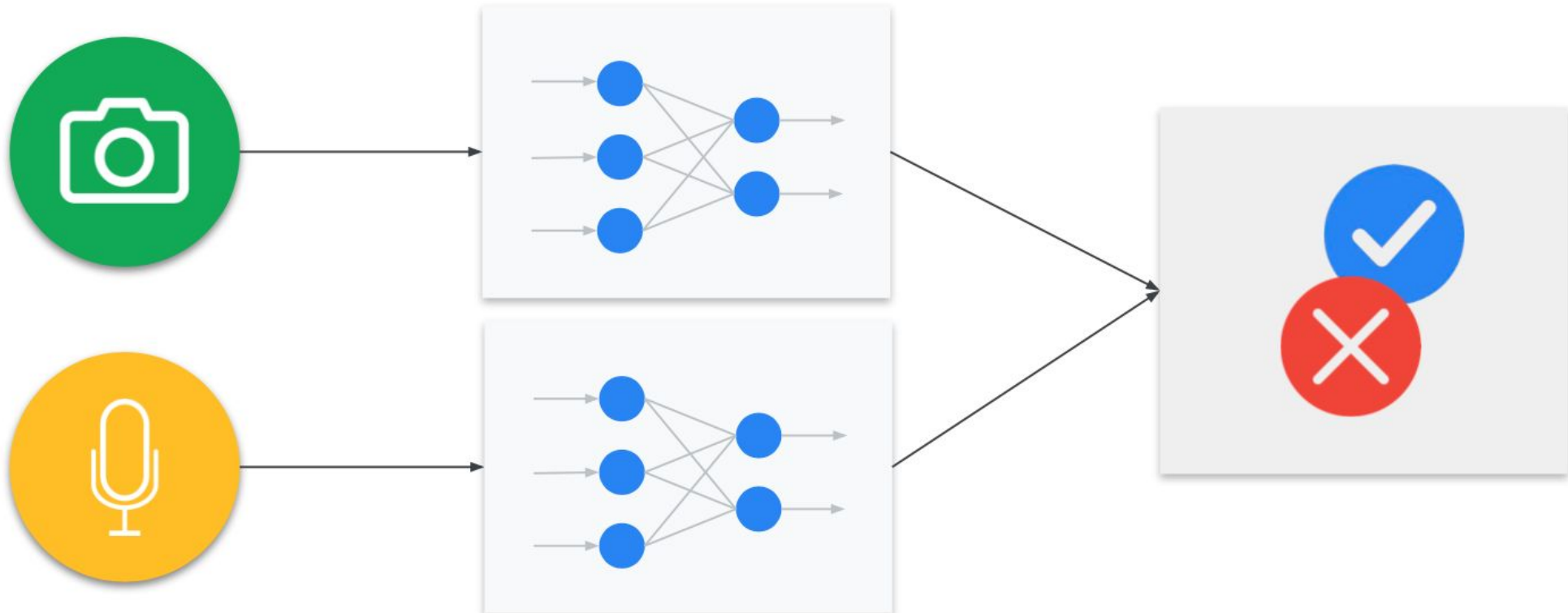
Collect Data → Preprocess Data → Design a Model → Train a Model → Evaluate Optimize → Convert Model → **Deploy Model** → **Make Inferences**



Example Person Detection Application

- Contact-free elevator control that enforces mask wearing
- Requires both **keyword spotting** and **mask detection**

MultiTenant

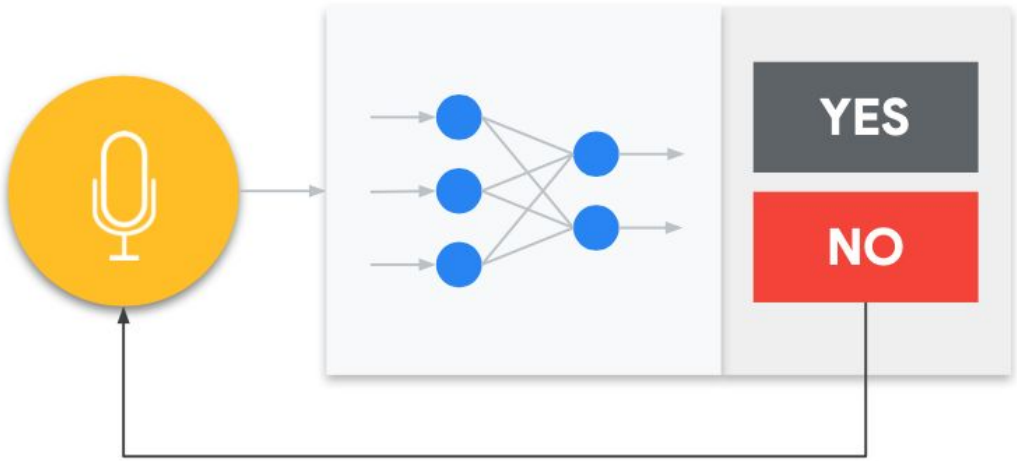


MultiTenant ML Workflow

same

MultiTenant ML Workflow

Cascade Multi Tenant



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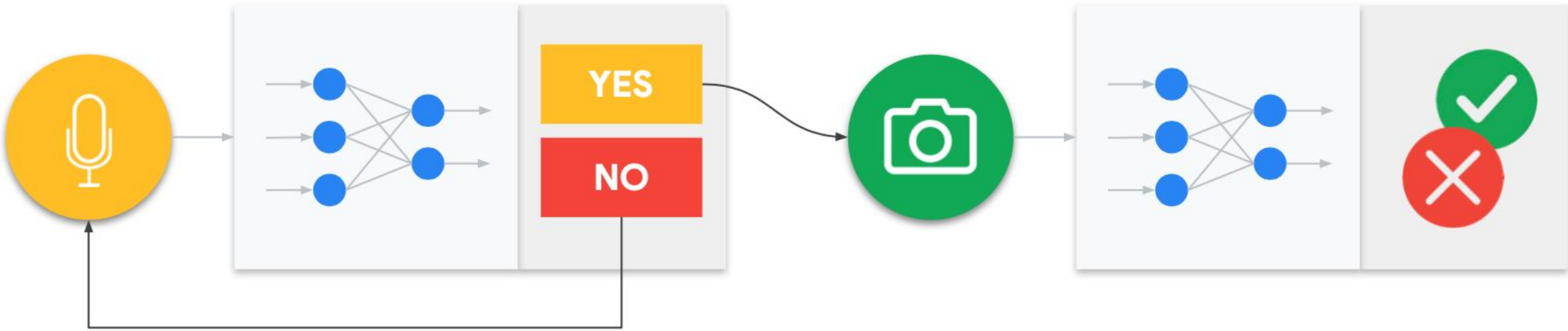

Reading Material

Main references

- Harvard School of Engineering and Applied Sciences - CS249r: Tiny Machine Learning
- Professional Certificate in Tiny Machine Learning (TinyML) – edX/Harvard
- Introduction to Embedded Machine Learning (Coursera)
- Text Book: "TinyML" by Pete Warden, Daniel Situnayake

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The IESTI01 course is part of the TinyML4D, an initiative to make TinyML education available to everyone globally.

Thanks

And stay safe!

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