µTVM

An AI Compiler and Framework for Arm Microcontrollers (and offload)

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What is TVM?

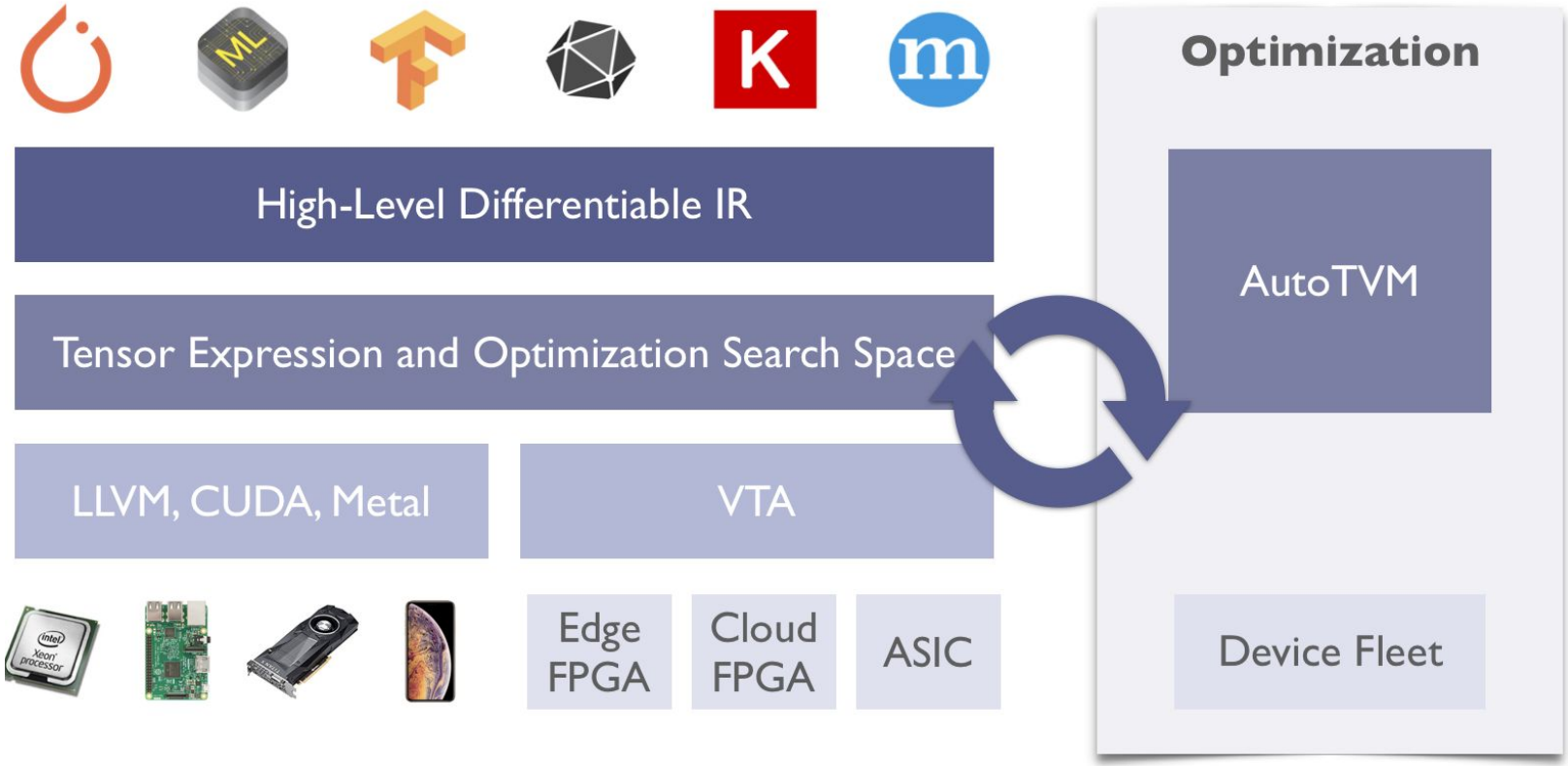
An ML Framework with agnostic compilation stack, capable of targeting CPUs, GPUs, DSPs and NPUs

Key characteristics

- Apache Project
- Open Source - Apache version 2
- https://tvm.apache.org
- Supports a range of hardware, microcontrollers to very large

TVM Architecture

Image credit : TVM Project



Great, wasn't this about microcontrollers?

Inference on Microcontrollers - Issues

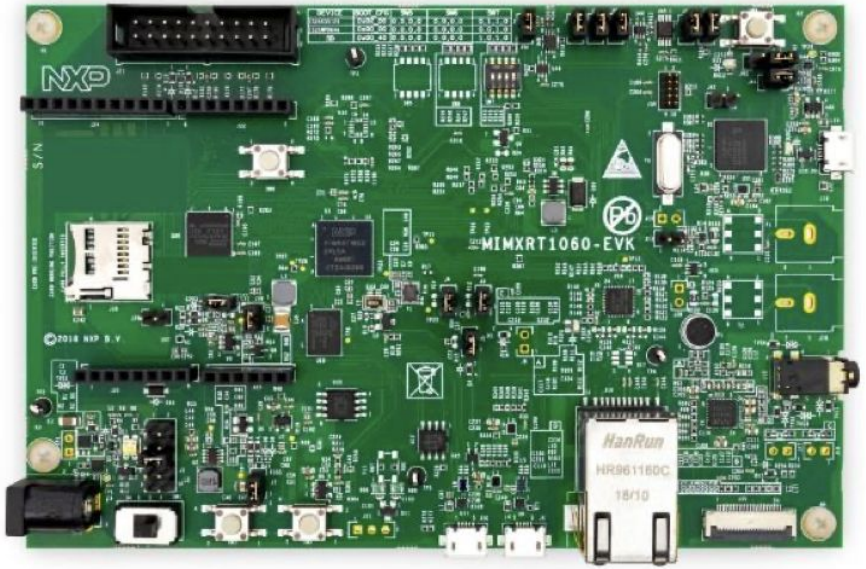
- Model Ingestion
- Cartesian product of models, frameworks and hardware
- Optimizations for microcontrollers must tune for a wider set of characteristics such as power, working set size, offload
- Quantization, pruning and distillation yet retaining accuracy is critical
- Model integration with application logic
- Integration with variety of RTOSes (everyone has a favorite) or RTOSless
- Support a range of hardware targets with different offload capabilities
- Deployment at scale

µTVM

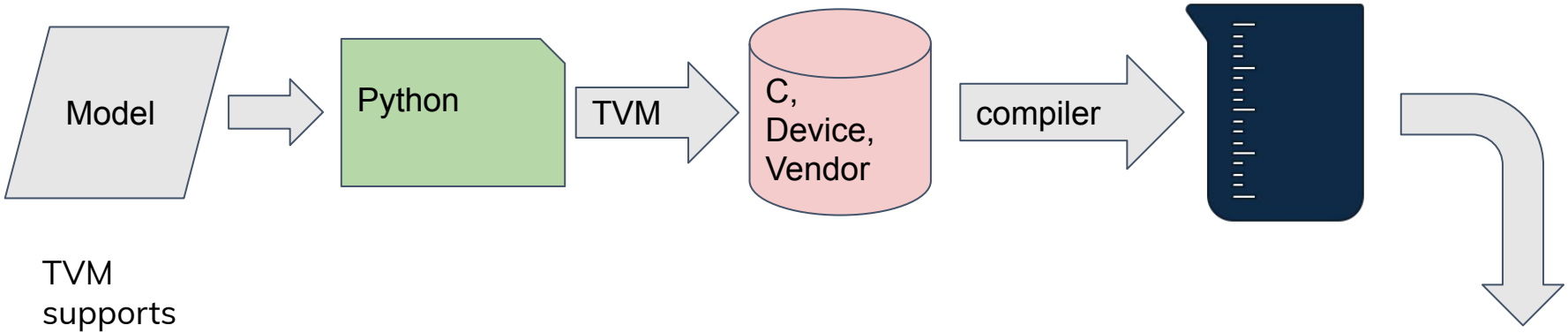
µTVM is part of the TVM project with features tailored to deeply embedded environments

- Leverages TVM framework
- Minimal runtime
- RPC for interactive development
- Zephyr, (Mbed OS) or RTOSless(*)
- C, C++ / Python language bindings

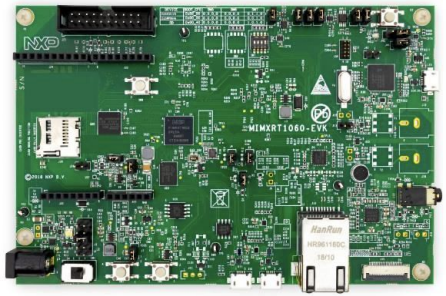
µTVM is a work in progress!



Development Workflow

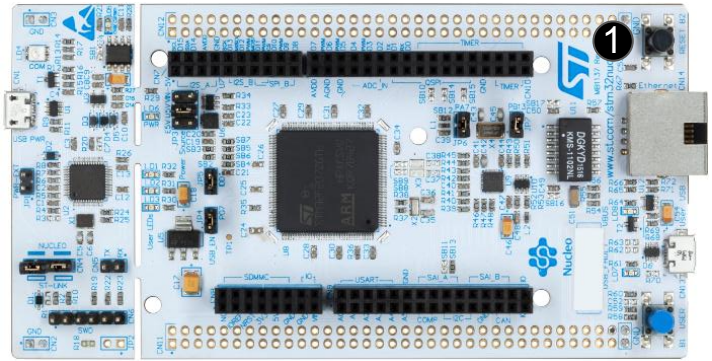


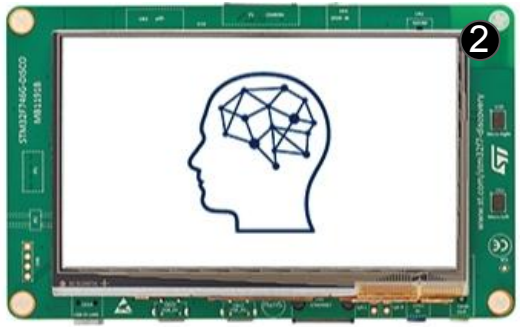
TVM supports a wide range of models



µTVM ARM targets

- Zephyr RTOS
  - µTVM -> Zephyr application
  - Supported boards:
    - ST NUCLEO-F746ZG board, Cortex-m7 ❶
    - ST STM32F746 Discovery board, Cortex-m7 ❷
    - MPS2-AN521 (QEMU), Cortex-m33 (WIP) ❸
    - MPS3-AN547 (emulated), Cortex-m55 (planned)
      - Issues:
        - Zephyr support (WIP)
        - No QEMU support





TVMC

- **tvmc** is the cli for TVM
- Two main use-cases: **a)** development workflow and **b)** integration with other projects (Makefile, etc)
- Currently only supports TVM targets (no microTVM targets)
- RFC proposed to add µTVM targets [1],
- Relies on two other RFCs:
  - The Model Library Format [2]
  - The Project API [3]
- **tvmc** allows to split TVM/µTVM workflow in independent stages: *compile*, *run*, and *autotune*
- The workflow stages that generate artifacts (like *compile*) use the Model Library Format to store the artifacts
- The Project API will allow a better integration with various RTOSes
- For **tvmc** supporting the **µTVM targets**, additional stages specific to µTVM are proposed under new context 'micro':

```
$ tvmc compile --target="c" ... (compile relay)
$ tvmc micro create-project --type zephyr ... --output=dir
$ tvmc micro build --input=dir --model compiled.tgz
$ tvmc micro flash --input=dir
$ tvmc micro run
```

[1] https://discuss.tvm.apache.org/t/rfc-tvmc-add-support-for-tvm/9049/6 - [RFC] TVMC: Add support for µTVM (**WIP**)
[2] https://discuss.tvm.apache.org/t/rfc-tvm-model-library-format/9121- [RFC] [µTVM] Model Library Format (Merged)
[3] To be published soon - Project API RFC

µTVM Binary

Low-level SoC control

- Device Startup
- Peripheral Support
- Time Control Libraries
- Vendor Code
  - Libraries - Example STM32F7Cube
- RTOS
  - Zephyr, MbedOS, FreeRTOS, Azure RTOS, etc..

µTVM RPC and Runtime

- MISRA-C Runtime
- µTVM RPC Server
  - Enables interactive development
  - Driven by developers workstation
- Framing and Session

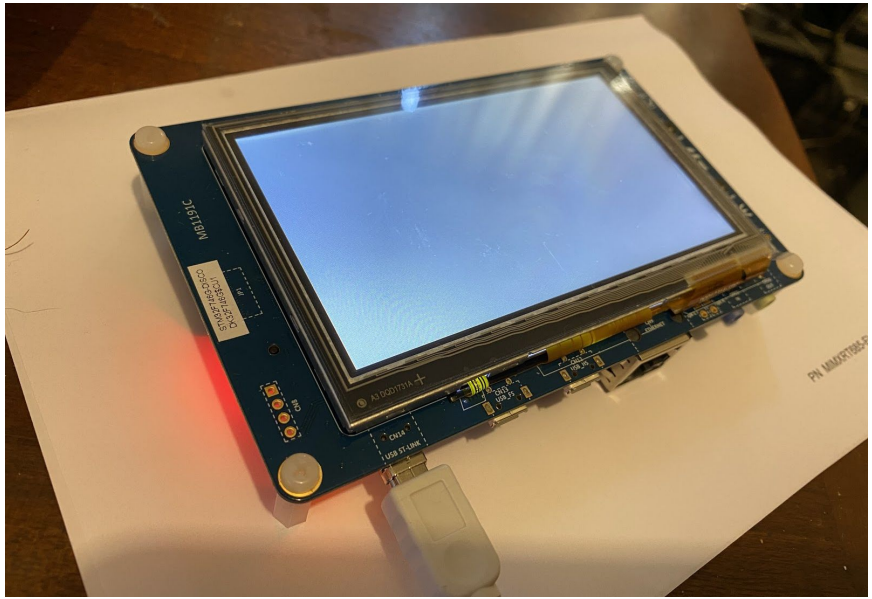
Compiled TVM operations

- Generated by TVM specific to user workload
- Maybe linked separately depending on RAM requirements

Example: running µTVM on ST discovery board

What: Interactive development example in Python (TVM repo, in tutorials/micro/micro_tflite.py)

1. Load model
   a. TensorFlow Lite format
   b. Prediction of sin(x)
2. Compile
3. Run uses Zephyr 2.4.0



Intel Host PC (Debian/Ubuntu)

- Native ARM hosted works too
- USB -> STM32F746 Discovery Board via STLink (OpenOCD, from Zephyr SDK)

[tutorials/micro/micro_tflite.py]():

Load model from **.tflite** "https://people.linaro.org/~tom.gall/sine_model.tflite"

```
137 tflite_model_buf = open(model_path, "rb").read()
```

```
142     import tflite
```

```
144     tflite_model = tflite.Model.GetRootAsModel(tflite_model_buf, 0)
```

Parse Python model object to convert it into a **relay module** and **weights**

```
169 mod, params = relay.frontend.from_tflite(
170     tflite_model, shape_dict={input_tensor: input_shape}, dtype_dict={input_tensor: input_dtype}
```

Specify the TARGET. It will be used by TVM to generate C source using LLVM API internally

```
193 TARGET = tvm.target.target.micro("stm32f746xx")
194 BOARD = "stm32f746g_disco" # or "nucleo_f746zg"
```

Given the TARGET, generate runtime graph (.json), C sources (**ops**), and model parameters per layer

```
202     graph, c_mod, c_params = relay.build(mod, target=TARGET, params=params)
```

Pick up a compiler using TARGET (and BOARD) to compile C sources into native code for the MCU

```
227 compiler = zephyr.ZephyrCompiler(
228     project_dir=project_dir,
229     board=BOARD if "stm32f746" in str(TARGET) else "qemu_x86",
230     zephyr_toolchain_variant="zephyr",
```

```
240 micro_binary = tvm.micro.build_static_runtime(
241     workspace,
242     compiler,
243     c_mod,
```

Build fw img using the specified compiler

RUN

```
269     graph_mod.set_input(
270     graph_mod.run()
```

Set input and run the model

```
258 with tvm.micro.Session(binary=micro_binary, flasher=flasher) as session:
259     graph_mod = tvm.micro.create_local_graph_runtime(
260         graph, session.get_system_lib(), session.context
```

Flash and open RPC session

Plans / Code / Coordination

Community Project RFCs

- Standalone uTVM Roadmap - https://discuss.tvm.apache.org/t/rfc-tvm-standalone-tvm-roadmap/6987
- uTVM RPC Server https://discuss.tvm.apache.org/t/rfc-tvm-tvm-rpc-server/7742
- M2 https://discuss.tvm.apache.org/t/tvm-microtvm-m2-roadmap/8821

Pull Requests

- Community : https://github.com/apache/tvm/pulls
- Linaro : https://collaborate.linaro.org/display/AIML/AI+on+Microcontrollers

Coordination - Contact tom.gall@linaro.org

- Linaro AI Project
- Weekly Sync meetings on Wednesday + Slack channel
- Product Level Spec - Linaro Member companies set goals for µTVM to propel it towards a product ready state
- https://collaborate.linaro.org/display/AIML/AI+on+Microcontrollers

µTVM - How to get involved

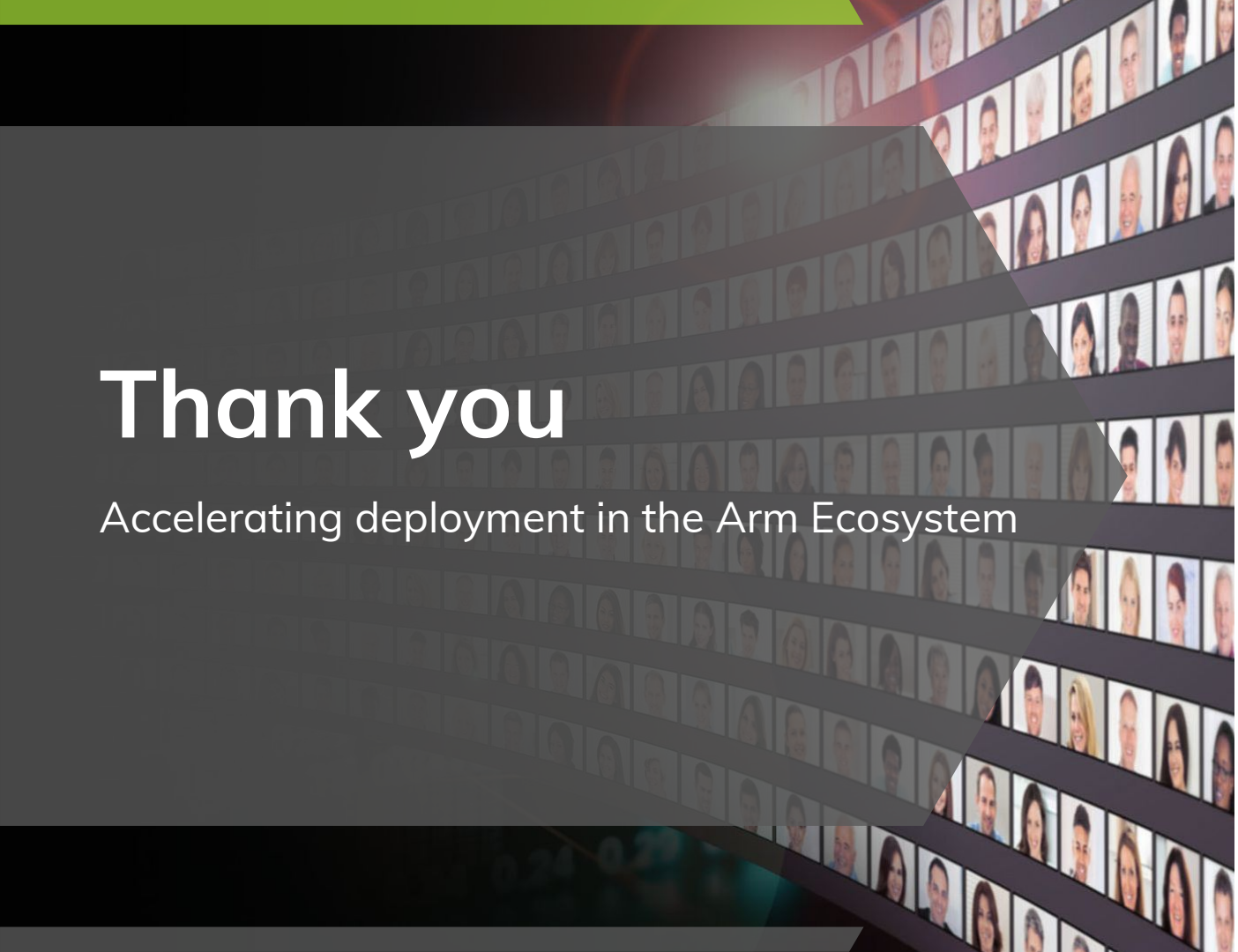
Source - https://github.com/apache/tvm

Contributor Guide - https://tvm.apache.org/docs/contribute/

Forum - https://discuss.tvm.ai

Slack - tvmai.slack.com

Bugs / Issues - https://github.com/apache/tvm/issues



Thank you

Accelerating deployment in the Arm Ecosystem

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