THE LINUX FOUNDATION
OPEN SOURCE SUMMIT
EUROPE

Linaro

Deep Learning Neural Network Acceleration at the Edge

Andrea Gallo
VP Segments and Strategic Initiatives
@twitterhandle

23-Oct-2018
Edinburgh

THE LINUX FOUNDATION

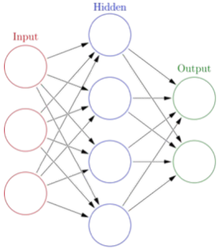
LEADING COLLABORATION IN THE ARM ECOSYSTEM

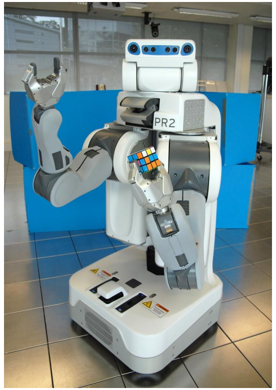
Disclaimer
All information in this session is public

No confidential information has been disclosed from private communication between Linaro and Linaro members

URL’s to the original source are provided in each slide

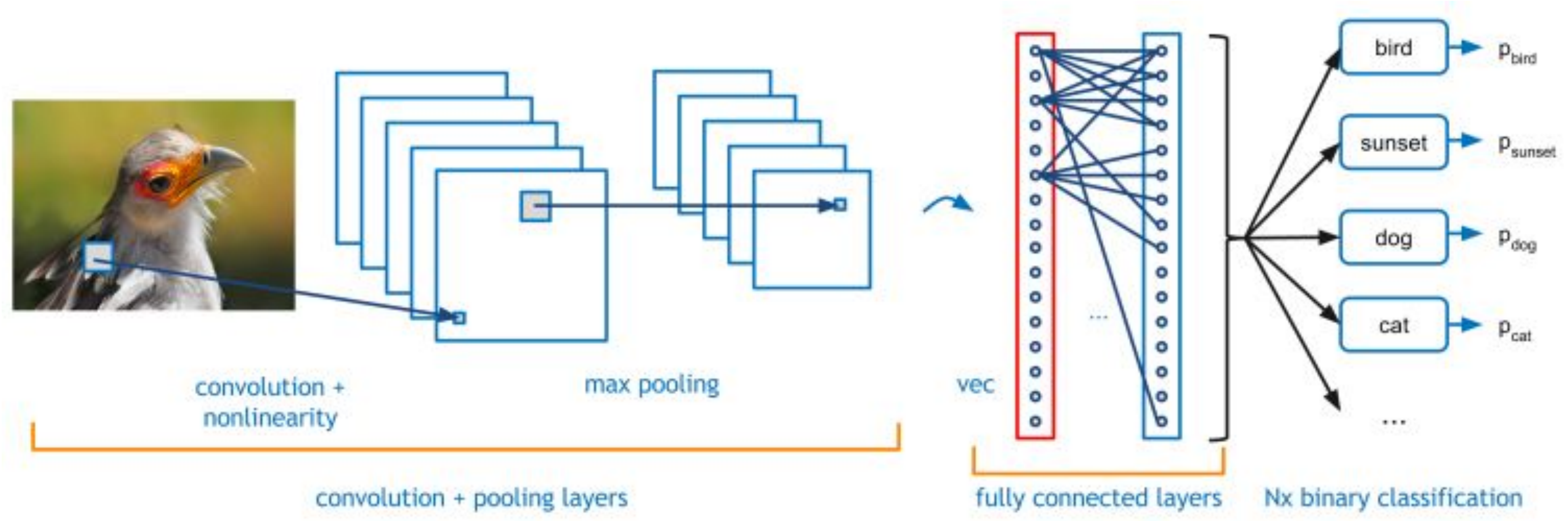
Why Deep Learning?
End-to-End Learning for Many Tasks





Slide from DIY Deep Learning for Vision: a Hands-On Tutorial with Caffe

It’s complex!!!



Slide from DIY Deep Learning for Vision: a Hands-On Tutorial with Caffe

From cloud to edge devices

From cloud to edge devices

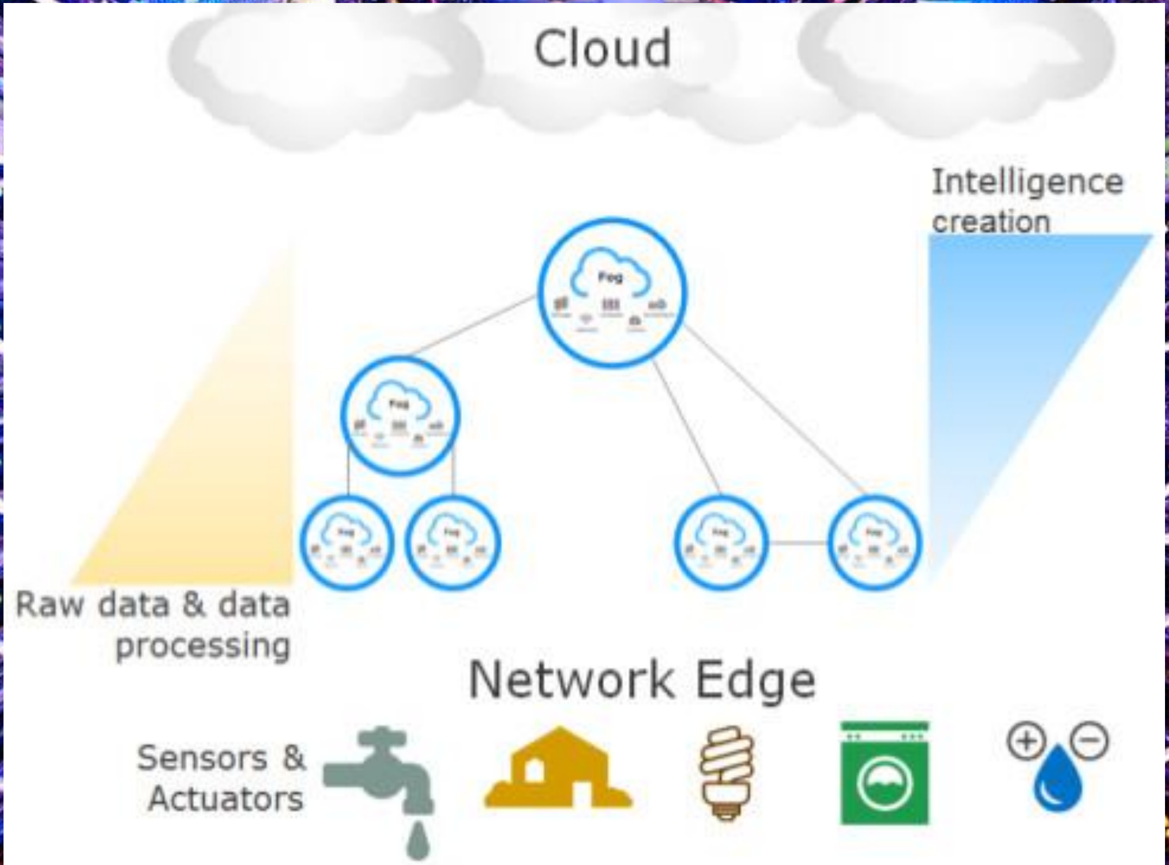
Always online

Uplink bandwidth and traffic

Latency vs real time constraints

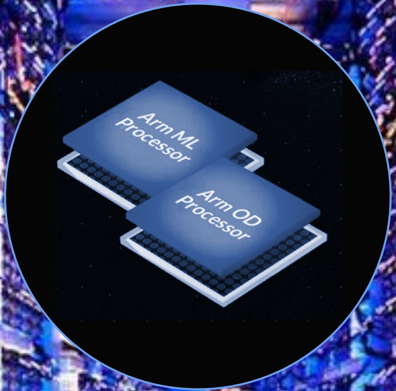
Privacy concerns

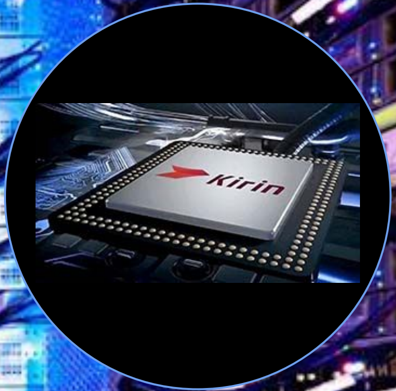
From cloud to edge devices

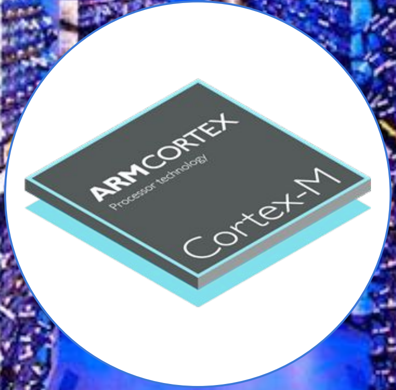


From cloud to edge devices

From cloud to edge devices

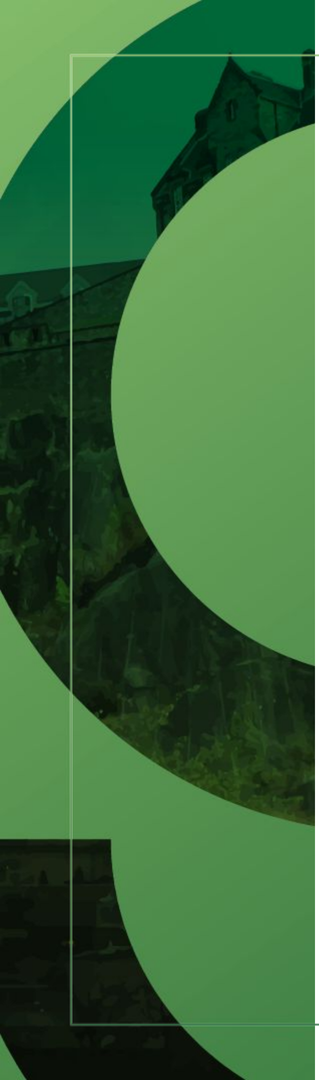






From cloud to edge devices

arm
SYNOPSYS®
Imagination
gyrfalcon technology
CEVA
cadence
VeriSilicon
brainchip
videantis
Cambricon
BITMAIN
cerebras
GREENWAVES TECHNOLOGIES
KALRAY
AI
skymizer
KORTIQ
Wave Computing



AI/ML Frameworks

TensorFlow

Developed in-house by the Google Brain team

- Started as DistBelief in 2011
- Evolved into TensorFlow with its first commit in November 2015
- V1.0.0 released on Feb 11, 2017

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TensorFlow can be built as

- TensorFlow for cloud and datacenters
- TensorFlow Lite for mobile devices
- TensorFlow.js for AI in web browsers

TensorFlow models on tensorflow github

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- TensorFlow.js for AI in web browsers

Support multiple accelerators

→ GPU and TPU

→ Android NNAPI and NN HAL

→ WebGL

TensorFlow models on [tensorflow github]

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TensorFlow models on [tensorflow github]

Support multiple accelerators

→ GPU ar

→ Androi

→ WebGL

31,713 commits

1,624 contributors

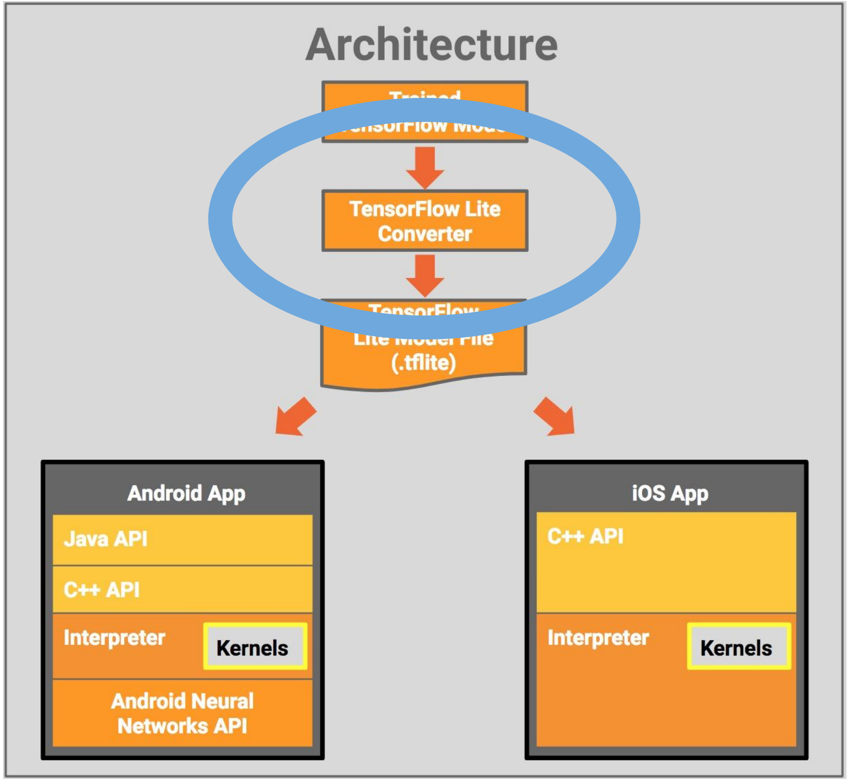
1,610,734 lines of code

456 years of effort

1st Commit Nov ‘15

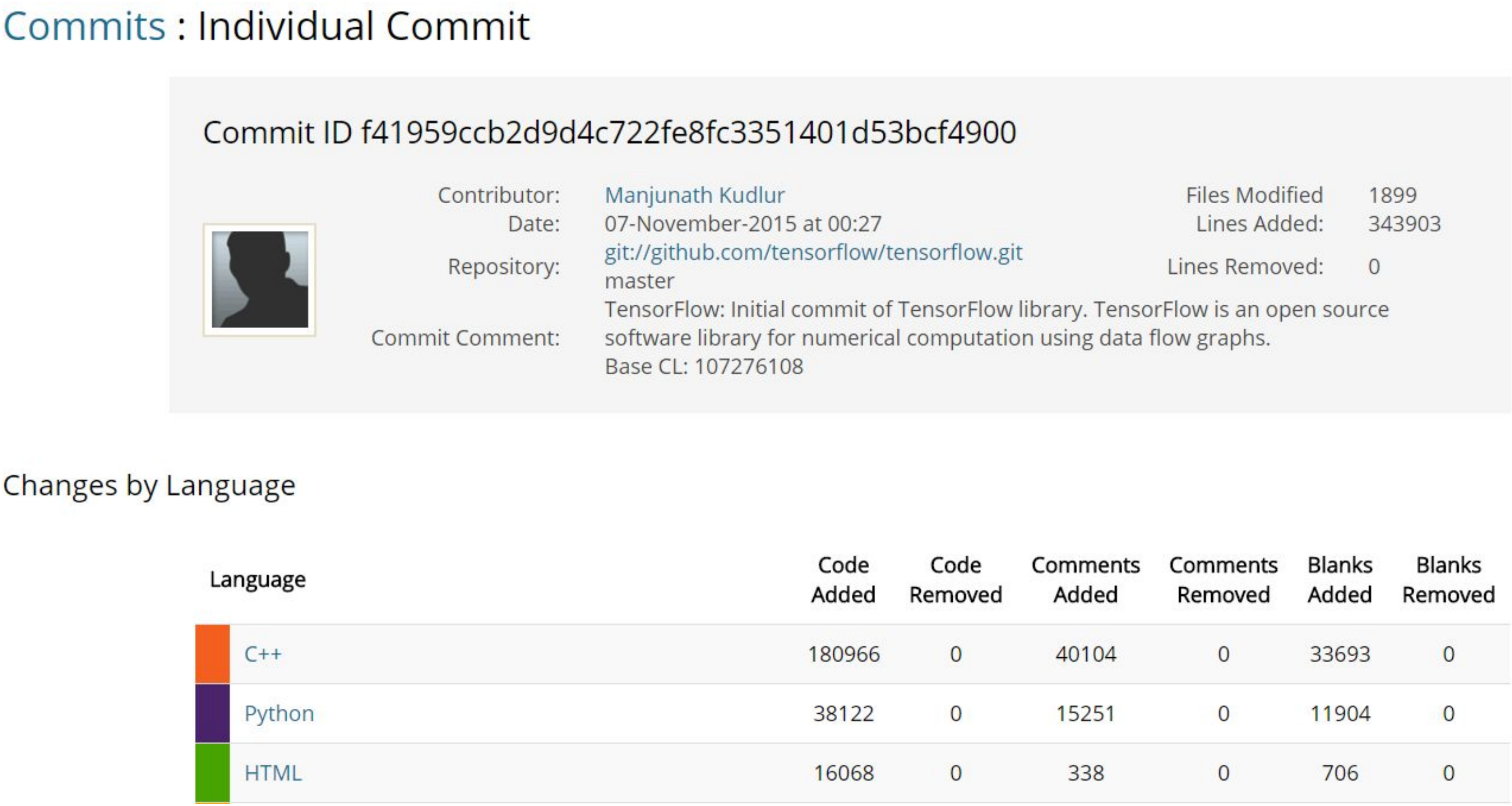
BLACKDUCK | Open Hub

From TensorFlow to TensorFlow Lite



TensorFlow Lite uses FlatBuffers

TensorFlow 1st Commit in November 2015



Commits : Individual Commit

Commit ID f41959ccb2d9d4c722fe8fc3351401d53bcf4900

Contributor:	Manjunath Kudlur	Files Modified	1899
Date:	07-November-2015 at 00:27	Lines Added:	343903
Repository:	git://github.com/tensorflow/tensorflow.git master	Lines Removed:	0
Commit Comment:	TensorFlow: Initial commit of TensorFlow library. TensorFlow is an open source software library for numerical computation using data flow graphs. Base CL: 107276108		

Changes by Language

Language	Code Added	Code Removed	Comments Added	Comments Removed	Blanks Added	Blanks Removed
🟧 C++	180966	0	40104	0	33693	0
🟪 Python	38122	0	15251	0	11904	0
🟩 HTML	16068	0	338	0	706	0

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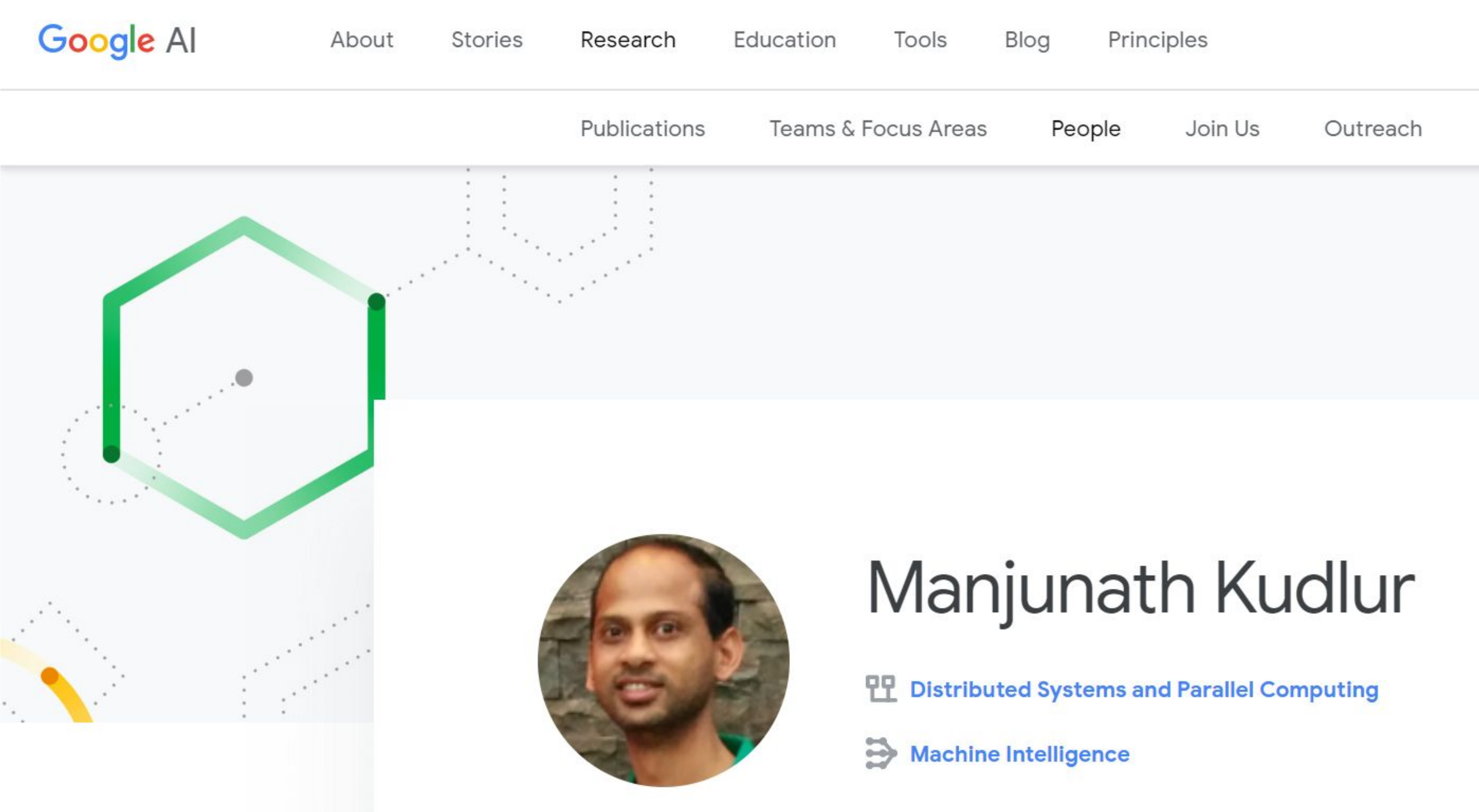

Manjunath Kudlur

Distributed Systems and Parallel Computing

Machine Intelligence

Caffe

- Made with expression, speed, and modularity in mind
- Developed by Berkeley AI Research (BAIR) and by community contributors
    - **Yangqing Jia** created the project during his PhD at UC Berkeley
    - Caffe is released under the BSD 2-Clause license
- Focus has been vision, but also handles sequences, speech, text
- Tools, reference models, demos, and recipes → Caffe Zoo
- Seamless switch between CPU and GPU

4,137 commits

314 contributors

76,076 lines of code

19 years of effort

1st commit in Sept'13

15,000+ forks

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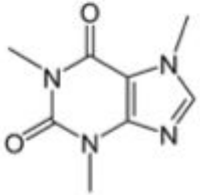

caffe.berkeleyvision.org

github.com/BVLC/caffe

BAIR

BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Caffe2

Facebook Open Source

Caffe2 improves Caffe 1.0 in a series of directions

- First-class support for large-scale distributed training
- Mobile deployment
- New hardware support (in addition to CPU and CUDA)
- Flexibility for future directions such as quantized computation
- Stress tested by the vast scale of Facebook applications
- Examples and pre-trained models available from the Caffe2 Zoo
- Running on mobile devices with Android and iOS
  - Step-by-step tutorial with camera demo
- Caffe1 models do not run with Caffe2
  - Converter tool available

3,678 commits

332 contributors

275,560 lines of code

73 years of effort

1st commit in June ‘15

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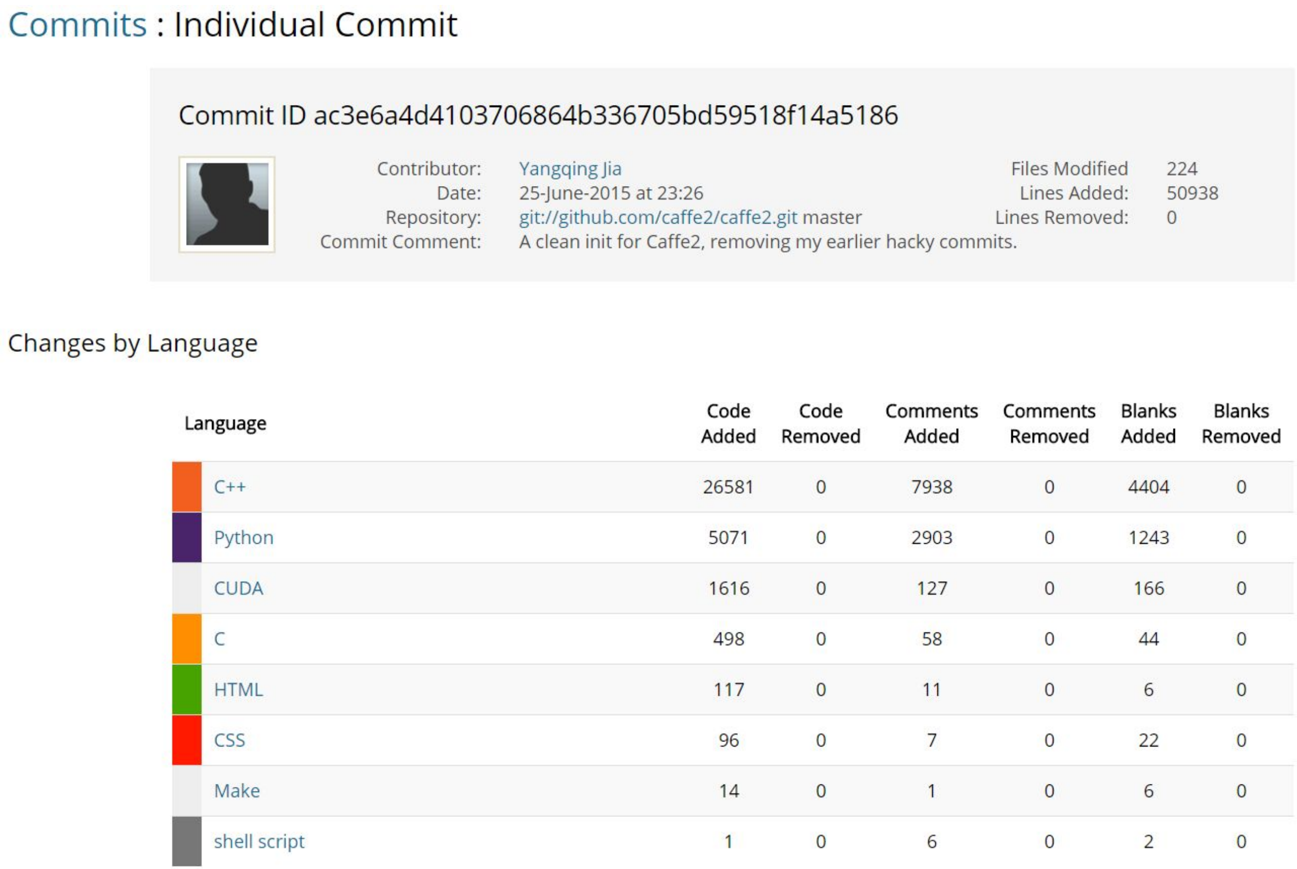
Caffe2 1st commit in June 2015

Facebook Open Source

Caffe2



Commits : Individual Commit

Commit ID ac3e6a4d4103706864b336705bd59518f14a5186

Contributor:	Yangqing Jia	Files Modified	224
Date:	25-June-2015 at 23:26	Lines Added:	50938
Repository:	git://github.com/caffe2/caffe2.git master	Lines Removed:	0
Commit Comment:	A clean init for Caffe2, removing my earlier hacky commits.		

Changes by Language

	Language	Code Added	Code Removed	Comments Added	Comments Removed	Blanks Added	Blanks Removed
🟧	C++	26581	0	7938	0	4404	0
🟪	Python	5071	0	2903	0	1243	0
⬜	CUDA	1616	0	127	0	166	0
🟧	C	498	0	58	0	44	0
🟩	HTML	117	0	11	0	6	0
🟥	CSS	96	0	7	0	22	0
⬜	Make	14	0	1	0	6	0
⬛	shell script	1	0	6	0	2	0

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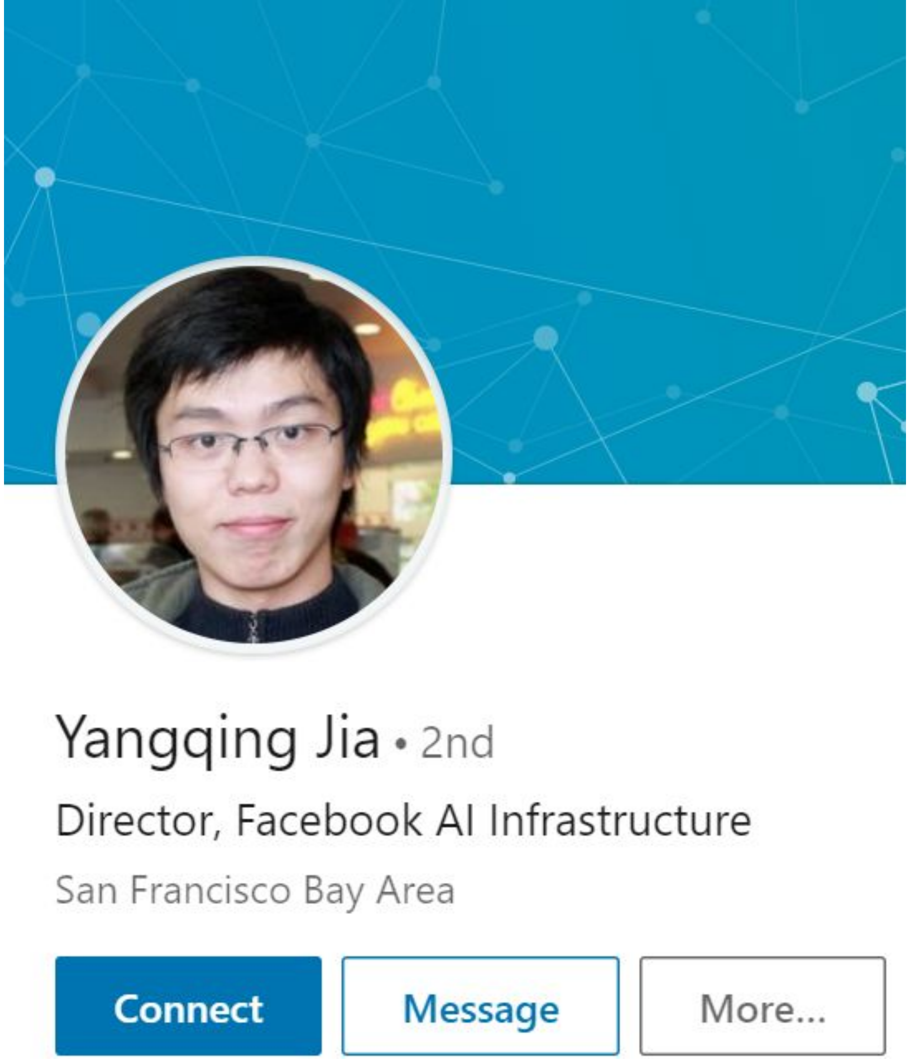
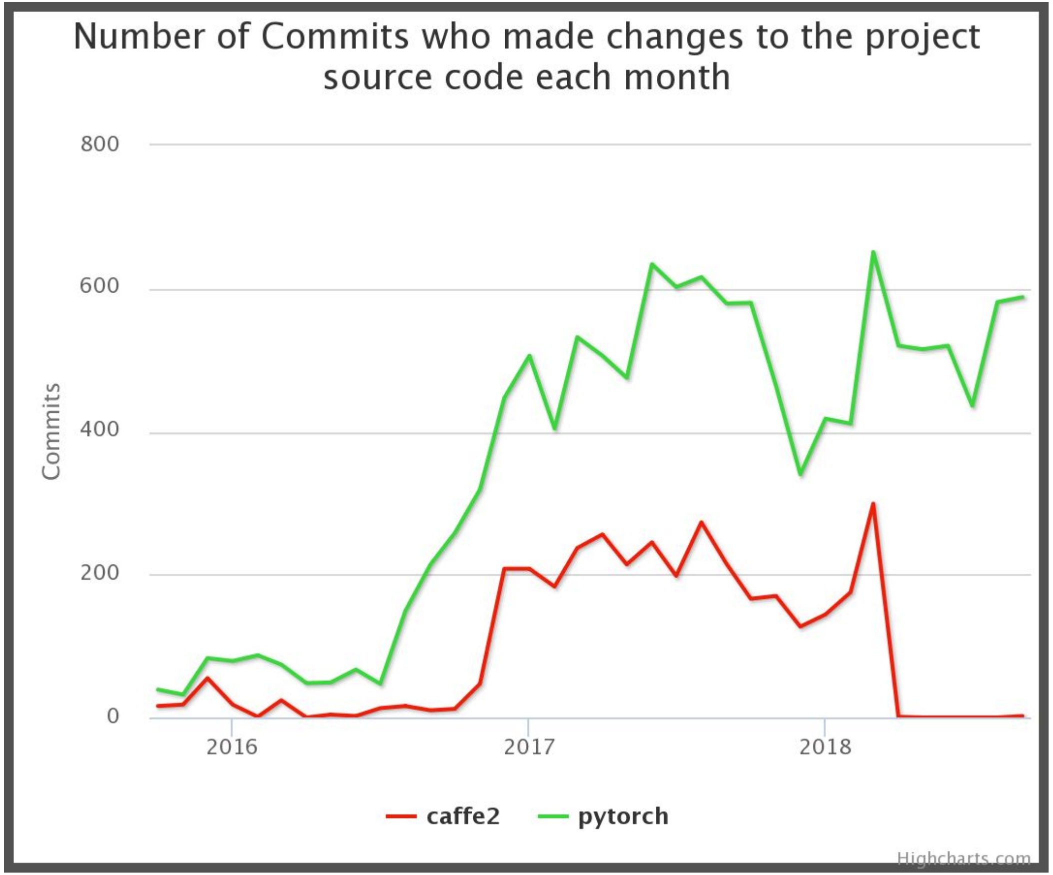


Yangqing Jia • 2nd

Director, Facebook AI Infrastructure

San Francisco Bay Area

Caffe2 and PyTorch join forces(*)



https://www.openhub.net/p/_compare?project_0=caffe2&project_1=pytorch

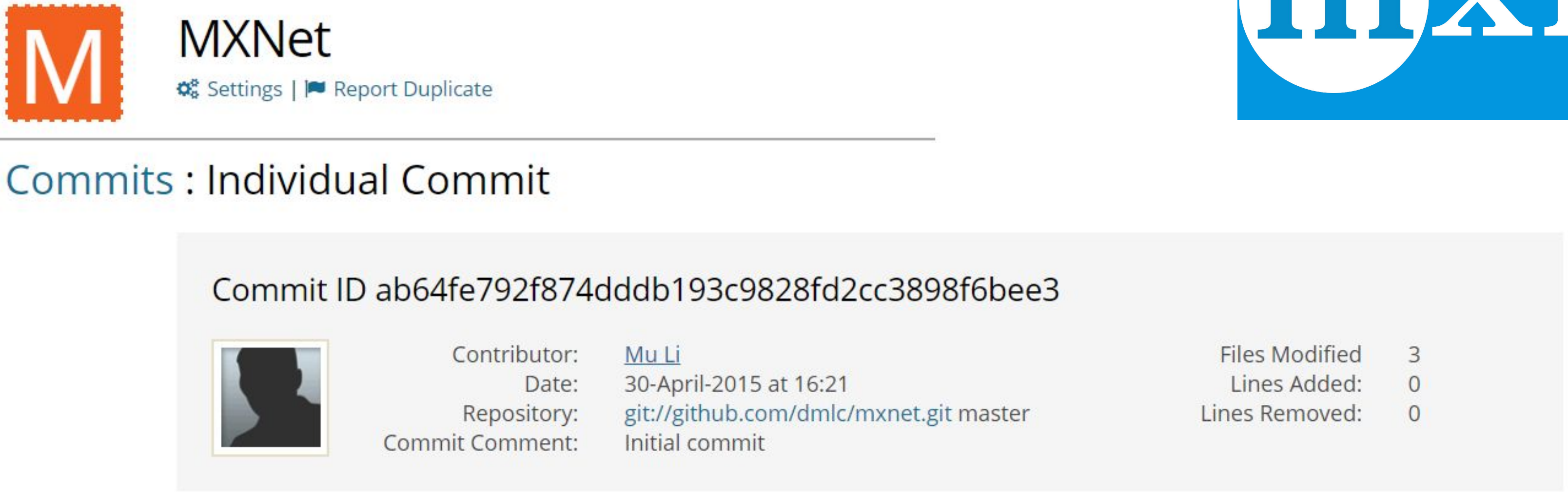
mxnet APACHE INCUBATOR amazon web services™

MXNet is a multi-language machine learning (ML) library to ease the development of ML algorithms, especially for deep neural networks. MXNet is computation and memory efficient and runs on various heterogeneous systems, ranging from mobile devices to distributed GPU clusters.

Currently, MXNet is supported by Intel, Dato, Baidu, Microsoft, Wolfram Research, and research institutions such as Carnegie Mellon, MIT, the University of Washington, and the Hong Kong University of Science and Technology.

Gluon API, examples, tutorials and pre-trained models from the Gluon model zoo

mxnet 1st Commit in April 2015



MXNet

Settings | Report Duplicate

Commits : Individual Commit

Commit ID ab64fe792f874dddb193c9828fd2cc3898f6bee3

Contributor:	Mu Li	Files Modified	3
Date:	30-April-2015 at 16:21	Lines Added:	0
Repository:	git://github.com/dmlc/mxnet.git master	Lines Removed:	0
Commit Comment:	Initial commit		

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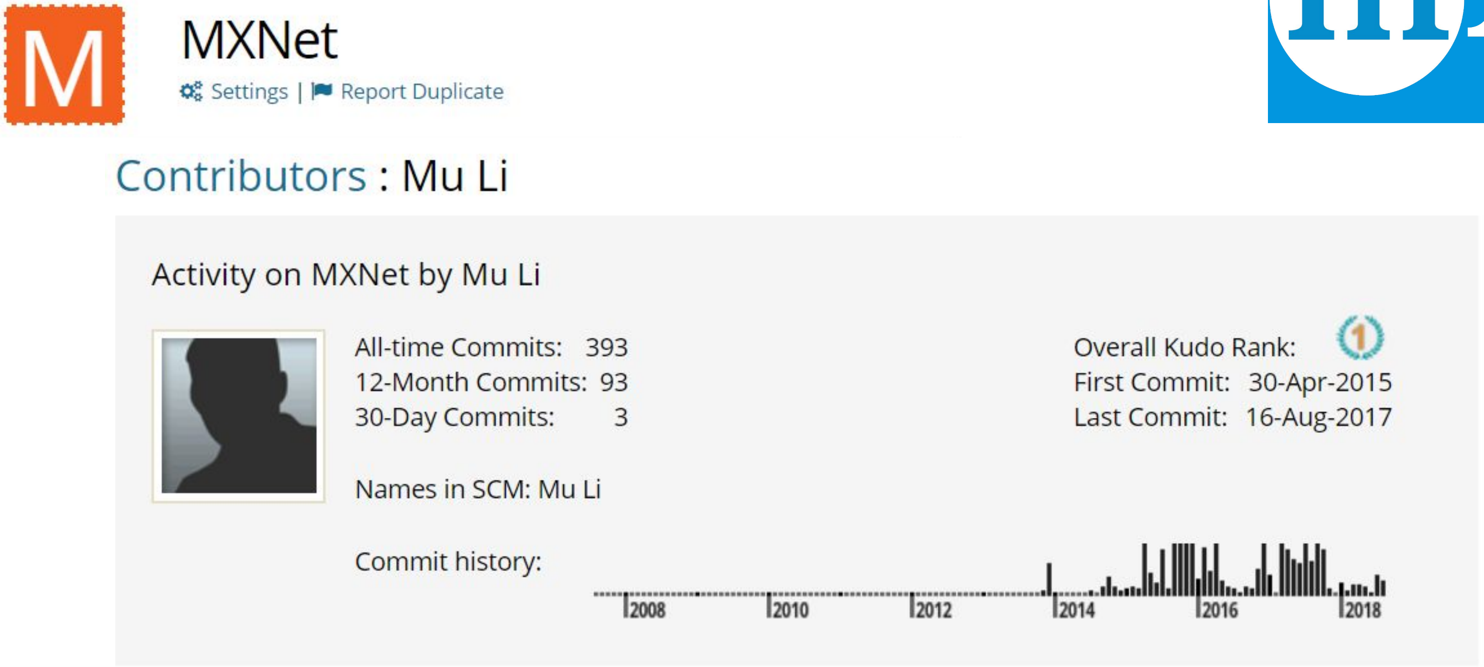
mxnet 1st Commit in April 2015



MXNet

Settings | Report Duplicate

Contributors : Mu Li

Activity on MXNet by Mu Li

All-time Commits: 393
12-Month Commits: 93
30-Day Commits: 3

Names in SCM: Mu Li

Overall Kudo Rank: 1
First Commit: 30-Apr-2015
Last Commit: 16-Aug-2017

Commit history:

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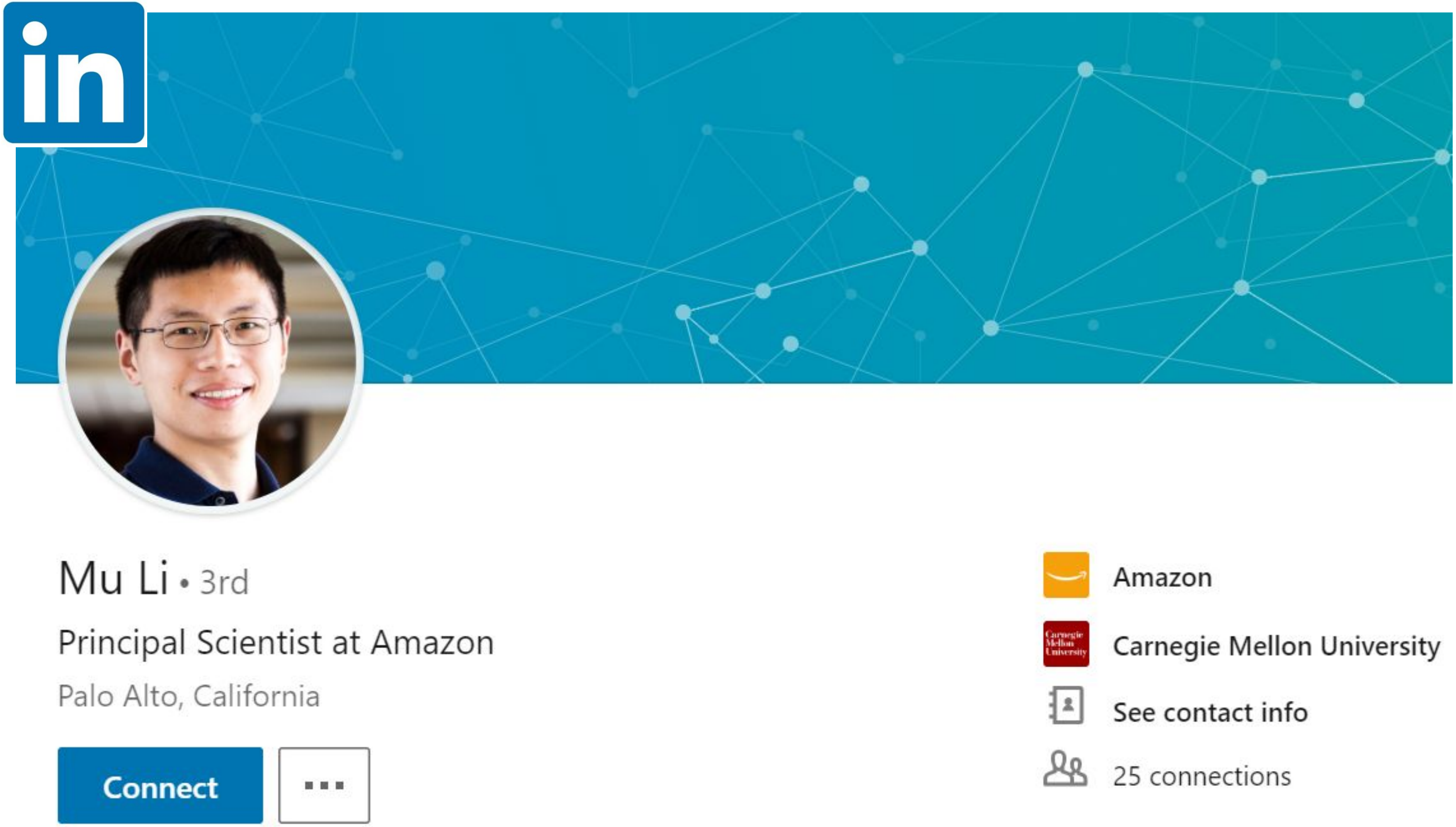


Mu Li • 3rd

Principal Scientist at Amazon

Palo Alto, California

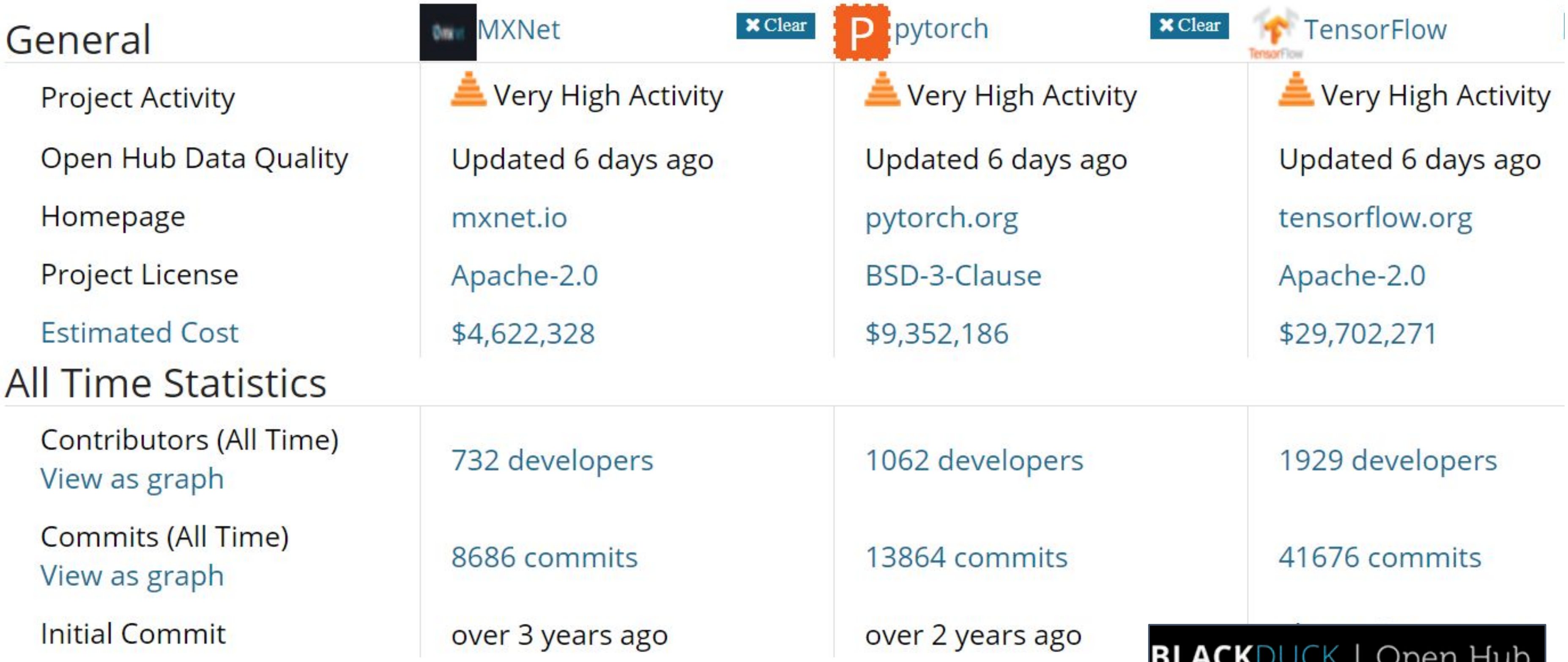
Amazon

Carnegie Mellon University

See contact info

25 connections

Deep Learning framework comparison



General	MXNet ✖ Clear	pytorch ✖ Clear	TensorFlow
Project Activity	Very High Activity	Very High Activity	Very High Activity
Open Hub Data Quality	Updated 6 days ago	Updated 6 days ago	Updated 6 days ago
Homepage	mxnet.io	pytorch.org	tensorflow.org
Project License	Apache-2.0	BSD-3-Clause	Apache-2.0
Estimated Cost	$4,622,328	$9,352,186	$29,702,271
All Time Statistics			
Contributors (All Time) View as graph	732 developers	1062 developers	1929 developers
Commits (All Time) View as graph	8686 commits	13864 commits	41676 commits
Initial Commit	over 3 years ago	over 2 years ago	

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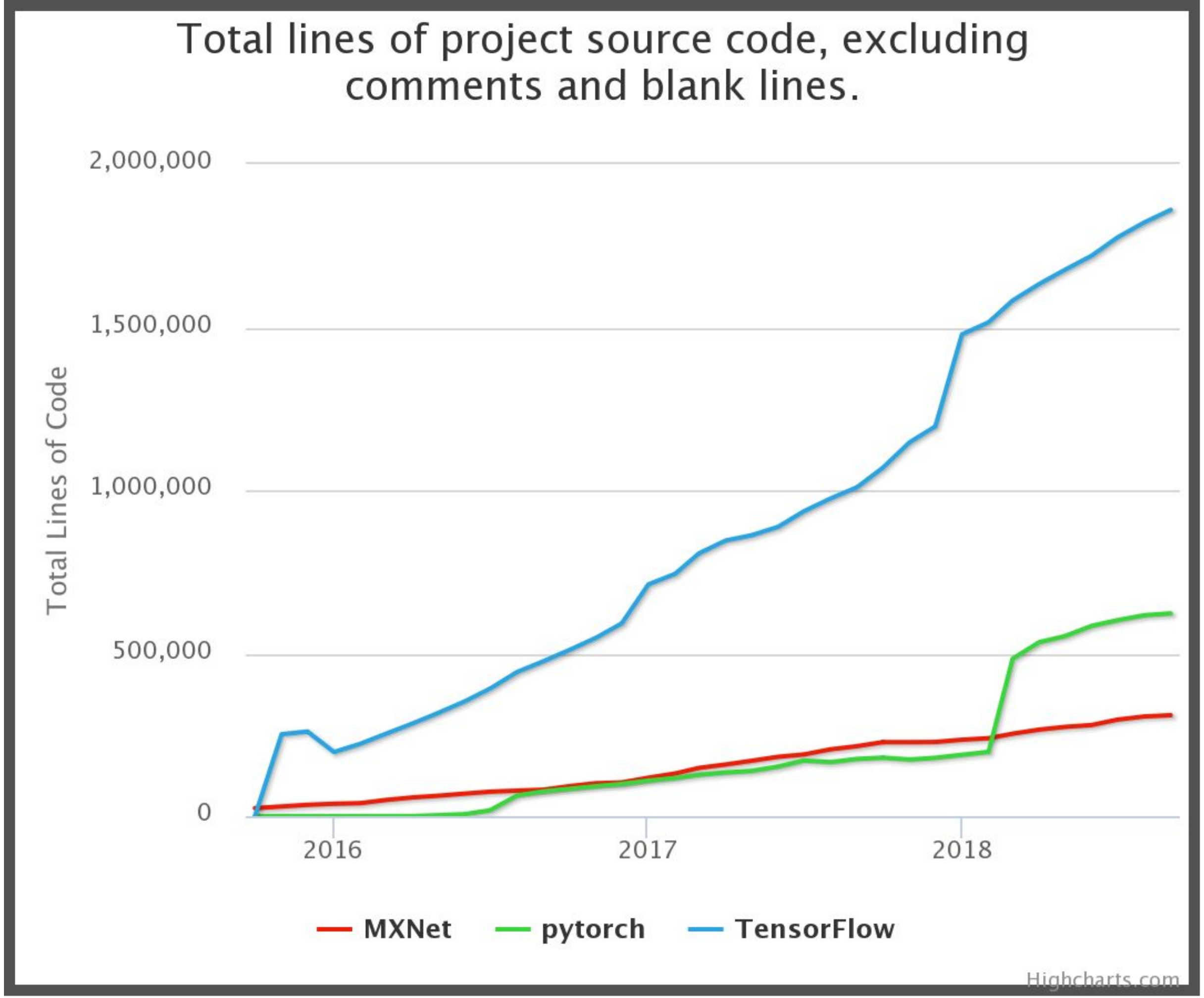
https://www.openhub.net/p/_compare?project_0=MXNet&project_1=caffe2&project_2=TensorFlow



https://www.openhub.net/p/_compare?project_0=MXNet&project_1=caffe2&project_2=TensorFlow

mxnet

PYTORCH

TensorFlow

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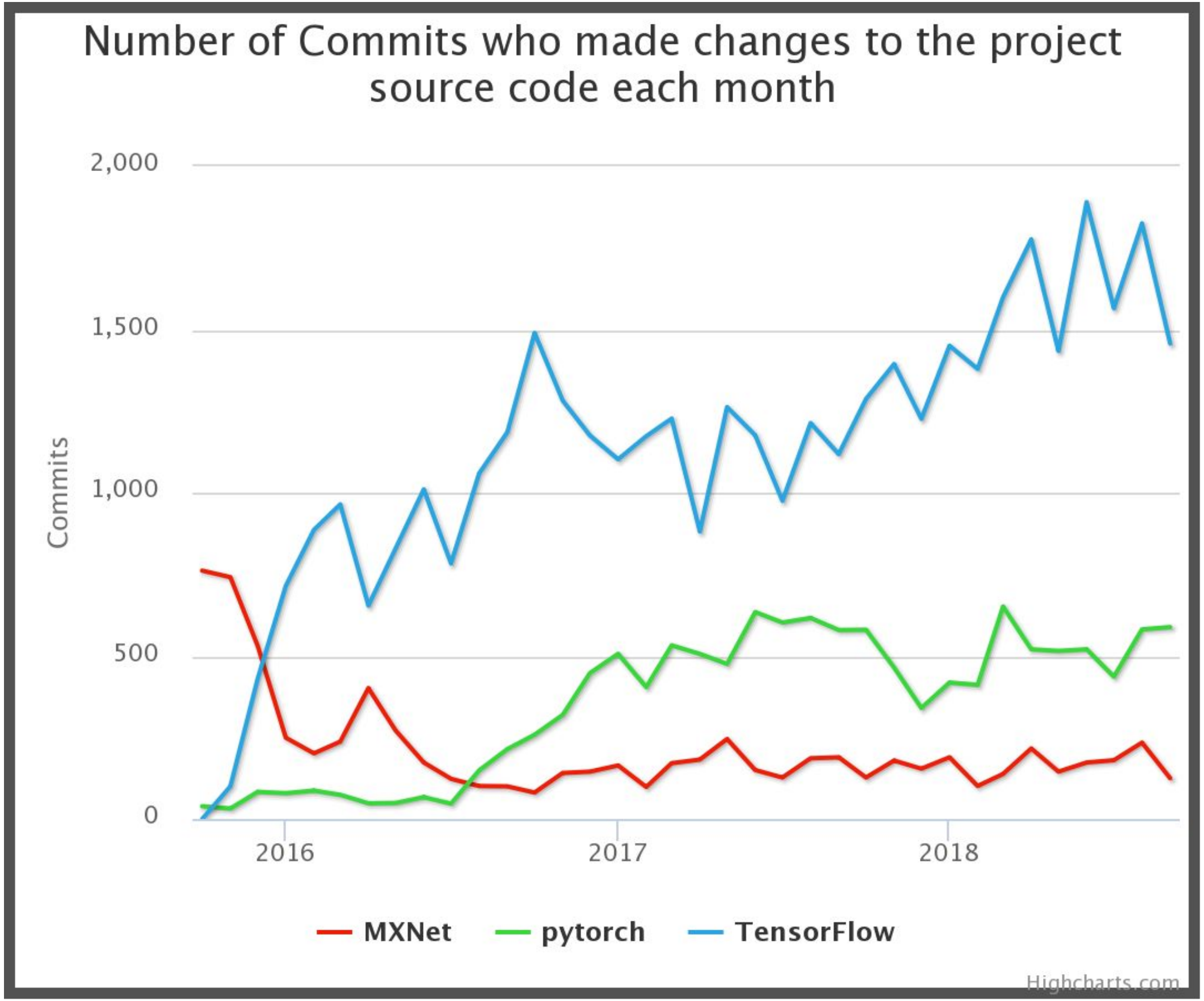

Number of Commits who made changes to the project source code each month

https://www.openhub.net/p/_compare?project_0=MXNet&project_1=caffe2&project_2=TensorFlow

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Observations

- Each cloud player has its own deep learning framework
- Each AI framework has its own entire ecosystem of formats, tools, model store
- Each AI framework represents a significant investment
- Scaling and acceleration are fundamental to performance

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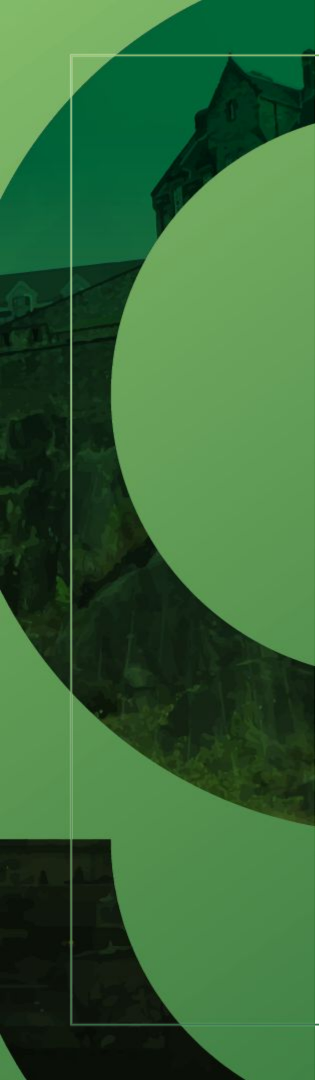
- Scaling and acceleration are fundamental to performance

If you want a really cool job like Manjunath, Yangqing or Mu Li….

INVENT A GREAT NEW AI/ML FRAMEWORK



NN accelerators and software solutions

Google Edge TPU

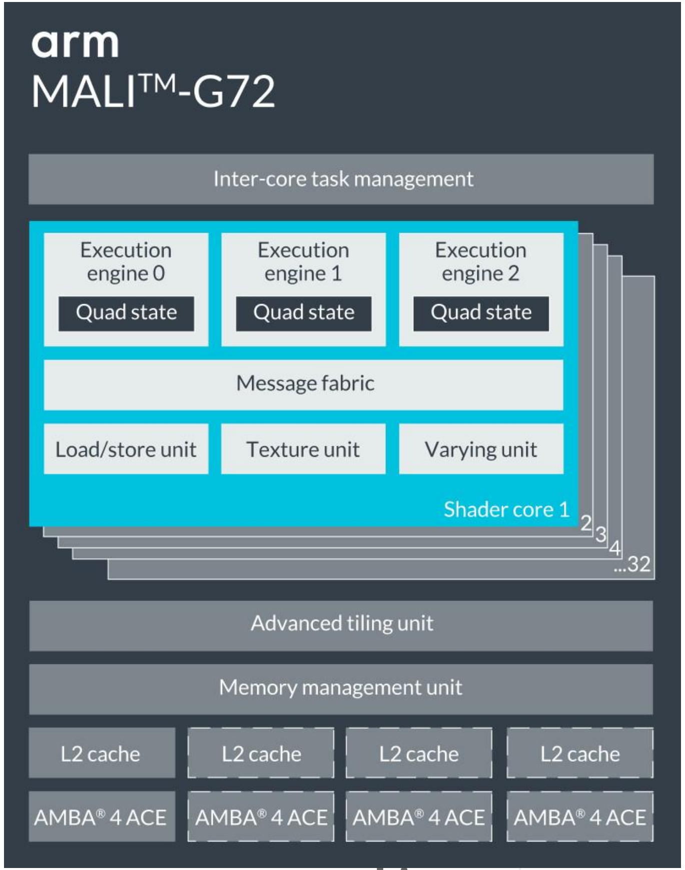
The Edge TPU is Google's purpose-built ASIC chip designed to run TensorFlow Lite ML inference at the edge

- AIY Edge TPU Dev Board
- AIY Edge TPU Accelerator

https://aiyprojects.withgoogle.com/edge-tpu/

Arm Mali-G72

Arm Mali-G72 is the second generation Bifrost-based GPU for High Performance products. Benefitting from advanced technologies such as claused shaders and full system coherency, Mali-G72 adds increased tile buffer memory supporting up to 16 x Multi-Sample Anti-Aliasing at minimal performance cost. Arithmetic optimizations tailored to complex Machine Learning and High Fidelity Mobile Gaming use cases provide 25% higher energy efficiency, 20% better performance density and 40% greater overall performance than devices based on previous generation Bifrost GPU.



https://developer.arm.com/products/graphics-and-multimedia/mali-gpus/mali-g72-gpu

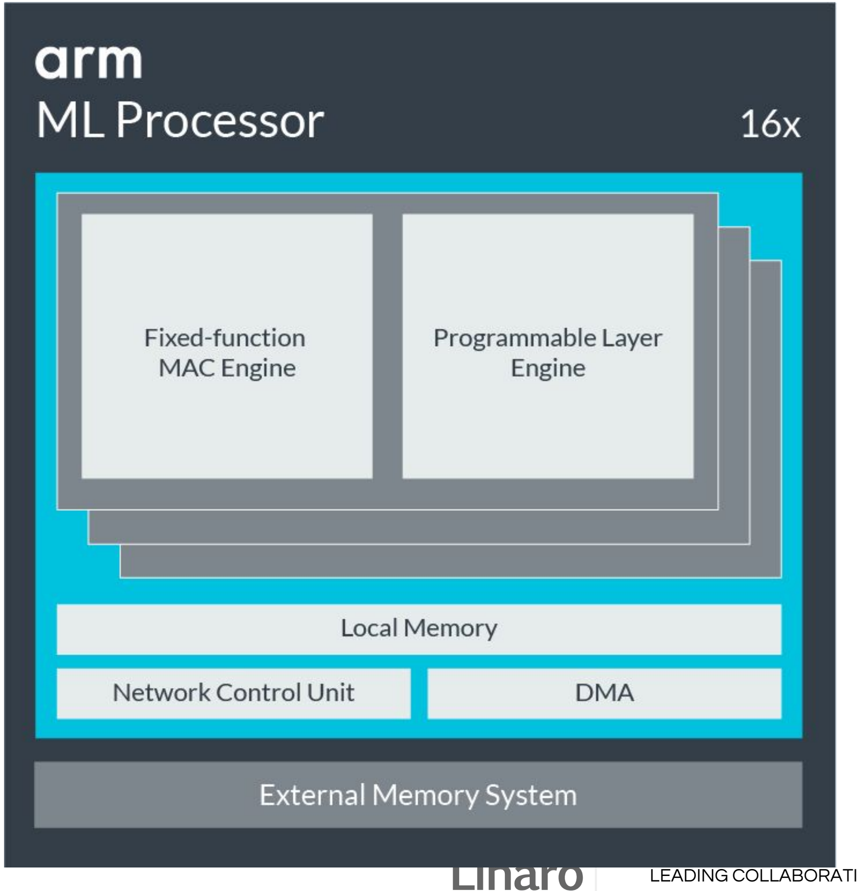
Arm ML processor

The Arm Machine Learning processor is an optimized, ground-up design for machine learning acceleration, targeting mobile and adjacent markets:

- optimized fixed-function engines for best-in-class performance
- additional programmable layer engines support the execution of non-convolution layers, and the implementation of selected primitives and operators

The network control unit manages the overall execution and traversal of the network and the DMA moves data in and out of the main memory.

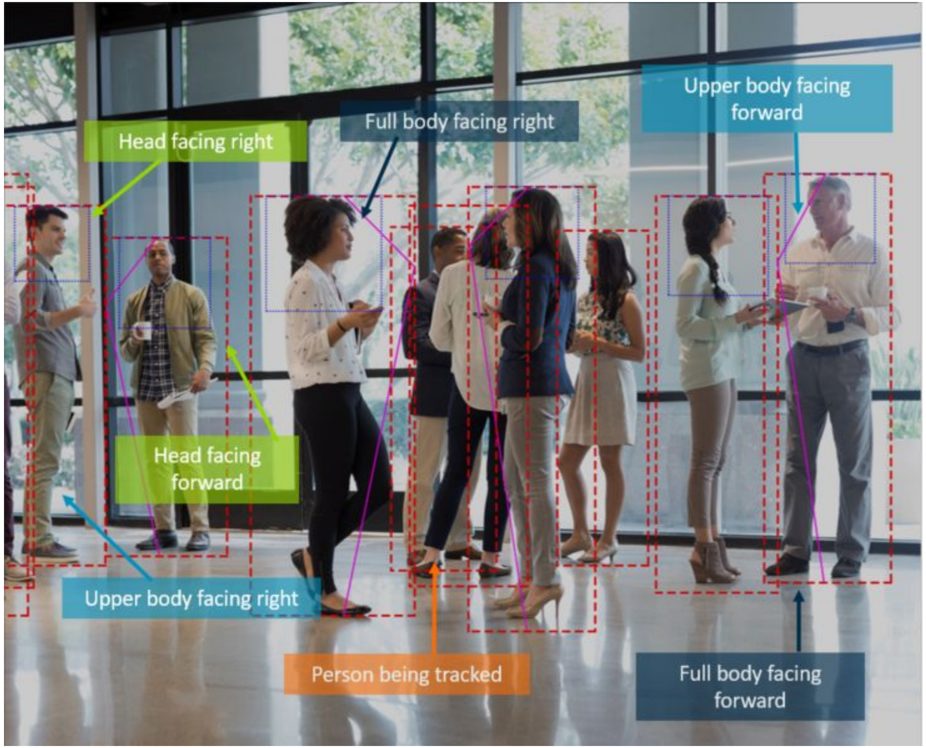
Onboard memory allows central storage for weights and feature maps



https://developer.arm.com/products/processors/machine-learning/arm-ml-processor

Arm OD processor

- Detects object in real time with Full HD at 60fps.
- Object sizes from 50x60 pixels to full screen.
- Virtually unlimited objects detected per frame.
- Detailed people model provides rich metadata and allows detection of direction, trajectory, pose and gesture.
- Advanced software running on accompanying application processor allows for higher-level behaviour to be determined, including sophisticated inter-frame tracking.
- Additional software libraries enable higher-level, on-device features, such as face recognition.

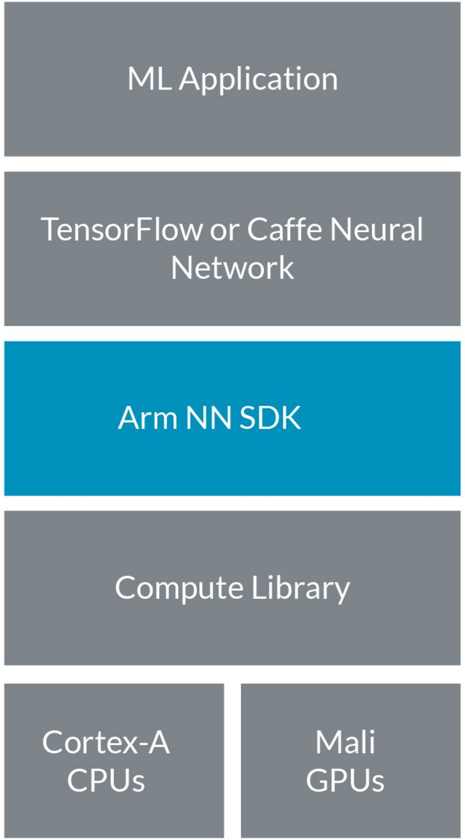


https://developer.arm.com/products/processors/machine-learning/arm-od-processor

Arm NN

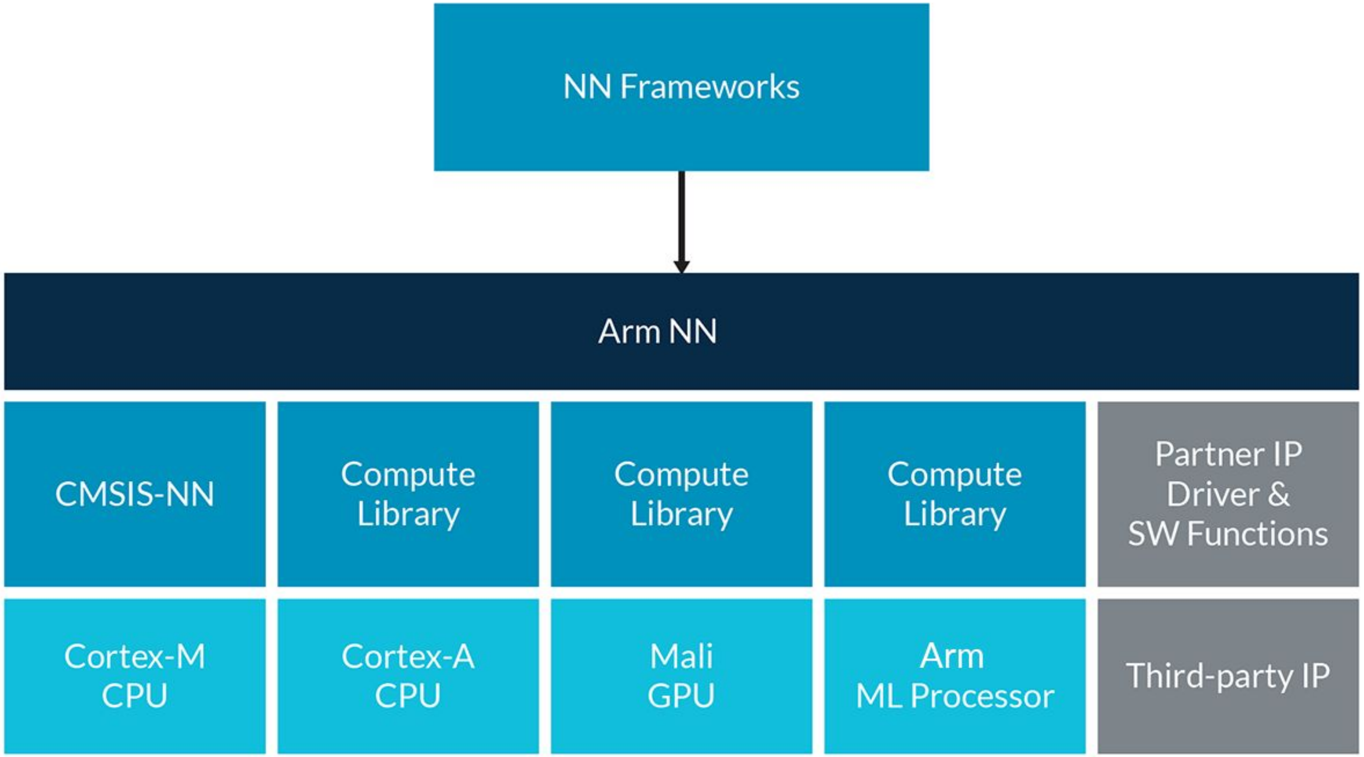
Arm NN SDK is a set of open-source Linux software and tools that enables machine learning workloads on power-efficient devices. It provides a bridge between existing neural network frameworks and power-efficient Arm Cortex CPUs, Arm Mali GPUs or the Arm Machine Learning processor.

Arm NN SDK utilizes the Compute Library to target programmable cores, such as Cortex-A CPUs and Mali GPUs, as efficiently as possible. It includes support for the Arm Machine Learning processor and, via CMSIS-NN, support for Cortex-M CPUs.



https://developer.arm.com/products/processors/machine-learning/arm-nn

Arm NN



NN Frameworks

Arm NN

CMSIS-NN

Compute Library

Compute Library

Compute Library

Partner IP Driver & SW Functions

Cortex-M CPU

Cortex-A CPU

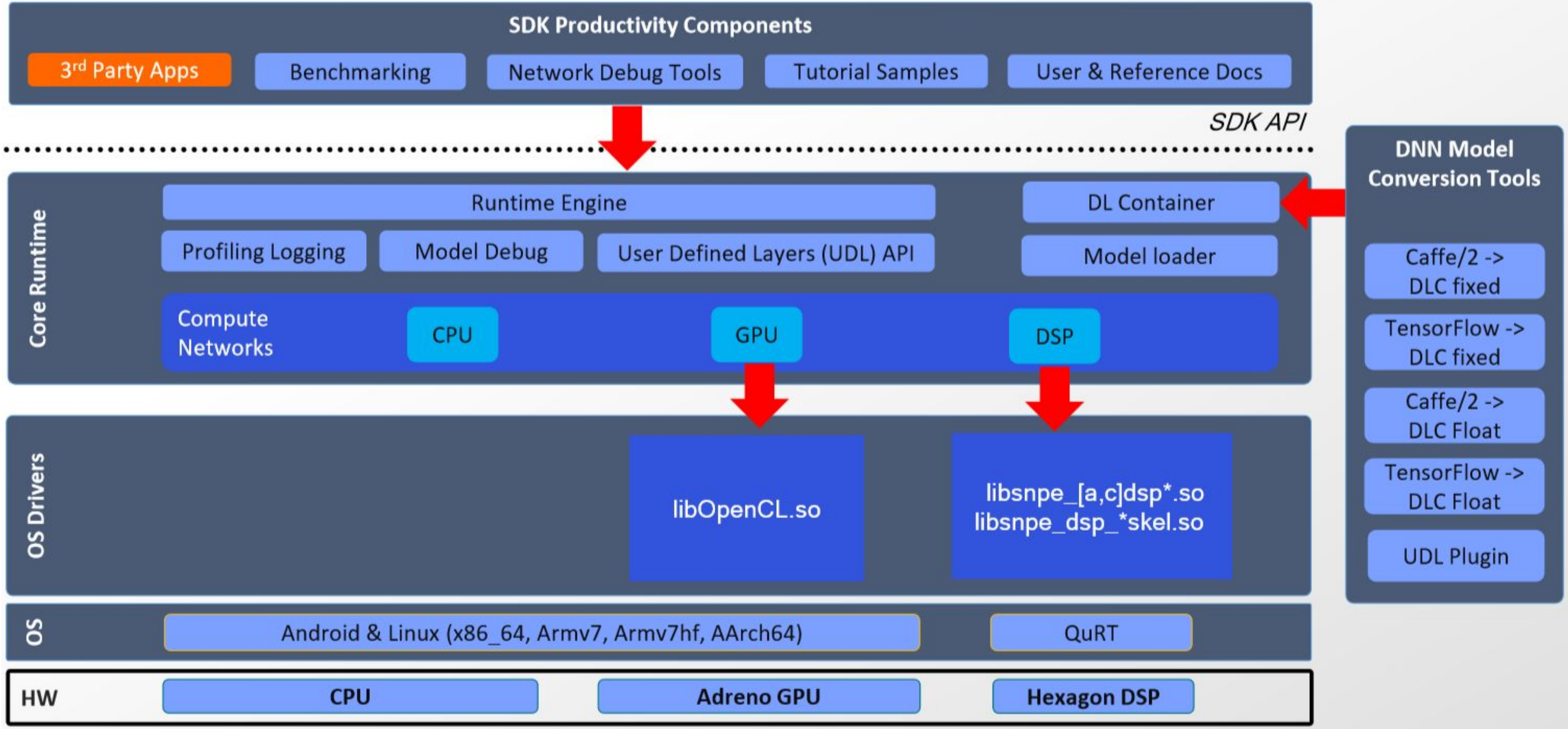
Mali GPU

Arm ML Processor

Third-party IP

https://developer.arm.com/products/processors/machine-learning/arm-nn

Snapdragon NPE SW Diagram


SDK Productivity Components

3rd Party Apps

Benchmarking

Network Debug Tools

Tutorial Samples

User & Reference Docs

SDK API

Core Runtime

Runtime Engine

DL Container

Profiling Logging

Model Debug

User Defined Layers (UDL) API

Model loader

Compute Networks

CPU

GPU

DSP

OS Drivers

libOpenCL.so

libsnpe_[a,c]dsp*.so
libsnpe_dsp_*skel.so

OS

Android & Linux (x86_64, Armv7, Armv7hf, AArch64)

QuRT

HW

CPU

Adreno GPU

Hexagon DSP

DNN Model Conversion Tools

Caffe/2 -> DLC fixed

TensorFlow -> DLC fixed

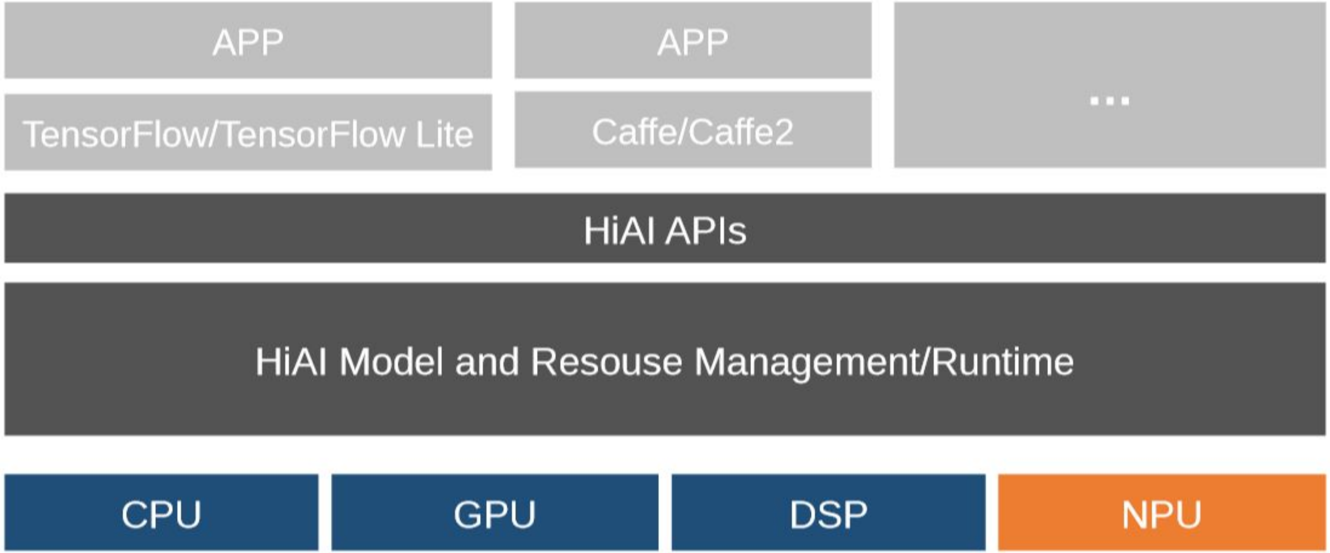
Caffe/2 -> DLC Float

TensorFlow -> DLC Float

UDL Plugin

https://connect.linaro.org/resources/hkg18/hkg18-306/

HISILICON



APP

TensorFlow/TensorFlow Lite

APP

Caffe/Caffe2

...

HiAI APIs

HiAI Model and Resouse Management/Runtime

CPU

GPU

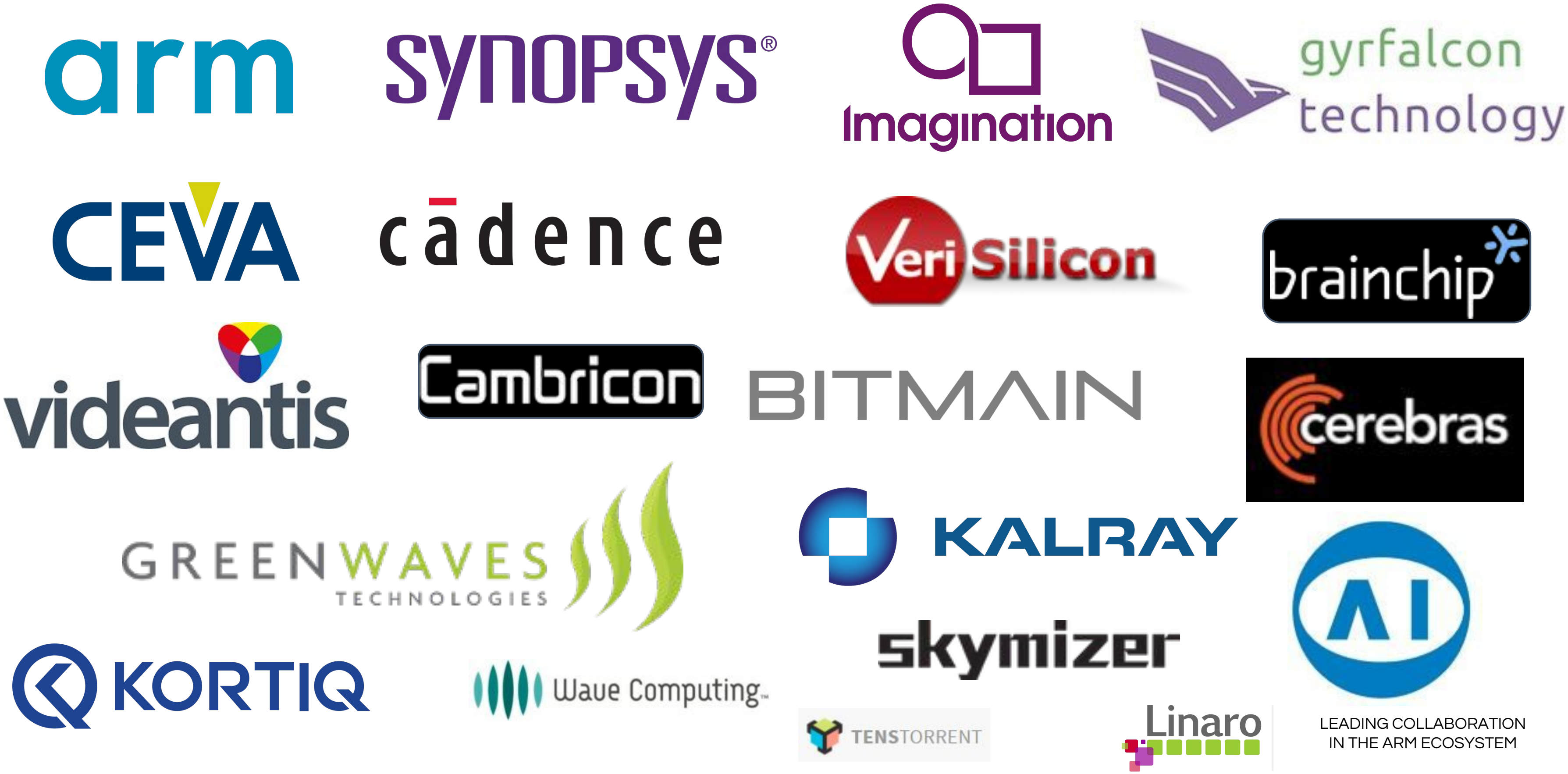
DSP

NPU

- 99 operators
- Caffe, TensorFlow, TensorFlow Lite, Huawei HiAI SDK, Android NN
- Converter tools from AI models to serialized offline model

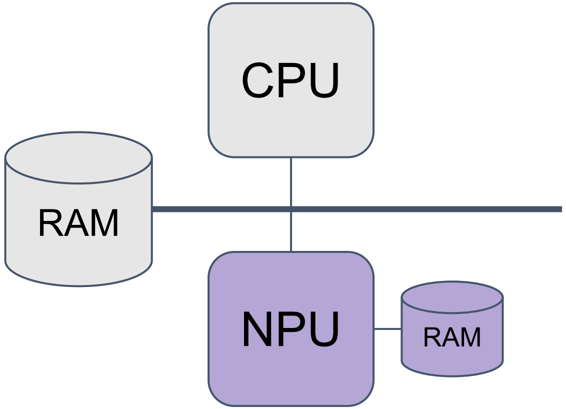
https://connect.linaro.org/resources/hkg18/hkg18-302/

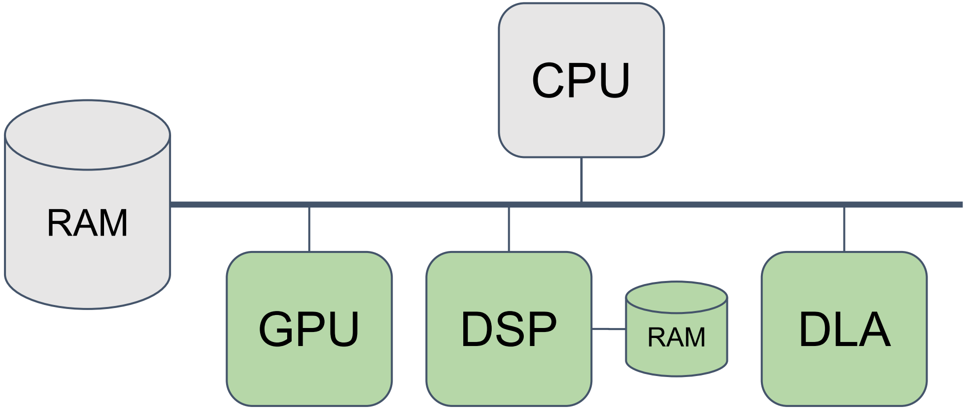
An ecosystem of 3rd parties providing NN IP and tools



Observations

- Complete offload vs heterogenous computing
- Shared memory vs sub-system memories and DMA
- Fixed operators and software fallback
- Graph split vs cost of context switch
- Serialized models and converter tools





Observations

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- Shared memory vs sub-system memories and DMA
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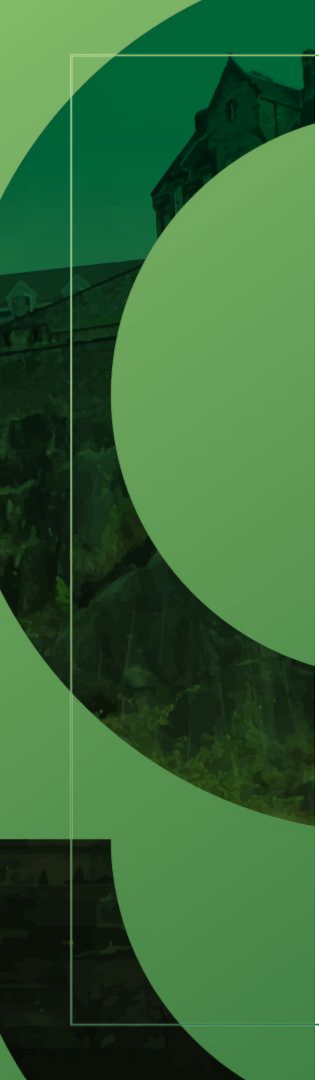
- Serialized models and converter tools

- Forked and accelerated inference engine for each NN IP and each framework
  → high total cost of ownership
  → delayed rebases and updates
  → delayed security fixes



Call to Action

Linaro Collaboration

Members fund Linaro and drive work through engineering steering committees

Member and Linaro engineers collaborate to develop work once, for all

Linaro delivers output to members, into open source projects, and into the community

Now ~25 members, up from 6 in 2010

Over 300 OSS engineers globally, including 140 Linaro staff

Core Members

arm

HISILICON

QUALCOMM INNOVATION CENTER, INC. QuIC

Club Members

Google

socionext

ST life.augmented

TEXAS INSTRUMENTS

UNISOC

ZTE

Group Members

CAVIUM

CISCO

COMCAST

CYPRESS EMBEDDED IN TOMORROW

ENEA

FUJITSU

HXT 华芯通半导体

KYLIN 银河麒麟

NOKIA

NXP

QUALCOMM QUALCOMM DATACENTER TECHNOLOGIES, INC.

redhat

SAMSUNG

XILINX ALL PROGRAMMABLE

Community Members

IBM

THE LINUX FOUNDATION

Linaro works Upstream

Delivering high value collaboration

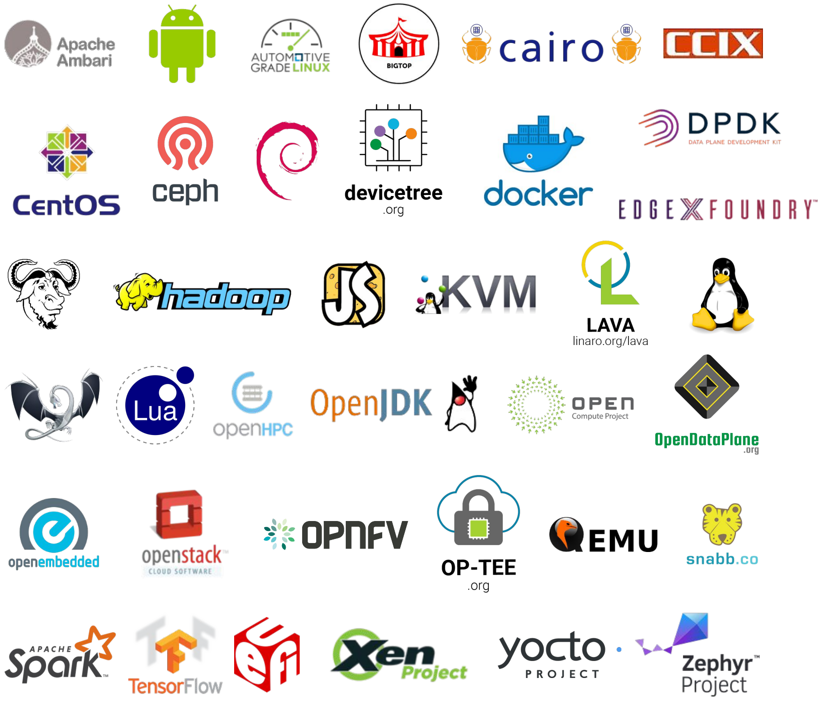
Top 5 company contributor to Linux and Zephyr kernels

Contributor to >70 open source projects; many maintained by Linaro engineers

	Company	4.8-4.13 Changesets	%
1	Intel	10,833	13.1%
2	Red Hat	5,965	7.2%
3	Linaro	4,636	5.6%

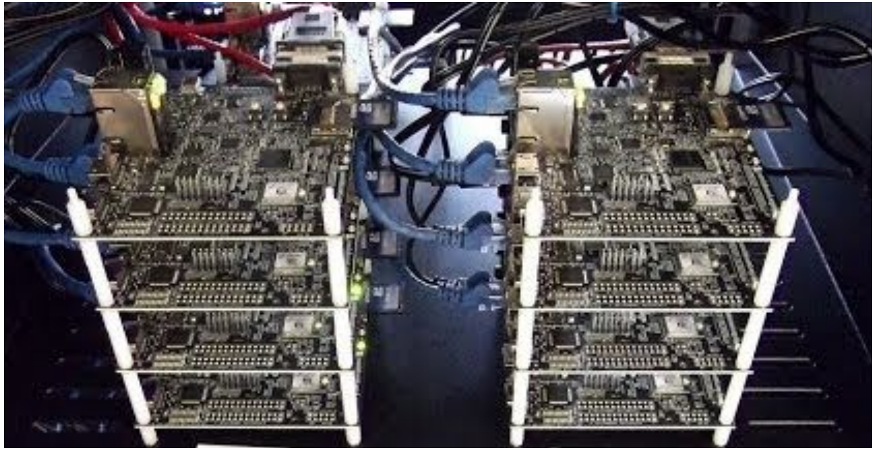
Source: 2017 Linux Kernel Development Report, Linux Foundation

Selected projects Linaro contributes to

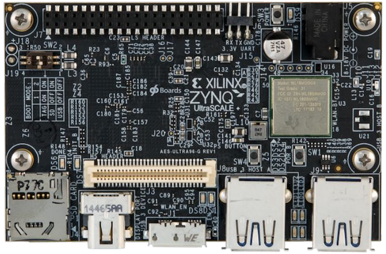


Linaro Machine Intelligence Initiative

- Common model description format and APIs to the runtime
- Common optimized runtime inference engine for Arm-based SoC
- Plug-in framework to support multiple 3rd party NPU, CPU, GPU, DSP
- CI loops on reference development boards to measure accuracy, performance speed up and regression testing



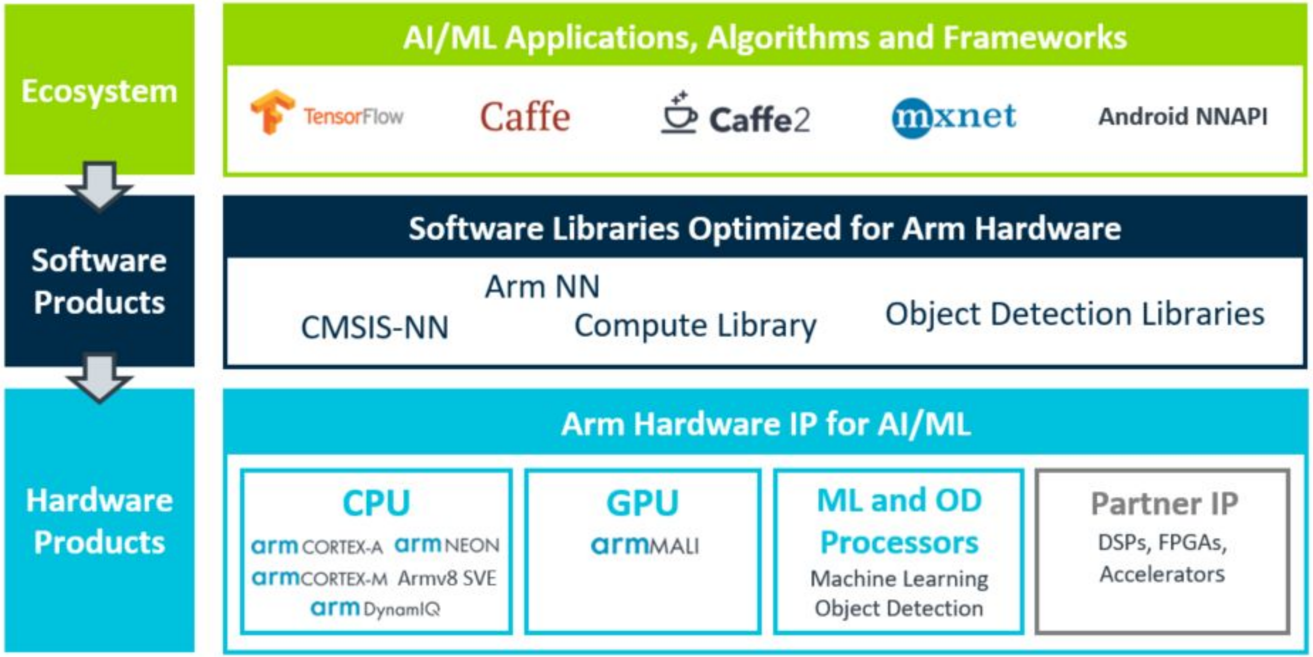
LAVA



Arm NN becomes an open source project

Arm: Accelerating ML Collaboration with Arm NN and Linaro

Arm and Linaro announce launch of Machine Intelligence Initiative



Ecosystem

AI/ML Applications, Algorithms and Frameworks

TensorFlow Caffe Caffe2 mxnet Android NNAPI

Software Products

Software Libraries Optimized for Arm Hardware

CMSIS-NN Arm NN Compute Library Object Detection Libraries

Hardware Products

Arm Hardware IP for AI/ML

CPU
arm CORTEX-A arm NEON
arm CORTEX-M Armv8 SVE
arm DynamIQ

GPU
arm MALI

ML and OD Processors
Machine Learning
Object Detection

Partner IP
DSPs, FPGAs, Accelerators

https://developer.arm.com/products/processors/machine-learning/arm-nn

ONNX

Open Neural Network Exchange (ONNX)

An open source format for AI models

An extensible computation graph model

Definitions of built-in operators and standard data types

Initial focus on inference

ONNX Interface for Framework Integration (ONNXIFI)

Standardized interface for neural network inference on special-purpose accelerators, CPUs, GPUs, DSPs, and FPGAs

f

Apache

amazon web services™

CNTK mxnet Caffe2 PYTORCH Microsoft

Linaro connect
Hong Kong 2018

Discussions started last March

AI/ML Resources from HKG18

HKG18-417 - OpenCL support by NNVM & TVM

HKG18-413 - AI and Machine Learning BoF

HKG18-405 - Accelerating Neural Networks with...

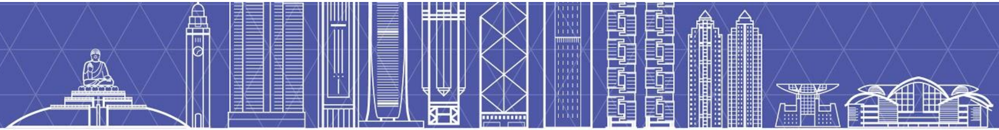
HKG18-312 - CMSIS-NN

HKG18-306 - Overview of Qualcomm SNPE

HKG18-304 - Scalable AI server

HKG18-302 - Huawei HiAI : Unlock The Future

HKG18-200K2 - Keynote: Accelerating AI from Cloud to Edge



Join us at the

AI and Neural Networks on Arm Summit

At **Linaro Connect Vancouver 2018**

Wednesday 19 September - Hyatt Regency Vancouver,
655 Burrard Street, V6C 2R7
$45 to attend the summit only

REGISTER HERE

https://connect.linaro.org/ai-neural-networks-arm-summit/

Speaker	Company	ID	Title
Chris Benson	AI Strategist	YVR18- 300K2	Keynote: Artificial Intelligence Strategy: Digital Transformation Through Deep Learning
Jem Davies	Arm	YVR18-300K1	Keynote: Enabling Machine Learning to Explode with Open Standards and Collaboration
Robert Elliott	Arm	YVR18-329	Arm NN intro
Pete Warden	Google Tensorflow	YVR18-338	Tensorflow for Arm devices
Mark Charlebois	Qualcomm	YVR18-330	Qualcomm Snapdragon AI Software
Thom Lane	Amazon AWS AI	YVR18-331	ONNX and Edge Deployments
Jammy Zhou	Linaro	YVR18-332	TVM compiler stack and ONNX support
Luba Tang	Skymizer	YVR18-333	ONNC (Open Neural Network Compiler) for ARM Cortex-M
Shouyong Liu	Thundersoft	YVR18-334	AI Alive: On Device and In-App
Ralph Wittig	Xilinx	YVR18-335	Xilinx: AI on FPGA and ACAP Roadmap
Andrea Gallo and others	Linaro, Arm, Qualcomm, Skymizer, Xilinx	YVR18-337	BoF: JIT vs offline compilers vs deploying at the Edge

Jem Davies, Arm Fellow and GM of the ML Group

Linaro

LEADING
COLLABORATION
IN THE ARM
ECOSYSTEM

Stay in touch!