



UNIVERSITY OF TWENTE.

EMBEDDED AI

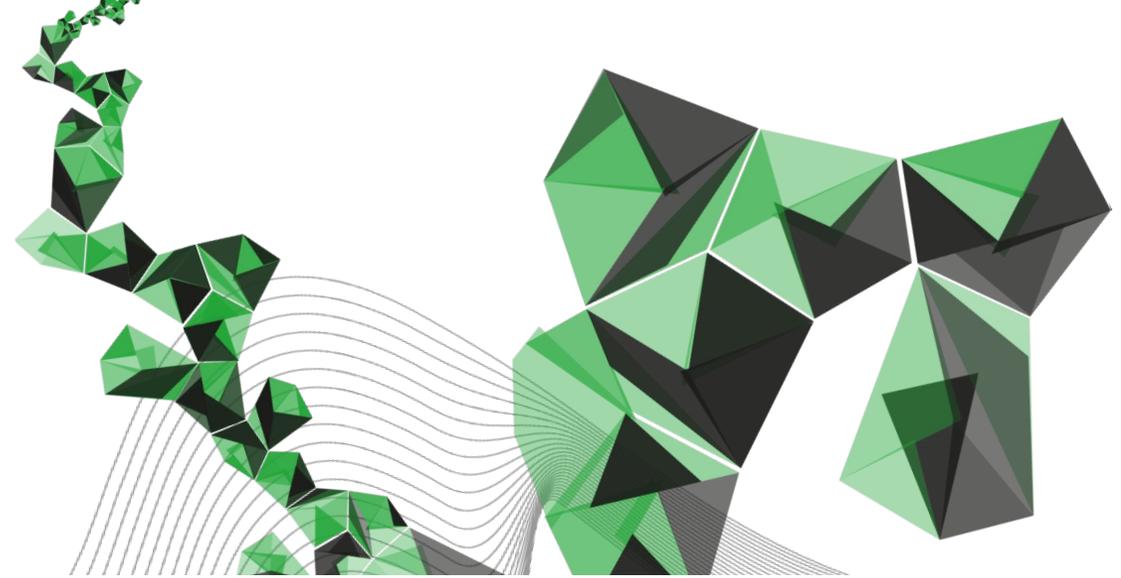
DSI SEMINAR BY SEBASTIAN BUNDA MSc



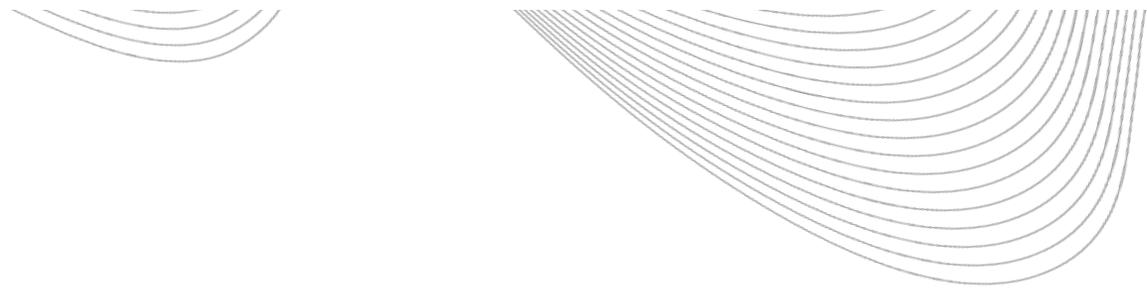
WHO AM I?

- PhD Student @ DMB and CAES
 - Subject: Embedded AI
- Background in Electrical Engineering: 2015-2022
 - Specialisation Computer Vision & Biometrics @Twente





EMBEDDED AI





ARTIFICIAL INTELLIGENCE

DEFINITION

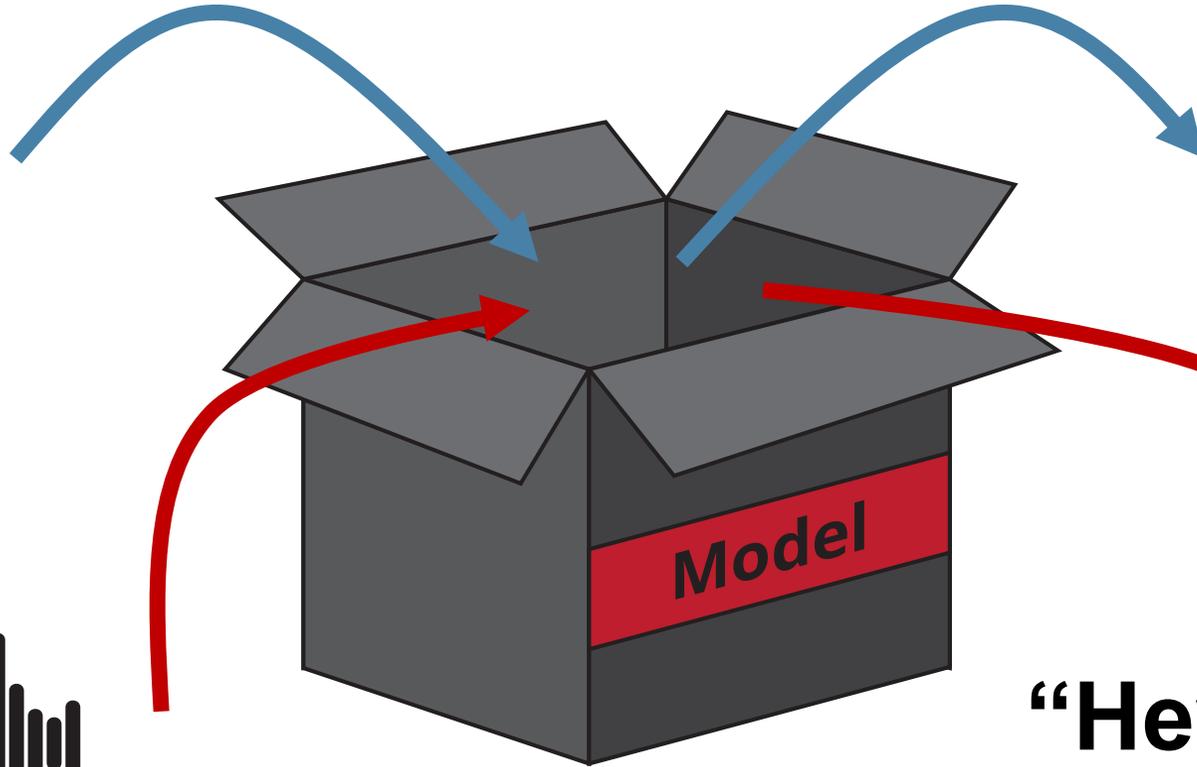
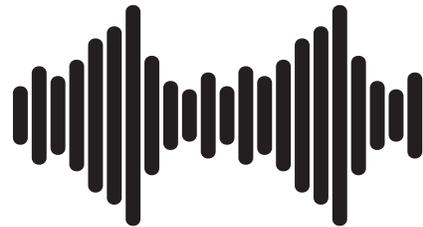
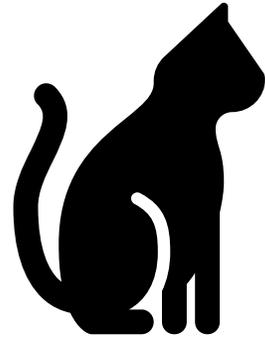
Artificial Intelligence is an umbrella term for various computational strategies able to display **human-like capabilities** such as reasoning and learning

Examples: machine learning, robotics and natural language processing



MACHINE LEARNING

DEEP LEARNING MODEL



CAT

“Hey Google”



Key Concepts



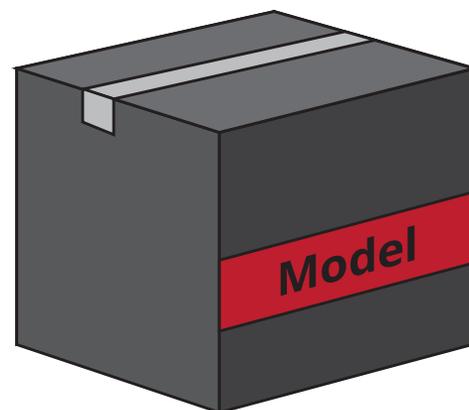
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TYPES DEEP NEURAL NETWORKS



**Convolutional
Neural Network**
e.g. Image Classification

**Recurrent
Neural Network**
e.g. Speech Processing



Transformer
e.g. Natural Language Processing

**Generative
Adversarial Networks**
e.g. Synthetic Face Generation



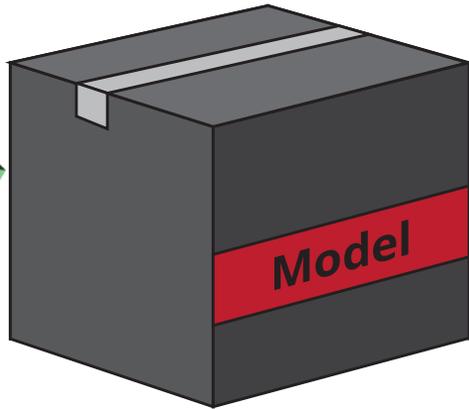
Key Concepts



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IMPLEMENTING AI ON EMBEDDED SYSTEMS

CHALLENGES



Embedded System

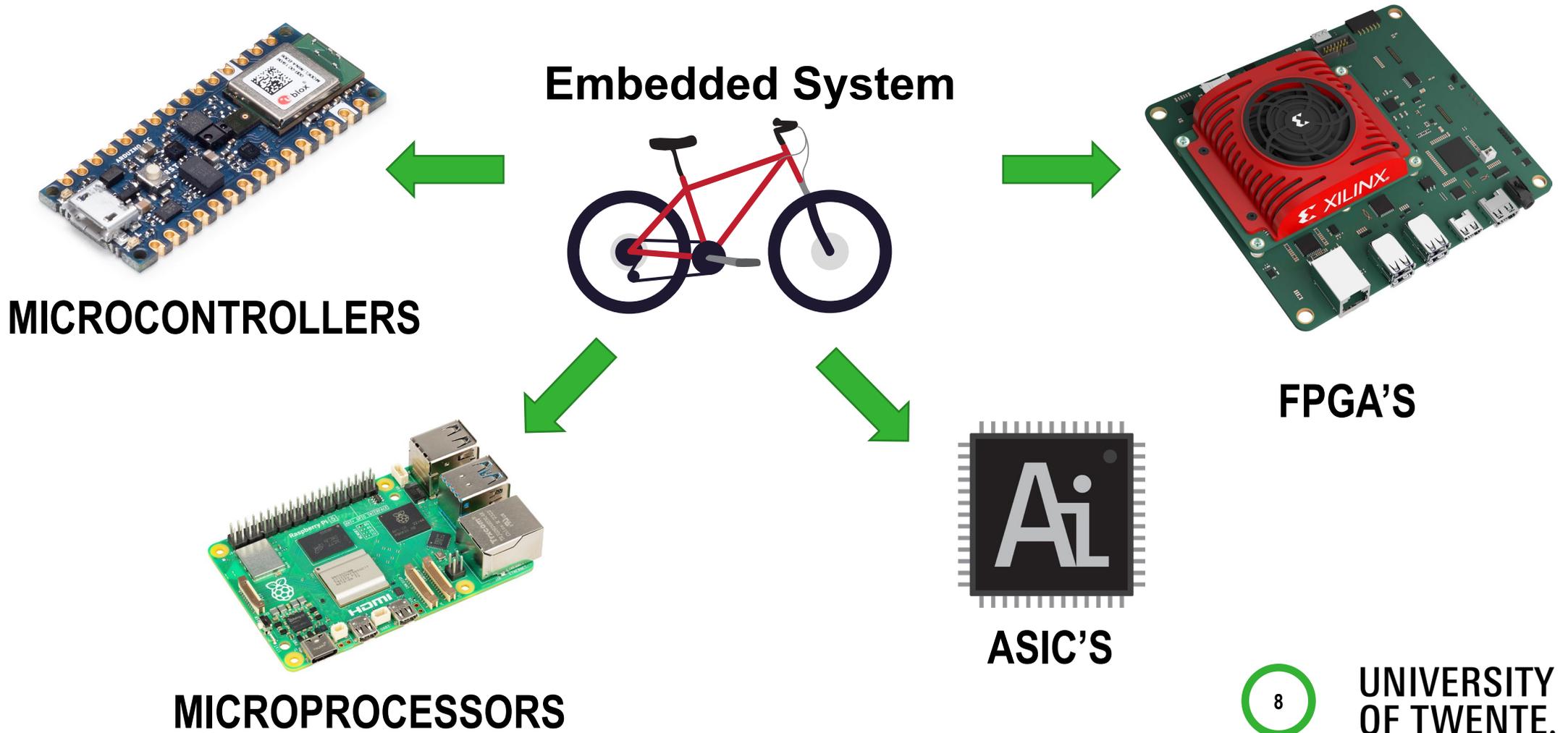


Key Concepts



EMBEDDED SYSTEMS

A DEVICE DESIGNED FOR ONE SPECIFIC TASK WITHIN A SYSTEM



Key Concepts



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IMPLEMENTING AI ON EMBEDDED SYSTEMS

COMPARE EMBEDDED SYSTEM WITH PC

Embedded System



- Special Purpose Hardware
- Pre-programmed firmware
- Real-time response and efficiency is key
- Little power consumption
- Cheap
- Local data processing



- Generic Hardware
- Programmable by user
- Performance and capacity is key
- High power consumption
- Expensive
- Cloud-based data processing

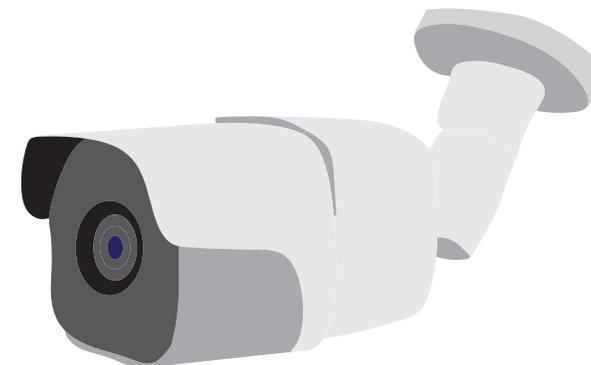
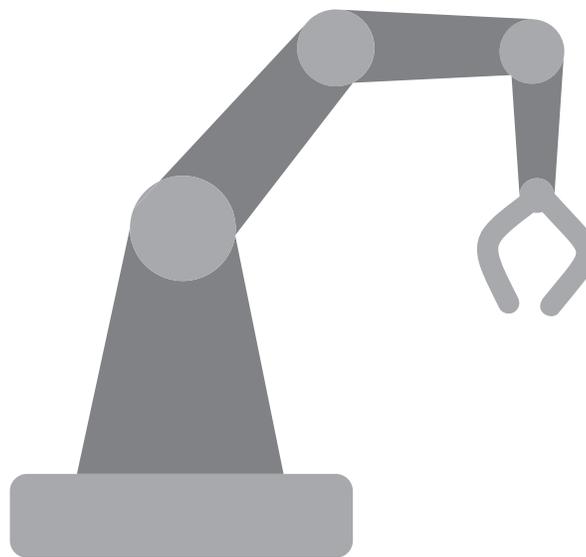


APPLICATIONS



Personal Healthcare

Predictive Maintenance



Smart Camera's

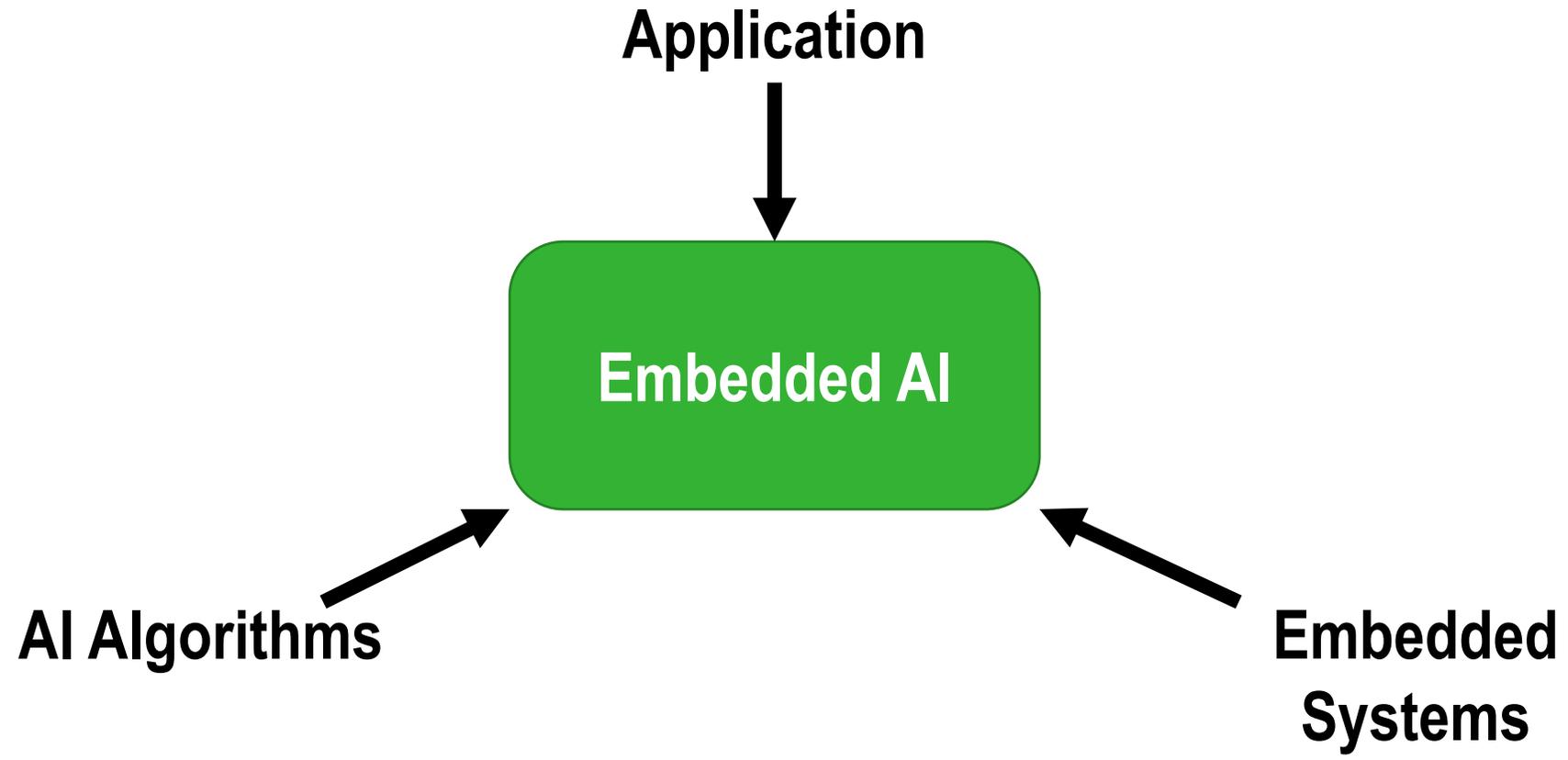


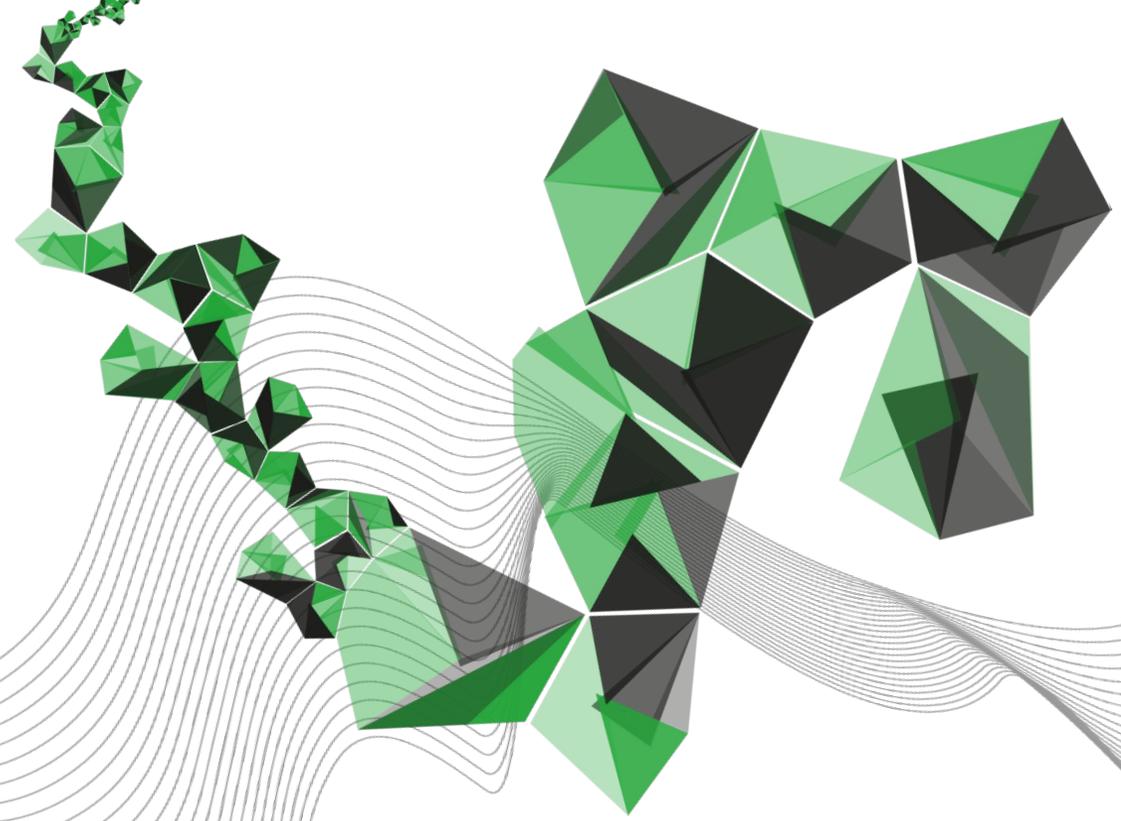


EMBEDDED AI



Key Concepts

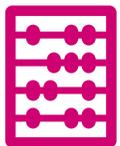
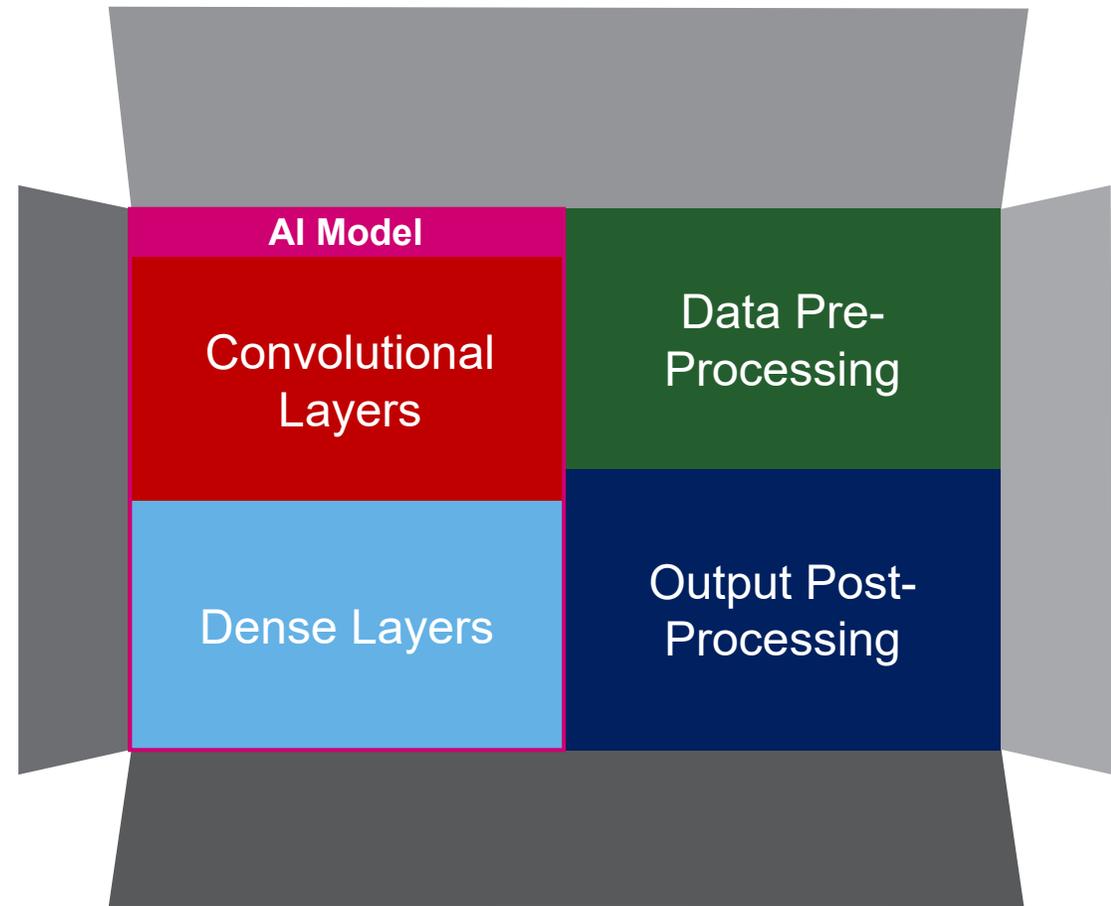




MY RESEARCH

MODEL DESIGN & PERFORMANCE

- AI model contains several different layers

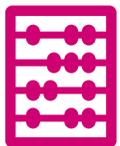
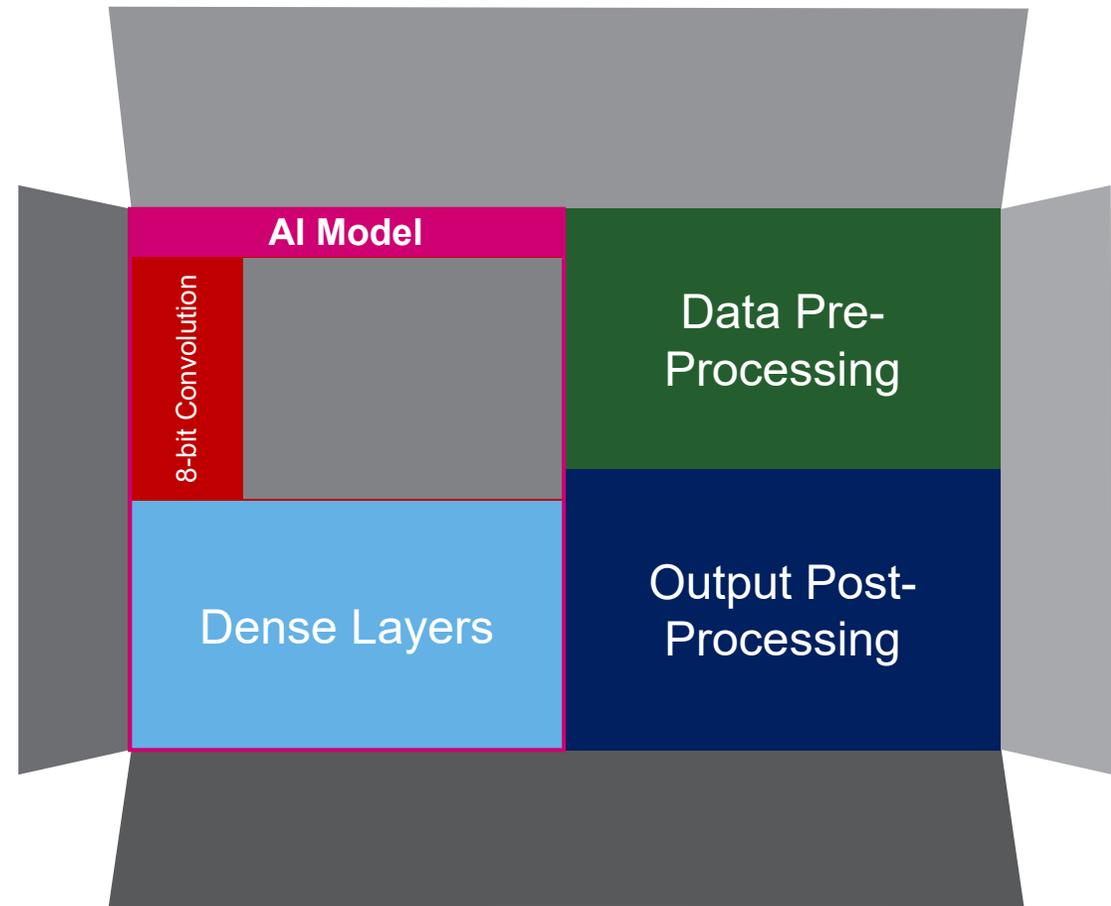


Techniques

Efficient Computation

MODEL DESIGN & PERFORMANCE

- Quantization
 - Approximating a 32-bit number with an 8-bit number
 - Can reduce footprint by a factor 4



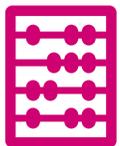
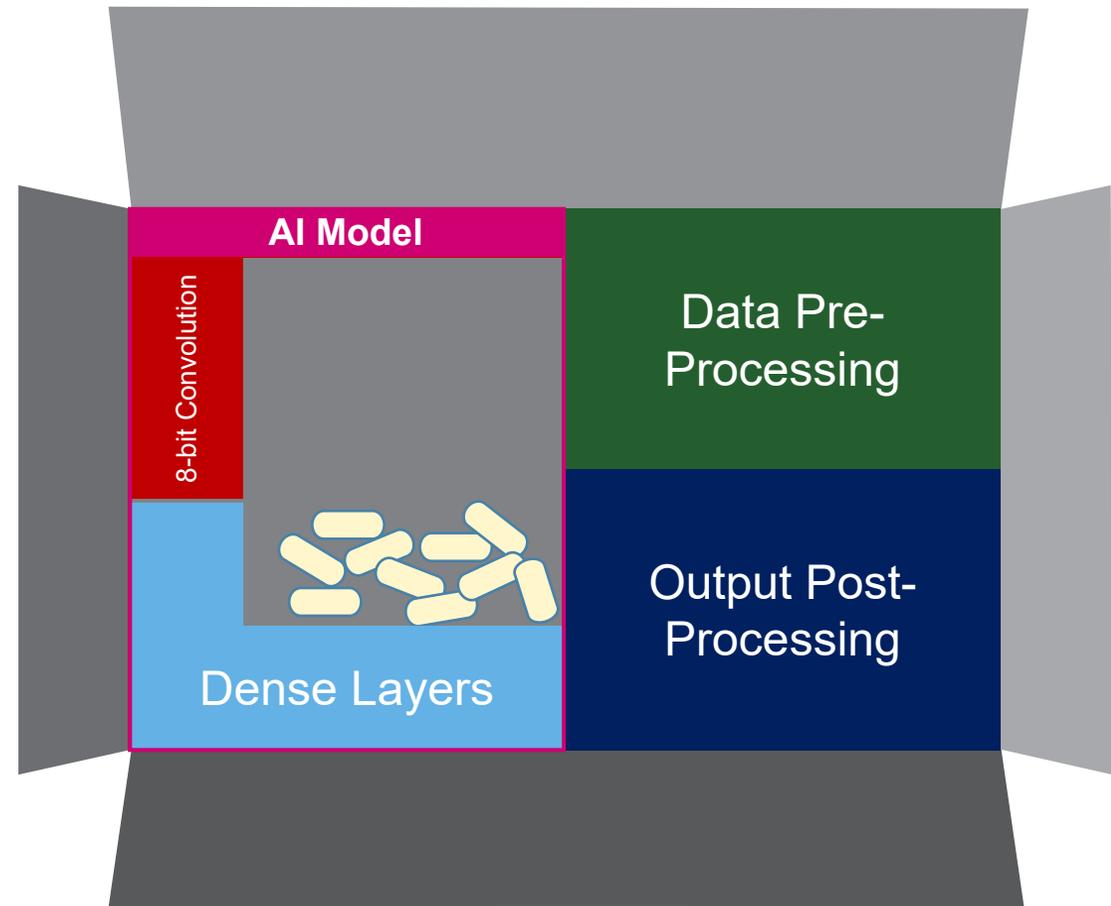
Techniques

Efficient Computation

MODEL DESIGN & PERFORMANCE

- Pruning

- Removing connections in neural network that do not contribute
- Like packaging peanuts that fill up space

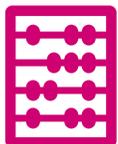


Techniques

Efficient Computation

EFFECT OF QUANTIZATION ON FACE RECOGNITION

Face Recognition Dataset	32-bit	8-bit	4-bit	2-bit
Post Training Quantization	98.85%	94.65%	63.15%	51.55%
Quantize Aware Training	98.85%	98.68 ± 1.15%	98.63 ± 0.18%	93.45 ± 0.66%



Techniques

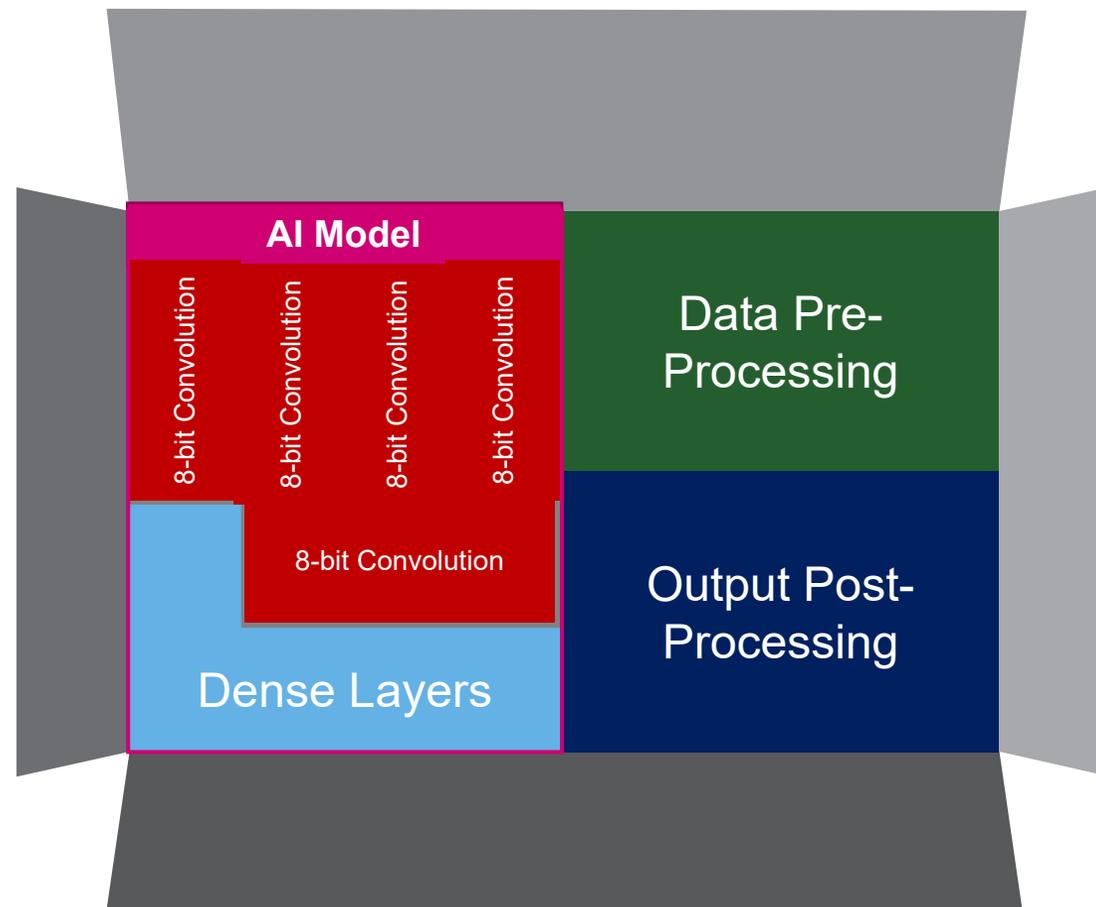
Efficient Computation

S. Bunda, L. Spreeuwers and C. Zeinstra, "Sub-byte quantization of Mobile Face Recognition Convolutional Neural Networks," 2022 International Conference of the Biometrics Special Interest Group (BIOSIG), Darmstadt, Germany, 2022, pp. 1-5, doi: 10.1109/BIOSIG55365.2022.9897025.

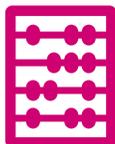


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OPTIMIZING HARDWARE USAGE



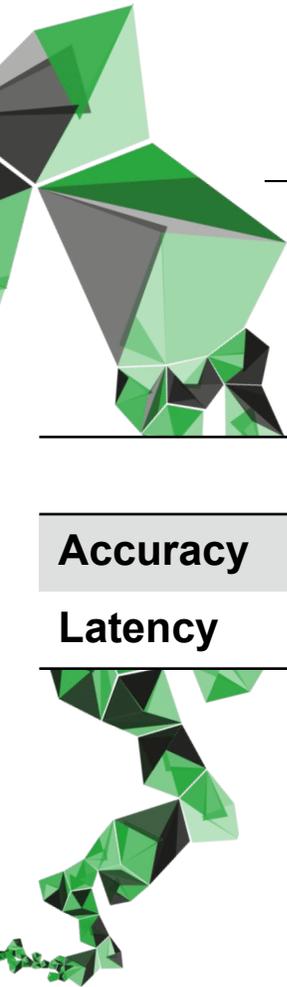
Beware power consumption and latency!



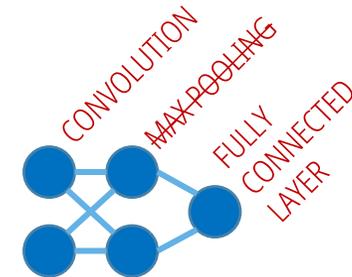
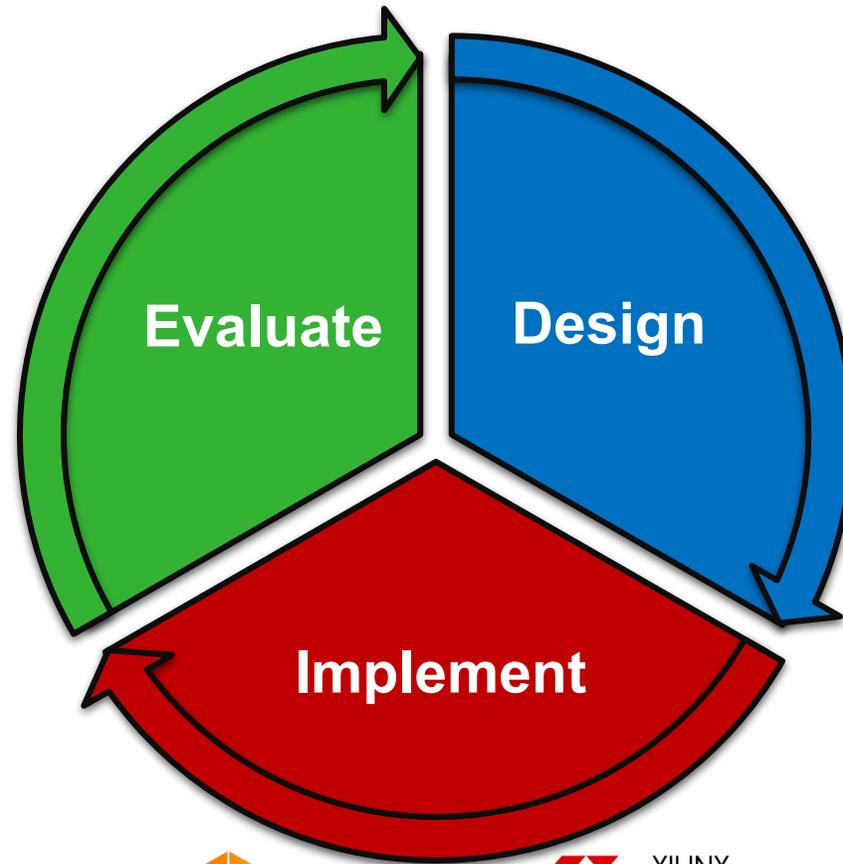
Techniques

Efficient Computation

MY RESEARCH



	Required	Measured
Accuracy	> 99 %	98%
Latency	< 100ms	89ms



Create/Adapt
Model
Architecture



Our current research
and goals





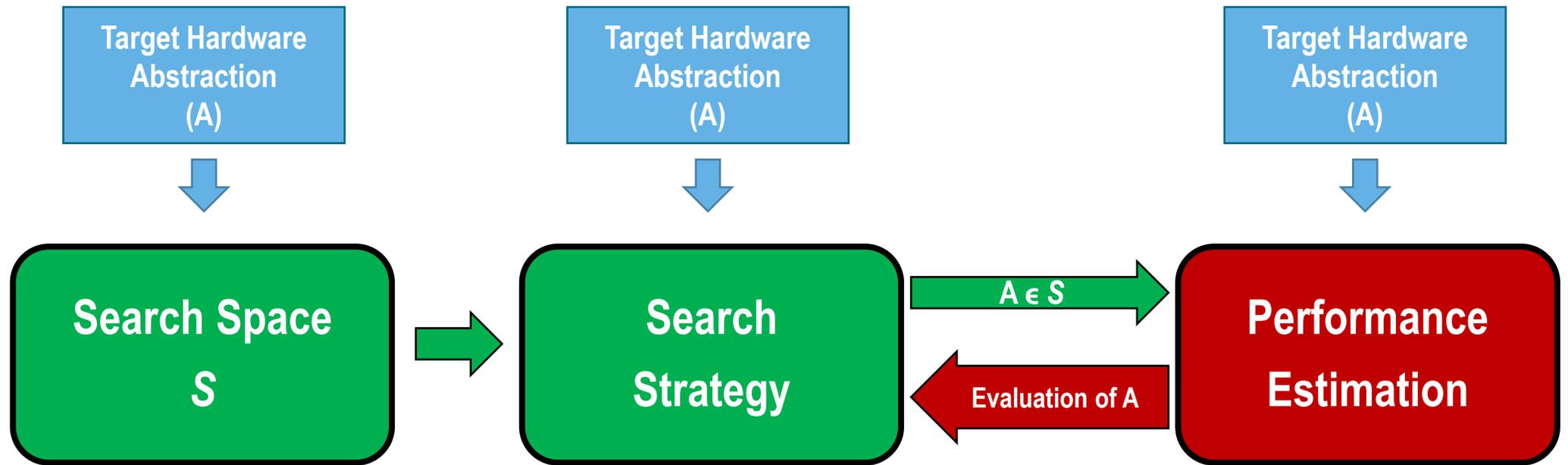
HARDWARE CO-DESIGN NEURAL ARCHITECTURE SEARCH

Optimize design by:

- Proposing models that fit within the **target hardware memory**
- Search for optimal **implementation**
- Evaluate based on e.g. **accuracy, latency and energy**

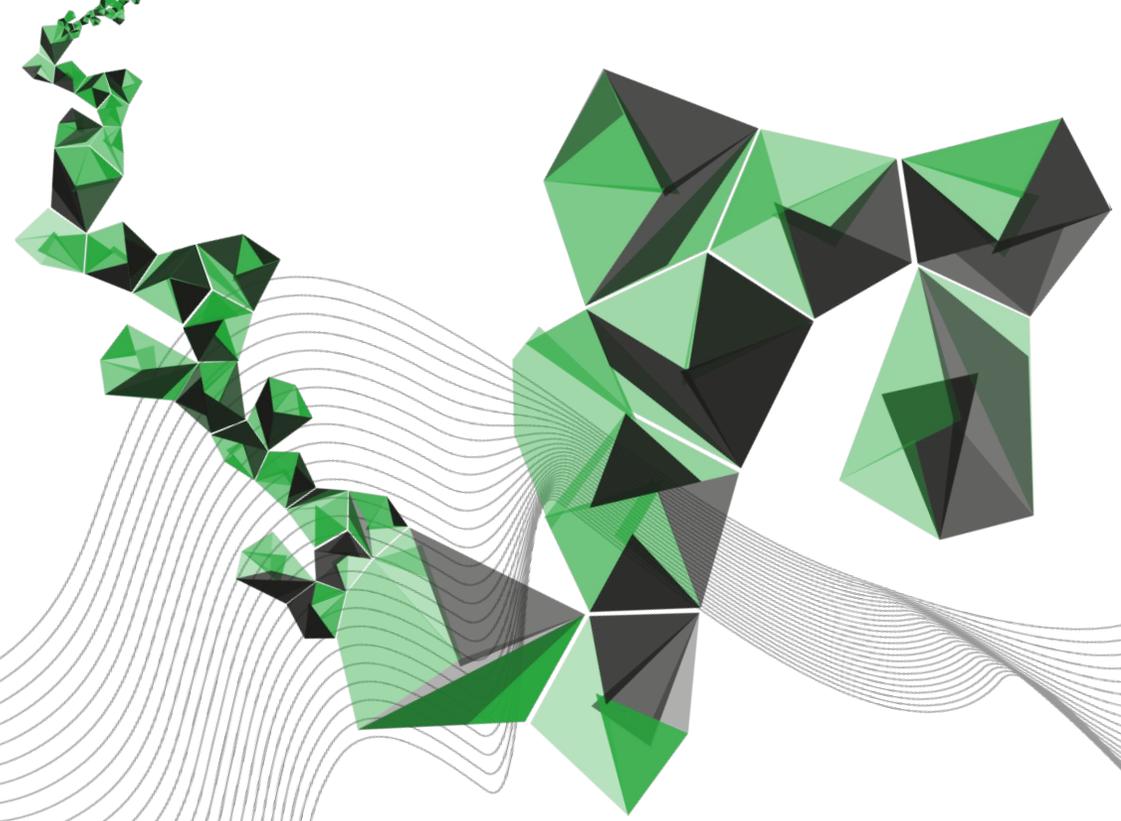


HARDWARE CO-DESIGN NEURAL ARCHITECTURE SEARCH





ACTIVE PROJECTS



SOME ACTIVE PROJECTS

- Image classification optimization using FINN-aware neural architecture search
- Vision-based object distribution detection using YOLO and Raspberry Pi
- Efficient Transformer Networks by researching 8-bit Arithmetics for Transformers
- Hardware acceleration for Genetic Selective Sweep Detection using modern technologies



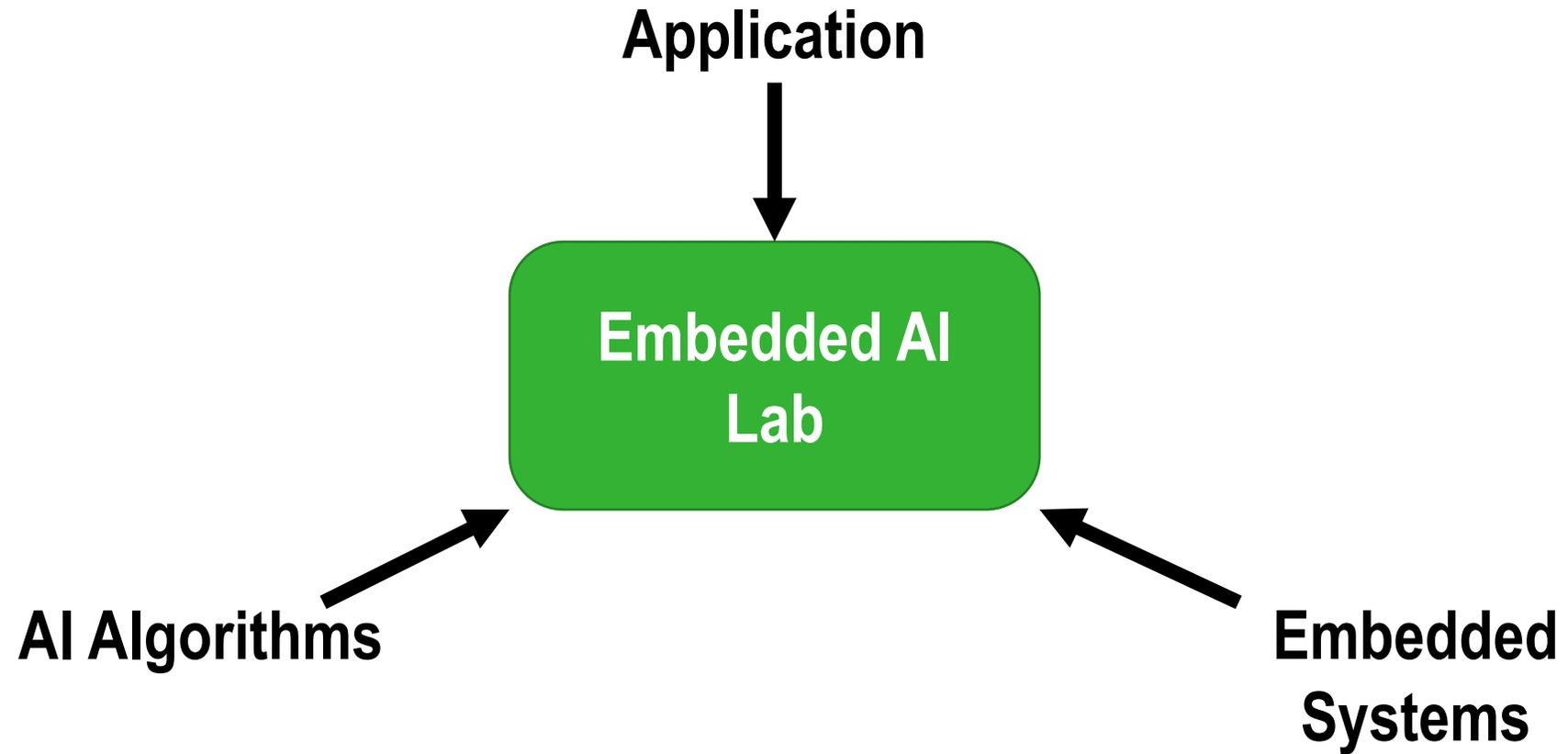


OUTLOOK OF EMBEDDED AI

- Expect new efficient AI-acceleration hardware
 - AMD Ryzen AI NPU
 - Neuromorphic Processors
- Leverage the knowledge of the domain of AI and Embedded Systems for Specific Applications



EMBEDDED AI LAB



OBJECTIVES EMBEDDED AI LAB

- **Objective 1:** Create an Embedded AI Community at UT
 - Creating new contacts and collaborations within the University of Twente
- **Objective 2:** Inspire using DSI Embedded AI Seminars
 - Everyone is welcome to present their work and start discussions
- **Objective 3:** Stimulate student projects through collaboration and teaching
 - Co-supervise students on Embedded AI topics
 - Teaching the basics through Master course



PLANNING



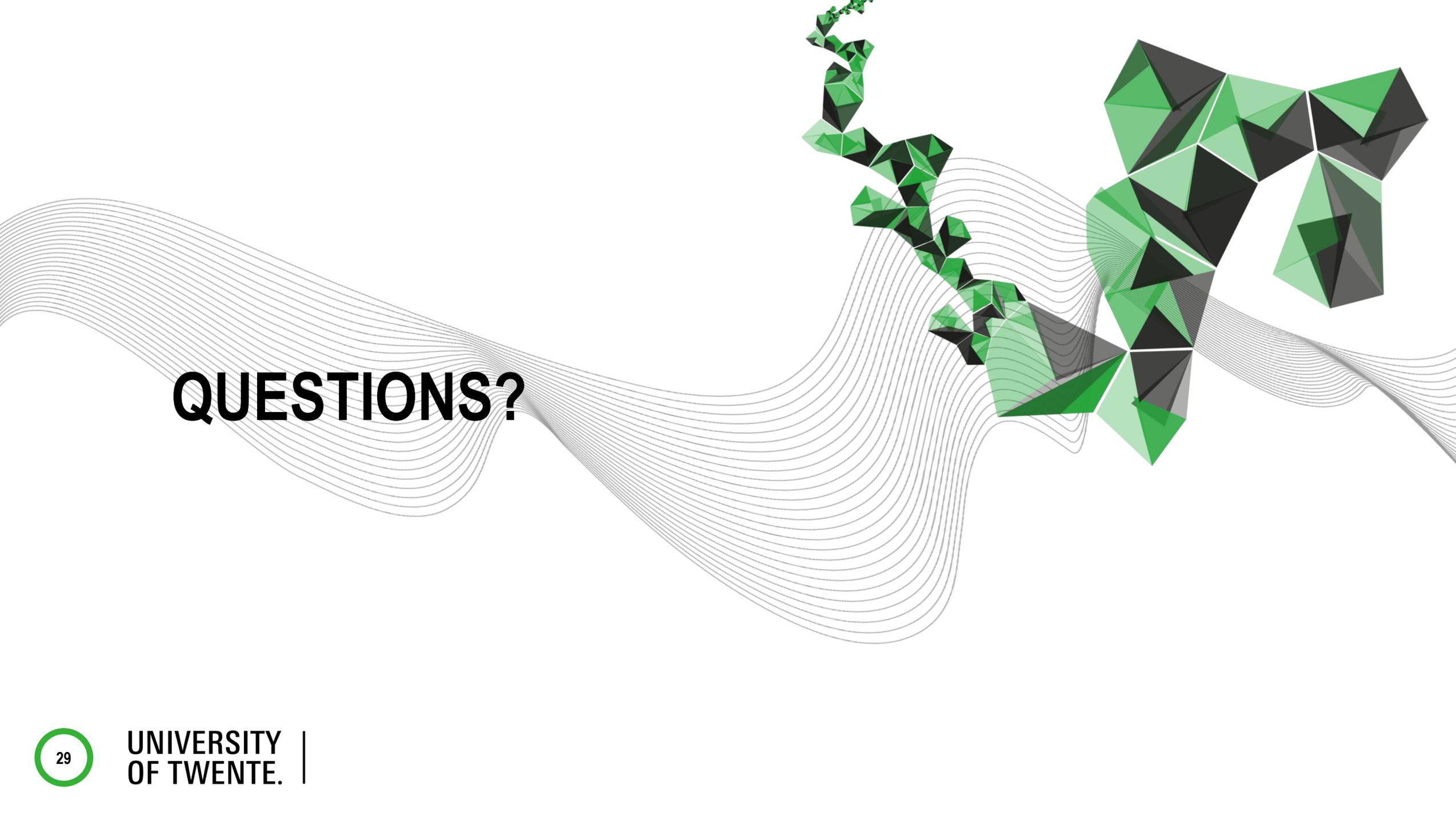
EMBEDDED AI LAB

- Simulate **collaboration** on the topic of **Embedded AI** within University of Twente and with industry
- Develop **AI** methods to achieve State-of-the-Art performance with **limited resources**
- Build **Demonstrators** to show applications

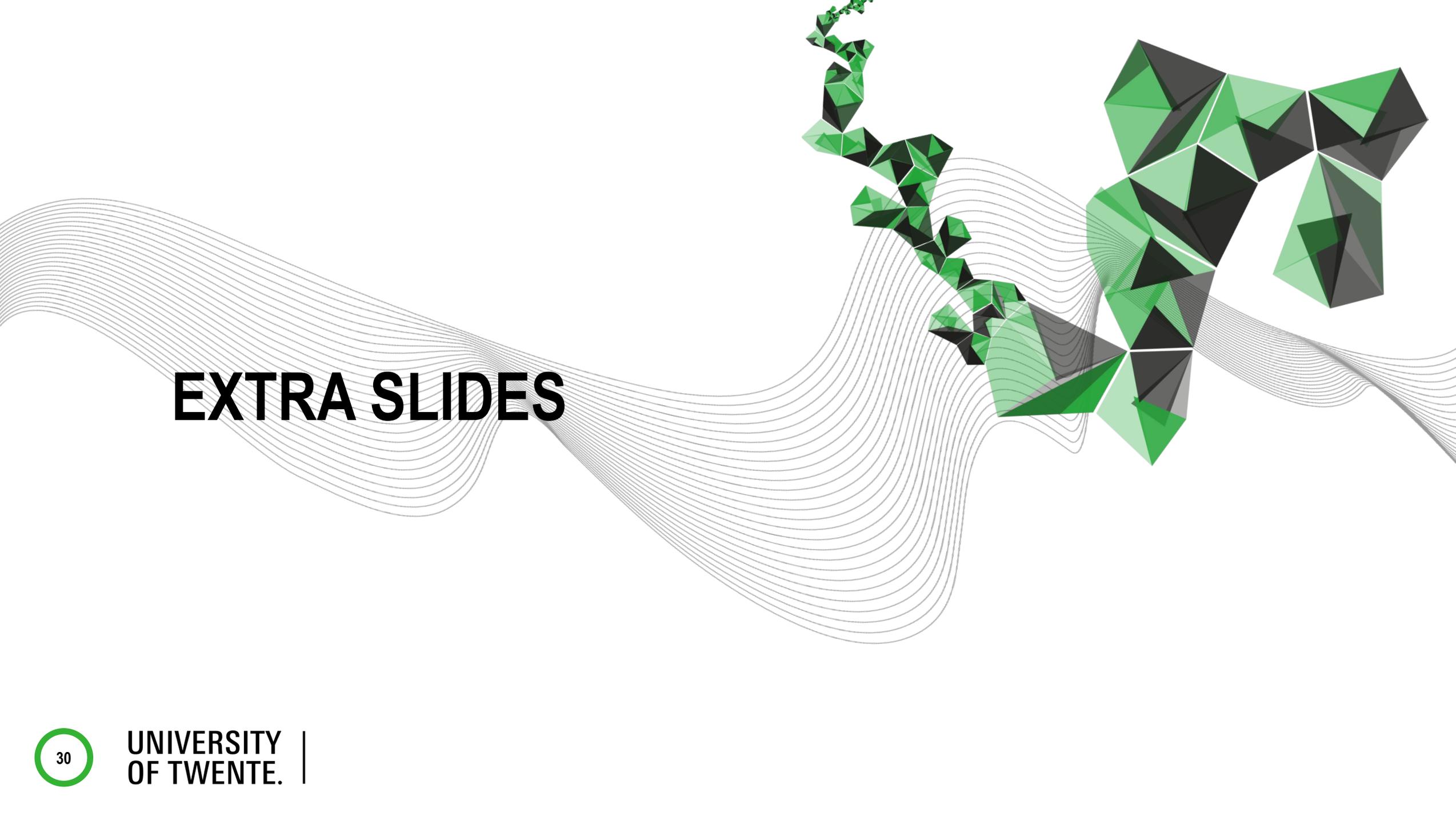


SIGN UP FOR NEXT SEMINAR 9TH OF OCTOBER



An abstract graphic featuring a series of thin, grey, wavy lines that flow from the left side towards the right. On the right side, there is a complex, three-dimensional geometric shape composed of many small, interconnected triangles. The shape is primarily green, with some dark grey or black triangular facets interspersed, creating a faceted, crystalline appearance. The overall composition is clean and modern, set against a plain white background.

QUESTIONS?

The background features a series of thin, grey, wavy lines that create a sense of motion and depth. On the right side, there is a complex, three-dimensional geometric structure composed of various green and black polyhedral shapes, resembling a stylized molecular model or a crystalline structure. The text 'EXTRA SLIDES' is centered horizontally across the middle of the page, overlaid on the wavy lines.

EXTRA SLIDES

ARTIFICIAL INTELLIGENCE



ARTIFICIAL INTELLIGENCE

A system that is able to display human-like capabilities such as reasoning and learning

Natural Language Processing

Robotics

Automatic Programming

MACHINE LEARNING

Algorithms whose performance improves by being exposed to more data

Random Forest

DEEP NEURAL NETWORKS

ML algorithm based on multi-layered neural networks

Decision Trees

Support Vector Machines

Convolutional
Neural Networks

Transformer
Networks

Logistic Regression

Principle Component Analysis

Recurrent Neural Network

k-means Clustering

TENSORFLOW LITE & TINYMML

COMPILATION TOOLING

- tensorflow.org/lite/microcontrollers
- tinyurl.com/tinymml-book



Overview of Available
Tools

EDGE IMPULSE

DEPLOYMENT TOOLING



Overview of Available Tools

The screenshot shows the Edge Impulse web interface. At the top, it displays the user's name 'Sebastian' and the project name 'm7715157-project-1'. The target device is set to 'Arduino Nicla Vis...'. The main content area is titled 'Impulse #1' and shows 'Step 2: Process "mobilenet-v1-tflite-0-25-128-q'.

On the left, there is a navigation menu with the following items: Dashboard, Devices, Data acquisition, Experiments, Impulse design (expanded), Upload model, Retrain model, Live classification, Model testing, Deployment, and Versioning. Below this is a 'GETTING STARTED' section with links to Documentation and Forums.

The main configuration area includes the following settings:

- Model input:** Image (RGB) (Input shape: (128, 128, 3))
- How is your input scaled?:** Pixels ranging 0..255 (not no) (Input should be in RGB format (one value per pixel). If your model uses a different channel order, or is scaled differently, then select "Other".)
- Model output:** Classification (Output shape: (1001))
- Output labels (1001):** class 1, class 2, class 3, class 4, c (Enter labels for your model separated by ',')

On the right, the 'On-device performance' section shows:

- PROCESSING TIME: 35 ms.
- FLASH USAGE: 485,6K
- Warning: This model won't run on MCUs. Calculated arena size is >6MB

Below this is the 'Check model behavior' section with an option to 'Upload test data to ensure correct model settings and proper model processing. (Optional)'. There is also an 'Upload an image' section with a 'Test sample' button.

At the bottom of the configuration area, there is a 'Save model' button. The footer of the interface reads '© 2024 Edgimpulse Inc. All rights reserved'.



MICROPYTHON IN OPENMV

DEPLOYMENT TOOLING



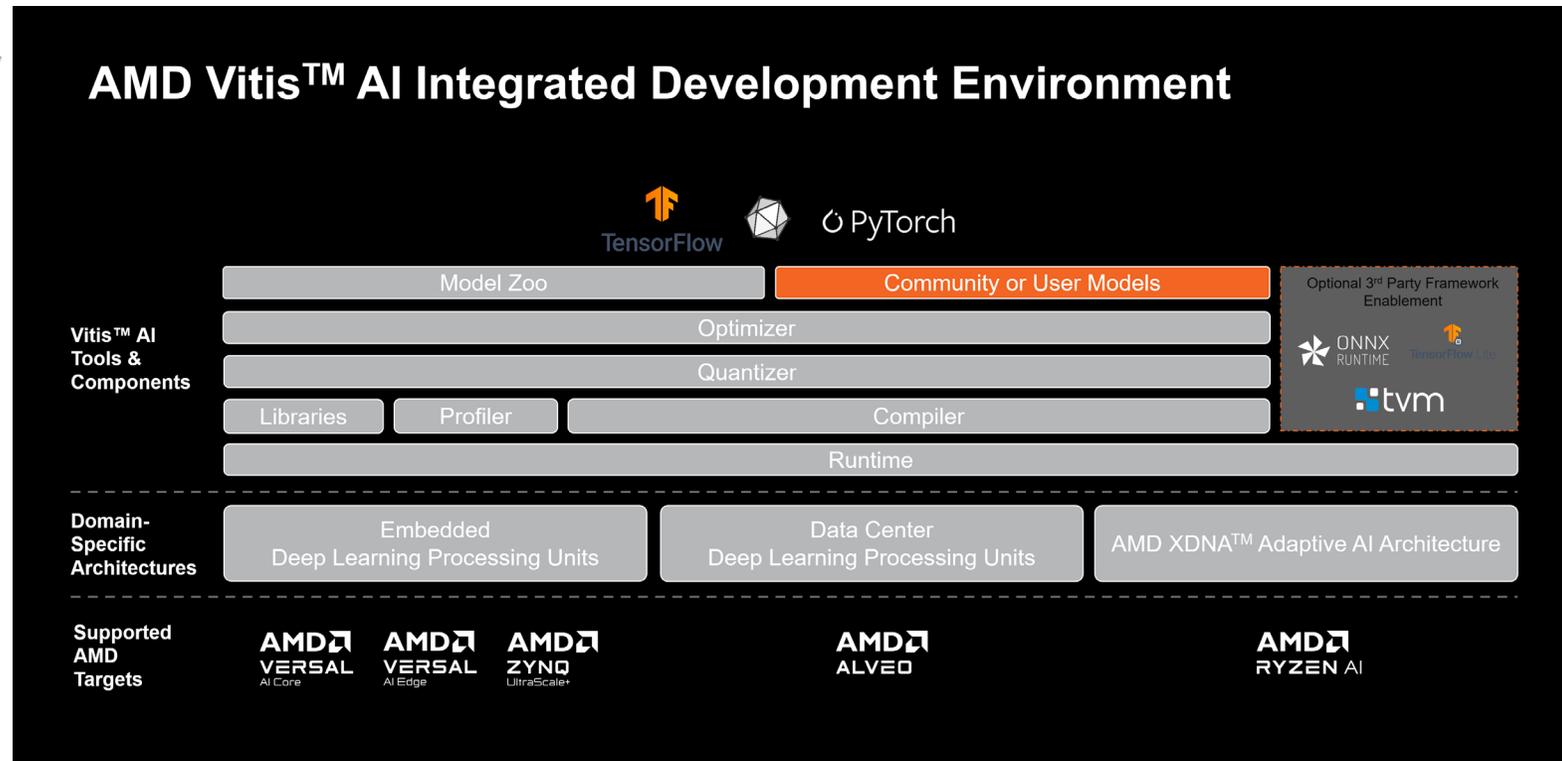
Overview of Available Tools

The screenshot shows the OpenMV IDE interface with a Python script for face detection. The script includes comments and code for setting up the sensor, loading a model, and processing frames. The Serial Terminal at the bottom shows the output of the script, including coordinates and scores for detected faces.

```
tf_object_detection_1.py - OpenMV IDE
File Edit Tools Window Help
helloworld_1_tf.py x face_detection_1.py x face_detection.py x helloworld_1.py x tf_object_detection_1.py x
tf_object_detection_1.py Line 1, Col 1 Frame Buffer Record Zoom Disable
1 # This work is licensed under the MIT license.
2 # Copyright (c) 2013-2024 OpenMV LLC. All rights reserved.
3 # https://github.com/openmv/openmv/blob/master/LICENSE
4 #
5 # TensorFlow Lite Object Detection Example
6 #
7 # This examples uses the builtin FOMO model to detect faces.
8
9 import sensor
10 import time
11 import ml
12 from ml.utils import NMS
13 import math
14 import image
15
16 sensor.reset() # Reset and initialize the sensor.
17 sensor.set_pixformat(sensor.RGB565) # Set pixel format to RGB565 (or GRAYSCALE)
18 sensor.set_framesize(sensor.QVGA) # Set frame size to QVGA (320x240)
19 sensor.set_windowing((240, 240)) # Set 240x240 window.
20 sensor.skip_frames(time=2000) # Let the camera adjust.
21
22 min_confidence = 0.4
23 threshold_list = [(math.ceil(min_confidence * 255), 255)]
24
25 # Load built-in FOMO face detection model
26 model = ml.Model("fomo_face_detection")
27 print(model)
28
29 # Alternatively, models can be loaded from the filesystem storage.
30 # model = ml.Model('object_detection_modelwork*.tflite', load_to_fb=True)
31 # labels = [line.rstrip('\n') for line in open("labels.txt")]
32
33 colors = [ # Add more colors if you are detecting more than 7 types of classes at once.
34     (255, 0, 0),
35     (0, 255, 0),
36     (255, 255, 0),
37     (0, 0, 255),
38     (255, 0, 255),
39     (0, 255, 255),
40     (255, 255, 255),
41 ]
42
43
44 # FOMO outputs an image per class where each pixel in the image is the centroid of the train
45 # object. So, we will get those output images and then run find_blobs() on them to extract th
46 # centroids. We will also run get_stats() on the detected blobs to determine their score.
47 # The Non-Max-Suppression (NMS) object then filters out overlapping detections and maps their
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VITIS AI & FINN

DEPLOYMENT TOOLING



<https://xilinx.github.io/Vitis-AI/3.5/html/index.html>
<https://xilinx.github.io/finn/>



Overview of Available Tools

STM32CUBE.AI

- Optimize and deploy Deep Neural Networks on STM32 microcontrollers:
 - <https://stm32ai.st.com/stm32-cube-ai/>

