Digital Oscillatory Neural Networks for AI Edge Applications

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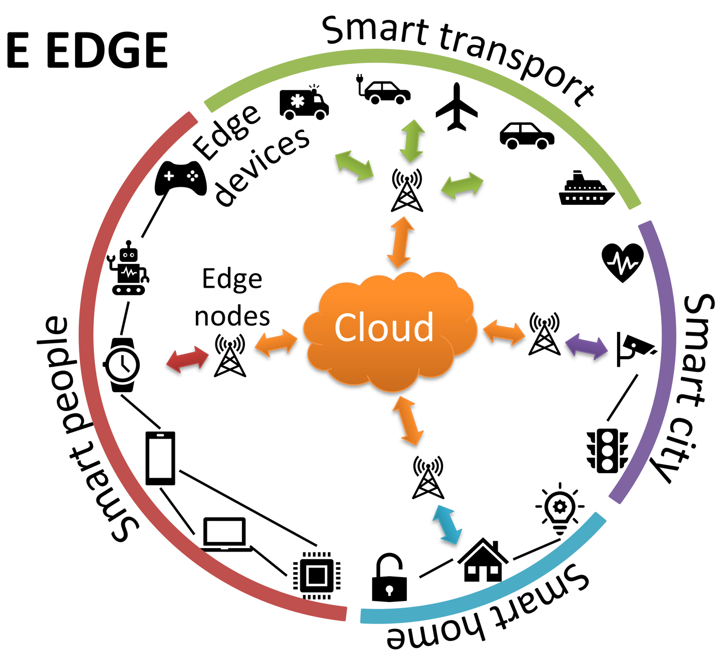
MOTIVATION AND GOALS

ARTIFICIAL INTELLIGENCE AT THE EDGE

- Constraints:
  - Bandwidth (inference/second)
  - Latency (frames/second)
  - Privacy concerns
  - Power consumption



NEUROMORPHIC COMPUTING

- Support online learning
- Fast and efficient inference
- Low power consumption
- Scalability
- Low cost

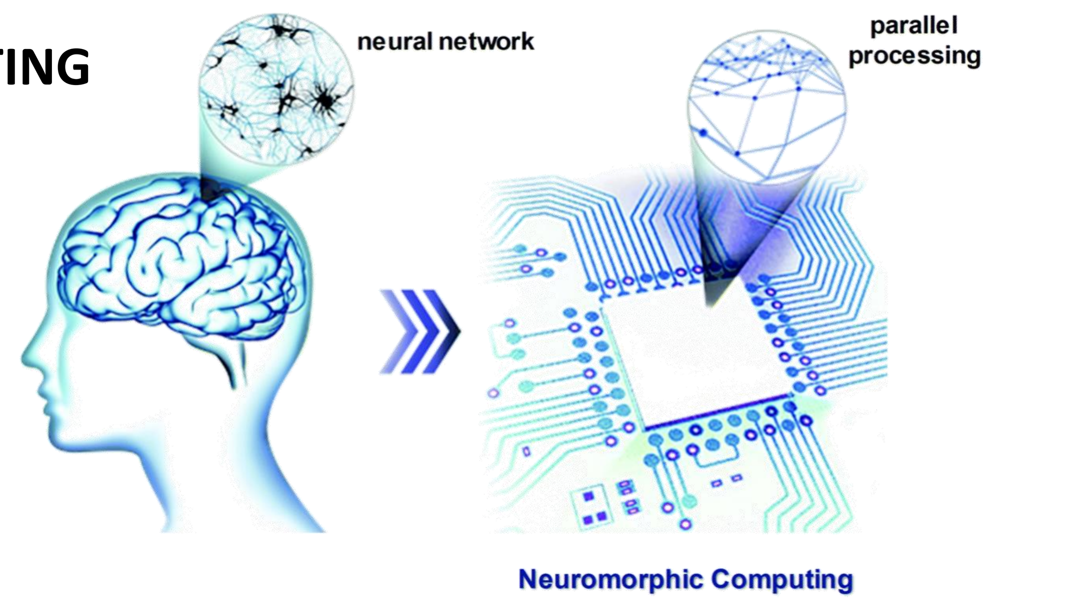


Image: Kim S , Lee Y , Kim HD , Choi SJ . Parallel weight update protocol for a carbon nanotube synaptic transistor array for accelerating neuromorphic computing, Nanoscale. 2020

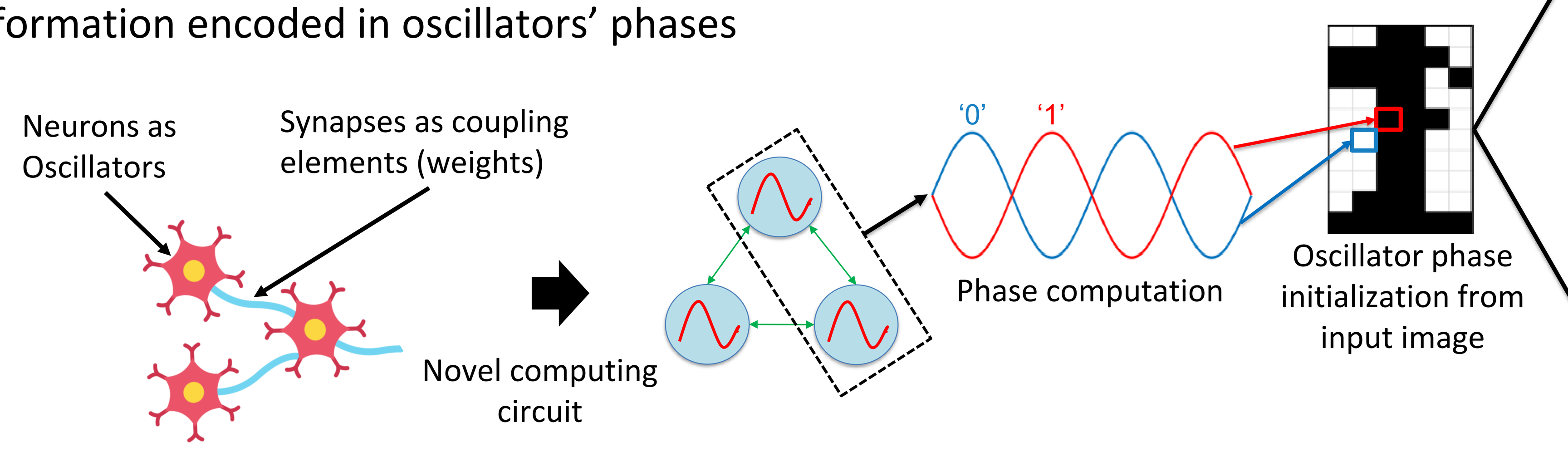
OSCILLATORY NEURAL NETWORKS

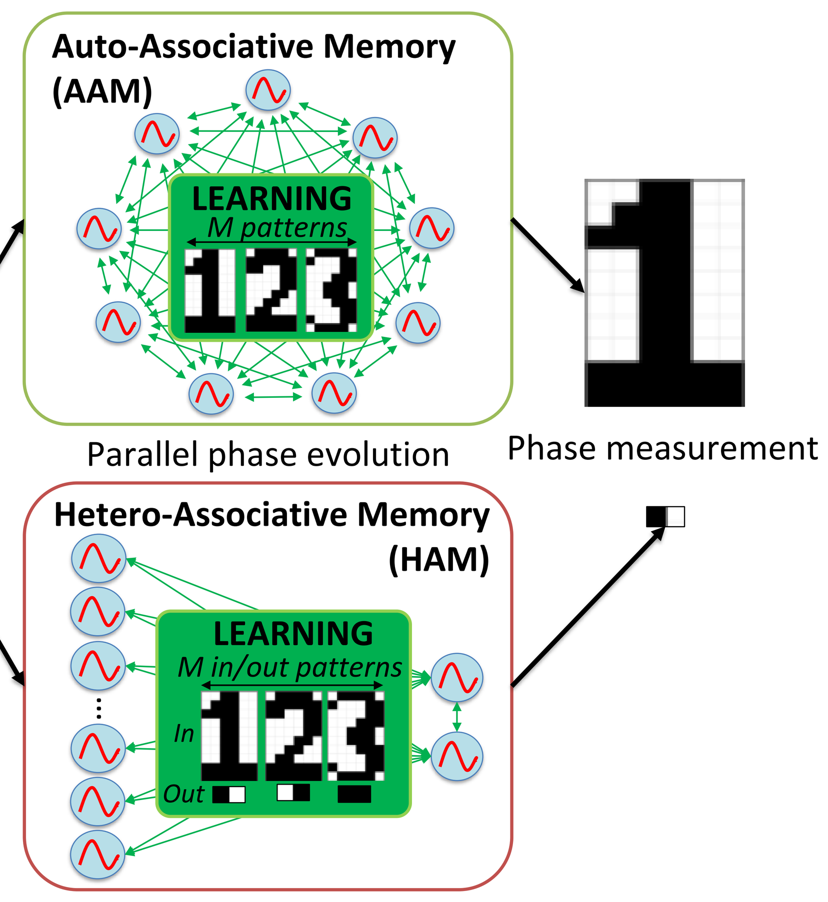
PHASE COMPUTING PARADIGM [1]

- Brain-inspired computing paradigm
- Neurons are oscillators
- Synapses are coupling elements between oscillators
- Information encoded in oscillators' phases

ASSOCIATIVE MEMORY

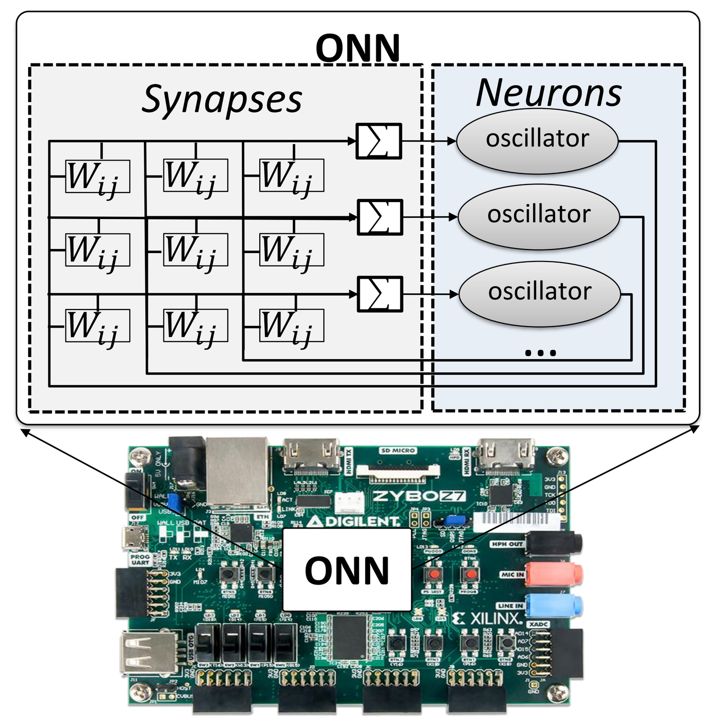
- Learn patterns
- Associate corrupted input with correct output





FPGA IMPLEMENTATION [2]

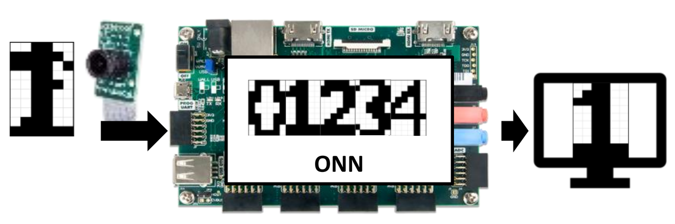
- Digital oscillators
- 5-bits signed registers as synapses



APPLICATIONS AND USE CASES

Digits recognition (AAM) [2]

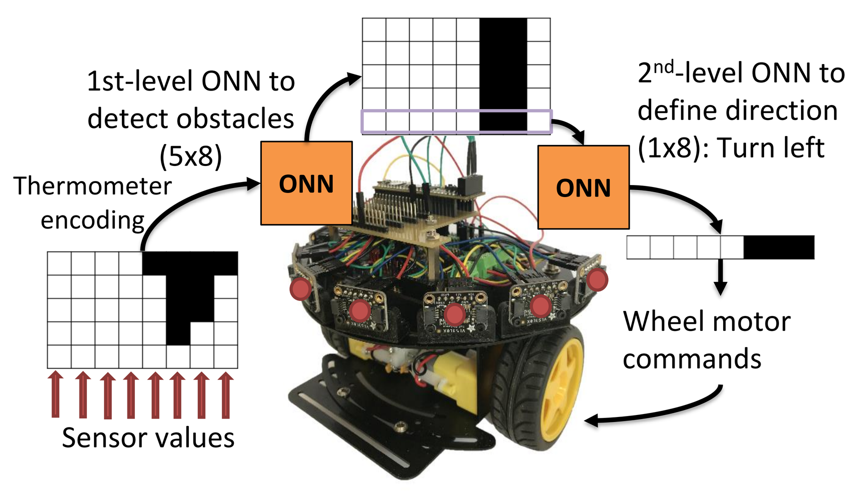
Camera stream to HDMI screen



ONN	10x6
LUTs	12%
Flip-Flops	2,6%
ONN Frequency	488 kHz
Init & comp time	13,2 us
FPS	75000
Accuracy (25 test images)	80 %

Obstacle avoidance (AAM) [3]

with an Arduino robot

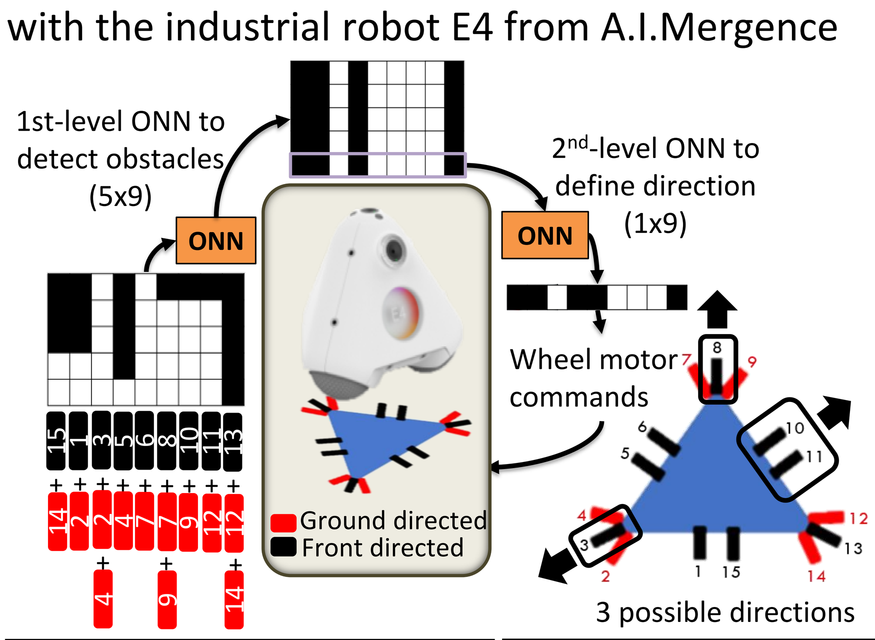


ONN Performances	5x8	1x8
#Training Patterns	256	16
LUTs (33 280)	11,5%	
Flip-Flops (41 600)	5,4%	
ONN freq. (KHz)	187,5	187,5
Init & Comp time	24 us	17 us
Accuracy	100 %	74 %

Full system performances (FPGA frequency: 12 MHz)	
8-sensor measurement	18 ms
FPS	40
Battery	6V/2850mAh
Current cons.	700 mA
Robot life time	4h

Obstacle avoidance (AAM) [4]

with the industrial robot E4 from A.I.Mergence

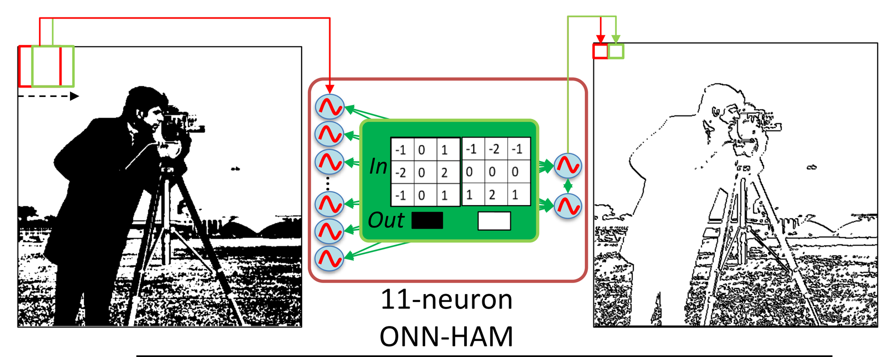


ONN Performances	5x9	1x9
#Training Patterns	512	64
LUTs (33 280)	20,07 %	
Flip-Flops (41 600)	7,74 %	
ONN freq. (KHz)	187,5	187,5
Init & Comp time	27 us	17 us
Accuracy	100 %	100 %

Full system performances (FPGA frequency: 12 MHz)	
15-sensor measurement	27 ms
FPS	30
Robot life time estimation	2h/3h

Image edge detection (HAM) [5]

Camera stream to HDMI screen (10x6 ONN)



11-neuron ONN-HAM

Single ONN characteristics	
Input – output size	9 - 2 neurons
ONN Frequency	2,7 MHz
Init - Comp time	240 ns – 1 or 2 us
Resources (LUTs)	402 (0,76 %)
Resources (Flip-Flops)	443 (0,42 %)
Estimation of full-image sequential processing with single ONN (computation time: 2 us)	
Image size	**Processing time**
28x28	1,5 ms
120x120	31,9 ms
512x512	582,6 ms

CONCLUSION

- Development of a proof of concept of the ONN computing paradigm with a digitally implemented ONN on FPGA
- Development of various demonstrators using the digital ONN on FPGA
  - Digits recognition from a camera stream
  - Obstacle avoidance on mobile robots from sensory data measurements
  - Image edge detection using ONN as HAM

REFERENCES

[1] A. Todri-Sanial, et al. EU H2020 NEURONN: Two-Dimensional Oscillatory Neural Networks for Energy Efficient Neuromorphic Computing. *EFECS*, 2020.
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[4] M. Abernot, et al. Oscillatory Neural Networks for Obstacle Avoidance on Mobile Surveillance Robot E4. *IJCNN*, 2022.
[5] M. Abernot, T. Gil, A. Todri-Sanial. Oscillatory Neural Network as Hetero-Associative Memory for Image Edge Detection. *NICE workshop*, 2022.

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