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Digital Oscillatory Neural Networks for AI Edge Applications

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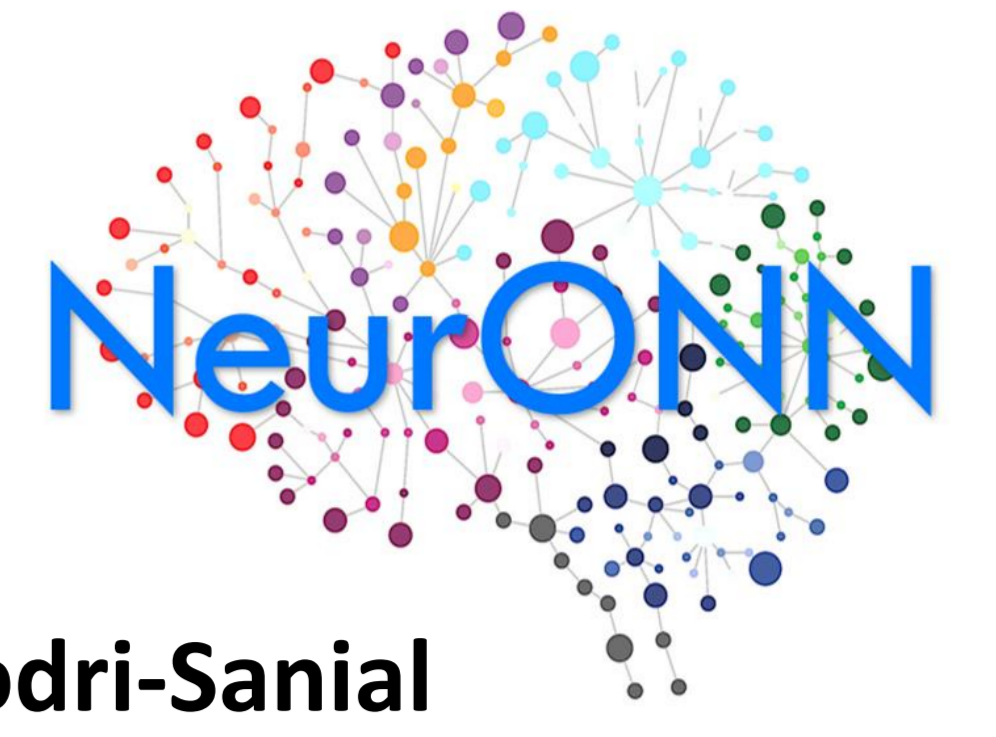
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Digital Oscillatory Neural Networks for AI Edge Applications

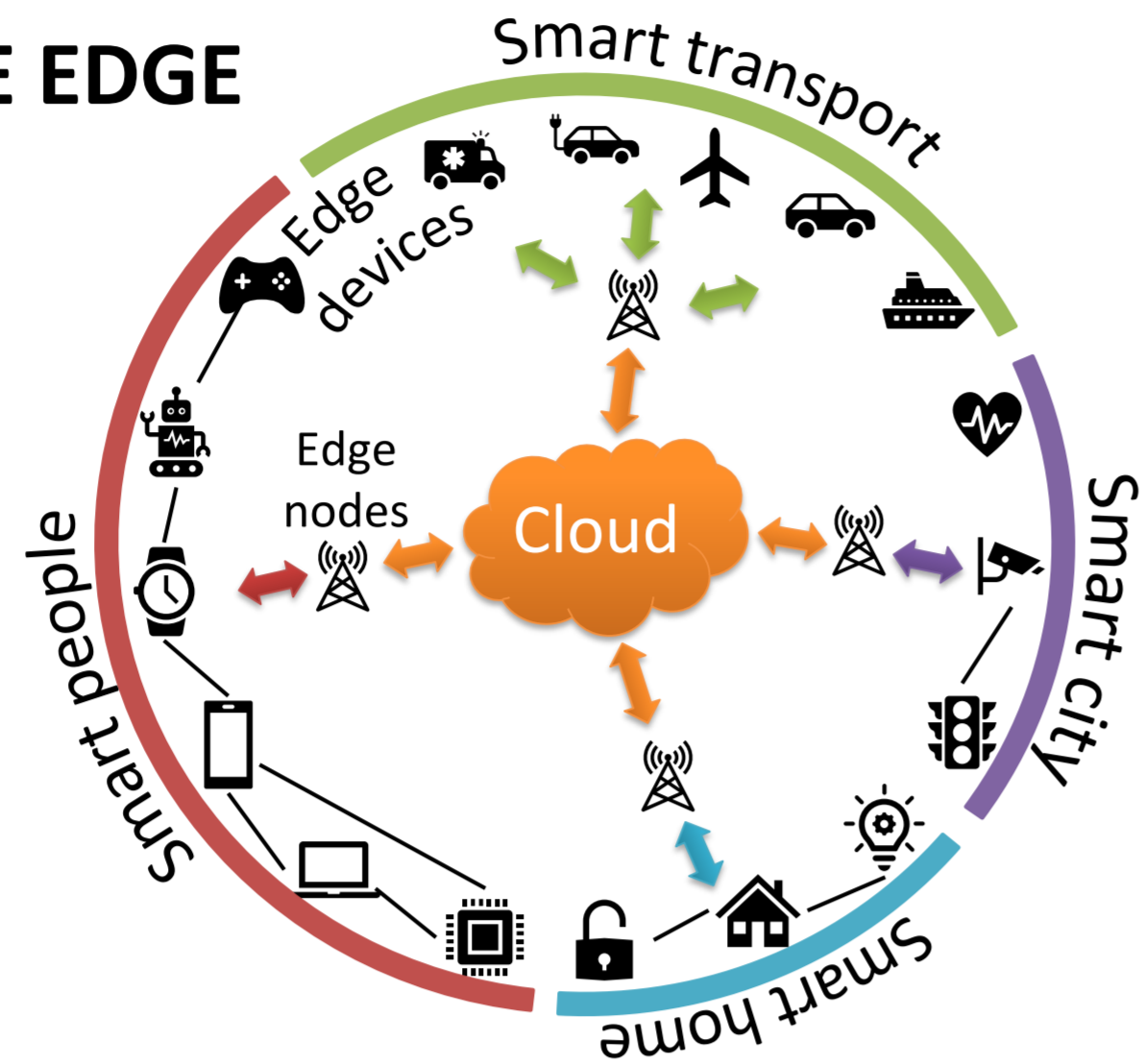


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MOTIVATION AND GOALS

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

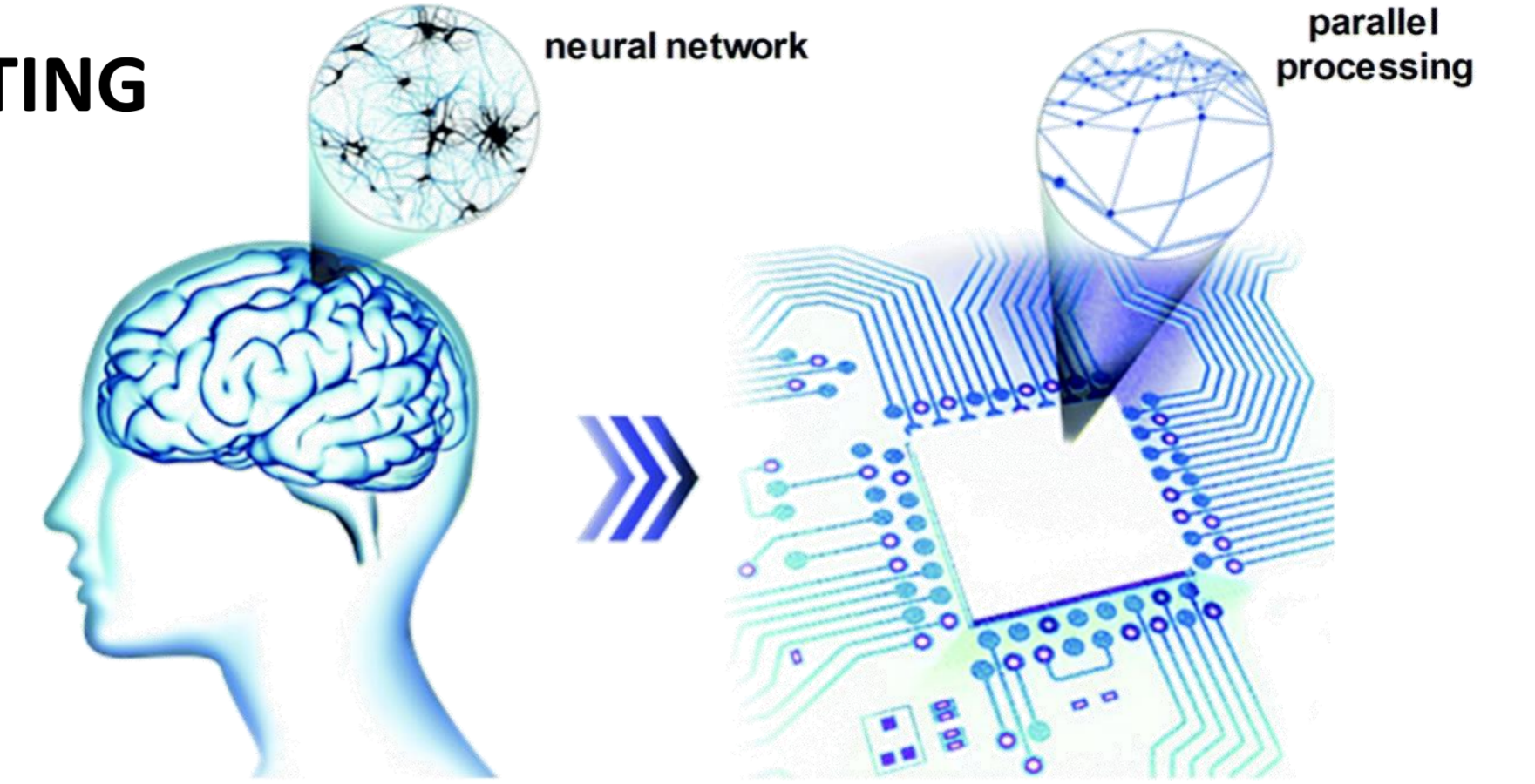
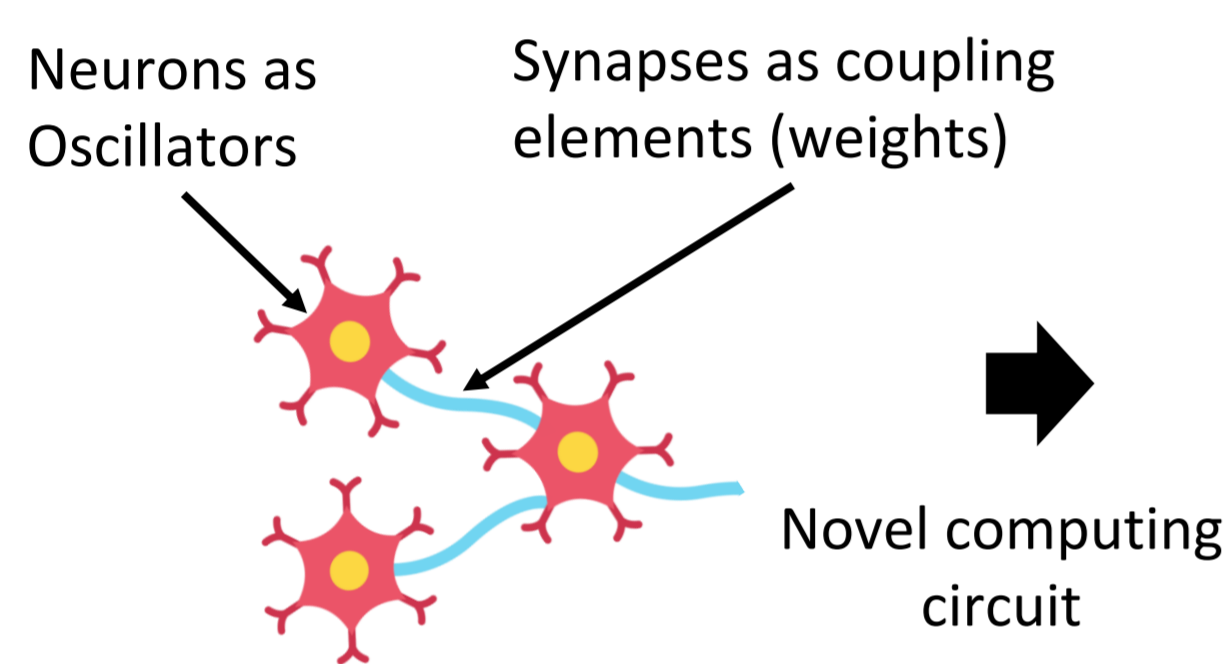


Image: Kim S., Lee Y., Kim H.D., Choi S.J. Parallel weight update protocol for a carbon nanotube synaptic transistor array for accelerating neuromorphic computing, Nanoscale, 2020

OSCILLATORY NEURAL NETWORKS

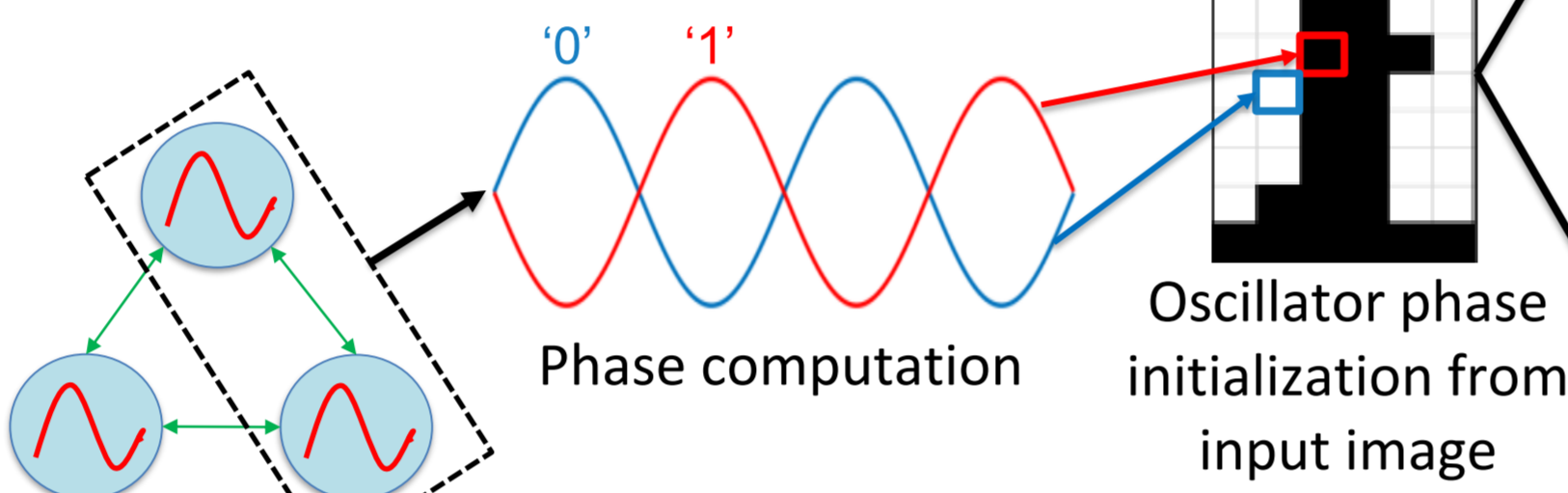
PHASE COMPUTING PARADIGM [1]

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

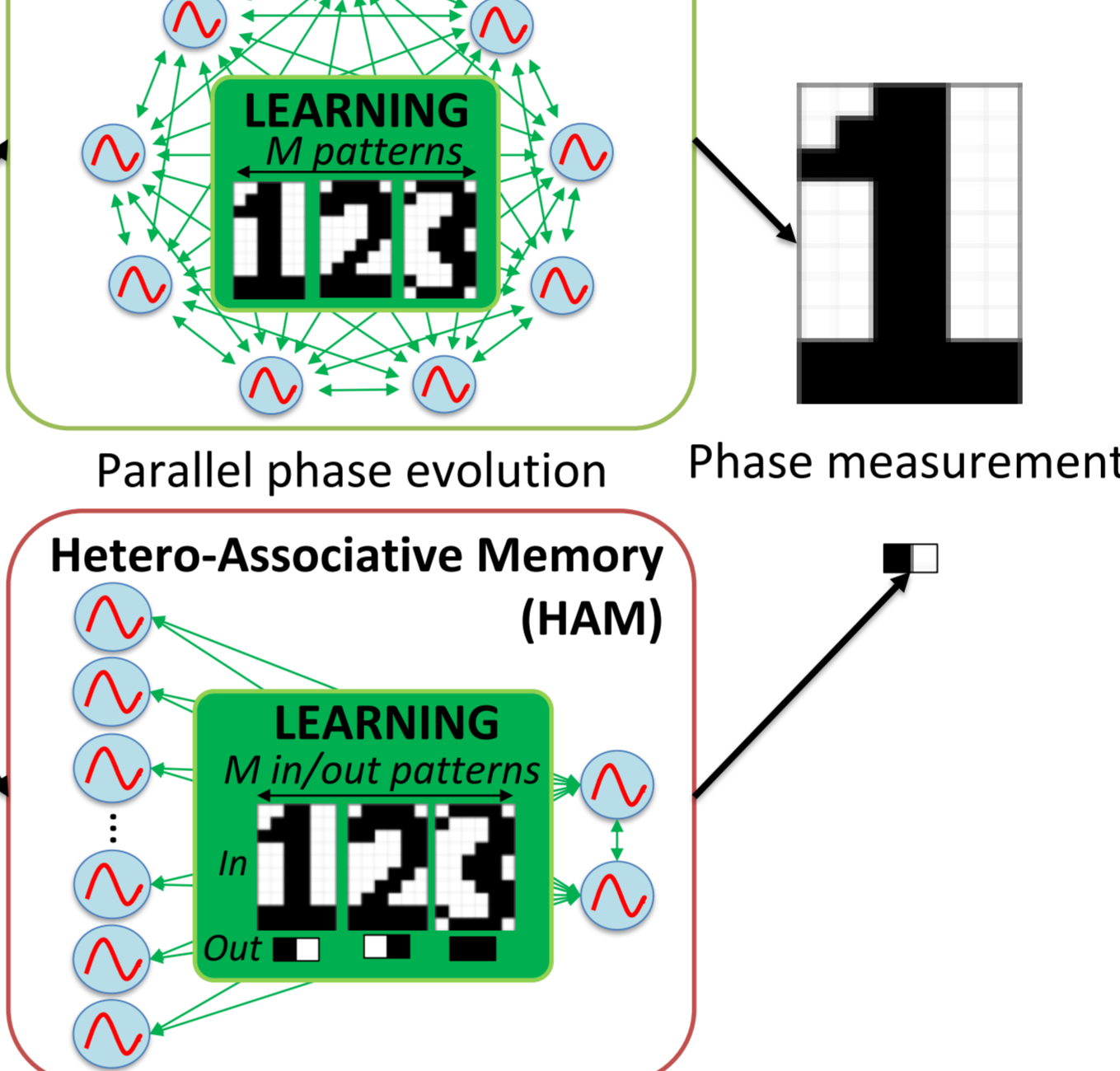


ASSOCIATIVE MEMORY

- Learn patterns
- Associate corrupted input with correct output



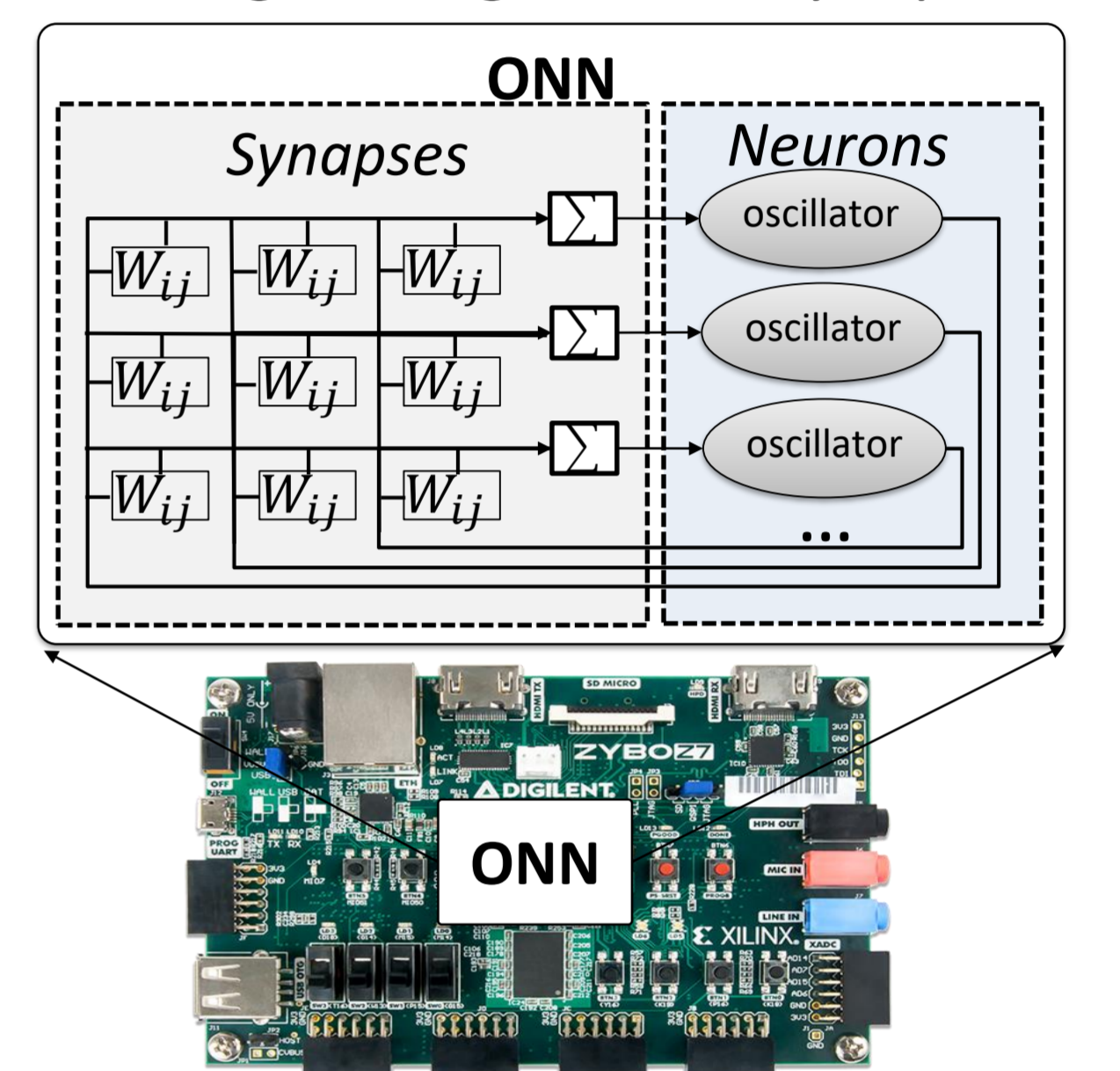
Auto-Associative Memory (AAM)



Hetero-Associative Memory (HAM)

FPGA IMPLEMENTATION [2]

- Digital oscillators
- 5-bits signed registers as synapses



APPLICATIONS AND USE CASES

Digits recognition (AAM) [2]

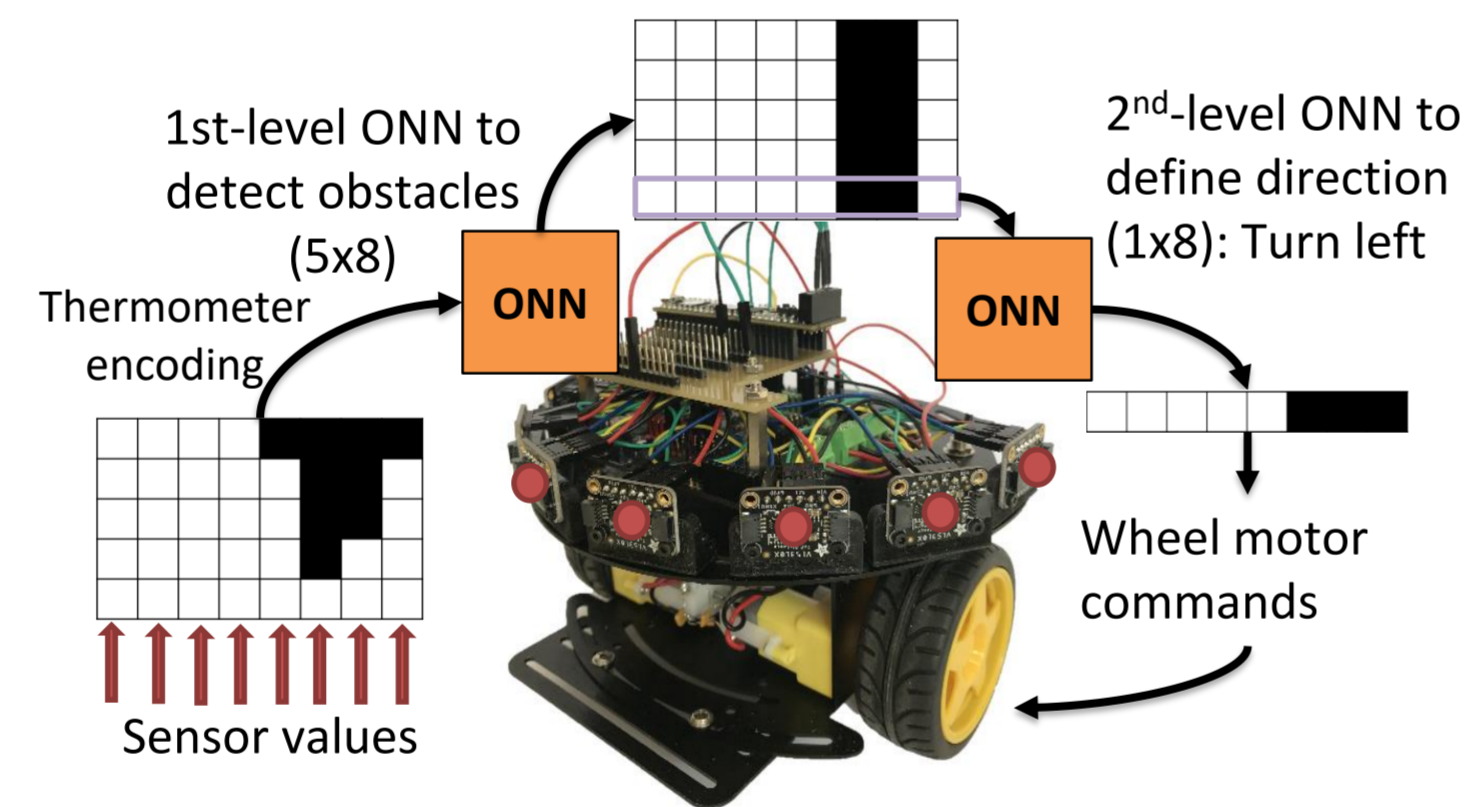
Camera stream to HDMI screen



| 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]

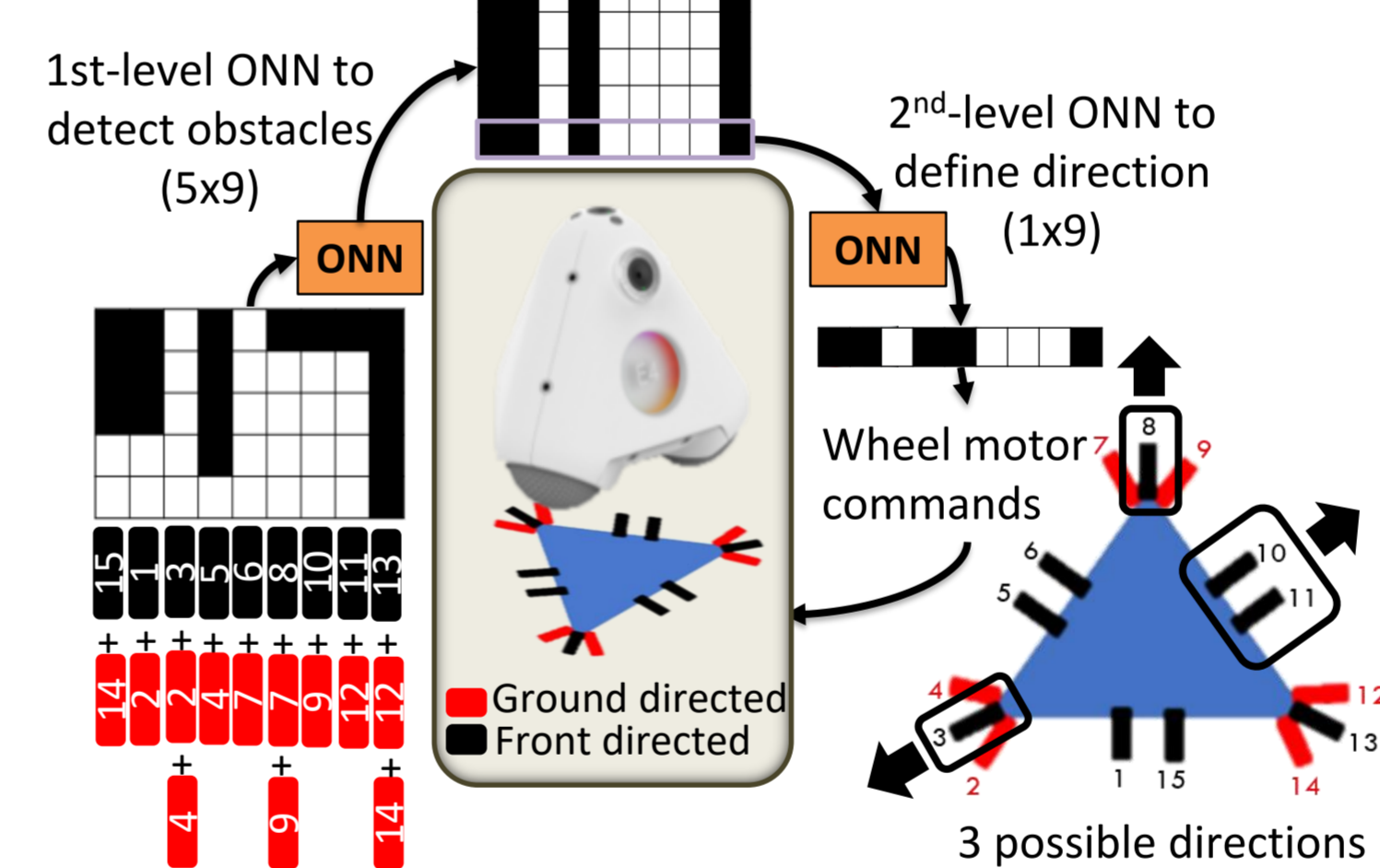
with an Arduino robot



| ONN Performances | 5x8 | 1x8 | Full system performances (FPGA frequency: 12 MHz) |
|---------------------|-------|-------|---|
| #Training Patterns | 256 | 16 | |
| LUTs (33 280) | | 11,5% | 8-sensor measurement 18 ms |
| Flip-Flops (41 600) | | 5,4% | FPS 40 |
| ONN freq. (KHz) | 187,5 | 187,5 | Battery 6V/2850mAh |
| Init & Comp time | 24 us | 17 us | Current cons. 700 mA |
| Accuracy | 100 % | 74 % | Robot life time 4h |

Obstacle avoidance (AAM) [4]

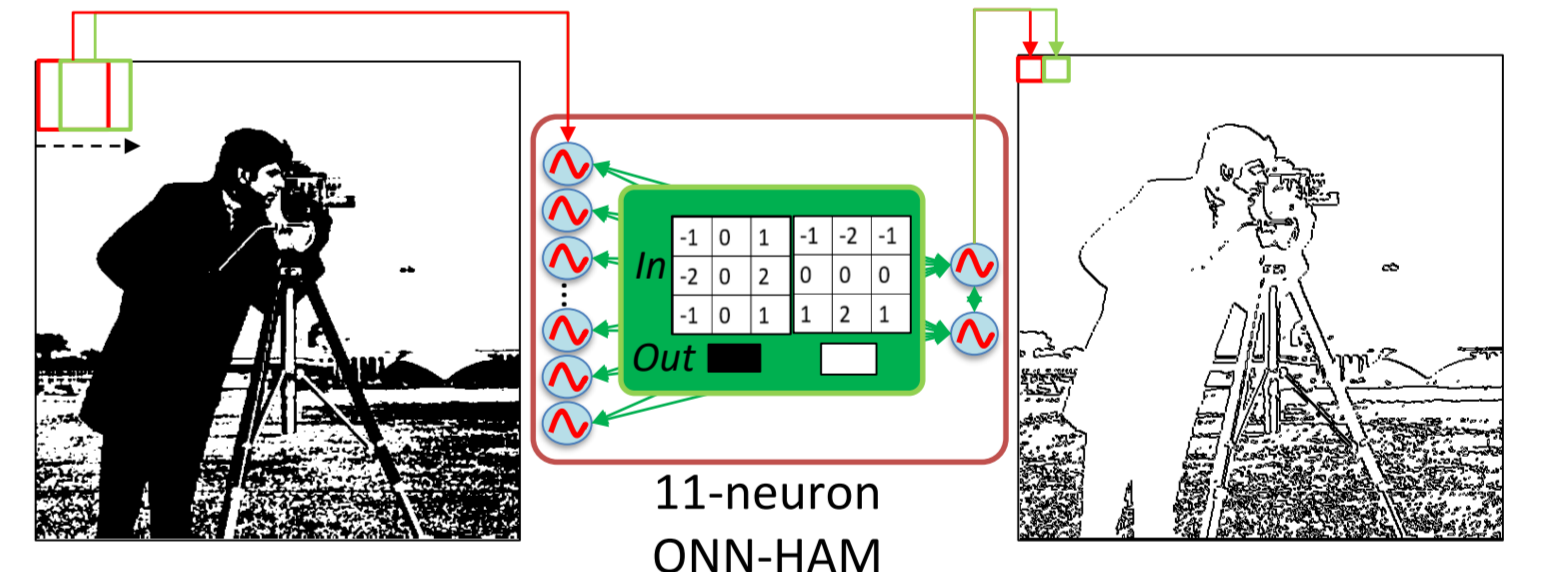
with the industrial robot E4 from A.I.Mergence



| ONN Performances | 5x9 | 1x9 | Full system performances (FPGA frequency: 12 MHz) |
|---------------------|-------|---------|---|
| #Training Patterns | 512 | 64 | |
| LUTs (33 280) | | 20,07 % | 15-sensor measurement 27 ms |
| Flip-Flops (41 600) | | 7,74 % | FPS 30 |
| ONN freq. (KHz) | 187,5 | 187,5 | Robot life time 2h/3h estimation |
| Init & Comp time | 27 us | 17 us | |
| Accuracy | 100 % | 100 % | |

Image edge detection (HAM) [5]

Camera stream to HDMI screen (10x6 ONN)



| 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

- A. Todri-Saniai, et al. EU H2020 NEURONN: Two-Dimensional Oscillatory Neural Networks for Energy Efficient Neuromorphic Computing. *EF ECS*, 2020.
- M. Abernot, et al. Digital Implementation of Oscillatory Neural Networks for Image Recognition Applications, *Front. In Neuroscience*, 2021.
- M. Abernot, et al.. Mobile Robot Obstacle Avoidance with Oscillatory Neural Networks on FPGA. *IBM-IEEE AI Compute Symposium*, 2021.
- M. Abernot, et al. Oscillatory Neural Networks for Obstacle Avoidance on Mobile Surveillance Robot E4. *IJCNN*, 2022.
- M. Abernot, T. Gil, A. Todri-Saniai. Oscillatory Neural Network as Hetero-Associative Memory for Image Edge Detection. *NICE workshop*, 2022.

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