



Physical Reservoir Computing: AI in a bucket of water

X-Student Research Group, Winter Semester 2023-24

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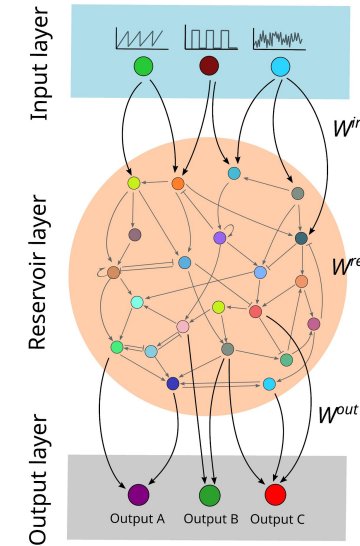
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Postdoctoral Researcher

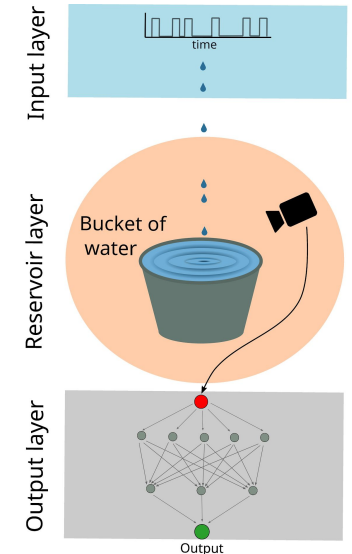
Cyber-Physical Systems in Mechanical Engineering, TU Berlin

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- This project presents a groundbreaking and unconventional approach to constructing an energy-efficient machine learning method utilizing a physical system, specifically employing a bucket of water.
- Collaborative efforts among students will encompass machine learning, micro-controller programming, computer vision, and data processing .
- Main research question:
 - To quantify the computing capabilities of the water-bucket reservoir computer.
 - assess the energy and data efficiency advantages of physical RC compared to classical learning methods.



a. Reservoir Computer architecture



b. Physical Reservoir Computer

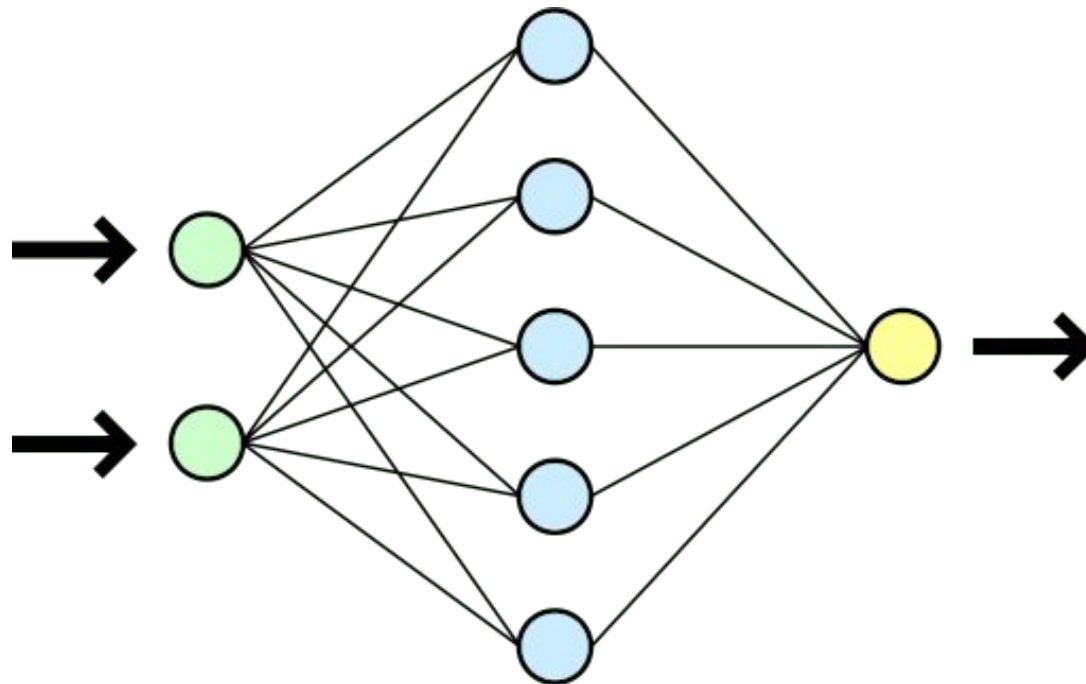
Agenda



- What is Reservoir Computing (RC)?
- What is physical RC?
- What is our idea?
- Results



- Deep neural network with 1 hidden layer:

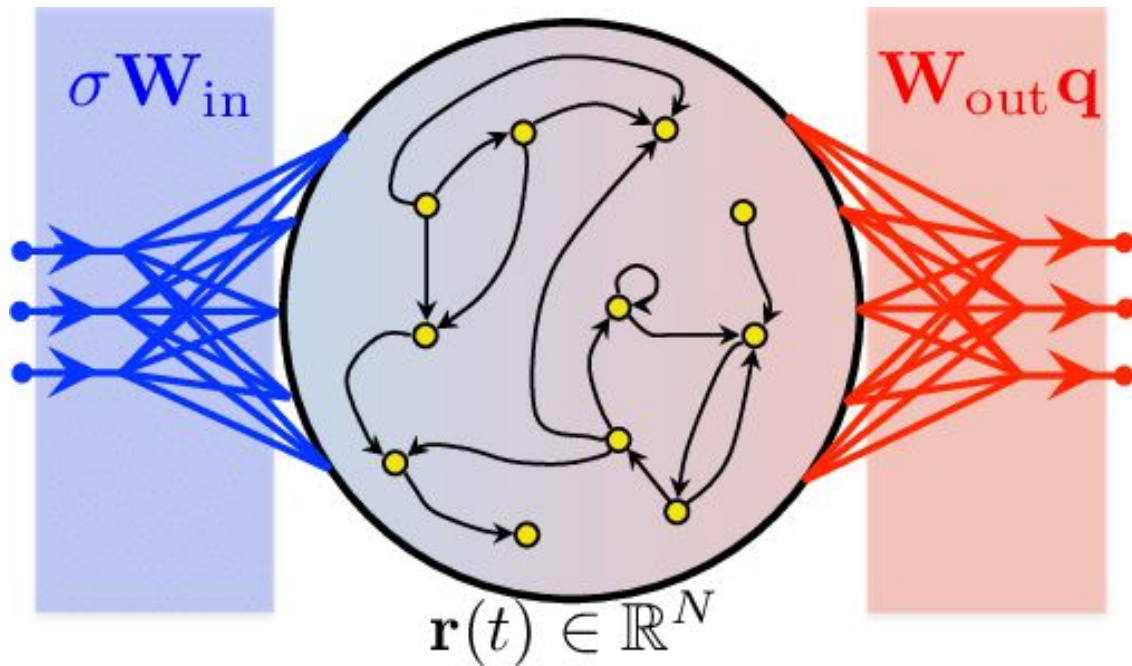


- High accuracy
- Large amounts of data required
- Energy-hungry

What is Reservoir Computer?



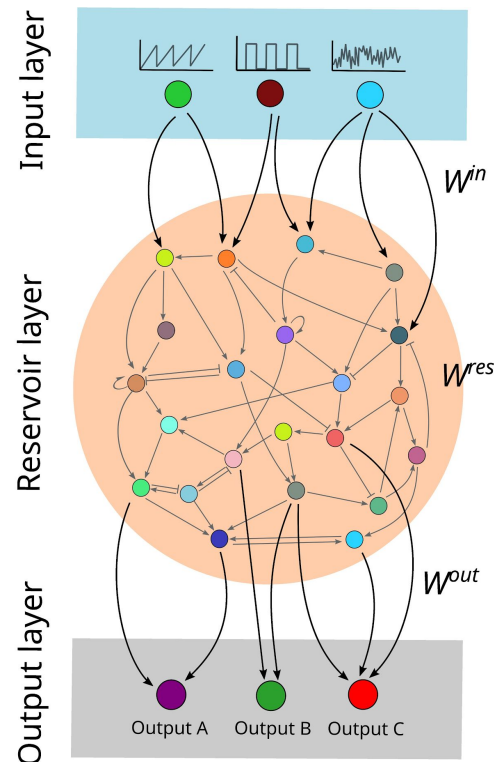
- A reservoir computer has **input**, **reservoir** and an **output** layer:



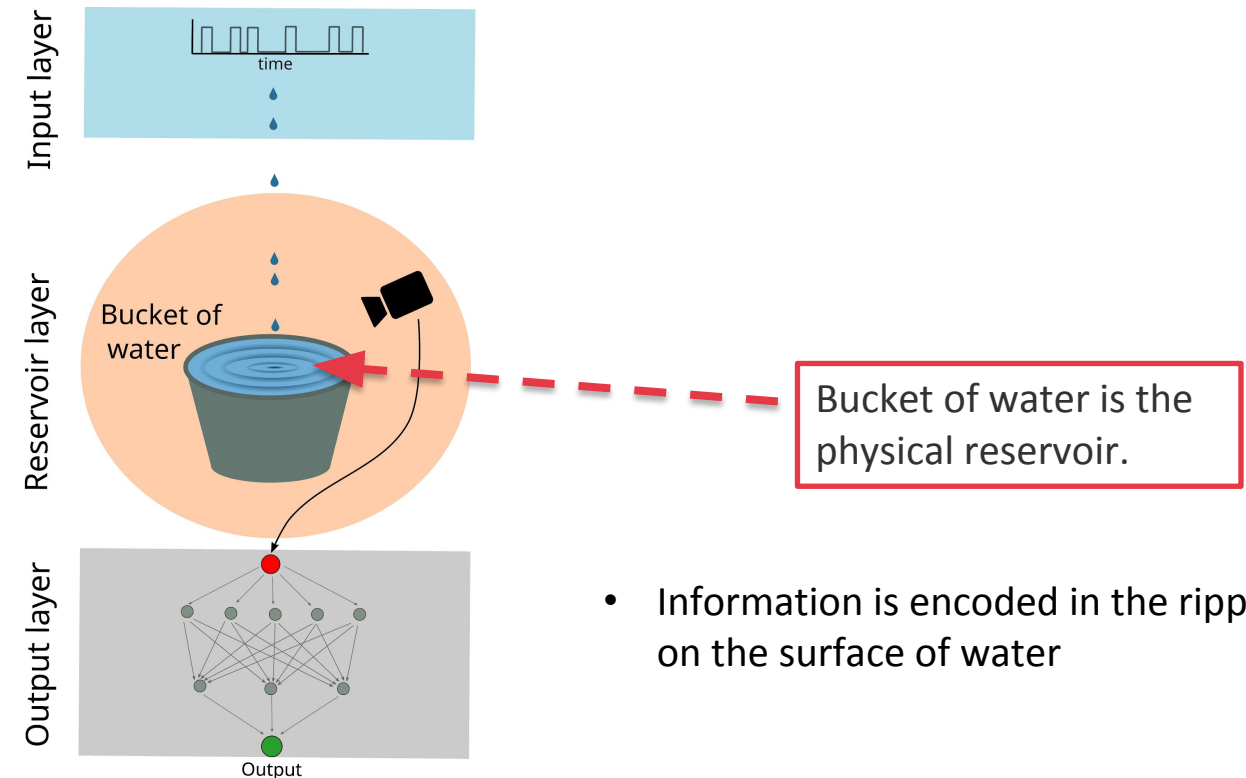
- Easy and Fast to train:
 - Only **output** layer is trainable
- Requires small data for training
- Lower accuracy compared to Feedforward

Neura Networks

- A design of the physical reservoir computer based on bucket of water:



a. Reservoir Computer architecture



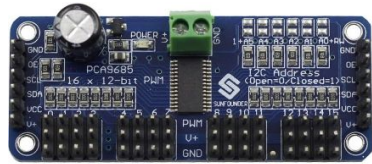
b. Physical Reservoir Computer

- Information is encoded in the ripples on the surface of water

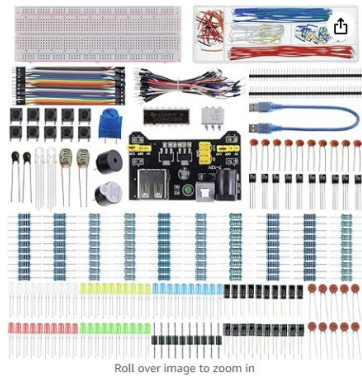
Physical Reservoir Computer



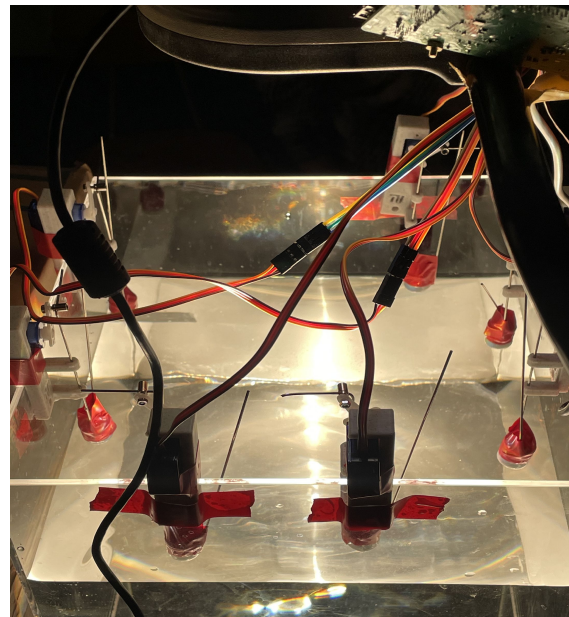
PCA9685 16 Channel 12 Bit
PWM Servo Driver



Raspberry Pi 3



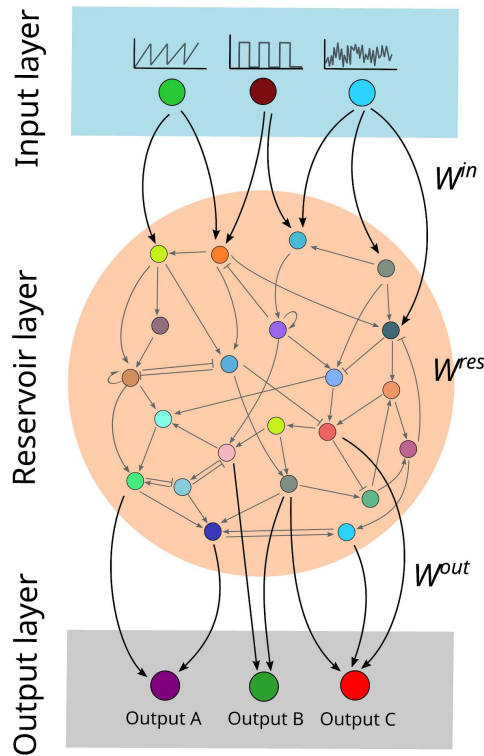
Roll over image to zoom in



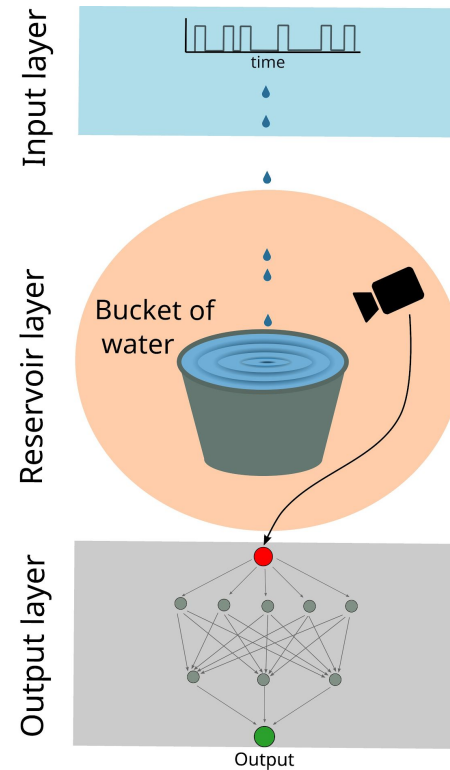
Physical Reservoir Computer



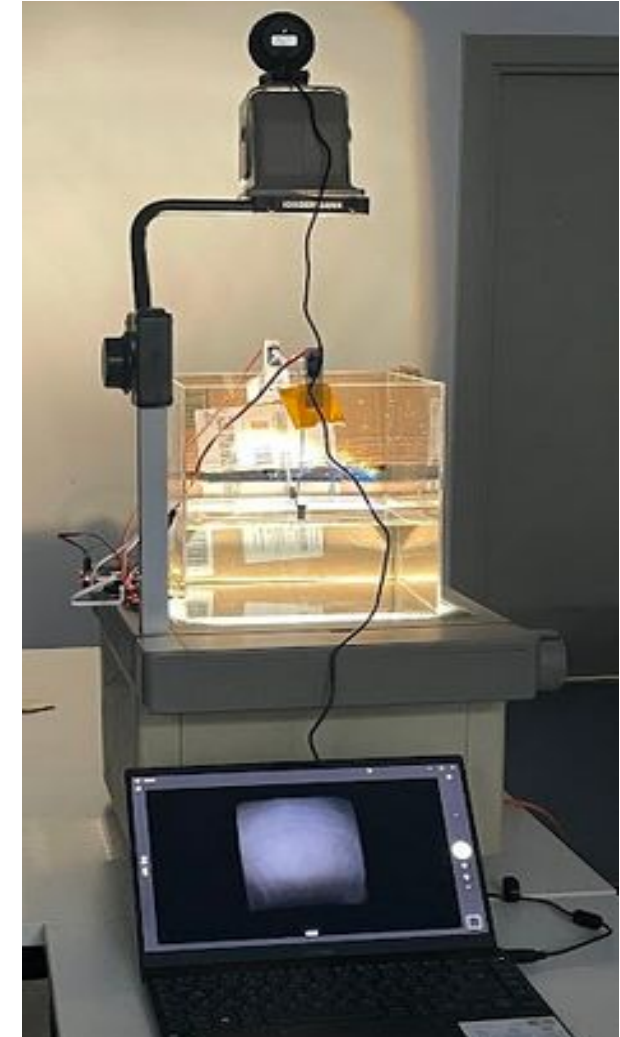
- Bucket of water simulating physical Reservoir Computer:



a. Reservoir Computer architecture



b. Physical Reservoir Computer

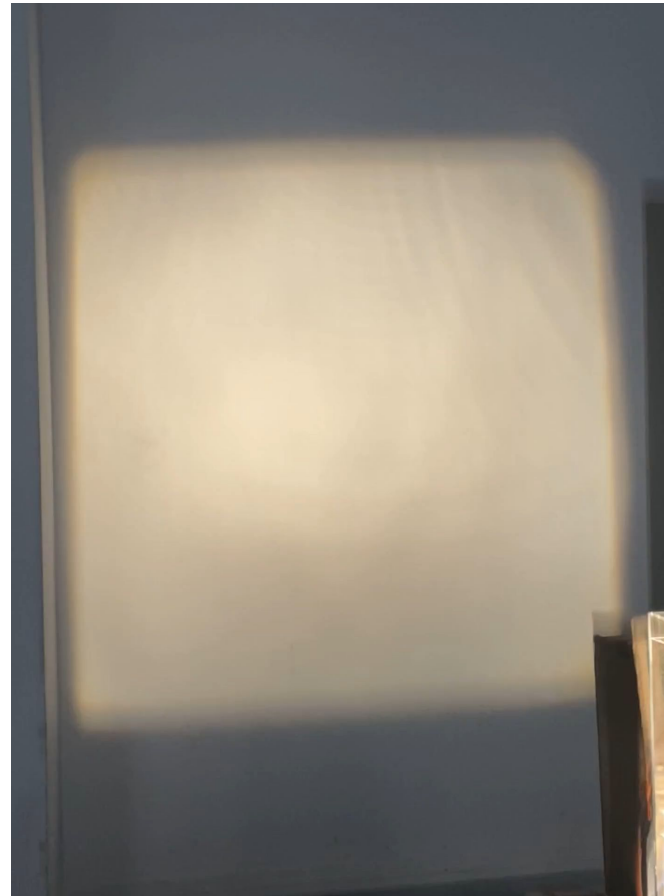
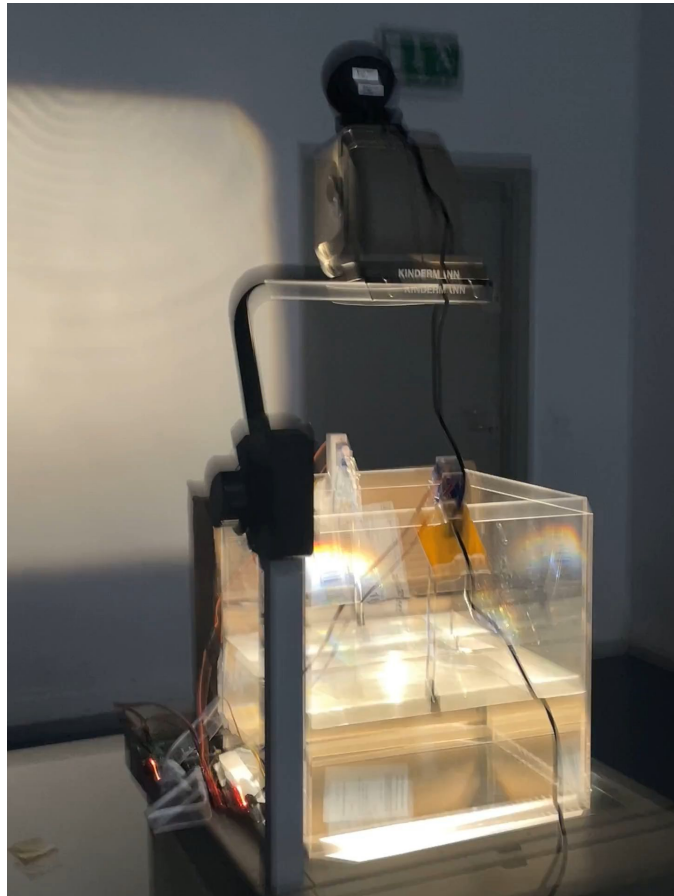


Physical Reservoir Computer



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- Bucket of water based physical reservoir computer in working:



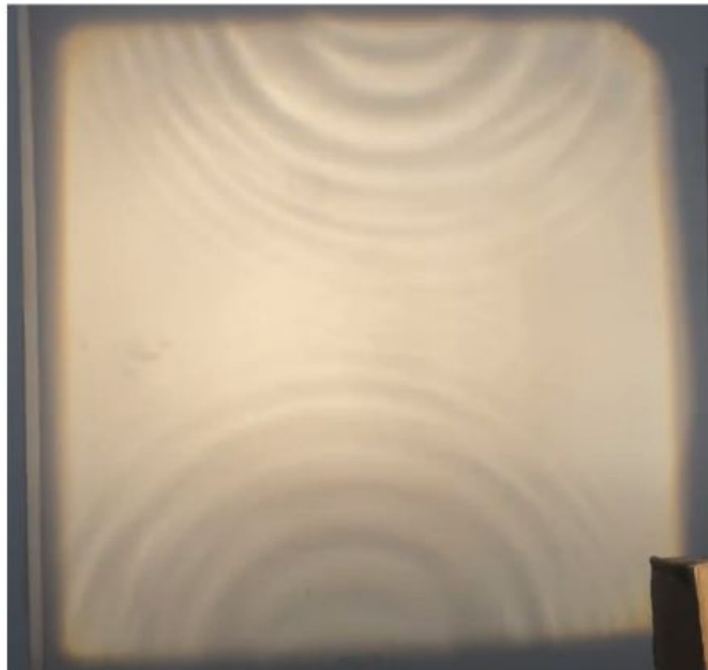
Apparatus arrangement with:

- Different locations of the motors
- Water level
- Distance to the wall (for projection)

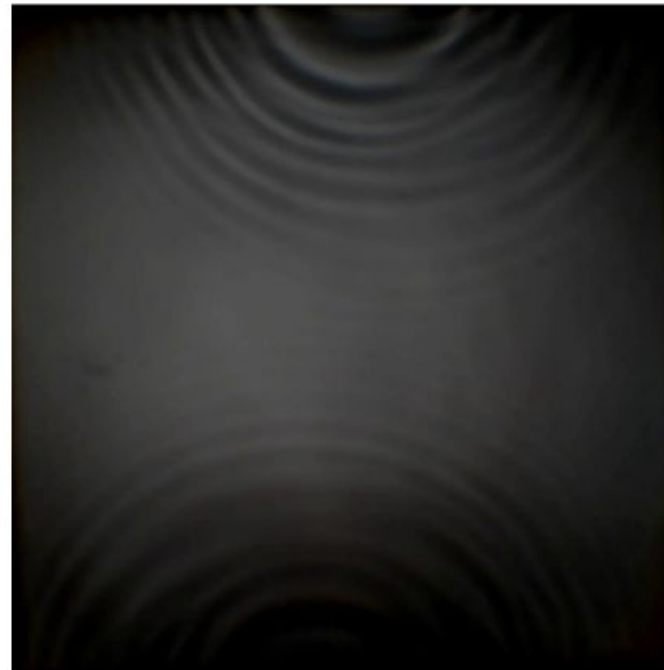
Images Captured by Camera



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Original display on the wall



Picture taken by camera

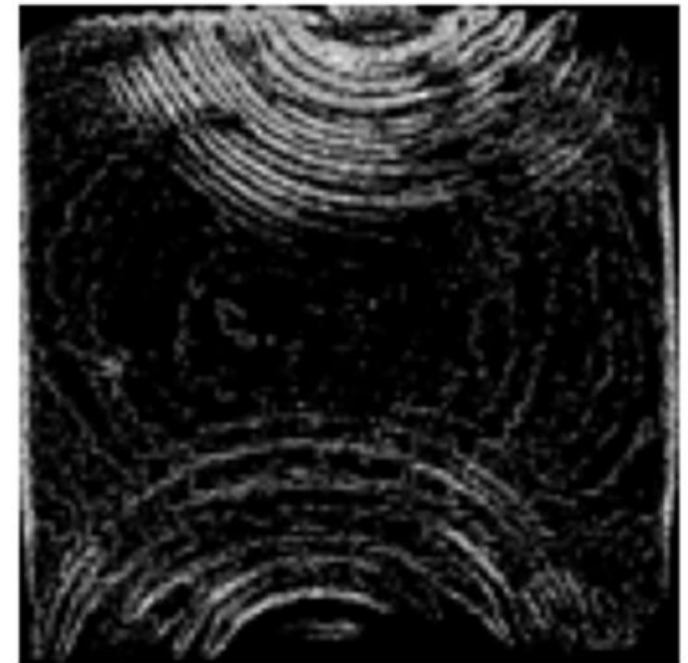
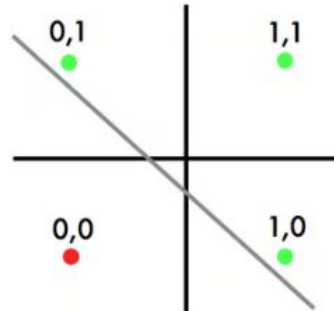


Image after pre-processing

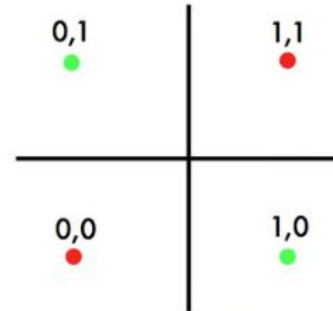
XOR Challenge



- RC to predict the outputs of XOR logic gates given two binary inputs
- Two inputs are not equal - True
- Two inputs are equal - False



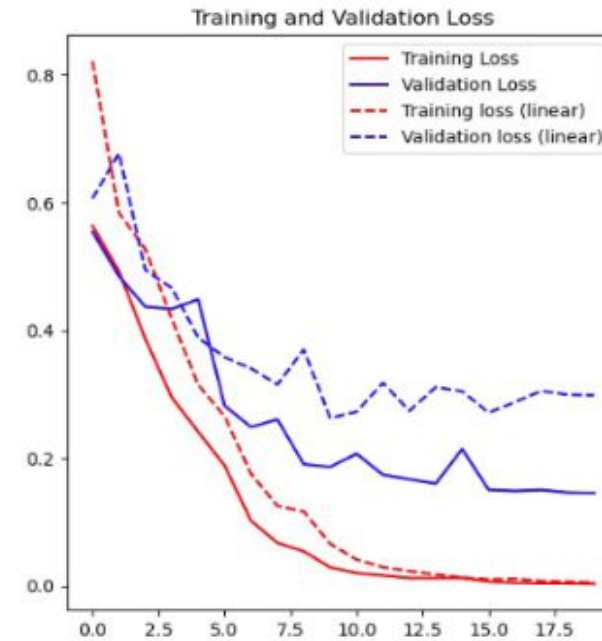
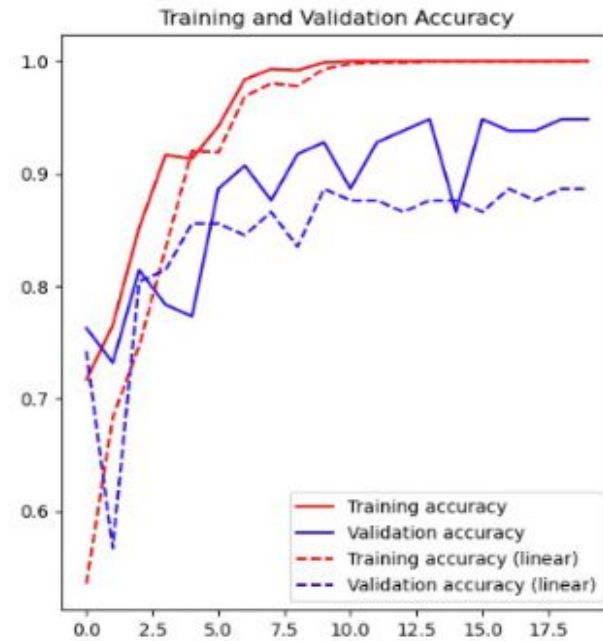
OR



XOR

Input 1	Input 2	Output
0	0	0
0	1	1
1	1	0
1	0	1

XOR Results



Model	BCE-Loss Accuracy	
Linear Model	0.5491	92.57%
Non-Linear Model (ReLU)	0.007	90.04%

Conclusion and Outlook



- XOR task is solved with high accuracy.
- Different servo motors arrangements have been explored for better performance
- Music can be generated with the same setup where each servo motor will act as a musical node.



Media Coverage



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Wohlfühl-Metropole
Gründächer, Kunst, klima-
freundliche Mobilität:
Stadtplanung kann positiv
auf die Psyche wirken

Sciencefluencer*innen
Netzwerken als wissen-
schaftliche Passion:
Wie die eigene Forschung
sichtbarer wird

Wassermangel
Unverstandene Phänomene:
Warum verliert der Groß-
Glienicker See mehr Wasser
als der Sacrower See?



Wir/Vier



Künstliche Intelligenz in einem Wassereimer

Ein Eimer Wasser, der sich in einen Computer verwandelt? Sieben Student*innen verschiedener Fachrichtungen haben in der X-Student Research Group „AI in a bucket of water“ das innovative Konzept eines physischen Reservoir-Computers verwirklicht. Schallwellen gesprochener Zahlen steuern

vertikale Schwimmer, die auf der Wasseroberfläche Wellen erzeugen. Eine Kamera fängt diese Wellen ein, während ein Algorithmus sie in klare visuelle Muster umwandelt und mit bestimmten Zahlen verknüpft. Das Ergebnis? Das Wasser verwandelt sich in ein intelligentes Lernsystem, Natur und Technologie verschmelzen. Das Experiment steht für

einen echten Paradigmenwechsel: weg von komplexen und energieintensiven KI-Systemen hin zur Nutzung natürlicher Ressourcen für intelligente Lösungen. So entsteht eine umweltfreundliche Alternative zu klassischen Deep-Learning-Techniken, die ein immenses Potenzial für umweltfreundliche KI bietet. (hal)



THANK YOU!

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