Brain-inspired Optical Computing

Gleb Anufriev

Dr Sendy Phang, Prof Angela Seddon, Dr David Furniss, Prof Mark Farries, Prof Trevor Benson.

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

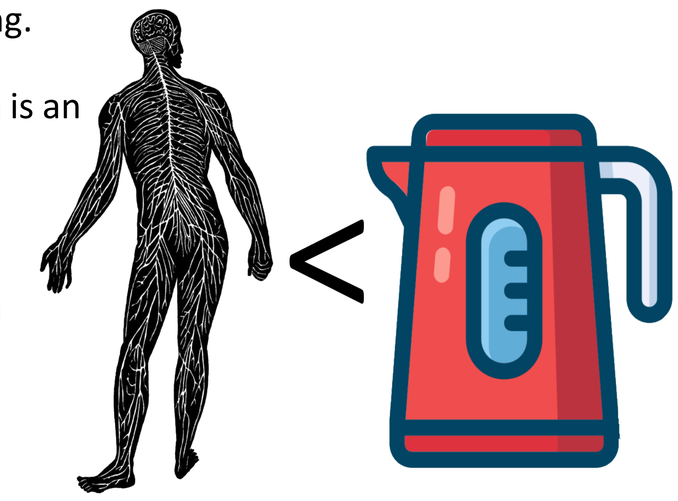
A Biological Computer

AIM: development of a novel sensing system inspired by human nervous system, i.e., Neuromorphic sensing.

FACT: The human nervous system is an efficient and powerful 'biological computer'.

FACT: The human nervous system consumes 20 Watts of power and can process an enormous stream of information in real-time.*

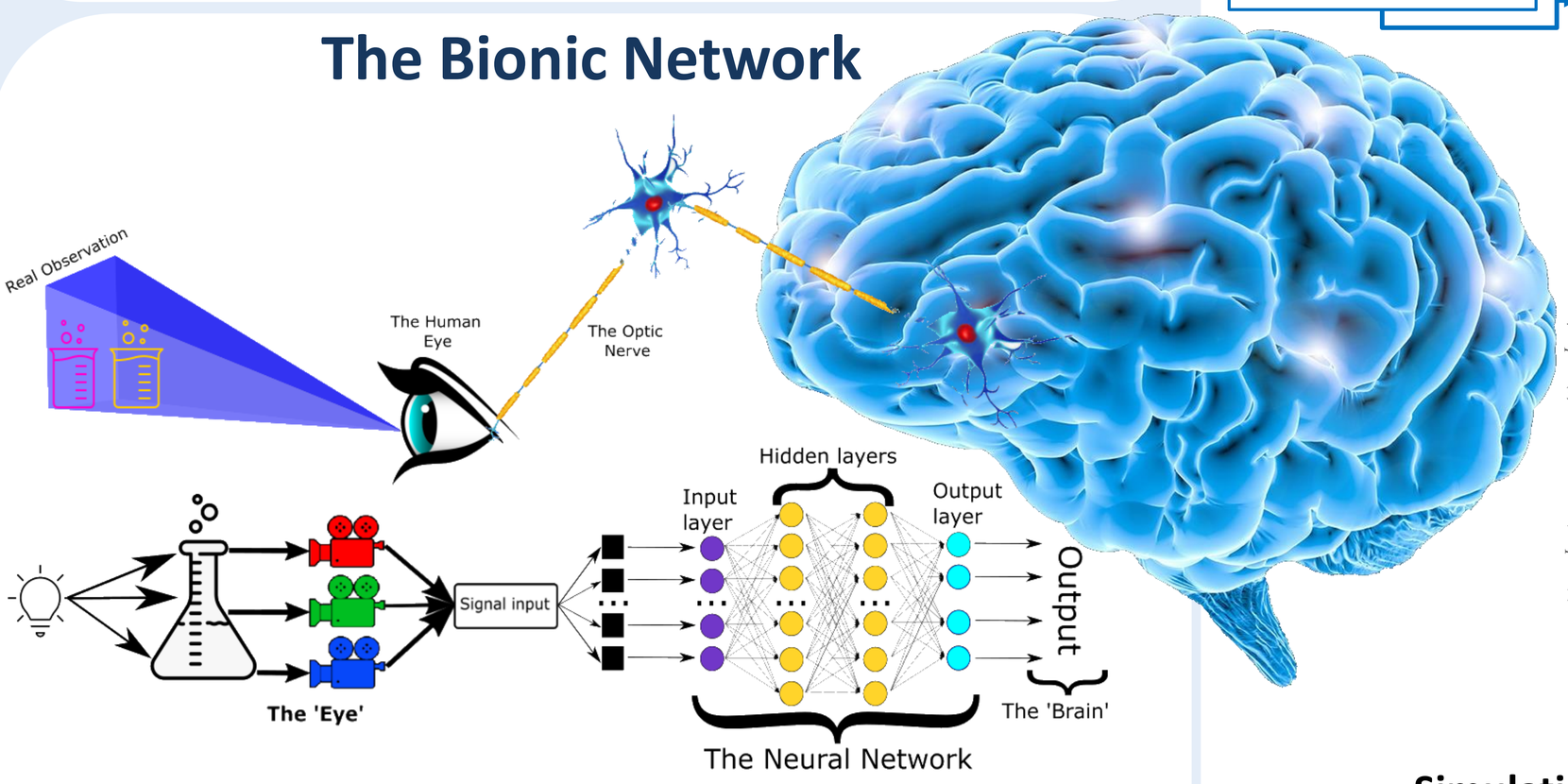
APPLICATIONS: Real-time monitoring and sensing applications.



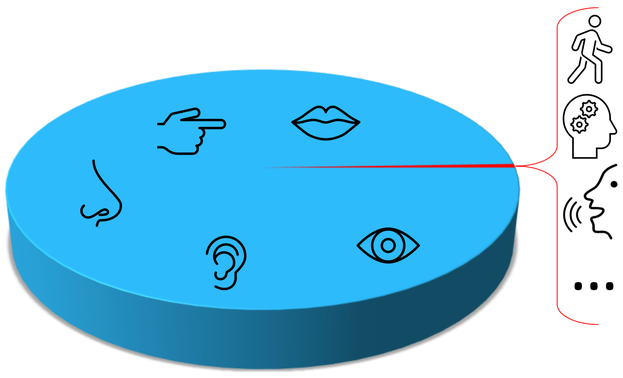
*The human nervous system consumes less than 1% power than the average kettle.**

* W. B. Levy "Computation in the human cerebral cortex uses less than 0.2 watts yet this great expense is optimal when considering communication costs," BioRxiv (2020).

The Bionic Network



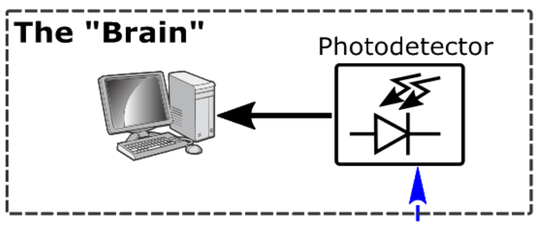
Artificial sensing system inspired by the human sensory system.



- ≈ 99.99% of human brain's computing capacity is used for sensory processing.
- < 0.01% is used for motor function, language, decision making, etc.

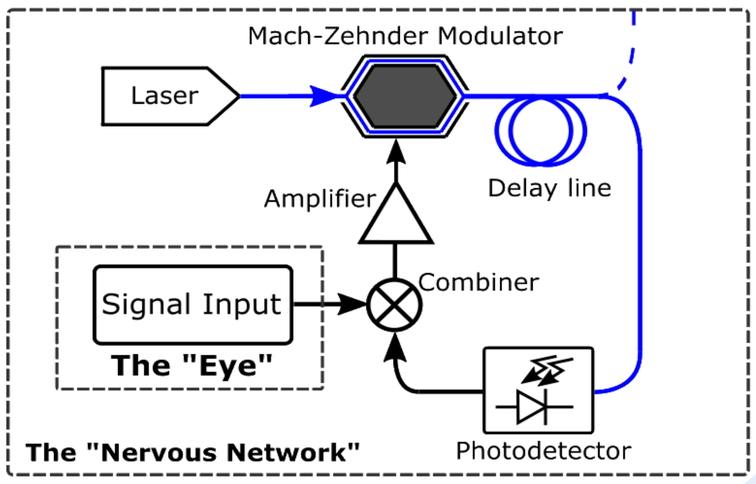
❖ **The 'Eye'**
Based on a trichromat configuration with three types of 'cone cells' similar to the in the human eye (red, green and blue).

❖ **The 'Brain'**
Computationally interprets received information.



❖ **The 'Nervous network'**
An optical fibre implementation of the human nervous system.

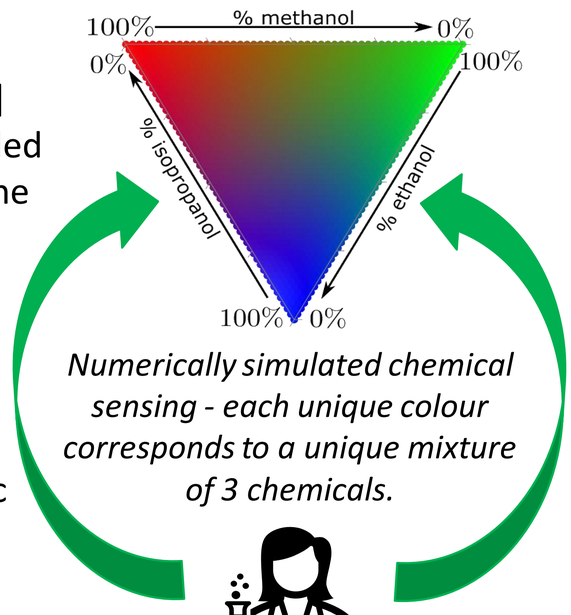
Properties:
- ✓ Complex
- ✓ Interconnected
- ✓ Chaotic
- ✓ Fading memory



Results

❖ **Mathematical and numerical model [1]**
A MATLAB software implementing coupled partial differential equations model of the 'bionic chemical sensing'.

❖ **Experimental – optical rig**
An experimental prototype of the brain-inspired computing system is employed. This relies on both optical and electronic components for its realisation.



Numerically simulated chemical sensing - each unique colour corresponds to a unique mixture of 3 chemicals.

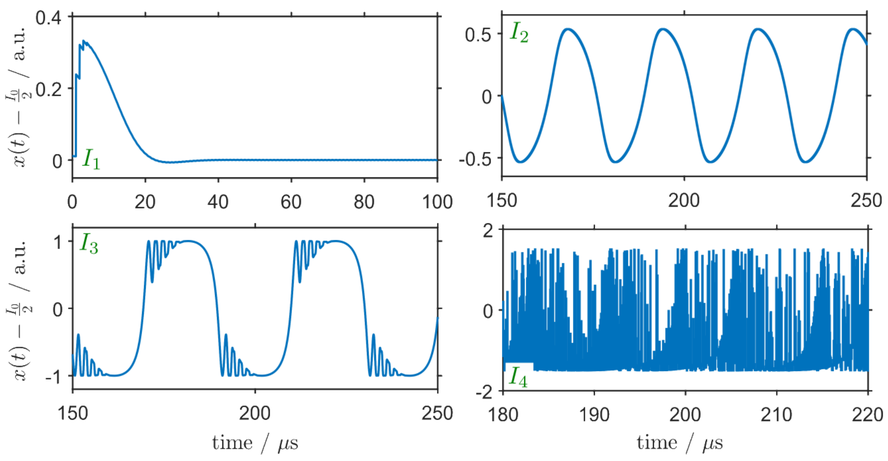
Experimental observation

❖ **Chaotic light**

The human nervous system is chaotic.

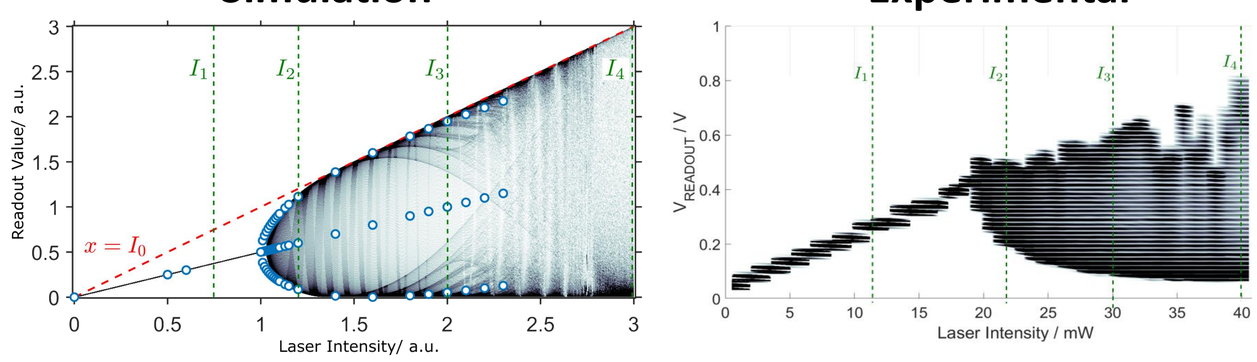
The experimental realisation mimics the behaviour of the human nervous system.

The experimental prototype system evolves from linear, to oscillating, to chaotic behaviour.



Temporal response of the artificial 'nervous network'

Simulation **Experimental**



The evolution of artificial 'nervous system' response with increasing laser intensity.[1]

Three distinct responses have be observed in simulation and experiment:

1. Linear region (I_1)
2. Oscillating region (I_2 and I_3)
3. Chaotic region (I_4)

Conclusions

- Brain-inspired computing is a new advancement in sensory applications.
- This novel type of sensory system can be used in conjunction with multiple sensors for different types of sensing applications.

Publication

1. Anufriev, G., Furniss, D., Farries, M., & Phang, S. (in press). Non-spectroscopic sensing enabled by electro-optical reservoir computer. Optical Materials Express, Vol. 12, Iss. 4 April 1, 2022, pp: 1303-1626.

The George Green Institute for Electromagnetic Research
ezxga2@nottingham.ac.uk