iPRONICS
Programmable Photonics

Photonics Research Labs

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

THE SPINOFF PRIZE
ONE TO WATCH 2020
nature research awards

Optical Computing with Programmable Photonics

José Capmany

erc

European Commission

www.ipronics.com

iPRONICS
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European Research Council
Established by the European Commission

European Innovation Council

European Innovation Council (EIC) established by the European Commission, under the Horizon Europe programme (2021-27)

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MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

CDTI Centro para el Desarrollo Tecnológico Industrial

Amadeus Capital Partners

Caixa Capital Risc

Introduction & Motivation

The current pain

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Emerging Applications with voracious processing & bandwidth appetite!!

5G and Beyond

Bio instruments

Lab-on-a-Chip Sensors

Internet of Things

Autonomous driving

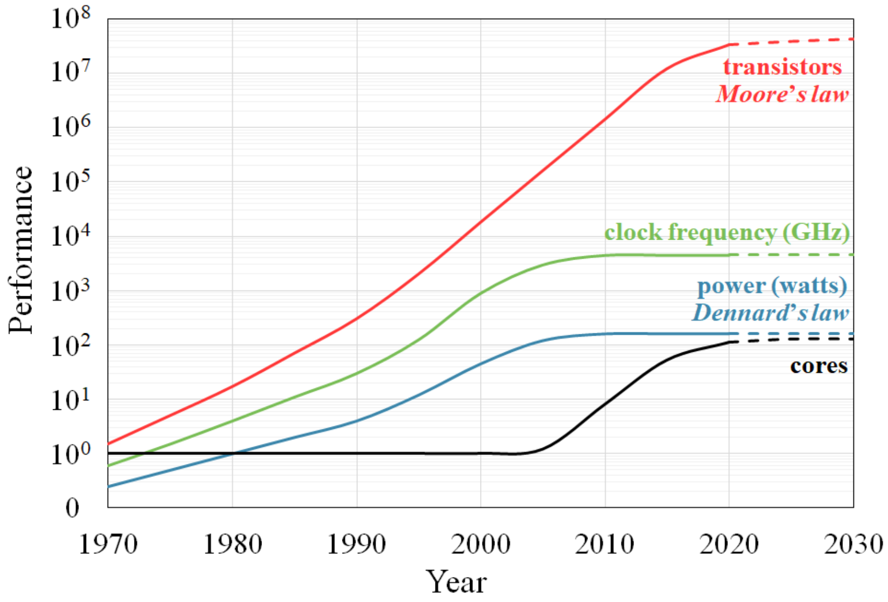
Neurocomputing and Artificial Intelligence

Hardware acceleration

Avionics & Space

Quantum Information

Demise of Moore and Dennard Scaling Laws



Most of these require heavy computing capabilities

Electronics needs to team up with other technologies to meet these requirements.

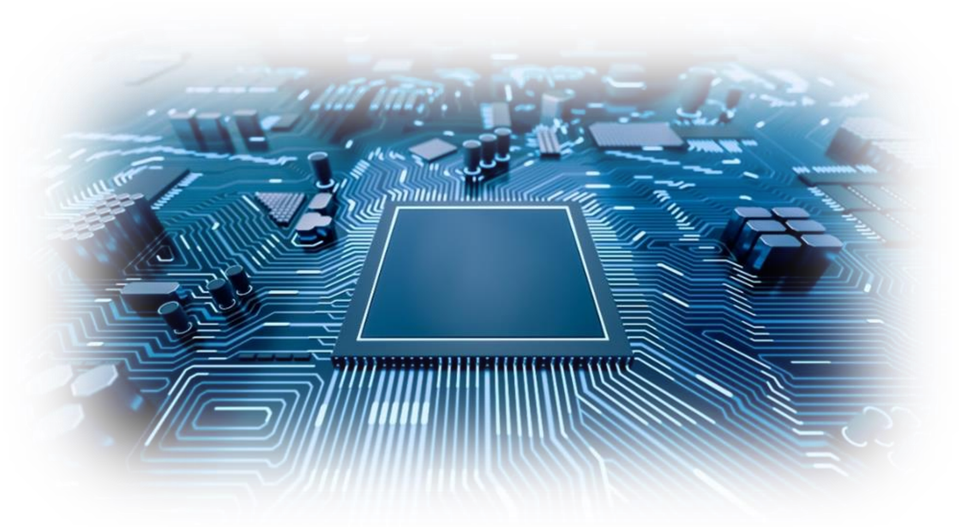
A win-win solution: Electronics + Photonics

Photonics provides bandwidth, low power consumption and is complementary to Electronics.

Application-Specific Photonic Integrated Circuits are being successfully integrated into applications yet, their time-to-market and fabrication cost is many times a show stopper.

The solution is ***Programmable Photonics!***

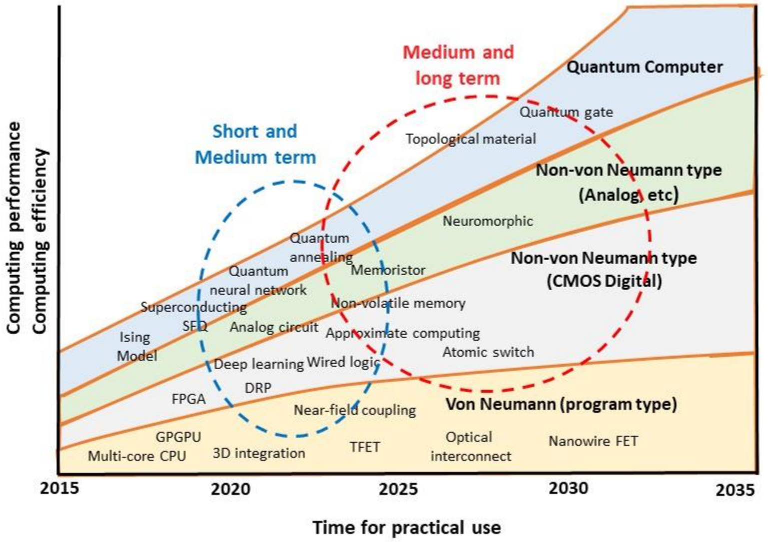
Solutions equivalent to FPGAs, DSPs, microprocessors and computers will be needed.

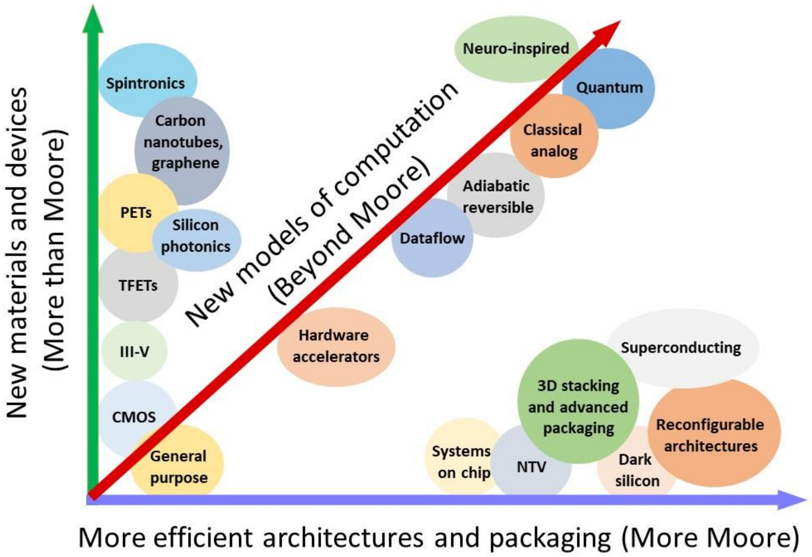


The paradigm shift

BUT….these computing approaches will not be non Von-Neumann inspired

- ✓ Hardware challenges (More than Moore)
- ✓ Computational challenges (Beyond Moore)
- ✓ Analog approach





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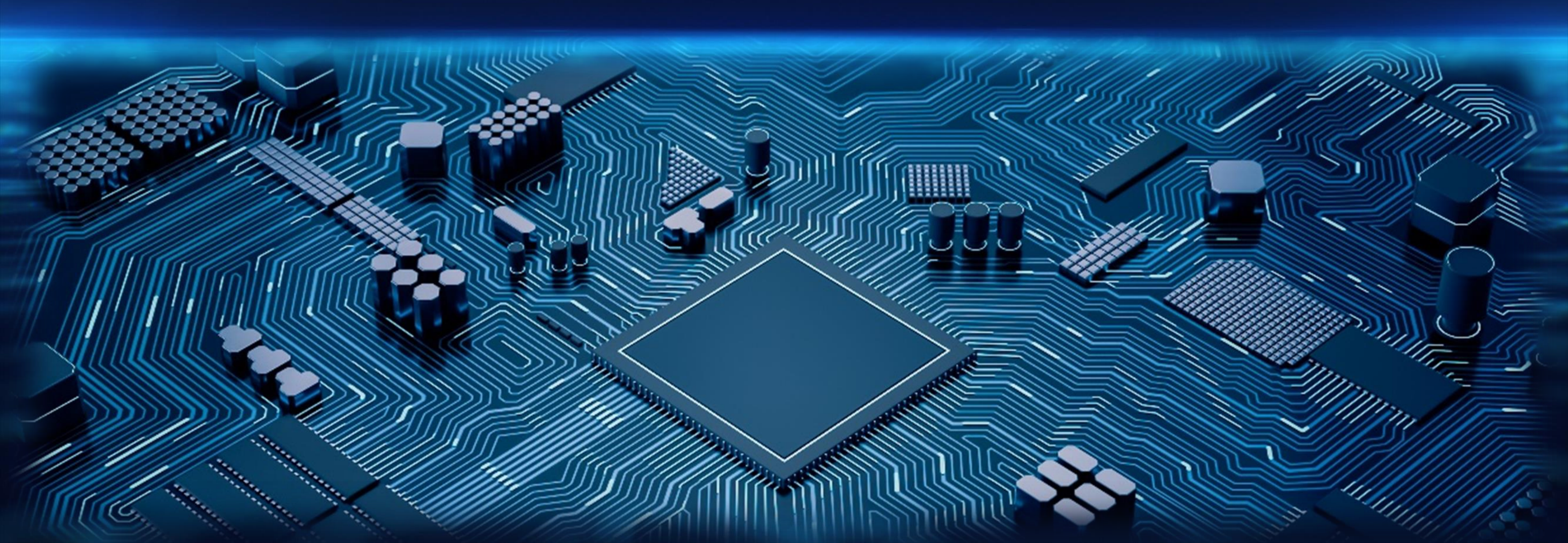


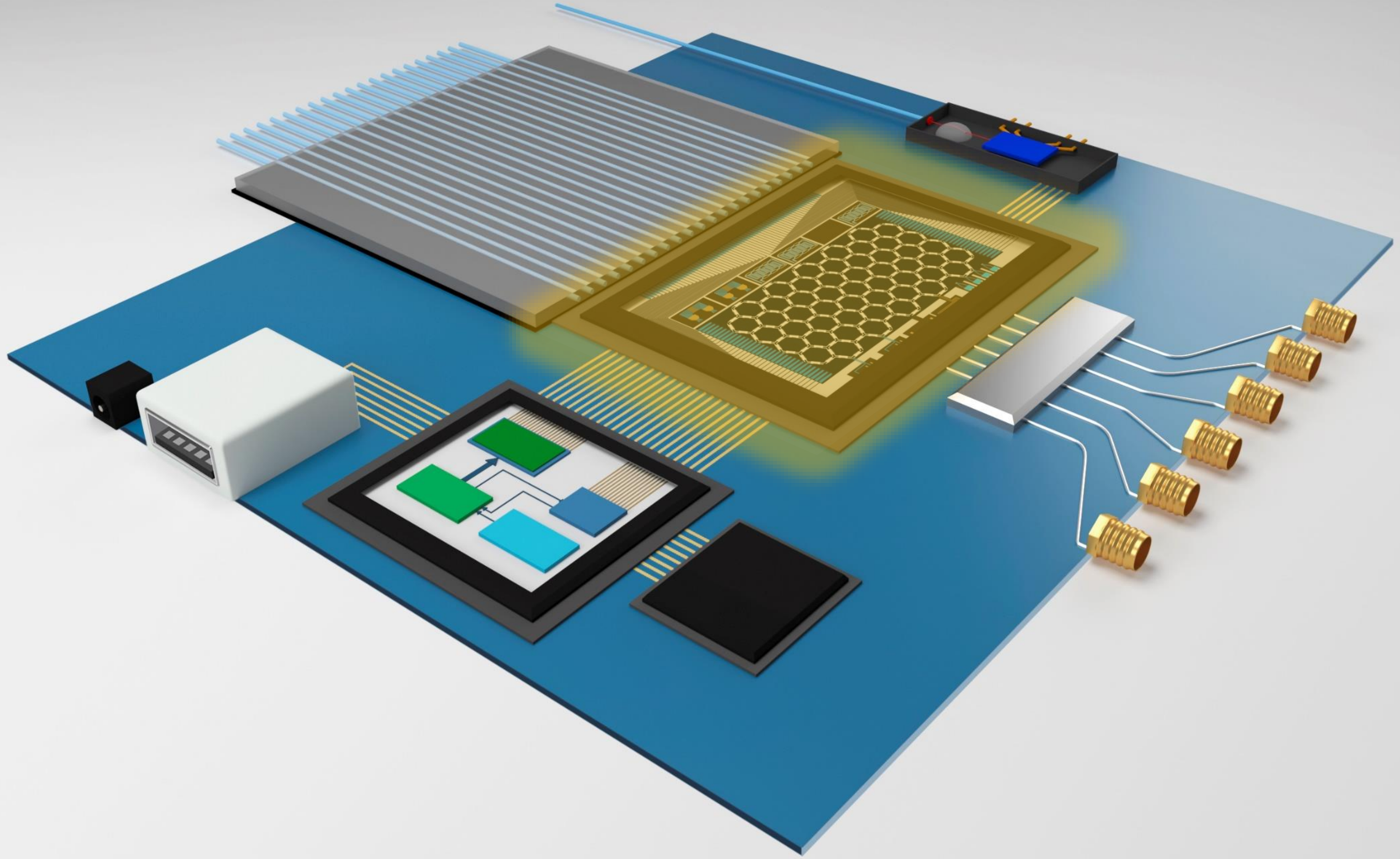
Plug & Play Programmable Processor

Multipurpose photonic processor including:

Photonic layer: a flexible optical core and IP/High performance blocks

Electronic layer: monitoring & control

Software layer: programming, optimization & interface with network control layer



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Programmable Unit Cell: How does it works?

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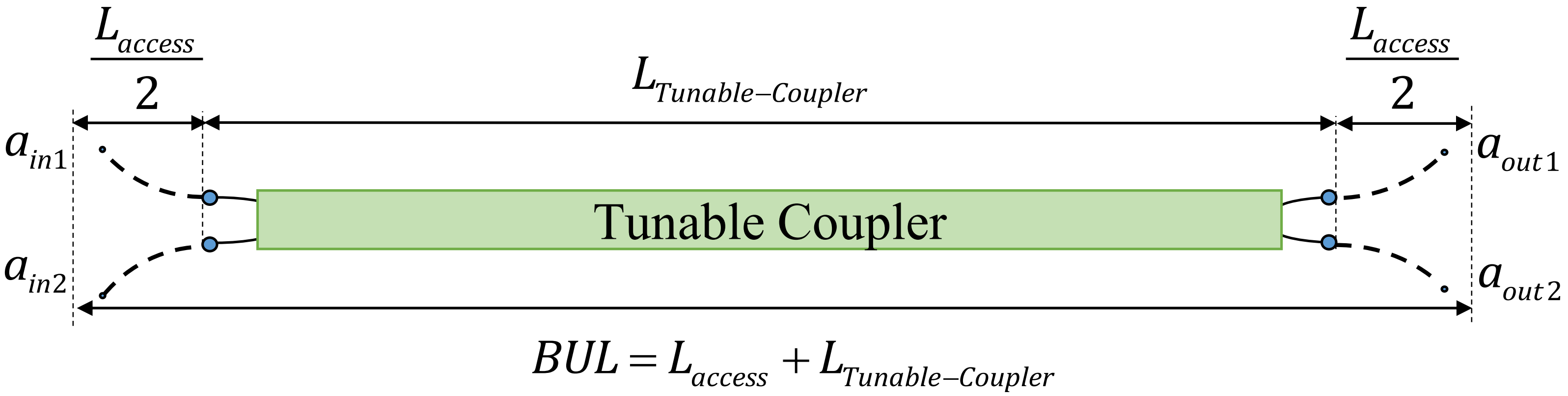
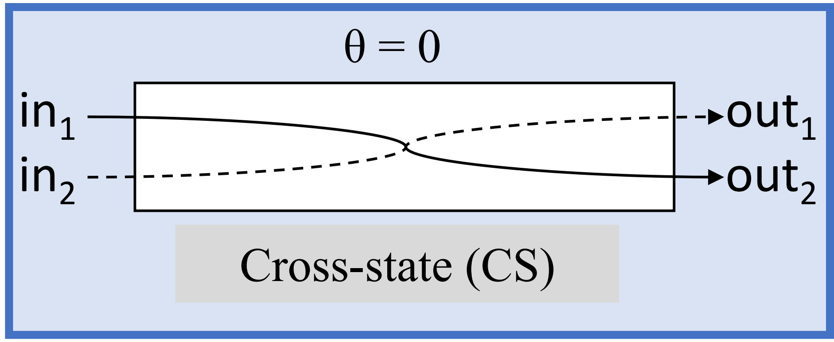
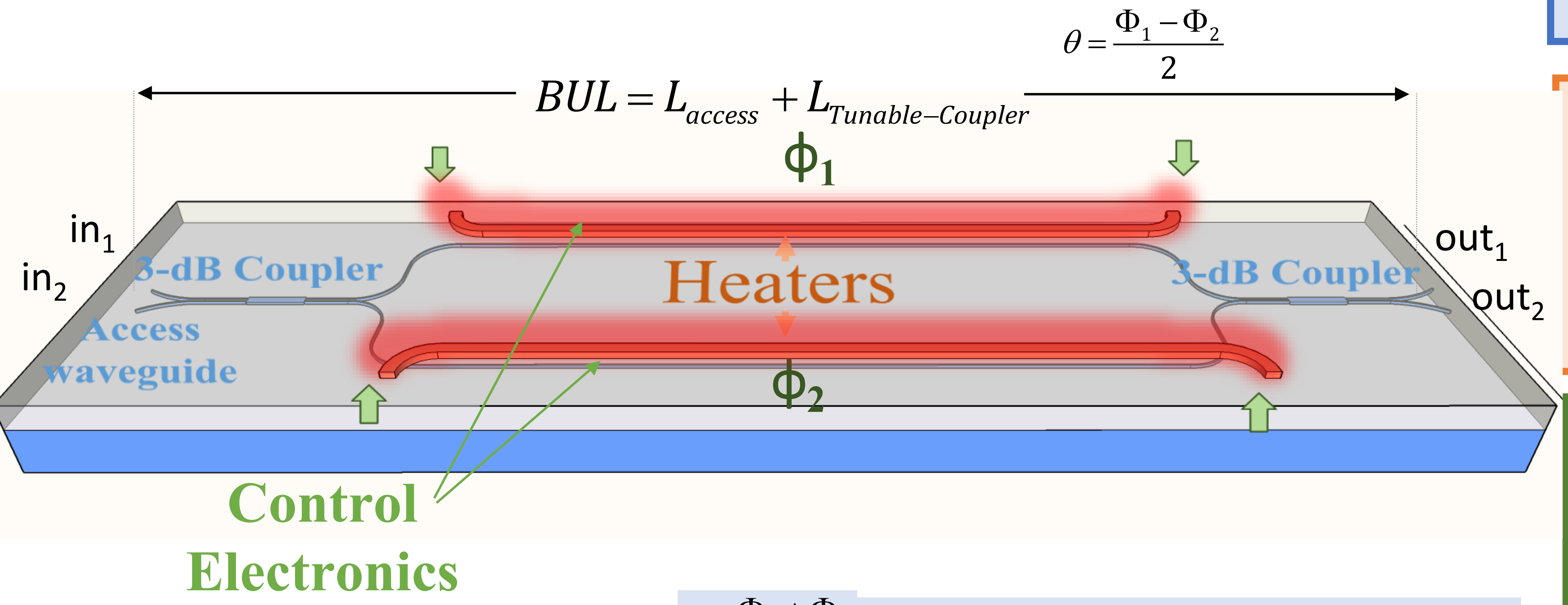
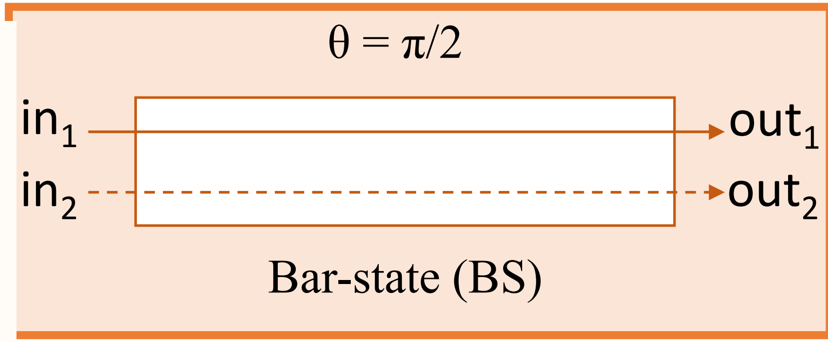
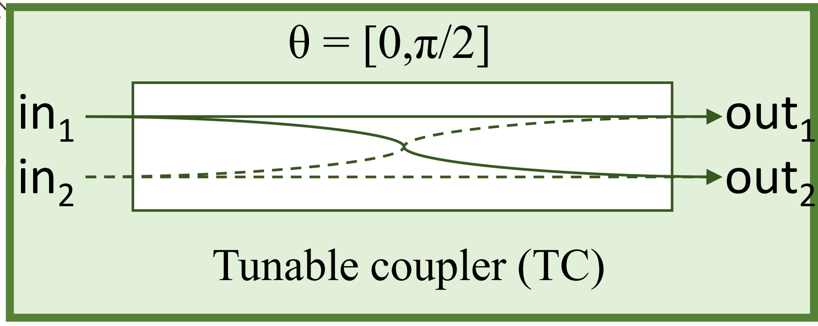


$\theta = \frac{\Phi_1 - \Phi_2}{2}$ Sets the **power division**









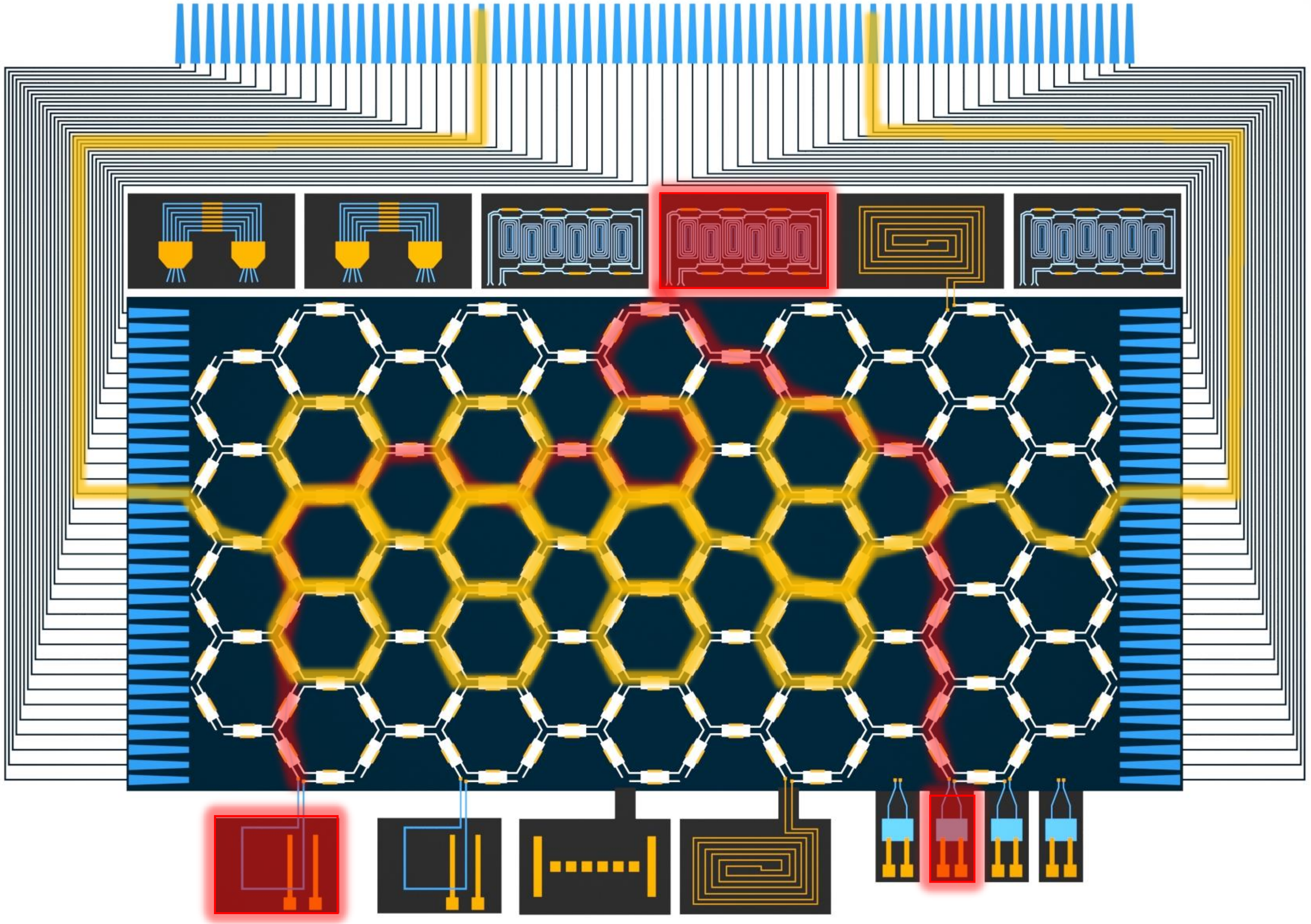
$\Delta = \frac{\Phi_1 + \Phi_2}{2}$ Sets the (independent) **phase shift**

Photonics Layer

Programmable Silicon photonics waveguide mesh

IP/High performance blocks

- Lasers
- Detectors
- Amplifiers
- WDM MUX/DEMUX
- etc



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Software Layer

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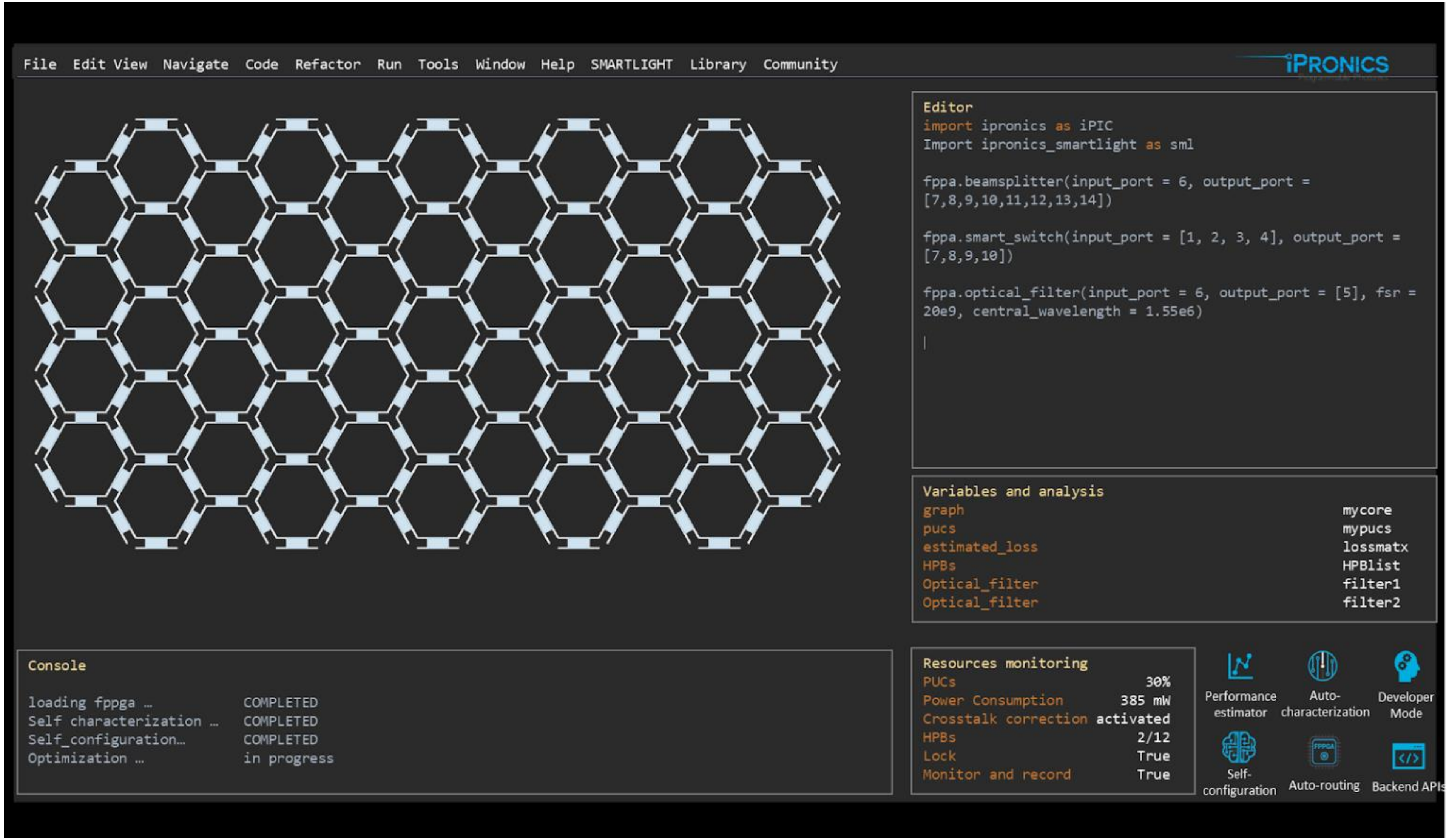
Software Framework

- Performance estimator
- Auto-characterization
- Self-configuration
- Auto-routing

- Developer Mode
- Backend APIs



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Some Computing approaches

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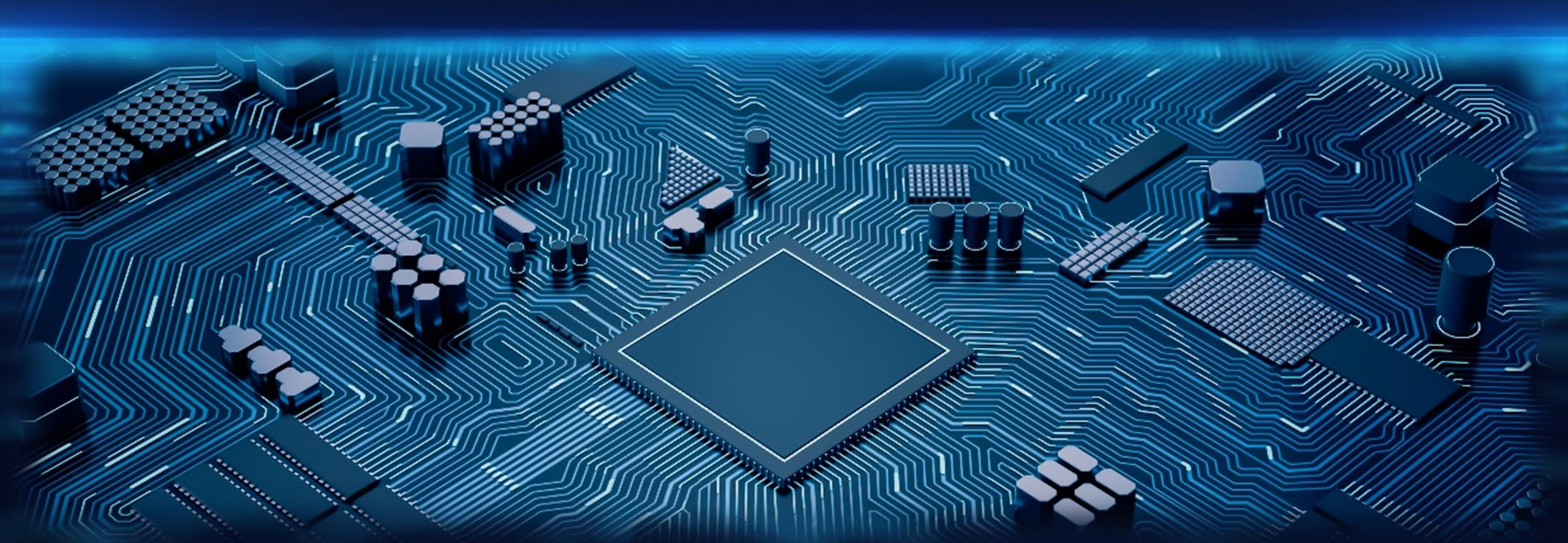
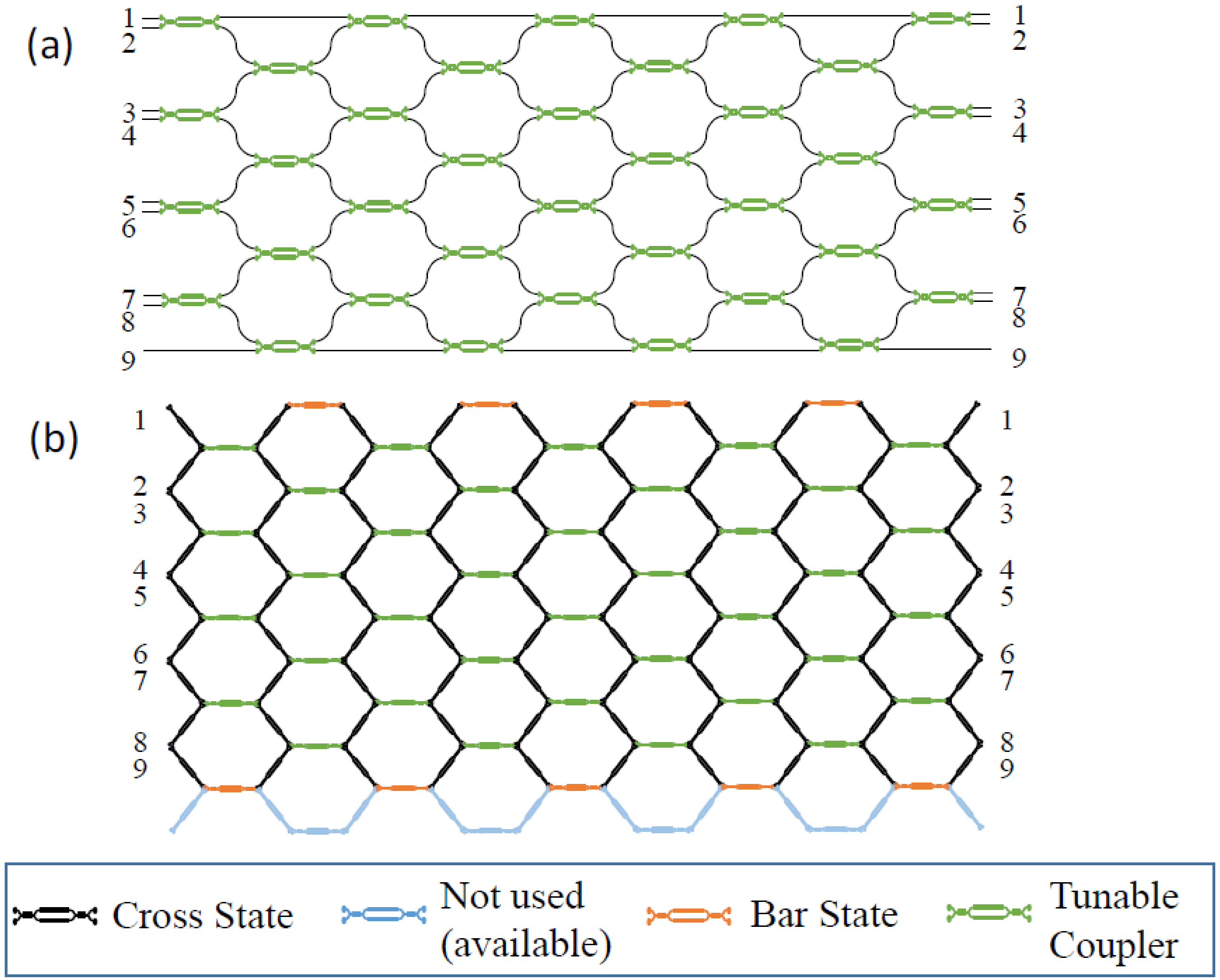


Some basic functionalities



Can implement any arbitrary complex-valued NxN Matrix transformation through the emulation of a multiport interferometer.

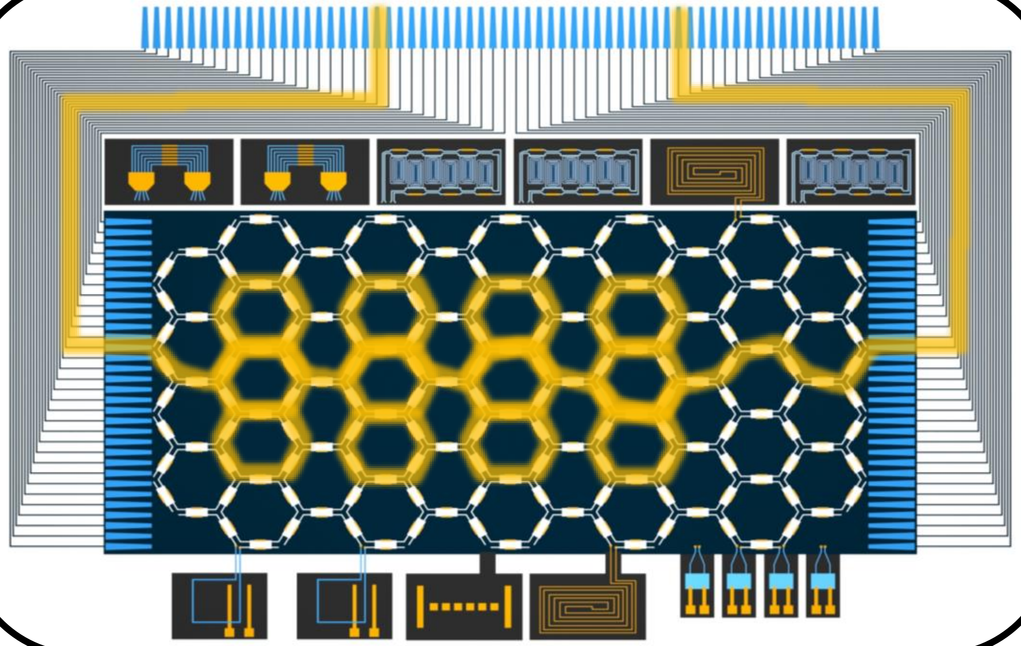
This includes:

a) Pure switching
b) Switching+Multicasting
c) Broadcasting
d) Complex interconnection maps
e) Matrix-vector multiplication
f) DFT

Matrix-Vector- Multiplication computing

Matrix M

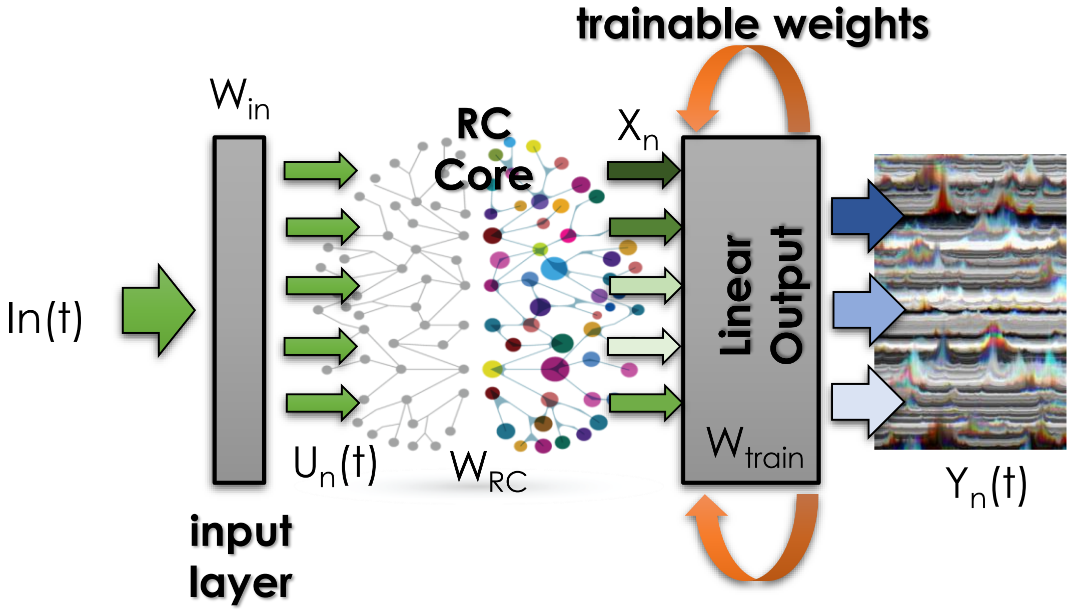
$$\begin{pmatrix} O_1 \\ O_2 \\ \vdots \\ O_N \end{pmatrix} =$$

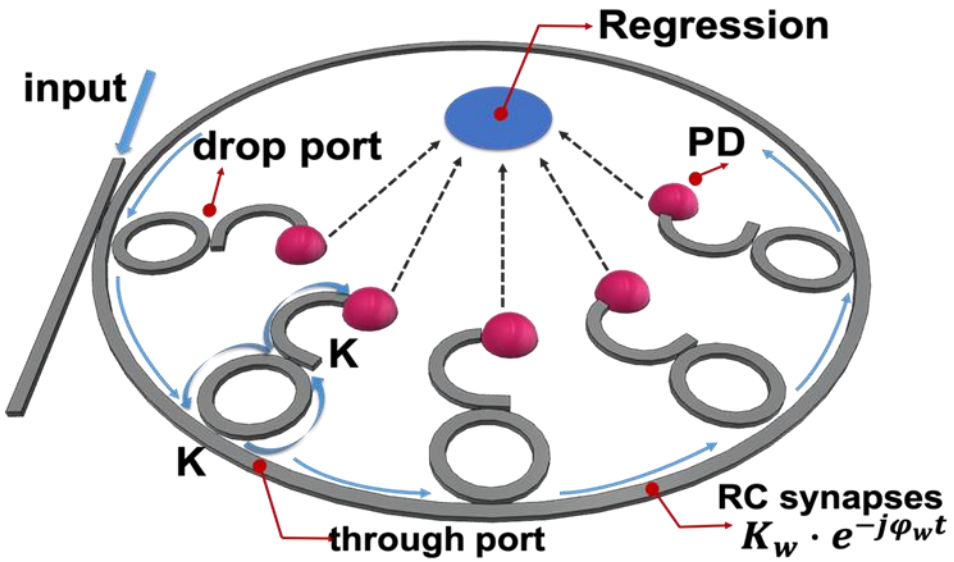


$$\begin{pmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \end{pmatrix}$$

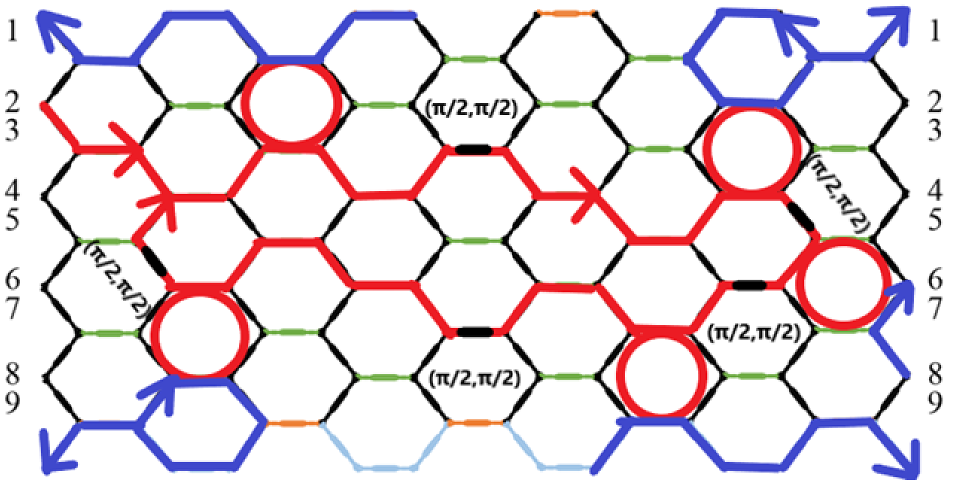
- Parallelized matrix vector multiplication
- Feedforward/feedbackward propagation – allows backpropagation
- Arbitrary unitary matrices can be programmed

Reservoir computing



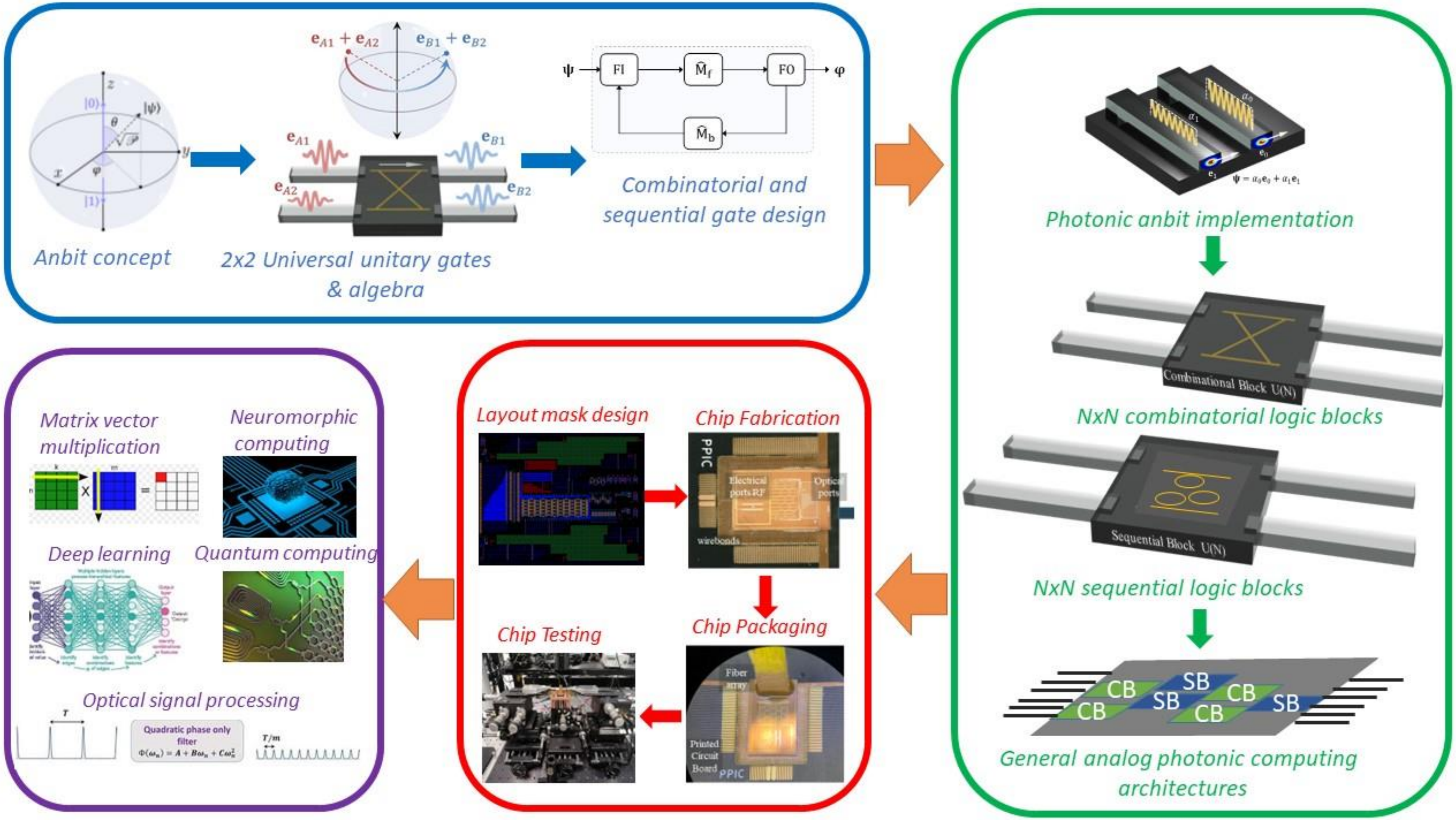


$$X_n(t) = f(\,W_{RC}X_n(t\text{-}1) + U_n(t)\,)$$



- A circular topology implemented by a waveguide mesh implementing MRRs can be employed
- MRR Drop ports are used as spatial outputs
- Electrical readout
- Waveguides between MRR-nodes exhibit random phase delay (φ_W) and attenuation K_W emulating the “random” connection matrix of the RC

Analog Photonic Computing



Summary & Conclusions

Adding Extra Flexibility to Coherent Transceivers

- **There is an increasing requirement for computing power that standalone electronics cannot meet.**
- **Programmable Integrated Photonics** is a matching technology compatible with electronics but brings different and complementary features that can be exploited for non Von-Neumann computing.
- In particular a **General Programmable Plug and Play Photonic Processor**, provides the required flexibility to implement feedforward and feedbackward computing architectures.
- **In the context of computing** programmable photonics can be employed to implement:
  - AI and ML via matrix-vector multiplication
  - Reservoir computing
  - Convolutional Neural Networks
  - Analog Photonic computation (using a new unit of information)