International Society for Digital Earth

济南超级计算技术研究院
JINAN INSTITUTE OF SUPERCOMPUTING TECHNOLOGY

Photonic AI for Digital Earth: Pushing the Horizon

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Laureate of the 2024 Chinese Government Friendship Award.

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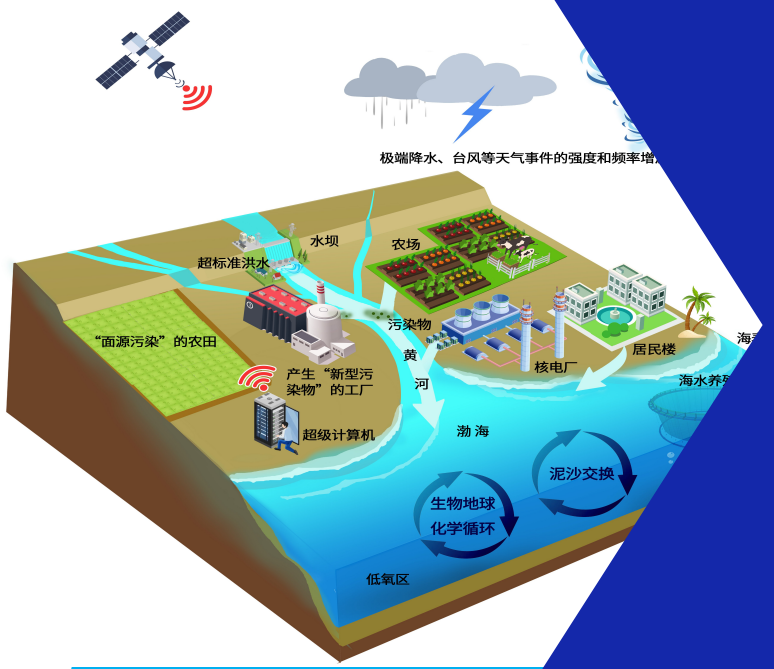
2026, March 26



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- Digital Earth (DE) challenges
- Strategic planning of Digital Belt and Road, BRICS, and SCO
- Modern AI challenges and reasons
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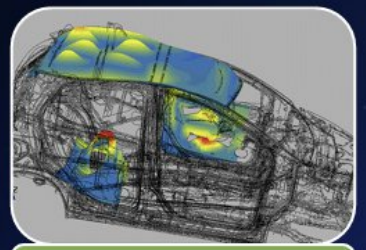
Jinan institute of supercomputing technology


New resource


Engineering Simulation Cloud


High-End Petroleum Equipment


Intelligent Manufacturing Equipment


Intelligent Connected Vehicles


High-End Agricultural Machinery


New Materials

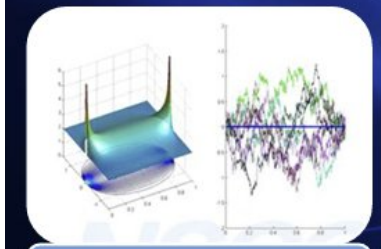

Ocean Numerical Simulation


Smart Ocean Engineering


Marine Pharmaceuticals


High-End Chemical Industry


Modern Efficient Agriculture


Modern Finance


Cultural and Creative Industries

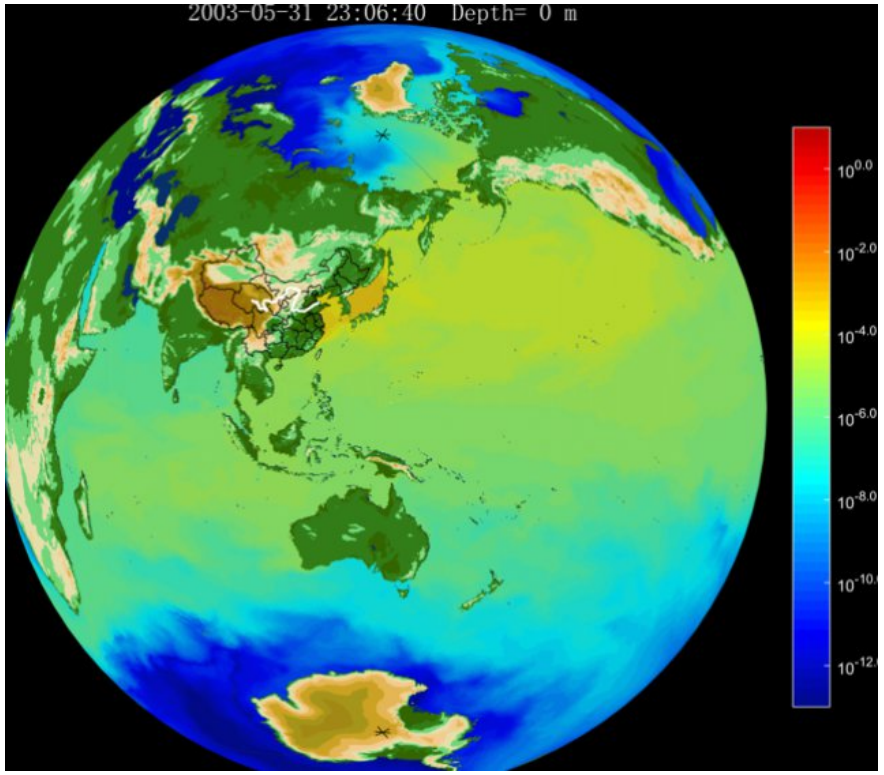

Premium Tourism


Astronomical Observation


Meteorology


Satellite Remote Sensing

Digital Earth challenges



1) Extreme computational requirements for high-resolution simulations;
2) Data volume and velocity, big data
3) Multi-scale complexity, coupling models and reality
4) Energy efficiency and sustainability
5) Integration of AI with physical models, embodied AI
6) Real-time processing for decision-making
7) Scalability of algorithms, hybrid models

DE example: Land-Ocean integrated emission reduction

Strategic planning of Digital Belt and Road, SCO, BRICS

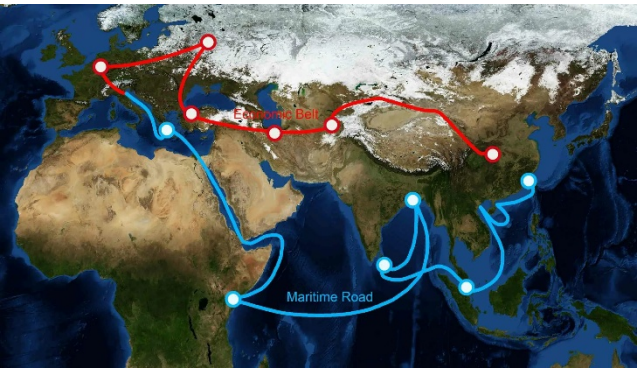
Accelerating strategic decision-making with AI:

1. **Environmental** problems (climate change, global warming, environmental pollution).
2. **Energy** problems (energy resources, geopolitical conflicts, renewable energy, scientific and technical collaboration)
3. **Humanitarian** issues (migration, health, culture)
4. **Geopolitical** issues (space, regional conflicts, security and stability, competition for resources and markets)
5. **Disasters** and emergencies

Strategic planning requires high-performance computing and artificial intelligence (AI)

Strategic issues's characteristic

Belt and Road Alliance



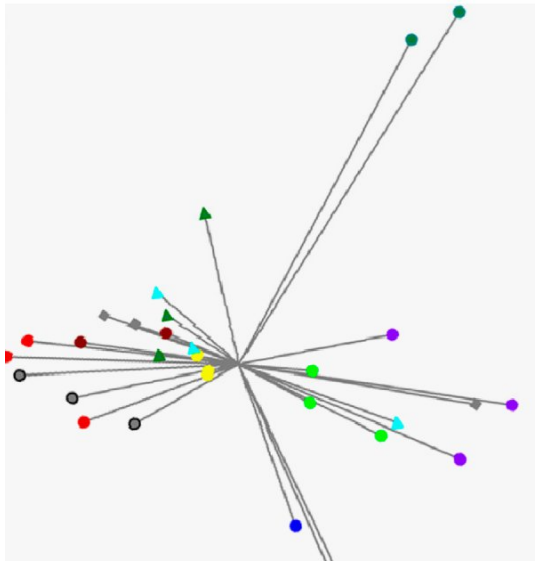
Shanghai Cooperation Organisation (SCO)

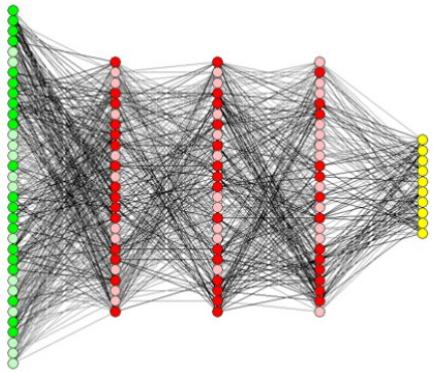
BRICS

- Participation of **multiple** states and members (authorities, experts, public organisations, the population)
- Thousands of **factors** (political, economic, social, technological, cultural, etc.)
- The **vagueness** of the description and the difference in the goals of the participants
- **Unreliability** and lack of documented information (statistics, sociology, experts, mass media)
- Presence of **disasters** and emergencies that require very quick solutions

Strategic planning requires AI

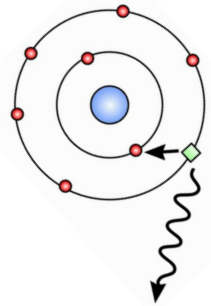
Modern AI challenges





1. The time and energy consumption of LLM.
2. Search in the 1,000 dimensions space
3. No semantic interpretation of factors
4. The regressive inference begs for creativity
5. Replacing a continuous natural signal by a digital one
6. There is no “Gut feeling“ or cognitive semantics
7. The inability to further reduce the size of the chip

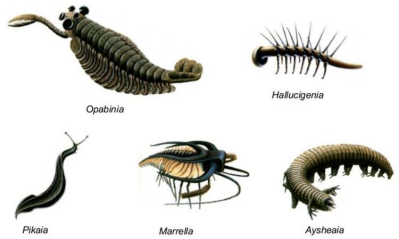
Reason 1: Analogue and Digital in life evolution



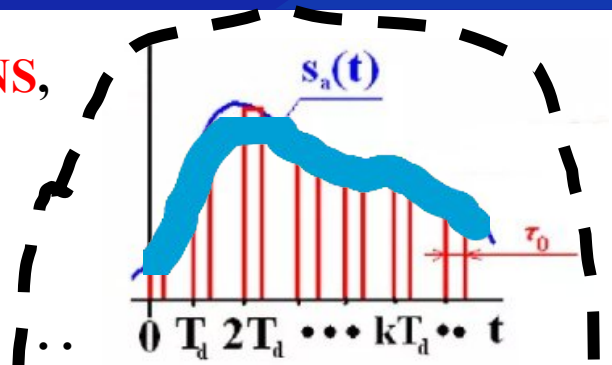
Invertebrate photosynthetic

635 million years ago

PROTEIN ABSORBS PHOTONS, creating "eye" and "ion channels"

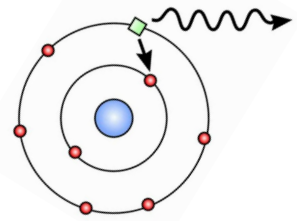


Cambrian explosion - 538.8 million years ago



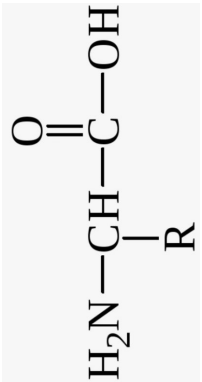
1936 year (sampling) – Turing, Kotelnikov

DIGITAL PERIOD



ANALOGUE + DIGITAL= PHOTONIC

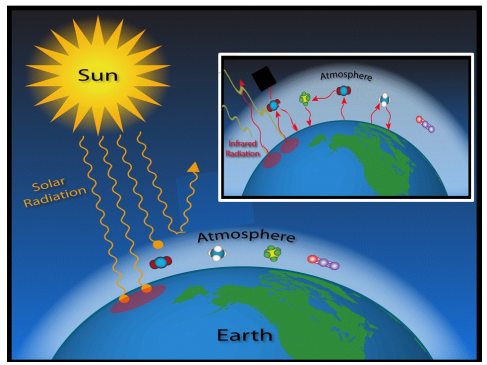
ANALOGUE PERIOD



Cyanobacteria with photosynthetic pigments

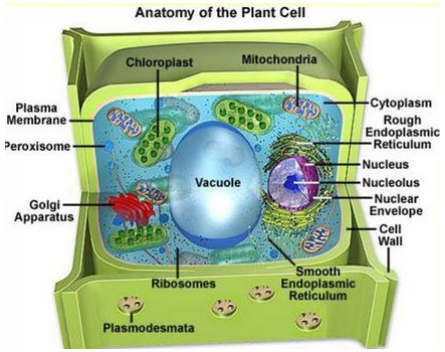
3.7 billion years ago

Oxygen photosynthesis, oxygenation of the atmosphere



2.5 billion years ado

Multicellular organisms perform photosynthesis



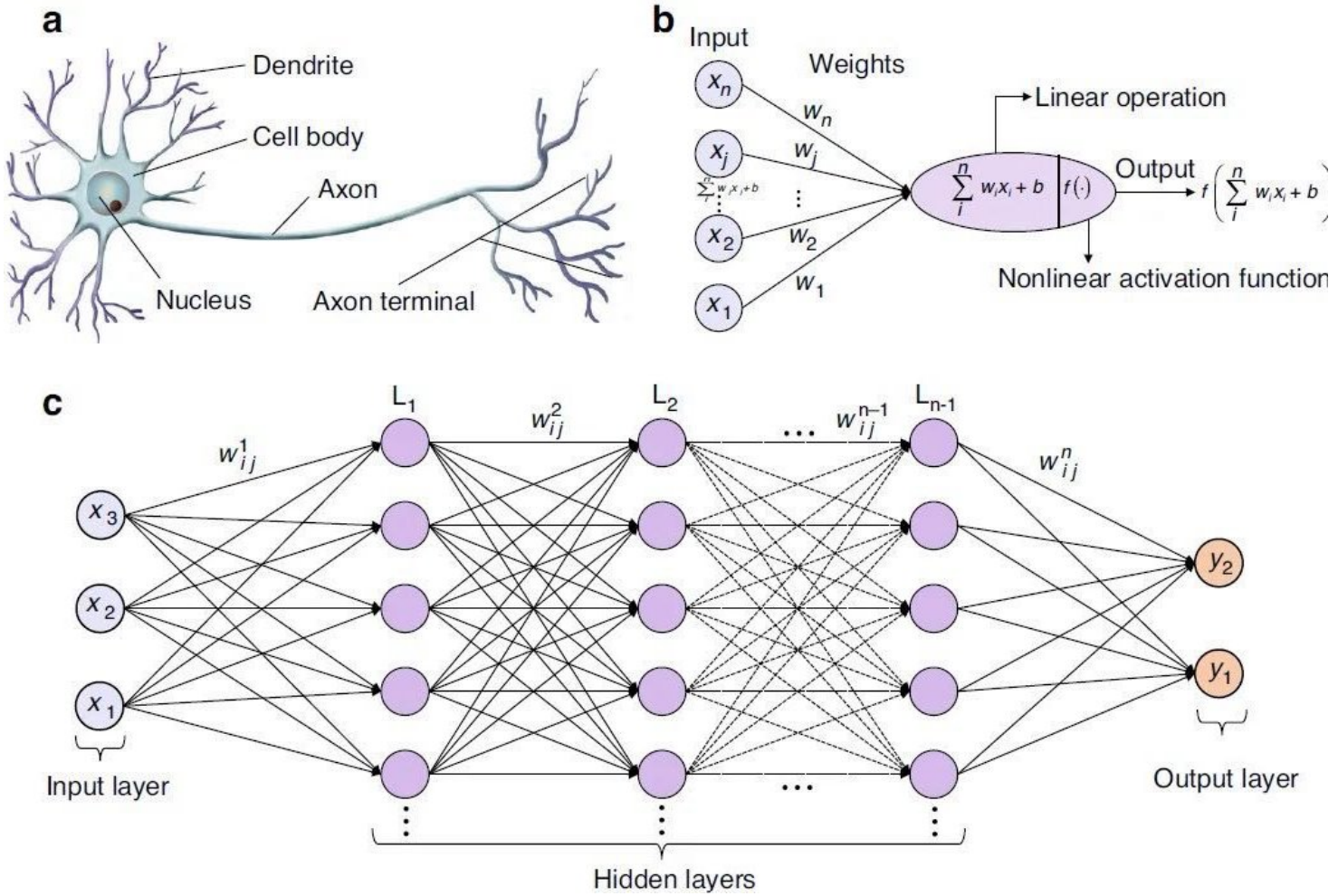
1.7 billion years ago

Algae, perform photosynthesis

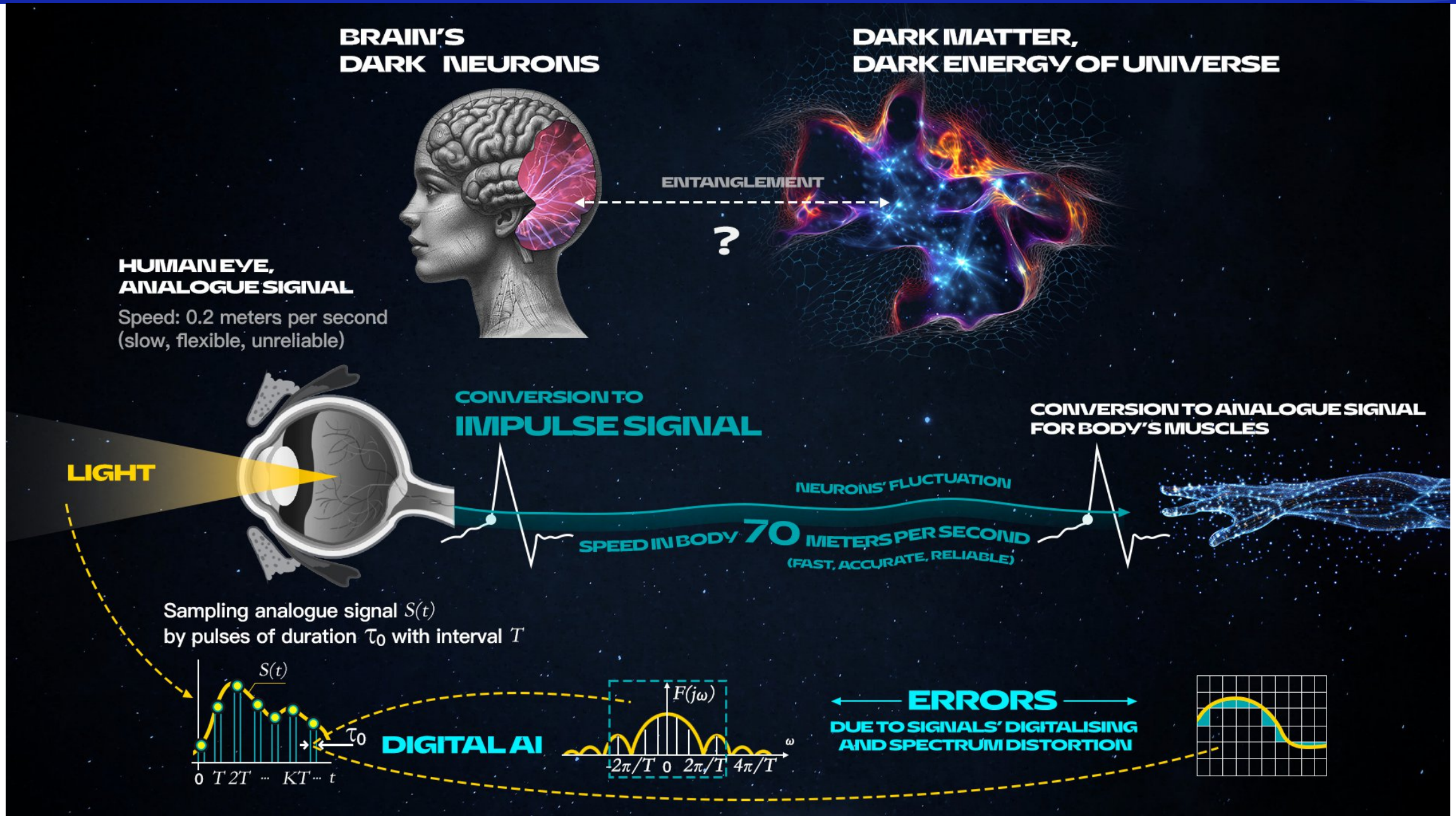
1.2 billion years ago

Reason 2: Digital neuron stereotype (1943)

Trying to copy the structure of the brain (neuron) is like **creating an airplane with wings**



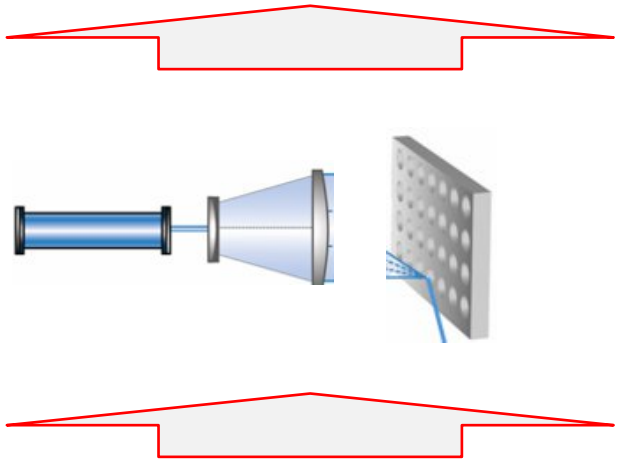
Reason 3: Artificial and Natural mind



To the Full-analogue Photonic AI

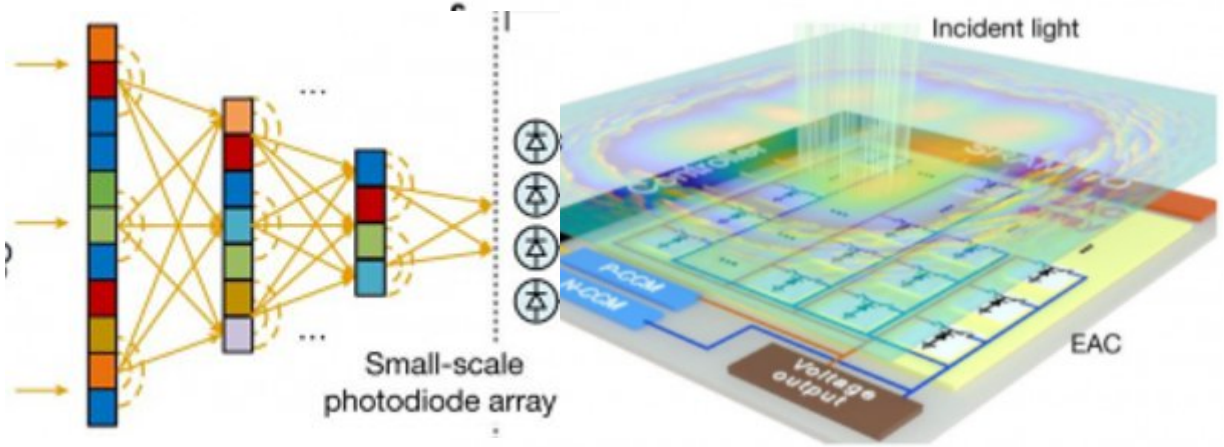
From digital to analogue through optics

One operation is required for the OPTICAL Fourier transform!



Millions of operations are required for the DIGITAL Fourier transform!

All-analog chip combining electronic and light (ACCEL)



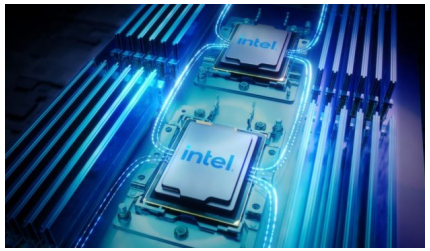
Tsinghua University

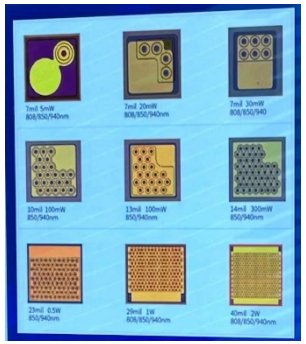
Reference	Method	Efficiency Speed/W	Speed
NVIDIA	GPU	0.52	156
All-Analogue	ACCEL	$7.48*10^4$	$4.55*10^3$

However, there are some layers and many connections. Multistep training!

World Commercial Optical Versions

1. **Lightelligence Technology ($1B):** 2018, Shanghai Xizhi Technology Co., Ltd., China; technologies of photonic matrix computing (oMAC), optical network on chip (oNOC), and optical network between chips (oNET)
2. **Lightmatter: Envise product, a general-purpose photonic AI accelerator:** 2017, headquartered in California, USA. Raised a new **$400 million** round of Series D financing at a valuation of **$4.4 billion**. Photonic computing platform, chip interconnection products, and adaptation software
3. **Intel** have created a **Silicon Photonics** division, with investments in which exceed **$100 million**.
4. **Xinxian Semiconductor (Suzhou) Co., Ltd.,** 2022, China: semiconductor device; optoelectronic device; optical communication; integrated circuit chip, special electronic materials, etc. Is expected to achieve an annual output of **80 million optical chips** and an output value of 1 billion yuan

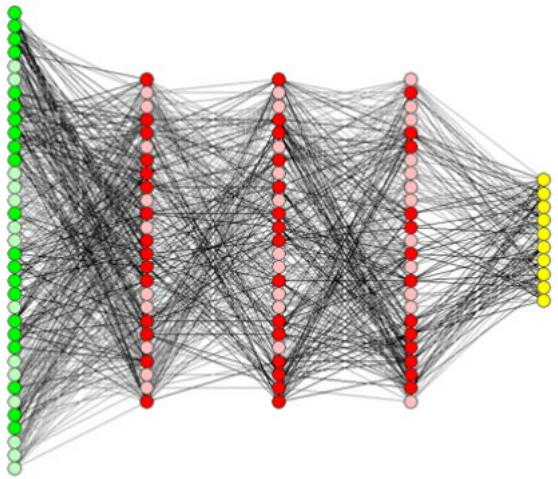




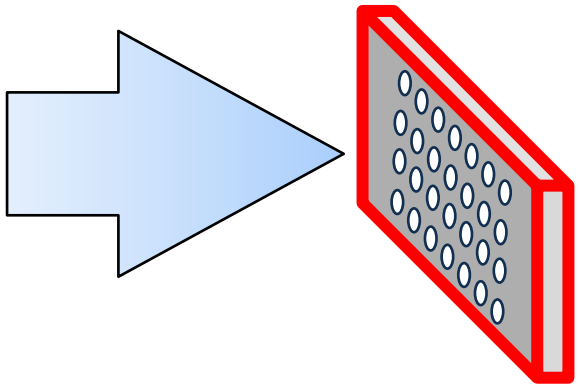
Full-analogue Photonic AI (PAI)

1. Rejection from pixels and digital representation of data

2. Rejection from a multi-level neural net and its multi-step training



REPLACE



Single level holographic plate of Fourier images

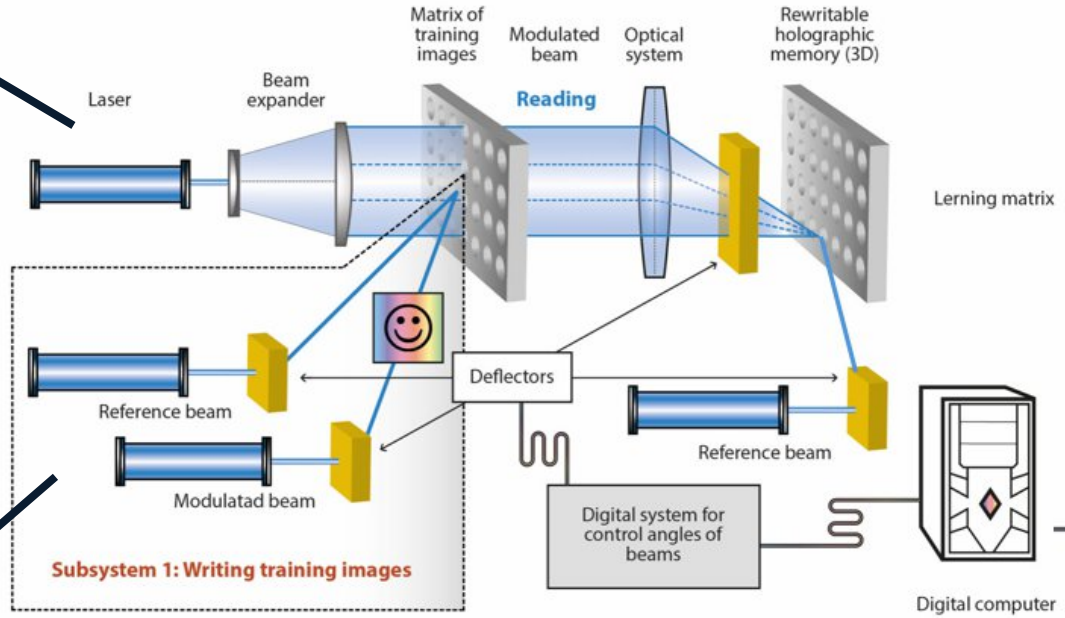
=

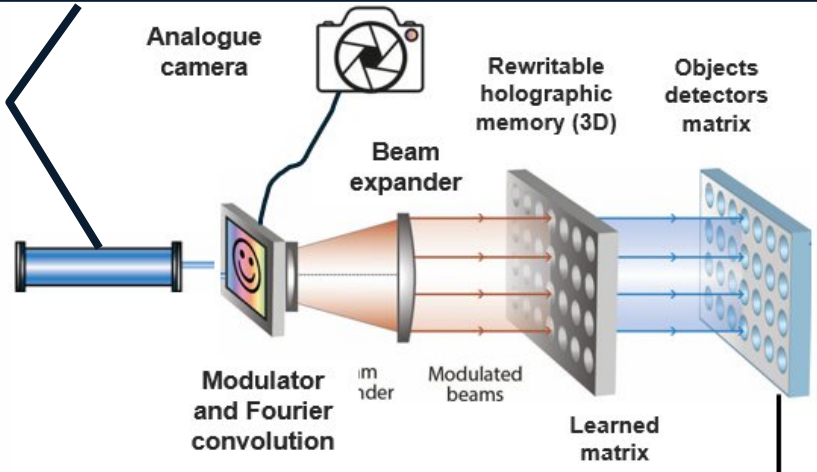
1. Instant learning time
2. Zeroing out energy consumption
3. Coverage of cognitive semantics

All-Analogue Photonic AI (PAI)

Subsystem 2: Responsible for training function. It takes one of the translucent matrices, reads all the recorded images simultaneously, and swiftly performs an optical Fourier convolution of these images. Then, all beams are directed to a specific point in the holographic memory.

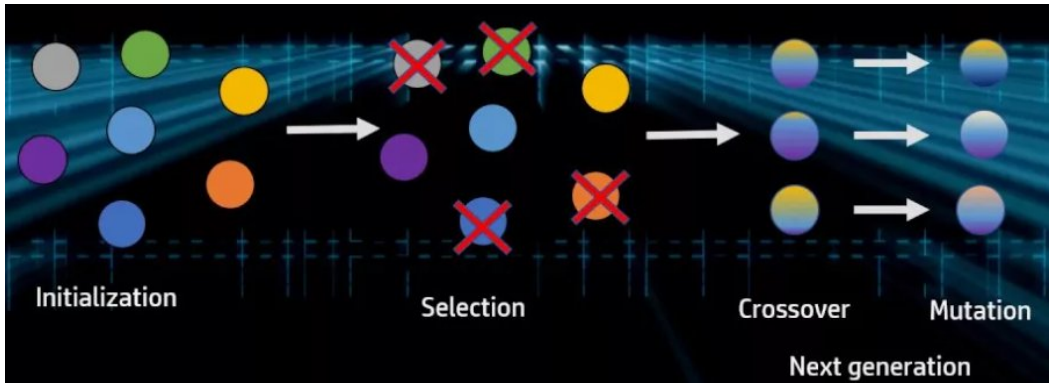
Subsystem 3: Full-analogue optical neural network for image recognition. The signal from the analogue camera goes to the Fourier modulator, and after the beam expander, all parallel beams go to the cells of the holographic memory. The detector matrix defines the luminance values of the resonating cells, which are relevant to one of the images' classes.



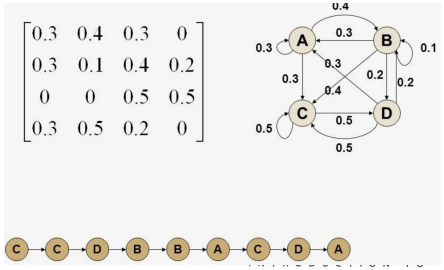


Subsystem 1: Creates an optical training set of images as a translucent matrix, where every cell includes one training image. Matrices are made on a holographic basis, and each translucent matrix corresponds to one of the classes of images

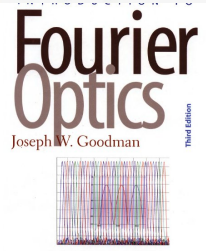
Optical solving of inverse problems



PAI: Markov chain, Monte Carlo, genetic algorithm



Digital Markov chain, Monte Carlo, genetic algorithm through Fourier transform.



Fourier transform can solve differential equations.

$$a_2\frac{d^2U}{dx^2}+a_1\frac{dU}{dx}+a_0U=V(x)$$

Differential equations can describe stochastic processes (Kolmogorov, 1930s)

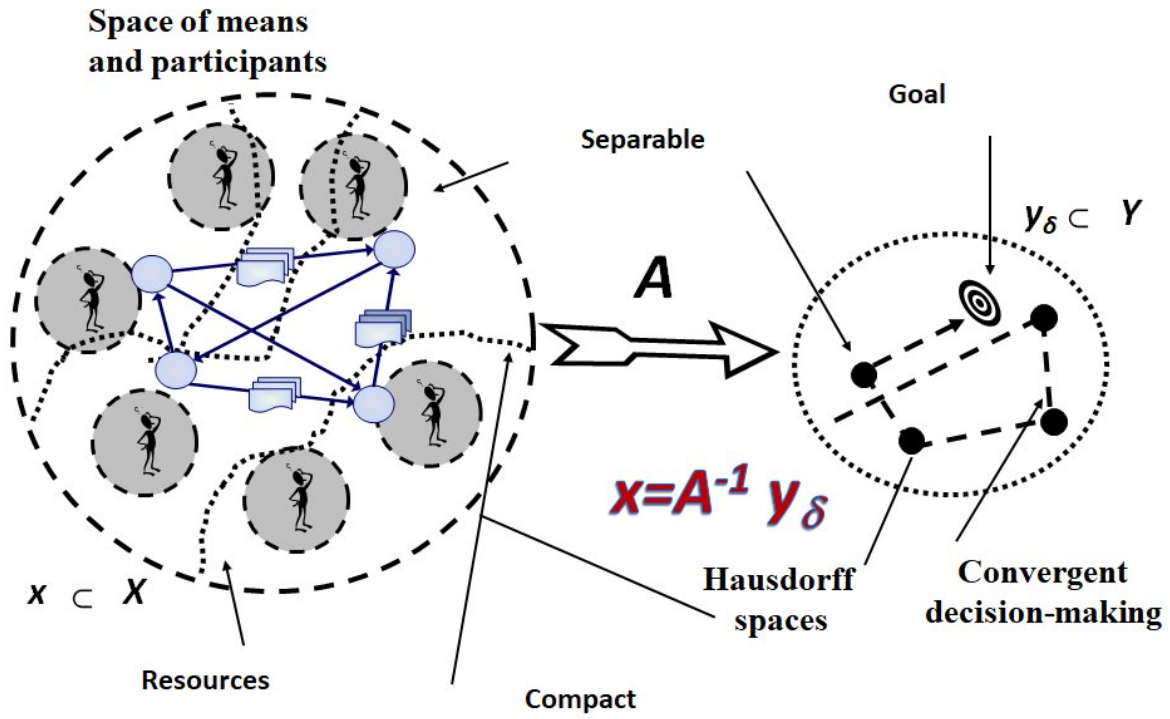
Convergent methodology: Purposeful

Goal

Inverse problem-solving on topology space

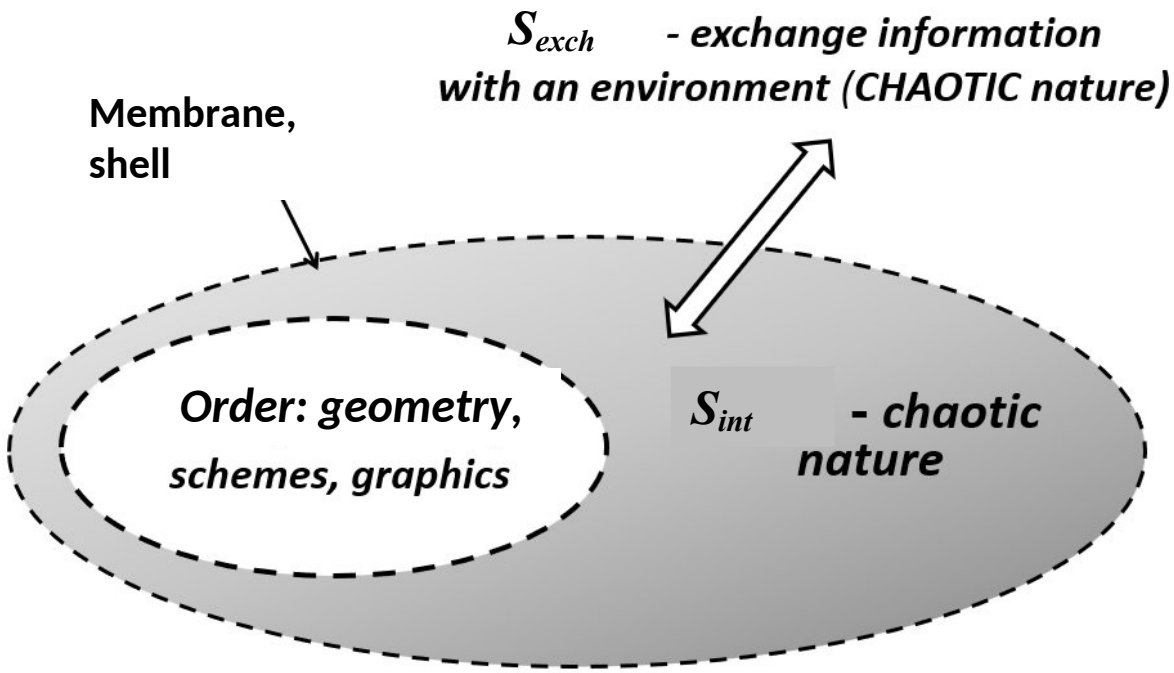
Goal

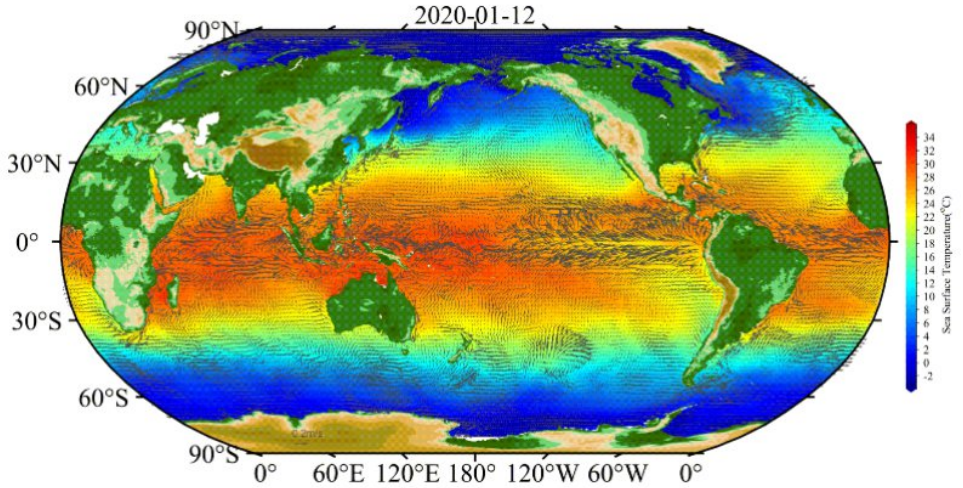
Divergent resources



Convergent resources

Convergent methodology: Stable





Sustainable interaction between the chaotic and ordered dynamics:

$$-S_{exch} \times (S'_{int} - S'_{exch}) < 0$$

S_{int} – local entropy
S_{exch} – exchange entropy
S'_{int} – local entropy (speed)
S'_{exch} – exchange entropy (speed)

Status and Plan

Status.

The project has a Technology Readiness Level (TRL) of 2-3: methodology and principles, concept, design, and algorithms. Some optical elements—micro-laser matrix, detectors, and deflectors—can be bought on the market

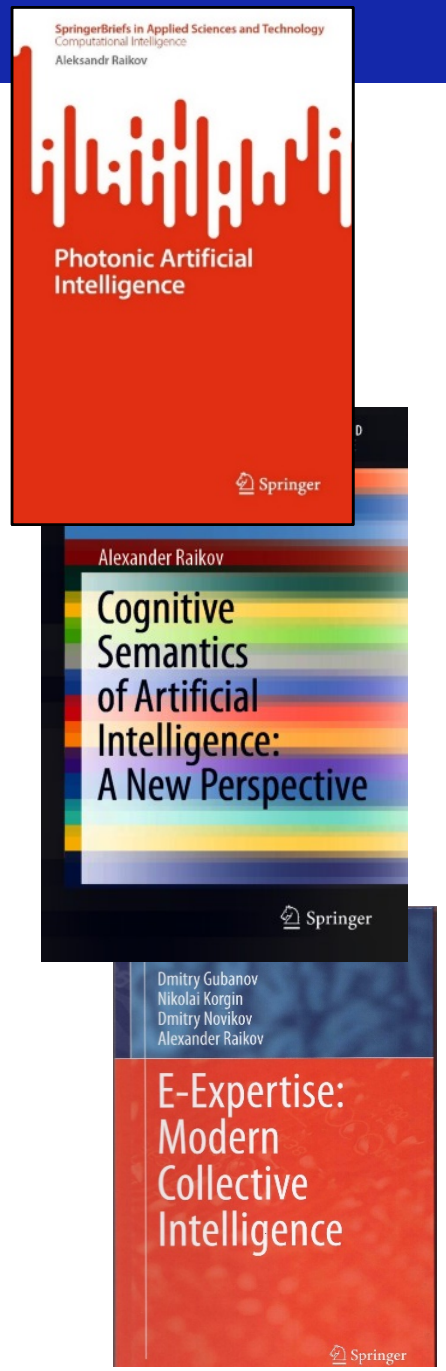
- First stage (2 years), an experimental research and commercial prototype of a PAI for pattern recognition is being created.
- Second stage (2,5 years), a fully analogue-based version of PAI is going to be created.

International collaboration is welcome. A Financial support is desirable on mutually beneficial terms.

Result

Accelerating decision-making. Increase the performance of supercomputing by 5-6 orders of magnitude

References



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