ВОЗМОЖНОСТИ КВАНТОВЫХ ВЫЧИСЛЕНИЙ ДЛЯ МОДЕЛИРОВАНИЯ НА ОСНОВЕ ЭПИДЕМИОЛОГИЧЕСКИХ БОЛЬШИХ ДАННЫХ

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QUANTUM COMPUTING CAPABILITY FOR PROCESSING AND MODELING EPIDEMIOLOGICAL BIG DATA

29 May 2023

Superconducting quantum computing; **Trapped ion** quantum computer; Molecular magnet; **Nuclear magnetic resonance** quantum computer;

Neutral atoms in optical lattices; Nonlinear optical quantum computer; Linear optical quantum computer; Quantum microprocessor based on laser photonics;

Fullerene-based electron spin resonance quantum computer; Solid-state nuclear magnetic resonance Kane quantum computer;

Electrons-on-helium quantum computer; **Quantum dot** computer, spin-based; Quantum dot computer, spatial-based; Cavity quantum electrodynamics;

Quantum computing using engineered quantum wells; Vibrational quantum computer; Rare-earth-metal-ion-doped inorganic crystal based quantum computer;

Diamond-based quantum computer;

Bose-Einstein condensate-based quantum computer;

Transistor-based quantum computer;

Metallic-like carbon nanospheres-based quantum computer.

decoherence times

The time for which a system remains quantum-mechanically coherent

Operation times

The time it takes to perform elementary unitary transformations

System	τ_Q	τ_{op}	n_{op}
Nuclear spin	$10^{-2} - 10^{8}$	$10^{-3} - 10^{-6}$	$10^{5} - 10^{14}$
Electron spin	10^{-3}	10^{-7}	10^{4}
Ion trap (In^{+})	10^{-1}	10^{-14}	10^{13}
Electron – Au	10^{-8}	10^{-14}	10^{6}
Electron – GaAs	10^{-10}	10^{-13}	10^{3}
Quantum dot	10^{-6}	10^{-9}	10^{3}
Optical cavity	10^{-5}	10^{-14}	10^{9}
Microwave cavity	10^{0}	10^{-4}	10^{4}

$$n_{op} = \tau_Q / \tau_{op}$$

квантовая память / quantum memory

квантовое хранилище / quantum storage

квантовая база данных / quantum database

quantum computing hardware

криогенные условия ниже −200°C

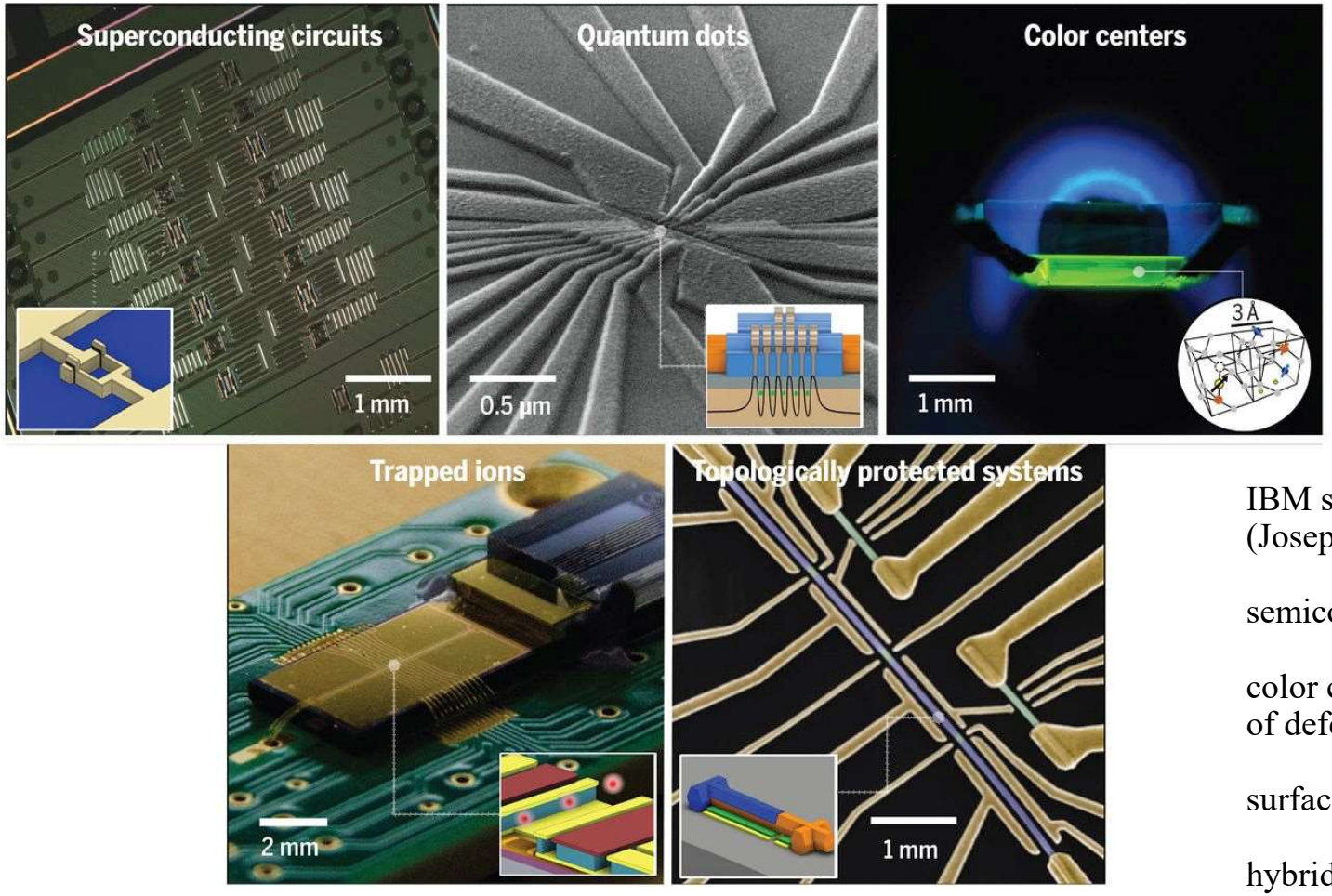
superposition, memory-memory entanglement (atom-photon entanglement, physically separated by 12.5 km)

Scaling to larger systems gives rise to new materials problems.

Materials challenges and opportunities for quantum computing hardware
Nathalie P. De Leon et al. SCIENCE 2021. Vol 372, Issue 6539. DOI: 10.1126/science.abb2823

Five quantum computing hardware platforms and associated sources of noise.

Platform	Where the quantum information is stored	Known sources of noise	
		Bulk materials	Surfaces and interfaces
Superconducting qubits	Energy eigenstates of Josephson junction–based electronic resonant circuits	• Substrate dielectric loss • Excess quasiparticles in superconducting metal cause dissipation and dephasing	• Uncontrolled oxides and contaminants host two-level systems, causing dissipation and dephasing • Surface spins and charges cause flux noise and charge noise, respectively
Gate-defined quantum dots	Spin states of electrons or holes confined in electrostatic potential	• High mobility required for individual dot formation • Nuclear spins limit T_2	• Charge traps and magnetic impurities at the dielectric interfaces • Interface inhomogeneity: Variation in valley splitting and spin-orbit coupling
Color centers	Electronic orbital and spin states	• Paramagnetic impurities and nuclear spins limit T_2 • Extended defects lead to strain and limit T_2^*	Dangling bonds and electron traps at the surface affect T_2 and optical coherence for shallow NV centers
Ion traps	Electronic transitions within individual atomic ions	(Not a significant noise source)	Electric-field noise heats ion motion
Majorana zero modes	Non-Abelian topological phase of Majorana zero modes	Defect density in nanowires	Semiconductor-superconductor nanowire interface that creates a proximity hard gap



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IBM superconducting qubit processor (Josephson junction)

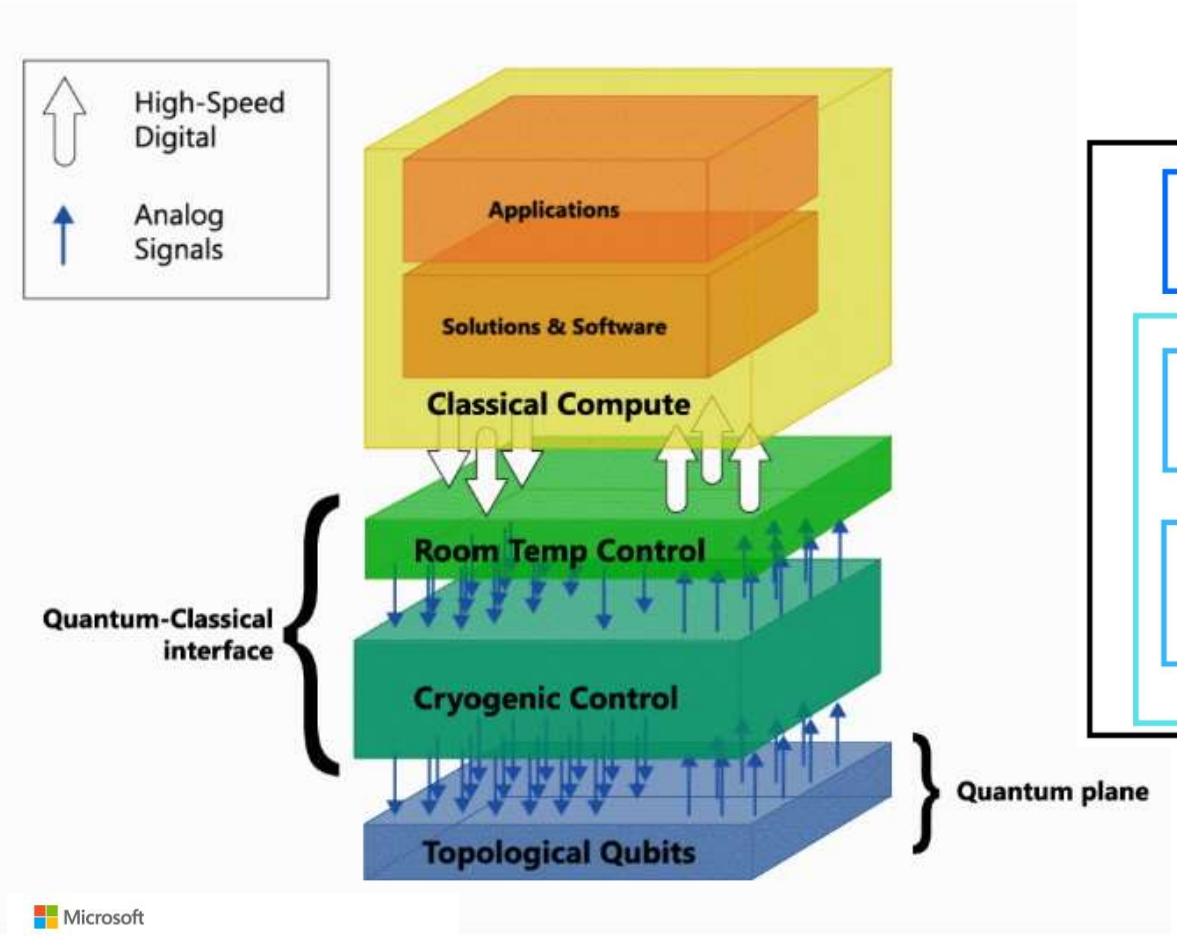
semiconductor quantum dots

color centers in diamond (atomistic model of defects)

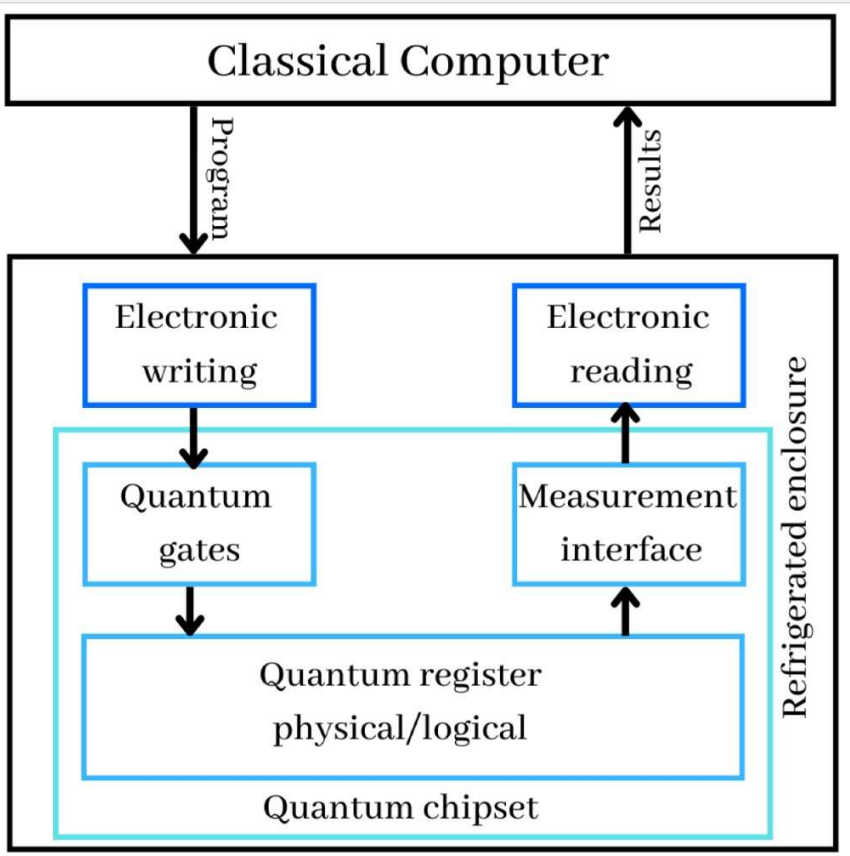
surface-electrode ion trap

hybrid semiconductor/superconductor, superconducting Al /алюминий/ shell (blue) on a faceted semiconducting InAs /арсенид индия/ nanowire (orange)

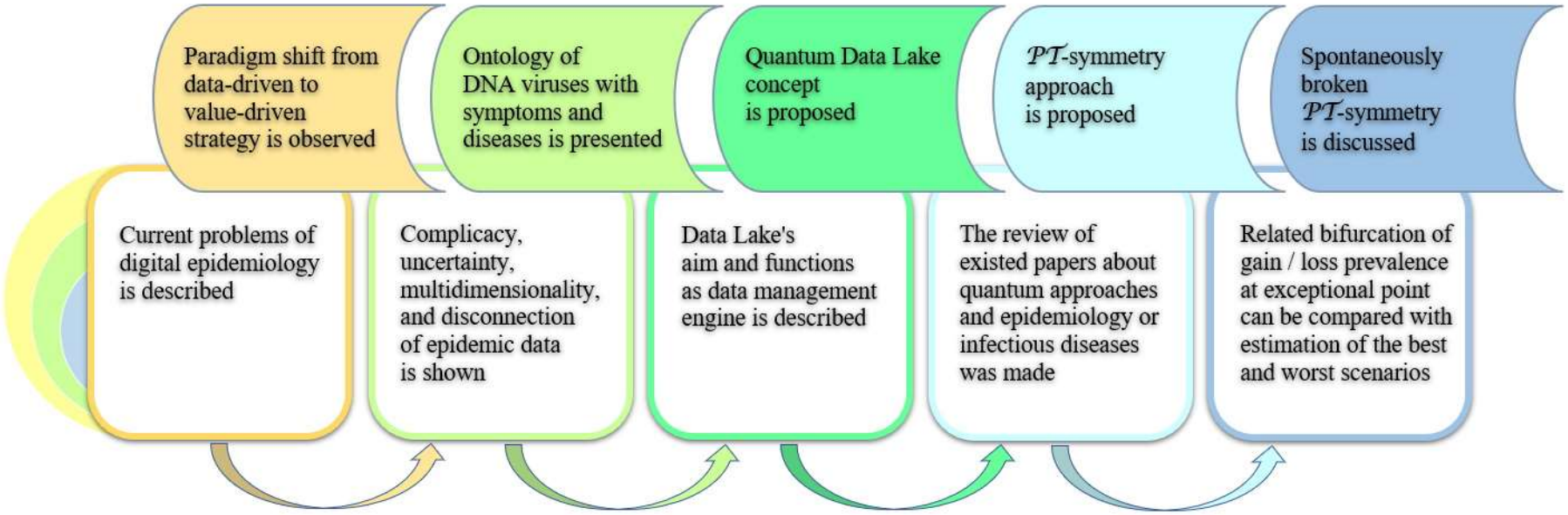
Архитектура квантового компьютера



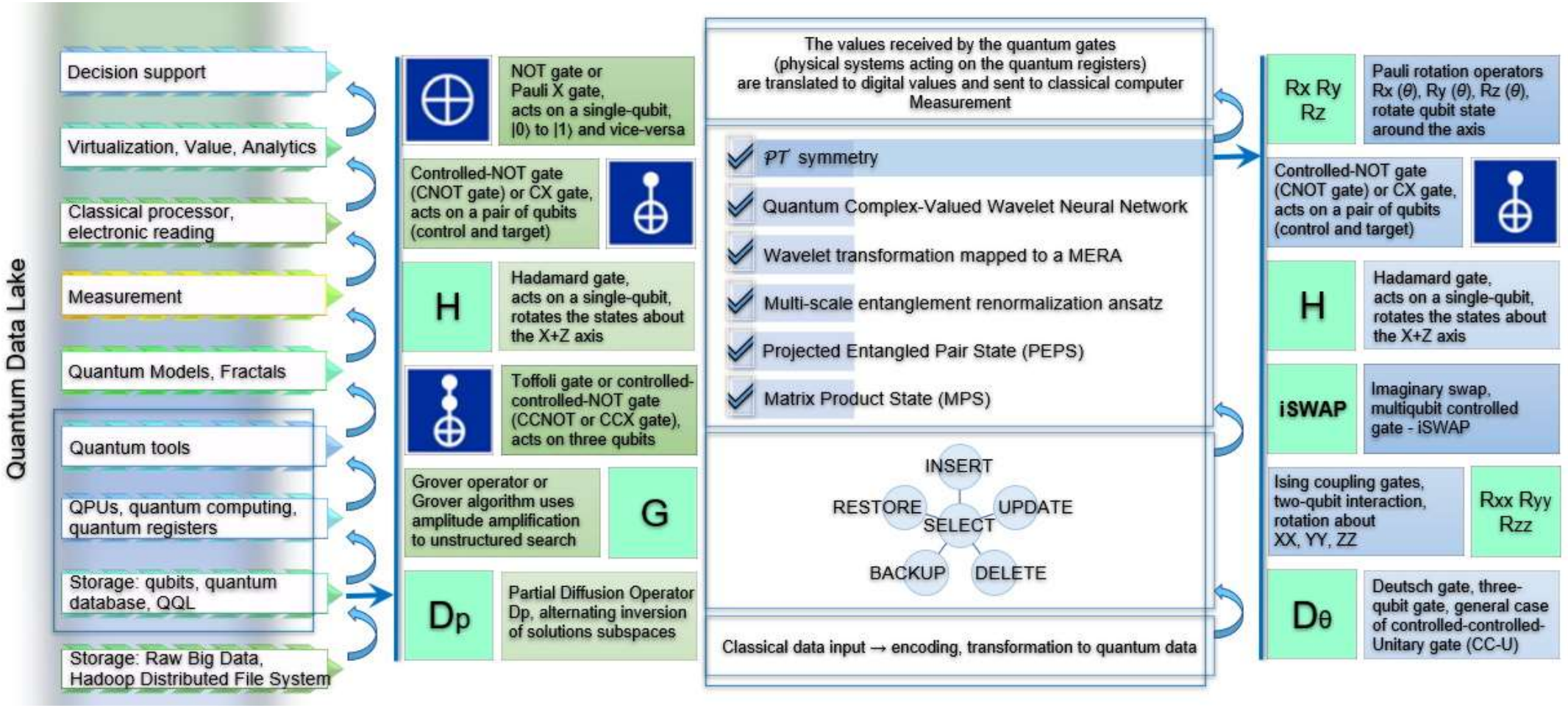
Microsoft Research Blog



Zeguendry A., Jarir Z., Quafafou M. Quantum Machine Learning: A Review and Case Studies. Entropy. 2023; 25(2):287. https://doi.org/10.3390/e25020287



Квантовое озеро данных



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Фундаментальные симметрии в физике:

Charge conjugation, Parity transformation, and Time reversal symmetry

C-симметрия: смена знака заряда с частицы на античастицу

P-симметрия: одновременная инверсия (поворот) положения в пространстве трех координат

T-симметрия: теоретический обратный ход времени

Parity transformation

P: (x, y, z, t) → (-x, -y, -z, t)

Coordinates r (x, y, z)

H (p, r, t) = H* (-p, -r, t)

Time reversal

T: (x, y, z, t) → (x, y, z, -t)

H (p, r, t) = H* (-p, r, -t)

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$\mathcal{PT}$-симметрия

Space-time reflection symmetry
Симметрия в комплексной сфере,
одновременно отражение в пространстве и времени.
Впервые описана Bender C.M. и Boettcher S. в 1998 году.

Square-root singularities или
exceptional point (Bender-Wu singularities) in the complex-g plane, где
g – константа, связывающая два энергетических состояния Гамильтониана:
состояние a и состояние b (энергия не дискретна).

H (оператор полной энергии системы) = $\begin{pmatrix} a & g \\ g & b \end{pmatrix}$

H (p, r, t) = H* (p, -r, -t)

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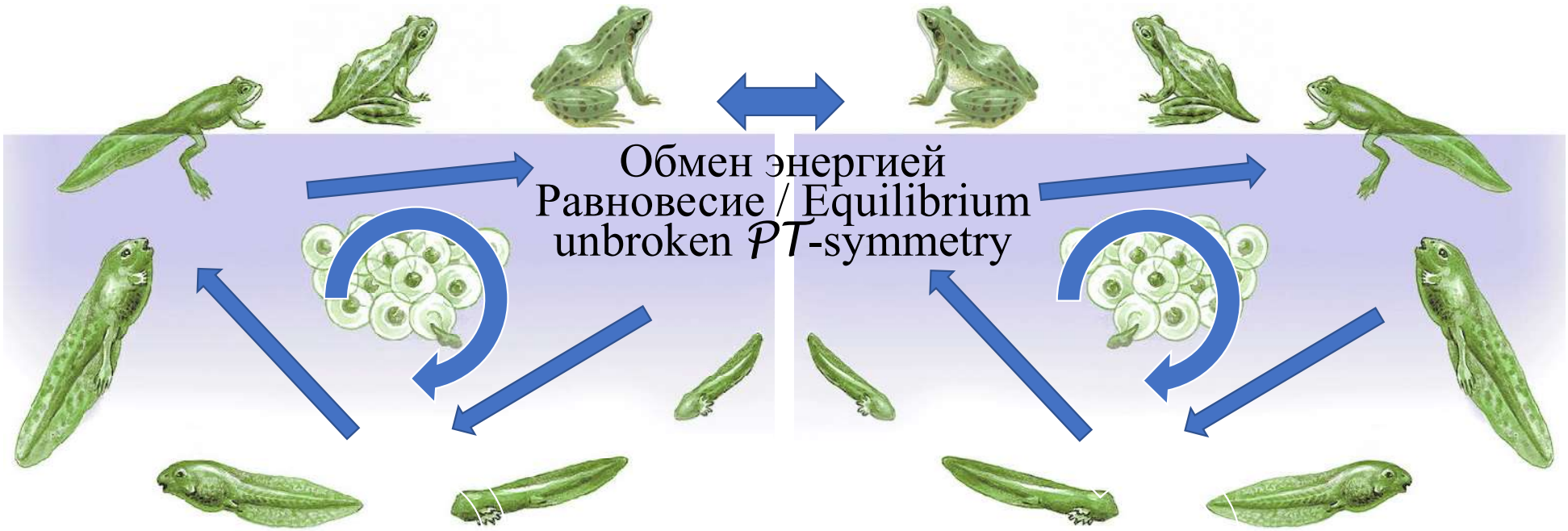

$\mathcal{PT}$-симметрия

Parity transformation – зеркальное отражение.

Time reversal – обратный ход времени в развитии (эволюции) системы.

Одновременное зеркальное отражение и обратный ход времени при неизменности всех частей системы соответствует **симметрии**.

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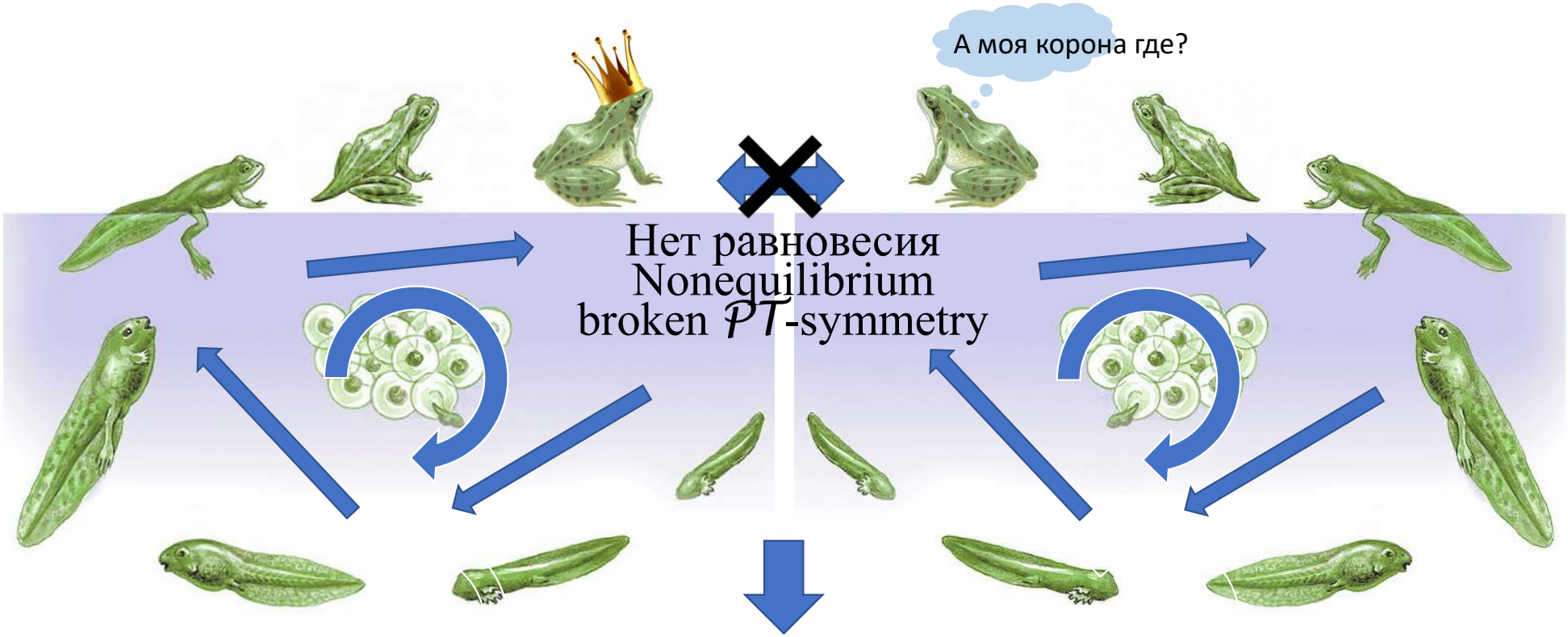
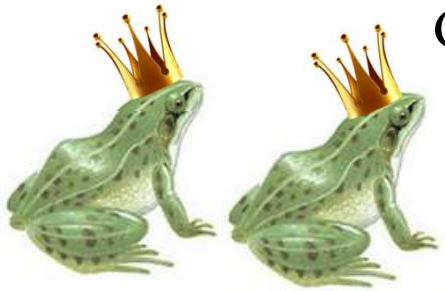
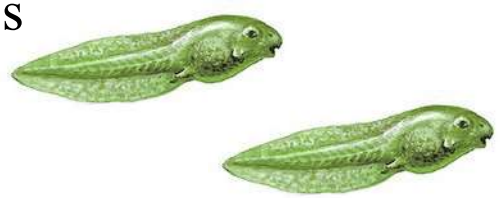


Если равновесие нарушается



Gain ← → Loss



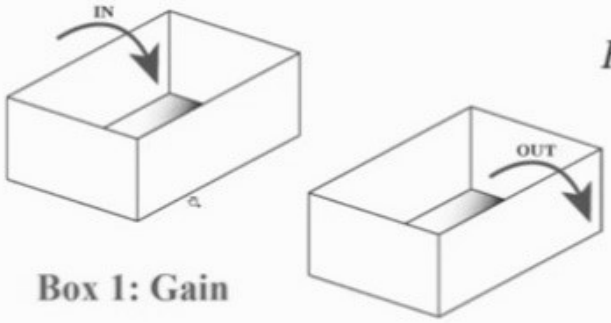
Нет обмена энергией
Вырождение (degeneracy)
Exceptional point

Theoretical Physics Colloquium

Parity-Time (PT) Symmetry

Theoretical-Physics-Colloquium

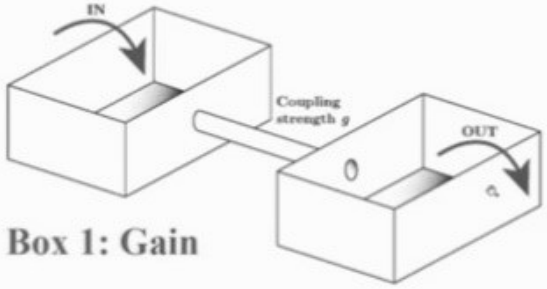
Two noninteracting closed boxes, one with gain, the other with loss:



$$H_{\text{combined}} = \begin{bmatrix} a+ib & 0 \\ 0 & a-ib \end{bmatrix}$$

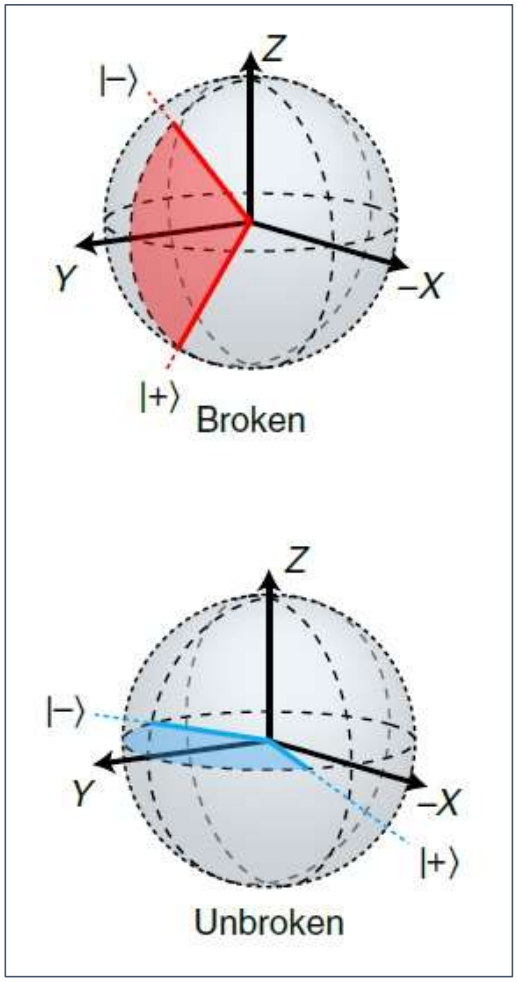
This system is *not in equilibrium*

Couple **the boxes**

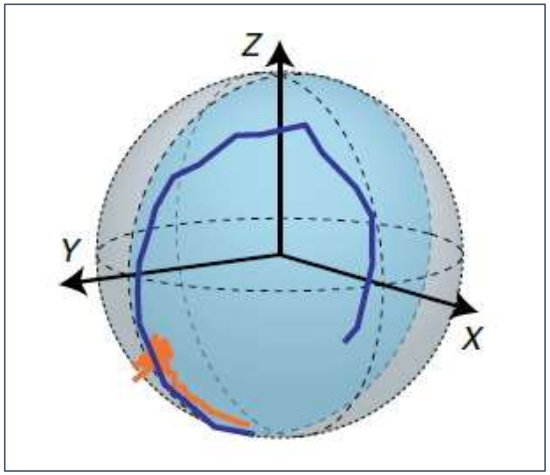


$$H_{\text{coupled}} = \begin{bmatrix} a+ib & g \\ g & a-ib \end{bmatrix}$$

This Hamiltonian is not Hermitian but it is *PT* symmetric



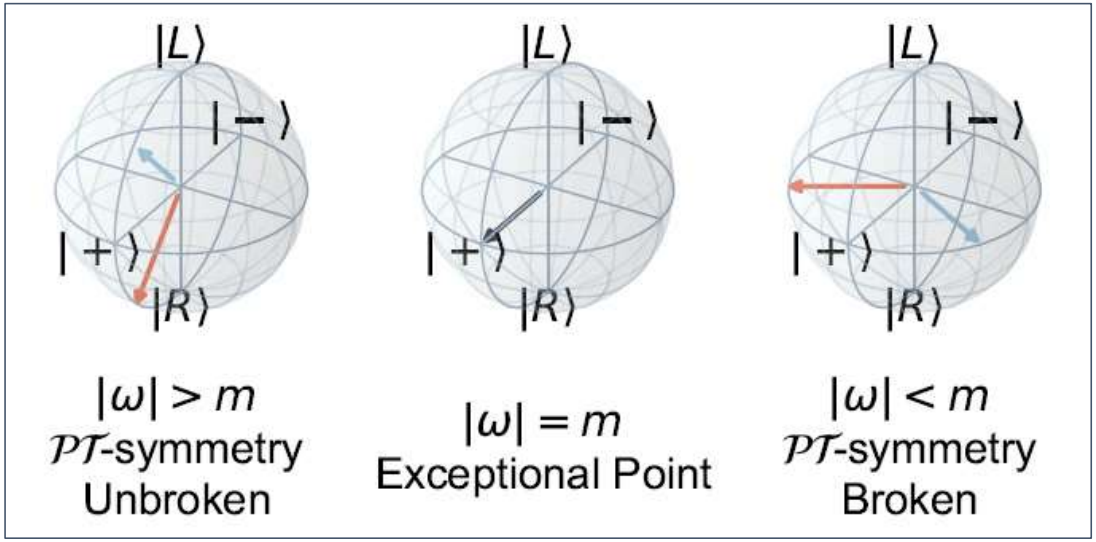
Non-orthogonality of eigenstates in the vicinity of the EP. The eigenstates in the broken (unbroken) region lie in the Y–Z (X–Y) plane (Bloch spheres). The calculated angles for the eigenstates in the broken (a) and unbroken (b) regions.



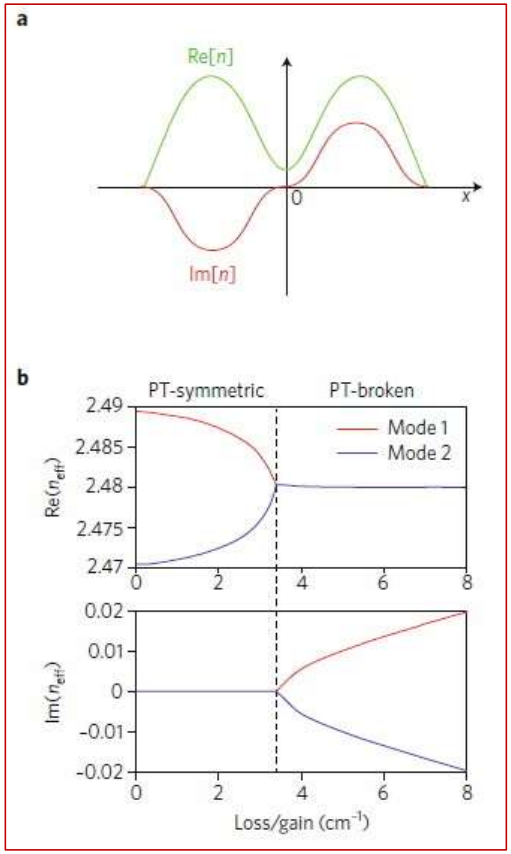
Evolution of the quantum state in the Bloch sphere for parameters in the PT-broken region (orange) and in the PT-symmetric region (blue).

Naghiloo, M.; Abbasi, M.; Joglekar, Y.N.; Murch, K.W. Quantum state tomography across the exceptional point in a single dissipative qubit. Nature Physics 2019, 15, 1232—1236. https://doi.org/10.1038/s41567-019-0652-z

The arrows represent the eigenvectors.
PT -symmetry is unbroken. The eigenmomenta are a pair of real numbers with opposite signs.
At the exceptional point the eigenmomenta are coalescing to 0.
PT -symmetry is broken. The eigenmomenta are a pair of purely imaginary numbers with opposite signs.

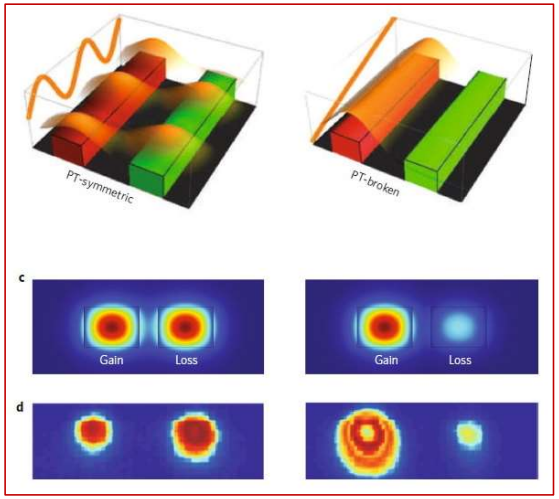


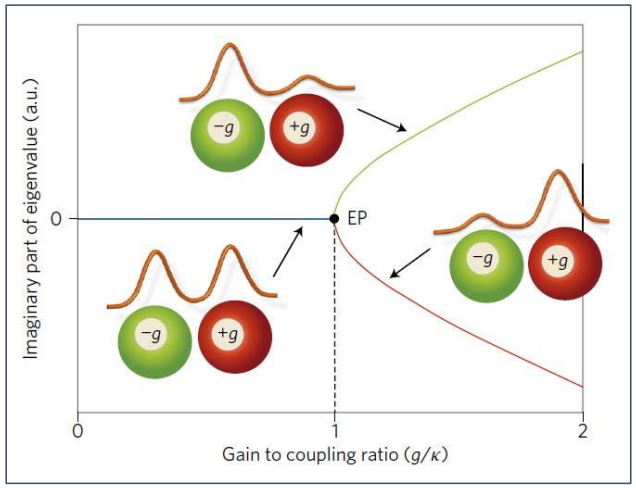
Song, X.; Murch, K. Parity-time symmetric holographic principle. Preprint arXiv 2022, 2210.01128v1. https://doi.org/10.48550/arXiv.2210.01128



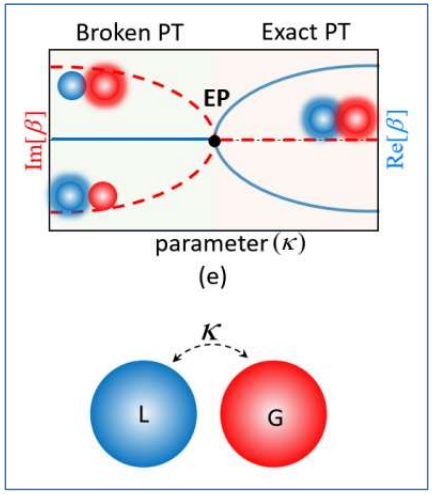
PT symmetry and phase transition in photonics. Schematics of the optical potential and its realization using two coupled waveguides.

Feng, L.; El-Ganainy, R.; Ge, L. Non-Hermitian photonics based on parity–time symmetry. Nature Photonics 2017, 11, 752—762. https://doi.org/10.1038/s41566-017-0031-1





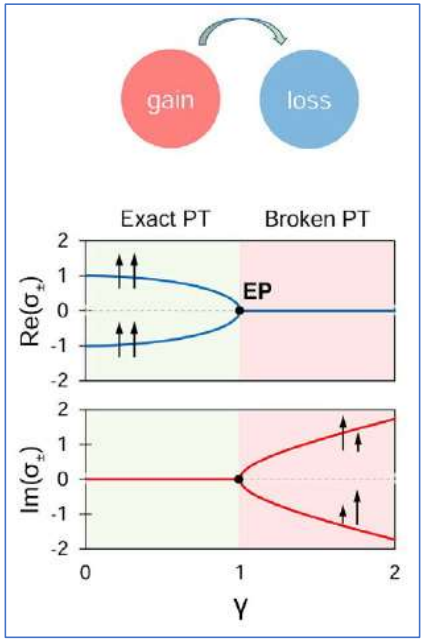
PT exact phase. The two eigenmodes are distributed over both sites and neither of them experiences a net gain or loss that is, they remain neutral.
PT-broken phase. The symmetry of each mode is broken such that one of them resides mostly in the gain cavity (and hence enjoys amplification) while the other one inhabits the lossy resonator (experiences attenuation).



System of two coupled waveguides. Schematic transition in the eigenvalues from purely real (exact PT symmetry) to purely imaginary (broken PT symmetry) in an active balanced system.

Krasnok, A.; Nefedkin, N.; Alú, A. Parity-Time Symmetry and Exceptional points: A Tutorial. Preprint arXiv 2021, 2103.08135v1. https://doi.org/10.48550/arXiv.2103.08135

El-Ganainy, R.; Makris, K.G.; Khajavikhan, M.; Musslimani, Z.H.; Rotter, S.; Christodoulides D.N. Non-Hermitian physics and PT symmetry. Nature Physics 2018, 14, 11—19. https://doi.org/10.1038/nphys4323



PT-symmetric system of two coupled waveguides (top) with gain (red) and loss (blue), and the corresponding eigenvalues (bottom) versus the gain-loss contrast. Transition in the eigenvalues from purely real (exact PT symmetry) to purely imaginary (broken PT symmetry).

Miri, M.-A.; Alù, A. Exceptional points in optics and photonics. Science 2019, 363 (6422). https://doi.org/10.1126/science.aar7709

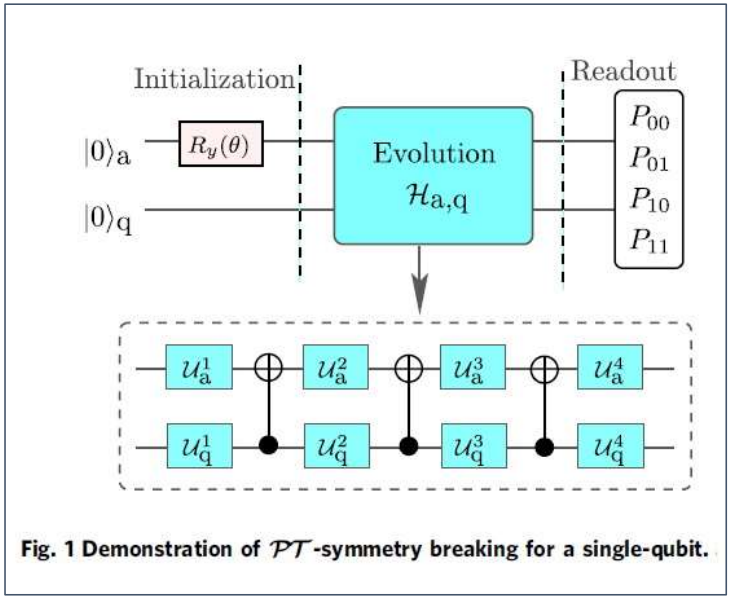


Fig. 1 Demonstration of $\mathcal{PT}$-symmetry breaking for a single-qubit.

Dogra, S.; Melnikov, A.A.; Paraoanu, G.S. Quantum simulation of parity–time symmetry breaking with a superconducting quantum processor. Communications Physics 2021, 4, 26. https://doi.org/10.1038/s42005-021-00534-2

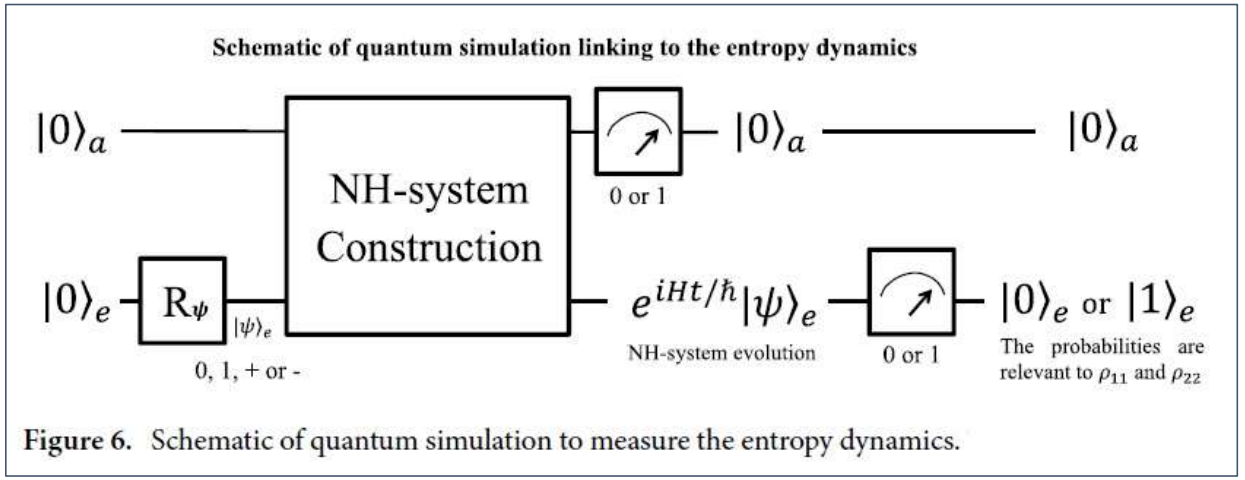


Figure 6. Schematic of quantum simulation to measure the entropy dynamics.

Zheng, C.; Li, D. Distinguish between typical non-Hermitian quantum systems by entropy dynamics. Scientific Reports 2022, 12, 2824. https://doi.org/10.1038/s41598-022-06808-1

Gao, W.-C.; Zheng, C.; Liu, L.; Wang, T.-J.; Wang, C. Experimental simulation of the parity-time symmetric dynamics using photonic qubits. Optics Express 2021, 29 (1), 517—526. https://doi.org/10.1364/OE.405815

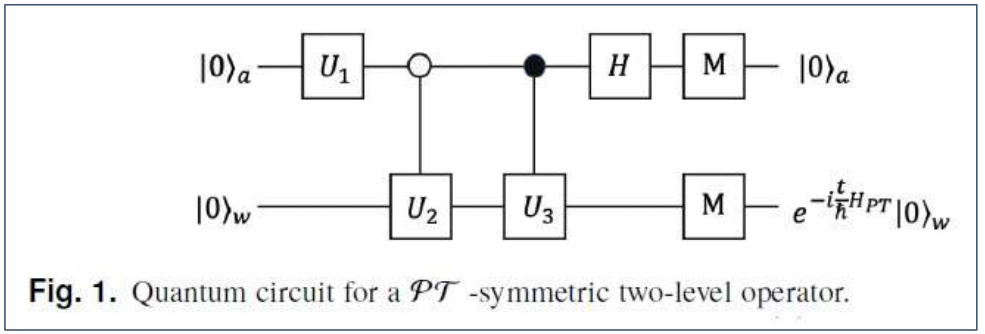


Fig. 1. Quantum circuit for a $\mathcal{PT}$ -symmetric two-level operator.

Zheng, C.; Hao, L.; Long G.L. Observation of a fast evolution in a parity-time-symmetric system. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 2013, 371 (1989), 20120053. https://doi.org/10.1098/rsta.2012.0053

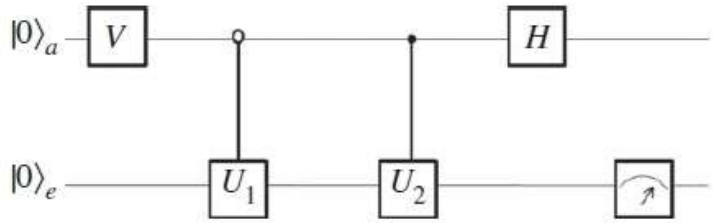


Figure 1. Quantum circuit for a $\mathcal{PT}$-symmetric system.

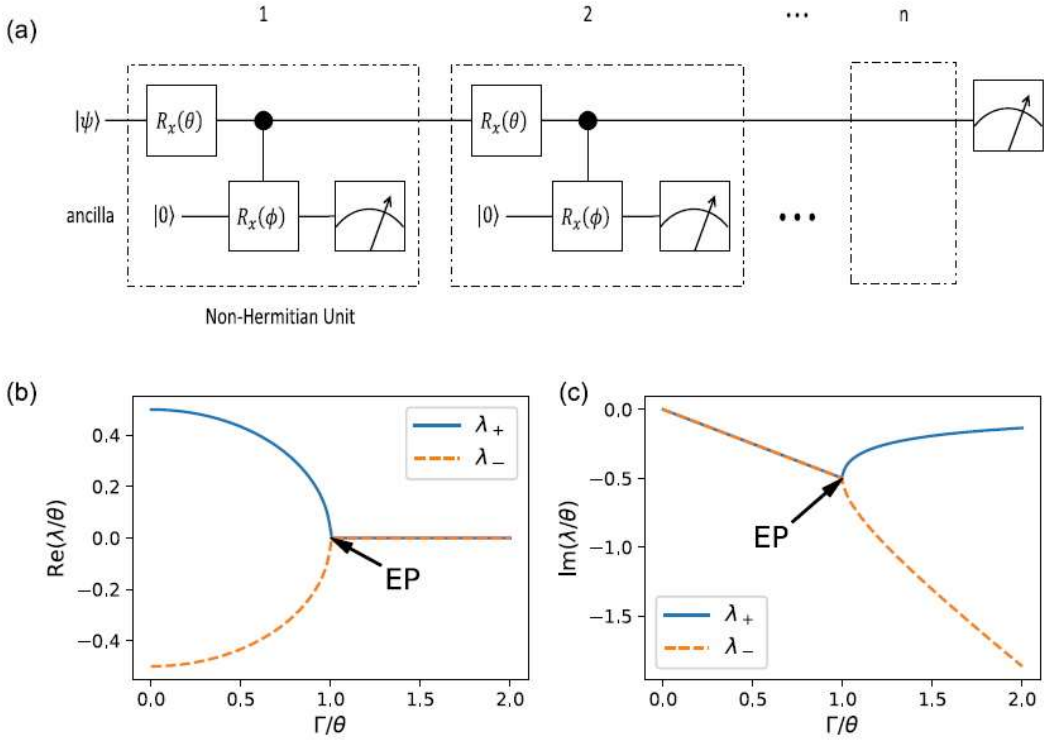


Figure 1. (a) The circuit for simulating a non-Hermitian system on quantum computers.

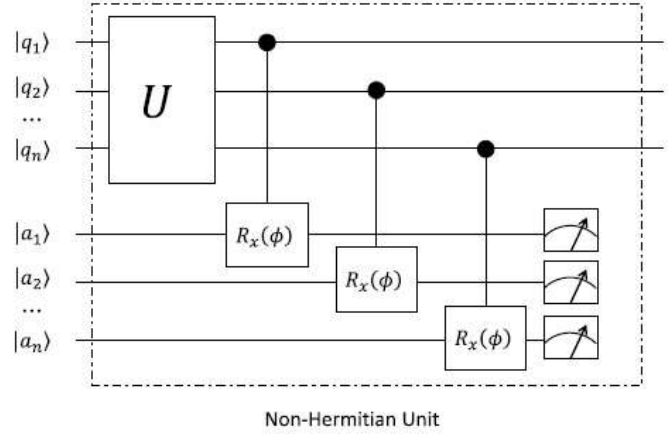
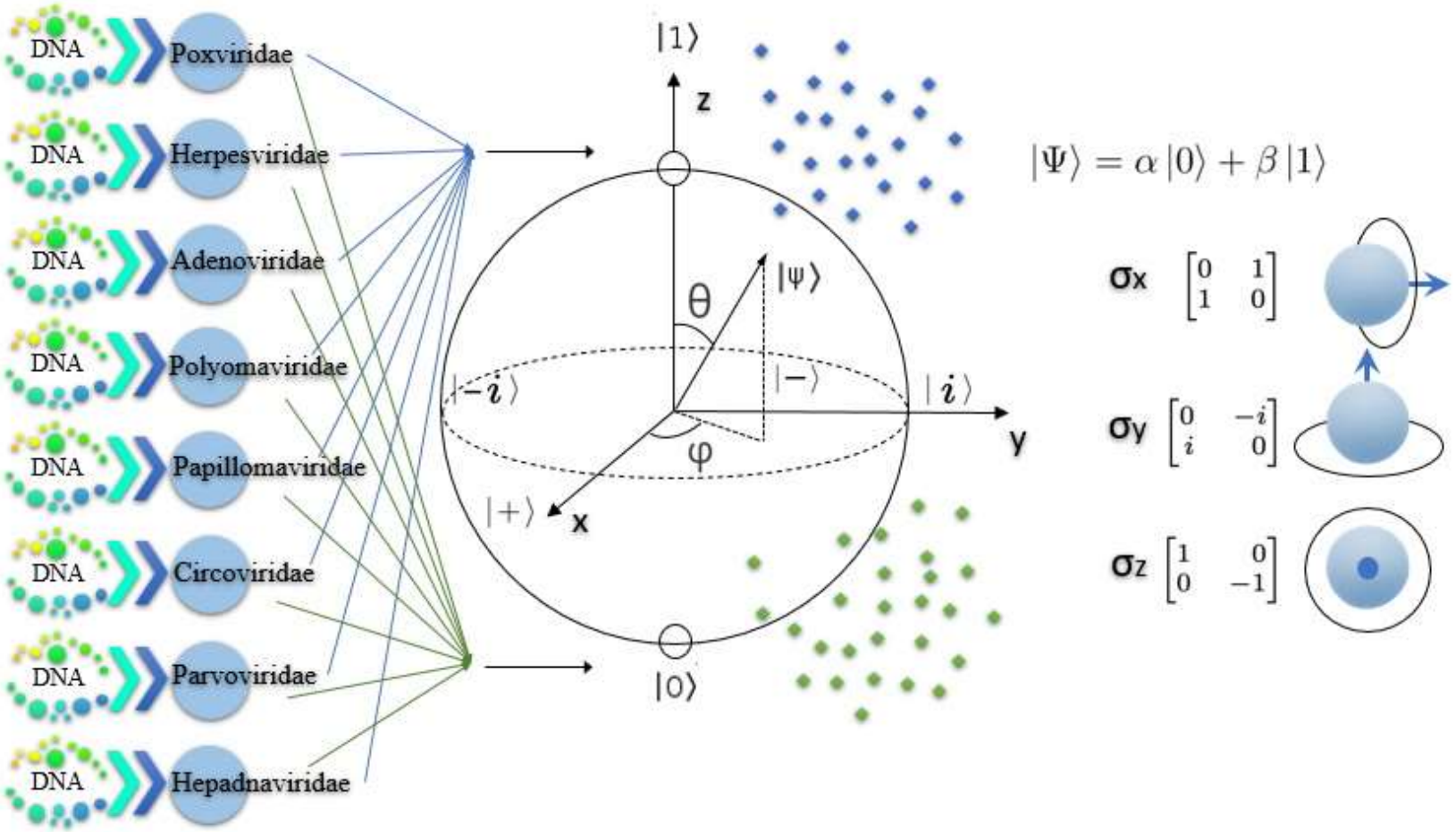


Figure 4. The circuit for simulating a N-qubits non-Hermitian system.

Zhang, G.-L.; Liu, D.; Yung, M.-H. Observation of exceptional point in a PT broken non-Hermitian system simulated using a quantum circuit. Scientific Reports 2021, 11, 13795. https://doi.org/10.1038/s41598-021-93192-x



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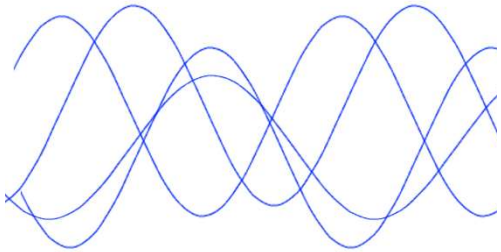
Данные в эпидемиологии

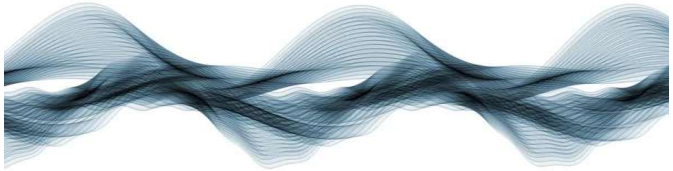
Dynamics over time

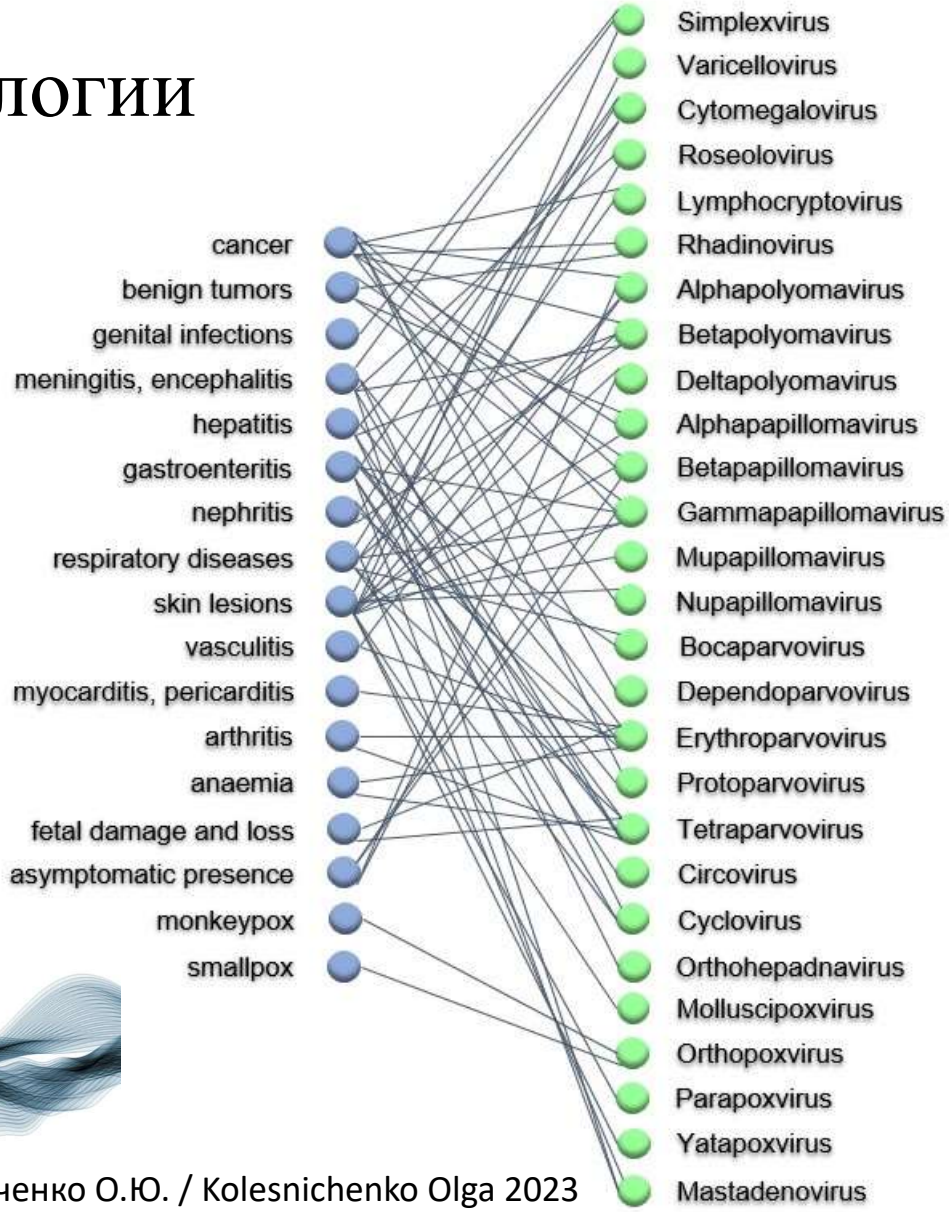
- Climate / ecological data
- Virus carriers in nature data
- Global / local mobility data
- Social data
- Transmission data
- Vaccination data
- Electronic health records data
- Human Omics data
- Virus Omics data



Нарастание энтропии

и “обратный ход времени”





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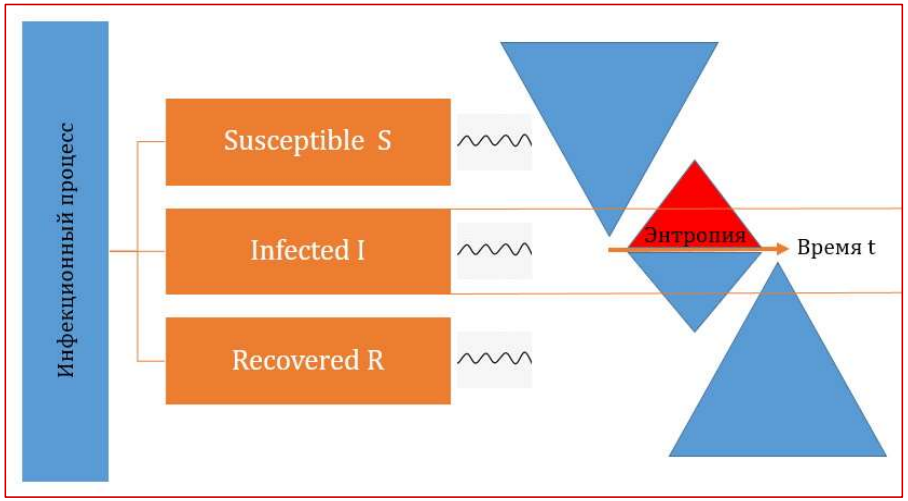

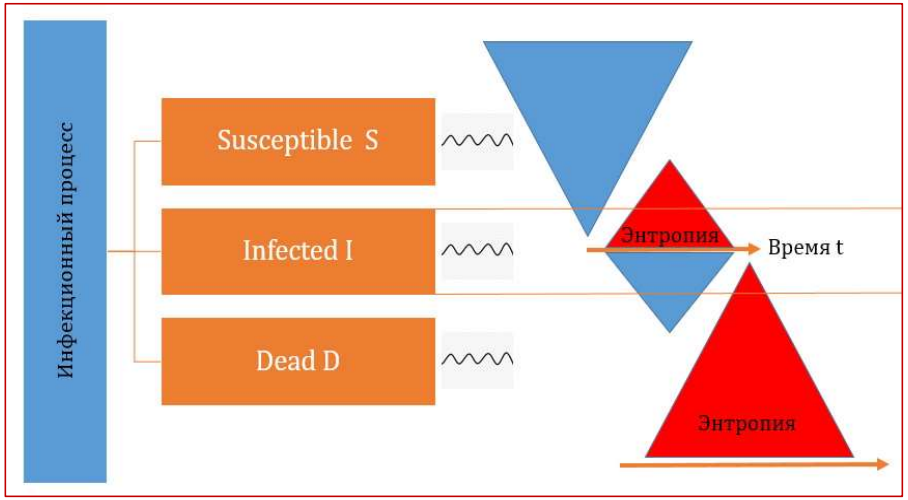

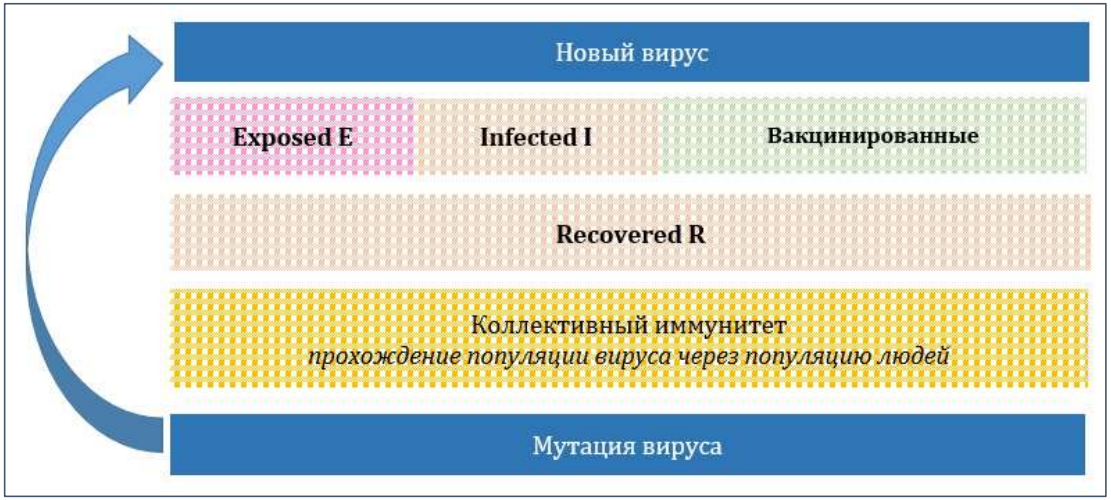

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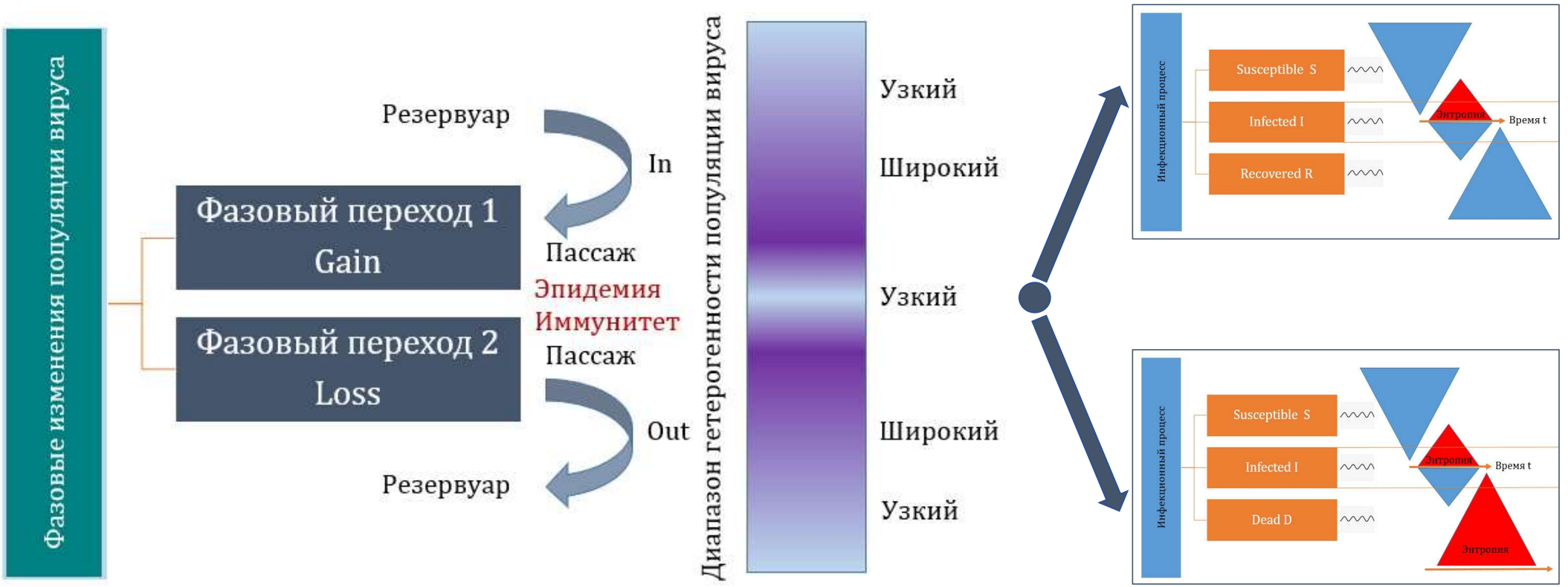
В.Д. Беляков, “Общие закономерности функционирования паразитарных систем (механизмы саморегуляции)”, Паразитология, Т. XX, № 4, С. 246–255, 1986.



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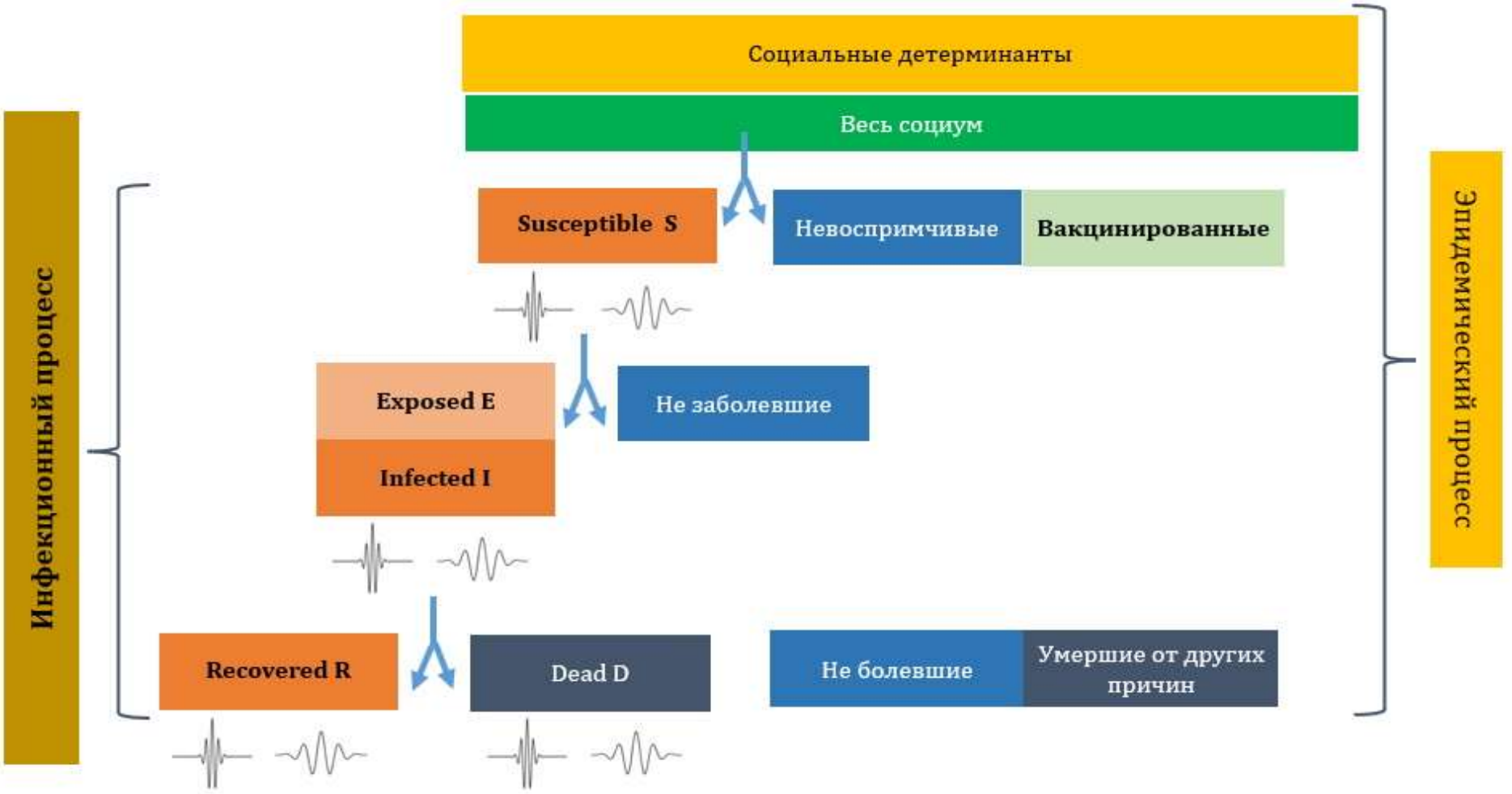

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Спасибо за внимание!

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