Biological Computing: Are We Missing the Obvious ?

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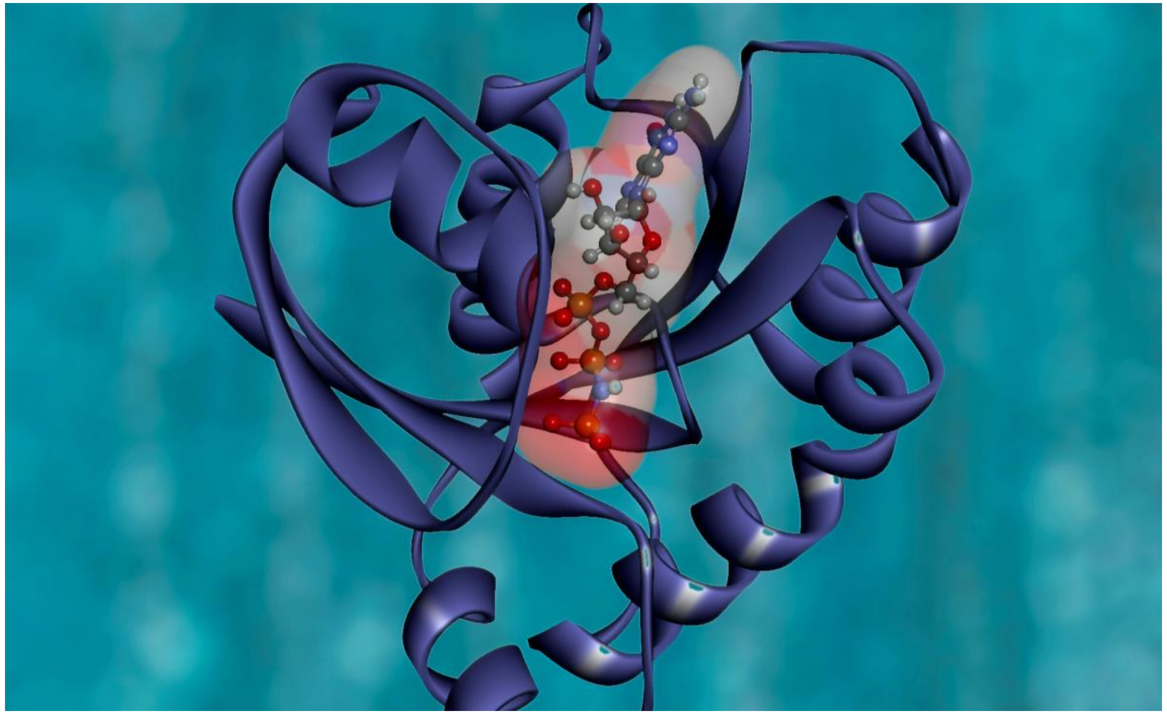
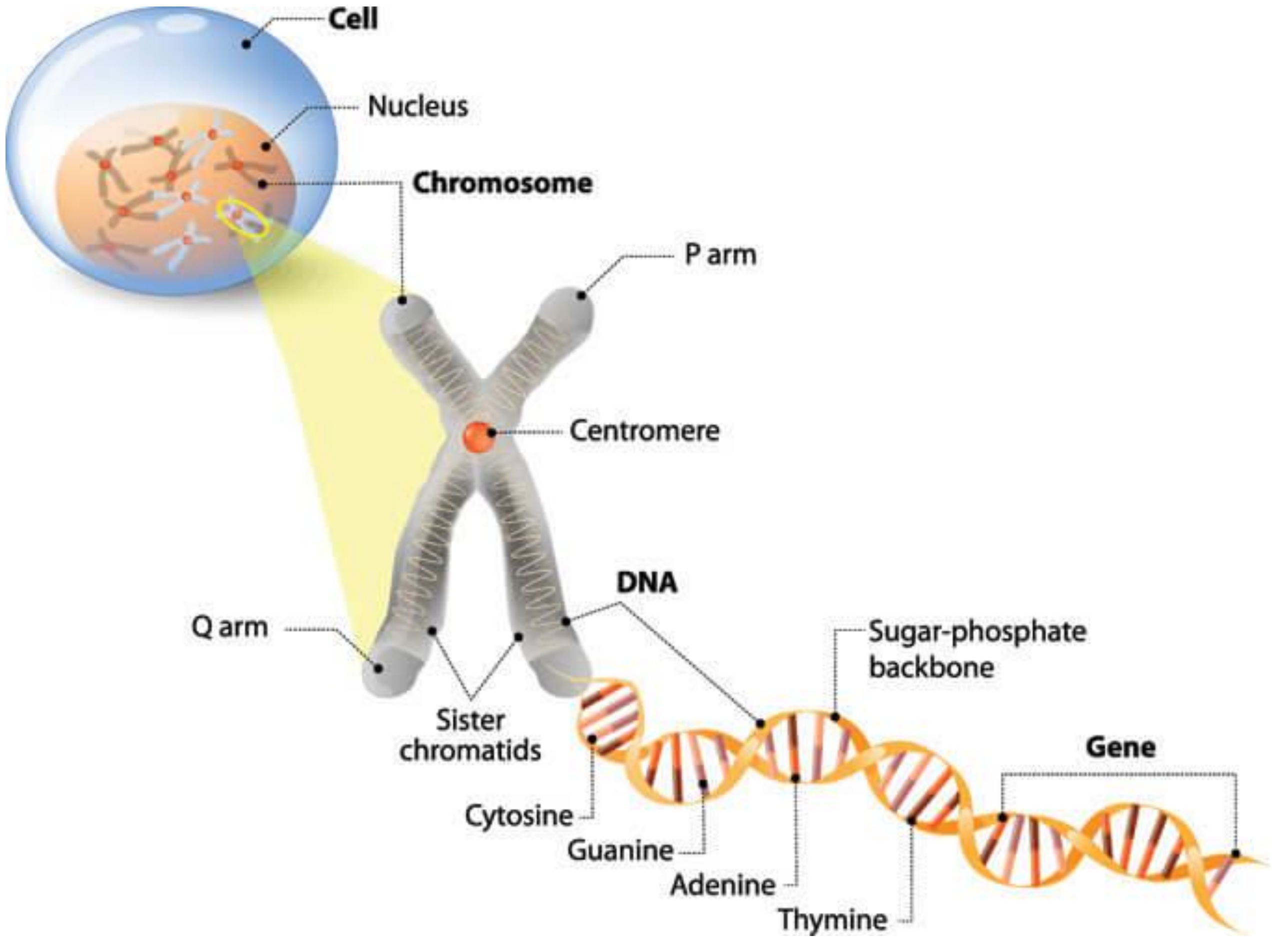
Biological computing

Concept of using biological molecules, processes, and systems—such as DNA, proteins, cells, or other biological materials—to perform computational tasks

Leverage the natural information-processing abilities of biological systems to solve complex problems



Nature operates at unmatched energy efficiency Single human cell: ~picowatts



Nucleus → Processing units

DNA → Memory

Biochemical Pathways → Logic Gates

Cellular Networks → Parallel Processing

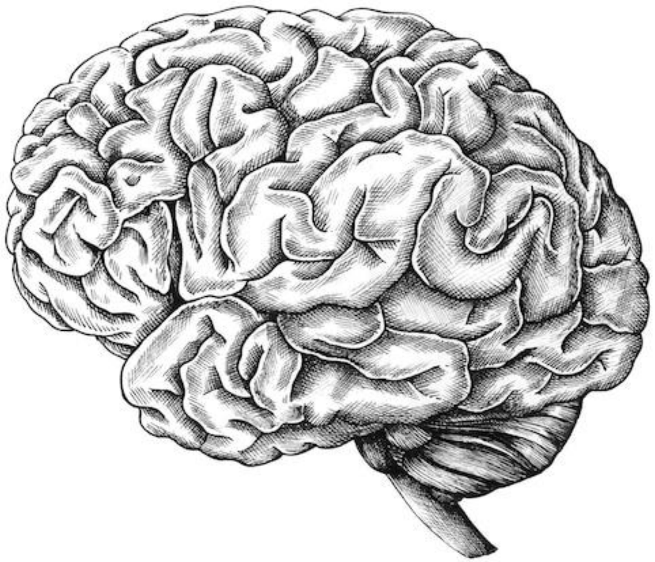
https://biologydictionary.net/deoxyribonucleic-acid/

Nature operates at unmatched energy efficiency
Larval zebrafish: ~0.1 microwatts

Nature operates at unmatched energy efficiency
Fruit fly: ~20 microwatts

https://en.wikipedia.org/wiki/Drosophila_melanogaster

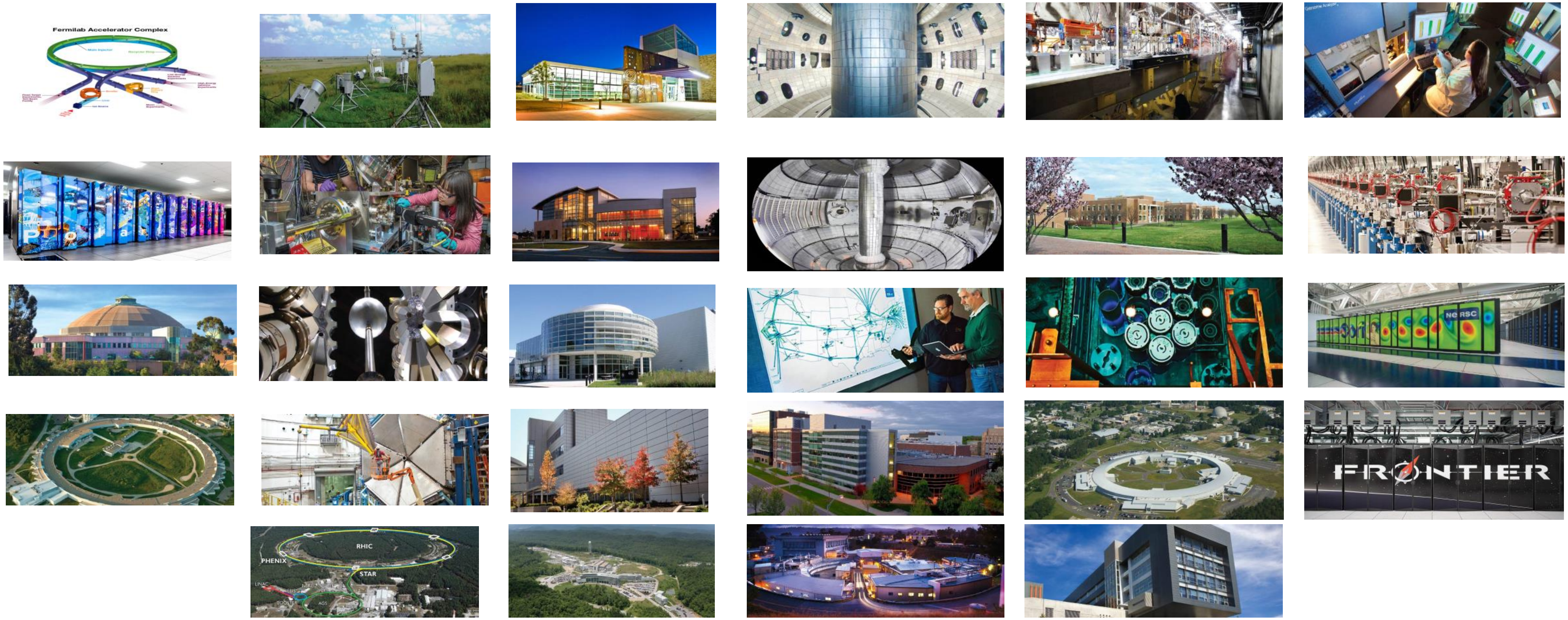
Nature operates at unmatched energy efficiency
Human brain: ~20 watts



Attribute	Frontier Supercomputer	Human Brain
Speed	1.102 exaFLOPS	~1 exaFLOPS (estimated)
Power Requirements	21 MW	10–20 W
Dimensions	680 m² (7,300 sq ft)	1.3–1.4 kg (2.9–3.1 lb)
Cabling	145 km (90 miles)	850,000 km (528,000 miles) of axons/dendrites
Memory	75 TB/s read; 35 TB/s write; 15 billion IOPS flash storage	2.5 PB (petabyte)
Storage	58 billion transistors	125 trillion synapses (4.7 bits each)

DOE is a world leader in producing diverse scientific data

28 scientific user facilities; 36,000+ users

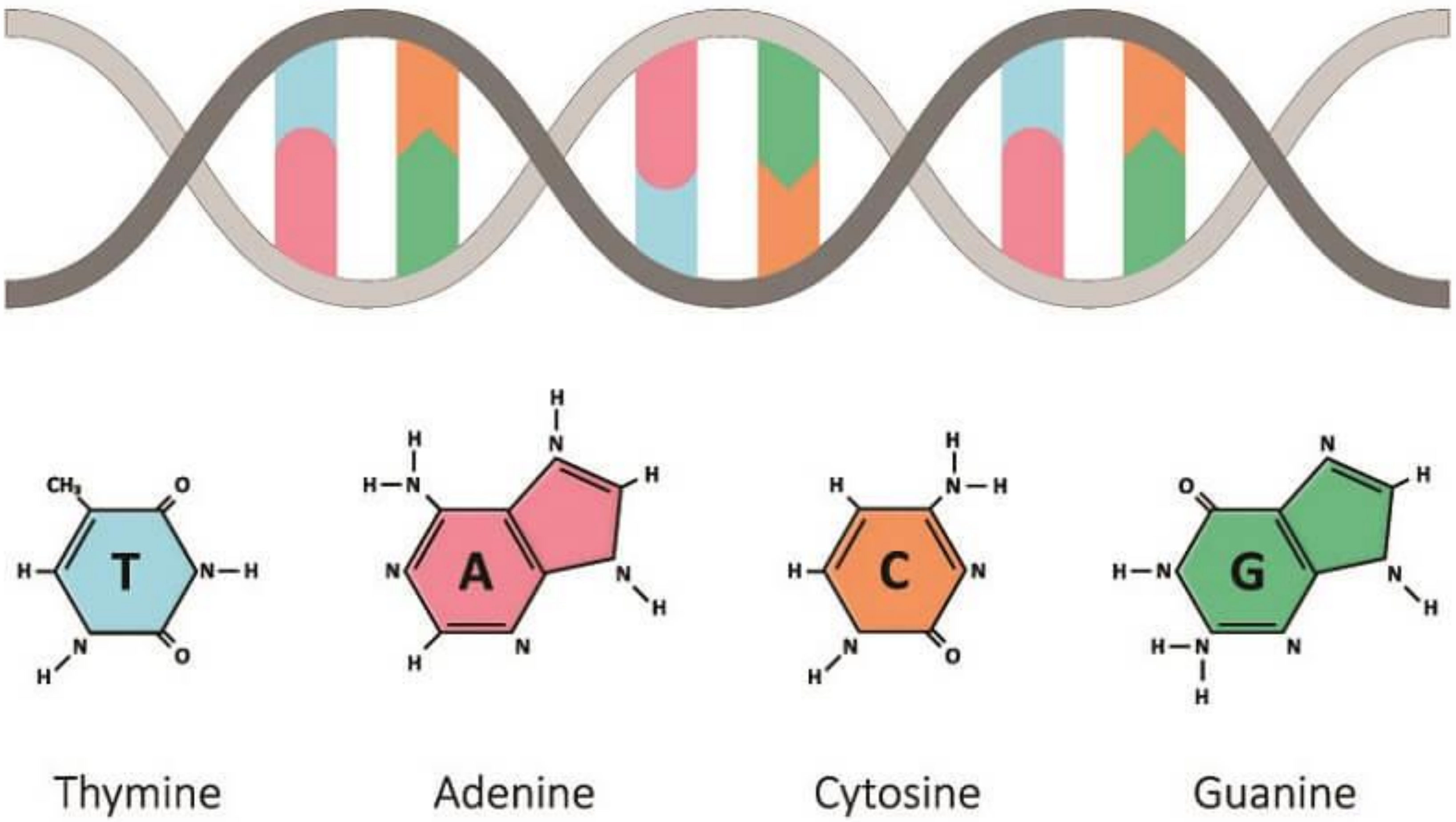


Can we store it all?

How to store?

How to store?

DNA



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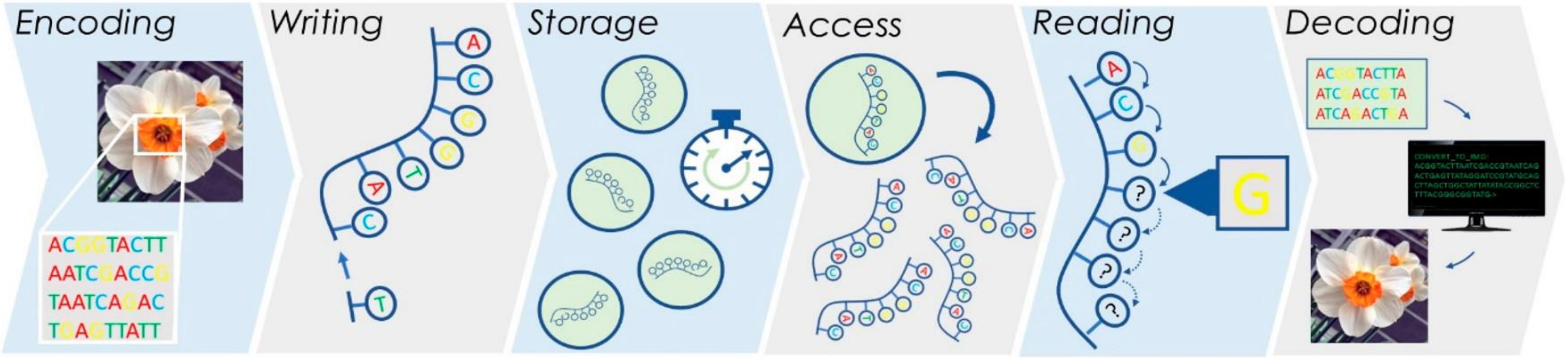
DNA storage



Doricchi, Andrea, Casey M. Platnich, Andreas Gimpel, Friederikee Horn, Max Earle, German Lanzavecchia, Aitziber L. Cortajarena et al. "Emerging approaches to DNA data storage: challenges and prospects." ACS nano 16, no. 11 (2022): 17552-17571.

What makes DNA computing attractive?

Limitless Storage

Extremely Dense: DNA storage is a million times denser than magnetic or solid-state media.

Highly Redundant: DNA can be replicated for redundancy and parallel computing.

Long-Term Stability: DNA is durable for thousands of years, ensuring lasting data relevance.

Limitless Compute

In-Storage Computing: Computations are performed directly on stored data, avoiding costly transfers.

Scalable Processing: Processing time and cost remain constant, regardless of data size.

DNA-Native Operations: DNA's structure enables efficient, specialized computing.

Challenges and opportunities

Technical Barriers

Slow biochemical reaction speeds

Error rates in DNA synthesis and sequencing

Difficulty integrating DNA computing with traditional electronic systems

Scalability

Scaling for large DOE AI applications requires advancements in biomanufacturing and automation

Cost Challenges

High costs in DNA synthesis

Collaboration

Collaboration across biology, computer science, and engineering is essential for progress

Skill Gaps

Need for interdisciplinary education and training among biologists, computer scientists, and engineers

Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem, because it doesn't look so easy. -- Richard Feynman