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https://www.gesundheitsindustrie-bw.de/en/article/press-release/molecular-biomimetics-cell-nucleus-model-dna-based-computer-chips

Molecular Biomimetics: The Cell Nucleus as a Model for DNA-based Computer Chips

In the human body, stem cells process genetic information in an exceptionally reliable and very fast manner. To do this, they specifically access certain sections of the DNA in the cell nucleus. Researchers at Karlsruhe Institute of Technology (KIT) have investigated how the DNA-based information processing system works. Their results show that this process is comparable to processes in modern computers and could therefore serve as a model for new types of DNA-based computer chips. Published in “Annals of the New York Academy of Sciences.”

In human cells, there are about 20,000 genes on a two-meter DNA strand – finely coiled up in a nucleus about 10 micrometers in diameter. By comparison, this corresponds to a 40-kilometer thread packed into a soccer ball. Despite this cramped space, stem cells manage to find and activate the correct genes in a matter of minutes. Which genes these are differs from cell to cell. Precise activation is crucial as errors in gene selection can lead to disease or cell death.

The investigations of KIT researchers have shown that biomolecular condensates enable fast yet reliable activation of the right genes. “Biomolecular condensates are tiny drops that form in specific places on the DNA – similar to the droplets on the bathroom mirror after a hot shower – and behave like oil in water,” says Professor Lennart Hilbert from the Institute of Biological and Chemical Systems (IBCS) at KIT. “They contain molecular machines, in other words a collection of certain molecules that are necessary for activating genes.” This process is reminiscent of a key principle in computer science that underlies modern computers and smartphones: the von Neumann architecture. In this architecture, a single processor can very quickly connect to a single address in a large memory, often called RAM. The researchers now want to apply this principle to artificial, DNA-based computer chips to be able to control biotechnological and biomedical applications, for example.

Surfaces That Do the Maths

“To replicate such biomolecular condensates, in other words the computing centers of the cell nuclei, and build artificial DNA nanostructures for computer chips, we combine traditional lab experiments with modern computer simulations. Using the digital models of DNA nanostructures, we can understand and even predict the behavior of the condensates,” says Mona Wellhäusser, doctoral researcher at IBCS and one of the paper’s co-authors.

To this end, the scientists digitally simulate a system in which enzymes work like small machines and perform specific tasks, like carrying out calculations for example. To get these enzymes to the right place on the DNA, they use surface condensation, in which the enzymes accumulate by themselves in specific places on the DNA – exactly where they are needed. If candidates that behave correctly are identified in the simulation, they will be synthesized in the lab and examined in test tubes for their actual properties. “This speeds up the research process enormously, as computer simulations require much less time than lab experiments,” says Hilbert. “So far, we’ve only been able to access one address. But thanks to our research, we’re paving the way for developing a more comprehensive address system and completely new, DNA-based storage and computer systems, the architecture of which is modeled on nature.”

The scientists say that the corona mRNA vaccine and a recently successful patient-specific, “programmed” gene therapy are already demonstrating the potential of biotechnologies that can be programmed by DNA and RNA. Another promising field of application are “DNA chips” for the intelligent control of cancer therapies. They could reprogram immune cells so that they become active as soon as they encounter cancer cells.

Publication:
Lennart Hilbert, Aaron Gadzekpo, Simon Lo Vecchio, Mona Wellhäusser, Xenia Tschurikow, Roshan Prizak, Barbara Becker, Sandra Burghart, Ewa Anna Oprzeska-Zingrebe: Chromatin-associated condensates as an inspiration for the system architecture of future DNA computers. Annals of the New York Academy of Sciences, 2025.
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Further information

- Karlsruhe Institute of Technology (KIT)