Barbie Nanoatelier: Open Source DNA-nanotechnology

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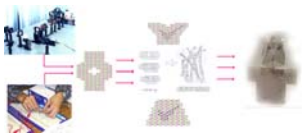
Abstract

We use the recently developed by Paul Rothemund DNA origami technique [1]. The idea is to design a strand of DNA such that it wraps into some meaningful shape. First, the DNA should fold into a two-dimensional rectangular sheet–*universal DNA-platform* [2]. Secondly, this sheet should wrap itself up into the shape of a short pipe. Next, these little pipes should hook themselves up to each other such that they form one single long pipe. Once the process of DNA folding into 3D structures is understood, shapes can be chosen arbitrarily. We hope it will be possible to maintain molecular sensors, logics, and actuators onto the surface of 3D DNA-objects to reach a swarm behavior of DNA-origami agents [3].



Introduction

Our DNA-folding project isn't a typical Synthetic Biology project, because we play a 'dead DNA' but not an 'alive DNA' coding proteins. We try to merge the DNA-origami static structures and the dynamic DNA-BioBricks constructs to reach really living machines. Because we're using DNA-synthesis very active, it could be called a Synthetic Biology or DNA-nanotechnology. The eventual aim is an Artificial Life and Origami Man. What is important, we try to pump some aesthetic principles and rules (symmetry, periodic patterns, recursion, and plasticity) into our future creatures. Crazy? Not at all!

The basic idea is to design a DNA such that it folds into DNA-sheet, which we called **the addressable platform with 6 nm scale resolution** [2]. It will be possible to mount some molecules in the desirable way on this DNA-sheet like on the blocked paper. Those molecules could play a role of sensors, logics, and actuators on this nano-platform. We'd attach a specific pattern of molecules to organize synthetic pathways in the space, or even to reach an assembly of molecules in the sense of Eric Drexler's assembler. Or we'd organize appropriate molecules, nanoparticles, or quantum dots (qubits) to build a new computer chip. We have a lot of fantasy...

"sea of parts"

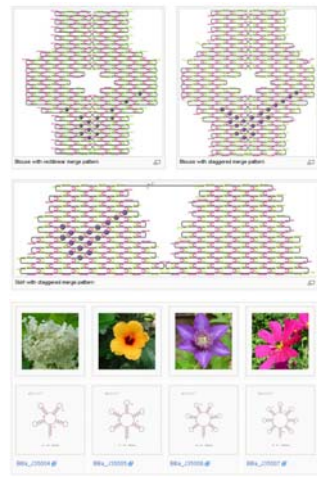
We started our Artificial Life Project with a semi-rational approach [4]. Now we tune into a rational way. We founded *Barbie Nanoatelier* to prove main assembling principles and to design complex DNA-forms. We organized the external depository for DNA-nanotechnology.

'Dead DNA' (structural DNA)	BBa_J35000 - BBa_J35399
Structures	BBa_J35000 - BBa_J35099
DNA origami	BBa_J35000 - BBa_J35029
protein binding parts	BBa_J35030 - BBa_J35059
aptamers	BBa_J35060 - BBa_J35089
others	BBa_J35090 - BBa_J35099
Devices	BBa_J35100 - BBa_J35199
tweezers	BBa_J35100 - BBa_J35119
nanomechanical switches	BBa_J35120 - BBa_J35139
nanoactuators	BBa_J35140 - BBa_J35159
walking nanomachines	BBa_J35160 - BBa_J35179
others	BBa_J35180 - BBa_J35199
Systems	BBa_J35200 - BBa_J35299
Others	BBa_J35300 - BBa_J35399
Alive DNA' (protein-coding DNA)	BBa_J35400 - BBa_J35799
Parts	BBa_J35400 - BBa_J35499
Devices	BBa_J35500 - BBa_J35599
Systems	BBa_J35600 - BBa_J35699
Others	BBa_J35700 - BBa_J35799
Other DNA	BBa_J35800 - BBa_J35999

We just put first examples of *LEGO set of DNA building blocks for Artificial Life*. These things allowed us to run in different directions. Irina pumps aesthetic principles into DNA-creatures. Mona builds DNA-chip. Andrew used DNA-origami to code images and to design a nanobot.

Surrealistic Science

The DNA-dresses for an imaginary nano-Barbie doll is most funny and nice job! We like it because it needs a huge of imagination and really very difficult. Nobody can build a bra! - *von Neumann's self-reproducing ... Bra.*



Design Rules

We dramatically simplified Rothemund's scaffold origami method. Now students need only a browser with access to standard bioinformatics tools and a text processor, if they didn't make too complex design [5]:

Abstraction

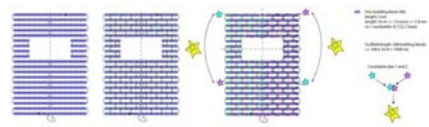
1. Take a block of paper; 1.5 block on paper = 1 building block of 16 nucleotides = 1.5 tern DNA = 5.4 nm horizontal and 4 nm vertical.
2. Find a "snake" path through the manhattan geometry horizontally with turns in the vertical direction, try to exploit symmetry.
3. Starting at one end of the DNA strand, insert a crossover to the strand section above every alternate building block. Add helper strands to bind the scaffold together. As first designed, most staples bind two helices and are 16-mers.
4. Merge helper strands to enhance the scaffold. As second designed, most staples bind three helices and are 32-mers.
5. Fill up the scaffold with letters A, T, G, C, define corresponding staple sequences by complementary mapping from scaffold to valid sequence (A, T and G, C).
6. We now have 1 long scaffold + many shorter staples.

Implementation

1. Send your request to a DNA synthesizing company such as *febit* in Heidelberg. You will have 2 bottles: 1 with the scaffold DNA, the other full of staples in 1xTAE (pH 7-8.4) buffer with 10 mM MgAc.
2. Get the following equipment: pipettes, gradient thermocycler, AFM, mica.
3. Mix the scaffold and staple DNAs in 1/10 (M/M) proportion (2 x 50 µl),
4. Warm to 92°C and program the cooling down to room temp 20°C, over 16 hours
5. Cleave the mica and place 5 µl droplet on the mica. Image with AFM, let say Heureka!

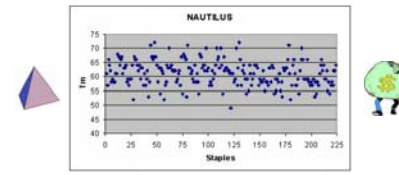
Methods of analysis

- DNA folding (electrophoresis in polyacrylamide gel)
- 2D structures
  - transmission electron microscopy
  - atom force microscopy
- 3D structures
  - trap of nanoparticles
  - quenching of fluorescence
  - *fluorescence correlation spectroscopy*



Nanobot NAUTILUS

The tetrahedron about 50 nm scale was designed as a derivate of the short pipe to be *a main building block of 4D-structures* (like protein complexes). We hope to use this building primitive to create smart materials and *a nanoswarm*.



Conclusions

1. We designed a lot of creatures from DNA. You see!
2. We realized *the DNA-synthesis is a bottle-neck* of DNA-nanotechnology.
3. We weren't able to create *"self-replicated" staples* and Artificial Life was not created this time. We'll try it again.
4. We'll design the Artificial Life firstly not in the tube, especially in the *DATABASE*. We'll manipulate DNA only by mouse, next by modeling, and then we'll bring it in labs…

Future projections

Unconventional computing, cryptography, nanoelectronics, nanooptics, nanosensors, drug delivery systems and smart nanomaterials as potential applications for near future.

References

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4. *Kuznetsov A., Schmitz M., Mueller K.* On Bio-Design of Argo-Machine // GWAL-7: 7th German Workshop on Artificial Life, Jena, Germany, 26-28 July 2006. P. 125-133.
5. *Olga Soboleva, Daniel Hautzinger, Marc Wilnauer, Andrey Kuznetsov, Svetlana Santer, Kristian Mueller, Albrecht Sippel, and Jan Korvink* T-shirt from DNA // ibid [2]

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