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Mimicking nanoscale natural movements with the help of DNA Origami

Researchers at the Max Planck Institute for Intelligent Systems together with researchers at the University of Heidelberg and the University of Stuttgart use a technique called DNA origami to mimic a multitude of vital movements seen in nature, such as the sliding motion exerted by protein motors during cell division. Their invention, which is a thousand times smaller than a human hair, features a preliminary attempt to construct nanoscale analogues of the mysterious natural machines in living cells.

Stuttgart – "We have managed to couple two origami filaments and to move them apart in a controlled fashion. We call this filament sliding. By doing so, we have imitated, to some extent, an essential movement behavior that occurs in nature, during cell division or muscle contraction." Maximilian Urban is proud that his research publication will appear in Nature Communications on Friday April 13th 2018, entitled "Gold nanocrystal-mediated sliding of doublet DNA origami filament". The 31-year old doctoral student is among a team of seven researchers in the "Smart Nanoplasmonics" research group at the Max Planck Institute for Intelligent Systems in Stuttgart. Since 2014 he has been working on different dynamic nanosystems enabled by DNA origami technique. "Our goal is to realize a variety of artificial functional systems on the nanoscale, taking direct inspirations from nature", says Laura Na Liu, who works with Urban and leads the research group.

Cell division is the fundamental means of reproduction, in which a mother cell divides into two daughter cells. A particular protein motor called Kinesin-5 is one of the crucial working elements behind this division process. Imagine a cell, which looks like a flexible sphere and splits in the middle, not by falling apart, but through a highly intelligent and coordinated way so that the two daughter cells form and drift in opposite directions. Kinesin-5 functions at the midzone and slides "tracks" called microtubules. The microtubule can be imaged as the crash barriers of a highway, with many Kinesin-5 protein motors in between. "These protein motors help the cell split by sliding," Urban explains. "They do so by hooking up to the microtubules on each side and, through a movement in opposite directions, they cause the splitting."

Urban´s research is all about imitating this sliding behavior on the nanoscale. To mimic it, Urban uses an artificial dynamic system made out of DNA (see the image below). The first challenge is to build the track, namely the microtubule, the crash barriers on either side. For this, Urban uses strands of DNA to make DNA bundles. "We call them origami bundles, because we take floppy DNA strands and fold them – much like the Japanese art of folding paper into objects," Laura Na Liu adds. The art of folding DNA to create nanoscale shapes and patterns was developed by Paul Rothemund in 2006. By rationally folding long, single-stranded DNA molecules, the DNA nanotechnology pioneer was able to make squares, disks and even smiley faces using DNA.

Scientists call these origami DNA bundles "filaments". Each filament is about 100 nanometers long, and by grouping helices next to each other – much like a wall is made of bricks – a track is formed. Also, the filaments have short single-stranded DNA strands sticking out from the track. Why will become clear later.

Back to the filaments. “If we only used a DNA strand, it would be very floppy. But if we fold the DNA into bundles, they become rigid enough so that gold nanocrystals can crosslink or hybridize and slide them,” Laura Na Liu explains. Hybridization means forming a pair between complementary regions of two single DNA strands that were not originally paired.

The second challenge is to build the counterpart of the protein motor, which in real cells is in charge of sliding, causing the two daughter cells to drift apart. Maximilian Urban uses gold nanocrystals to mimic the protein motors. “They look like tiny golden balls, ten nanometers in size. I coat them with hundreds of threads of single-stranded DNA, which stick out as if the nanocrystal had a bad-hair-day,” he says with a smile. These DNA threads on the nanocrystal enable it to hook onto the crash barriers, the origami bundles. Through such binding, this creates a DNA double strand like a connector between the gold ball and the track. “By adding finely tuned DNA snippets, we can open these connectors and thereby release the gold ball at one point. At the same time we can use another set of DNA snippets to tie the ball to the track at next location. This causes the gold crystal between the origami tracks to start rotating. It´s like a double rack pinion railway, that employs gears to slide two linear tracks along opposite directions. By clever arrangement of the building blocks in our system, it is possible to move two filaments in opposite directions back and forth.”

Both Urban and Liu invested a lot of time and effort into a research field called dynamic DNA nanotechnology. “We would like to explore the different functions natural systems can perform – in this case, molecular motors”, says Urban. “Our research is about the ability to move things, in a directed and defined way, in a liquid environment where molecules float randomly. We managed to couple two filaments together using gold nanocrystals and to move the filaments apart in resemblance to the sliding motion carried out by protein motors on microtubules”.

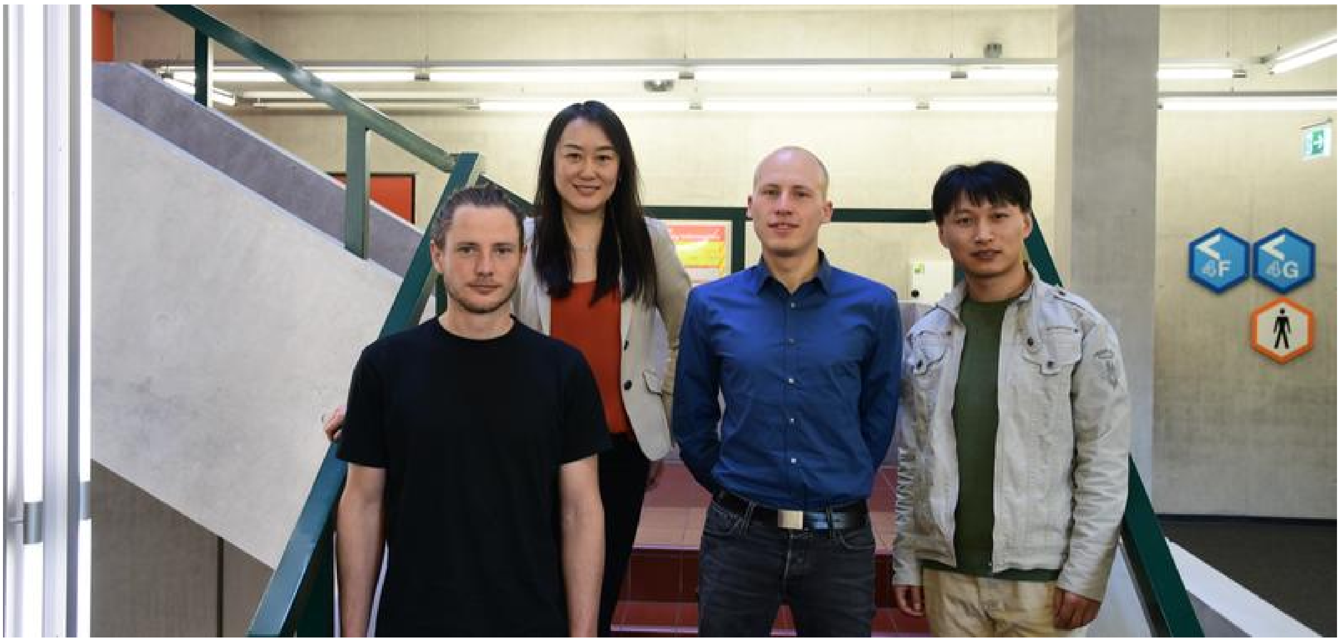
Nanomachines made from molecules - research trio Jean-Pierre Sauvage, J. Fraser Stoddart and Bernard Feringa have developed molecular systems with controllable movements for carrying out certain tasks when energy is supplied to them. They were awarded the Nobel Prize in 2016 for their significant contributions to chemistry. "There has been exciting and inspiring progress on the synthesis of tiny machines that carry out basic functions including linear motions or rotations. That is the direction we have been following as well but using DNA nanotechnology," says Urban. “Our motivation is that when you try to mimic something, that´s when you understand it best. Secondly – but this is far off in the future – we aim for applications in nanomedicine by designing nanorobots that can perform predesignated tasks in the body on their own. We would like to build artificial molecular factories where we can produce nanorobots with effective sensing and feedback control so that they can carry drugs and deliver them to where they are needed, for instance to a cancer cell.”

Other potential areas of applications are artificial cell systems. Na Liu elaborates: “In our research field the lofty question is still not fully unraveled, namely, how we can understand better and whether we can build artificial cells with all artificial components.”

The publication "Gold nanocrystal-mediated sliding of doublet DNA origami filaments" (DOI 10.1038/s41467-018-03882-w) has been scheduled for publication on the Nature Communications website on Friday, 13th April 2018. The embargo on the paper will lift at 10:00 London time. It will be available to view at www.nature.com/ncomms.

URL zur Pressemitteilung: http://www.nature.com/ncomms

Anhang Electron microscope image of the nanostructure http://idw-online.de/de/attachment65249



From left to right: Maximilian Urban, Laura Na Liu, Steffen Both, and Chao Zhou
Max Planck Institute for Intelligent Systems

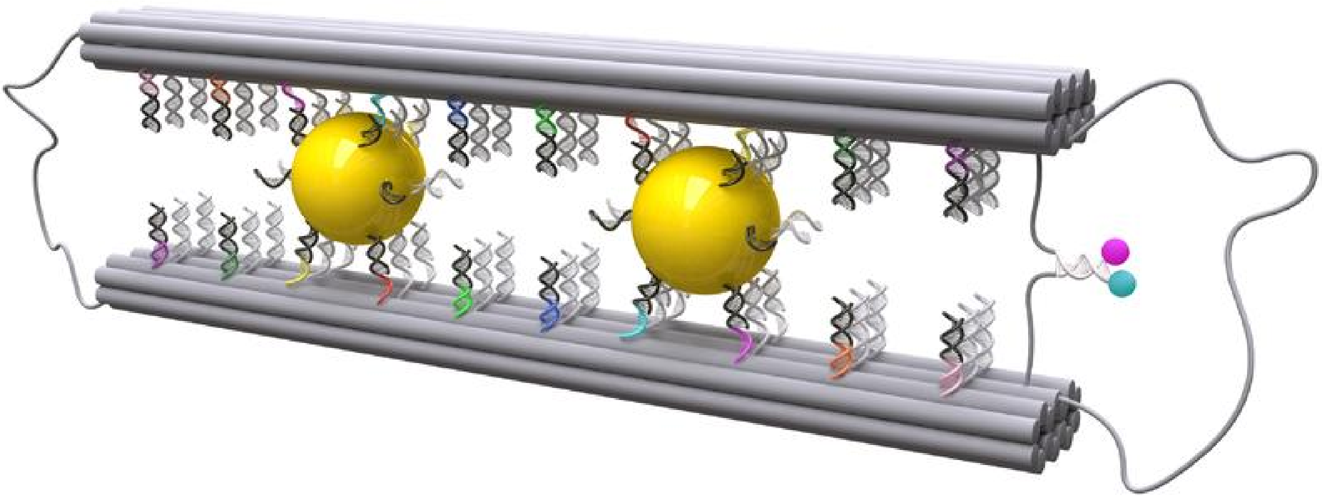


Illustration of the nano structure
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