
Programming Matter

Smart Surfaces, Molecular Machines,
and Invisibility Cloaks

Lauren Zarzar

Nick Schade

Adam Marblestone

Outline for the Evening

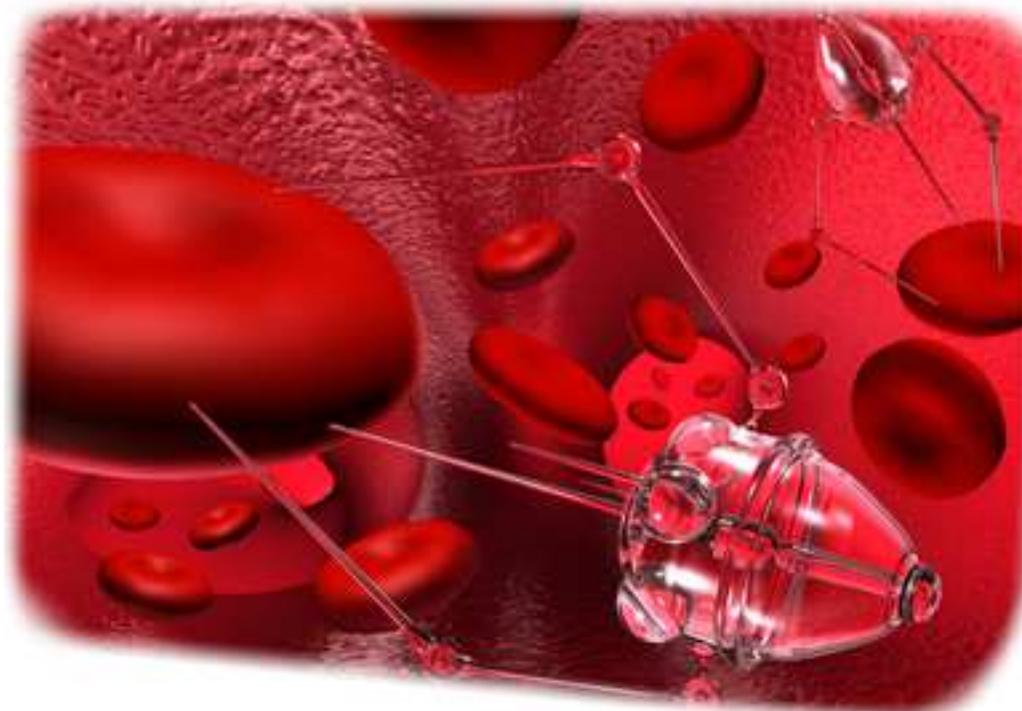
- Lauren Zarzar – Programming smart surfaces with hydrogels
- Nicholas Schade – Controlling the way matter interacts with light
- Adam Marblestone – Building **tiny molecular machines** using DNA

Why build tiny machines?

Answer: much biology occurs at the scale of molecules and cells

To advance medicine, we must build technology at that scale!

*An artist's conception
of nano-medicine*



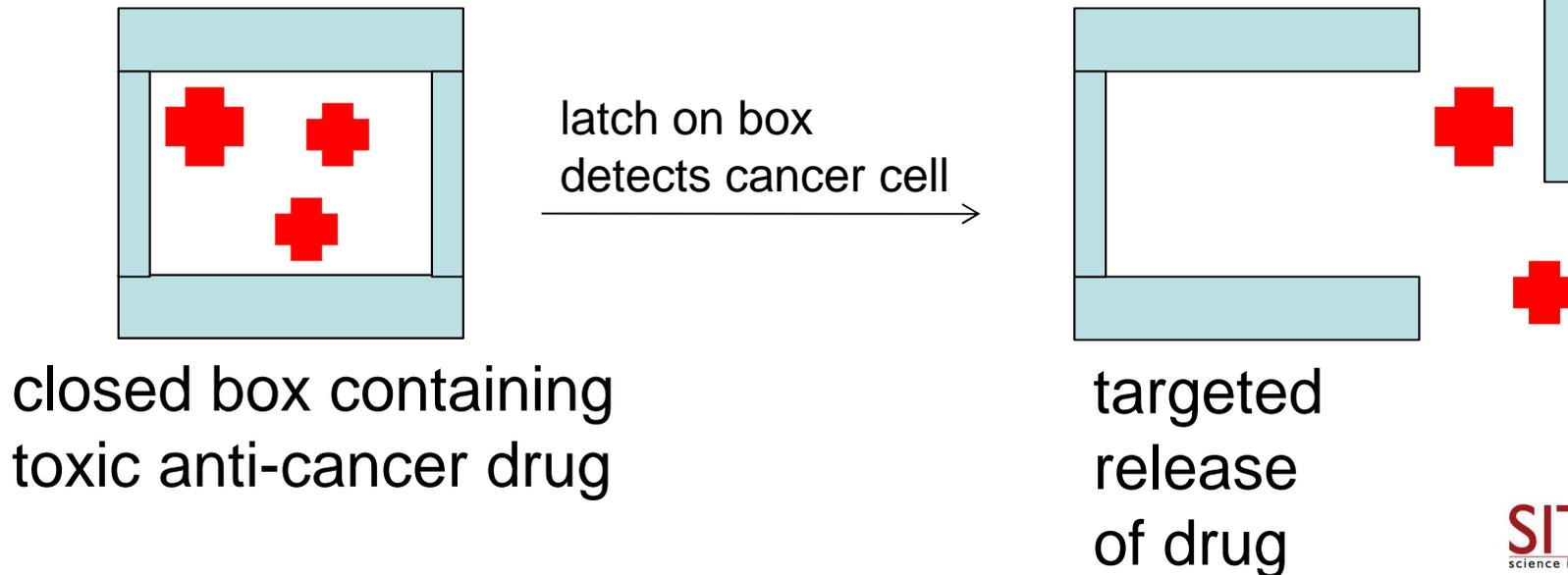
http://cordis.europa.eu/technology-platforms/nano_en.html

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Example: smart drug-delivery



BIG PROBLEM

Machines can't yet directly manipulate objects at a sub-cellular length scale by *picking them up* and *moving them around*



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Machines can't yet directly manipulate objects at a sub-cellular length scale by *picking them up* and *moving them around*



how to *build* if you can't pick and place objects?

Instead we must endow molecular building blocks with the ability to assemble themselves!



random
jiggling
→



But what are the right LEGOs to use at the molecular scale?



=

smaller than a cell

?

bigger than an atom

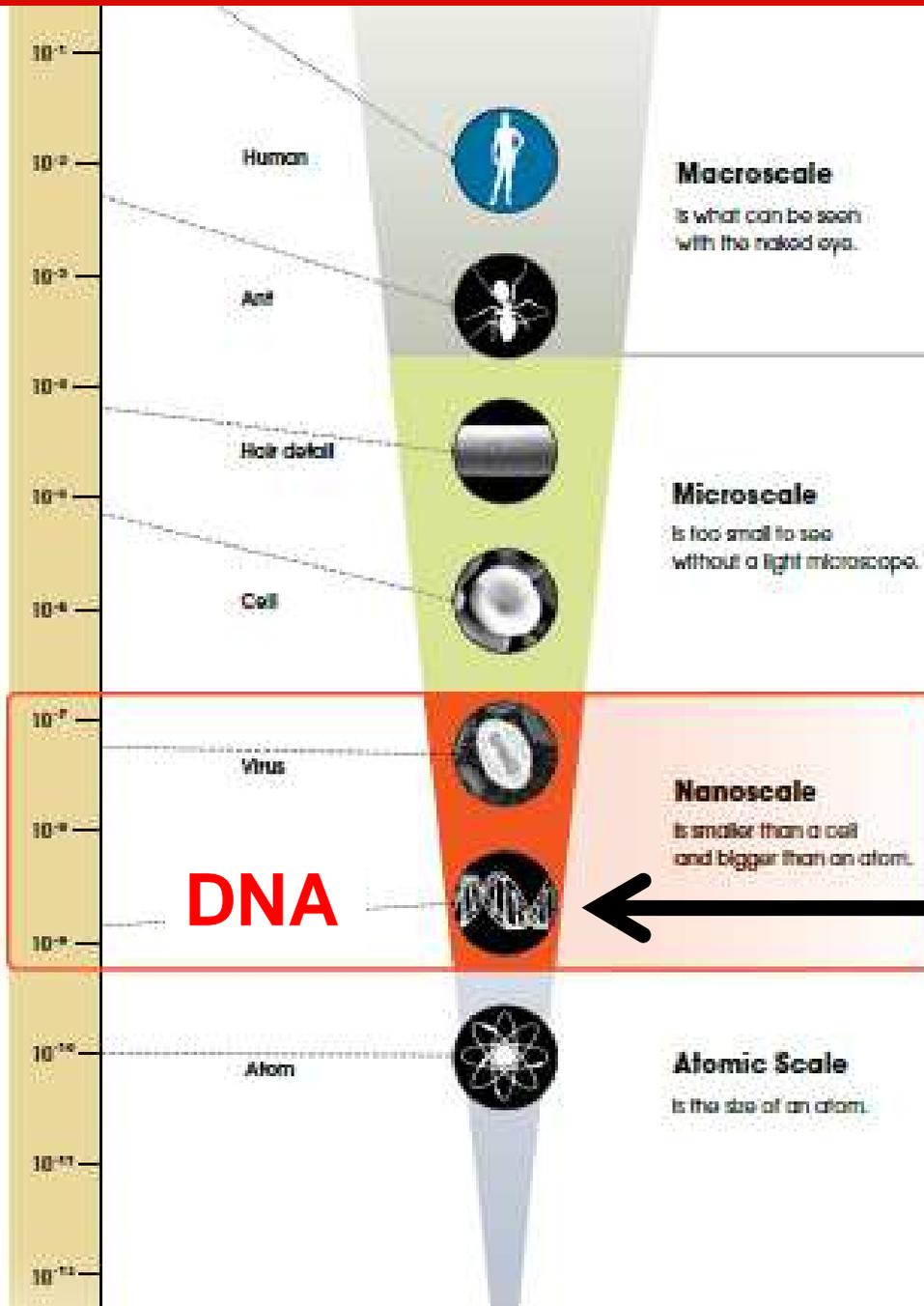
But what are the right LEGOs to use at the molecular scale?



=



DNA

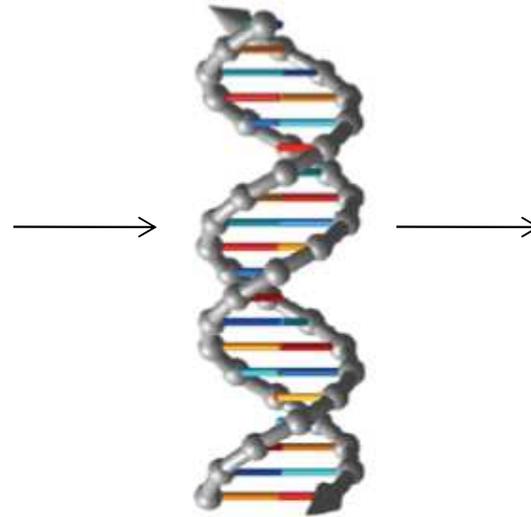


DNA as brick and mortar!

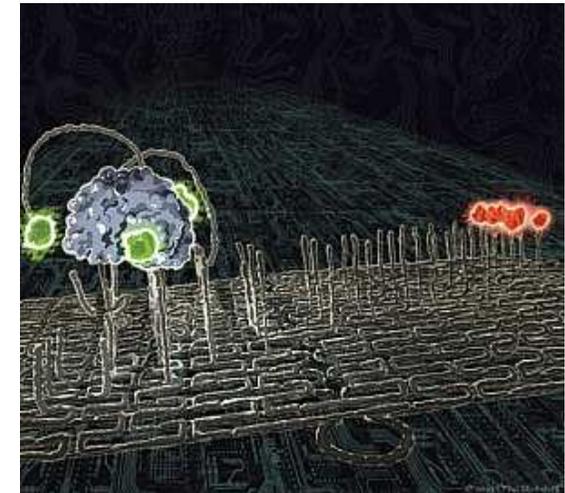
FORTUNATELY, WE CAN MAKE DNA CHAINS IN THE LAB



DNA synthesis machine

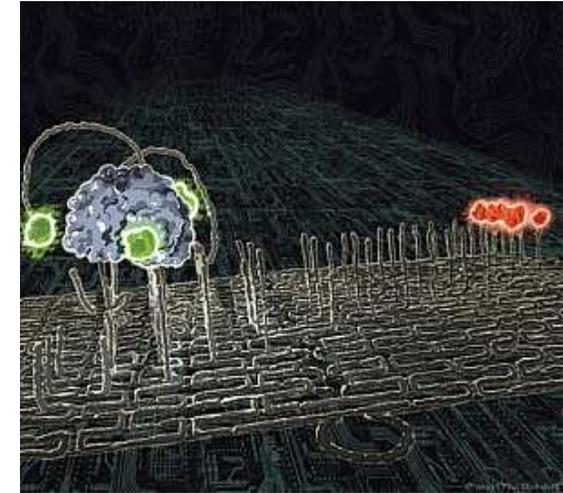
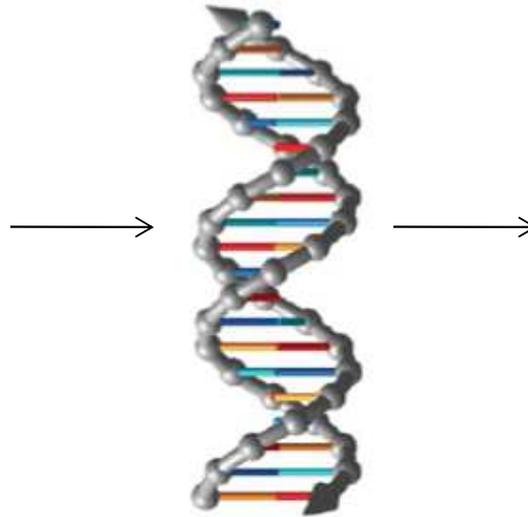


DNA



MOLECULAR
STRUCTURES
& ROBOTS

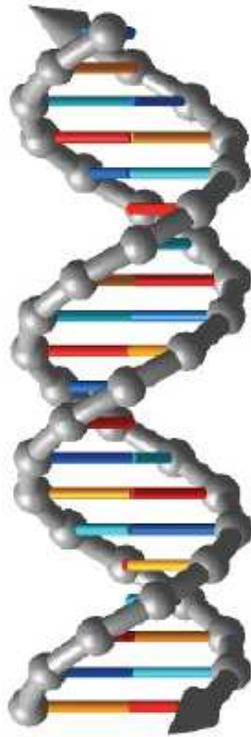
FORTUNATELY, WE CAN MAKE DNA CHAINS IN THE LAB



... or buy it online!



Why DNA is like LEGO

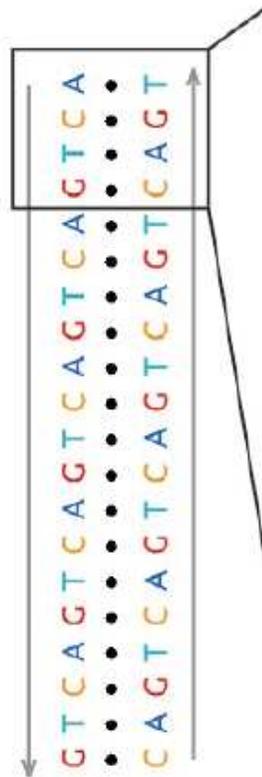
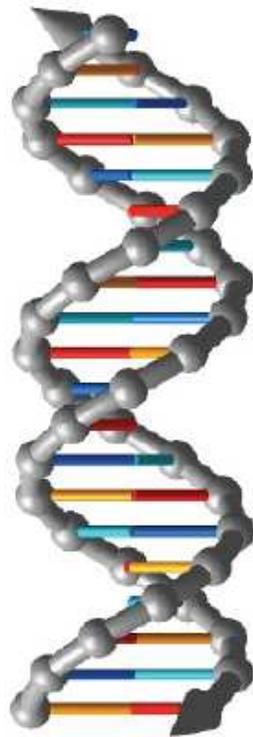


geometry

Why DNA is like LEGO

DNA is a chain made of 4 letters:

A, T, G and C



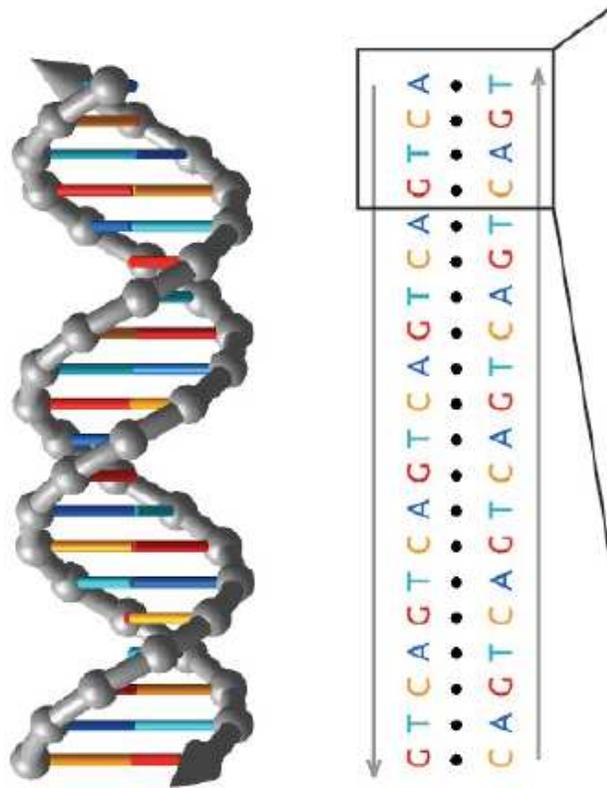
A sticks to **T**

C sticks to **G**

geometry

sequence

Why DNA is like LEGO



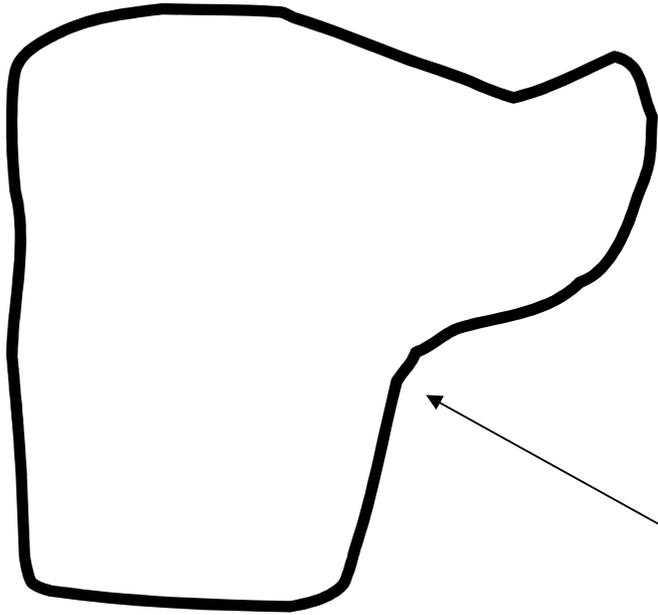
TWO DNA STRANDS
THAT STICK TOGETHER
PERFECTLY ARE
COMPLEMENTARY

... **G** **T** **C** **A** ...
... **C** **A** **G** **T** ...

geometry

sequence

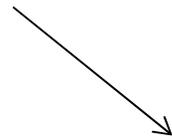
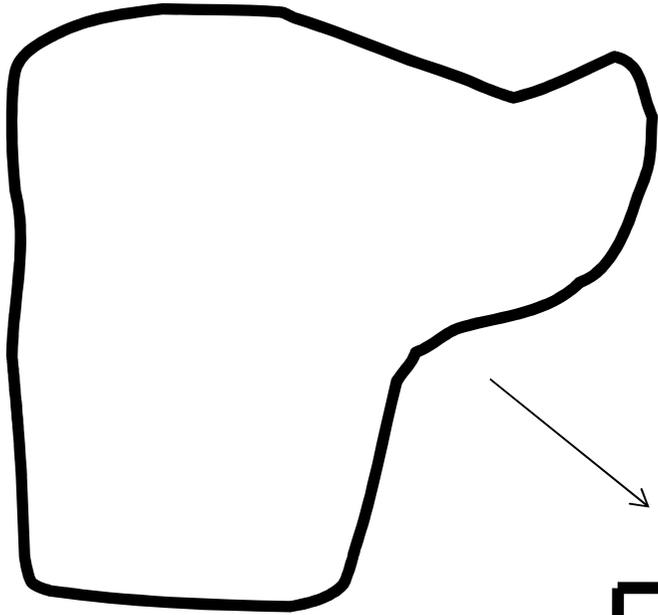
scaffolded DNA origami



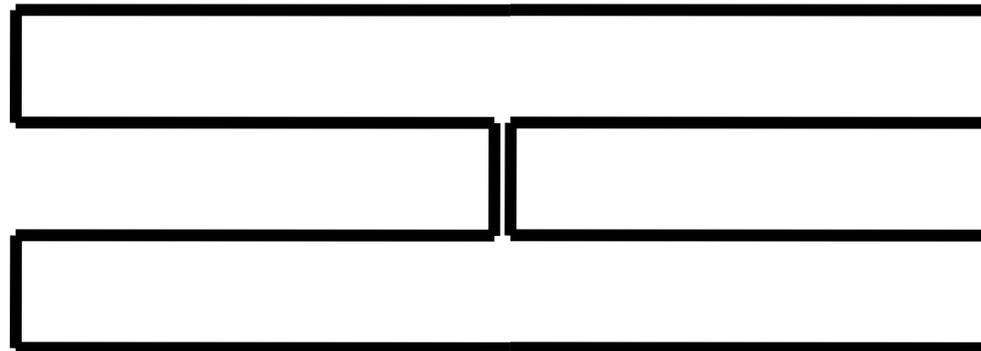
Scaffold Strand:

Long single-stranded DNA molecule
of *known sequence*

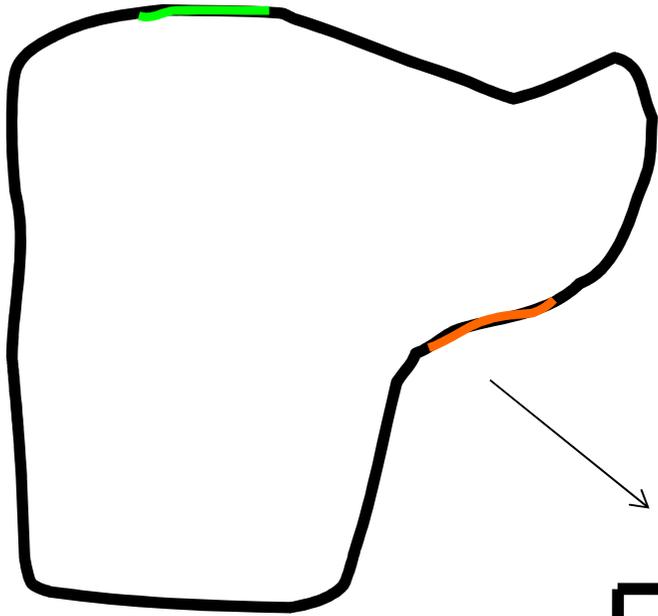
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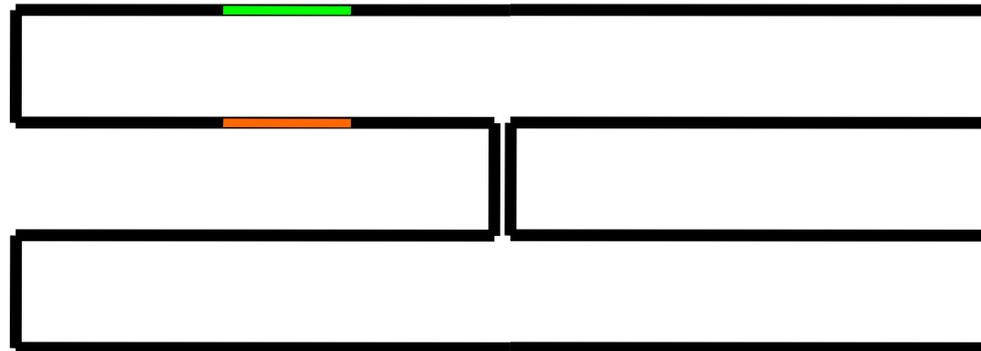
Let's fold it into a rectangle!

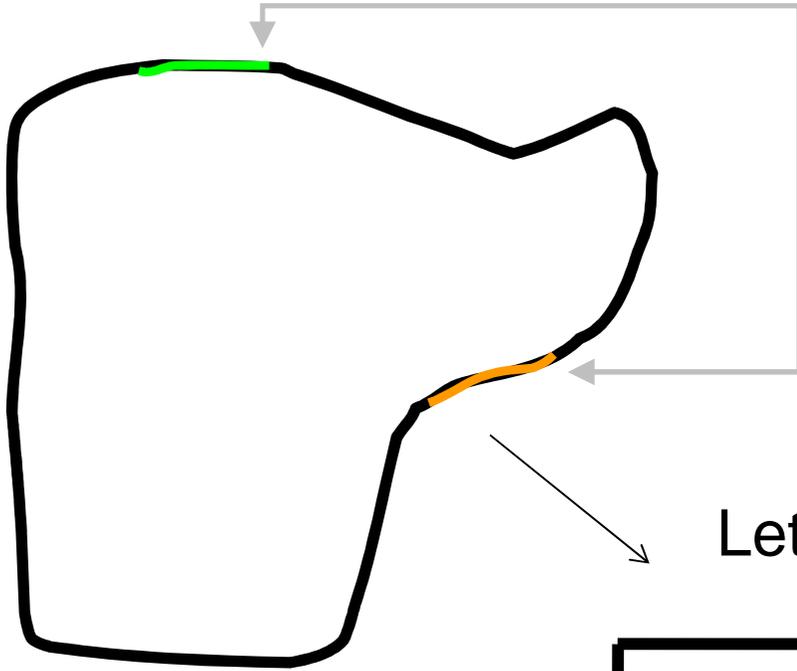


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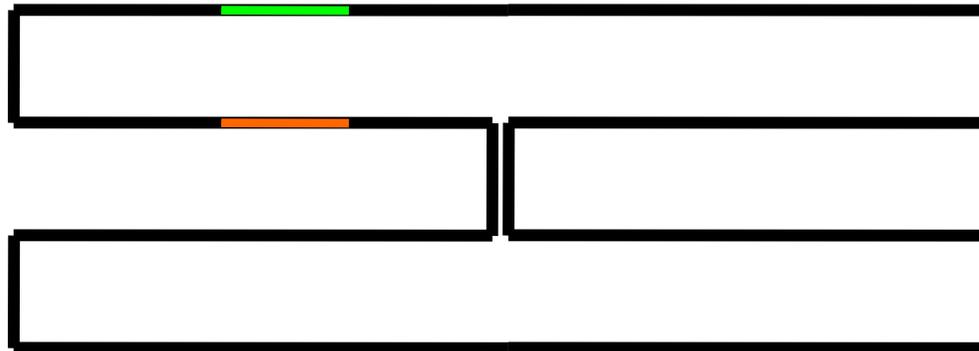
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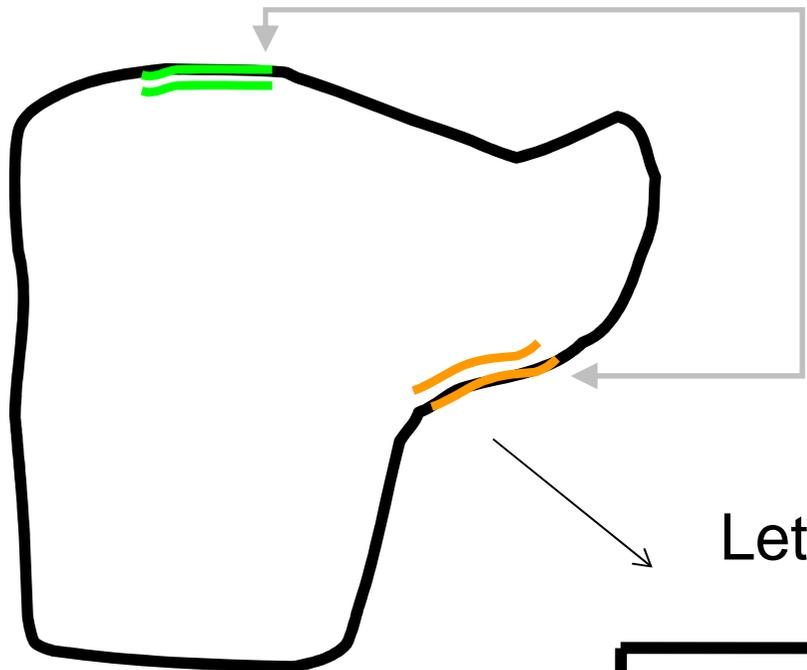




Want to pinch together these two points in the final structure....

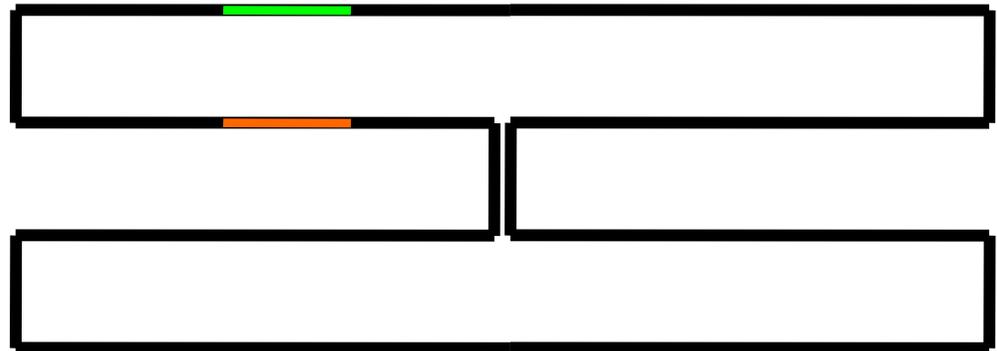
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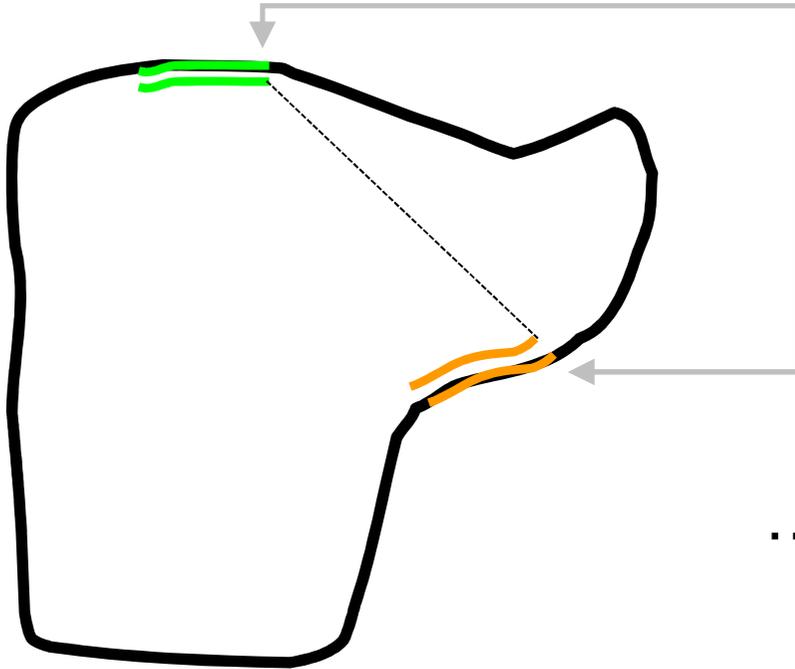




Want to pinch together these two points in the final structure....

Let's fold it into a rectangle!

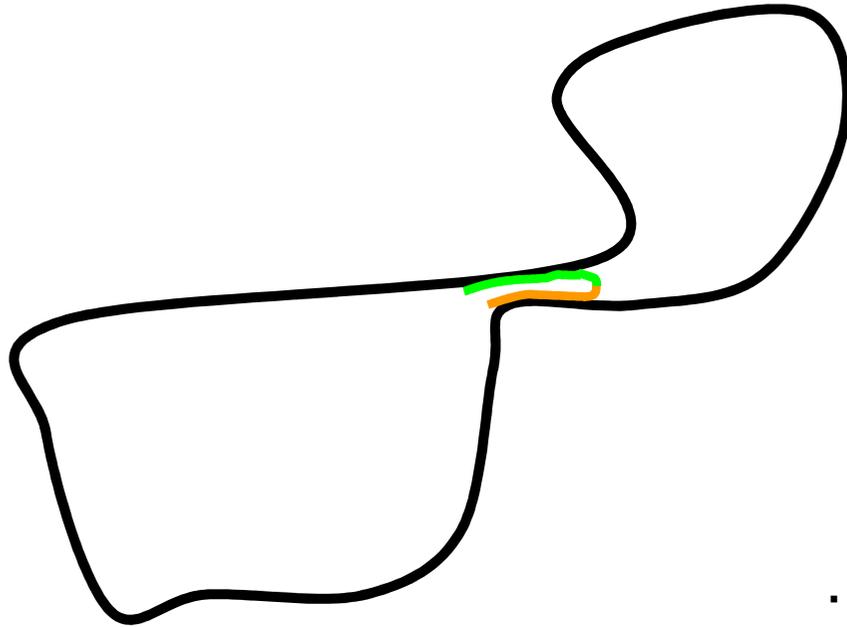




Want to pinch together these two points in the final structure....

... so create a two-part **staple** strand which joins them!

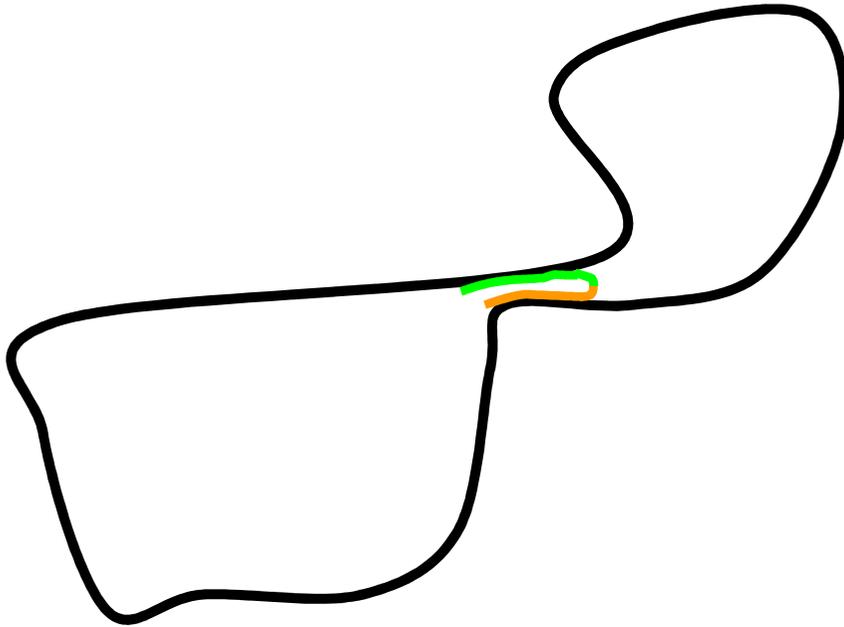




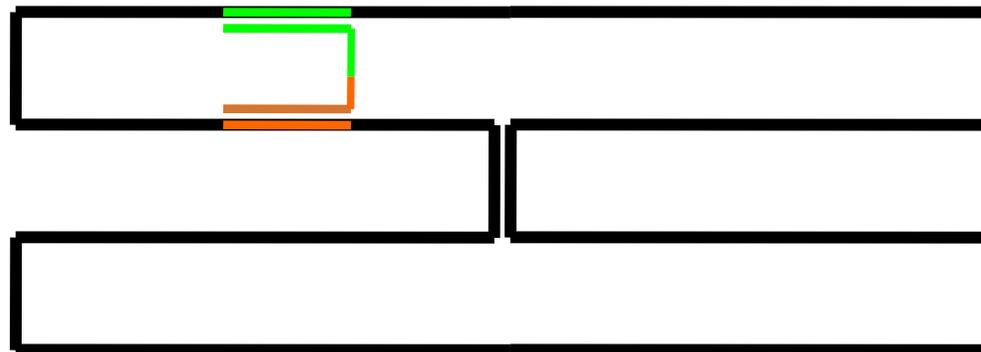
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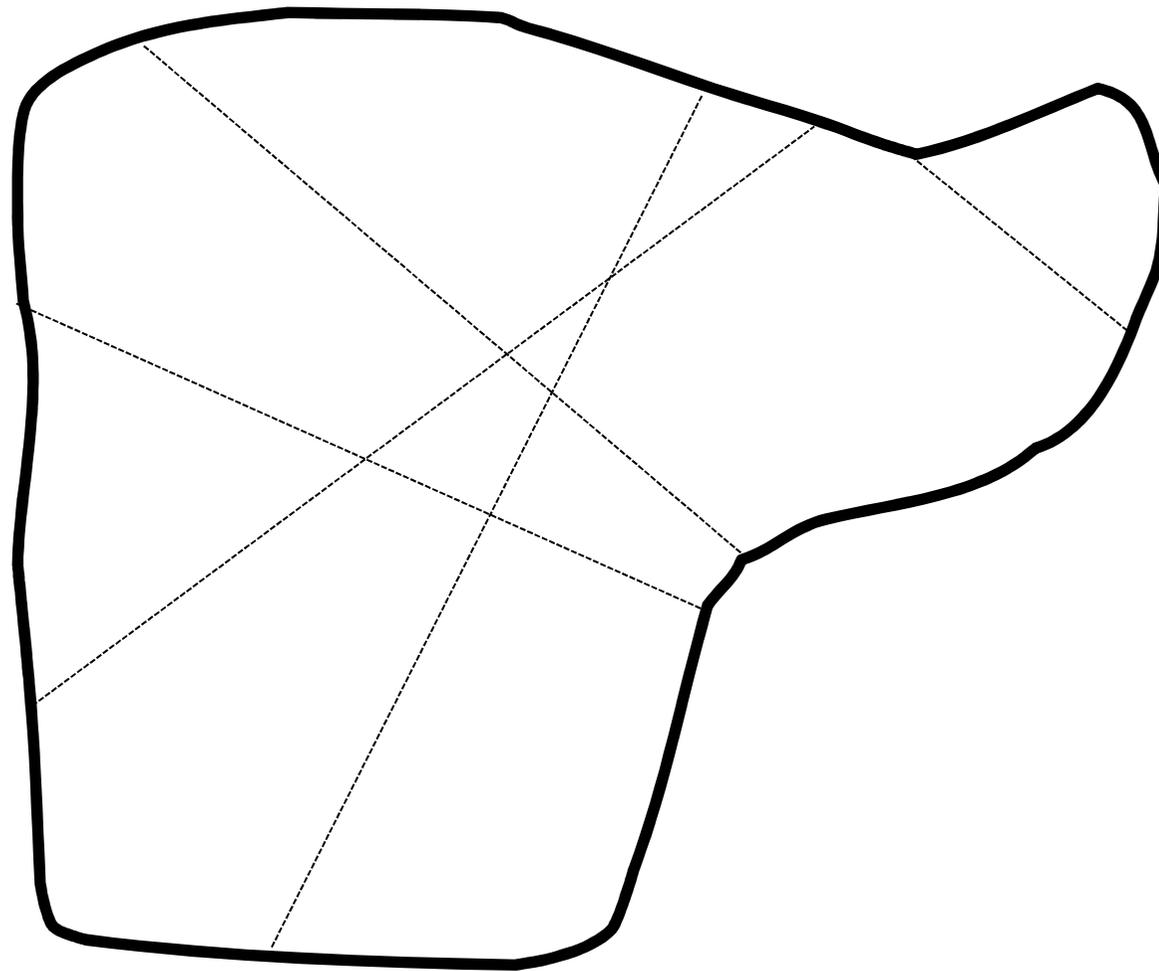
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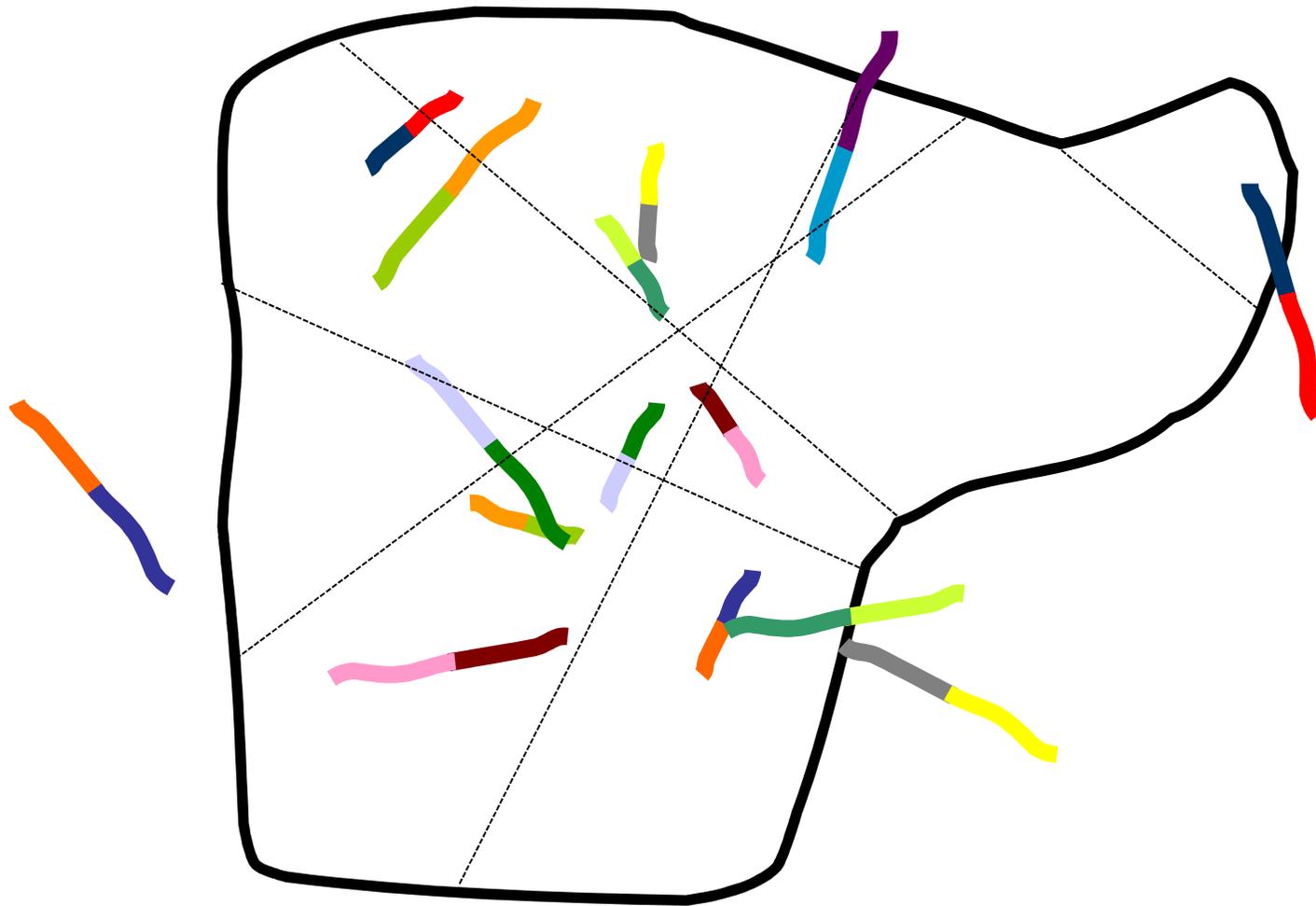


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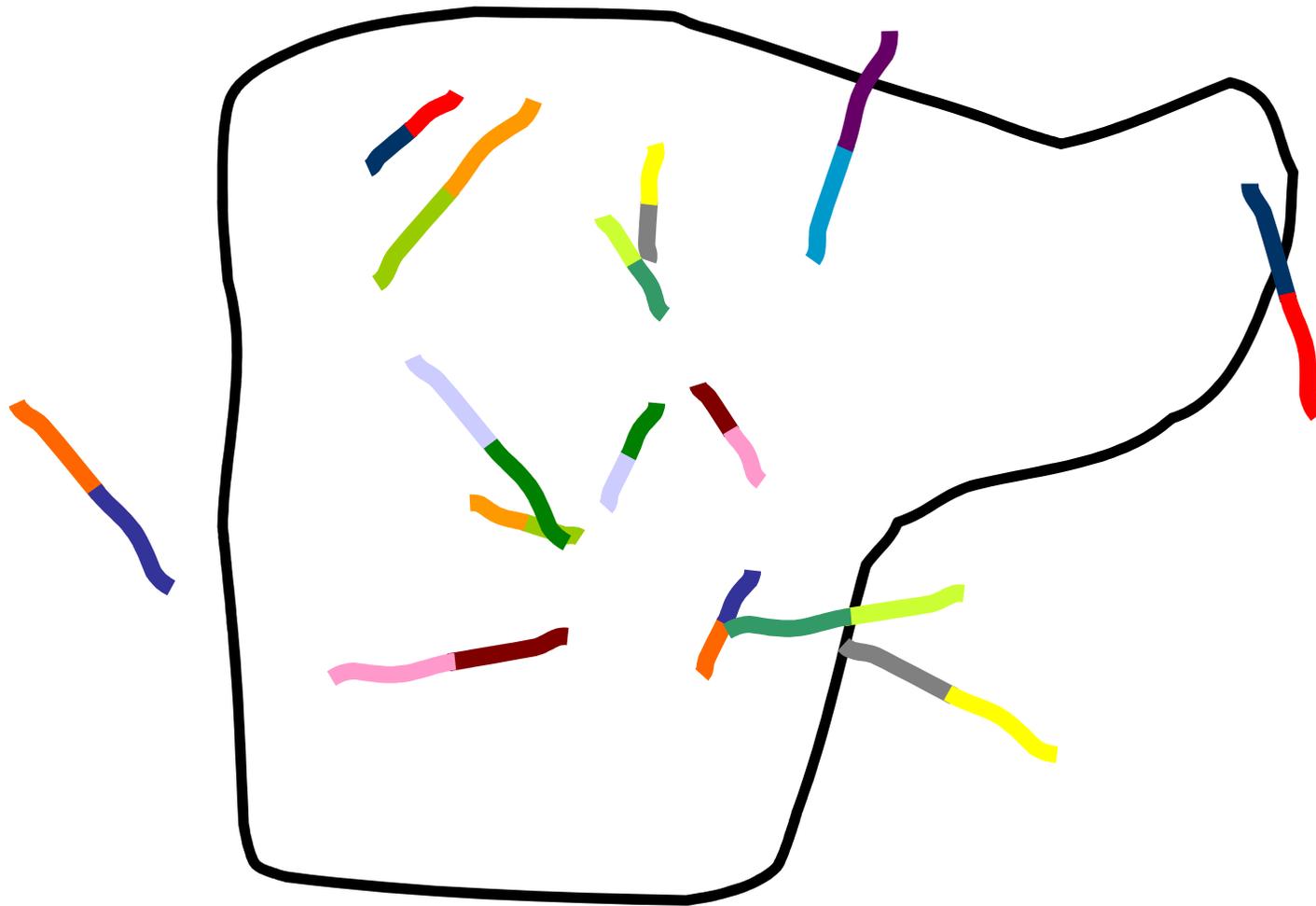




Folding a complete shape requires many staples...



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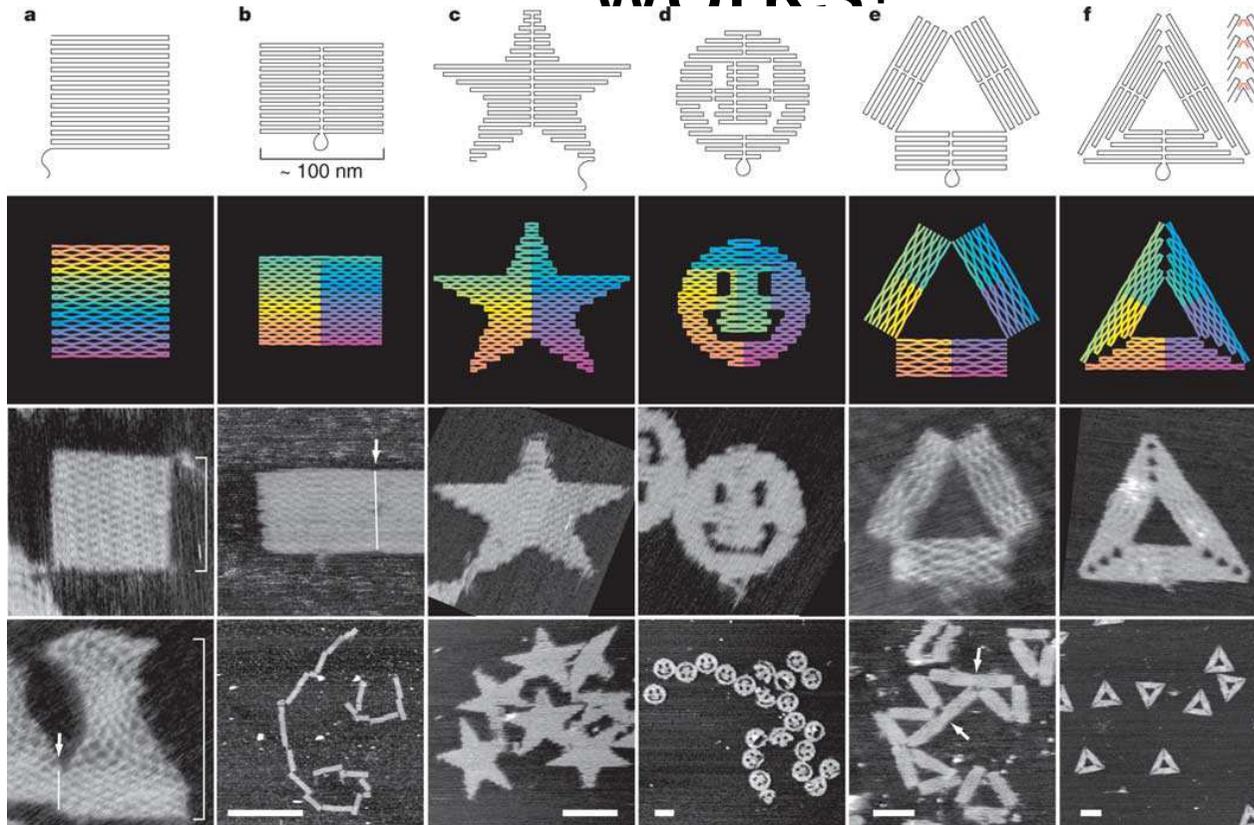
Recipe: scaffold + staples $\xrightarrow{\text{self-assembly}}$ DNA object



Animation by Shawn Douglas

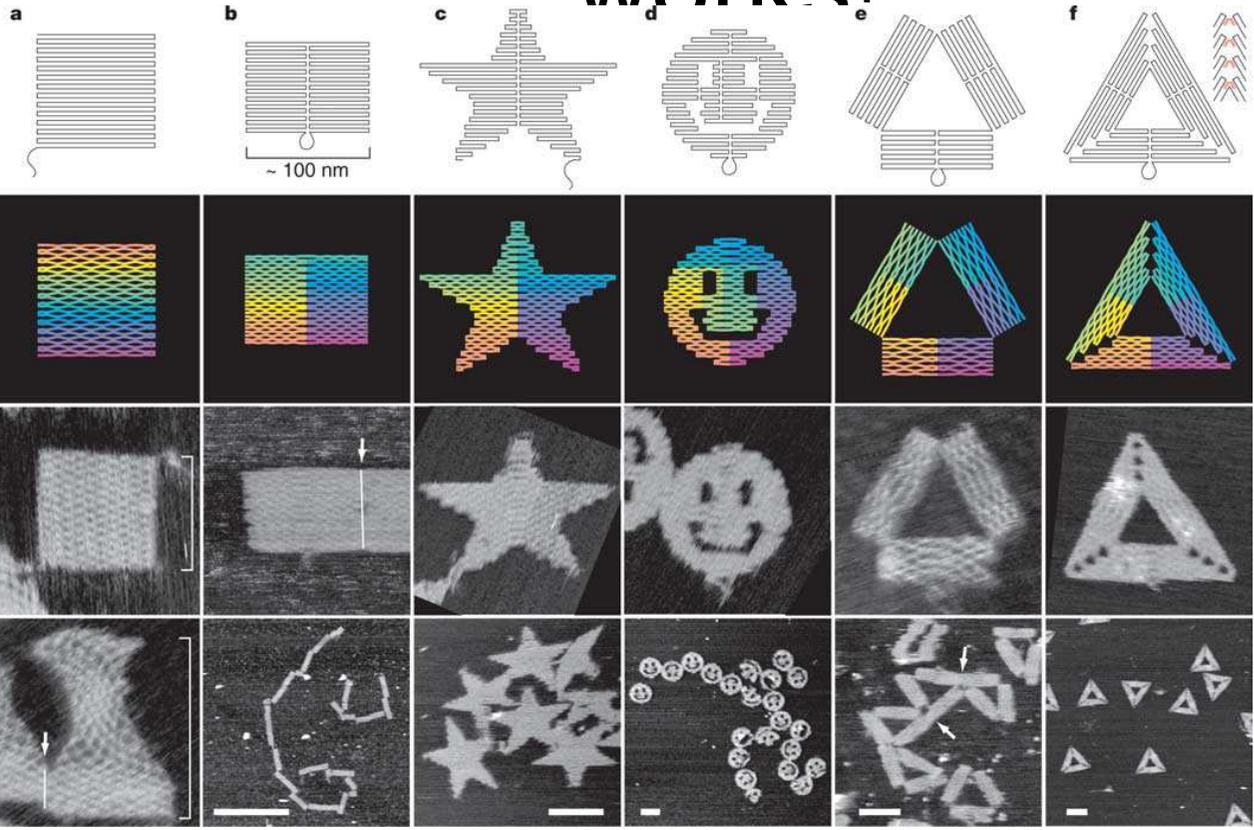


scaffolded DNA origami – it works!



Paul
Rothemund

scaffolded DNA origami – it works!

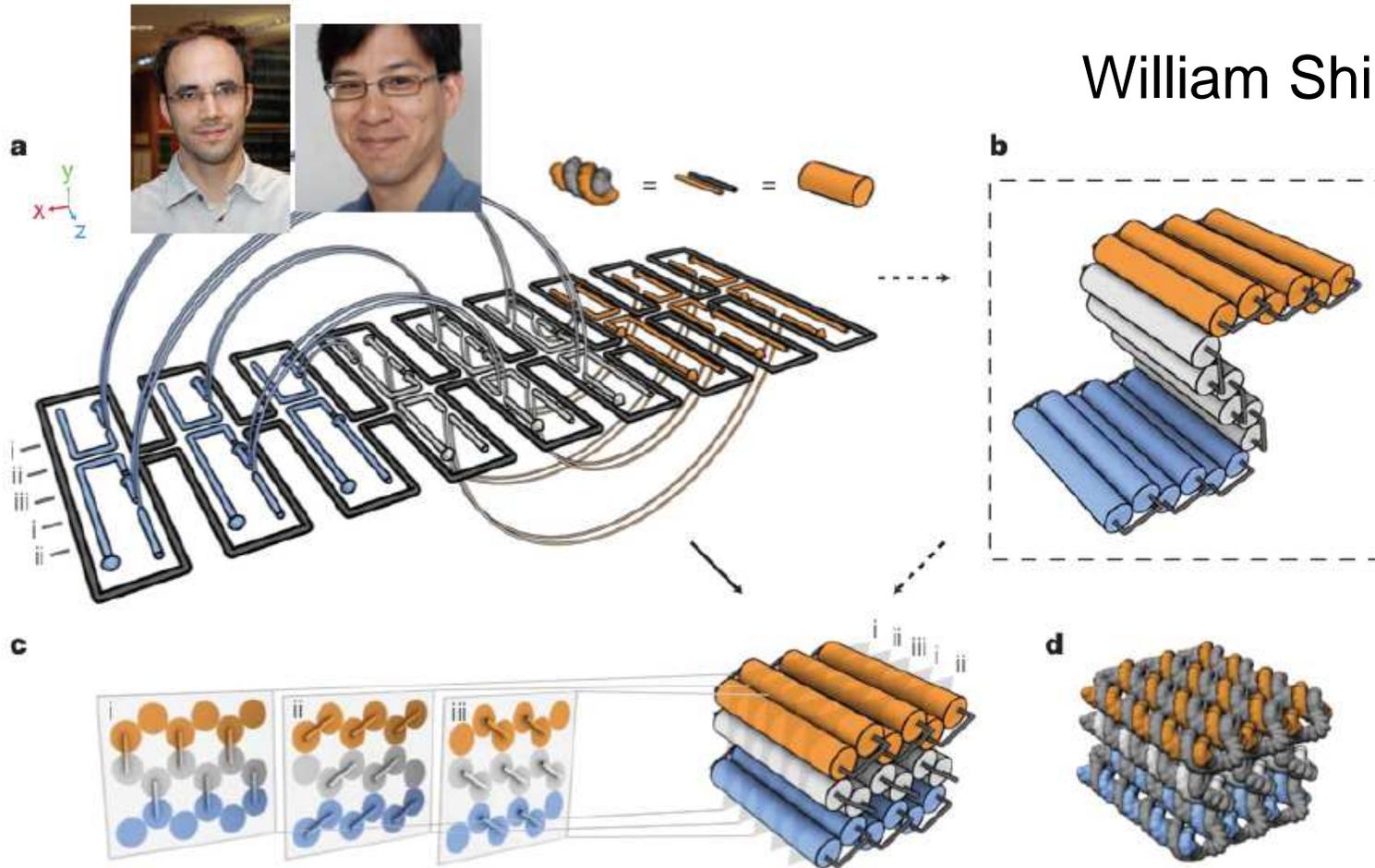


Paul Rothemund

These are **real pictures** taken with an *atomic force microscope*

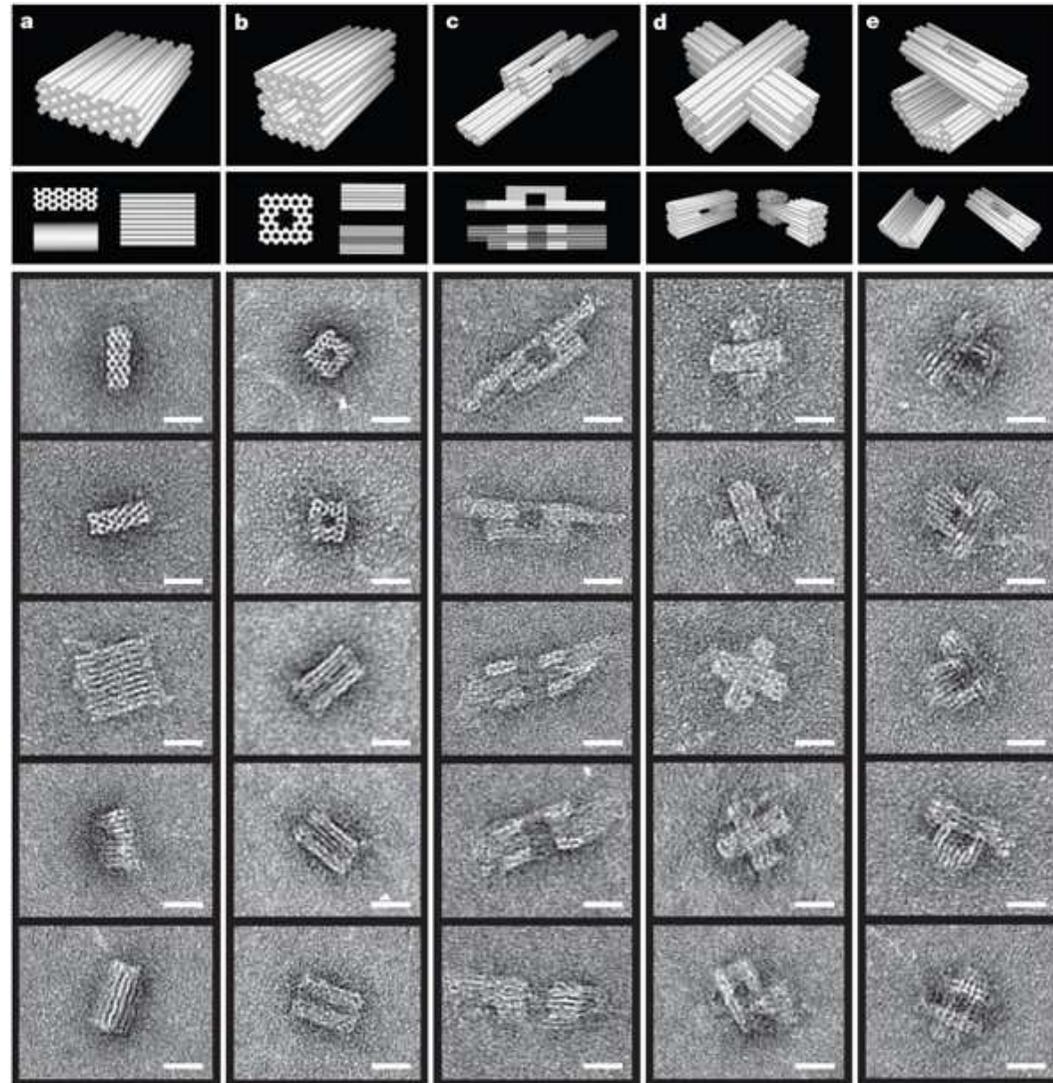
From 2D to 3D

William Shih's lab

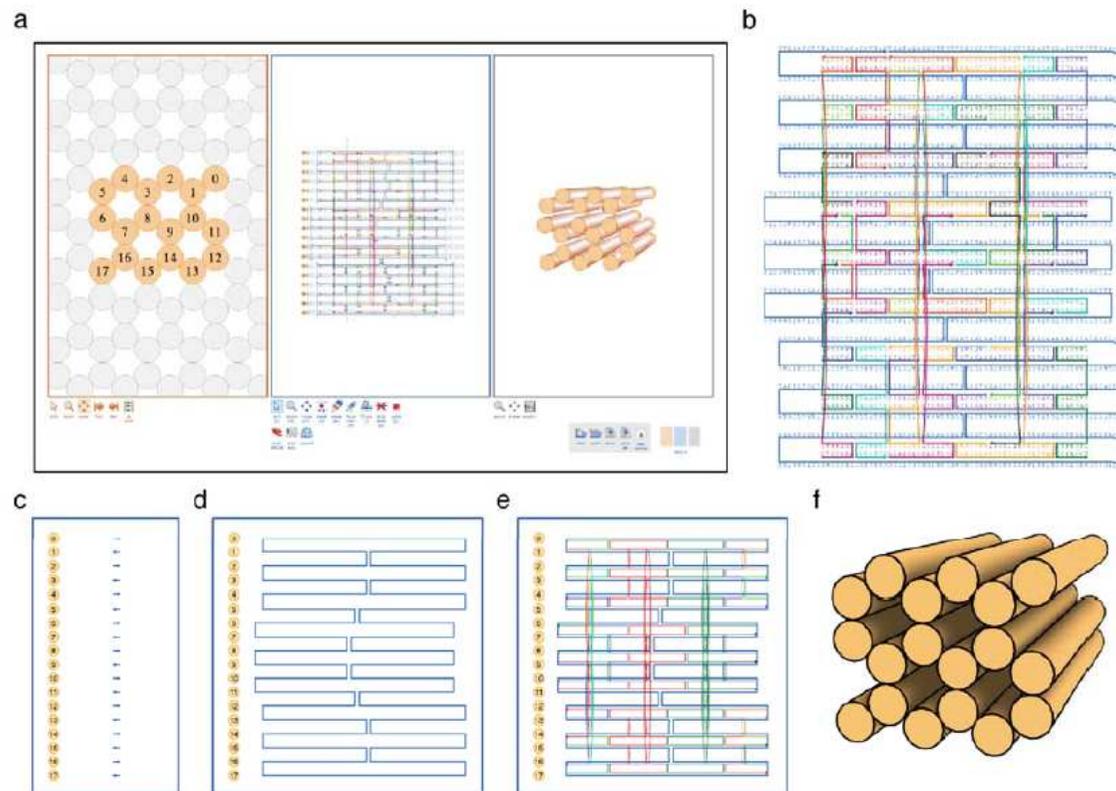


Douglas, S.M. et al. Self-assembly of DNA into nanoscale three-dimensional shapes. *Nature* 459, 414–418 (2008).

From 2D to 3D

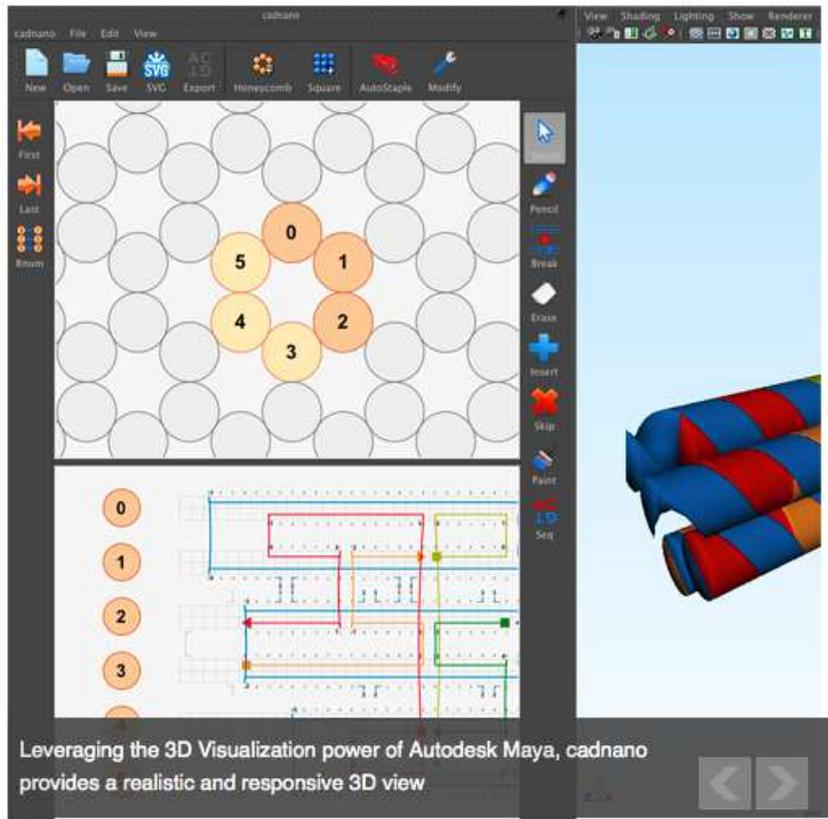


cad-nano software for designing DNA origami nano-structures



Shawn Douglas et al

cad-nano software for designing DNA origami nano-structures



cadnano simplifies and enhances the process of designing three-dimensional DNA origami nanostructures. Through its user-friendly 2D and 3D interfaces it accelerates the creation of arbitrary designs. The embedded rules within **cadnano** paired with the finite element analysis performed by **cando**, provide relative certainty of the stability of the structures.

cadnano features:

- Platform independent (tested in Windows, OSX and Linux)
- Visual cues aid design process for stable structures
- 3D interface powered by Autodesk Maya*
- Open architecture for plug-in creation
- Free and open source (MIT license)

DOWNLOAD CADNANO

It's free and open source.

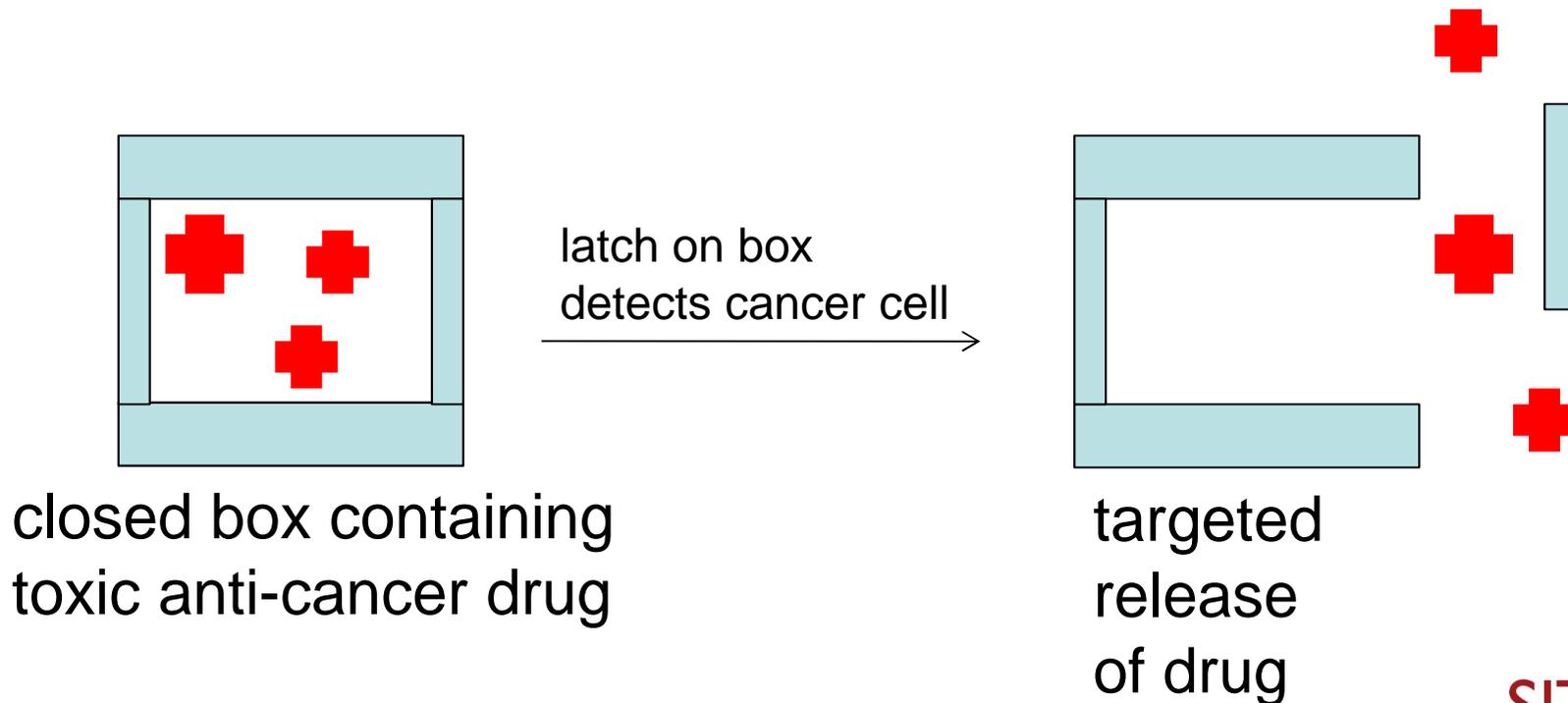


Shawn Douglas et al

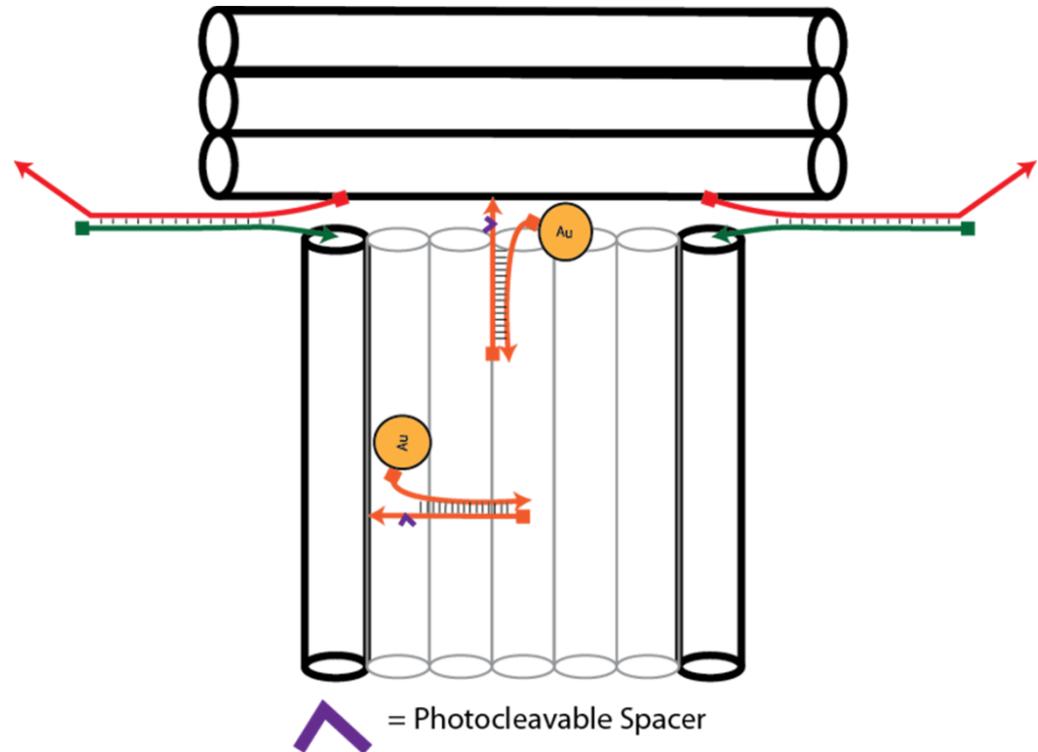
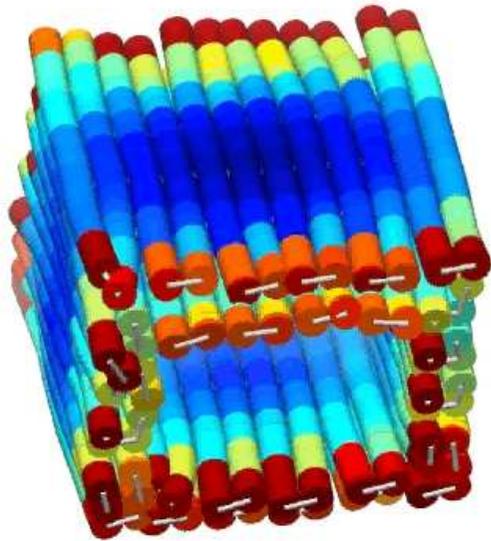
www.cadnano.org



Question: can we use DNA nano-structures for delivering drugs to targeted locations in the body?

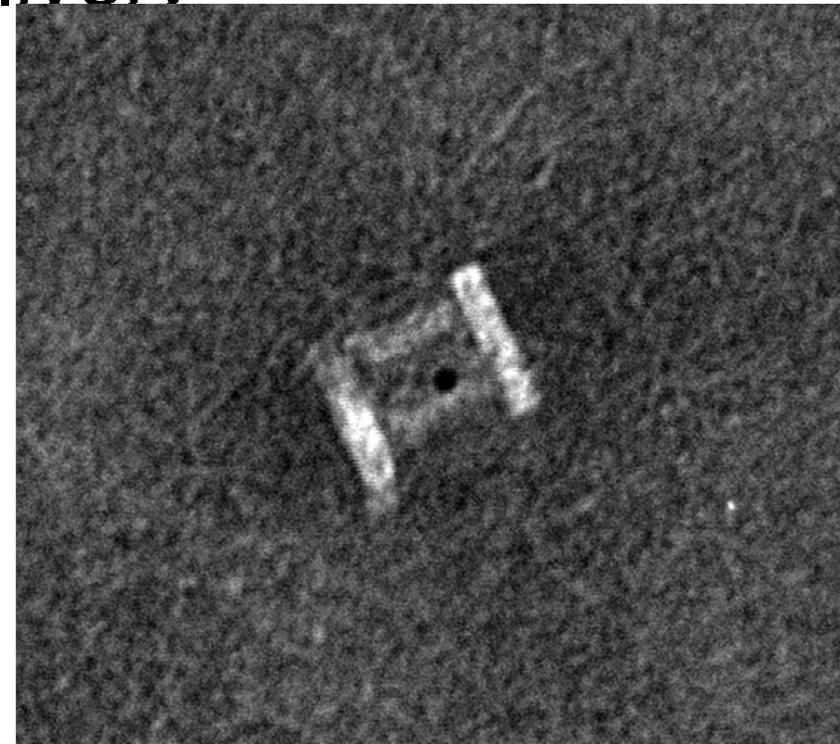
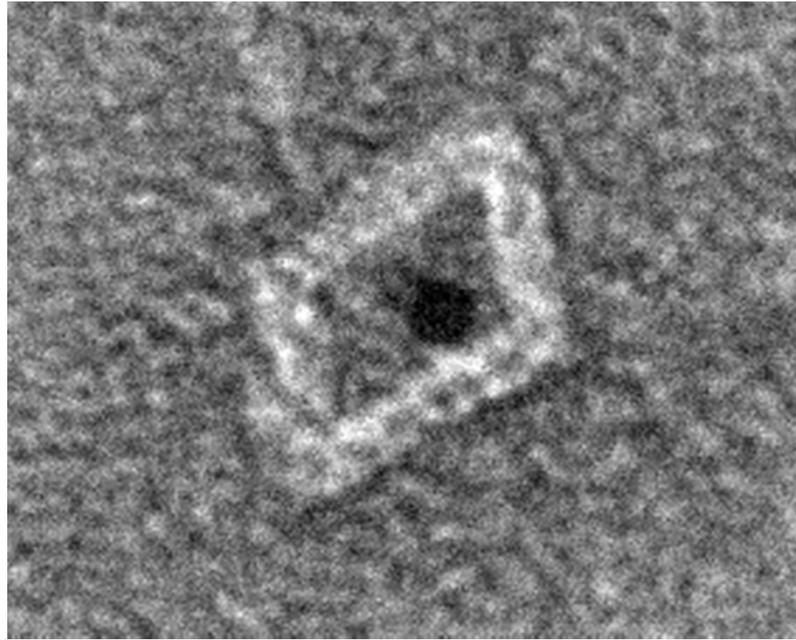


College freshmen designing “nano-submarines” (molecular containers) for targeted drug delivery



<http://openwetware.org/wiki/Biomod/2011/Harvard/HarvarDNAnos>

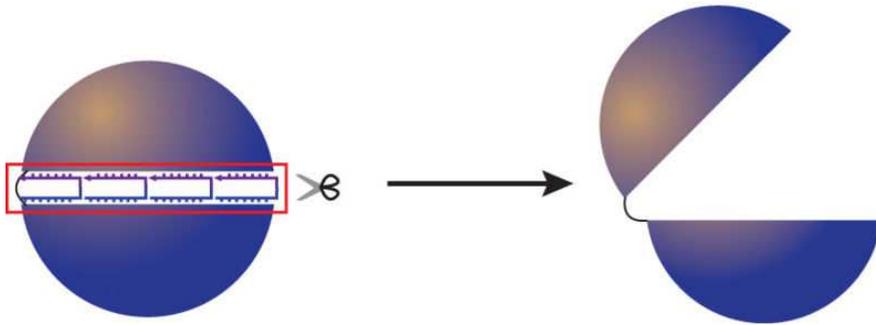
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Creating the Open Sphere



<http://openwetware.org/wiki/Biomod/2011/Harvard/HarvarDNAnos>



Take home messages

DNA is an excellent tool for building devices
at a scale comparable to sub-cellular structures

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At this scale, it is necessary to use self-assembly
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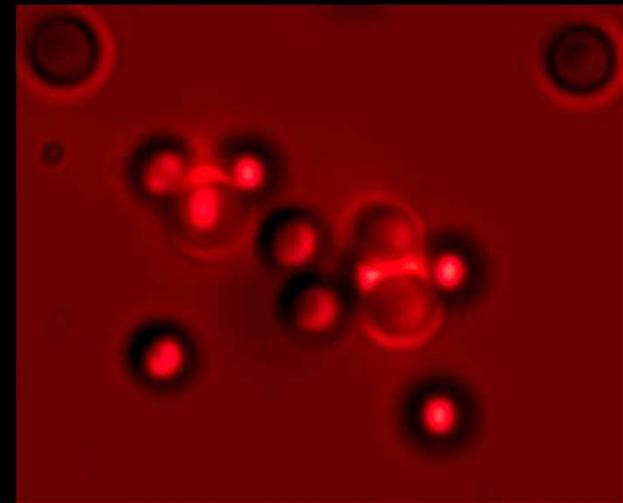
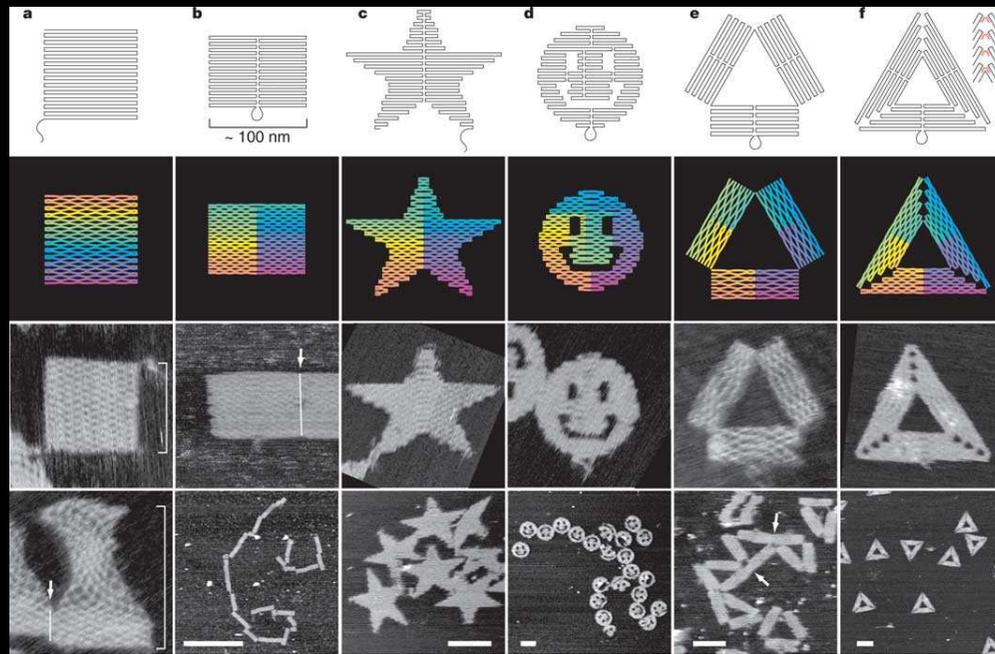
DNA is an excellent tool for building devices at a scale comparable to sub-cellular structures

At this scale, it is necessary to use self-assembly as the manufacturing principle – by writing the necessary information into the molecular building blocks

This technology may be useful for constructing targeted drug delivery vehicles and for other so-far-unimagined purposes

The New Science of Self-Assembly

How synthetic DNA, sticky spheres, and social robots will
change the way you work and play



April 12 – 14
Harvard Science Center

Learn about the science of things that build themselves!

www.harvardscienceweeks.org

Thank you!

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(BGSO)**

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