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

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Example: smart drug-delivery

- closed box containing toxic anti-cancer drug
- latch on box detects cancer cell
- targeted release of drug
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!
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

design
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
Why DNA is like LEGO

geometry  sequence  atomic structure
scaffolded DNA origami

Scaffold Strand:

Long single-stranded DNA molecule of *known sequence*
scaffolded DNA origami

Let’s fold it into a rectangle!
scaffolded DNA origami

Let’s fold it into a rectangle!
Let’s fold it into a rectangle!

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

... so create a two-part staple strand which joins them!
Want to pinch together these two points in the final structure....
Folding a complete shape requires many staples…
Folding a complete shape requires many staples…
Folding a complete shape requires many staples...
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!

These are real pictures taken with an atomic force microscope
From 2D to 3D

William Shih’s lab

From 2D to 3D

pictures taken with an electron microscope
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)

Shawn Douglas et al [www.cadnano.org](http://www.cadnano.org)
Question: can we use DNA nanostructures for delivering drugs to targeted locations in the body?
College freshmen designing “nano-submarines” (molecular containers) for targeted drug delivery

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Take home messages

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