భారతీయ సాంకేతిక విజ్ఞాన సంస్థ హైదరాబాద్
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Introduction of Bio-nanotechnolgy

BT1110

Lecture 4 : Nucleic Acid Nanotechnology

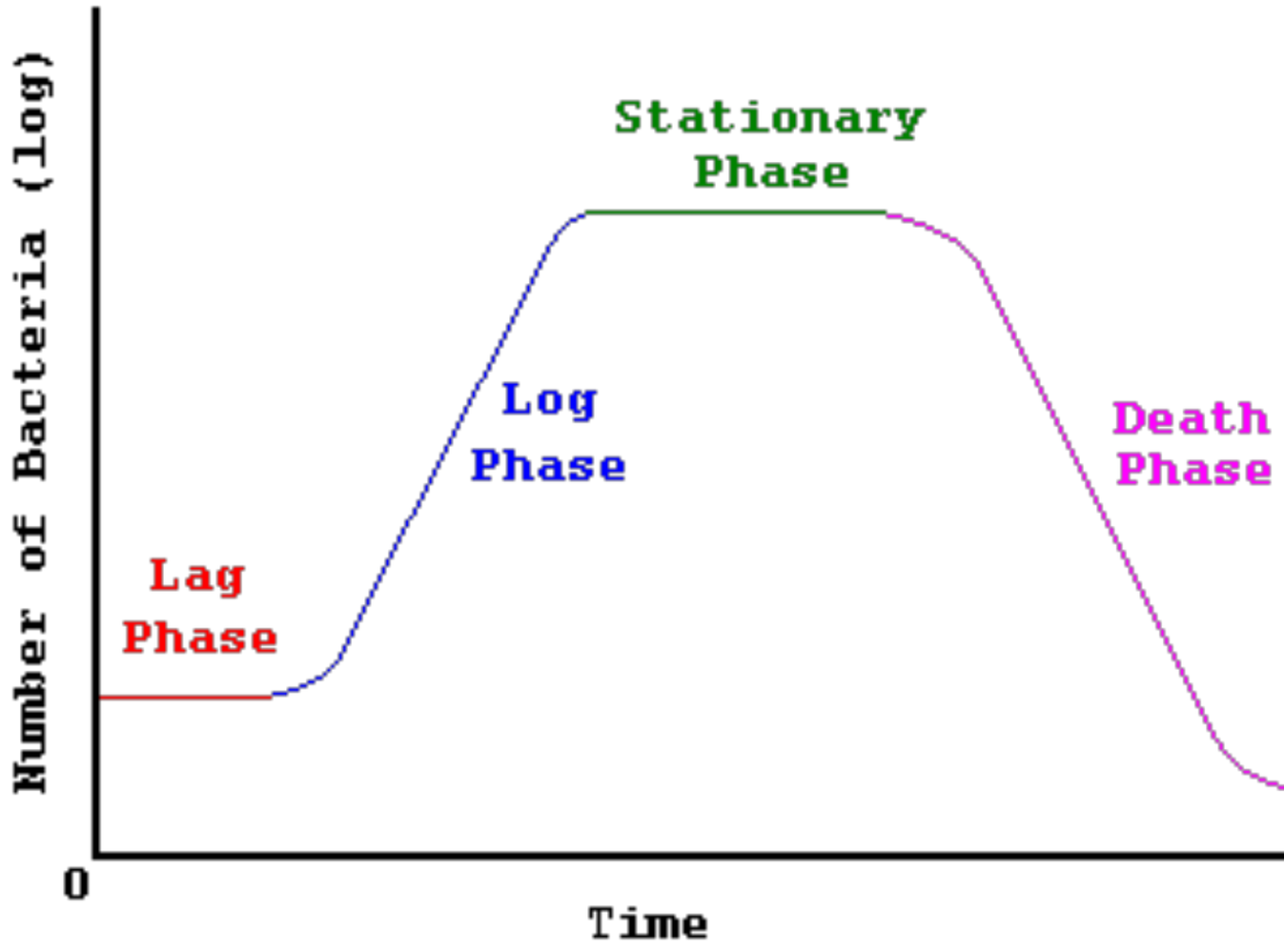
Himanshu Joshi 7 November 2023

भारतीय सांकेतिक विज्ञान संस्थ हैदराबाद
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Course contents

- Introduction to nanotechnology and bionanotechnology,
- Biological self-assembly
- Biologically inspired nanostructures - introduction to biomimetics
- **Nucleic acid nanotechnology**
- DNA origami
- Protein engineering
- Lipid nanotechnology
- Chirality in biological systems
- Interaction of nanomaterials with biological systems
- Virology: viruses and vaccines

Bacterial growth curve



Depicting DNA Nanotechnology growth

Various forms of DNA

ssDNA

A-DNA

B-DNA
(canonical)

Z-DNA

G-quadruplex

Goal of nucleic acid nanotechnology

Creating functional DNA nanostructure

for applications in

1. Nanomedicine
2. Memory devices
3. Nanomechanical devices
4. Nano/optoelectronics
5. Nanobiotechnology

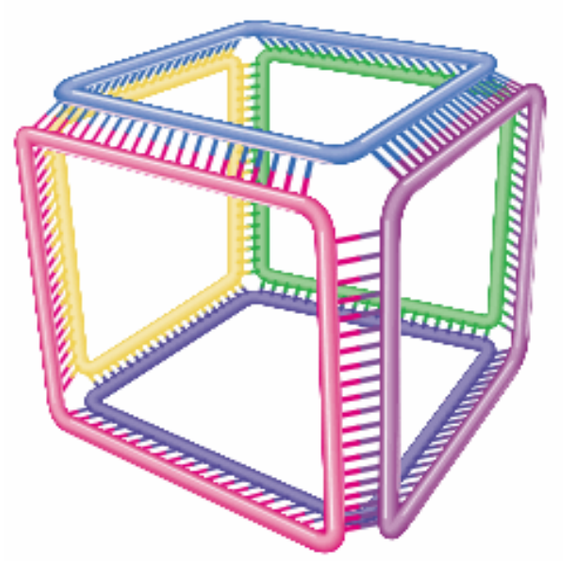
DNA Nanotechnology: One pot process

Driven by the hydrogen bonding of base pairs which had energy of a Hydrogen bond 5 kcal/mole

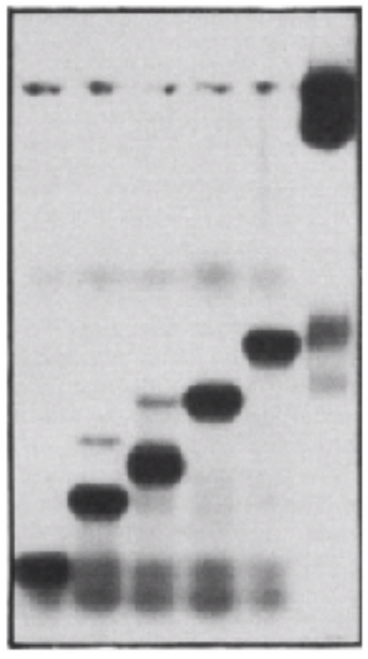
Structural DNA Nanotechnology

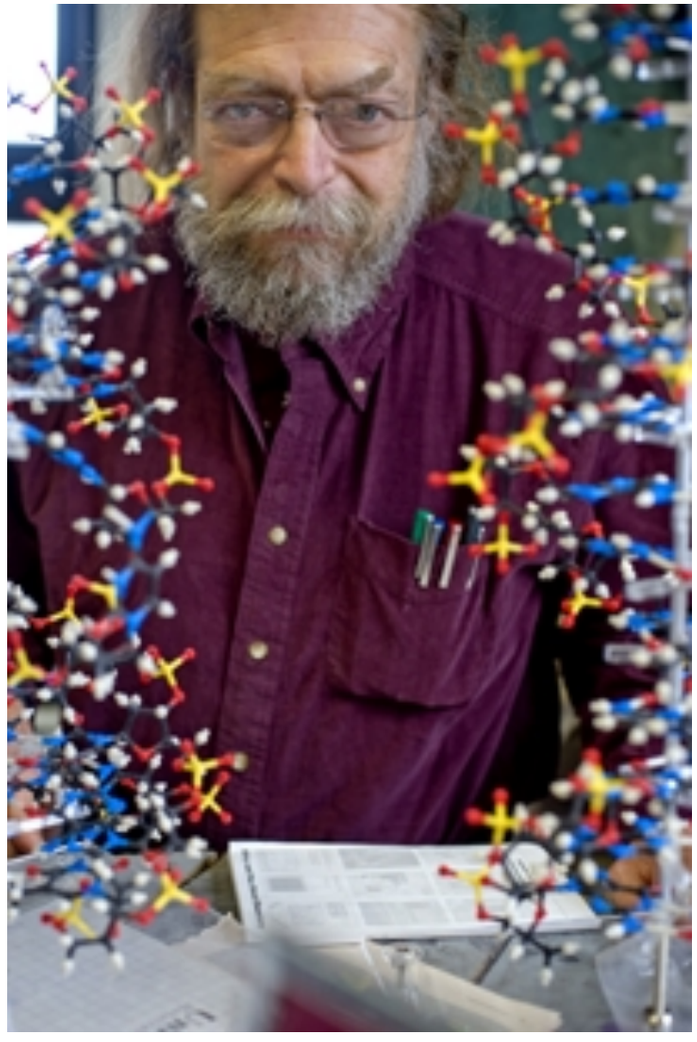
Dynamic DNA nanotechnology

DNA Nanotechnology



DNA cube,
Chen and Seeman. Nature 1991





DNA Nanotechnology

- A method to create nanoscale object using DNA/RNA as construction material

- Incepted by Nadrian C. Seeman, in 1982 to crystalize protein which is a very hard problem to solve.

- The field was inspired by using DNA nanostructure as a tool to in biophysics but now taken as a entire

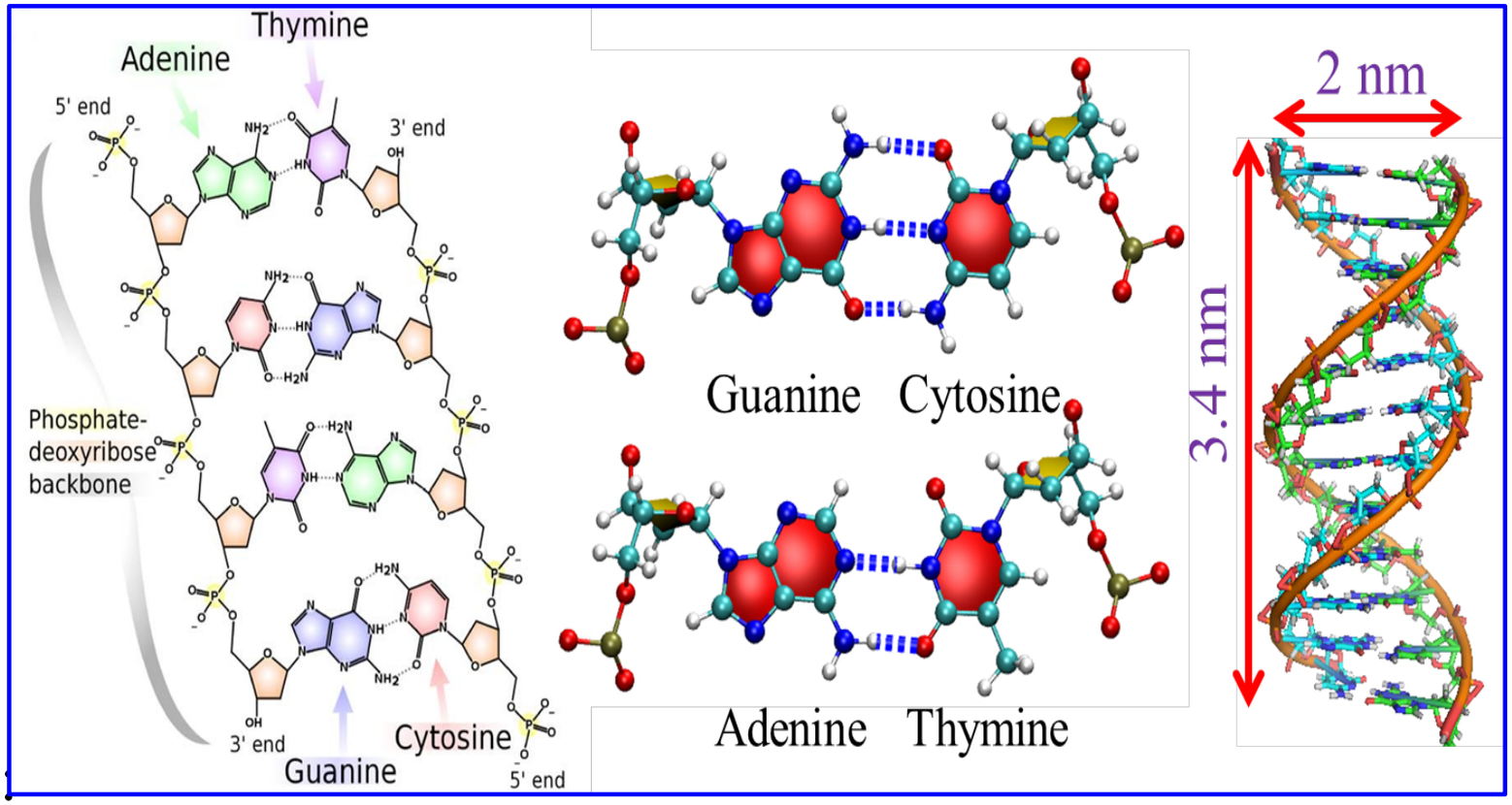
Ned Seeman
1945-2021

Chemist saw it as a water-soluble polymer whose growth could be controlled and whose branching, or cross-linking, could be rationally manipulated.

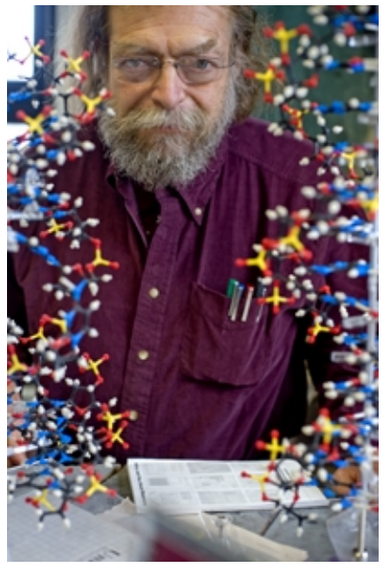
Yamuna and Ned, 2019

Structural DNA Nanotechnology

- There is plenty of room at the bottom.
- Bottom up self-assembly : DNA as a construction material



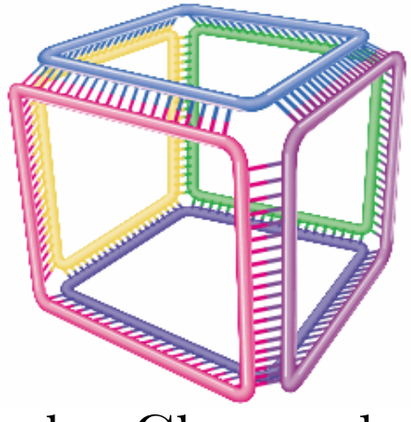
R. Feynman



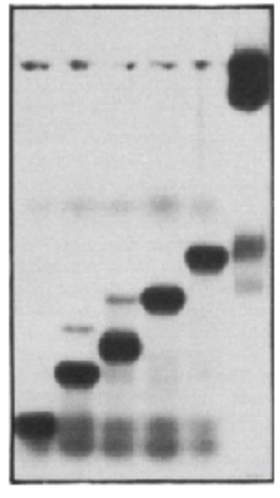
N. Seeman

Why DNA ?

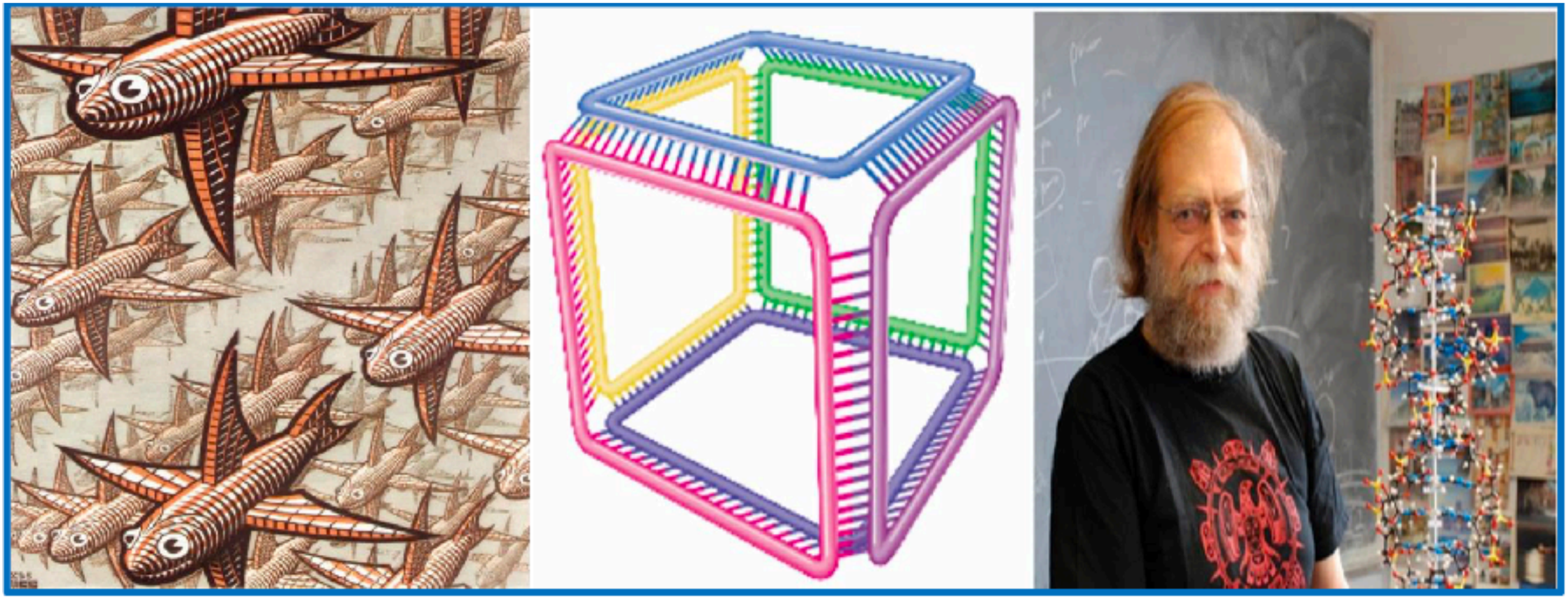
1. Molecular recognition property
2. Chemically easy to modify the backbone
3. Well studied molecule.



DNA cube, Chen and Seeman. Nature 1991



DNA Nanotechnology



Why DNA for nanotechnology

1. Truly nanoscale object.

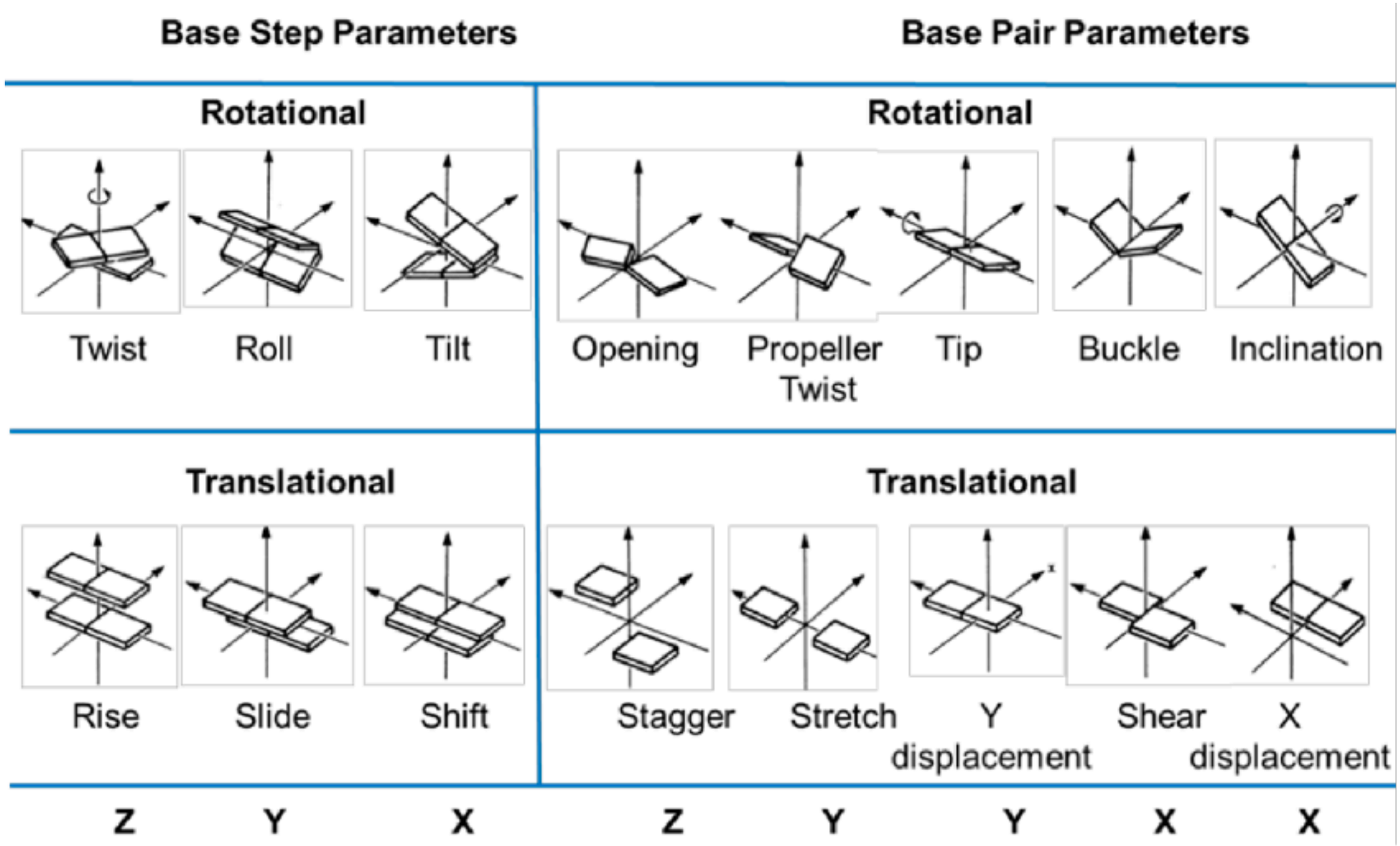
2. Smart molecule

3. Prograamable self assembly

4. Easy to chemically modify the backbone.

5. Studied extensively.

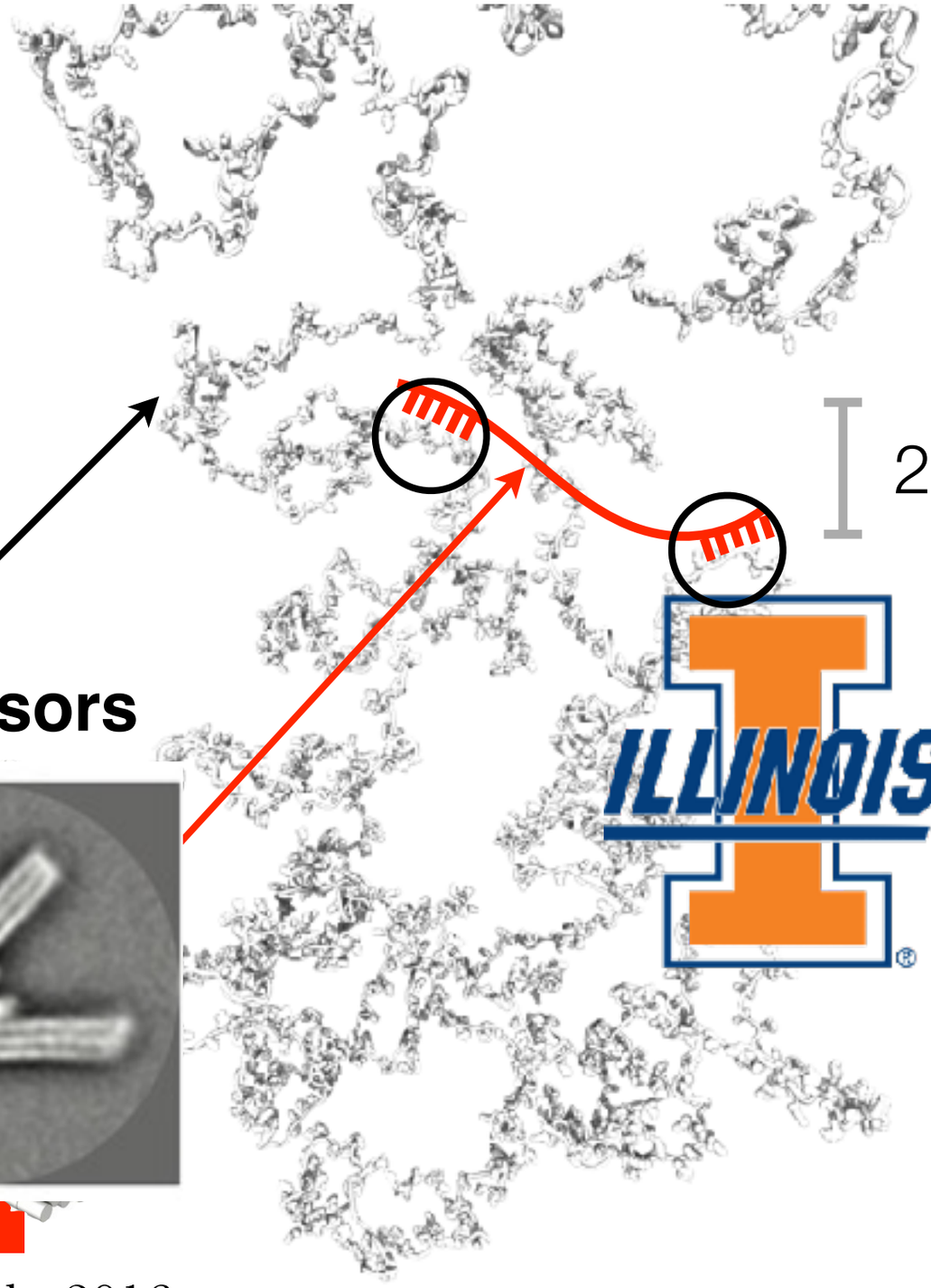
Geometrical parameters characterizing the structure of dsDNA

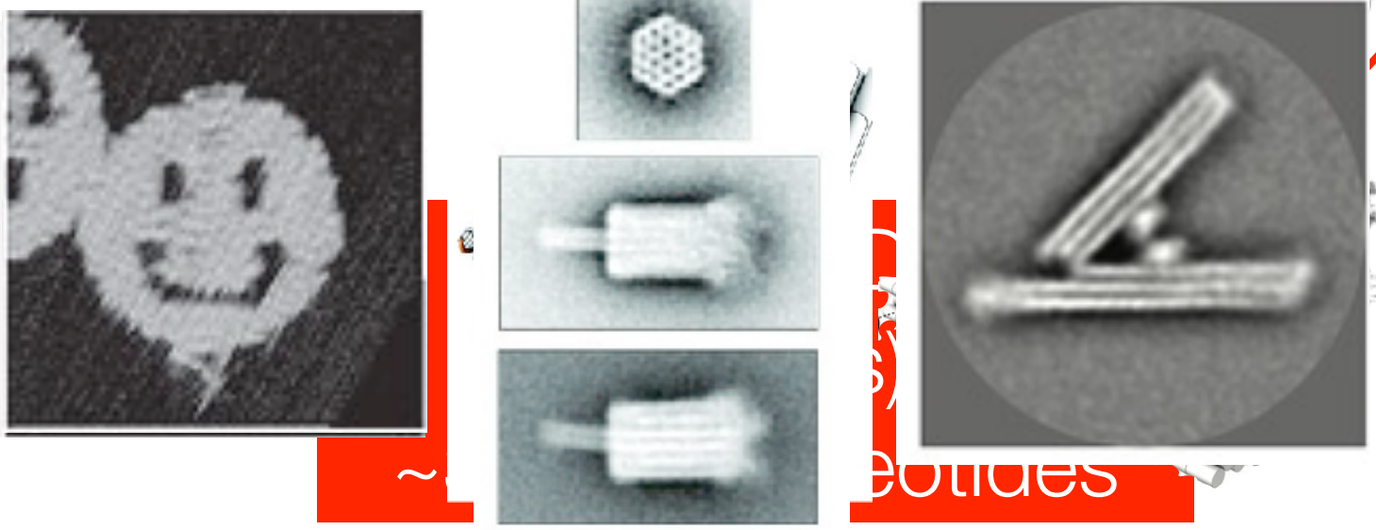


Geometrical parameters of various form of dsDNA

Structure	Helical Twist	Helical Rise	X-Displ	Inclin.	Roll	Propeller Twist	Diameter
A-DNA	33°	2.56 Å	-4.5 Å	21°	6°	-7.5°	23 Å
B-DNA	36°	3.38 Å	0.23 Å	-6°	0°	-4.4°	20 Å
Z-DNA	-30°	3.7Å	3.0 Å	-6.2°	0°	-4.4°	18 Å

Custom shapes, channels, and sensors





Nature 2005
Paul Rothemund

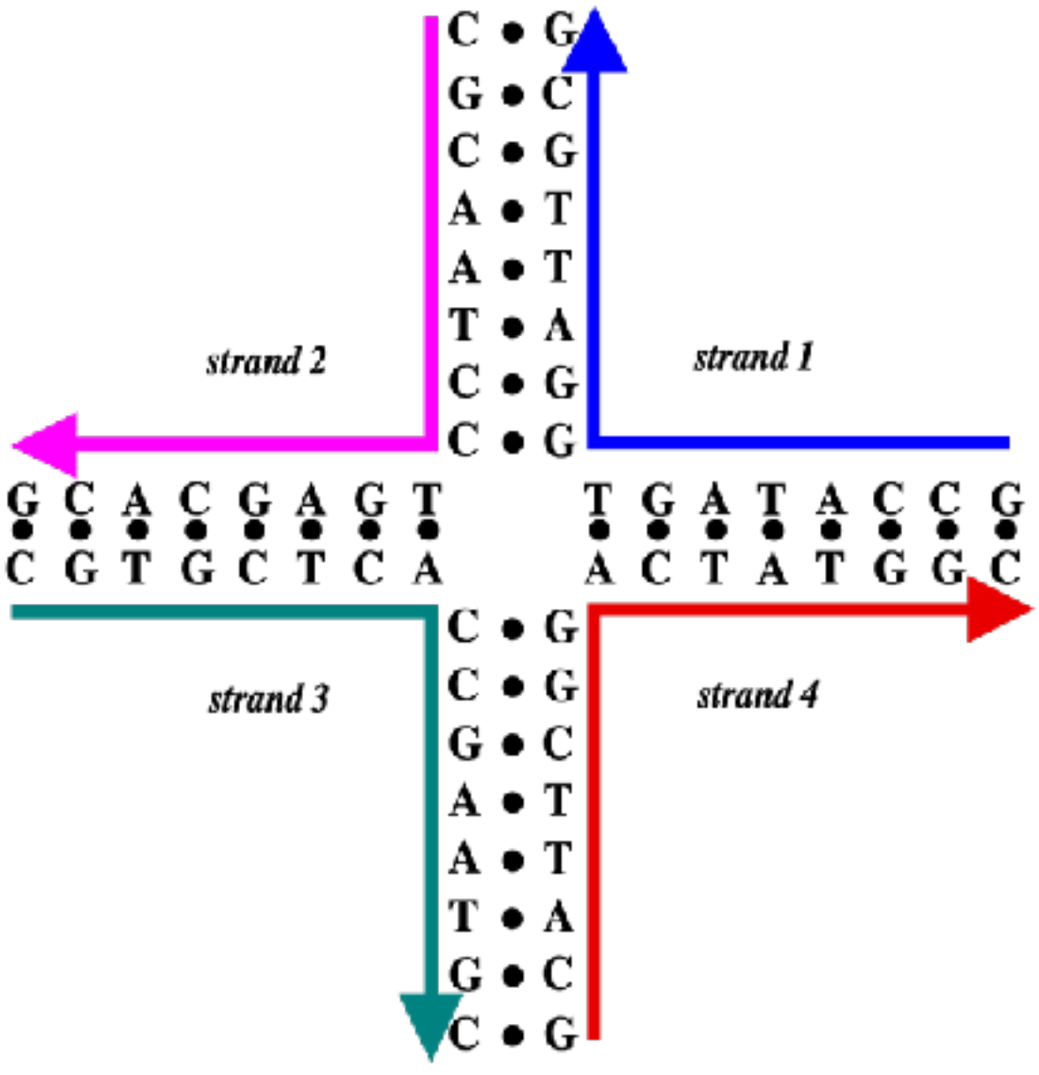
Science 2012
Simmel el al.

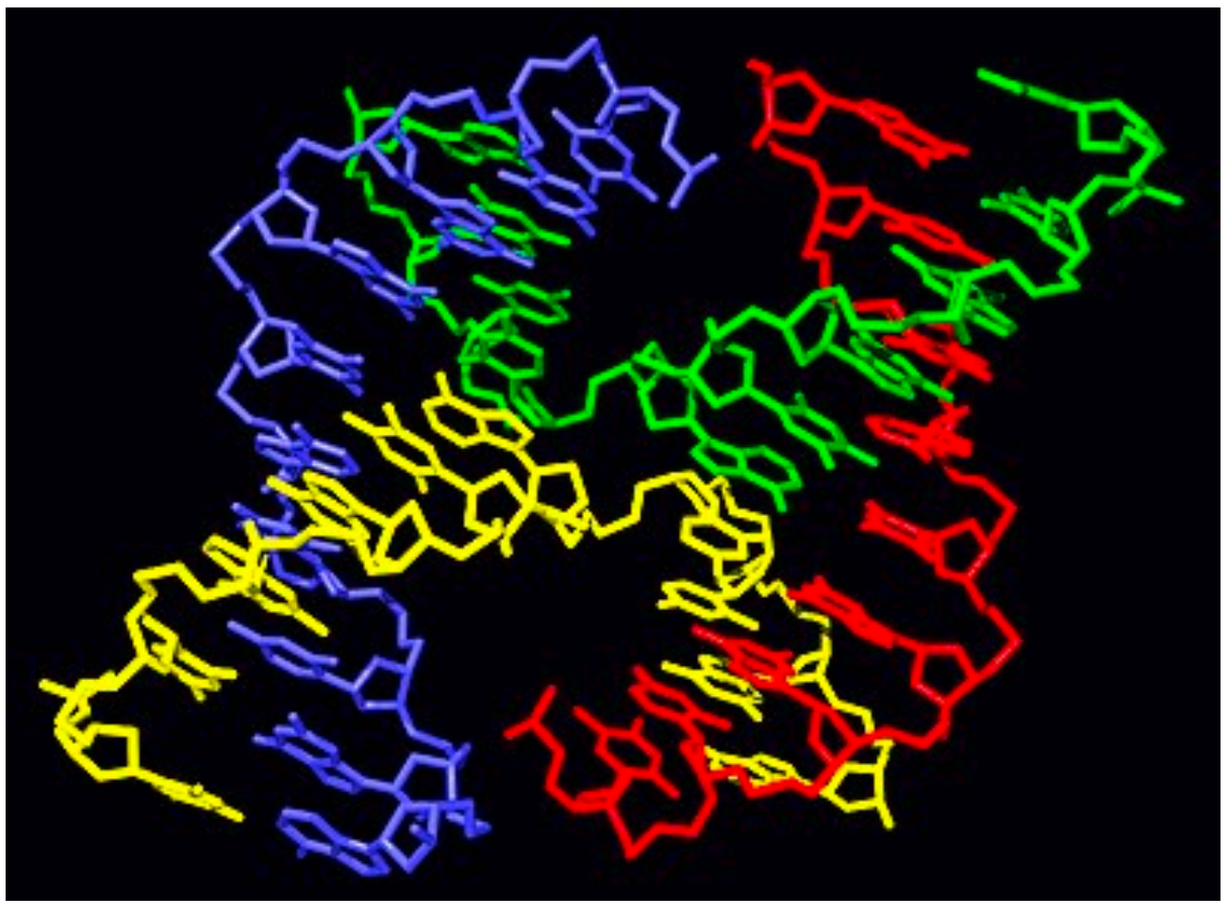
Science Adv. 2016
Dietz et al.

Source: J. Yoo, Aksimentiev lab

Holliday Junction

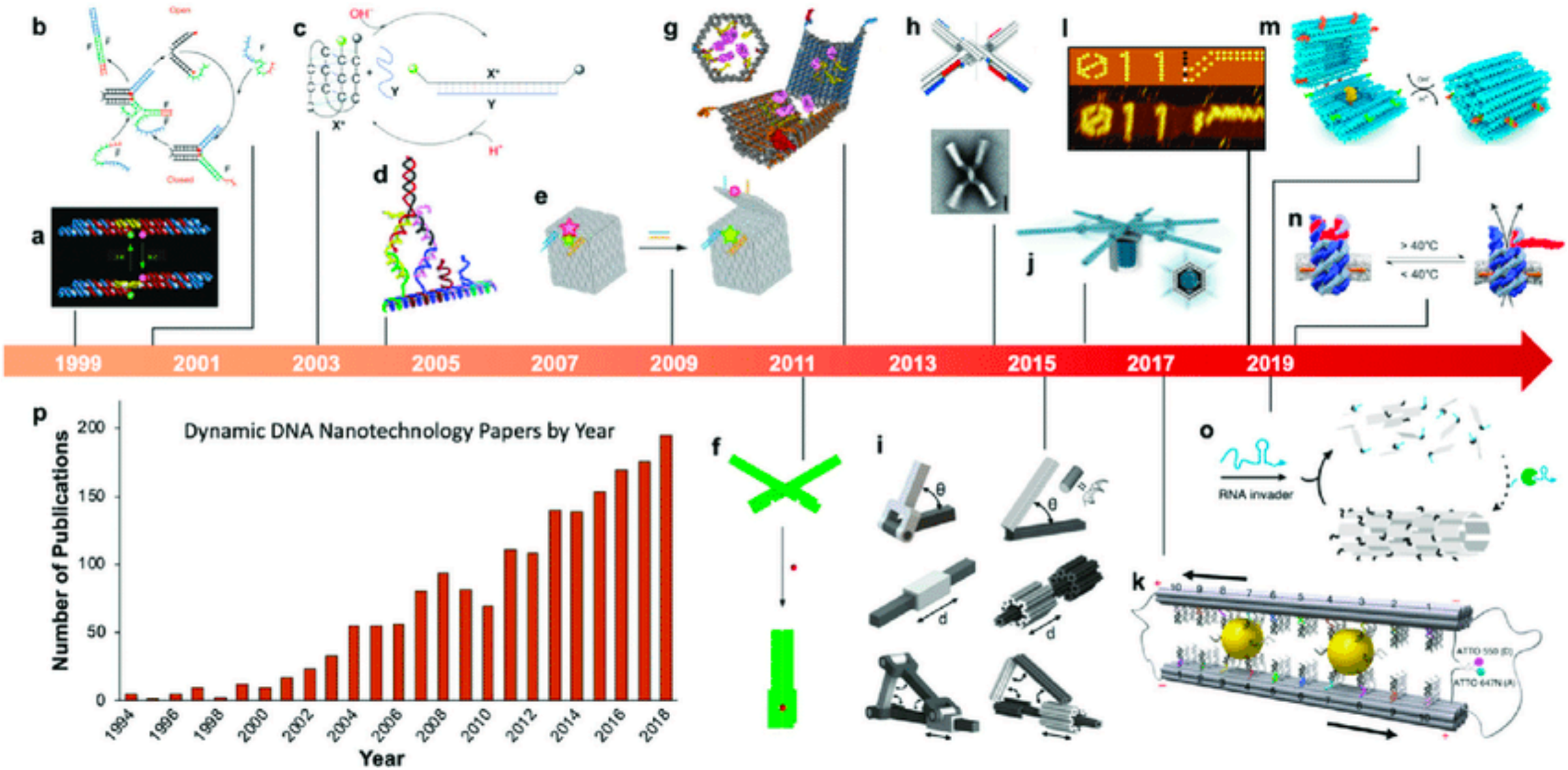
They are a key intermediate in many types of genetic recombination, as well as in double-strand break repair.





Immobile hoiday junctions are building blocks in DNA nanotechnology

Growth and complexity of DNA nanostructues



Reference:
DOI: 10.1039/c5cs00700c

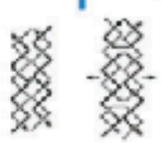
Timeline of DNA Nanotechnology

1982 — The origin of DNA nanotechnology, Seeman proposed branched DNA junctions to assemble 2D DNA array.[2]

1983 — Seeman's pioneering work, the first experimentally proved DNA motif.[3]

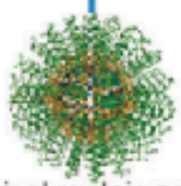
1991 — 3D DNA cube.[4]

1993 — DNA double crossover, foundation for many DNA nanostructures.[5]



1998 — The first DNA 2D lattices.[88]

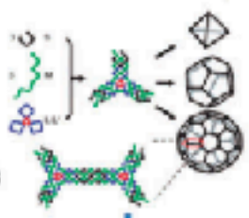
1996 — spherical nucleic acid (SNA). Nanoparticles decorated with dense oriented nucleic acids.[108]



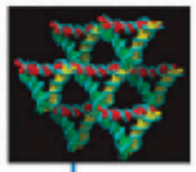
2004 — Octahedron designed with "scaffold folding strategy".[20]

2006 — DNA origami.[97]

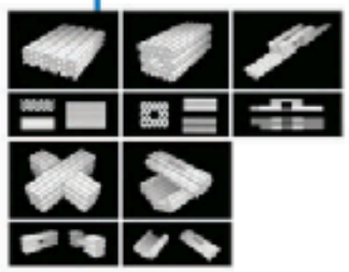
2008 — Hierarchical self-assembly of DNA into symmetric supramolecular polyhedral.[91]



2009 — First 3D DNA crystal.[9]

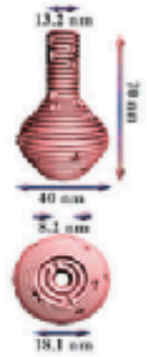


2009 — DNA origami was extended to 3D shapes with stacked double helices.[93]



2011 — A logic-gated nanorobot for targeted transport of molecular Payloads.[102]

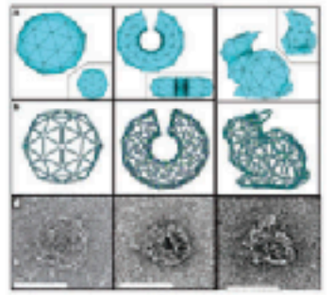
2011 — DNA origami with complex curvatures in three-dimensional space.[83]



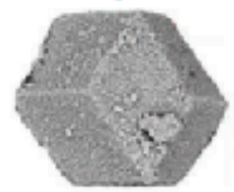
2012 — Complex shapes self-assembled from "Single strand tiles(SST)" method.[96]

2012 — "Single strand tiles(SST)" strategy was extended to 3D.[95]

2015 — DNA rending polyhedral meshes at nanoscale.[107]

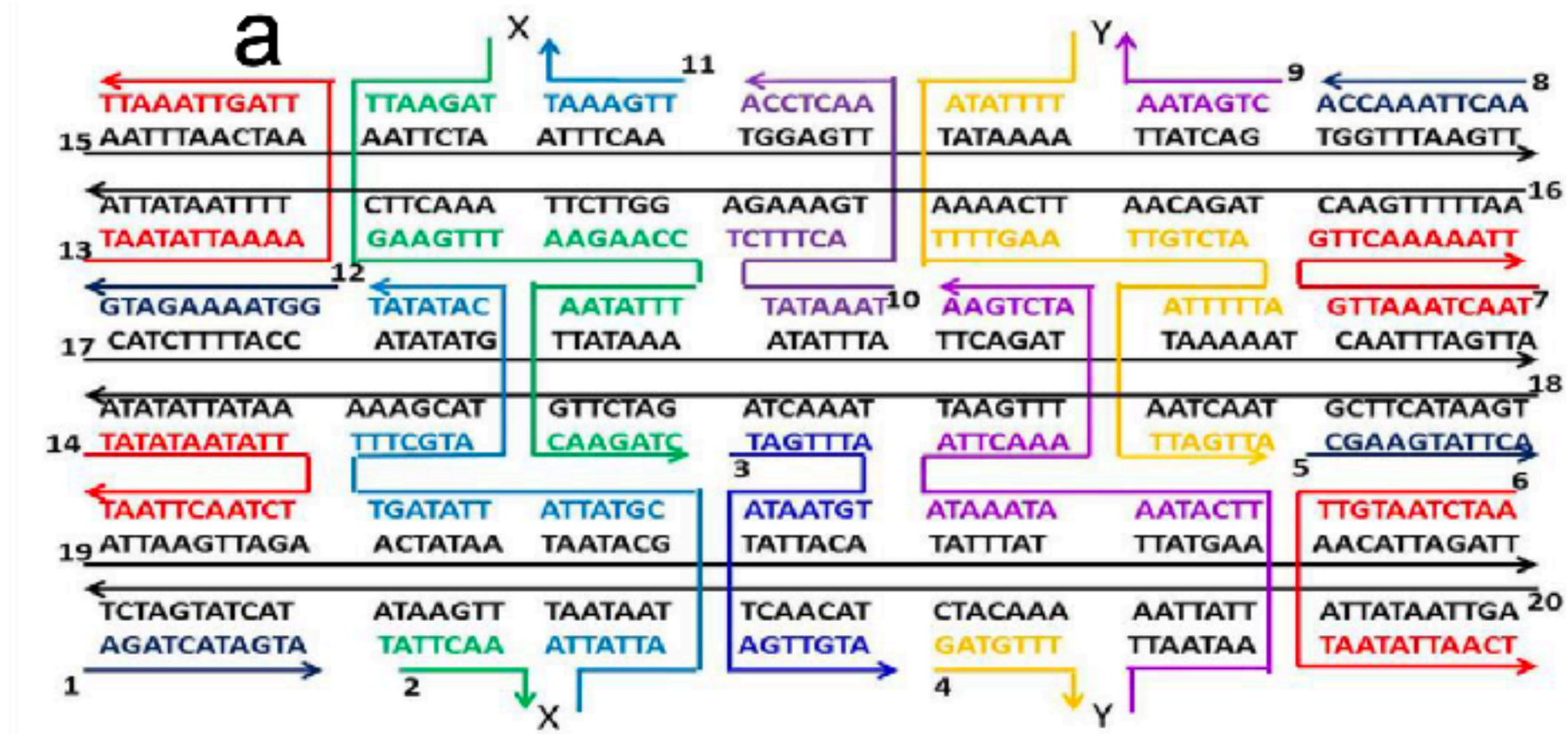


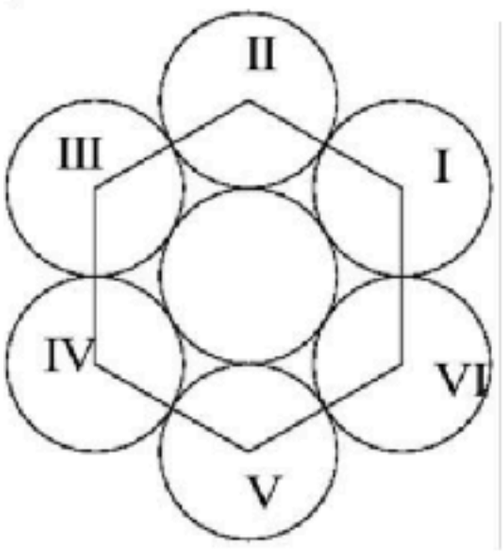
2014 — DNA-mediated self-assembly into single crystals.[119]

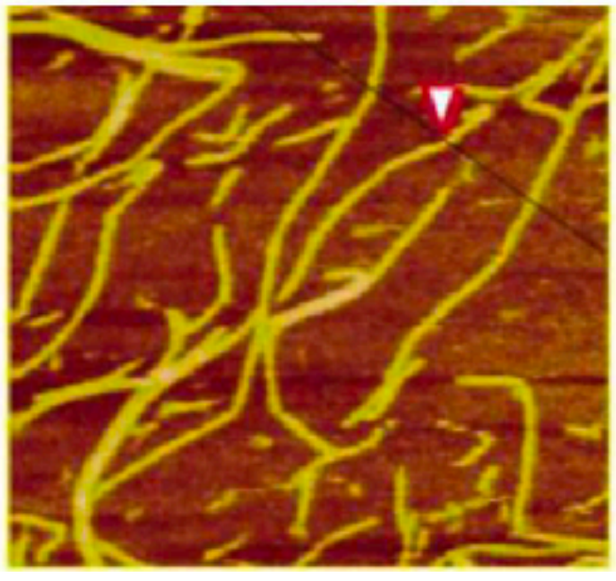


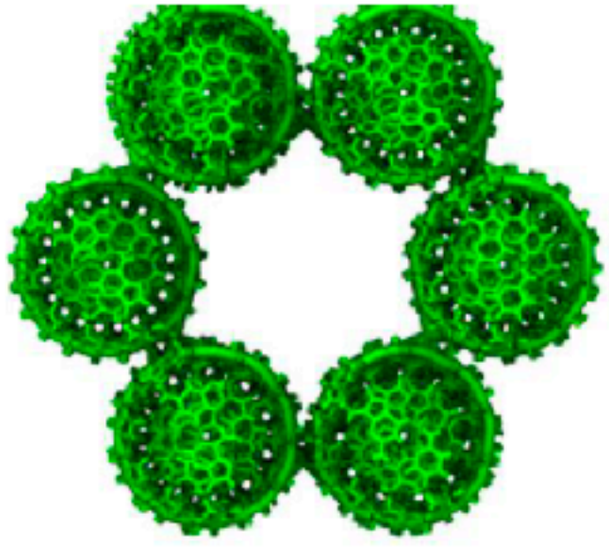
Reference:
DOI: 10.1039/c5cs00700c

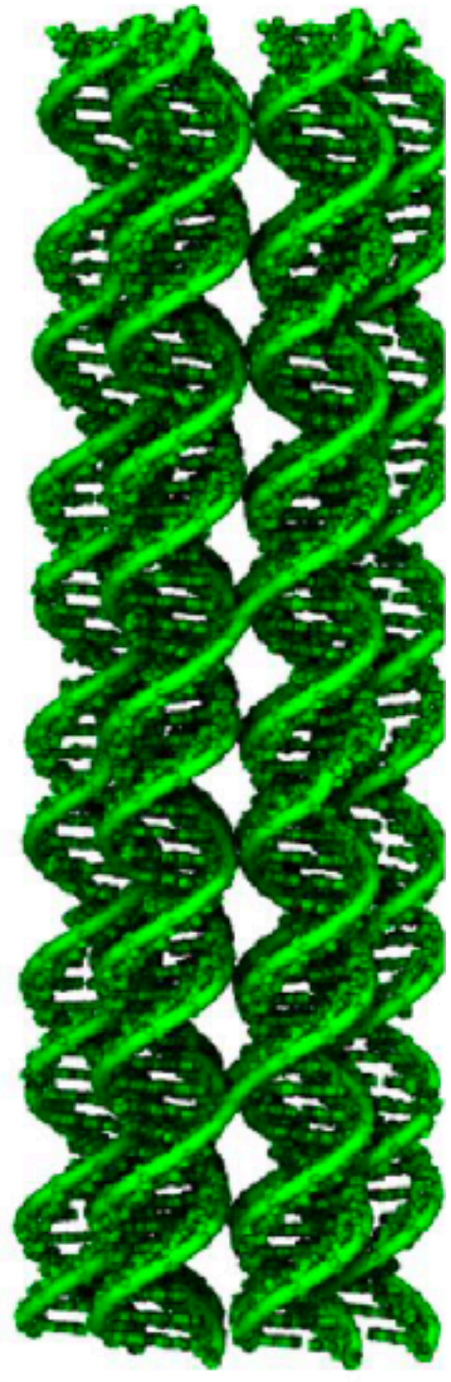
DNA nanotubes





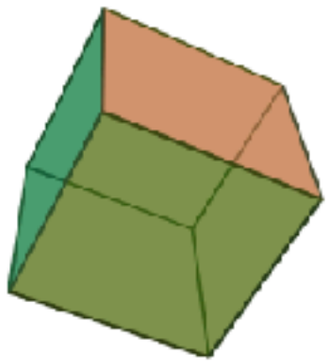
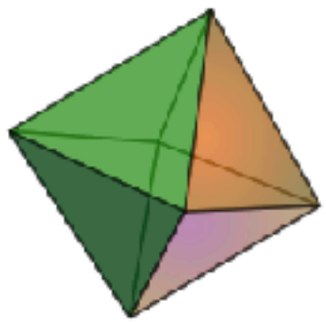
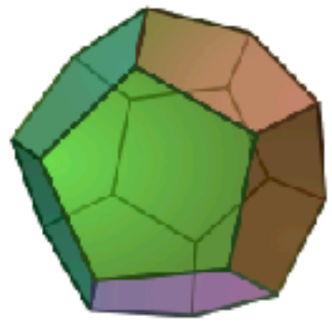
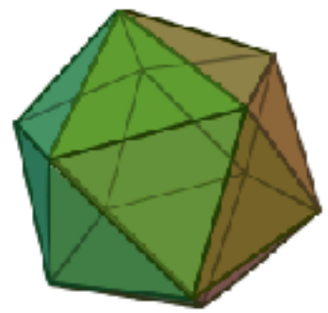






Platonic solids

Only five convex regular polyhedron exist in 3d euclidian space

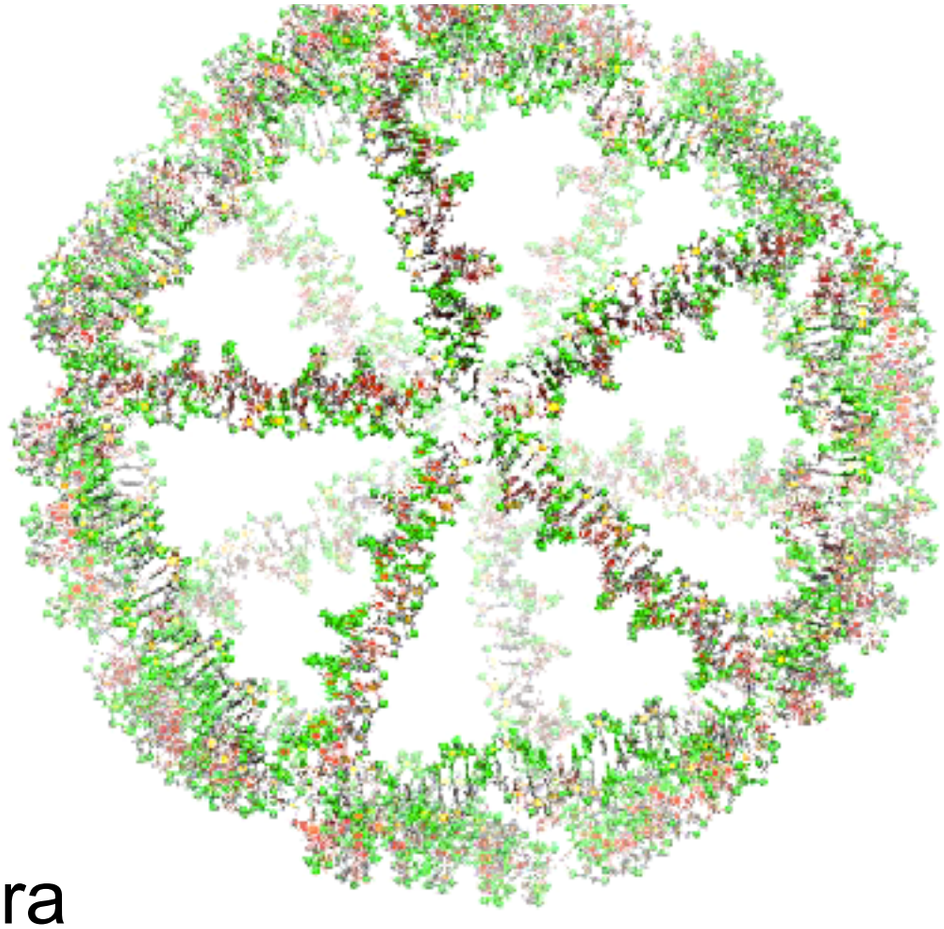
Tetrahedron	Cube	Octahedron	Dodecahedron	Icosahedron
Four faces	Six faces	Eight faces	Twelve faces	Twenty faces
				

Parameters

Figure	Tetrahedron		Octahedron	Cube	Icosahedron		Dodecahedron	
Faces	4		8	6	20		12	
Vertices	4		6 (2 × 3)	8	12 (4 × 3)		20 (8 + 4 × 3)	
Position	1	2			1	2	1	2
Vertex coordinates	(1, 1, 1) (1, −1, −1) (−1, 1, −1) (−1, −1, 1)	(−1, −1, −1) (−1, 1, 1) (1, −1, 1) (1, 1, −1)	(±1, 0, 0) (0, ±1, 0) (0, 0, ±1)	(±1, ±1, ±1)	(0, ±1, ±ϕ) (±1, ±ϕ, 0) (±ϕ, 0, ±1)	(0, ±ϕ, (±ϕ, ±1, (±1, 0, ±ϕ)	(±$\frac{1}{\phi}$, ±ϕ, 0) (±ϕ, 0, ±$\frac{1}{\phi}$)	(±ϕ, ±$\frac{1}{\phi}$, 0) (±$\frac{1}{\phi}$, 0, ±ϕ)

Virus assembly

Polyhedral DNA Nanostrucrutres



DNA Icosahedra