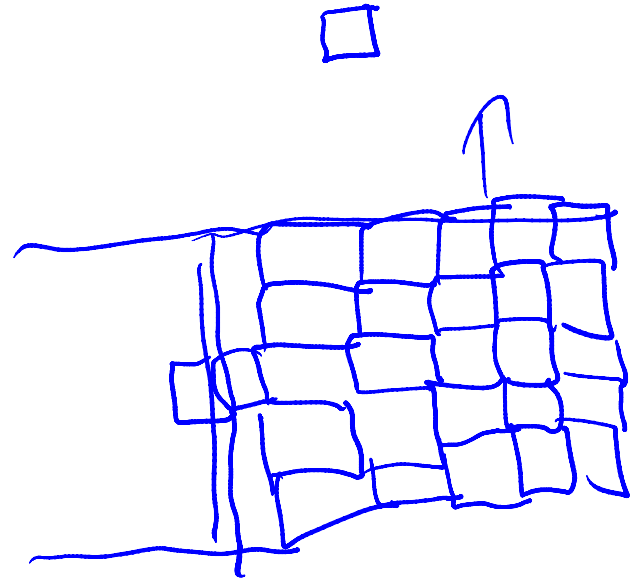# life - matter = algorithms

Manoj Gopalkrishnan

School of Technology and Computer Science

Tata Institute of Fundamental Research
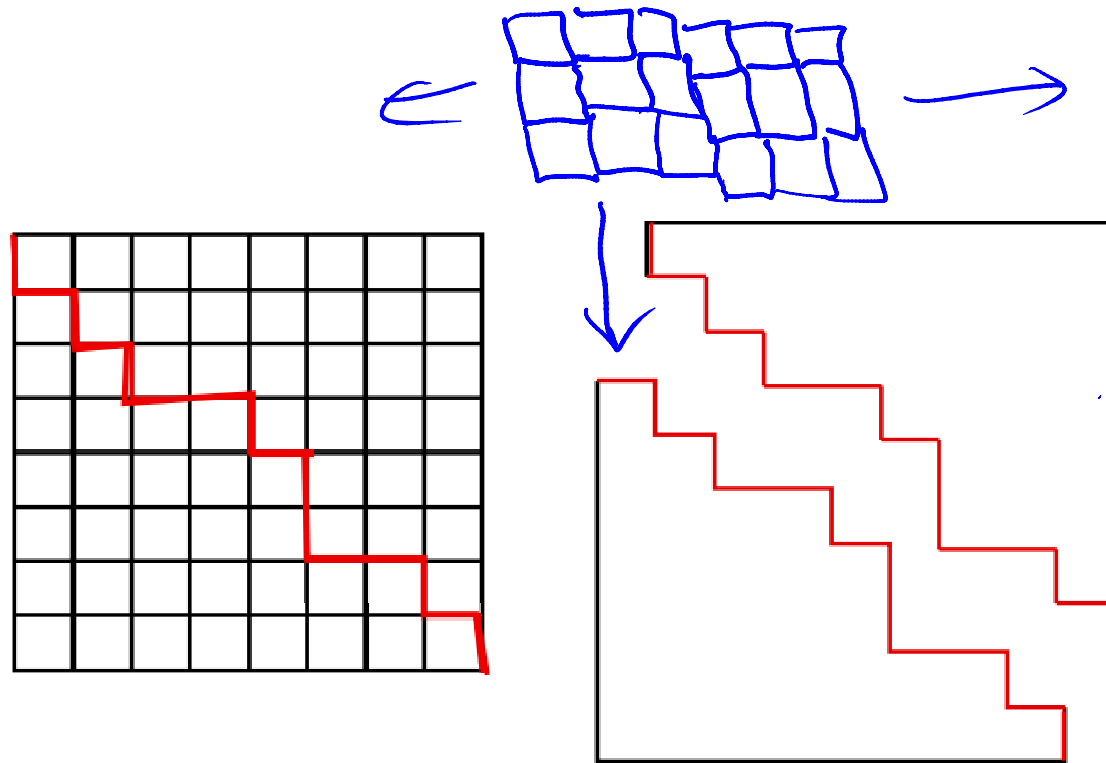
Crystal

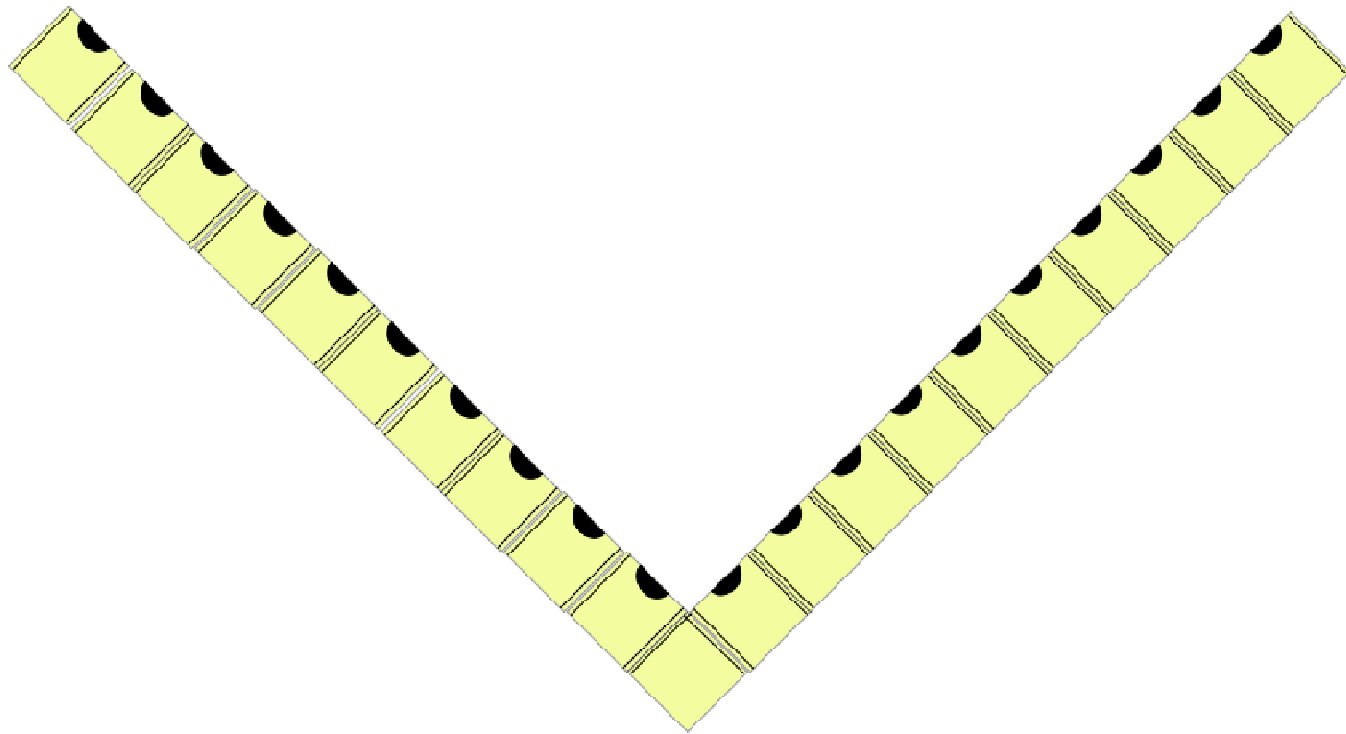

How is it so regular?

- It grows faster where it is rough.
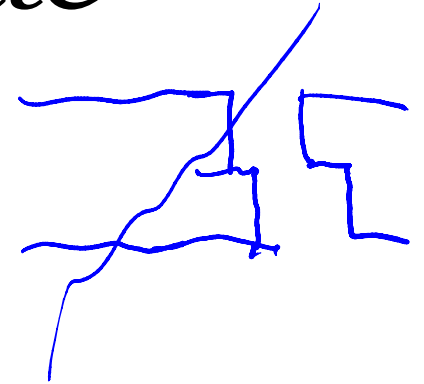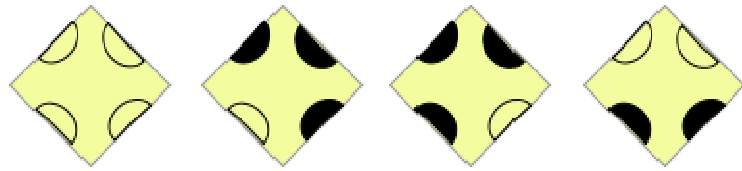- It grows faster where it is thin.

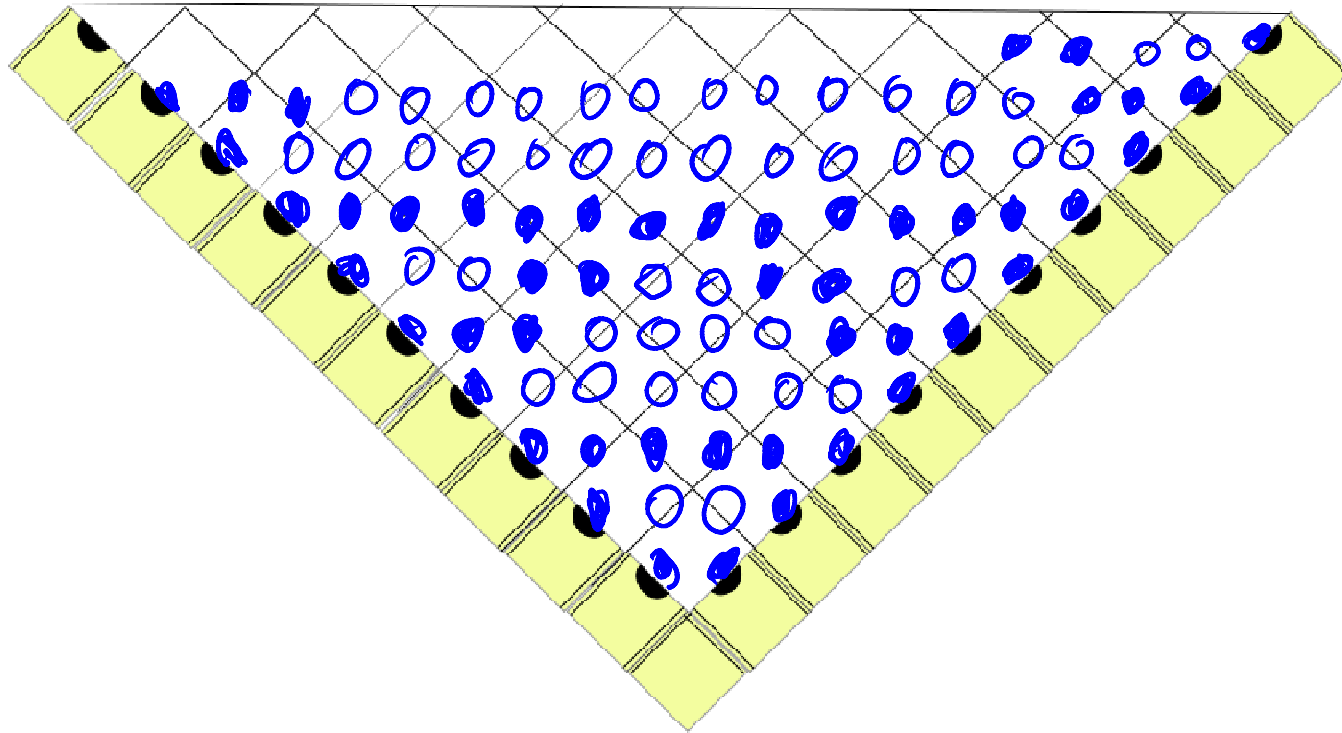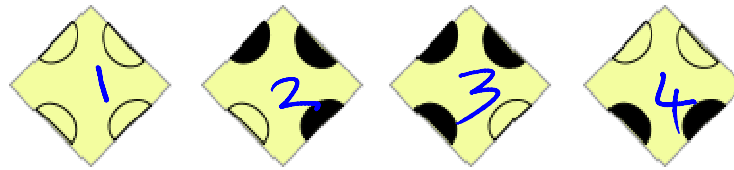# Crystals can self-replicate

The origin of life and the nature of the primitive gene
A. G. Cairns-Smith, Journal of Theoretical Biology, 10, 53-88, 1966;

Crystals can compute

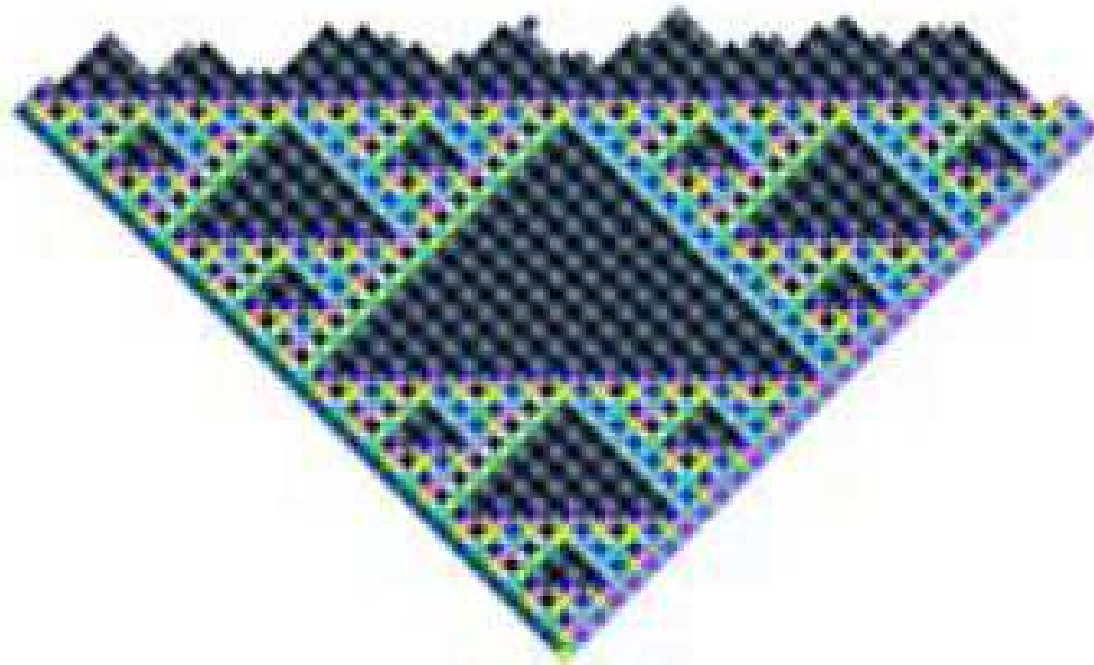# Crystals can compute

The Sierpinski fractal

Figure from "Proofreading Tile Sets" by Winfree and Bekbolatov

DNA Origami
(Rothemund 2006)
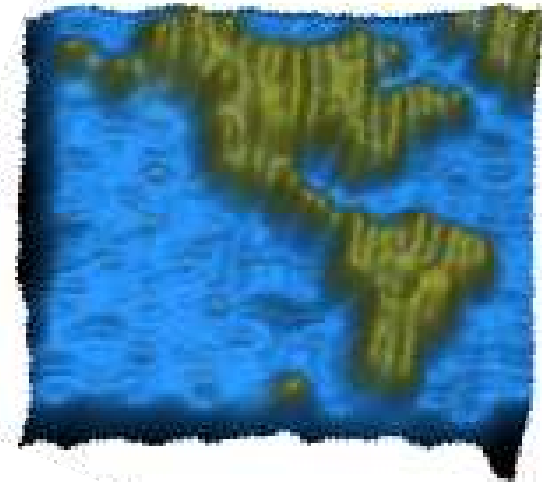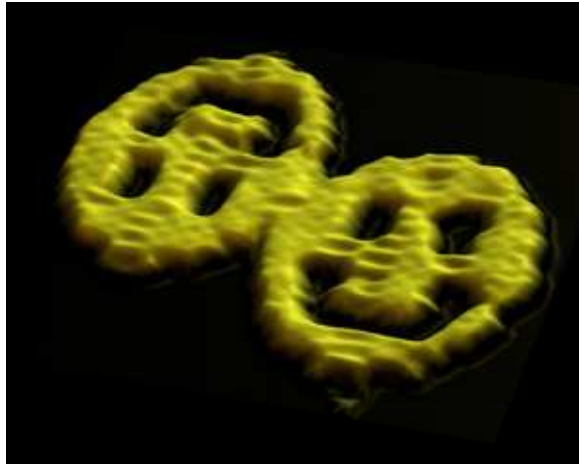
What is DNA?

- A string of molecules

- Can be made by chemistry

- Sticks with other pieces of DNA
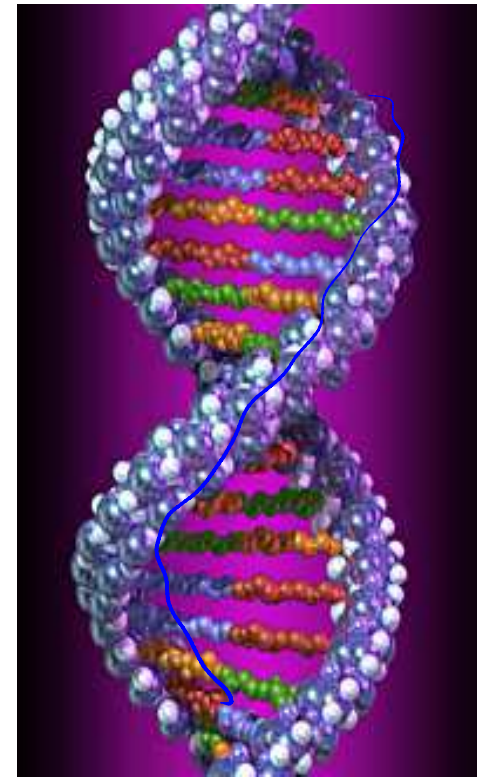
A, T, G, C

DNA Origami Square
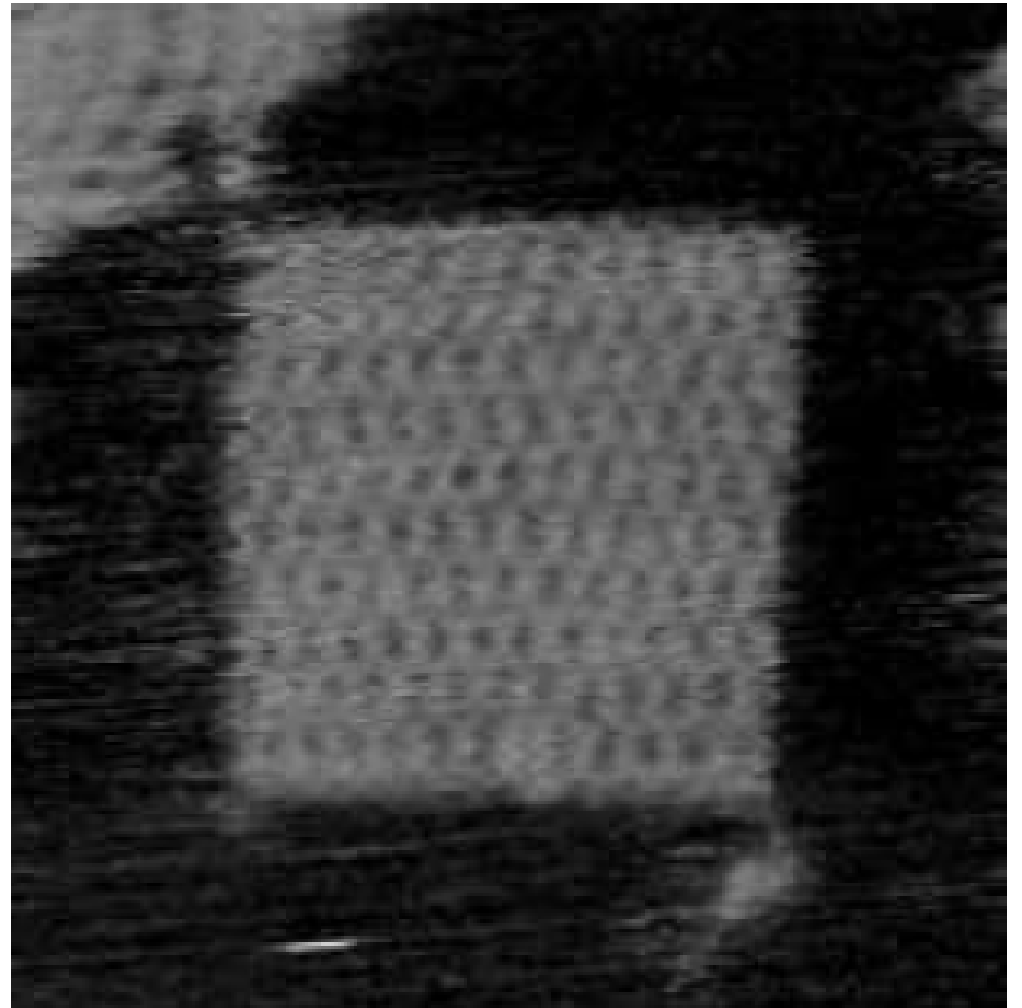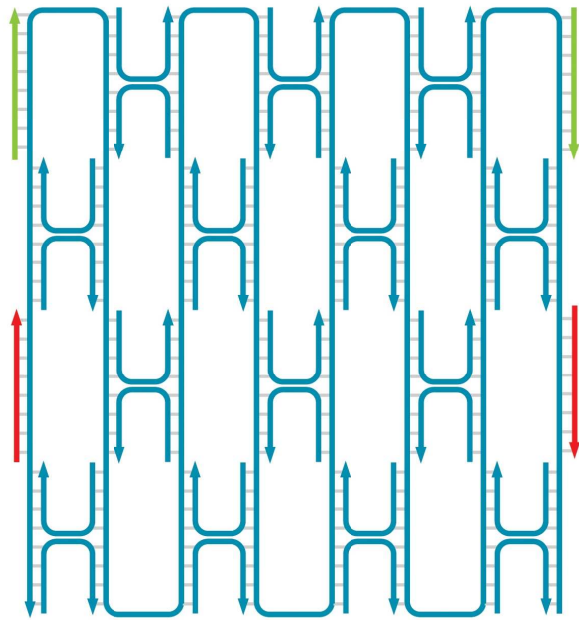
Sketch by Nickolas Peter Chelyapov

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DNA Origami

Gopalkrishnan M., Gopalkrishnan N., Adleman L., DNA 14

DNA Origami

Gopalkrishnan M., Gopalkrishnan N., Adleman L., DNA 14
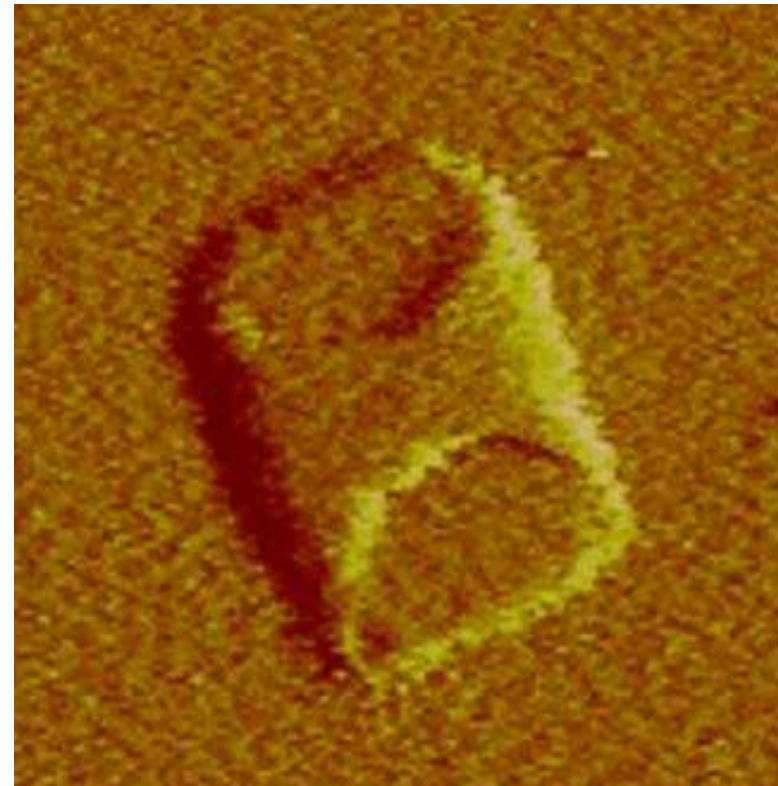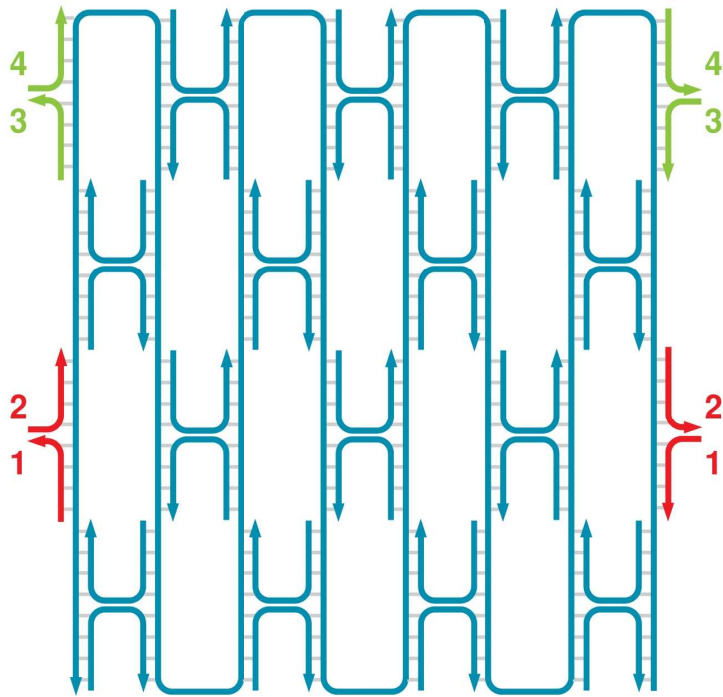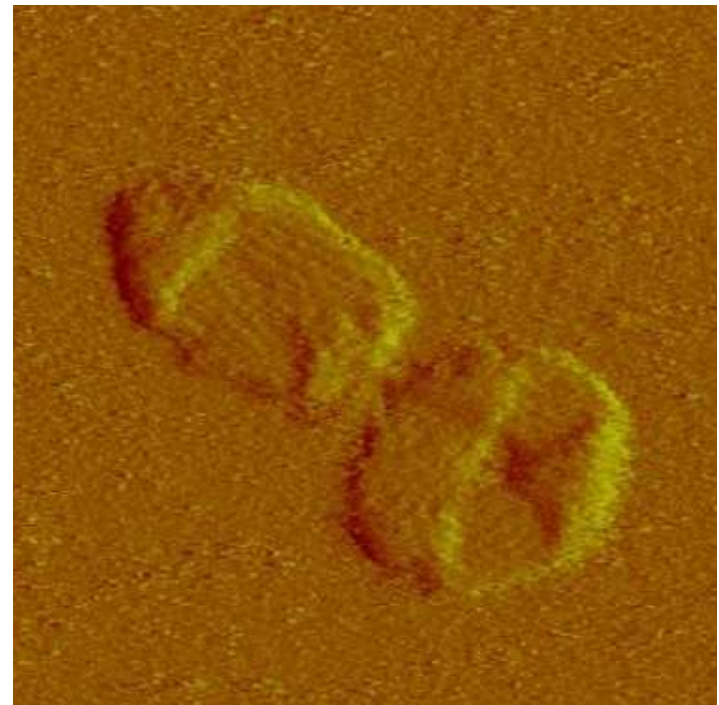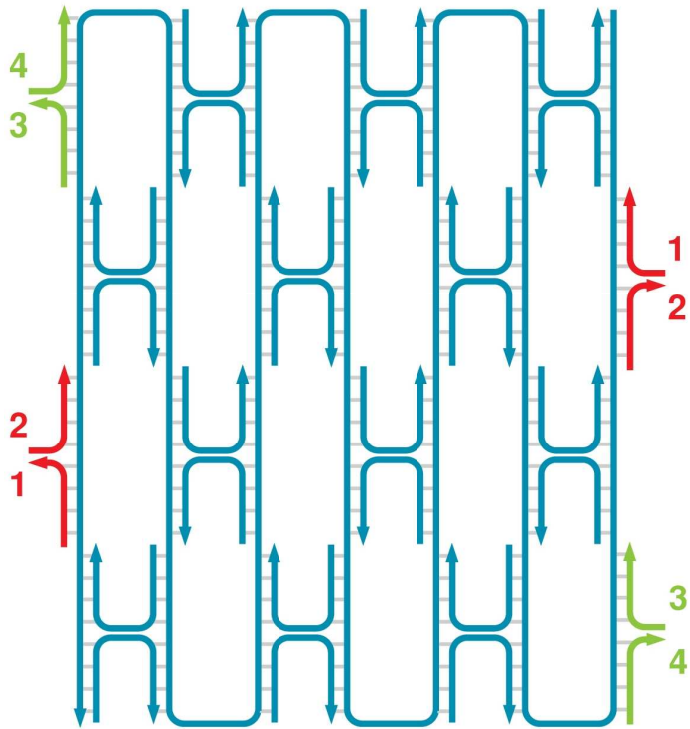
Where is the tree inside a seed?

Seed

Cell

DNA

Nucleus

A, T, G, C
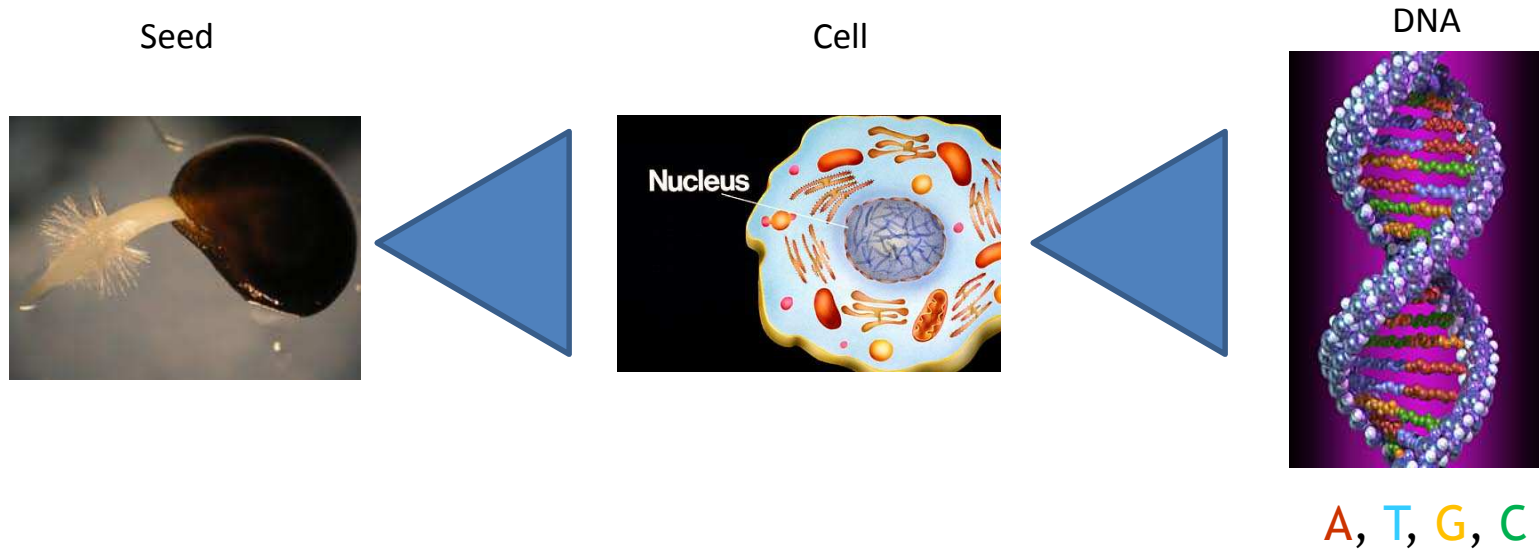
• The DNA sequence inside a seed is software for making a tree.

How did life get so sophisticated?

- Evolution?
- Randomly scratch a million DVD's of Windows XP.
- What is the chance that one of the DVD's will have a better version of Windows XP on it?
- The human genome is approximately the size of Windows XP.

Do humans evolve?

- Bacteria reproduce very frequently (as fast as 20 minutes per generation).

- Humans ~ 20 years per generation.

- Bacteria reproduce half a million times in one human generation.

- Lots of generations for bacteria to evolve!

- If the human genome remains fixed, its fate is at the mercy of bacterial evolution!

The Red Queen

'Well, in our country,' said Alice, still panting a little, 'you'd generally get to somewhere else — if you ran very fast for a long time, as we've been doing.'

'A slow sort of country!' said the Queen. 'Now, here, you see, <u>it takes all the running you can do, to keep in the same place</u>.'

"Through the Looking Glass," by Lewis Carroll, illustration by John Tenniel

The Red Queen

- Idea 1: Variation

- Idea 2: Redundancy ➔ more variation
- Each cell carries two copies of its program.
- Each individual program can be "less perfect."

The Red Queen

- Idea 3: Recombination
- Mix-and-match parts of two programs to create a new program completely different from the original two.
- Less risky than mutation.

Recombination

- Take two different (but similar) programs that perform similar tasks.
- Randomly glue the first half of one program to the second half of the second program.
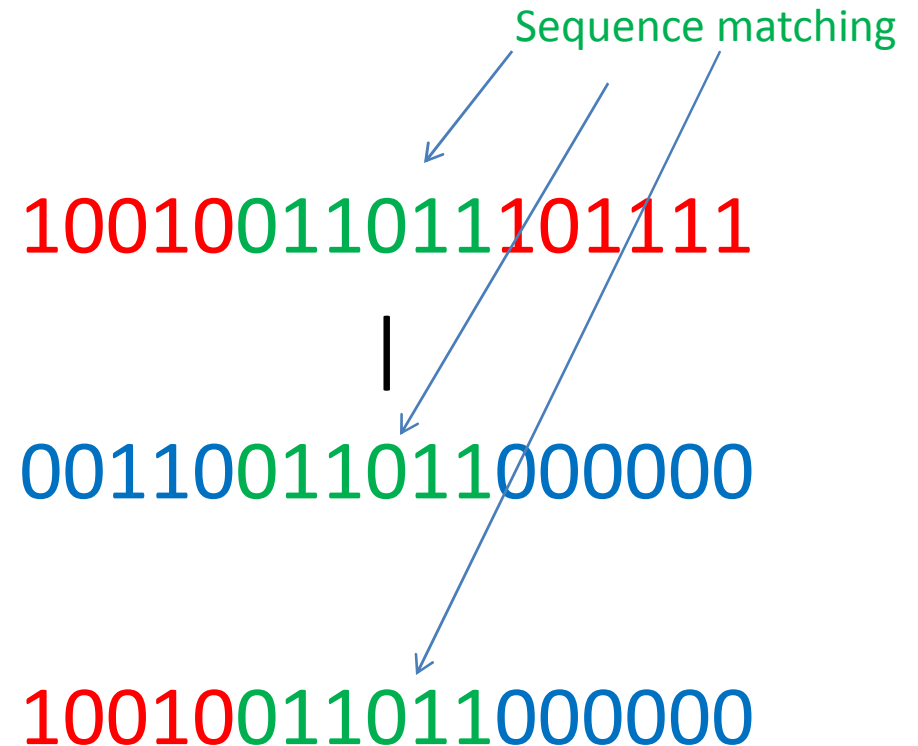
  syntax error

- Solution?

10010010001101111

|

00110111011000000

1001001011000000

Making recombination work

- Programs must be modular.

- Align programs using sequence matching.

- Glue the first half of one program to the second half of the second program.

- "Homologous recombination."

Sequence matching

10010011011101111

|

00110011011000000

10010011011000000

Aging

- Bug or feature?
- Some cells and organisms do not age, and are potentially immortal.
  - Examples include a jellyfish, some bacteria, and human cancer cells.
- Perhaps aging is a feature carefully programmed into us!
- What is the evolutionary advantage of aging?

Intelligence

- Alan Turing's definition

- "If you will tell me precisely what it is that a machine cannot do, then I can always make a machine which will do just that."
  – John von Neumann
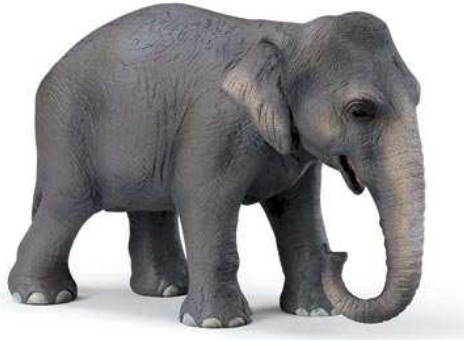
Life minus   *Matter*

Life minus *Matter* = *Algorithms*