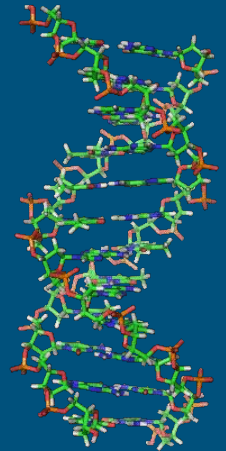
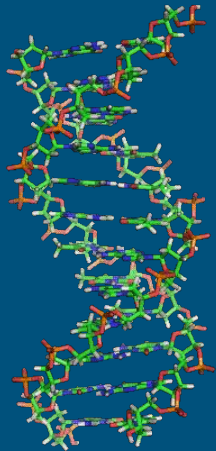


A brief 2025 recap DNA: the code of life



Credits

- This presentation leans heavily on other people's work and graphics
- All credits are available in the **speaker notes** which you should consult to find out who made all these great movies and images
- **Thank you so much Wikipedia Commons in particular!**

<https://berthub.eu/whydna>





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Original Article

The ISME Journal (2016) **10**, 30–38; doi:10.1038/ismej.2015.107; published online 3 July 2015

Density-dependent adaptive resistance allows swimming bacteria to colonize an antibiotic gradient

Felix J H Hol¹, Bert Hubert¹, Cees Dekker¹ and Juan E Keymer^{1,2,3}

¹Department of Bionanoscience, Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands

²Department of Ecology, Faculty of Biological Sciences, P. Catholic University of Chile, Santiago, Chile

³Institute of Physics, Faculty of Physics, P. Catholic University of Chile, Santiago, Chile

Correspondence: FJH Hol or JE Keymer, Department of Bionanoscience, Kavli Institute of Nanoscience, Delft University of Technology, Lorentzweg 1, Delft 2628CJ, The Netherlands. E-mail: f.j.h.hol@tudelft.nl or jkeymer@uc.cl

Received 5 January 2015; Revised 9 April 2015; Accepted 19 May 2015

Advance online publication 3 July 2015

Abstract

[Top](#)

During antibiotic treatment, antibiotic concentration gradients develop. Little is known regarding the effects of antibiotic gradients on populations of nonresistant bacteria. Using a microfluidic device, we show that high-density motile *Escherichia coli* populations composed of nonresistant

FULL TEXT

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Data Descriptor | [Open access](#) | Published: 22 March 2022

SkewDB, a comprehensive database of GC and 10 other skews for over 30,000 chromosomes and plasmids

[Bert Hubert](#) 

[Scientific Data](#) **9**, Article number: 92 (2022) | [Cite this article](#)

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Sections	Figures
Abstract	
Background & Summary	
Methods	
Data Records	

“Imagine a flashy spaceship lands in your backyard. The door opens and you are invited to investigate everything to see what you can learn. The technology is clearly millions of years beyond what we can make.

This is biology.”

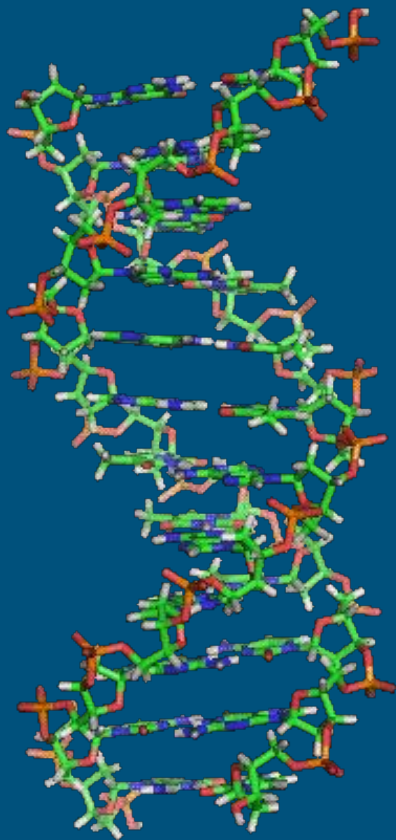




Although...

© NASA (oddly enough)

1. Information storage
2. The 3D printer of life
3. Algorithms & control
4. Hacks



- DNA: Millions, billions of nucleotides or “bases”:
 - A, C, G, T
- Organized in chromosomes & genes
- Absolutely **atom for atom** universal across all life
 - >4 billion years old
- Stable for 100s of thousands of years

ARCHAEA

ANIMALS,
PLANTS, FUNGI,
US

BACTERIA

2 billion years ago

4 billion years ago

First water: 4.2 billion

Age of earth: 4.5 billion



Basics: Each nucleotide is 2 (arbitrary) bits

A 00

C 01

G 10

T 11



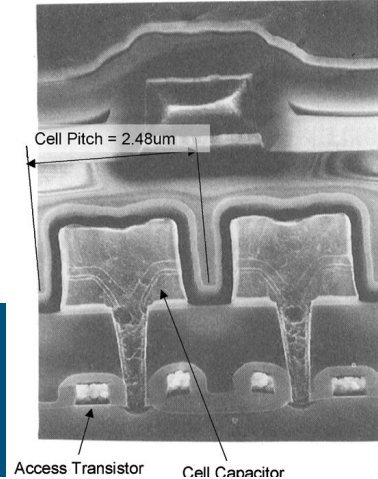
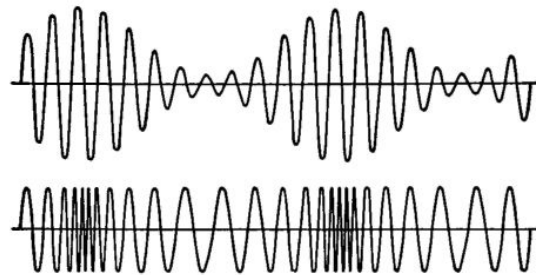
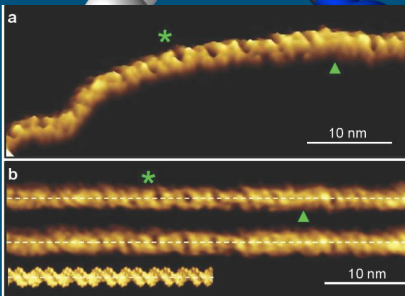
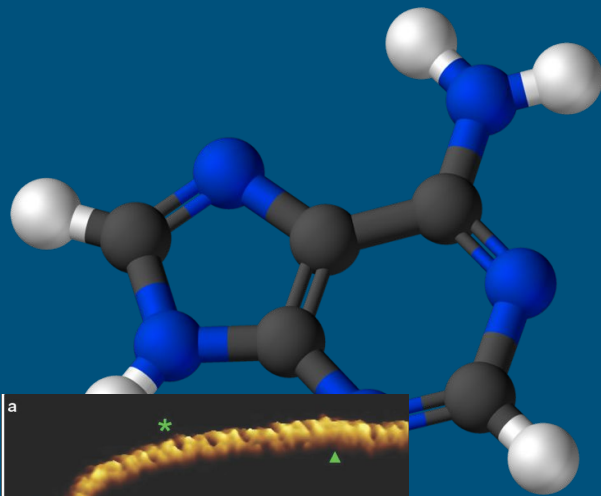
Basics: DNA

A

C

G

T



00

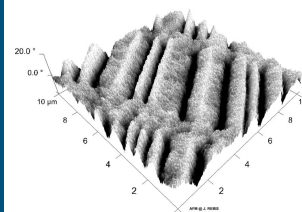
01

10

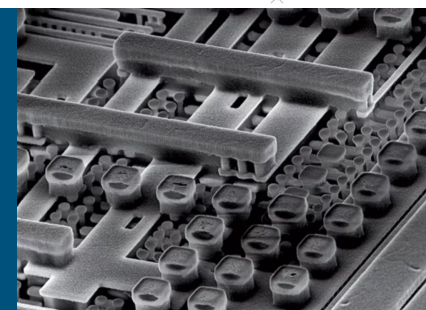
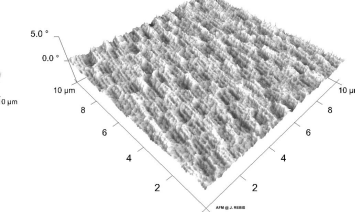
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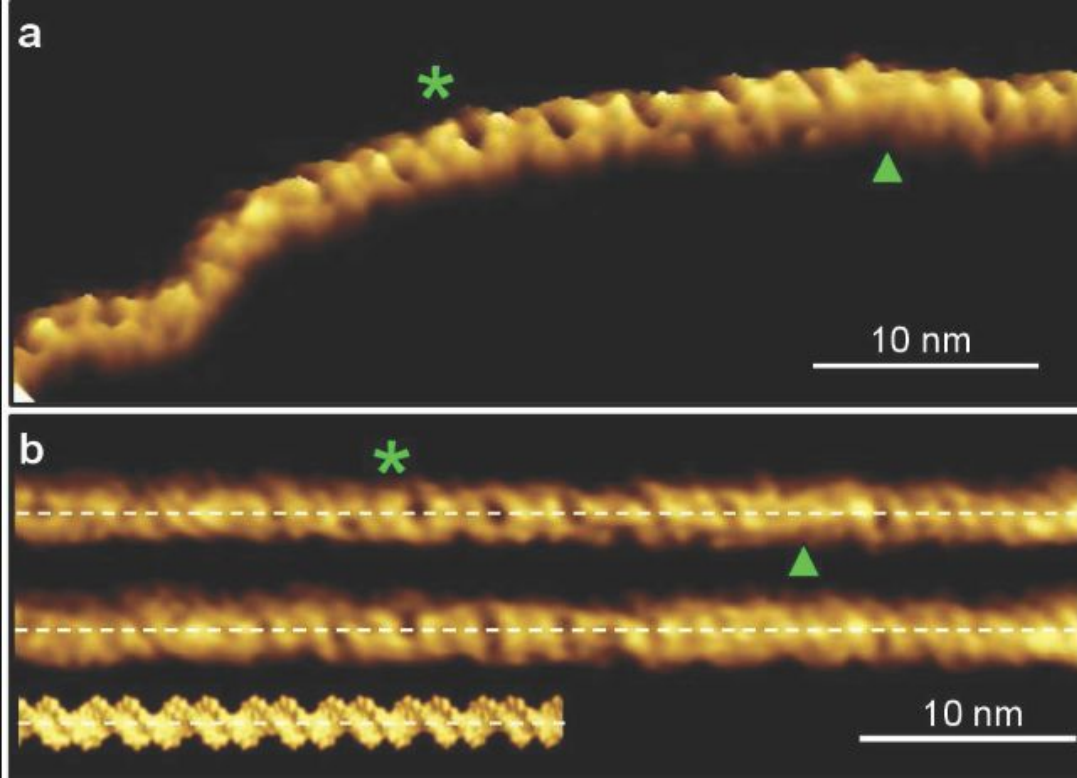
MAGNETIC FORCE MICROSCOPY

Dysk twardy magnetyczny 3.2 Gb



Dysk twardy magnetyczny 30 Gb





DNA is very much like tape

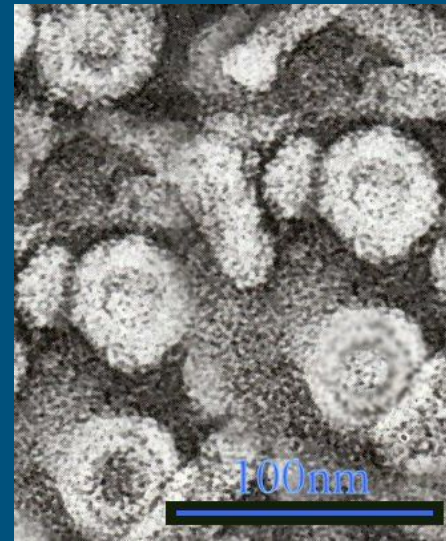
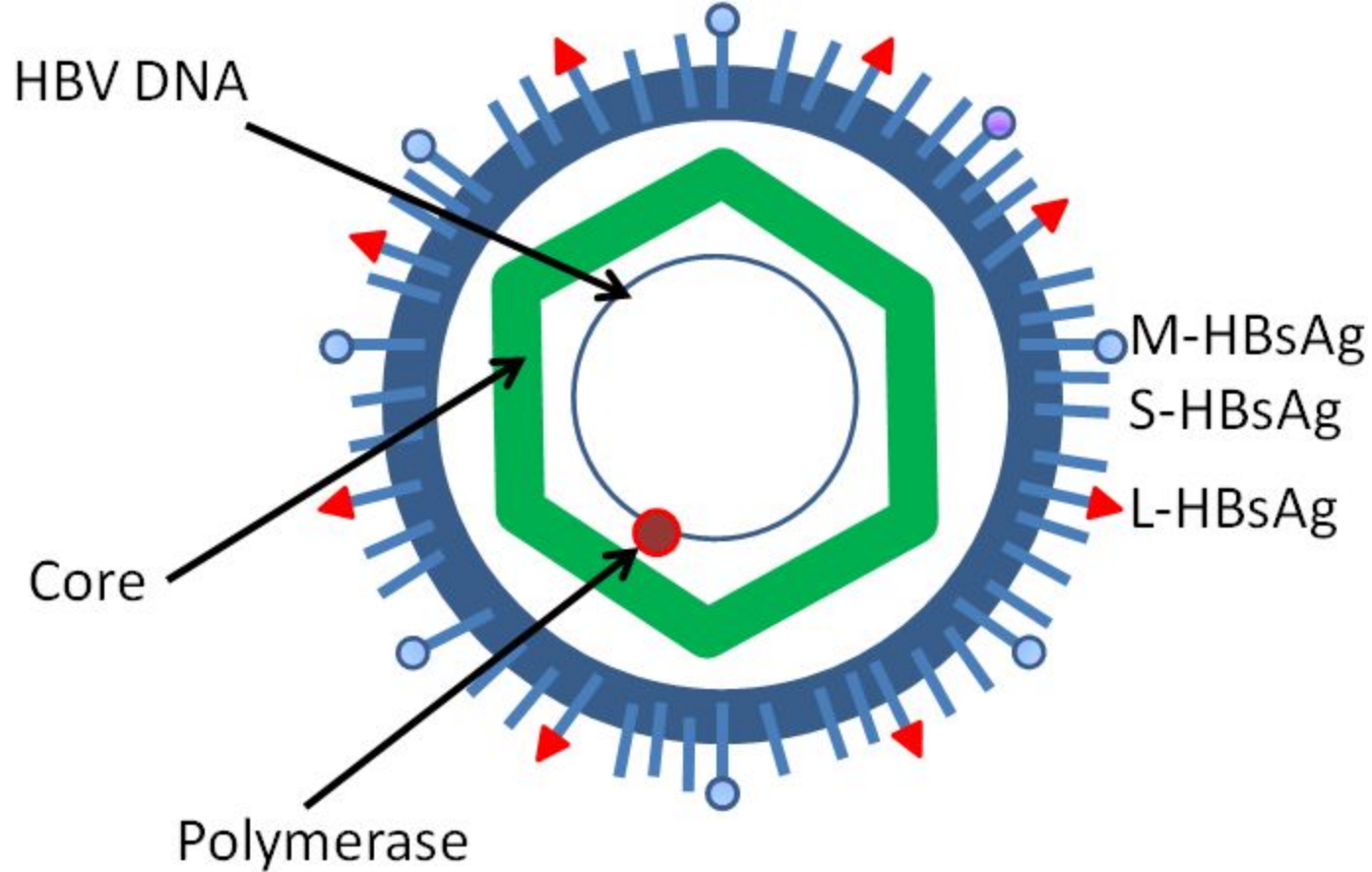
Sometimes circular tape - no beginning, no end!

No addressing! No alignment!

It is a **nucleotide stream** which can be compared to a **bitstream**

It IS however **content addressable!**

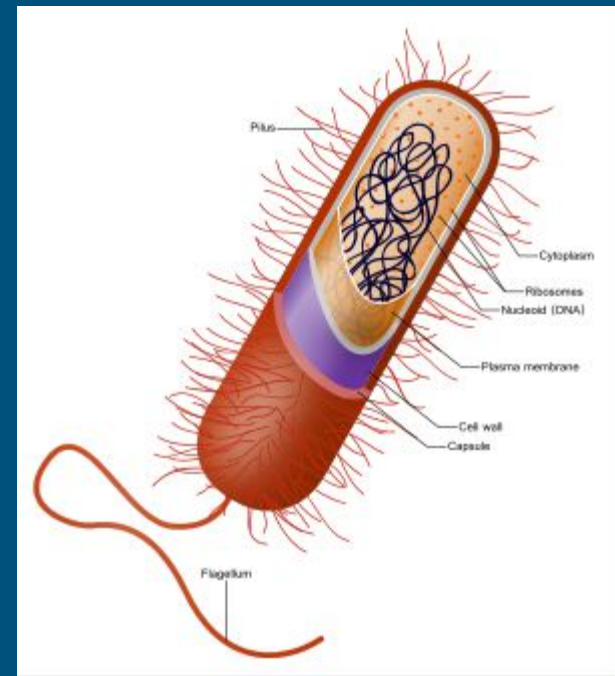
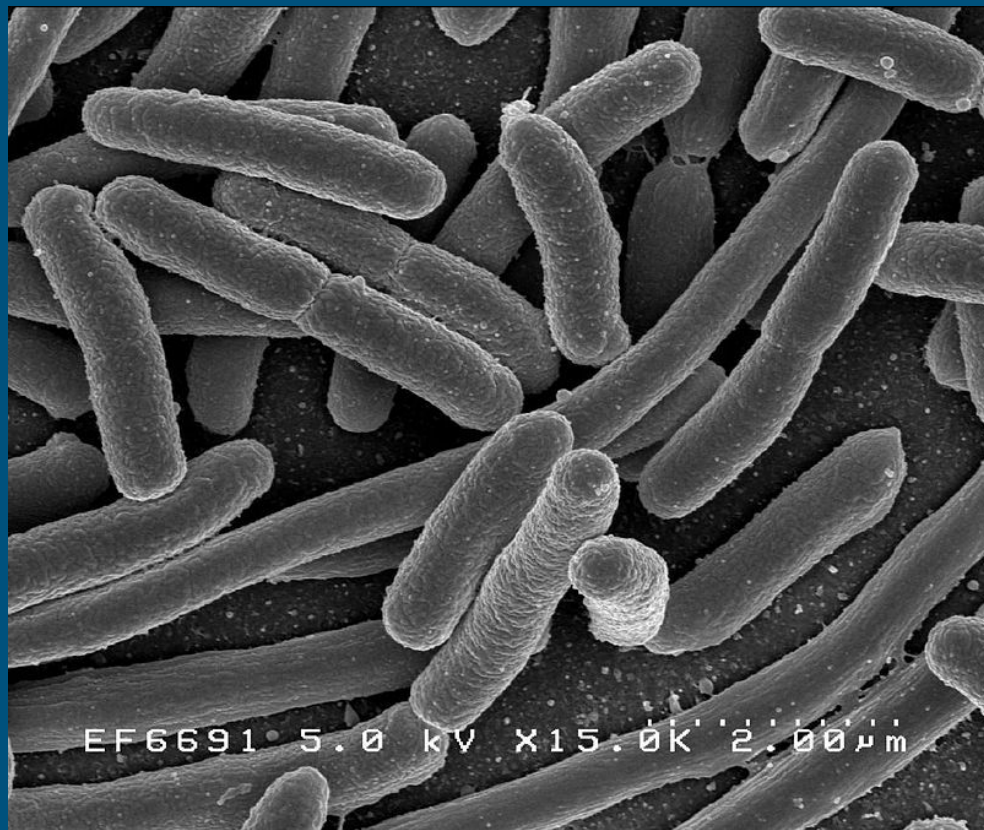
And it has FRAMING ~~challenges~~ **possibilities**



Hepatitis B - 800 bytes (unpleasant)

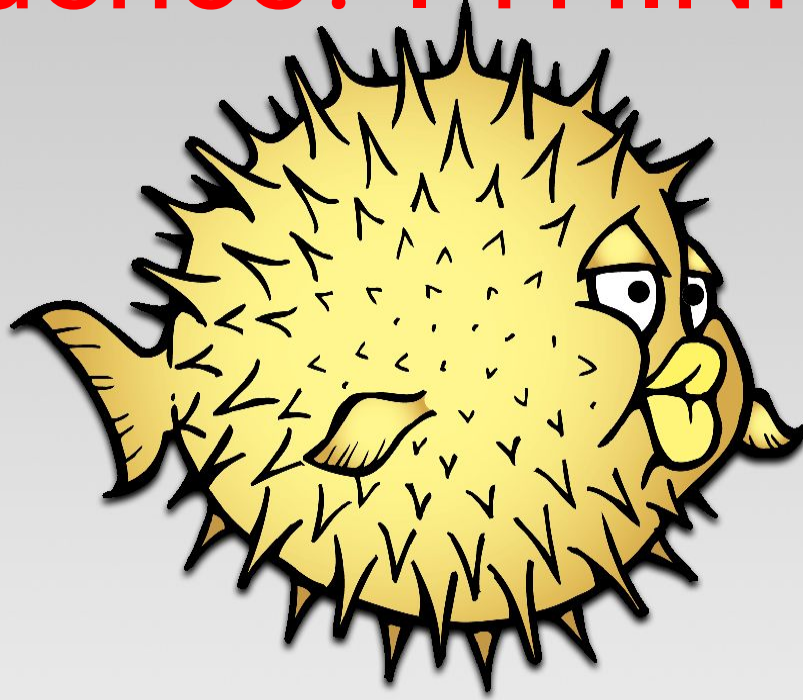
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ccaccaaatgccccatcttatcaacacttccggaaactactgttgttagacgacgggaccgaggcagggtcccttagaagaagaactccctcgcctcgaaacgcagatctcaat
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attgaccacagtgtaacaattcctcctcctgcctccaccaatcggcagtcaggaaggcagcctactcccatctctccacctctaagagacagtcacctcaggccatgcagtgg
aa

All of Hepatitis-B - 800 bytes

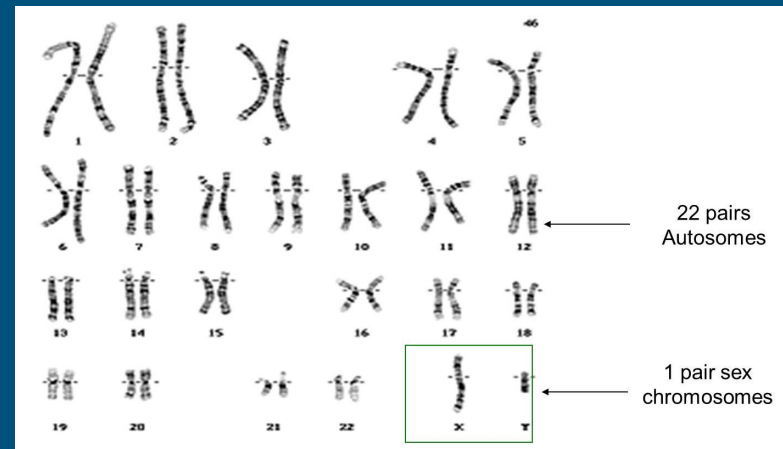
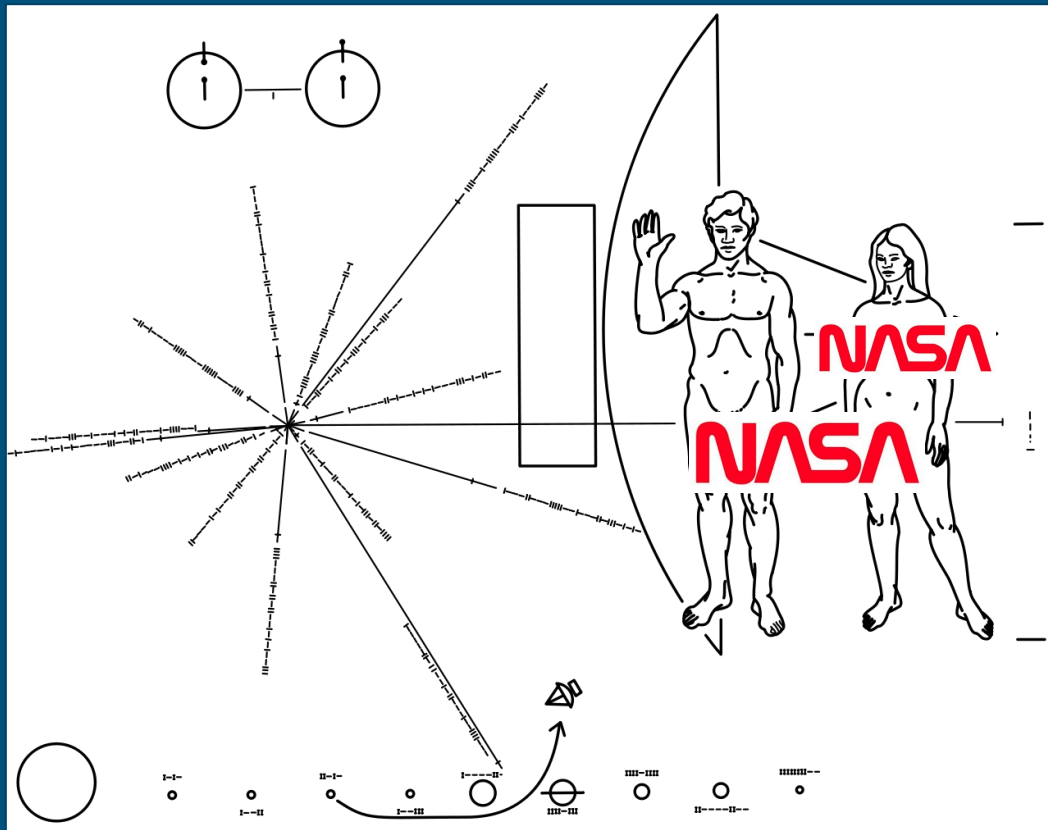


E. Coli: 750KB (can be good, can be unpleasant)

Coincidence? I THINK NOT!



Pufferfish: 100MB, smallest & tightest genome of all animals (lethal)



Your unique DNA *diff* is around 1-10 megabyte. HOWEVER - could be way more: the pangenome

Homo sapiens: **750MB** (lethal)



Paris Japonica: 37.5GB (quite pleasant)



Marbled Lungfish: 33GB

But is life REALLY digital?

Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome

DANIEL G. GIBSON, JOHN I. GLASS, CAROLE LARTIGUE, VLADIMIR N. NOSKOV, RAY-YUAN CHUANG, MIKKEL A. ALGIRE, GWYNEDD A. BENDERS, MICHAEL G. MONTAGUE, LIMA [...], AND J. CRAIG VENTER [+14 authors](#) [Authors Info & Affiliations](#)

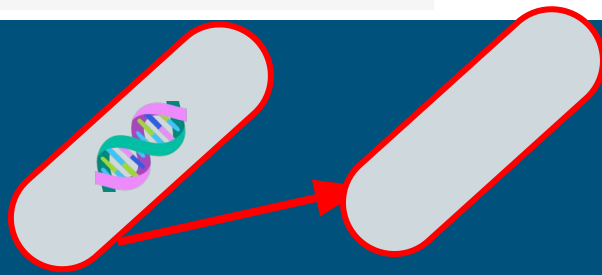
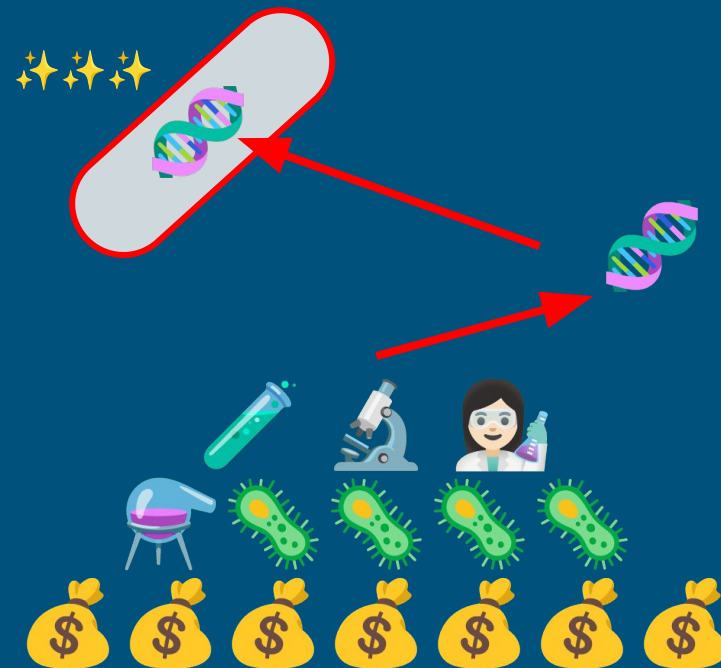
SCIENCE • 20 May 2010 • Vol 329, Issue 5987 • pp. 52-56 • DOI:10.1126/science.1190719

 62,812  1,912

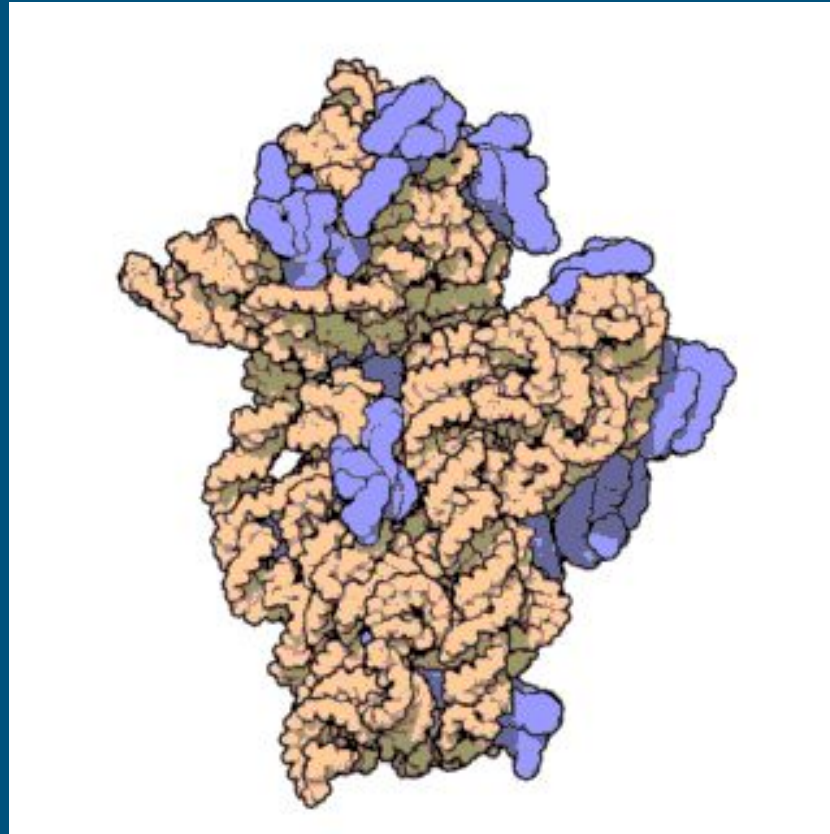


Let There Be Life

The DNA sequence information from thousands of genomes is stored digitally as ones and zeros in computer memory. Now, **Gibson *et al.*** (p. 52, published online 20 May; see the cover; see the Policy Forum by **Cho and Relman**) have brought together technologies from the past 15 years to start from digital information on the genome of *Mycoplasma mycoides* to chemically synthesize the genomic DNA as segments that could then be assembled in yeast and transplanted into the cytoplasm of another organism. A number of methods were also incorporated to facilitate testing and error correction of the synthetic genome segments. The transplanted genome became established in the recipient cell, replacing the recipient genome, which was lost from the cell. The reconstituted cells were able to replicate and form colonies, providing a proof-of-principle for future developments in synthetic biology.



Behold! The source of all life & you



~10
nanometers

BEHOLD! Part of the Ribosome, the 1D/3D printer of life!
It printed you or the things that made you!

The Central Dogma

Long term storage: **DNA** (*/dev/sda*)

Converts to live form: **RNA** (*RAM*)

RNA converts to: **Proteins**

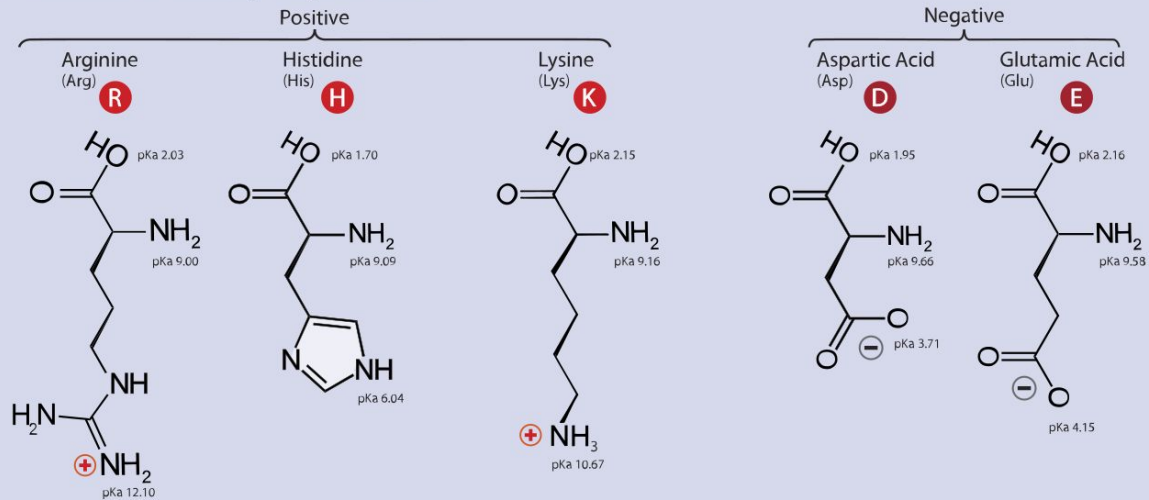
Proteins: **Sense and Do**



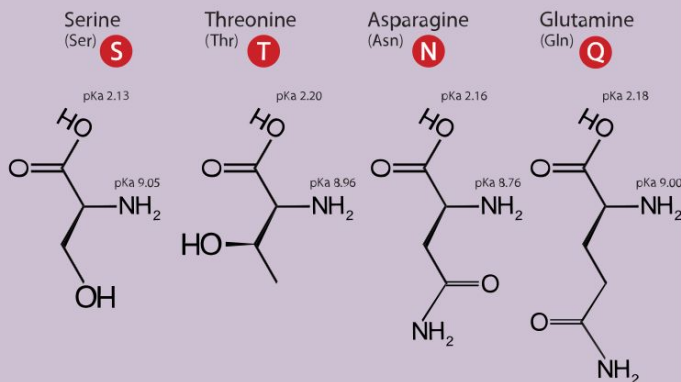
Twenty-One Amino Acids

⊕ Positive
⊖ Negative
• Side chain charge at physiological pH 7.4

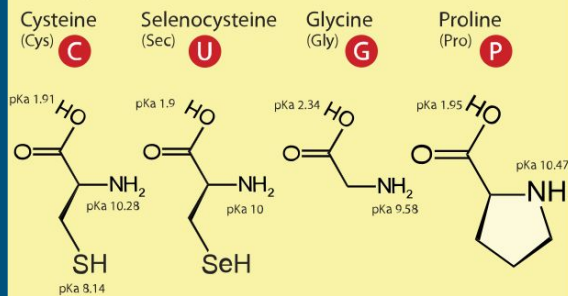
A. Amino Acids with Electrically Charged Side Chains



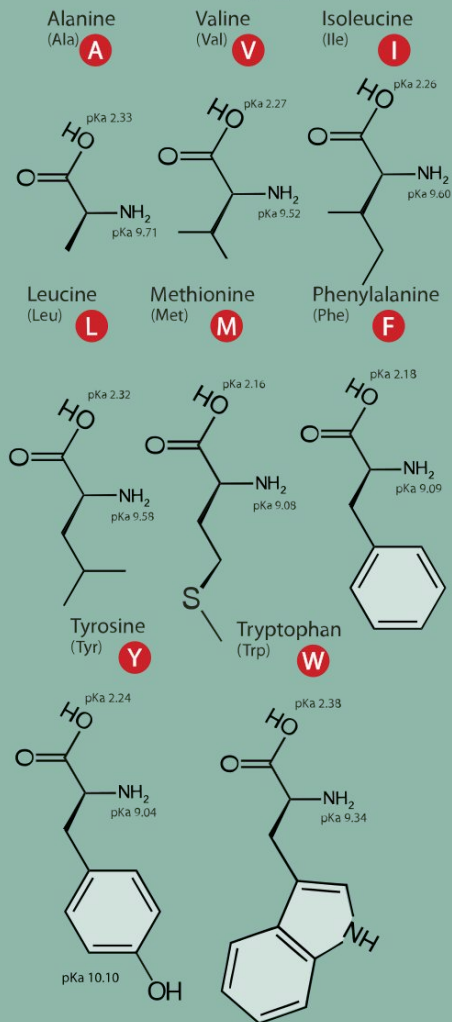
B. Amino Acids with Polar Uncharged Side Chains



C. Special Cases



D. Amino Acids with Hydrophobic Side Chain



1st base	2nd base								3rd base	
	T		C		A		G			
T	TTT	(Phe/F) Phenylalanine	TCT	(Ser/S) Serine (p)	TAT	(Tyr/Y) Tyrosine (p)	TGT	(Cys/C) Cysteine (p)	T	
	TTC	(np)	TCC		TAC		TGC		C	
	TTA		TCA		TAA	Stop (Ochre) *[note 2]	TGA	Stop (Opal) *[note 2]	A	
	TTG ⇒		TCG		TAG	Stop (Amber) *[note 2]	TGG	(Trp/W) Tryptophan (np)	G	
C	CTT	(Leu/L) Leucine (np)	CCT	(Pro/P) Proline (np)	CAT	(His/H) Histidine (b)	CGT	(Arg/R) Arginine (b)	T	
	CTC		CCC		CAC		CGC			C
	CTA		CCA		CAA	(Gln/Q) Glutamine (p)	CGA			A
	CTG		CCG		CAG		CGG			G
A	ATT	(Ile/I) Isoleucine (np)	ACT	(Thr/T) Threonine (p)	AAT	(Asn/N) Asparagine (p)	AGT	(Ser/S) Serine (p)	T	
	ATC		ACC		AAC		AGC		C	
	ATA		ACA		AAA	(Lys/K) Lysine (b)	AGA	(Arg/R) Arginine (b)	A	
	ATG ⇒		ACG		AAG		AGG		G	
G	GTT	(Val/V) Valine (np)	GCT	(Ala/A) Alanine (np)	GAT	(Asp/D) Aspartic acid (a)	GGT	(Gly/G) Glycine (np)	T	
	GTC		GCC		GAC		GGC			C
	GTA		GCA		GAA	(Glu/E) Glutamic acid (a)	GGA			A
	GTG ⇒		GCG		GAG		GGG			G

Multi-billion year old table!

Multiple codons for same amino acids

This allows for **dialects** and shaping DNA

```
>gn1|ECOLI|G0-10439 kdpF MONOMER0-12 (complement(728732..728821)) Escherichia coli  
K-12 substr. MG1655
```

```
gtgAGTGCAGGCGTGATAACCGGCGTATTGCTGGTGTTTTTATTACTGGGTATCTGGTTTATGCCCTGA  
TCAATGCGGAGGCGTTtga
```

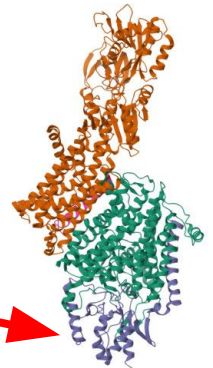
```
>gn1|ECOLI|G0-10439 kdpF MONOMER0-12 (complement(728732..728821)) Escherichia coli  
K-12 substr. MG1655
```

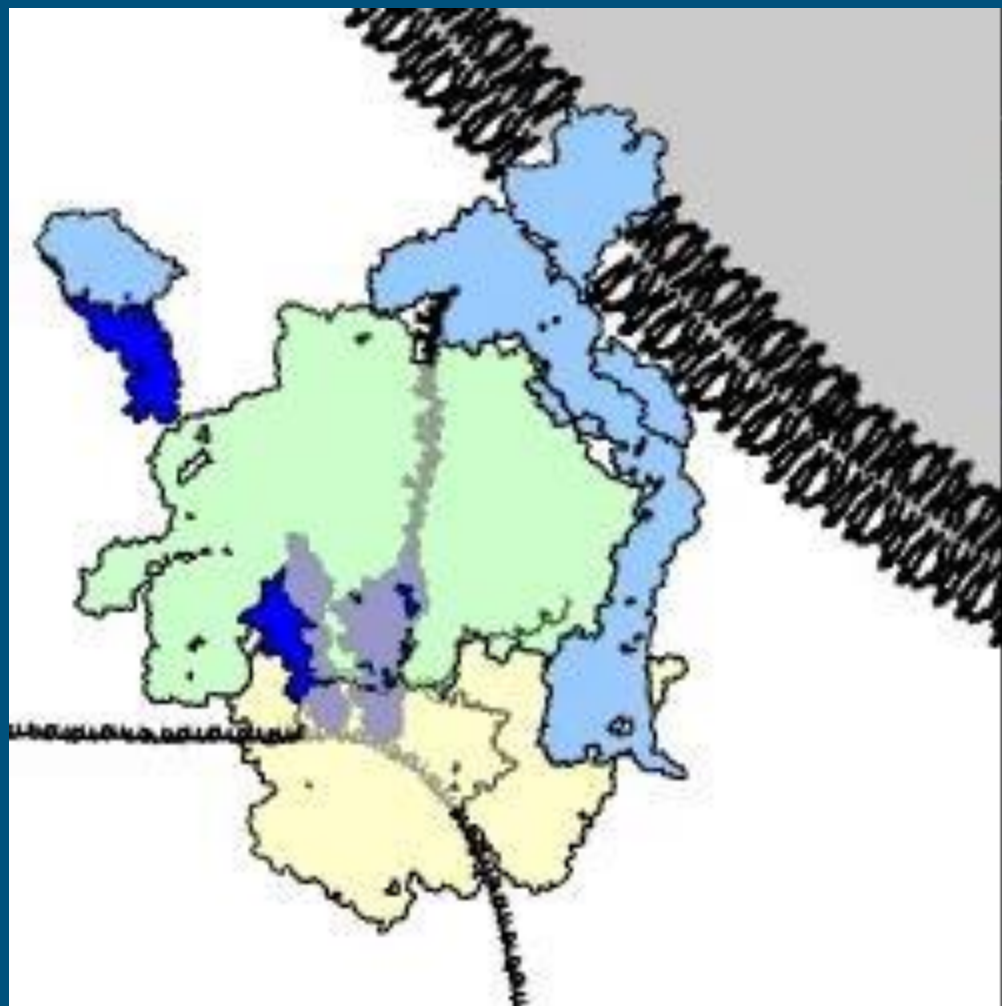
```
gtg AGT GCA GGC GTG ATA ACC GGC GTA TTG CTG GTG TTT TTA TTA CTG GGT TAT CTG GTT  
TAT GCC CTG ATC AAT GCG GAG GCG TTC tga
```

```
>gn1|ECOLI|MONOMER0-12 gn=kdpF K+ transporting P-type ATPase subunit KdpF  
(complement(728732..728821)) Escherichia coli K-12 substr. MG1655
```

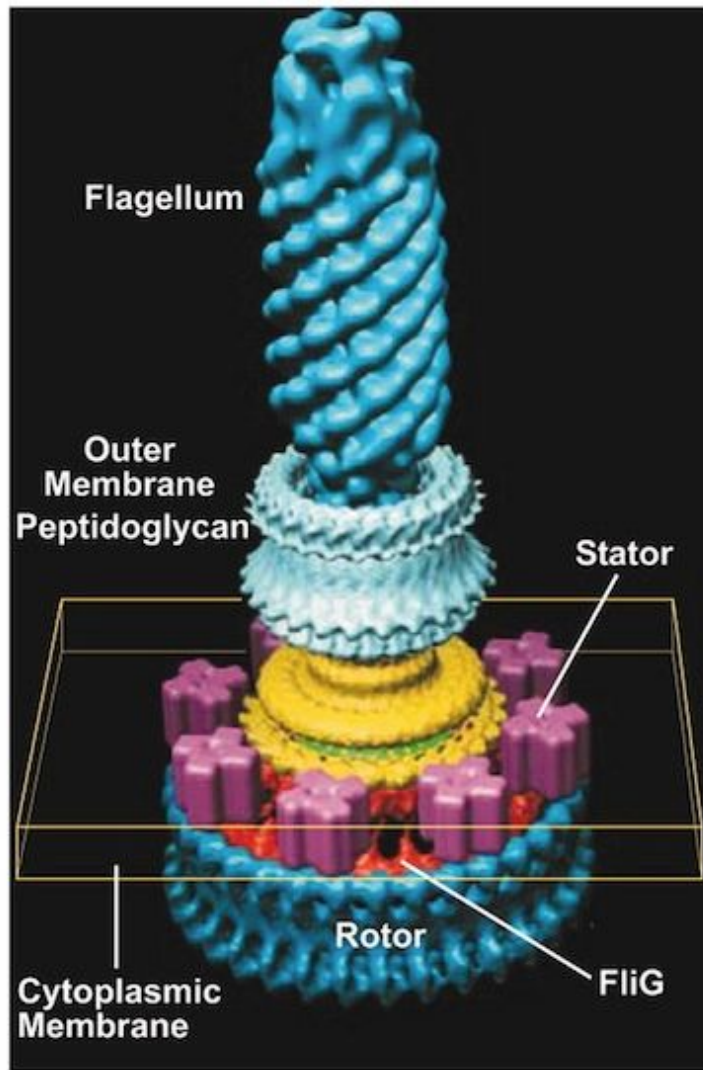
```
MSAGVITGVLLVFLLLGYLVYALINAEAF<EOP>
```

“A 1D printer that leads to 3D objects with ATOMIC resolution”

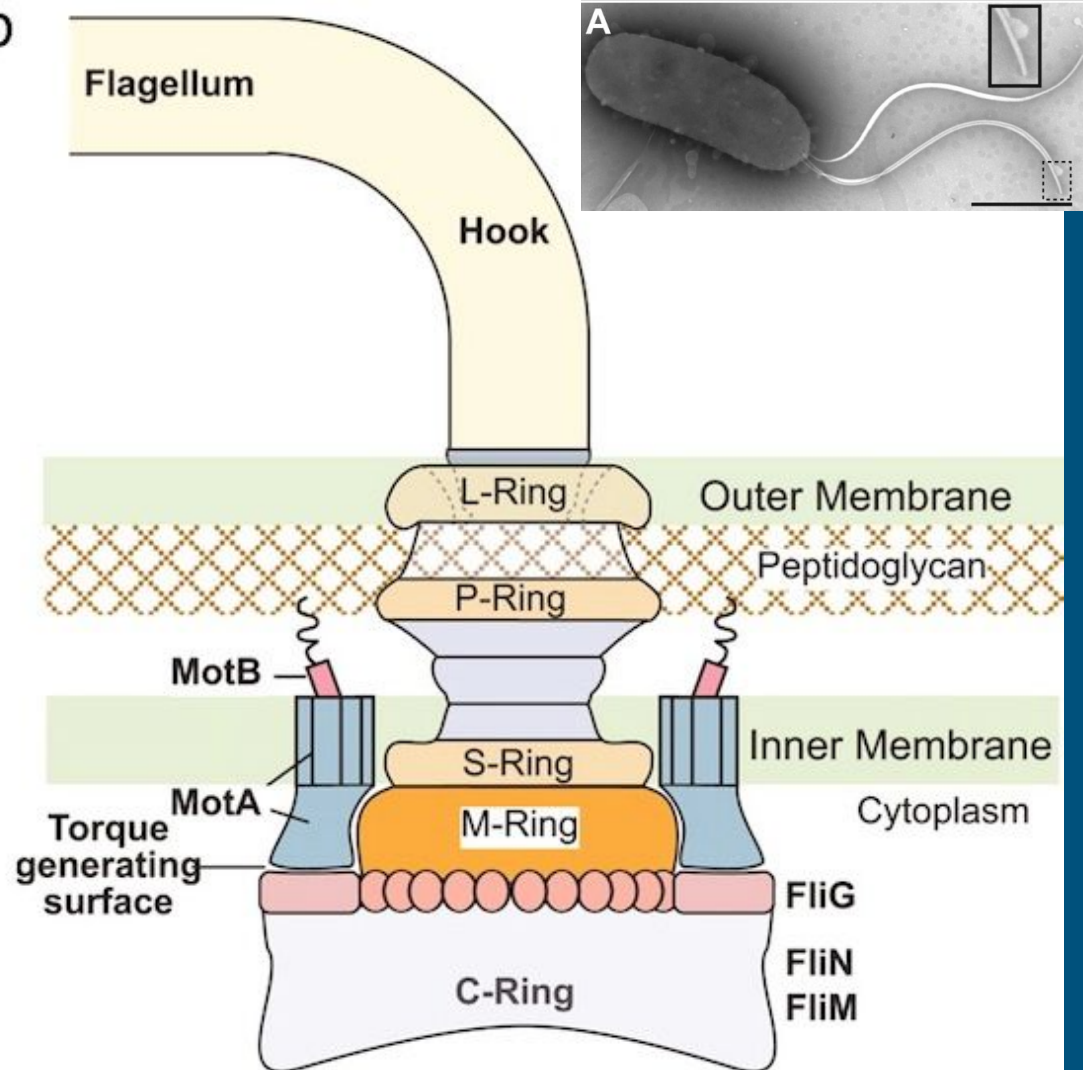




a



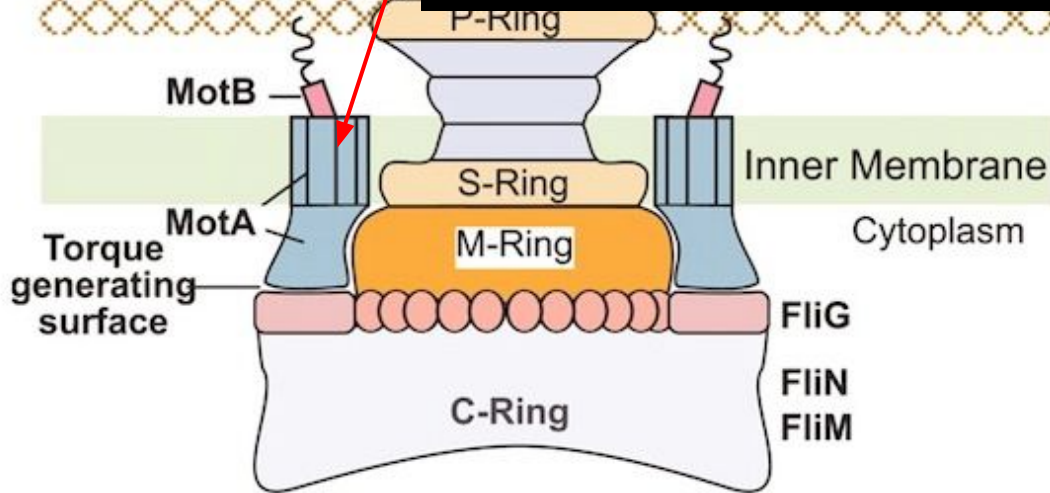
b



Flagellum

>[gene=motA] [protein=proton conductor component of flagella motor]

```
GTGCTTATCTTATTAGGTTACCTGGTTGTTCTCGGTACAGTTTTTCGGCGGTTATTTGATGACCGGTGGAAGCCTTGGAGC
ACTCTATCAACCCGCTGAACTGGTGATTATTGCCGGTGACAGGGATTGGGTCGTTTATCGTCGGCAATAATGGCAAAGCGA
TTAAAGGCACGCTGAAGGCGCTGCCGTTGCTGTTTCGTCGCTCCAAATACACCAAAGCAATGTATATGGATCTGCTGGCT
CTGCTTTATCGGTTGATGGCGAAATCGCGGCAGATGGGGATGTTTTTCGCTGGAACGTGATATTGAAAATCCCCGTGAGAG
CGAGATCTTCGCCAGCTACCCACGCATCCTCGCGGATAGCGTCATGCTTGATTTTATCGTCGATTATCTGCGCCTGATTA
TCAGCGGTCACATGAACACCTTCGAAATCGAAGCTCTGATGGATGAAGAGATTGAGACGCACGAAAGCGAGGCAGAAGTC
CGGGCGAACAGTCTGGCGCTGGTCGGGGACTCACTTCGGGCGTTTGGTATTGTTGCGGCTGTAATGGGGGTGCTTCACGC
GTTAGGTTCAGCCGATCGTCCTGCCGCCGAGCTGGGTGCGCTTATCGCACATGCGATGGTGCGGGACTTTCCTCGGCATTT
TATTGGCTTACGGATTTATTTCCCCATTAGCGACTGTTTTACGTCAGAAAAGCGCCGAAACCAGCAAAATGATGCAGTGC
GTCAAAGTCACTCTGCTTTCTAATCTGAACGGTTACGCACCGCCTATCGCCGTTGAGTTTGGTCGCAAAACGCTCTATTC
CAGCGAACGTCCGTCGTTTATTGAACTGGAAGAGCATGTGCGTGCGGTGAAAAATCCGCAACAACAGACGACAACCGAGG
AAGCATGA
```





If you 3D print this model yourself:

- Your resolution is like 10 million times too coarse
- Your flagellar motor does not actually work
- It looks remarkably silly! ('honestly, this is for science!')

Gene control & how it hangs together

DNA layer
RNA layer
Amino acid layer
..
RNA layer
DNA layer



Amino Acids

RNA



Promoter

-35

-10

Shine-Dalgarno

Amino acids
code

ATG...TGA

“TTGACA”

“TATAAT”

“AGGAGG”

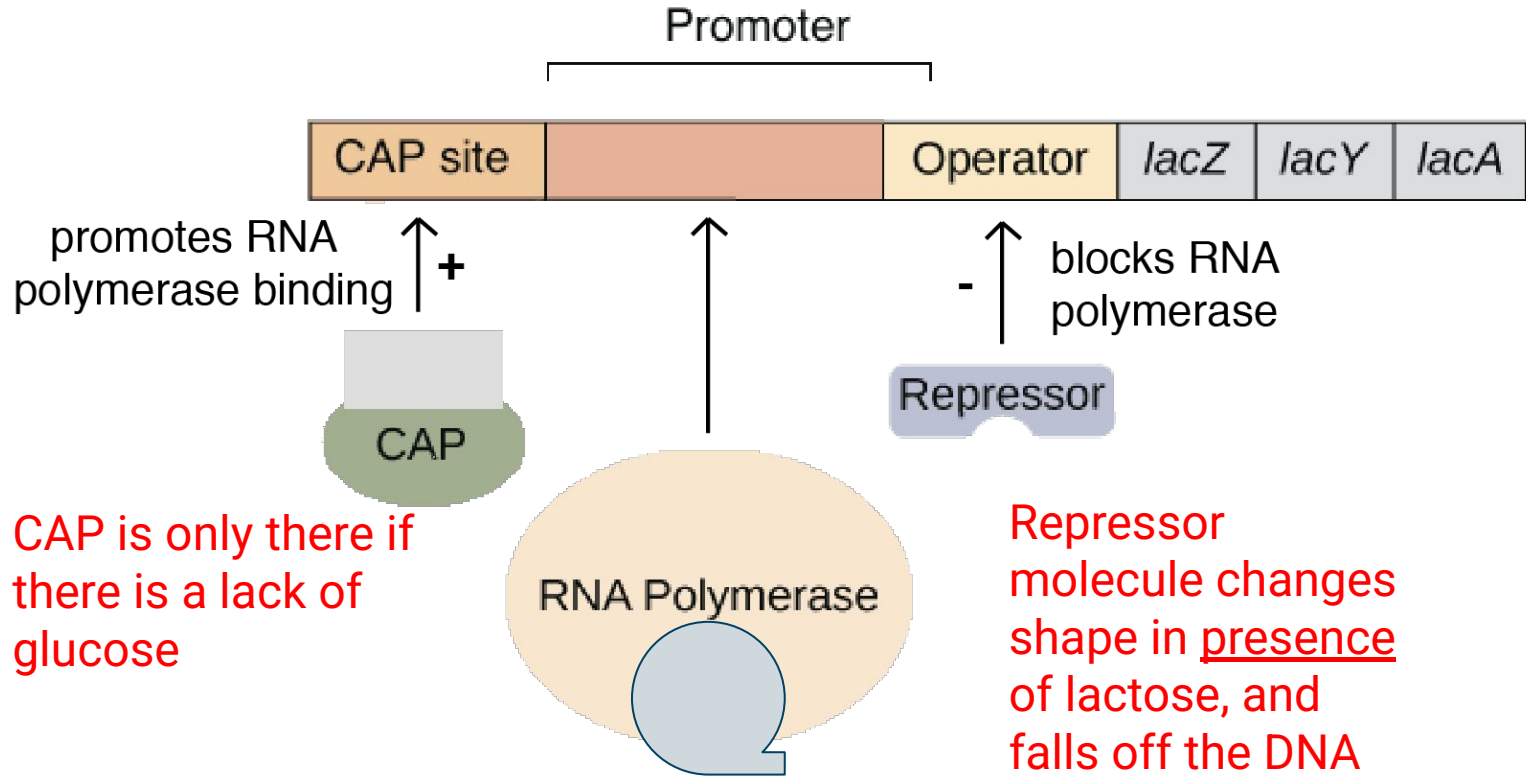
E. coli



- Needs power to run
 - 0.5pW
- Loves glucose
- Can run on **lactose** if it must
 - Through conversion
 - Less efficient
- Algorithm required:

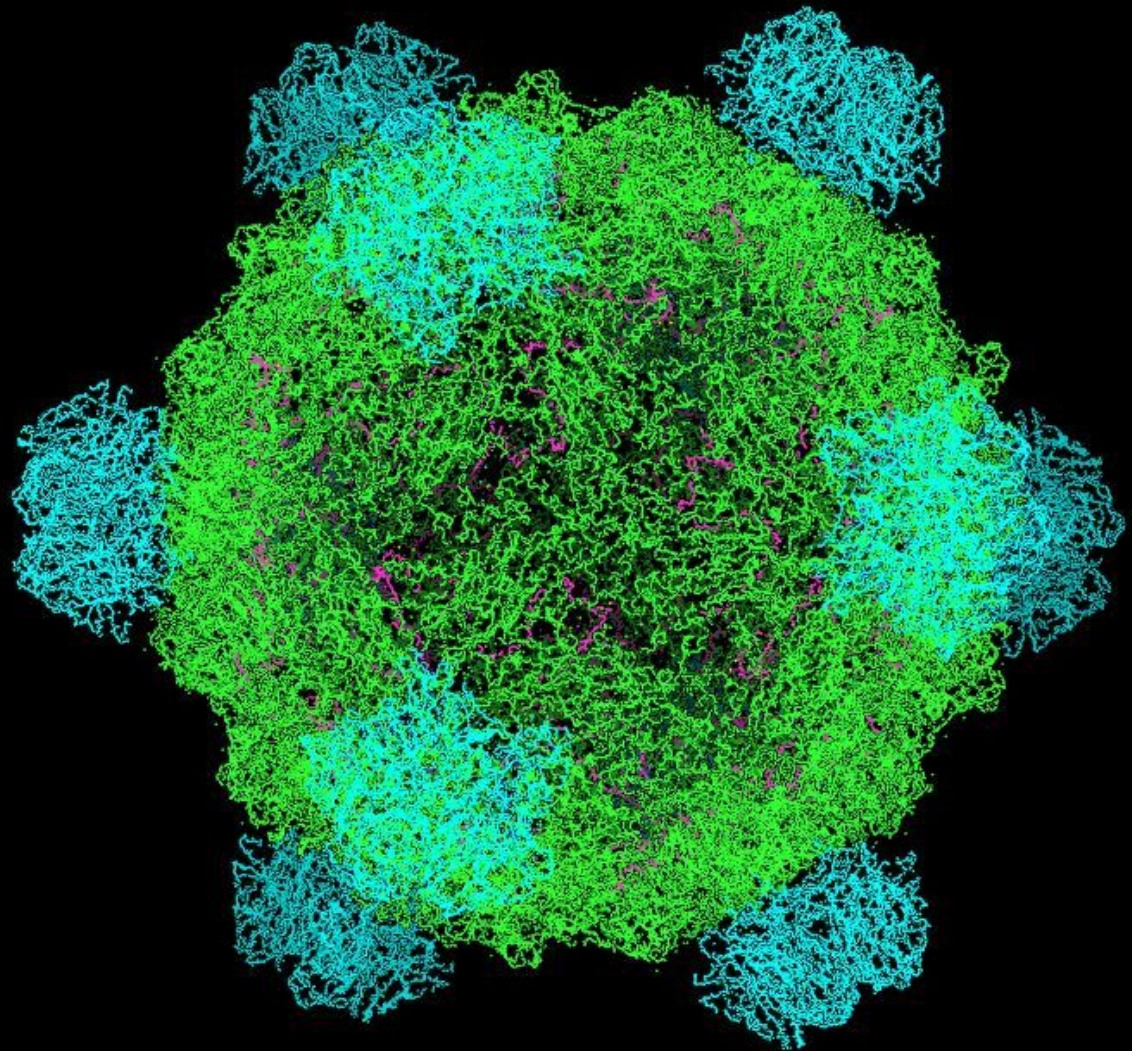
```
if (!glucosePresent && lactosePresent)  
  
    convertLactoseToGlucose();
```

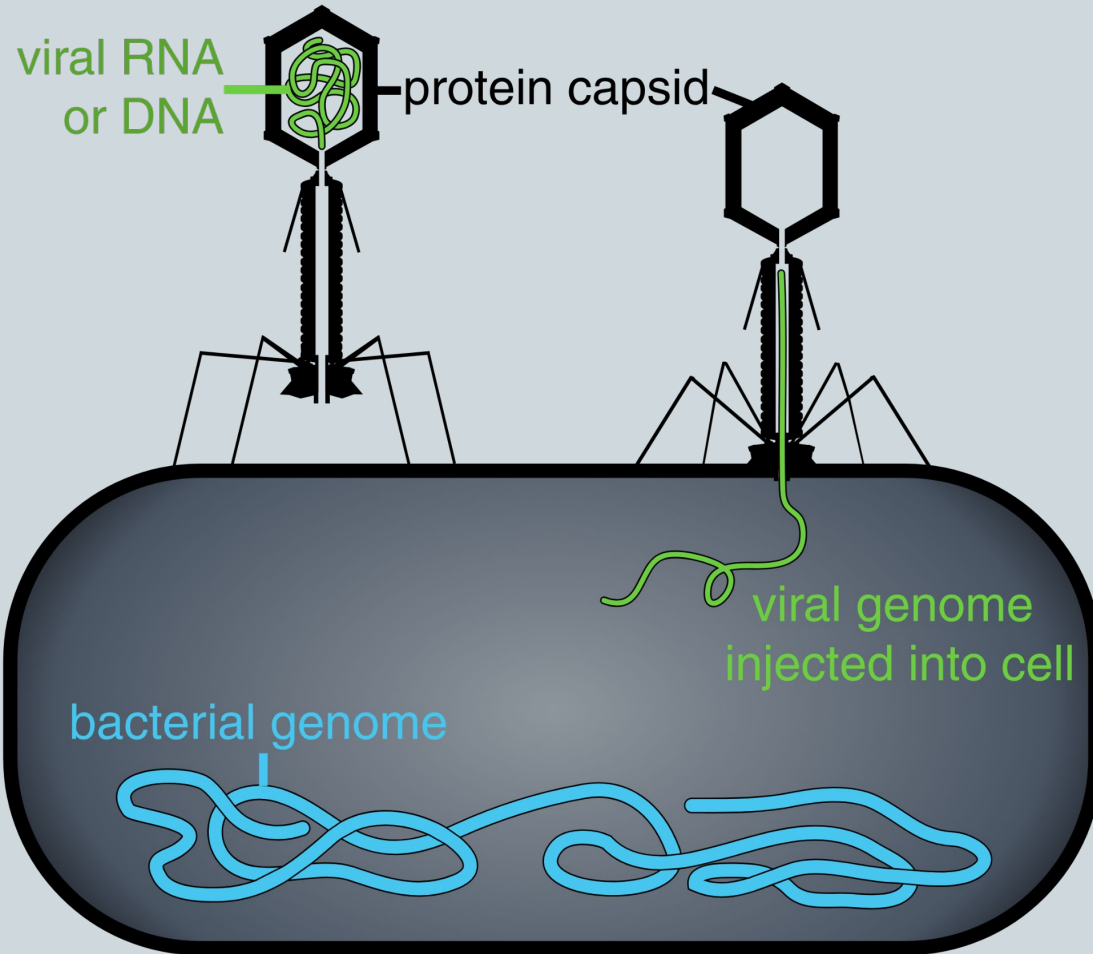
The *lac* operon:



Viruses: the ultimate hackers

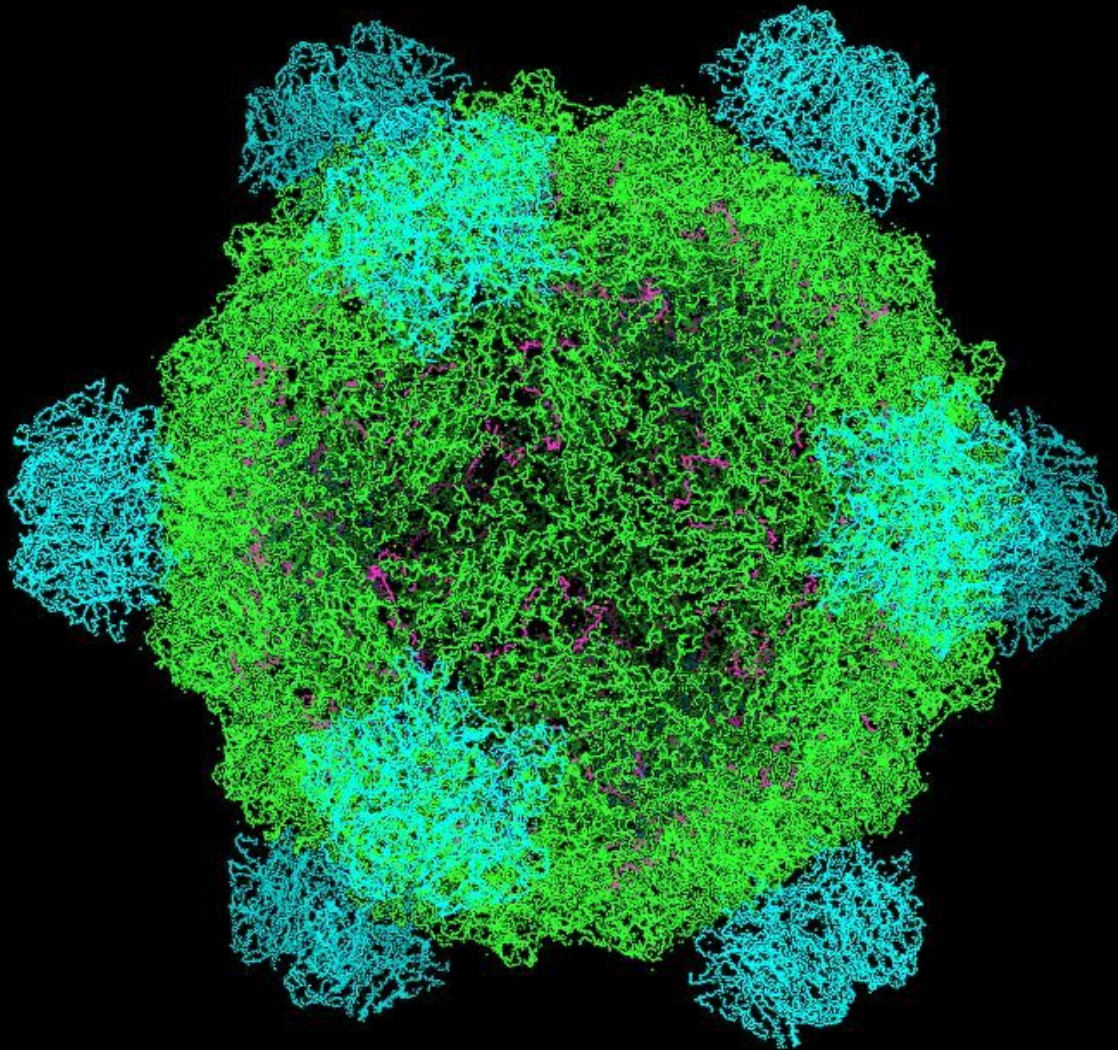
“Shell code”





“Does not end well...”

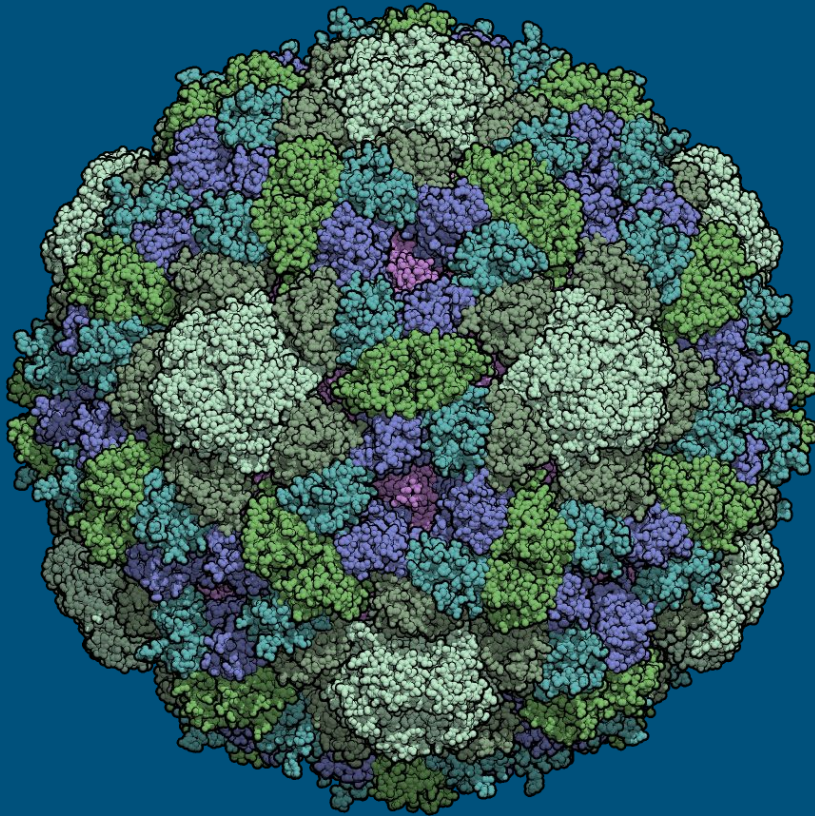




Φ X174 infects *e* coli.

Having **less DNA** means faster copying, smaller virion, **evading defences**

“Shell code shaping”



Φ X174 has 5386 DNA
letters

Enough for $5386/3 = 1795$
amino acids, TOPS

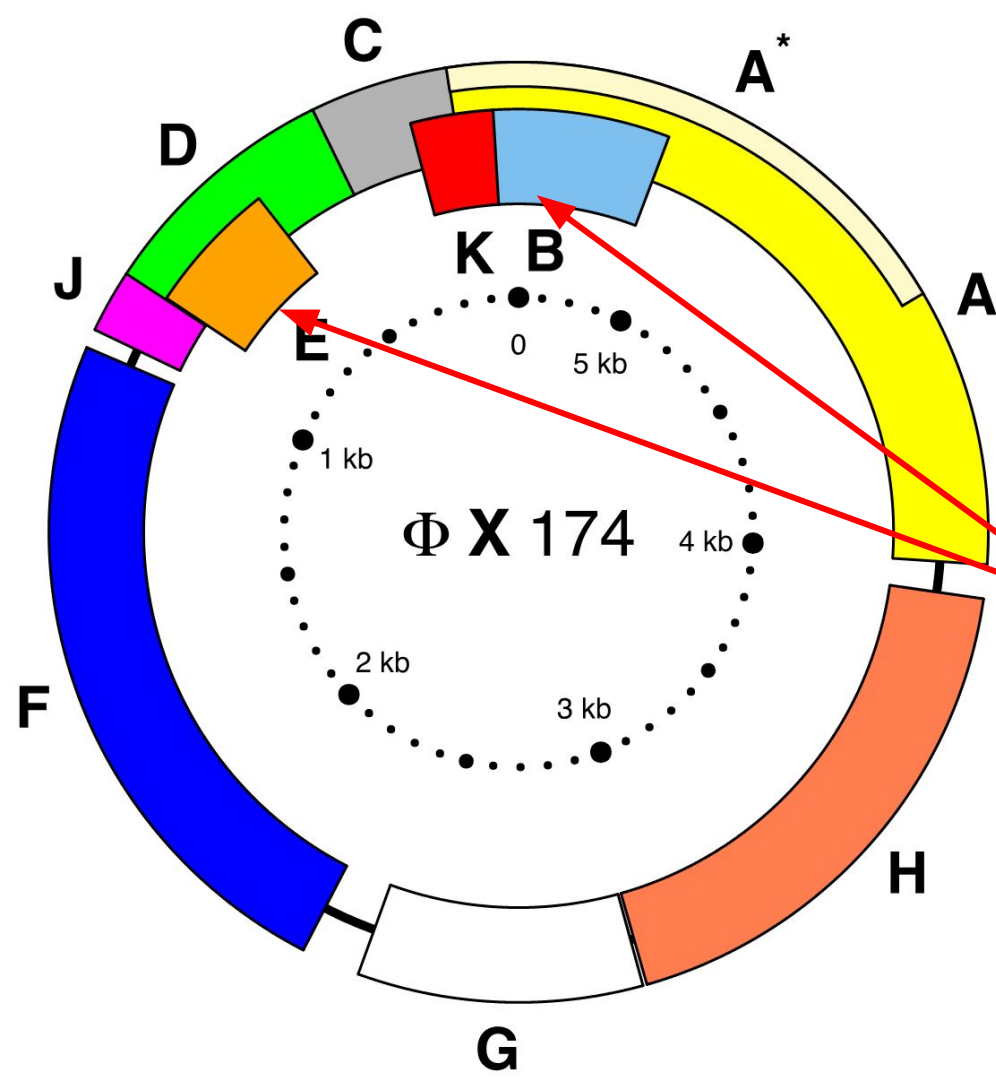
... it has **2334 amino
acids!**

?????

```
>|c1|NC_001422.1_cds_NP_040706.1_4 [protein=K]
ATG AGT CGA AAA ATT ATC TTG ATA AAG CAG GAA TTA CTA CTG CTT GTT TAC GAA TTA AAT CGA AGT GGA
CTG CTG GCG GAA AAT GAG AAA ATT CCA CCT ATC CTT GCG CAG CTC GAG AAG CTC TTA CTT TGC GAC CTT
TCG CCA TCA ACT AAC GAT TCT GTC AAA AAC TGA
```

0123456789

0123456789



OVERLAPPING
GENES!!!

Even more DNA!!

Tomorrow, Sunday, 20:00, Andromeda (this) tent:

Reverse Engineering Life: What we can learn from the DNA

Monday, 15:00, Cassiopeia:

Afterparty for the talks, more Q&A and some bonus content.

A brief 2025 recap DNA: the code of life

