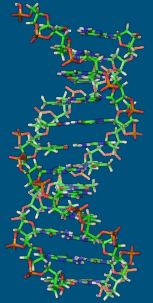
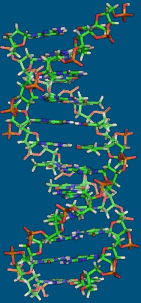


A brief 2025 recap DNA: the code of life



<https://berthub.eu/dna> <https://berthub.eu/articles/posts/mch-dna-and-gps-gnss-talks/>

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>



→ C www.nature.com/ismej/journal/v10/n1/full/ismej2015107a.html

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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}

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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

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-

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 Previous | Next
 Table of contents
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 Introduction
 Materials and methods
 Results and Discussion
 Conflict of interest
 References
 Acknowledgements
 Figures and Tables
 Supplementary info

TU Delft Delft University of Technology

<https://www.nature.com/articles/ismej2015107>

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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](#)

6123 Accesses | **13** Citations | **4** Altmetric | [Metrics](#)

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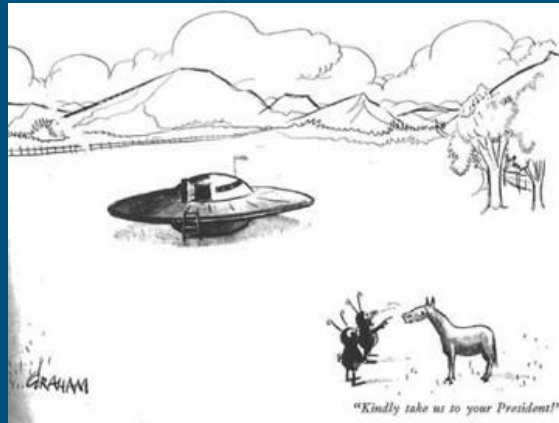
Sections [Figures](#)

- [Abstract](#)
- [Background & Summary](#)
- [Methods](#)
- [Data Records](#)

<https://skewdb.org/>

“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.”



<https://jsomers.net/i-should-have-loved-biology/>

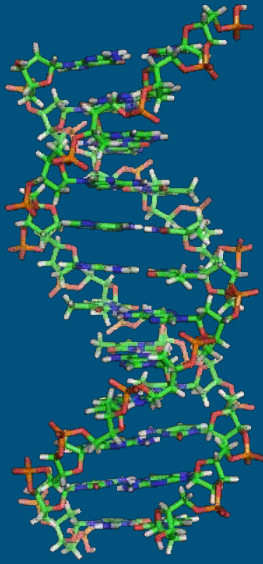


Although...

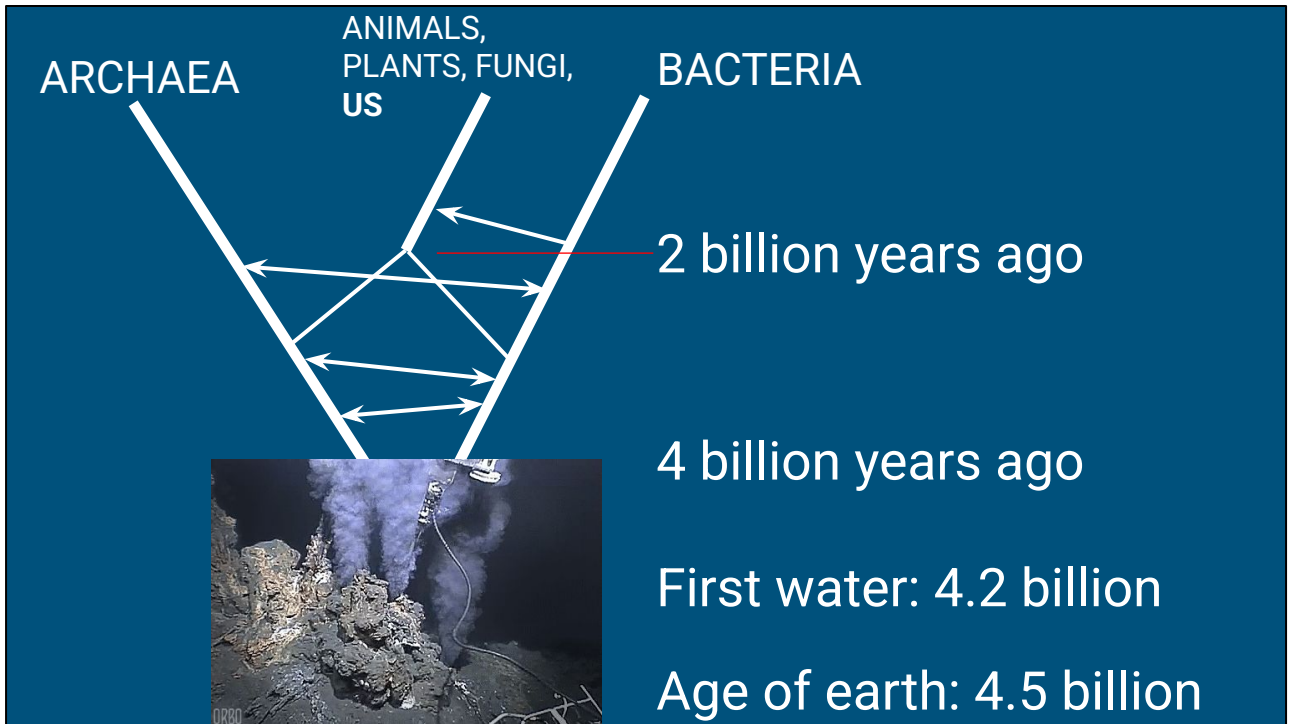
© NASA (oddly enough)

[https://en.wikipedia.org/wiki/Little_green_men#/media/File:Mars_New_Year's_Celebration_\(201506200007HQ\)_cropped.jpg](https://en.wikipedia.org/wiki/Little_green_men#/media/File:Mars_New_Year's_Celebration_(201506200007HQ)_cropped.jpg)

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



<https://giphy.com/gifs/sea-vents-hydrothermal-1bTEQnjArFBy8>

<https://en.wikipedia.org/wiki/Archaea>

https://en.wikipedia.org/wiki/Three-domain_system

Basics: Each nucleotide is 2 (arbitrary) bits

A 00

C 01

G 10

T 11



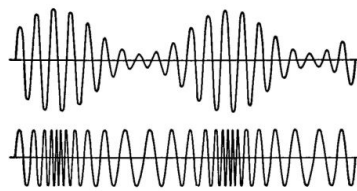
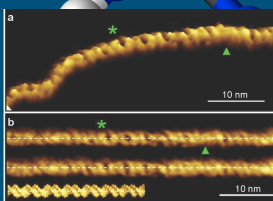
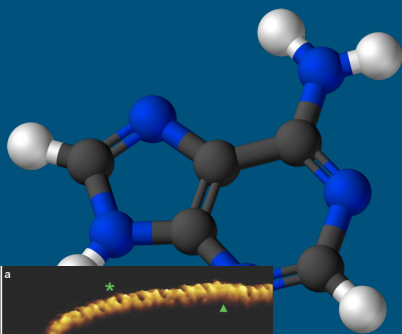
Basics: DNA

A

C

G

T

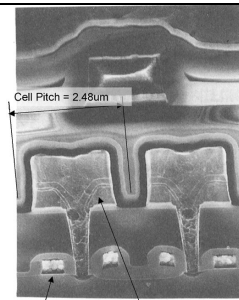


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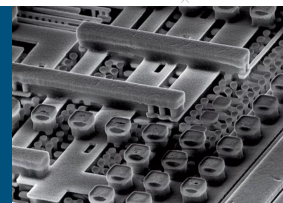
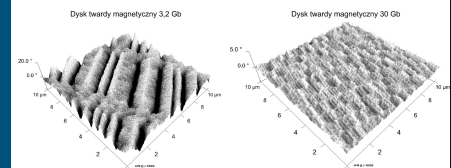
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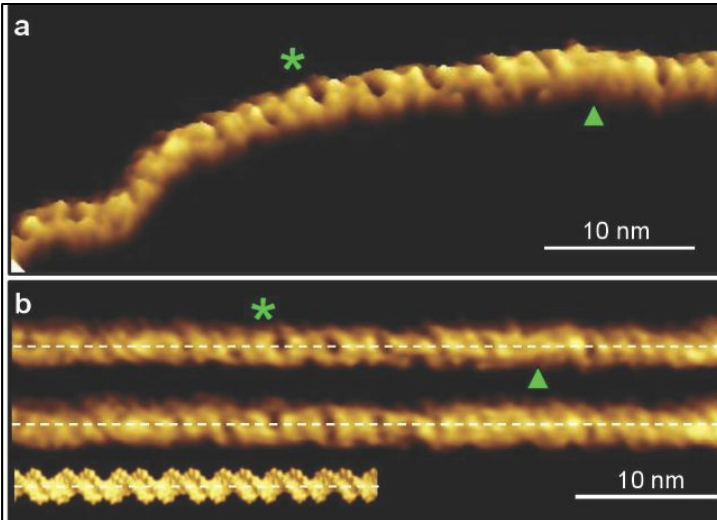
10

11



MAGNETIC FORCE MICROSCOPY





DNA is very much like tape

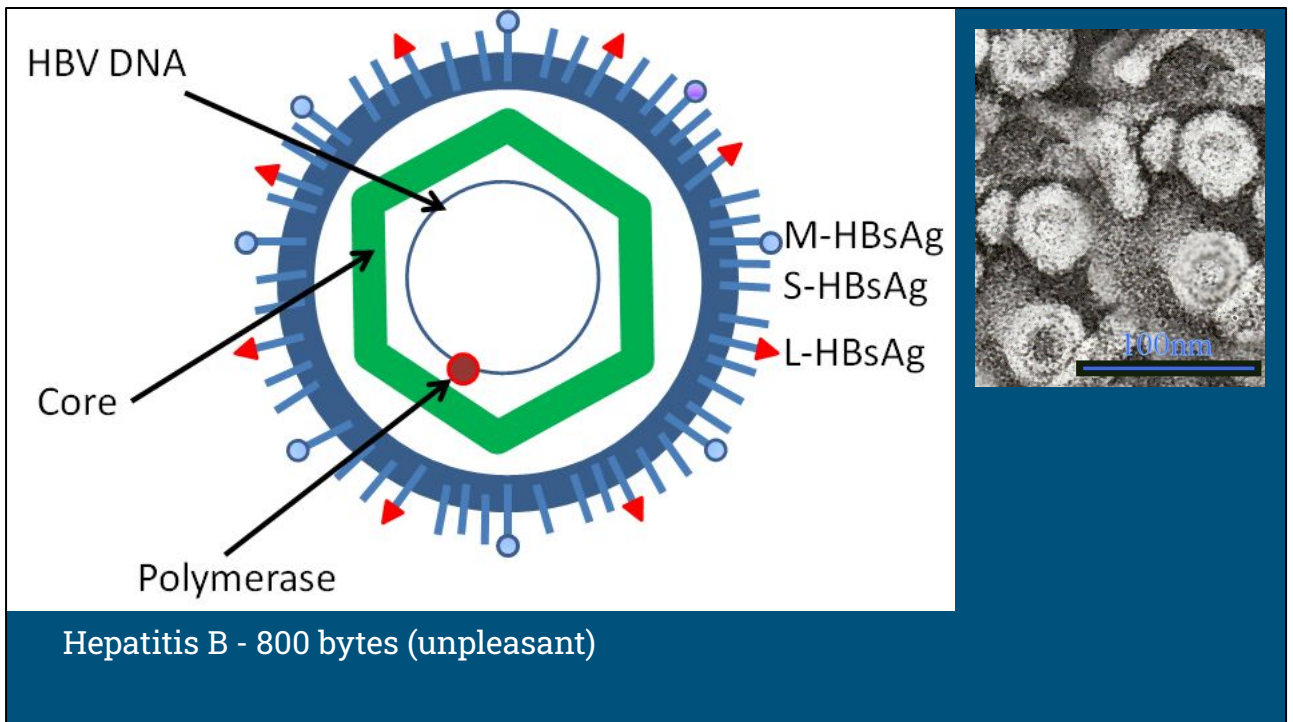
Sometimes circular tape - no beginning, no end!

No addressing! No alignment!

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

It IS however **content addressable!**

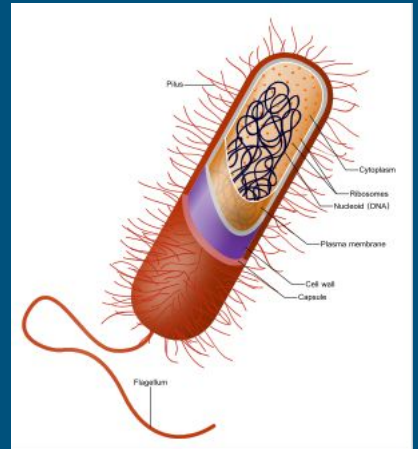
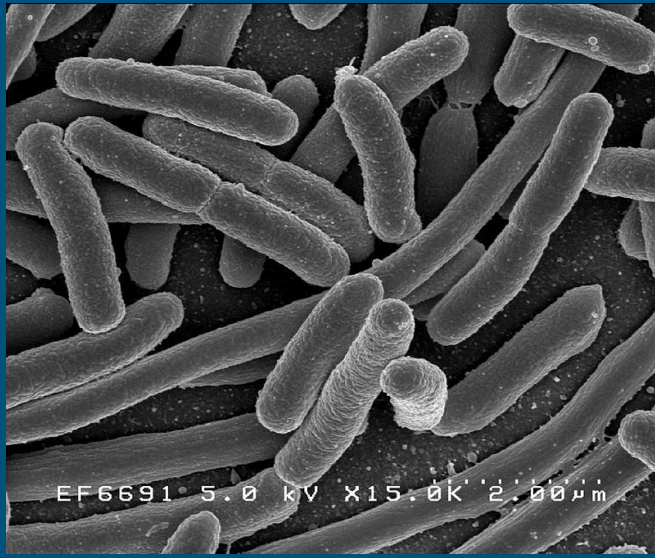
And it has FRAMING challenges possibilities



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<https://commons.wikimedia.org/w/index.php?curid=24121844>
By GrahamColm at English Wikipedia, CC BY 3.0,
<https://commons.wikimedia.org/w/index.php?curid=6032684>
https://en.wikipedia.org/wiki/Hepatitis_B_virus

ctccactgccttcaccaagctctgcaggatcccaaagtcaggggtctgtattttctgctgggtccagttcaggaacagtaaacctgctccgaatattgcctctcacatc
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aa

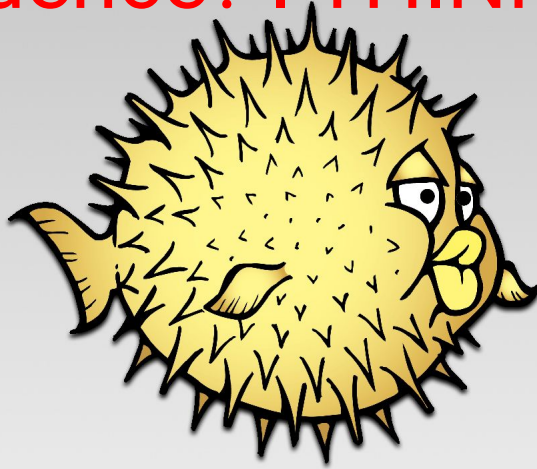
All of Hepatitis-B - 800 bytes



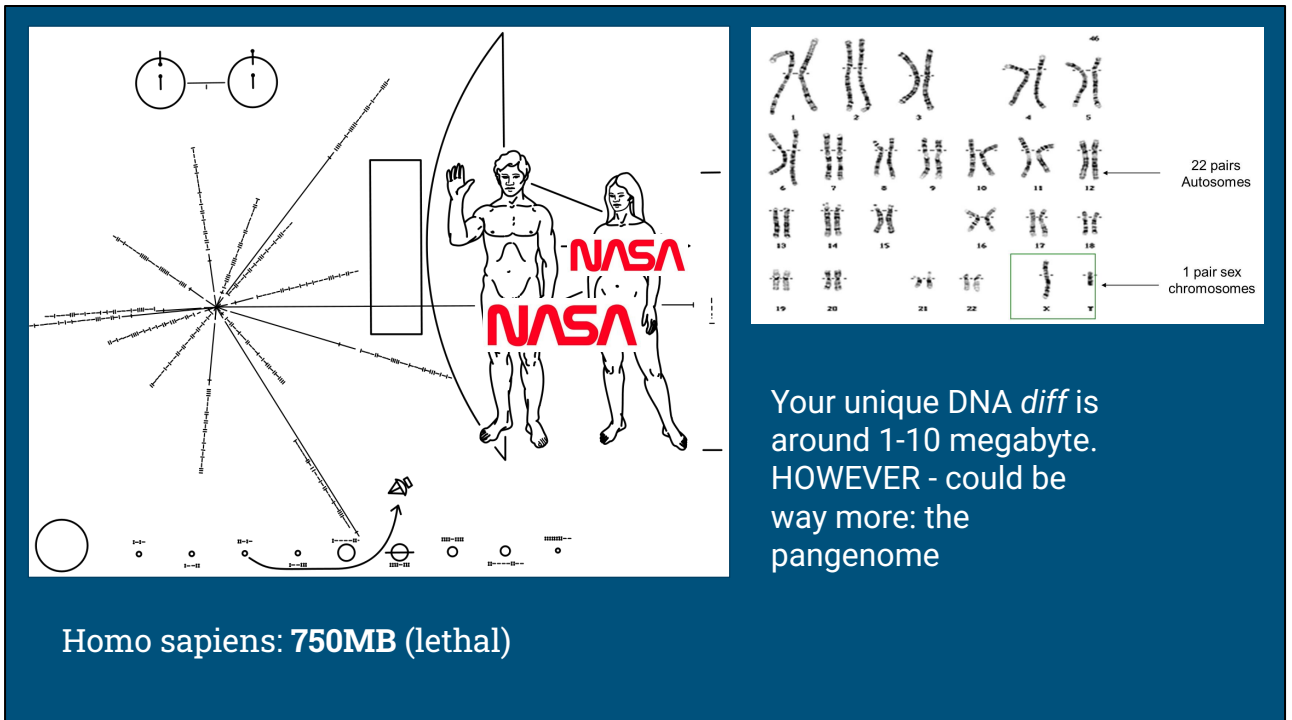
E. Coli: 750KB (can be good, can be unpleasant)

By Credit: Rocky Mountain Laboratories, NIAID, NIH - NIAID: These high-resolution (300 dpi) images may be downloaded directly from this site. All the images, except specified ones from the World Health Organization (WHO), are in the public domain. For the public domain images, there is no copyright, no permission required, and no charge for their use., Public Domain,
<https://commons.wikimedia.org/w/index.php?curid=104228>

Coincidence? I THINK NOT!



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



Source: NASA

We find that a typical genome differs from the reference human genome at 4.1 million to 5.0 million sites. Although >99.9% of variants consist of SNPs and short indels, [structural variants](#) affect more bases: the typical genome contains an estimated 2,100 to 2,500 structural variants (~1,000 large deletions, ~160 copy-number variants, ~915 Alu insertions, ~128 L1 insertions, ~51 SVA insertions, ~4 NUMTs, and ~10 inversions), affecting ~20 million bases of sequence.



Paris Japonica: 37.5GB (quite pleasant)



Marbled Lungfish: 33GB

By OpenCage = User:OpenCage - http://opencage.info/pics.e/large_11454.asp, CC BY 2.5, <https://commons.wikimedia.org/w/index.php?curid=11750275>

But is life REALLY digital?

Science

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RESEARCH ARTICLE

Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome

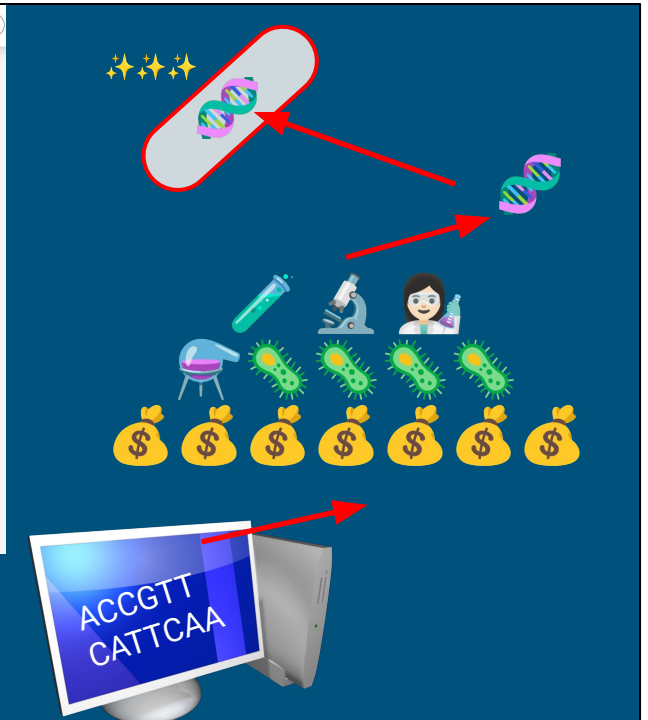
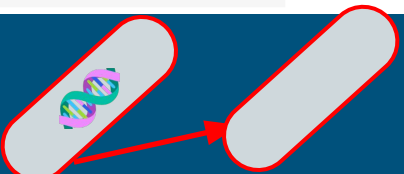
DANIEL G. GIBSON, JOHN I. GLASS, CAROLE L. ARTIGUE, VLADIMIR N. NODKOV, RAYJUAN CHUANG, MIKKEL A. ALDRIDGE, GWYNETH A. BENDERS, MICHAEL G. MONTAGUE, LI MA, [...] AND J. CRAIG VENTER +14 authors [Authors Info & Affiliations](#)

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

62,812 1,912

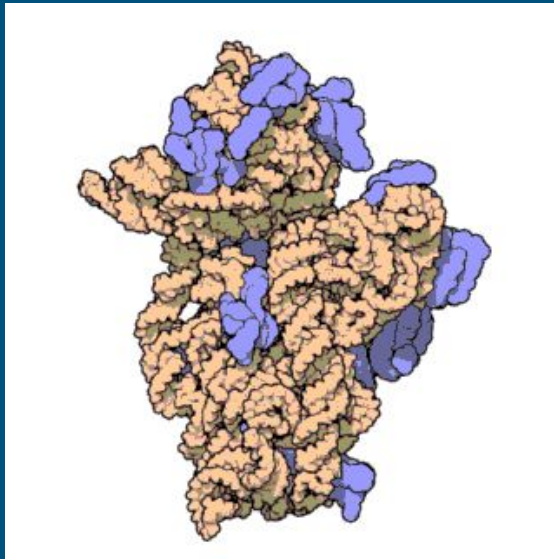
Let There Be Life

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.



<https://www.science.org/doi/10.1126/science.1190719>

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!

By Animation by David S. Goodsell, RCSB Protein Data Bank - Molecule of the Month
at the RCSB Protein Data Bank, Public Domain,
<https://commons.wikimedia.org/w/index.php?curid=2839678>

The Central Dogma

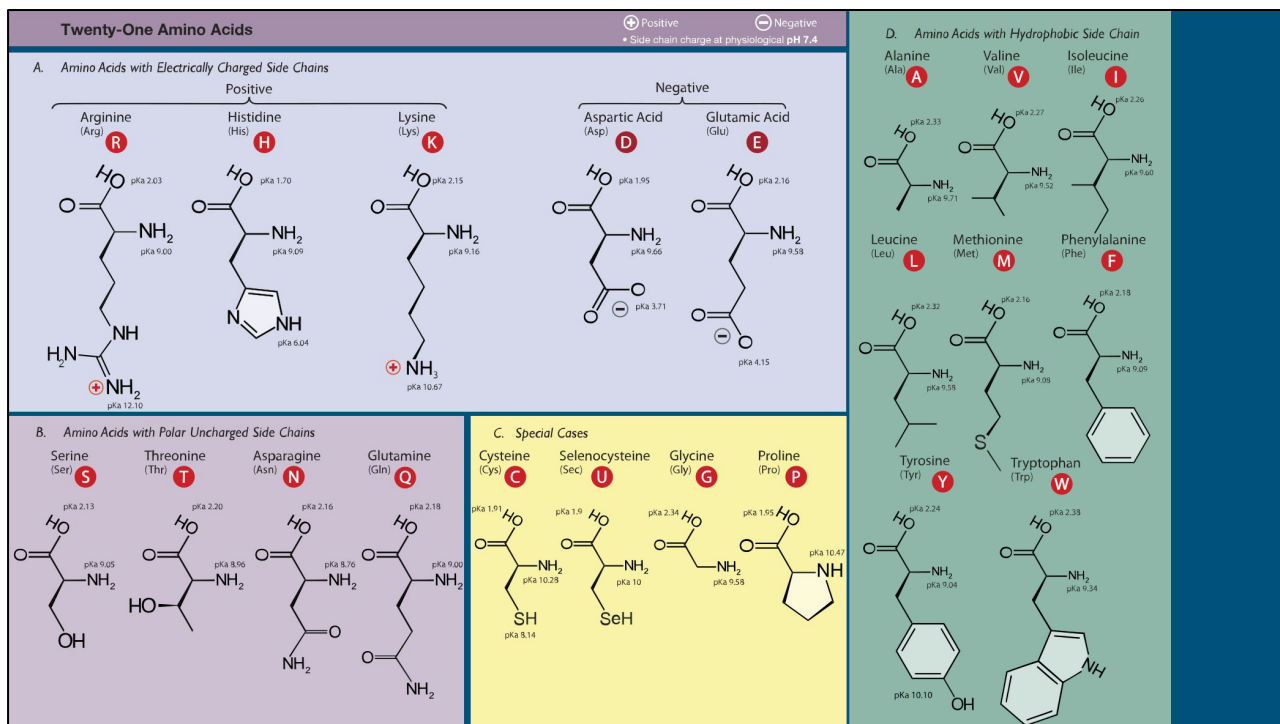
Long term storage: **DNA** (*/dev/sda*)

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

RNA converts to: **Proteins**

Proteins: **Sense and Do**





Modified from https://commons.wikimedia.org/wiki/File:Amino_Acids.svg

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

Multi-billion
year old table!

Multiple
codons for
same amino
acids

This allows for
dialects and
shaping DNA

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

```
gtgAGTGCAGGCGTGATAACCGGCGTATTGCTGGTGTTTTTATTACTGGGTATCTGGTTTATGCCCTGA  
TCAATGCGGAGGCGTTTctga
```

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

```
gtg ACT 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
```

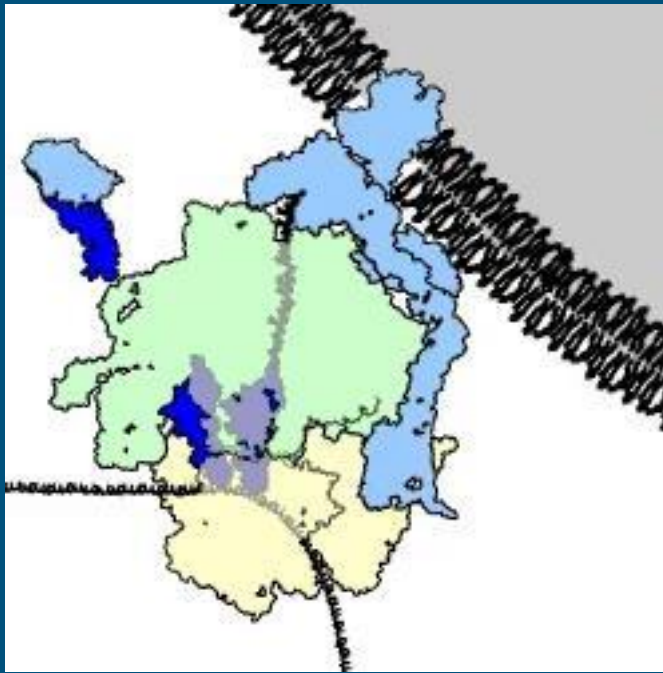
```
>gnl|ECOLI|MONOMER0-12 gn=kdpF K+ transporting P-type ATPase subunit KdpF  
(complement(728732..728821)) Escherichia coli K-12 substr. MG1655
```

```
MSAGVITGVLLVFLLLGYLVYALINAEAF<EOP>
```

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

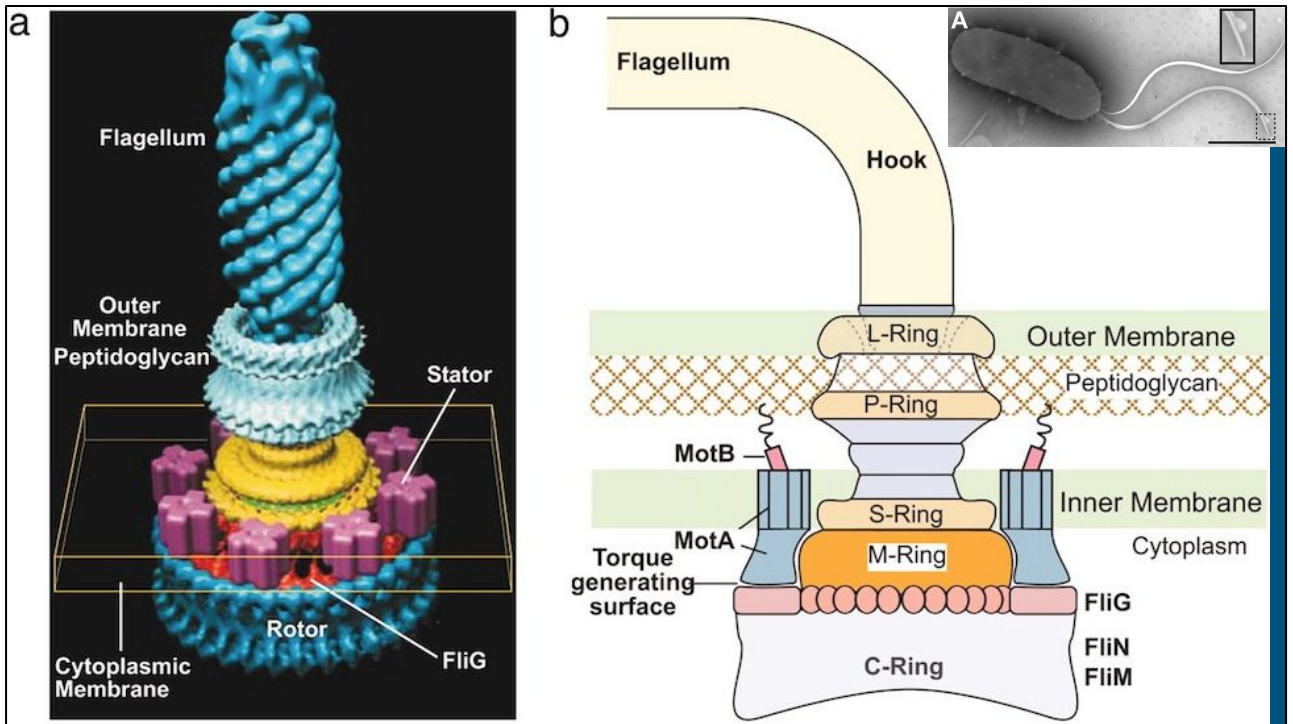


<https://www.rcsb.org/structure/6HRB>



<https://commons.wikimedia.org/w/index.php?curid=8287100>

https://upload.wikimedia.org/wikipedia/commons/9/94/Protein_translation.gif

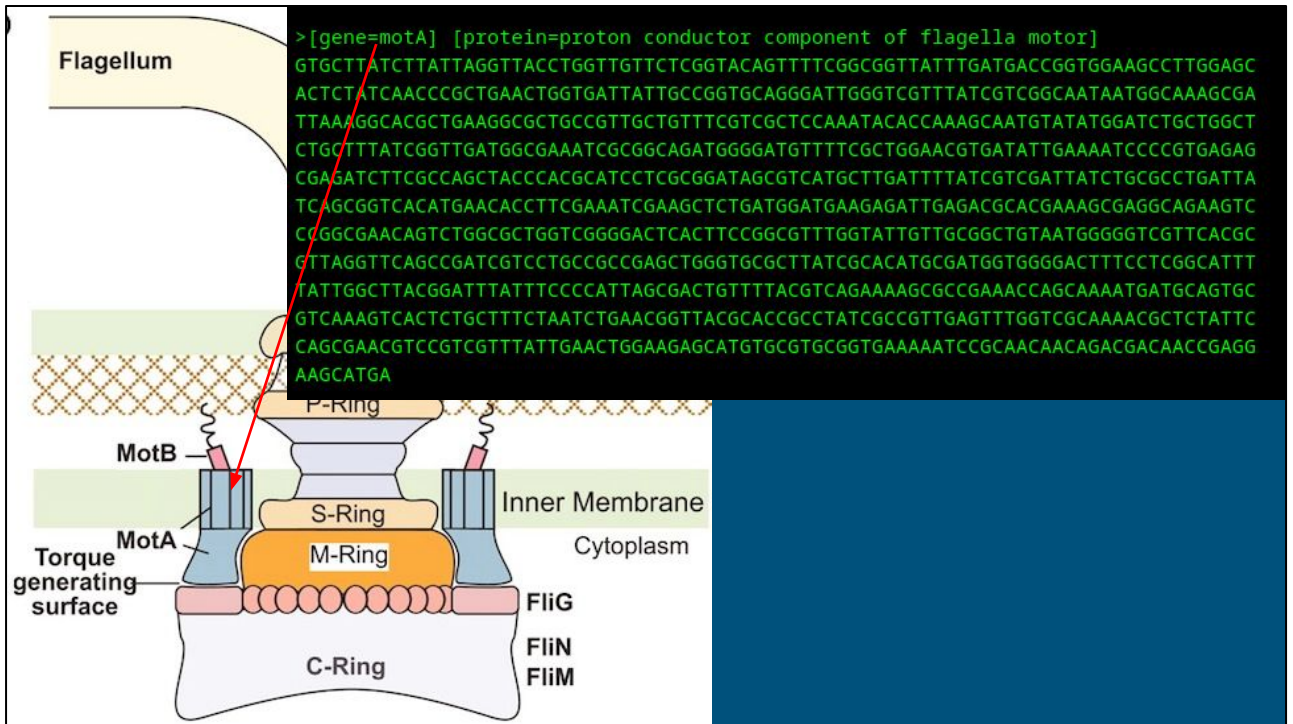


Credit: David DeRosie

<https://www.thunderbolts.info/wp/2013/07/19/flagellar-motors/>

<https://elifesciences.org/articles/01579> Caitlin A Brennan, Jason R Hunt, Natacha Kremer, Benjamin C Krasity, Michael A Apicella, Margaret J McFall-Ngai, Edward G Ruby (2014) A model symbiosis reveals a role for sheathed-flagellum rotation in the release of immunogenic lipopolysaccharide *eLife* 3:e01579

<https://doi.org/>



Credit: David DeRosie

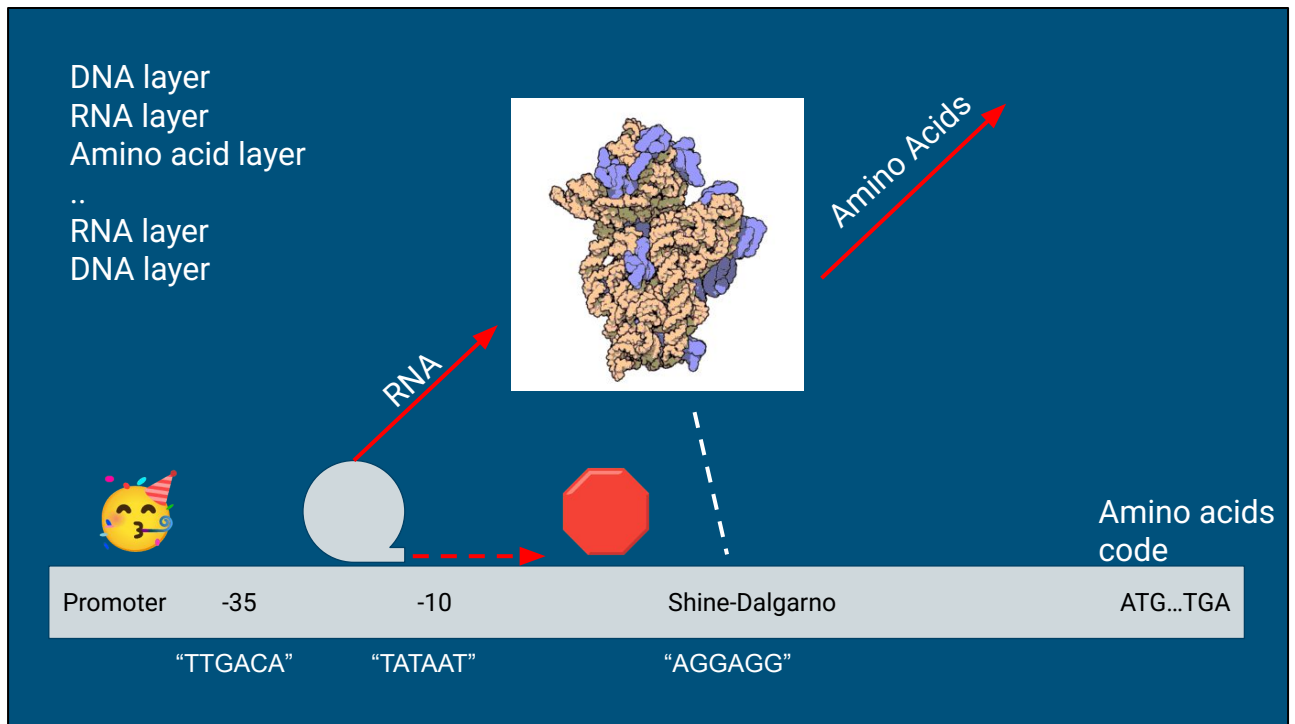
<https://www.thunderbolts.info/wp/2013/07/19/flagellar-motors/>



If you 3D print this model yourself:

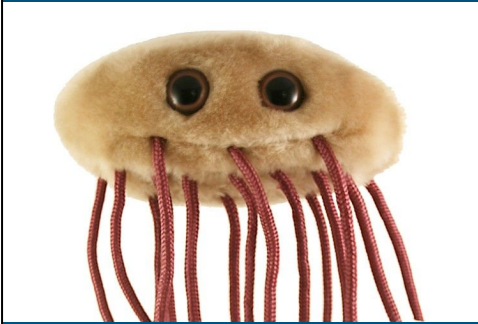
- Your resolution is like 10 million times too coarse
- Your flagellar motor does not actually work
- It looks remarkably silly!
('honestly, this is for science!')

Gene control & how it hangs together



<https://www.biorxiv.org/content/10.1101/2025.01.23.634641v2.full>

E. coli

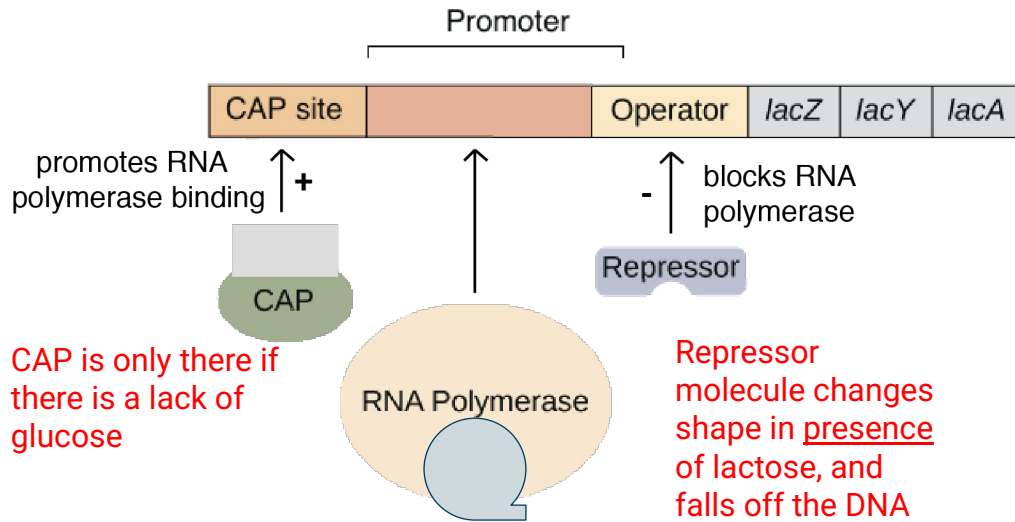


- Needs power to run
 - 0.5pW
- Loves glucose
- Can run on **lactose** if it must
 - Through conversion
 - Less efficient
- Algorithm required:

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

<https://www.khanacademy.org/science/biology/gene-regulation/gene-regulation-in-bacteria/a/the-lac-operon>

The *lac* operon:

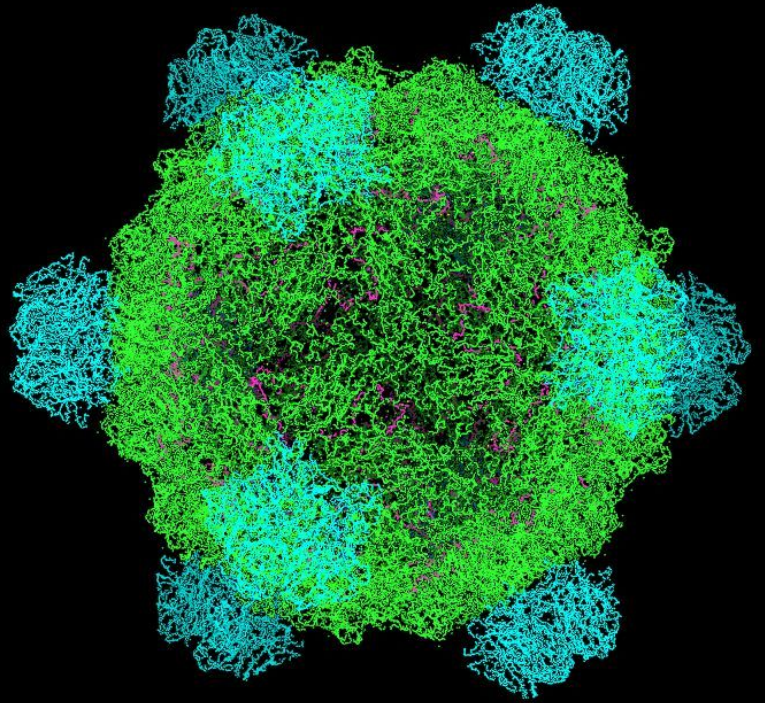


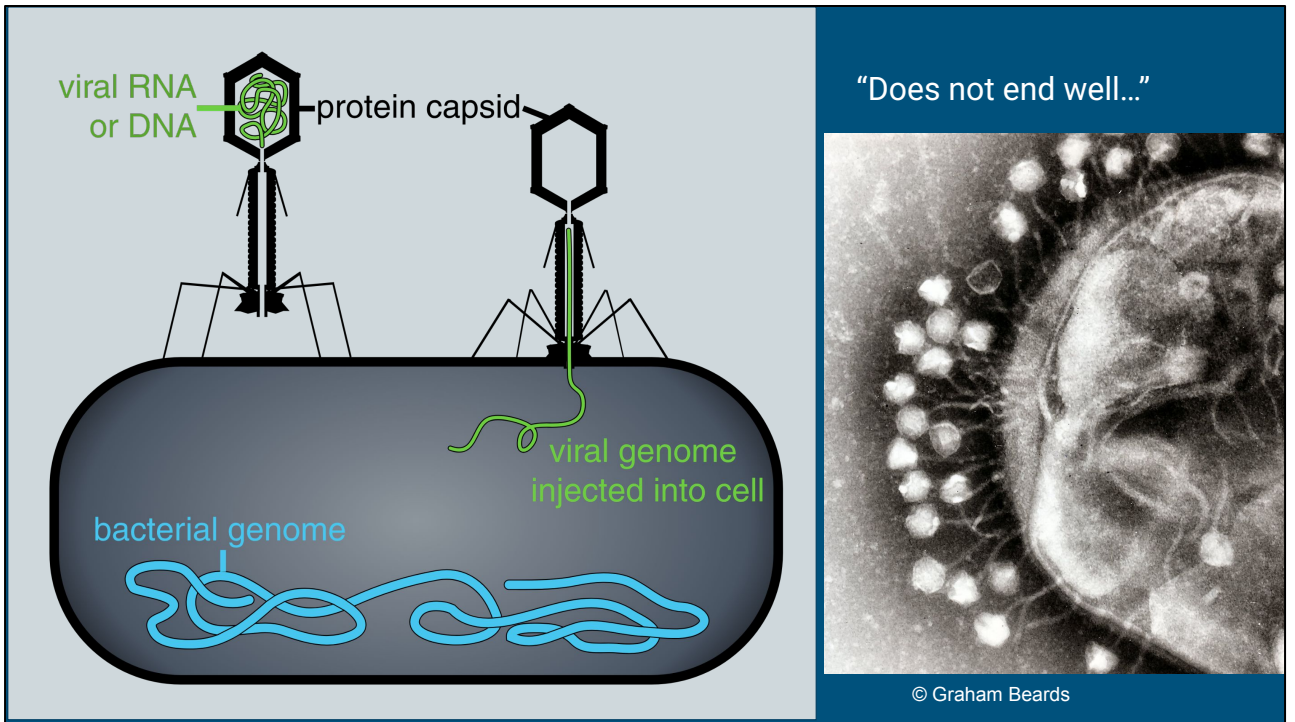
<https://biocyc.org/ECOLI/NEW-IMAGE?type=LOCUS-POSITION&object=G6201&chromosome=COLI-K12>

https://en.wikipedia.org/wiki/Lac_operon

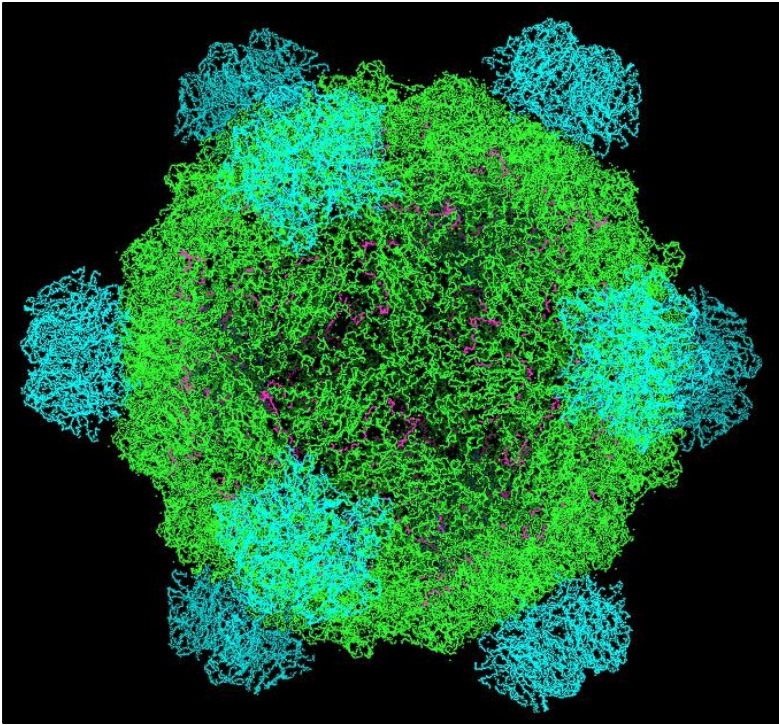
Viruses: the ultimate hackers

"Shell code"





By Professor Graham Beards - en:Image:Phage.jpg, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=5035798>
[https://commons.wikimedia.org/wiki/File:Phage_injecting_its_genome_into_bacteria.s
vg](https://commons.wikimedia.org/wiki/File:Phage_injecting_its_genome_into_bacteria.svg)

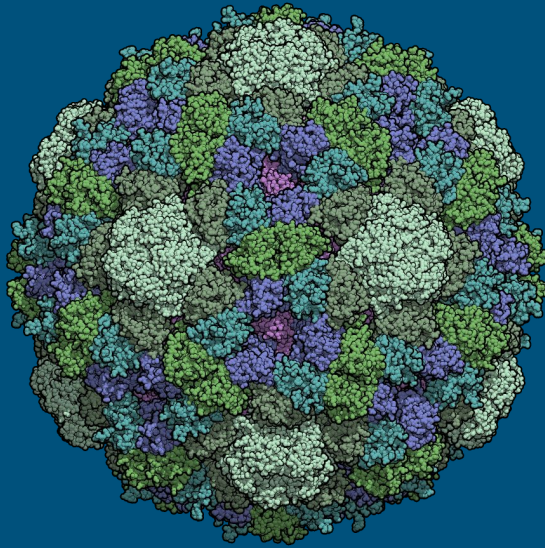


Φ X174 infects e coli.

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

“Shell code shaping”

By Fdardel - Own work, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=6296568>



ΦX174 has 5386 DNA letters

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

... it has 2334 amino acids!

?????

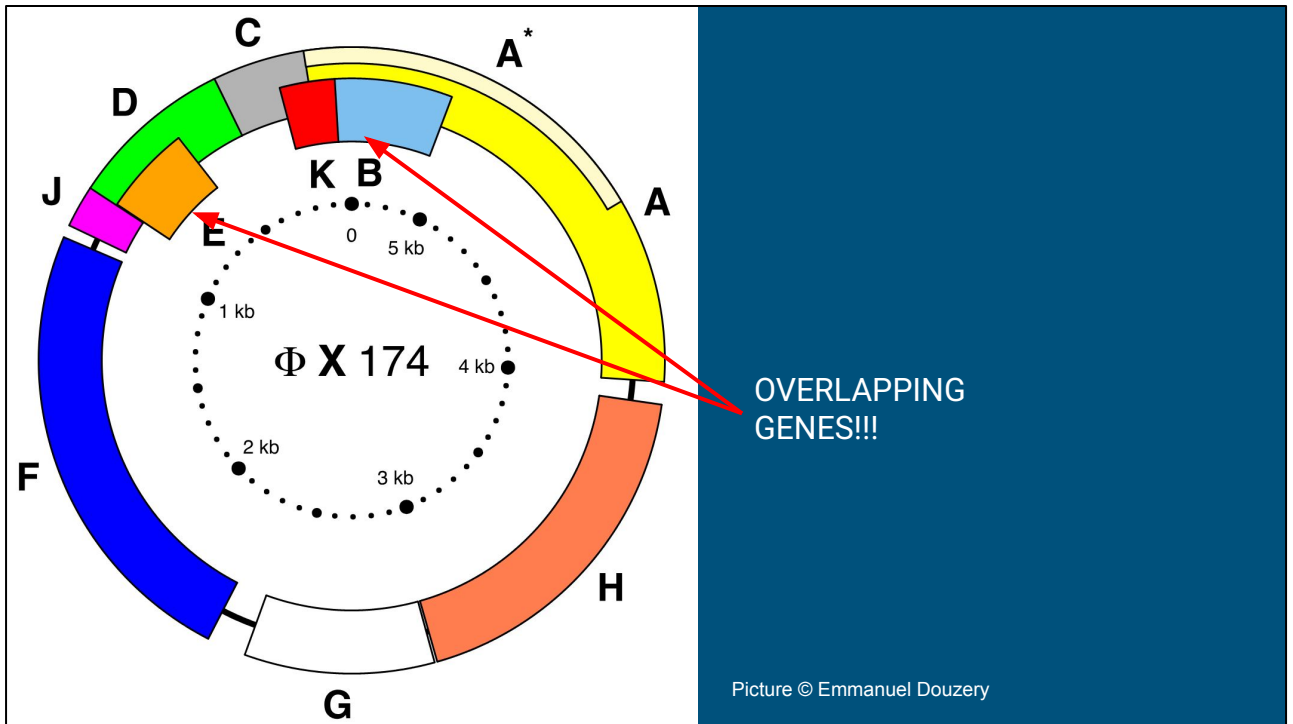
https://commons.wikimedia.org/wiki/File:Phi_X_174_pro_capsid.png

>lcl|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



https://en.wikipedia.org/wiki/Overlapping_gene

https://en.wikipedia.org/wiki/Phi_X_174#/media/File:Genome_map_of_the_bacteriophage_%CE%A6X174_showing_overlapping_genes.svg

By This picture is a work by Emmanuel Douzery. Please credit this with: Picture : Emmanuel Douzery in the immediate vicinity of the picture. If you use one of my works, please email me (account needed) or leave me a short message on my discussion page. It would be greatly appreciated! Do not copy this picture illegally by ignoring the terms of the license below, as it is not in the public domain. If you would like special permission to use, license, or purchase the picture, please contact me to negotiate terms. - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=46682223>

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

