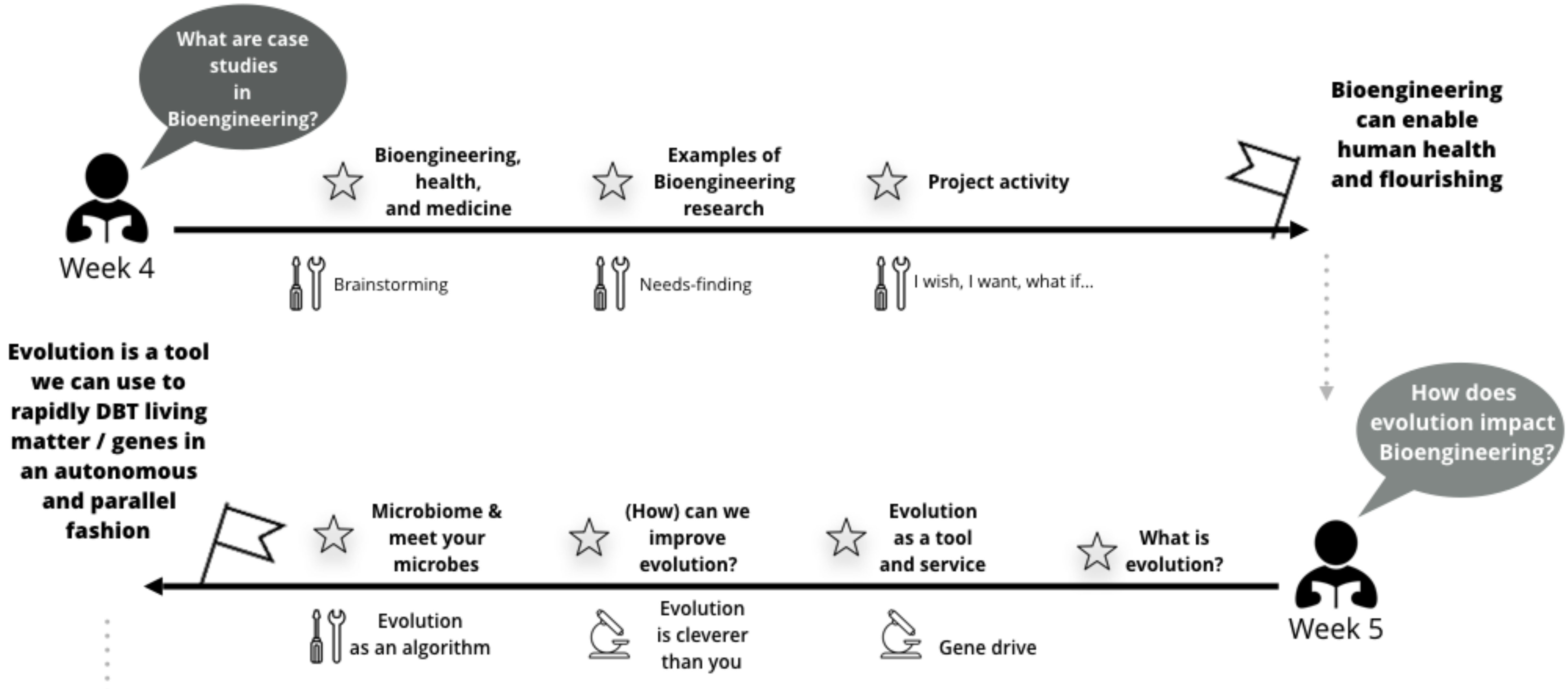
What is evolution from an engineering perspective?
&
How to use & change evolution?

Week - 5

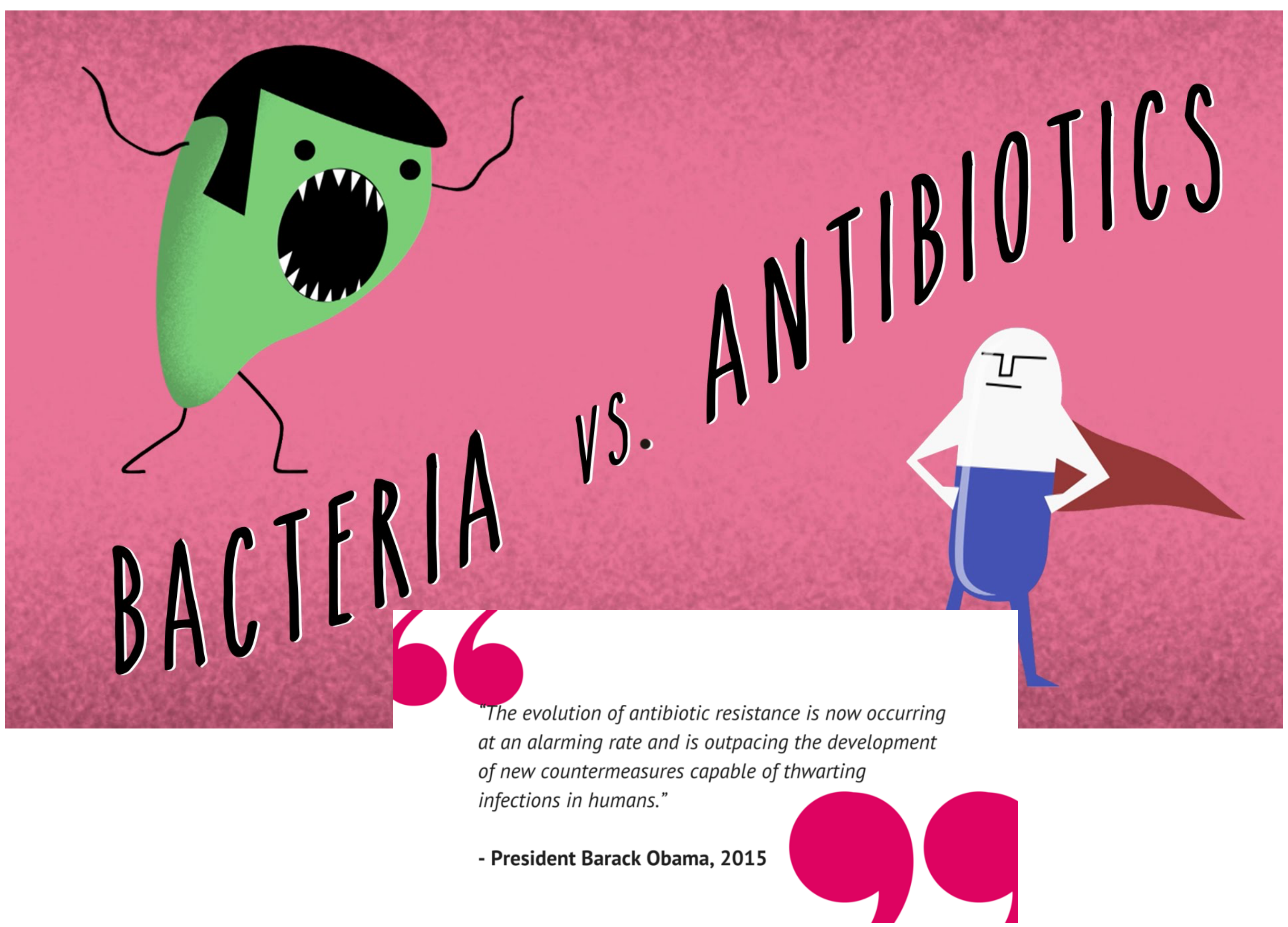
Where are we in the course?

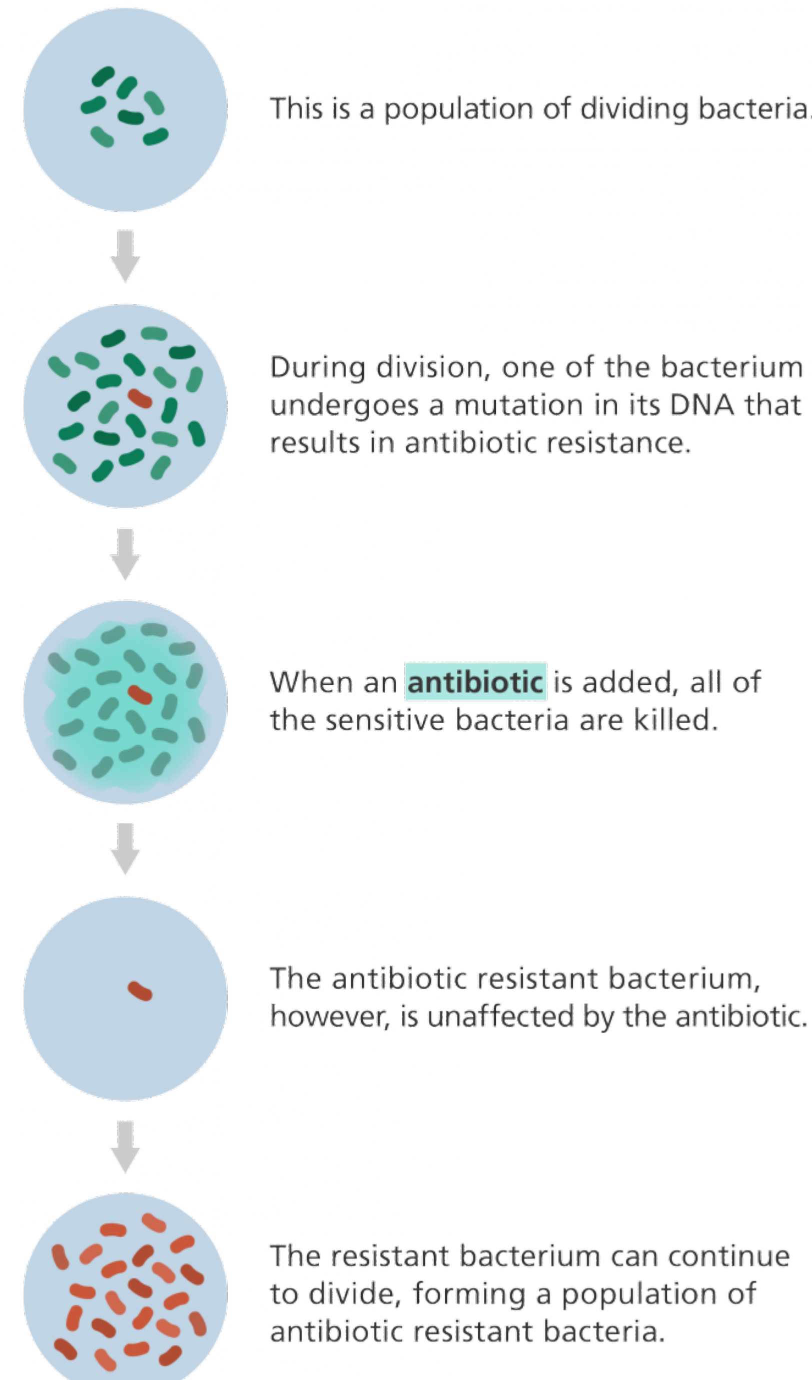


Drug Resistance (via evolution)

1. Antibiotic resistance

2. Malaria parasites resistance to artemisinin





Source

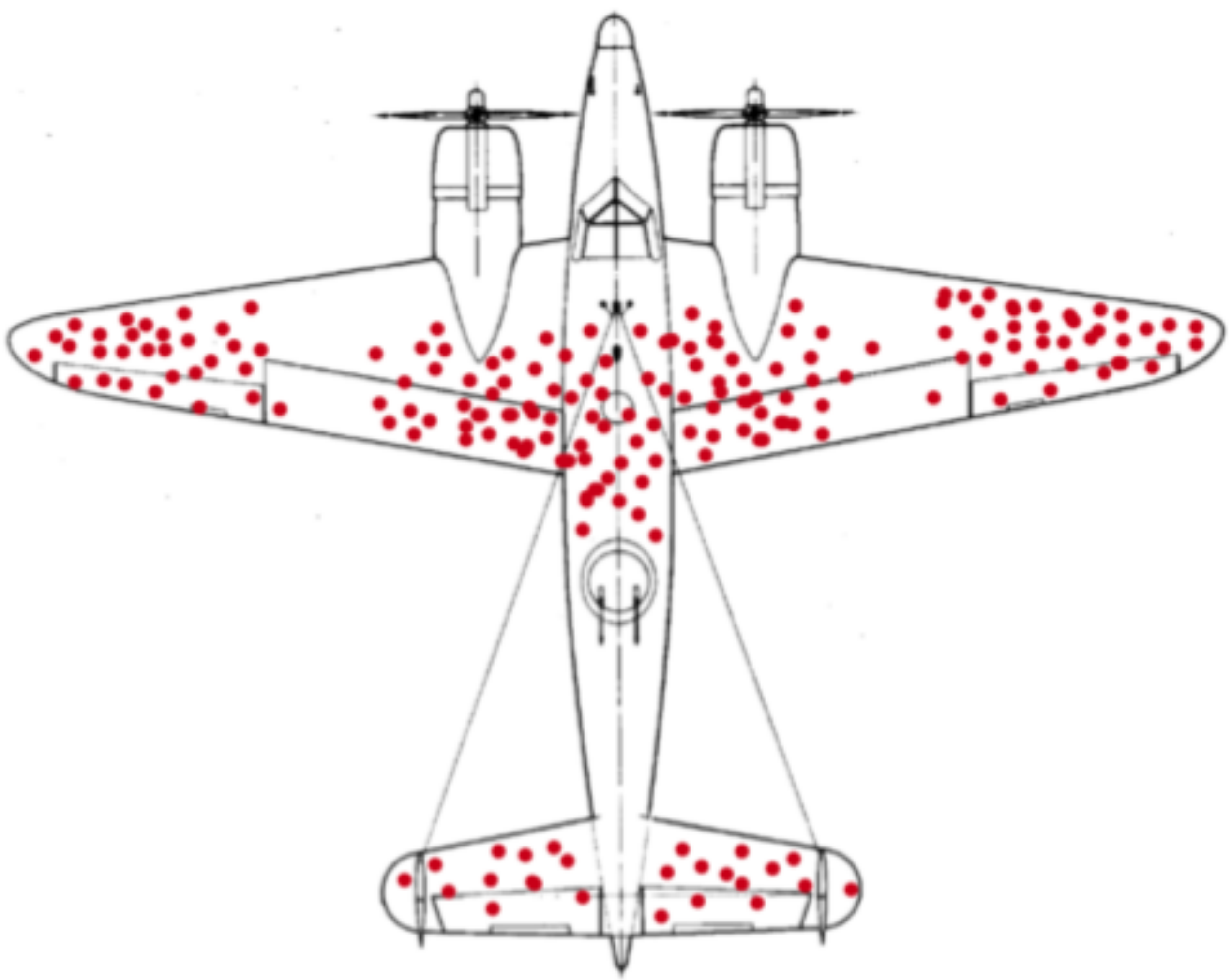
Our goals for Week-5:

- Goal-1: Describe **evolution** as an **algorithm** that follows a set of rules.

- Goal-2: **Utilize evolution** as an algorithm. "Evolution, at your service!": This robust algorithm is a service that can be deployed in diverse contexts.

- Goal-3: Describe the **limitations** when used as a service, and begin to describe what evolution could look like in the future ("**Evolution 2.0**").

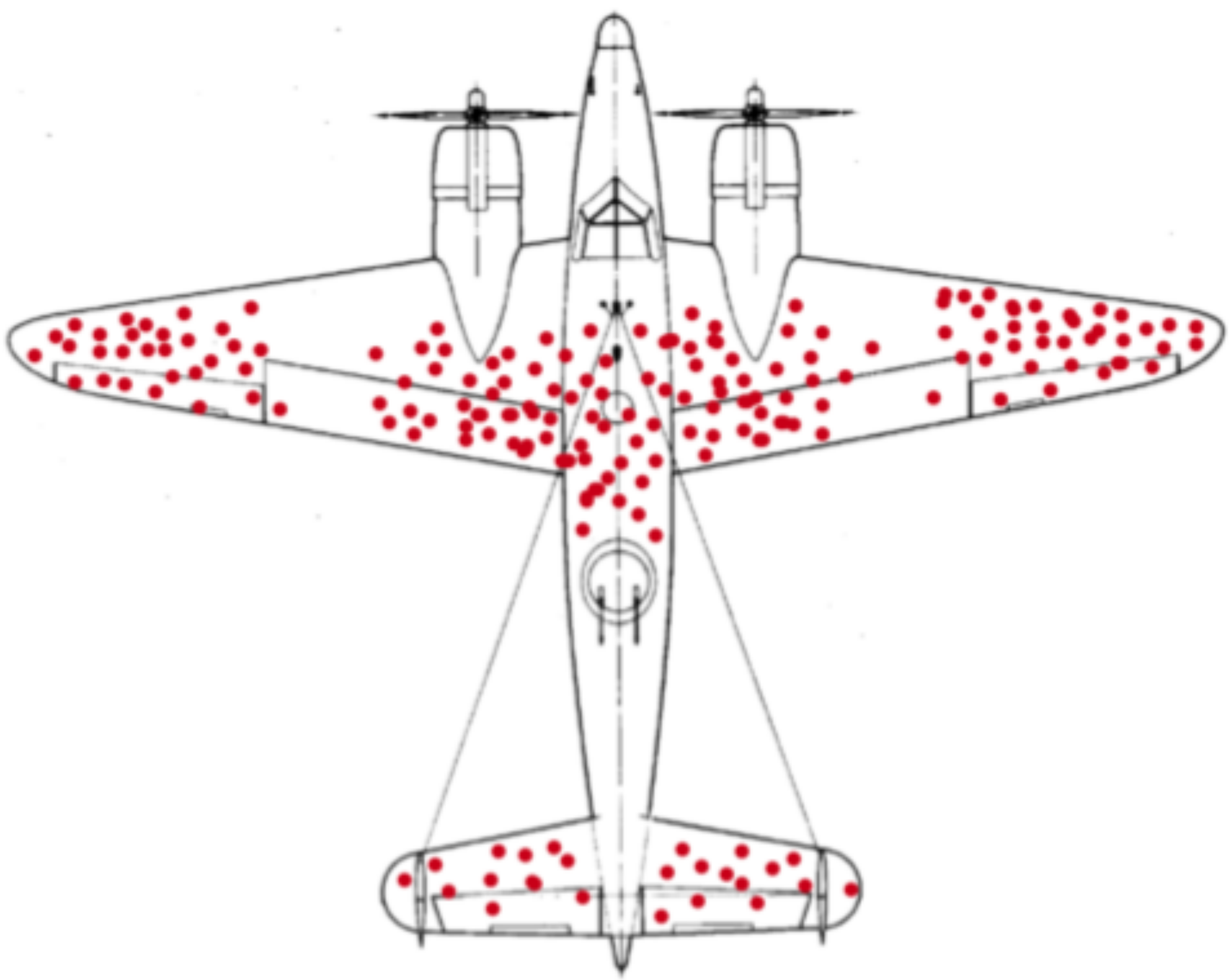
Activity-1: Think first to yourself, shoutout



Q: Where should the extra armor go?

Source

Activity-1: Think first to yourself, shoutout



Q: Where should the extra armor go?

Source

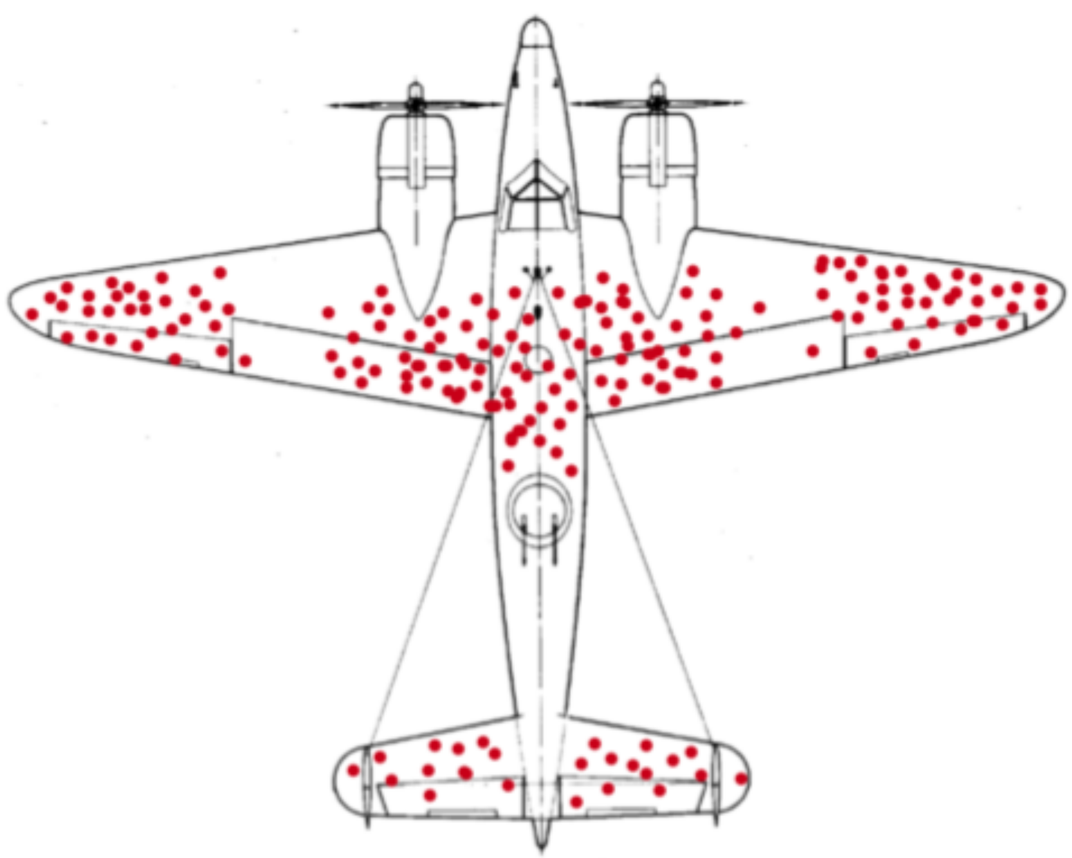
Answer: **The armor, said Wald, doesn't go where the bullet holes are.**
It goes where the bullet holes aren't: on the engines.

What do we learn from this activity?

- What if you sequenced a population to find which mutations greatly increase cancer risk? Accelerate Aging? Cause debilitating cognitive impairment?

- **Survivorship bias**

- applies to: Airplanes, finance, health, evolution, diagnosis.



Is evolution useful for an engineer of living matter?

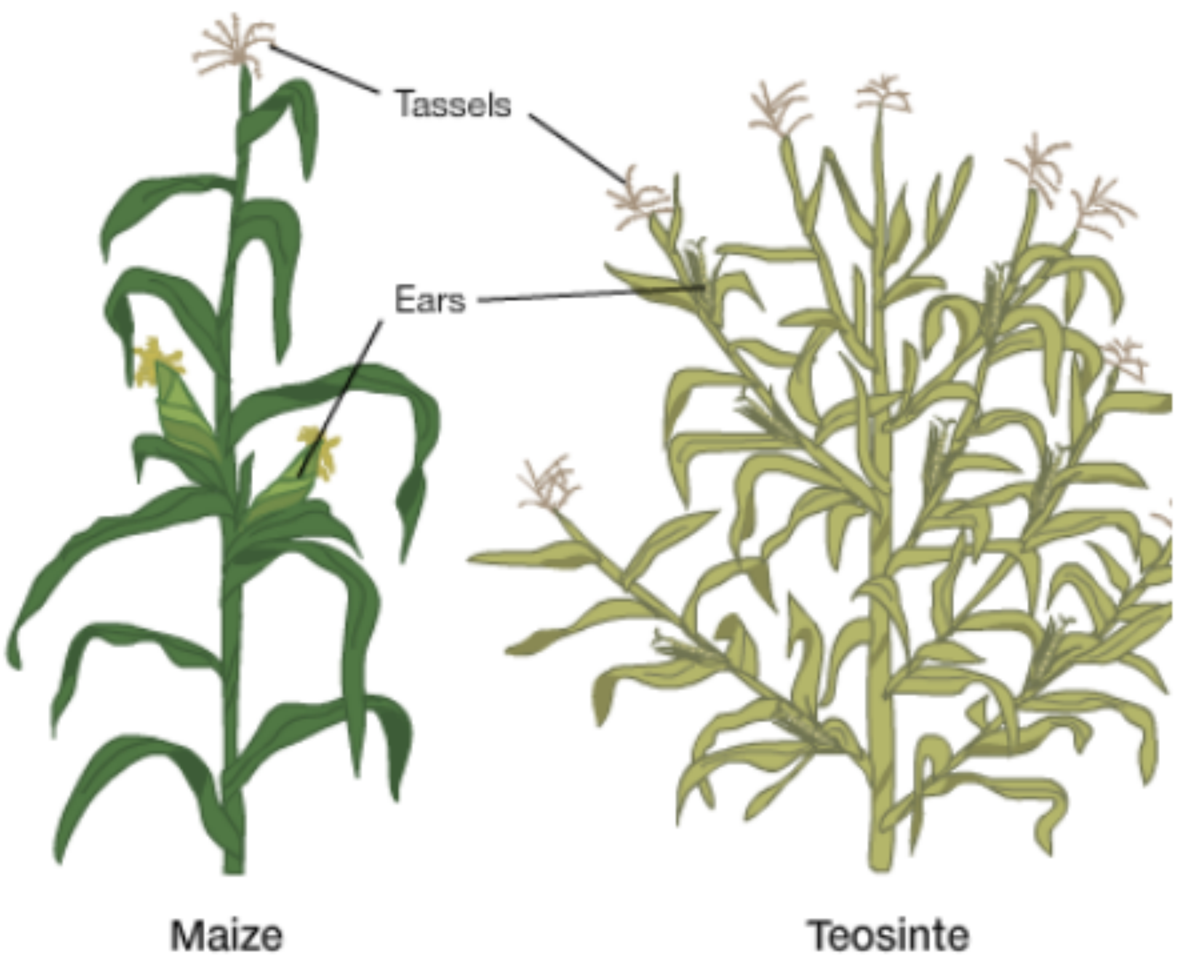
Is evolution relevant for engineering of living matter?
(or is it **too slow**?)

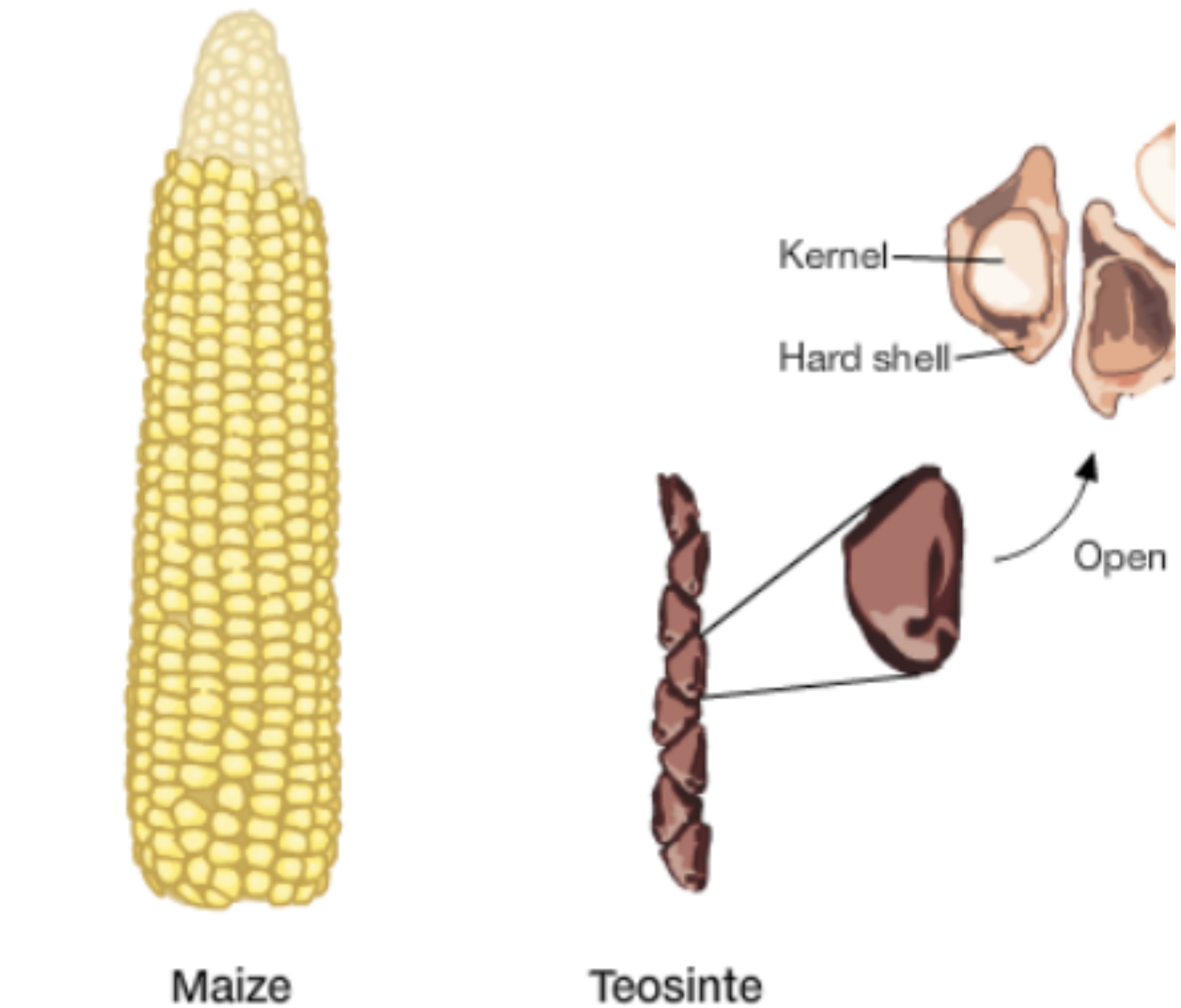
Is **evolution a stopgap** till we know all the fundamental equations of living matter?

Are there safety concerns?
(are we ok with evolving products?)

When and where do we use evolution as a tool?

We breed organisms for utility





http://learn.genetics.utah.edu/content/selection/corn/

Timescales?

Farmers and Their Languages: The First Expansions

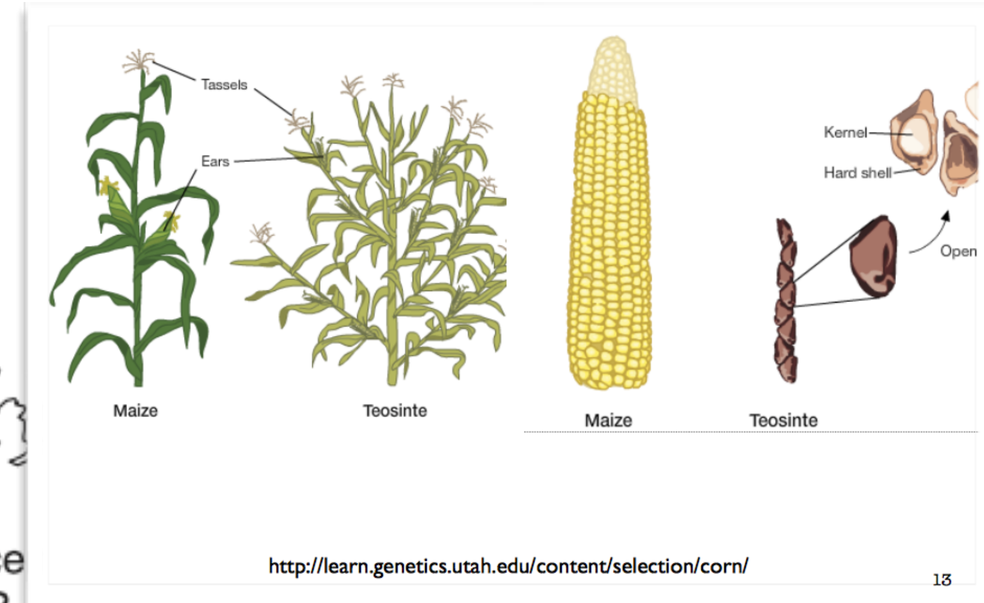
Jared Diamond[1] and Peter Bellwood[2]

The largest movements and replacements of human populations since the end of the Ice Ages resulted from the geographically uneven rise of food production around the world. The first farming societies thereby gained great advantages over hunter-gatherer societies. But most of those resulting shifts of populations and languages are complex, controversial, or both. We discuss the main complications and specific examples involving 15 language families. Further progress will depend on interdisciplinary research that combines archaeology, crop and livestock studies, physical anthropology, genetics, and linguistics.

described their conquests in writing, most of the major pre-Columbian expansions of agricultural populations occurred in pre-literate times. Hence the evidence for them comes from five other independent sources: archaeology, records of plant and animal domestication, human skeletal remains, modern human genes (and sometimes ancient DNA), and dispersal histories of existing or extinct but attested languages.

10,000 years

Timescales?



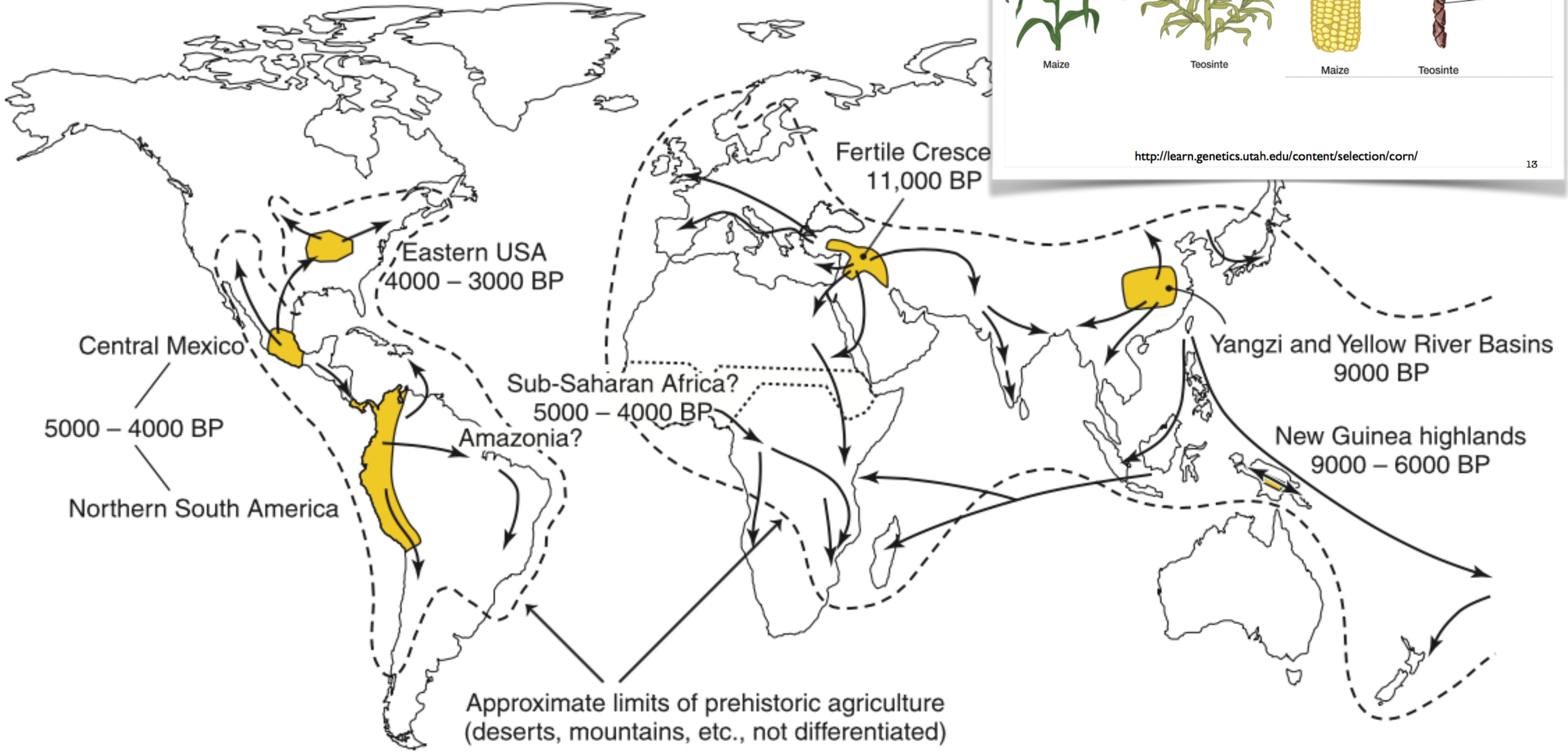


Fig. 1. Archaeological map of agricultural homelands and spreads of Neolithic/Formative cultures, with approximate radiocarbon dates.

10,000 years

Timescales?

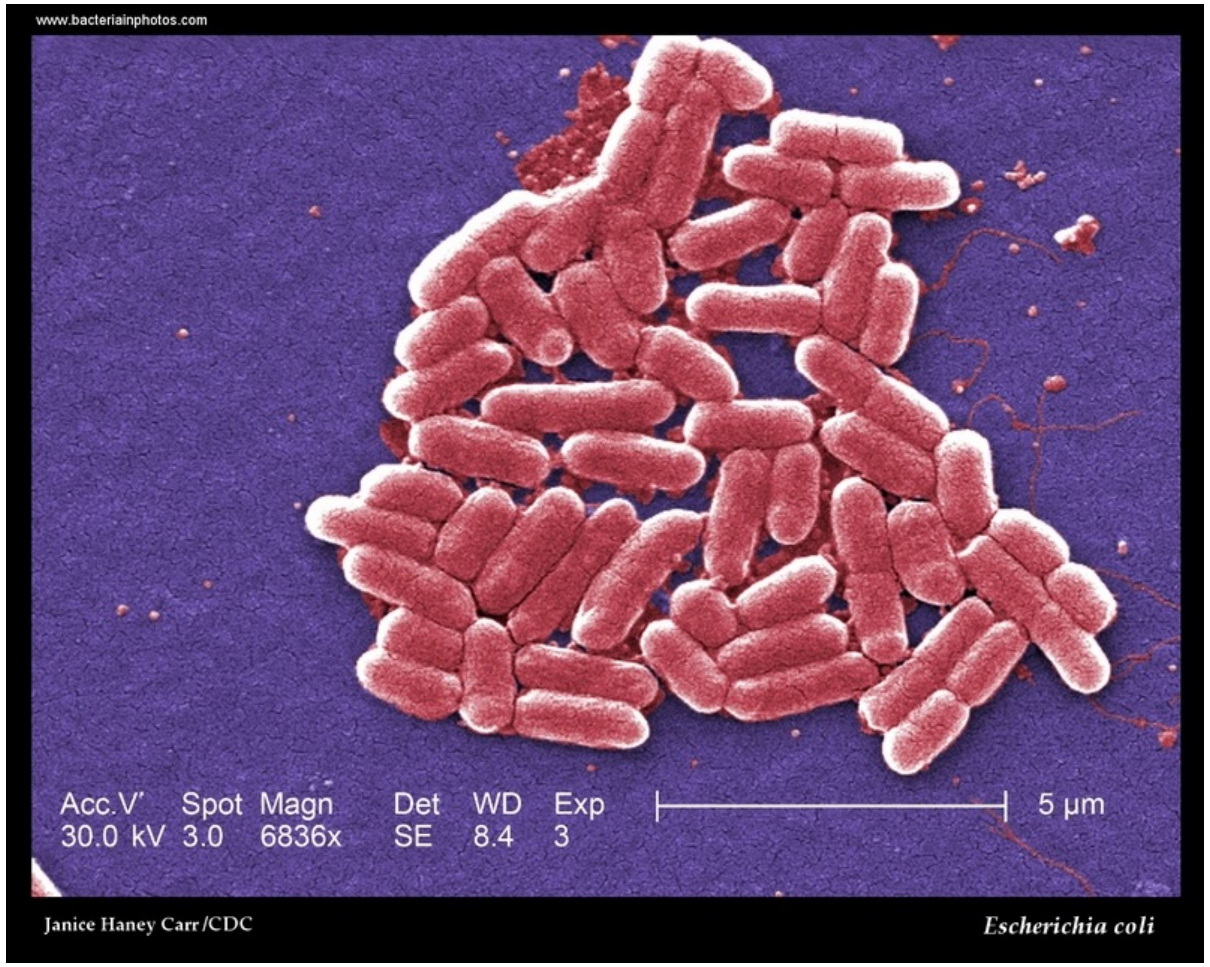
Selection for traits; breeding - years to a decade

Timescales? Selection for traits in *E. coli*

Assume that it takes *E. coli* 16 mins to replicate
(30 mins on average)

How many generations of *E. Coli* in a day?

90 generations



Escherichia coli (strainO157:H7)
Source

EVOLUTION EXPERIMENTS WITH MICROORGANISMS: THE DYNAMICS AND GENETIC BASES OF ADAPTATION

Santiago F. Elena and Richard E. Lenski‡*

Microorganisms have been mutating and evolving on Earth for billions of years. Now, a field of research has developed around the idea of using microorganisms to study evolution in action. Controlled and replicated experiments are using viruses, bacteria and yeast to investigate how their genomes and phenotypic properties evolve over hundreds and even thousands of generations. Here, we examine the dynamics of evolutionary adaptation, the genetic bases of adaptation, tradeoffs and the environmental specificity of adaptation, the origin and evolutionary consequences of mutators, and the process of drift decay in very small populations.

One feature that is seen in several experiments, with both bacteria and viruses, is that fitness gains are initially rapid but tend to decelerate over time[13,25–30]. Such dynamics indicate that populations, after being placed in a new environment, are evolving from a region of low fitness towards an adaptive peak or plateau (FIG. 1). For example, in a long-term experiment with 12 *Escherichia coli* populations, the average fitness gain in the first 5,000 generations was approximately tenfold greater than that between 15,000 and 20,000 generations[26].

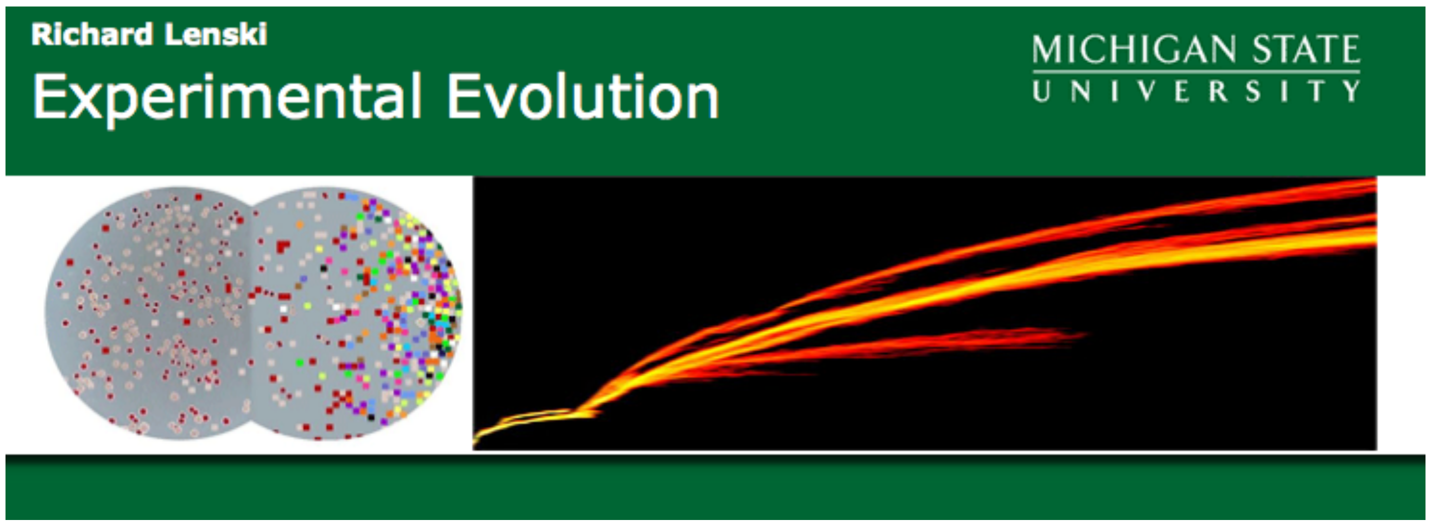
***E. coli* -**

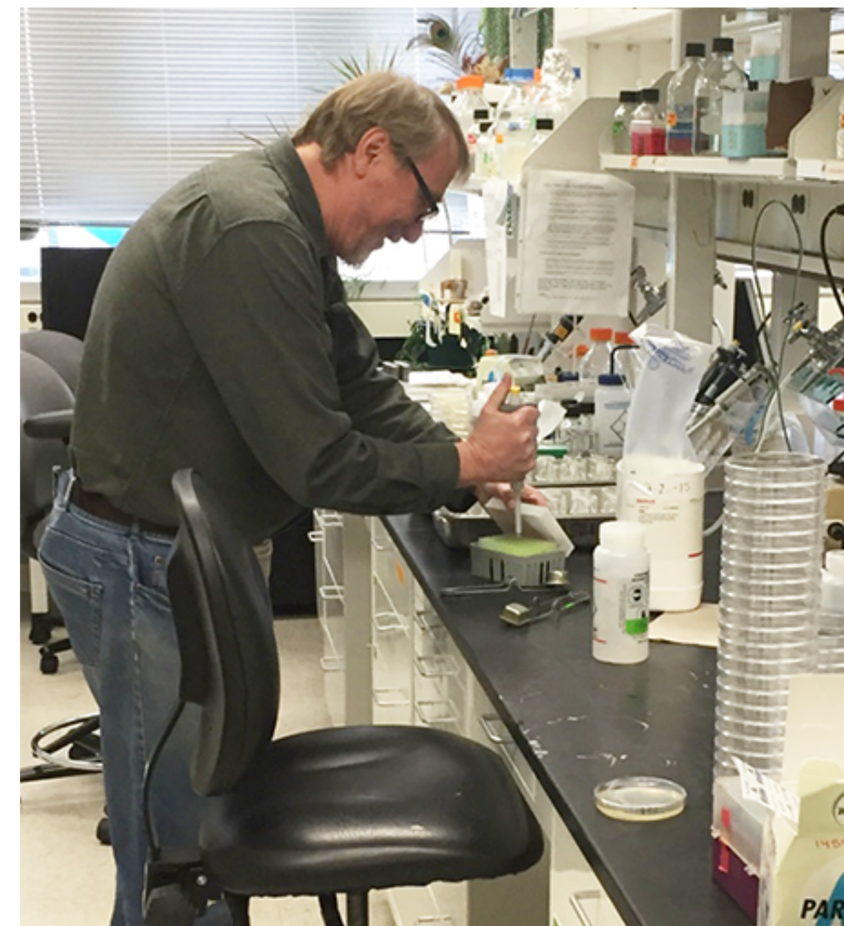
16 min per division

90 generations per day

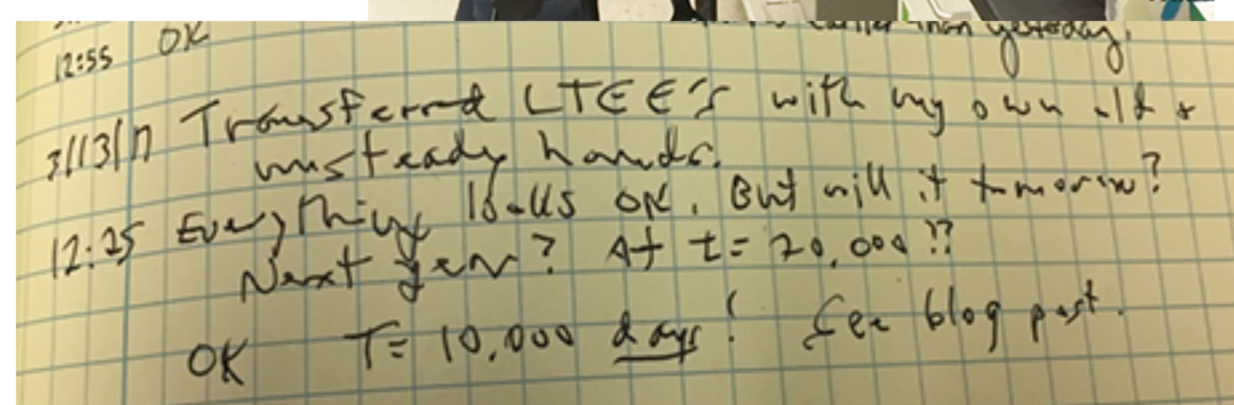
90

50,000 generations
a decade or two





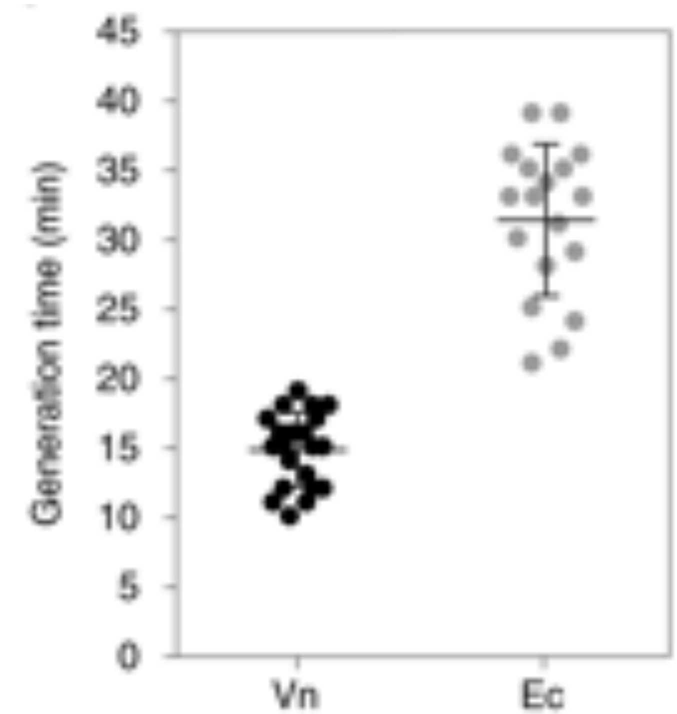
71793.2 generations of *E. coli* evolution and counting.

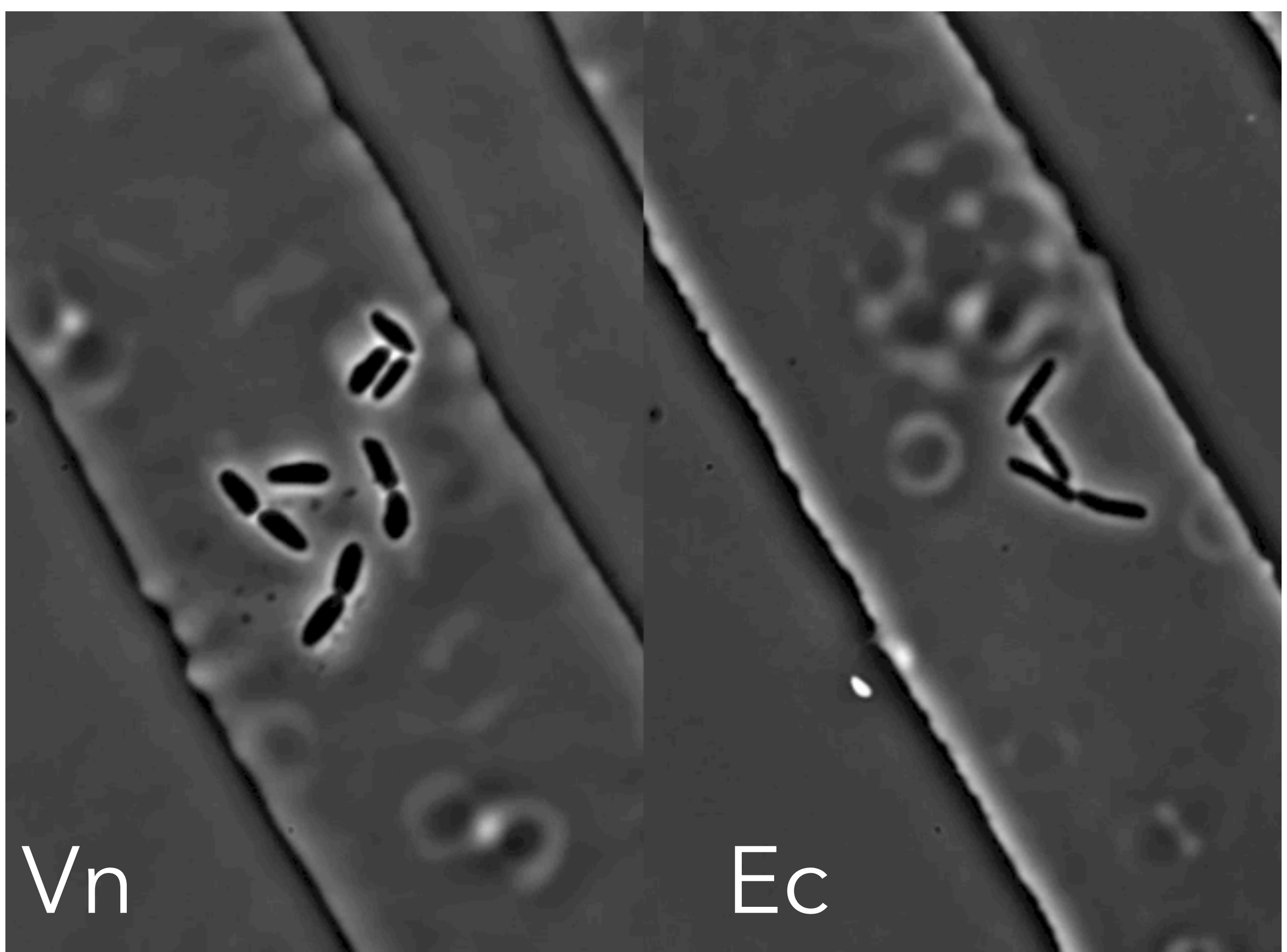


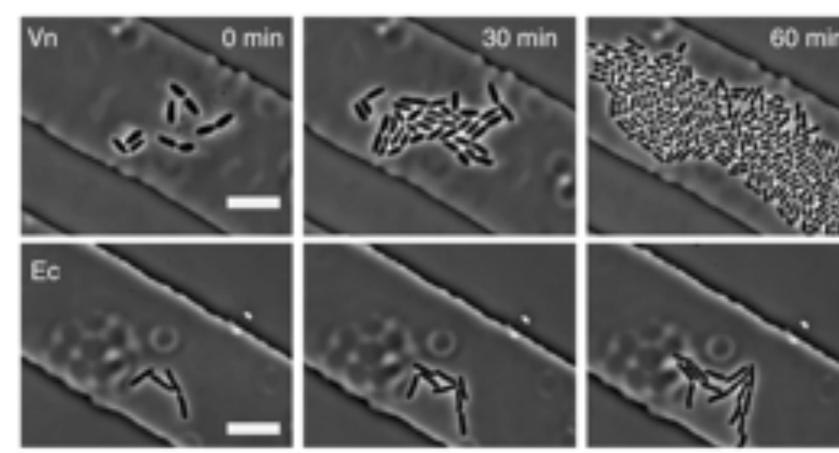
Functional genomics of the rapidly replicating bacterium *Vibrio natriegens* by CRISPRi

Henry H. Lee, Nili Ostrov, Brandon G. Wong, Michaela A. Gold, Ahmad S. Khalil & George M. Church

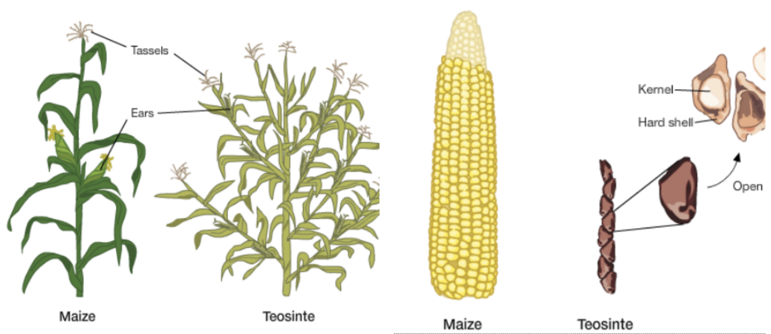
News flash April. 8







We breed organisms for utility

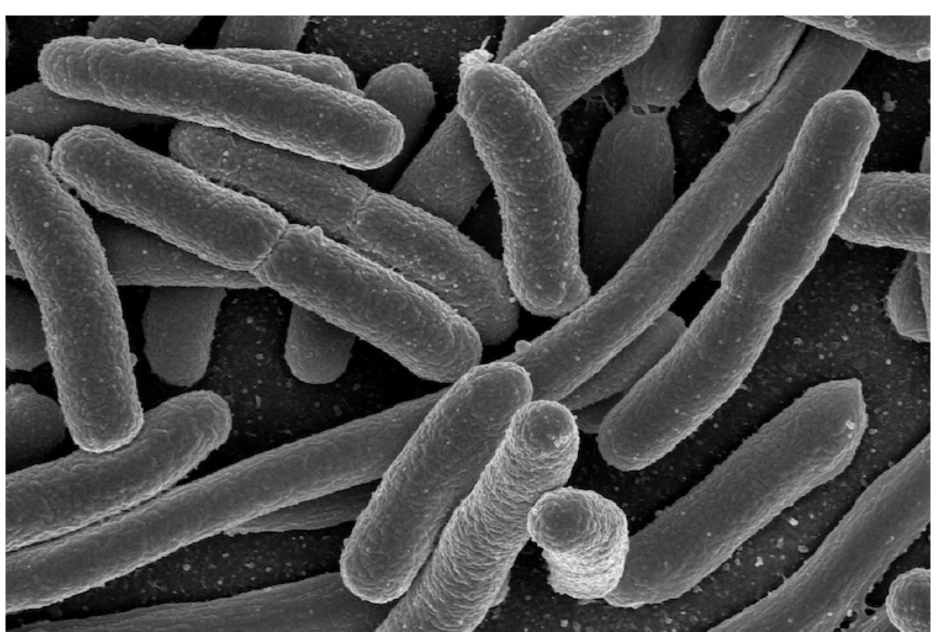


http://learn.genetics.utah.edu/content/selection/corn/

13

10,000 years

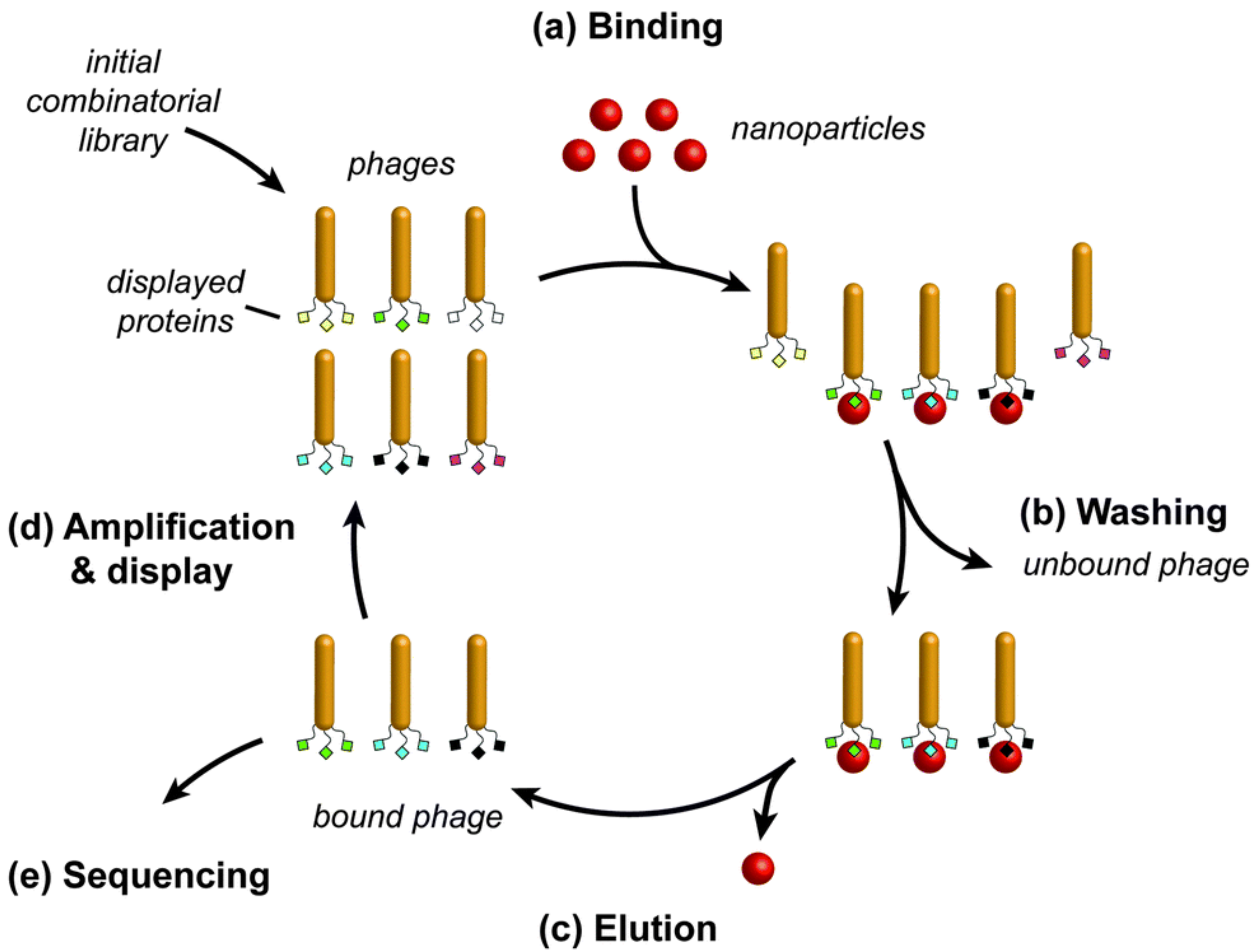
10-100 years



Weeks -
a massive clinical problem
or an engineering approach

Timescales?

In vitro evolution



10 generations - a few days

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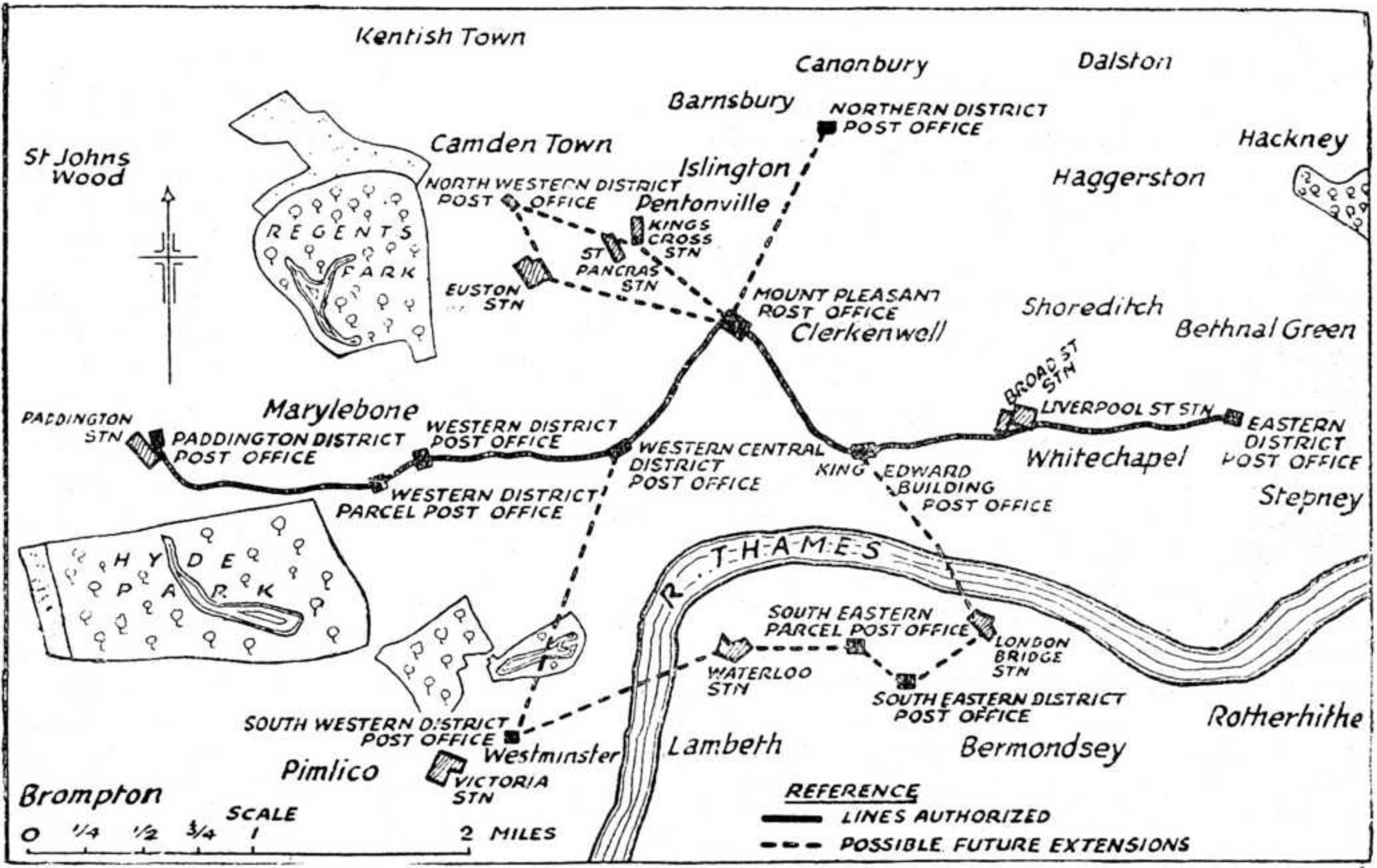


The route of the Post Office Tube Railway in London.

Algorithms - Speed

al·go·rithm
/ˈalgəˌriTHəm/

noun
plural noun: **algorithms**

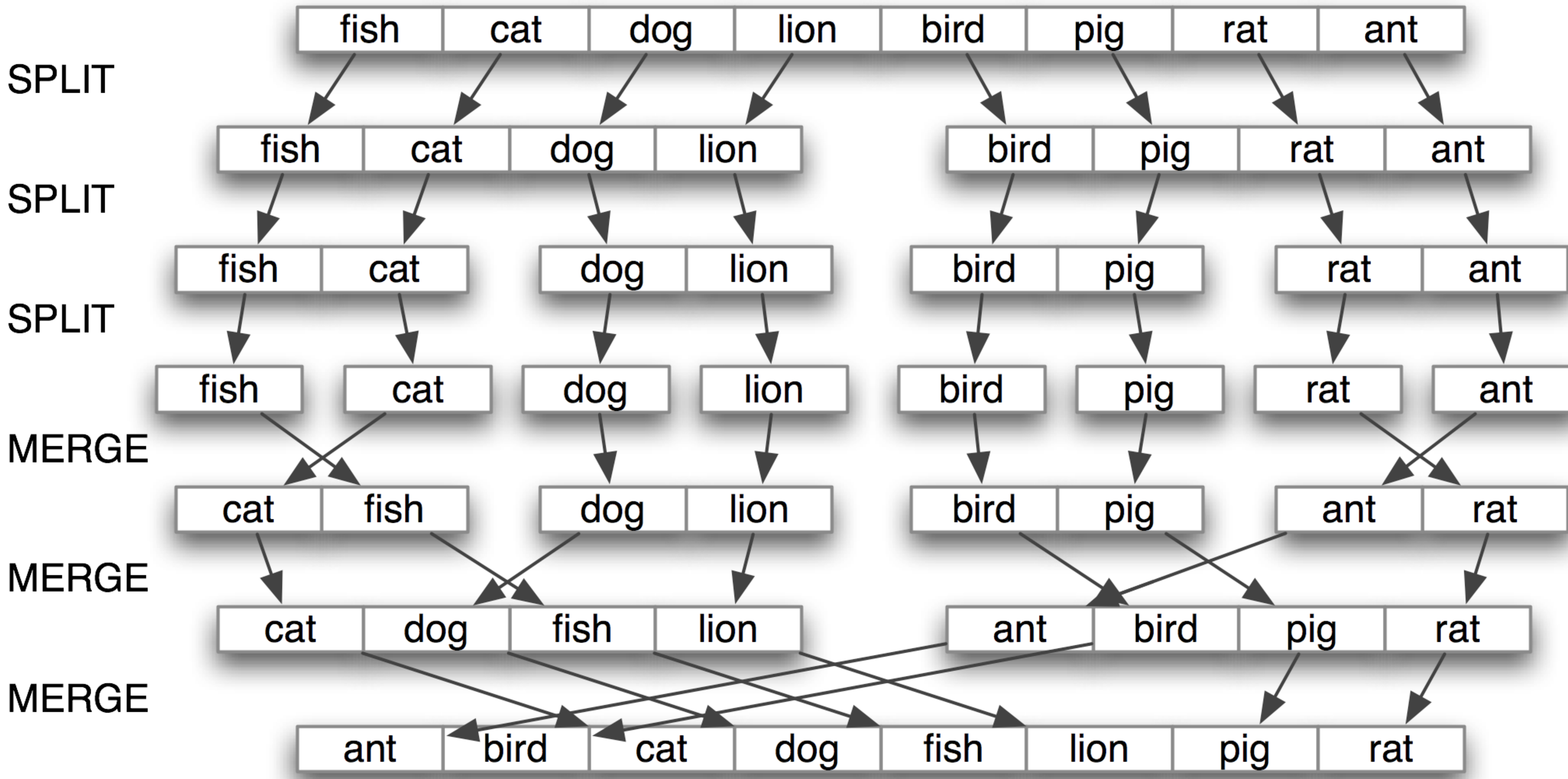
> a process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer.
> "a basic **algorithm for** division"

Translations, word origin, and more definitions

The **post-office problem** (Knuth, 1973)

How do you efficiently route letters to people?

Algorithms - merge sort

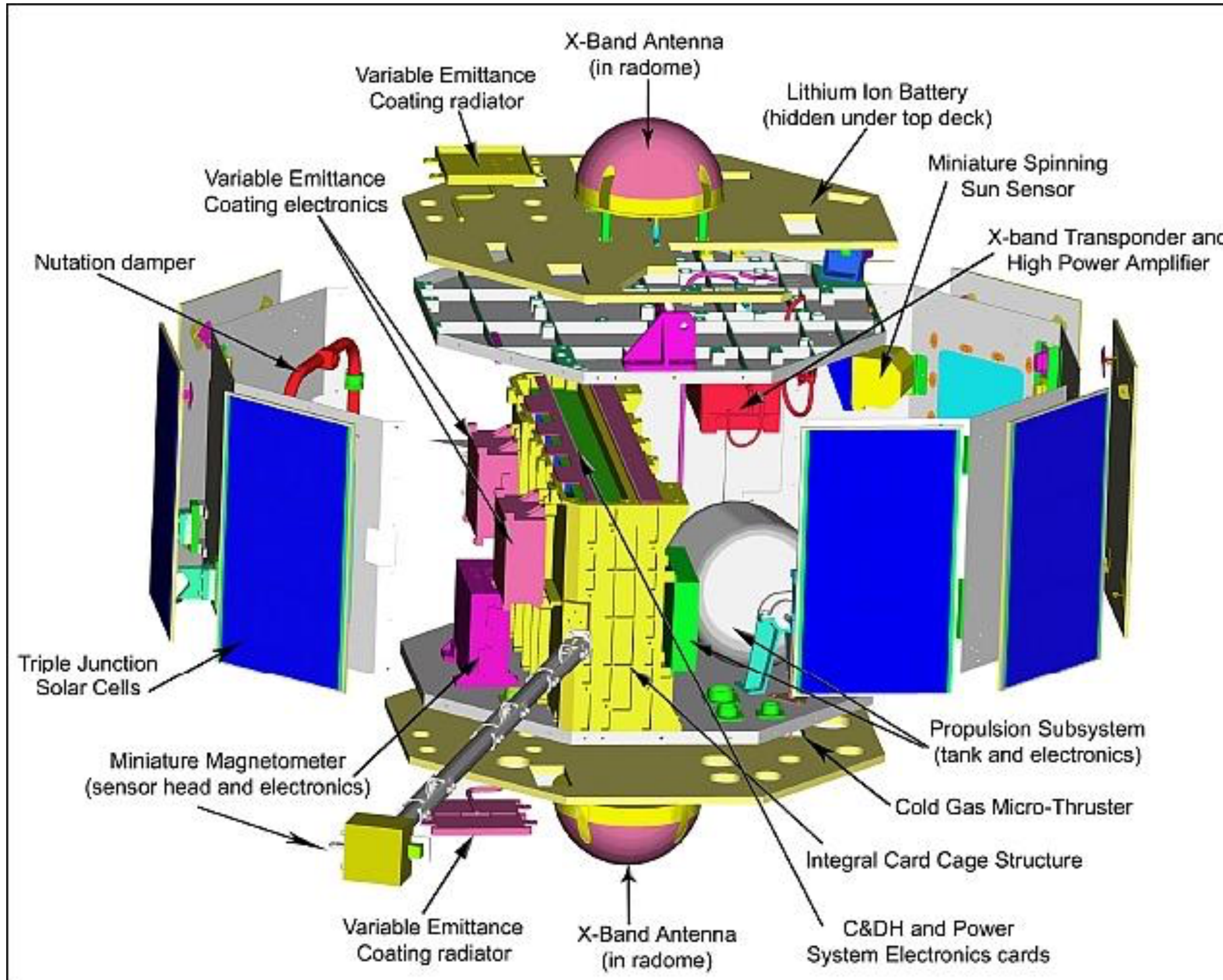


http://www.nltk.org/book/ch04.html

Algorithms - Optimization

Algorithms - Optimization

Question - given this shape, materials, composition, curvatures, what is the best antenna?



Algorithms - Optimization

How does NASA design antennas?

Stupid question?

Did all NASA engineers take a class on Maxwell's Equations - sure!

Just look up the answer, right?

$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \times \vec{E} = \boxed{-\frac{\partial \vec{B}}{\partial t}}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \boxed{\mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}}$$

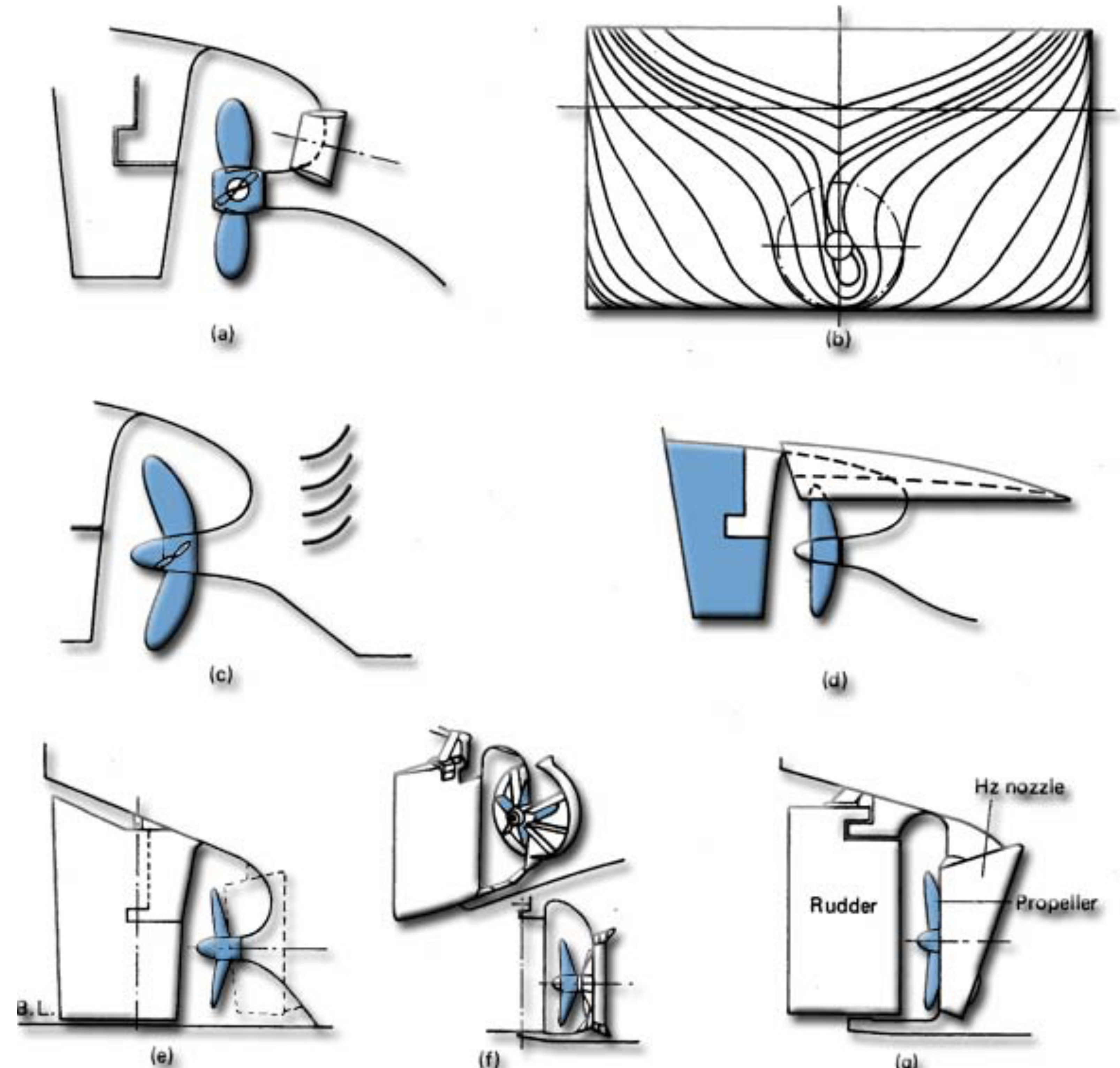
Algorithms - Optimization

Just look up the answer,
right?

No

There are certain complex optimization problems in engineering that are extremely hard to solve

What is the best propellor, given 29 parameters?



Zone 1 and Zone 1/2 devices: (a) wake equalizing duct; (b) asymmetric stern-body plan; (c) Grothues spoilers; (d) stern tunnel; (e) Mitsui integrated ducted propeller; (f) reaction fins and (g) Hitachi Zosen nozzle

What is the best propellor, given 29 parameters?

Easy, right - just look it up in Navier Stokes!

Navier–Stokes Equations

3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)

Velocity Components: (u,v,w)

Time : t

Density: ρ

Total Energy: Et

Pressure: p

Stress: τ

Heat Flux: q

Reynolds Number: Re

Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\tau_{xx} + v\tau_{xy} + w\tau_{xz}) + \frac{\partial}{\partial y}(u\tau_{xy} + v\tau_{yy} + w\tau_{yz}) + \frac{\partial}{\partial z}(u\tau_{xz} + v\tau_{yz} + w\tau_{zz})\right]$$

Algorithms - Optimization

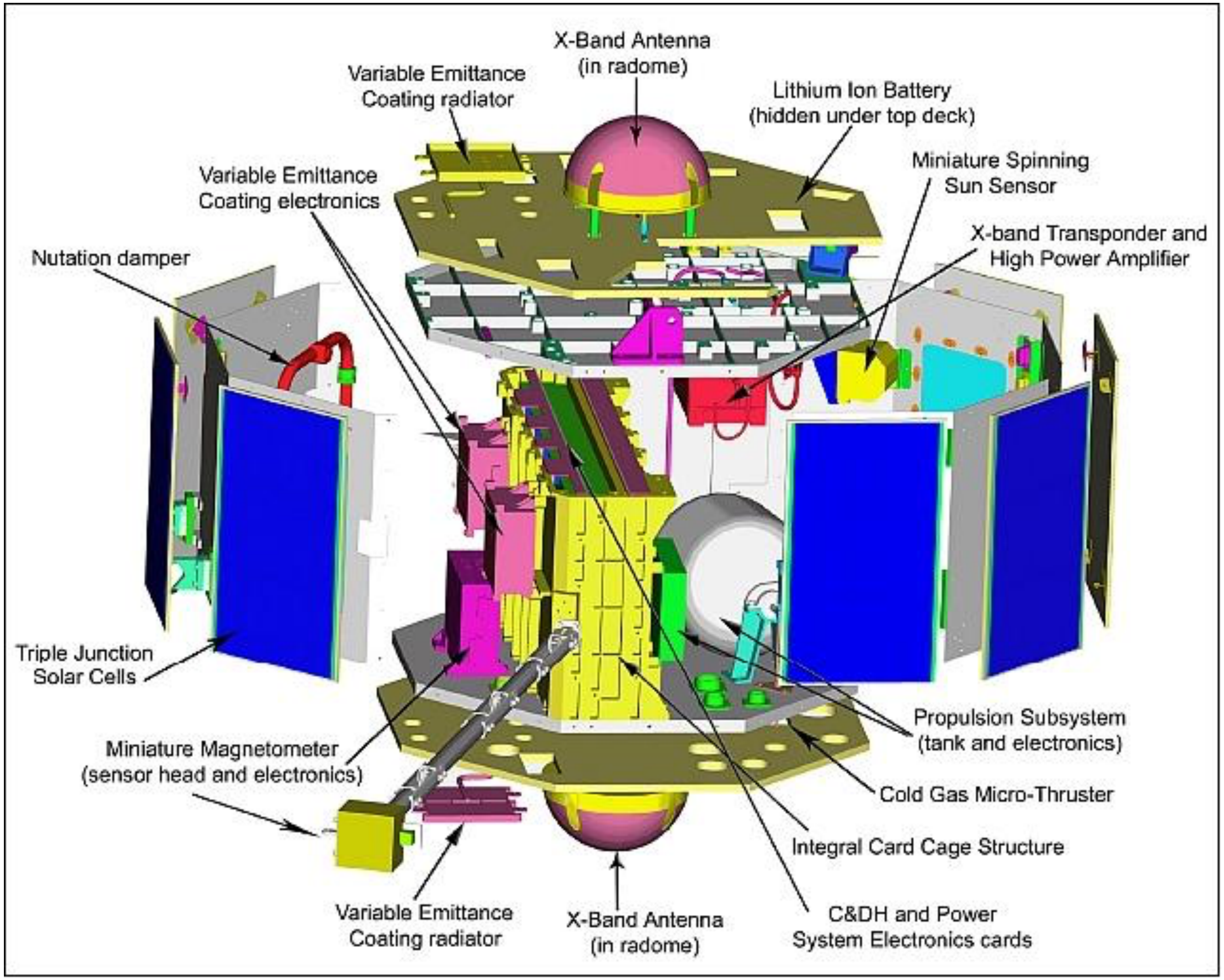
Just look up the answer,
right?

No

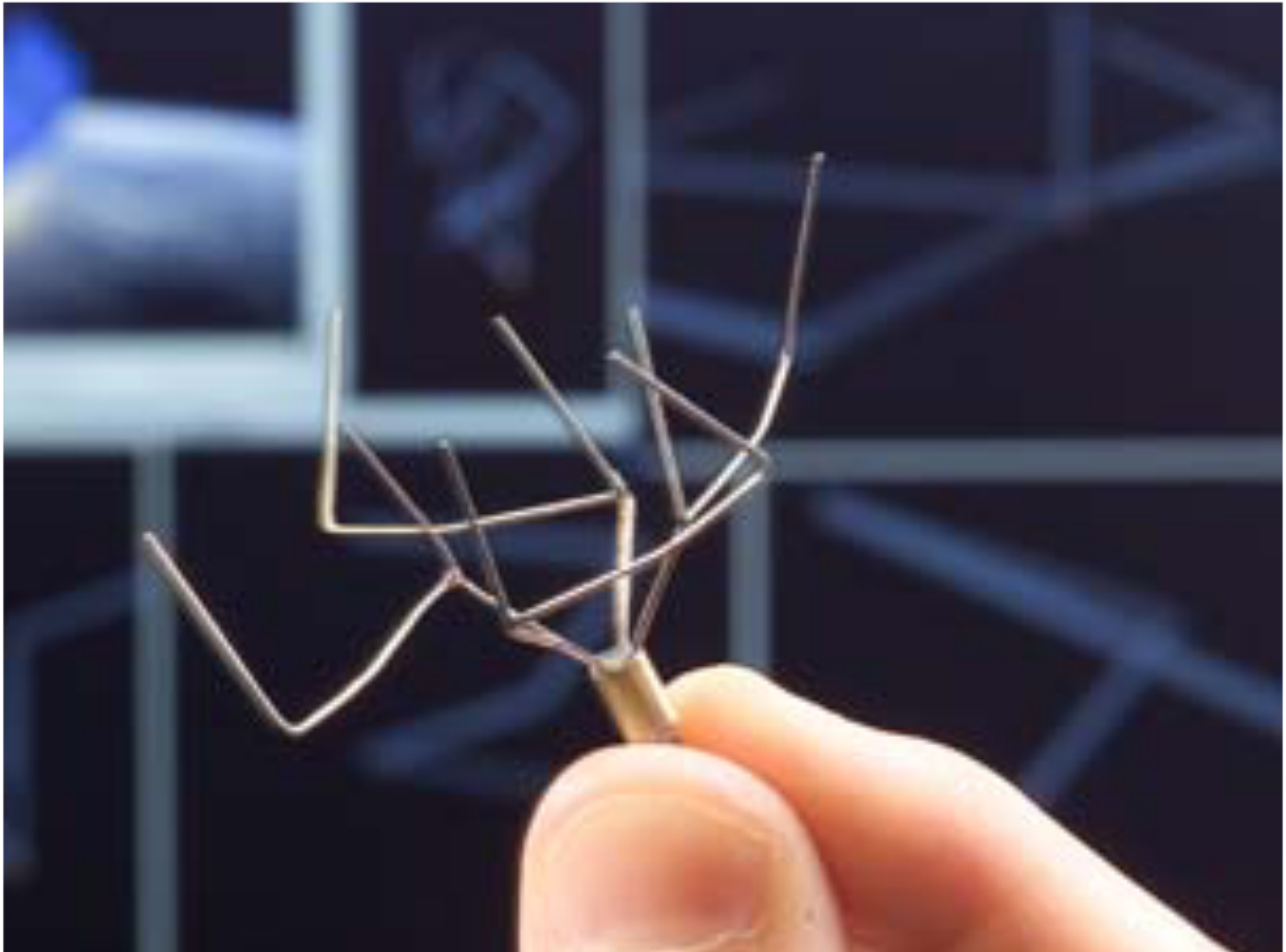
There are certain complex optimization problems in engineering that are extremely hard to solve

Fortunately, there are certain computational procedures that **are** good at solving complex optimization problems,

just like binary search is good a finding numbers in a phone book



For this specific spacecraft, the best antenna looks like….



Algorithms - Optimization

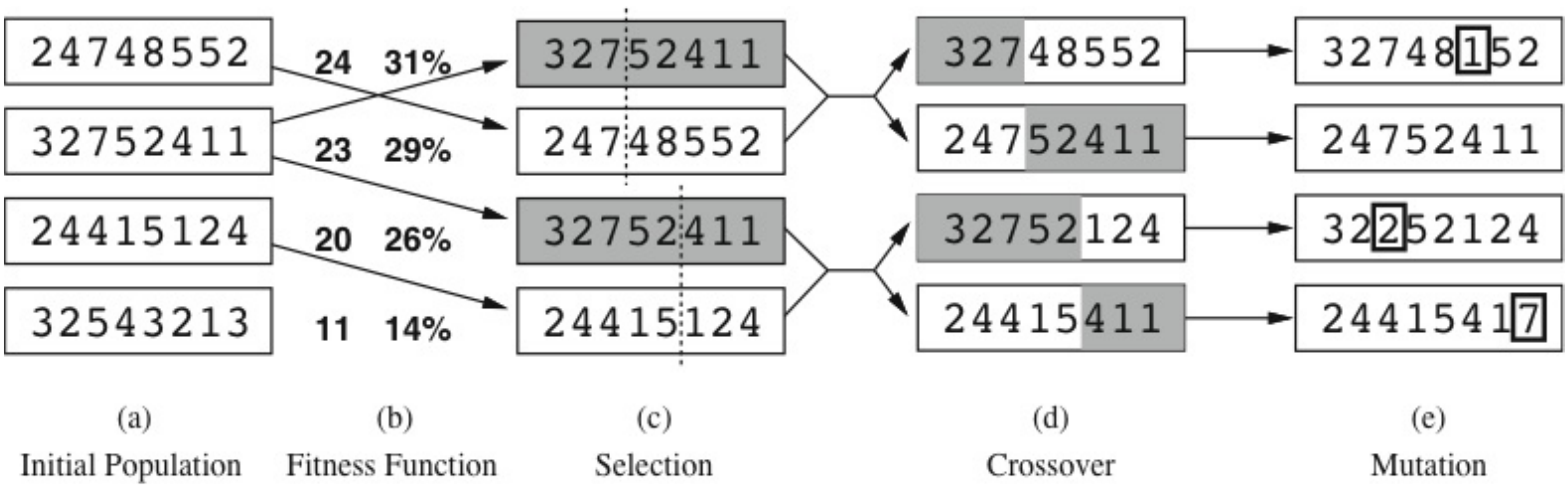
Even if you know all the basic laws, it can be exceedingly tough to find the “best” shape, size, composition…

Evolutionary / Genetic algorithms.

There is nothing (inherently) biological about Evolutionary / Genetic algorithms.

They are an exceptionally powerful set of tools for NASA, electrical engineers, nature, …

Evolutionary / Genetic algorithms.



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Microbial Evolution

Can we engineer evolution timescales?

You bet - use the logic that Drew described (Week-3) to turn on/off circuits that control expression of DNA repair machinery.

Impact of a stress-inducible switch to mutagenic repair of DNA breaks on mutation in *Escherichia coli*

Chandan Shee[a], Janet L. Gibson[a], Michele C. Darrow[b], Caleb Gonzalez[a,1], and Susan M. Rosenberg[a,b,c,2]

[a]Department of Molecular and Human Genetics, [b]Department of Biochemistry and Molecular Biology, [c]Department of Molecular Virology and Microbiology, and The Dan L. Duncan Cancer Center, Baylor College of Medicine, Houston, TX 77030

Edited* by Marlene Belfort, Wadsworth Center, Albany, NY, and approved July 11, 2011 (received for review March 24, 2011)

Promote evolution - disfavor/slow evolution - but can't stop it - unless?

Evolve!

Safety and Control

Scary, right - fundamentally, you have (little) idea what
your living device/cell will be up to in X years

Ideas, please

Activity-2: What strategies (if any)
can be used to implement
safety and control in living devices (cells)
that are subject to evolution?