Evolution and Probability

Luca Peliti
SMRI (Italy)

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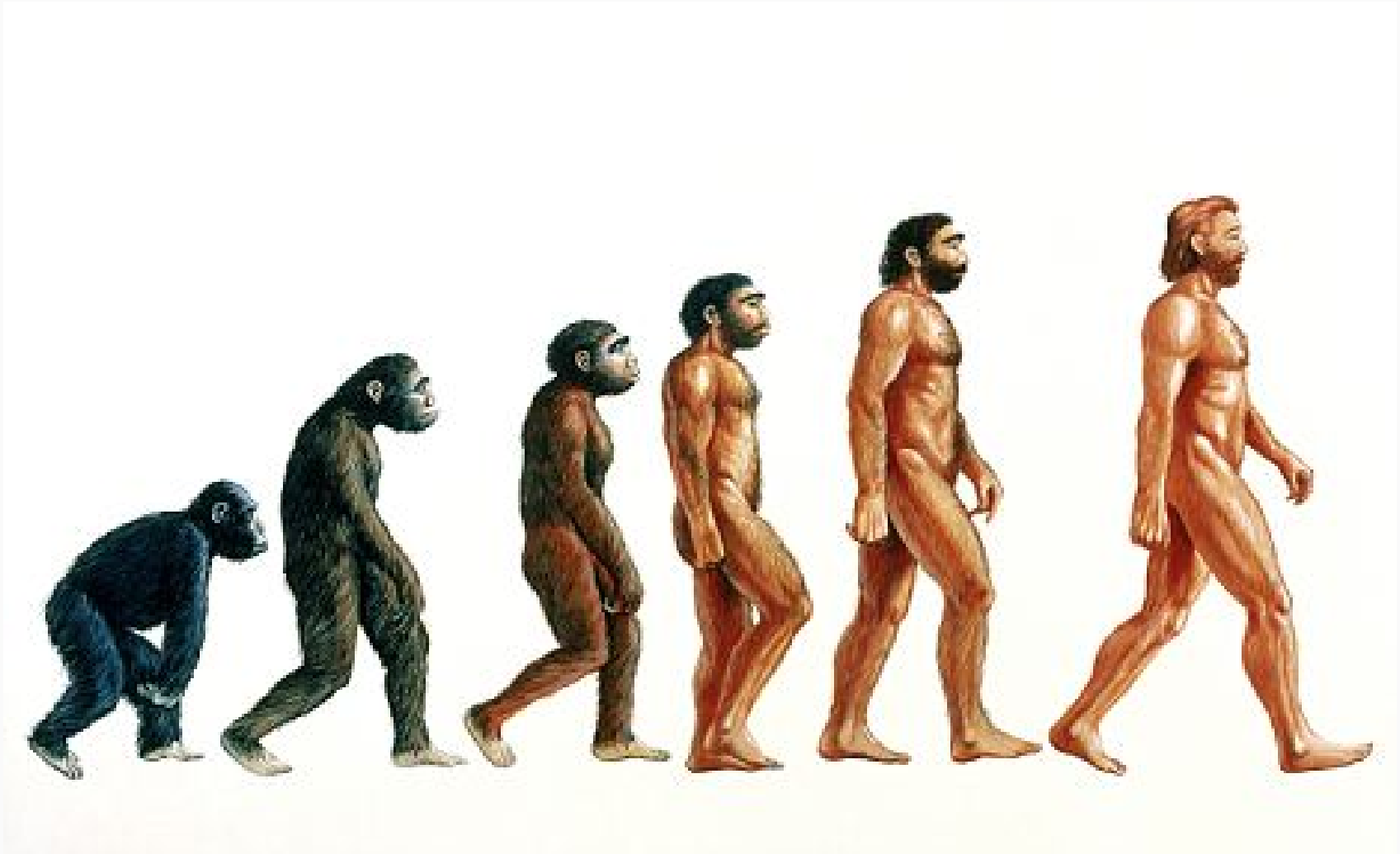
Contents

Selection and probability

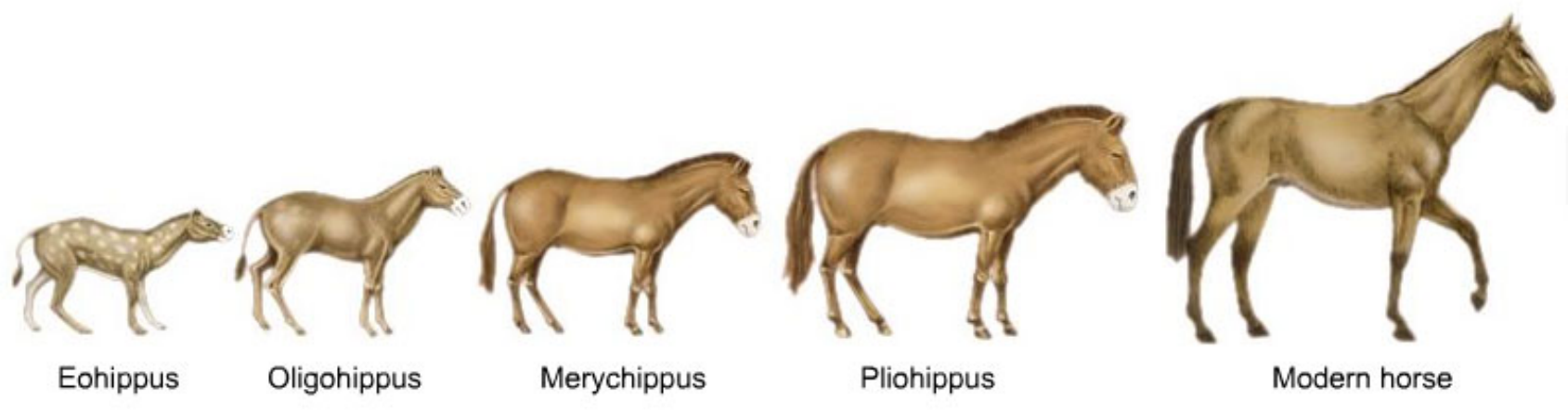
Natural selection is a mechanism for generating an exceedingly high degree of improbability.

R. A. Fisher

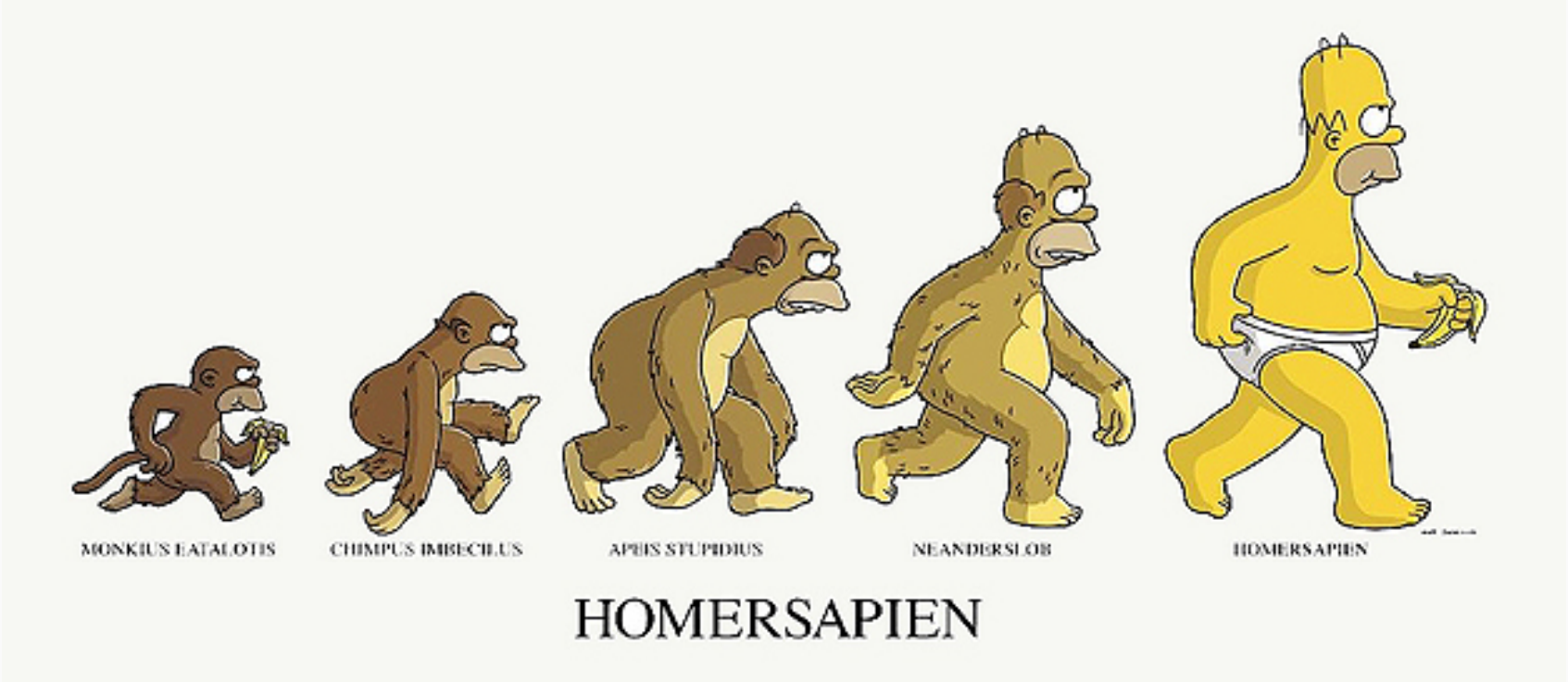
Evolution as Progress



Evolution as Progress

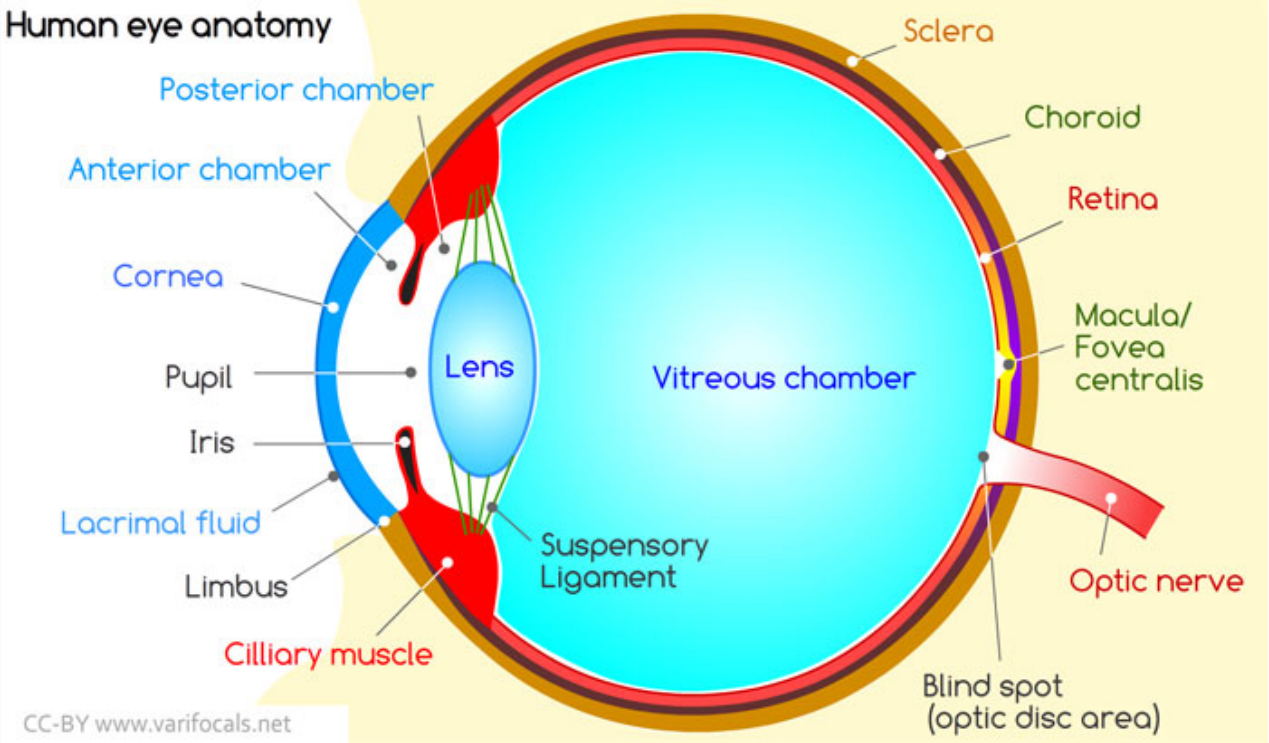


Evolution as Progress



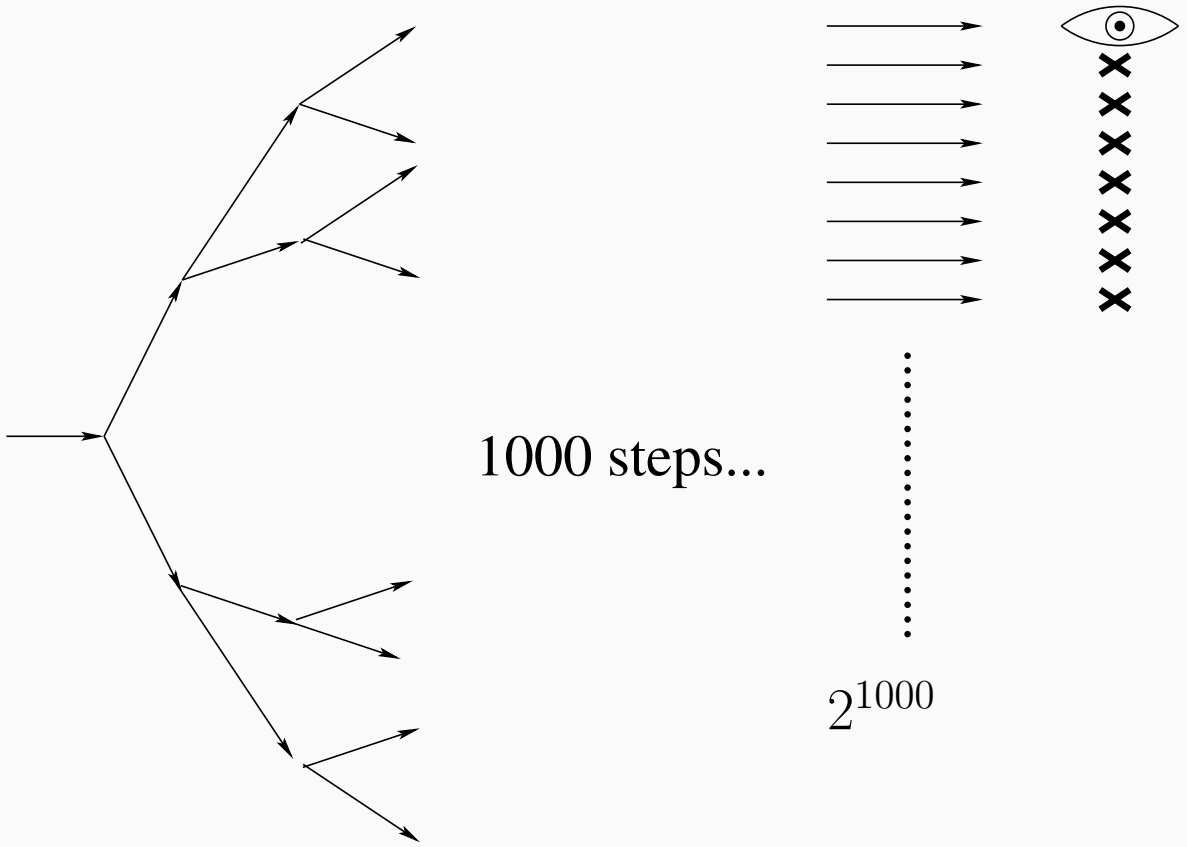
Evolution as Progress

How could the human eye be evolved?



Varifocals

The adaptation paradox

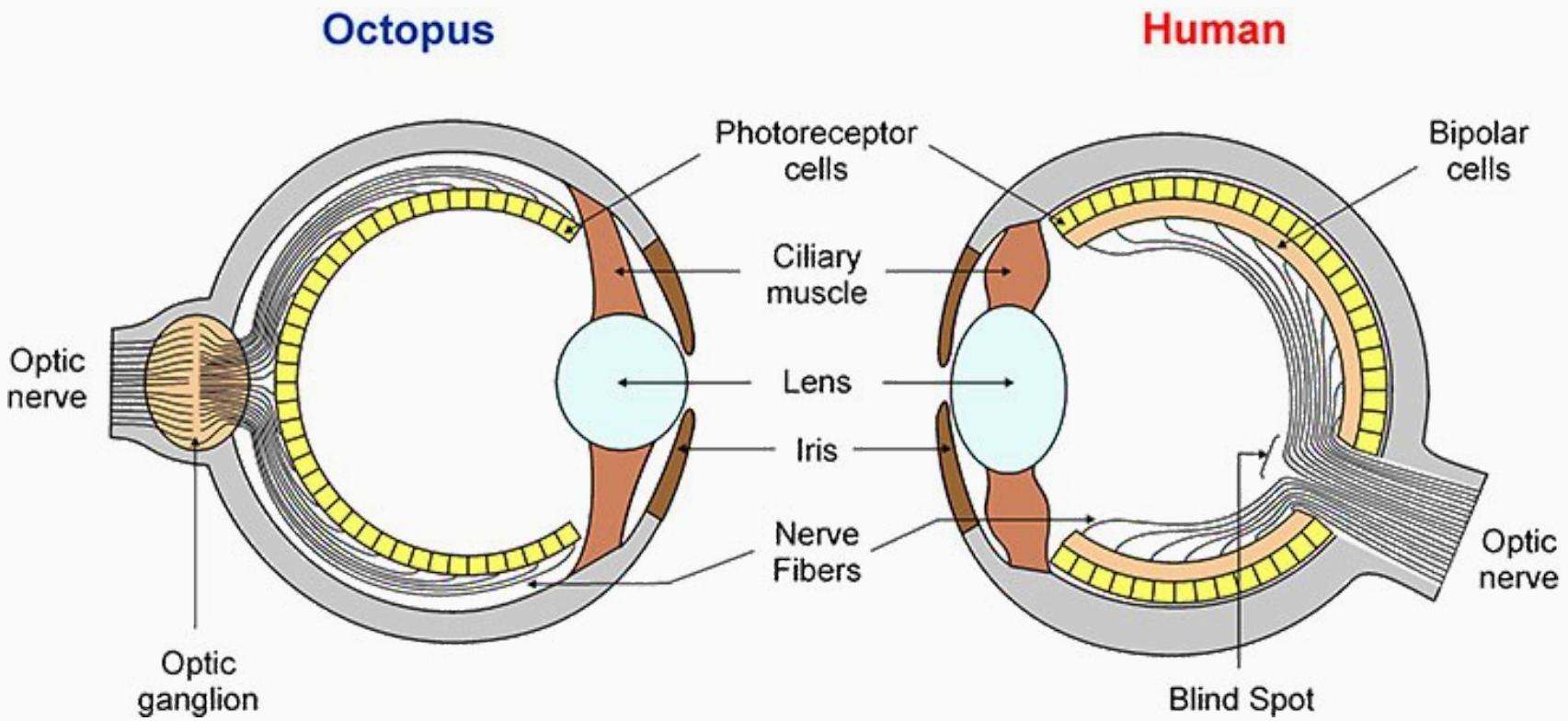


Probability: $2^{-1000} \simeq 1/10^{300}$???

And yet…

The octopus eye

The devil dwells in the details…



Evolution shaped an eye very similar to the vertebrate one, but via a wholly independent process!

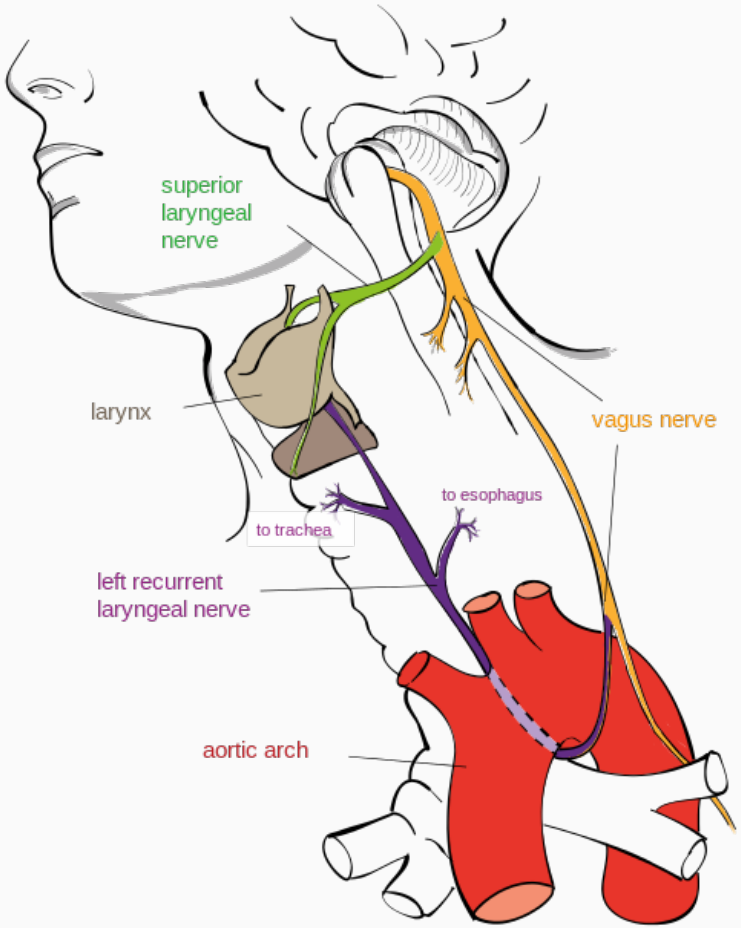
Evolution and tinkering

[...] natural selection does not work as an engineer works. It works like a tinkerer [...] who uses everything at his disposal to produce some kind of workable object.

F. Jacob

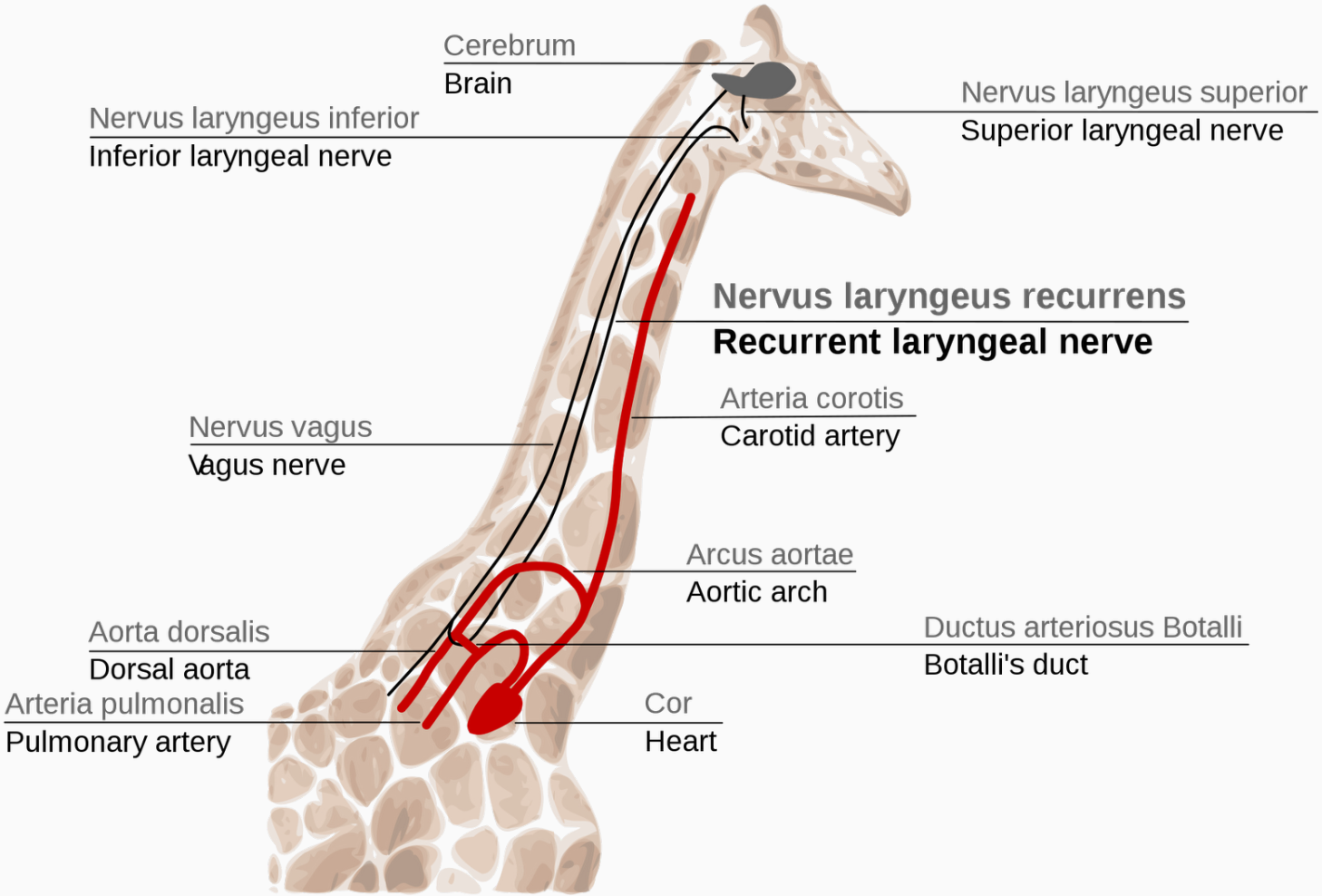
Small revealing imperfections…

The recurrent laryngeal nerve



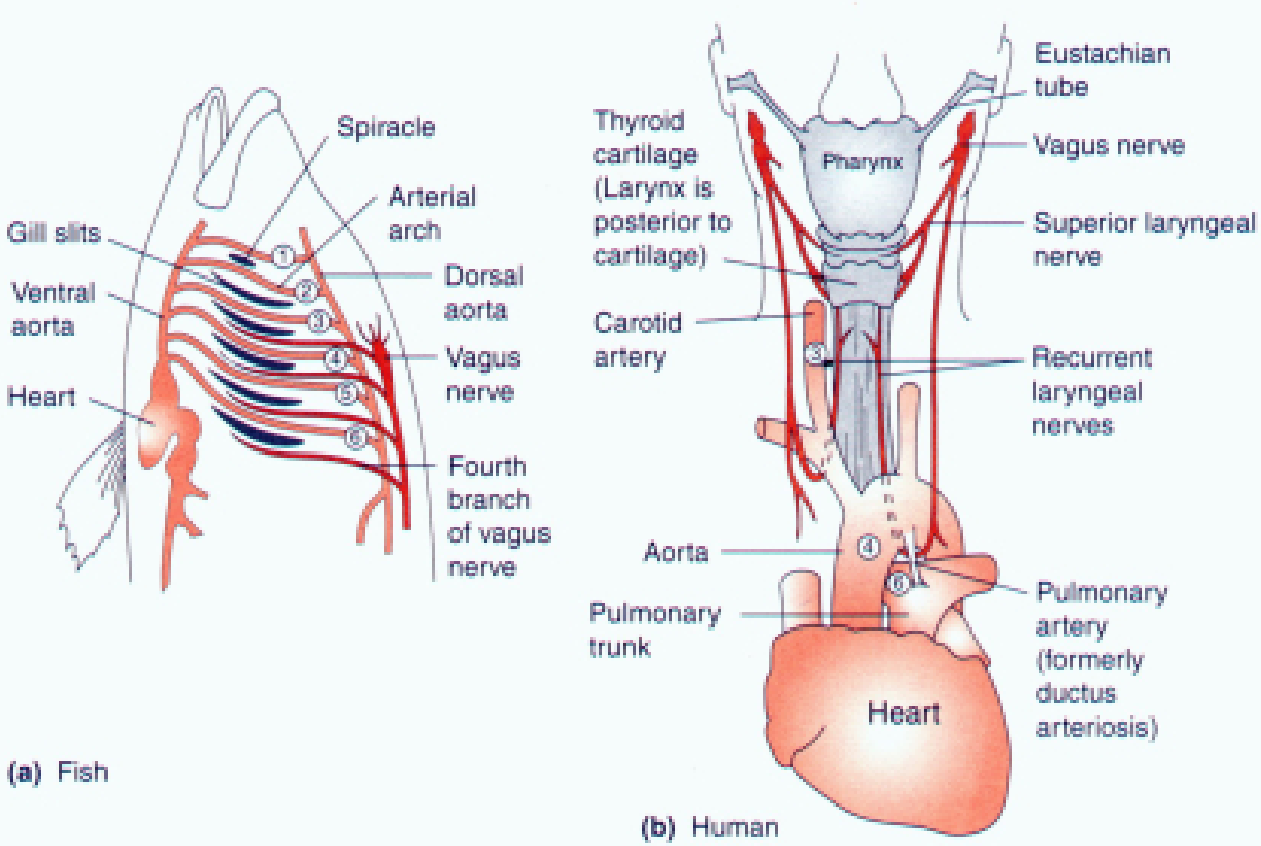
Small revealing imperfections…

The recurrent laryngeal nerve



Small revealing imperfections…

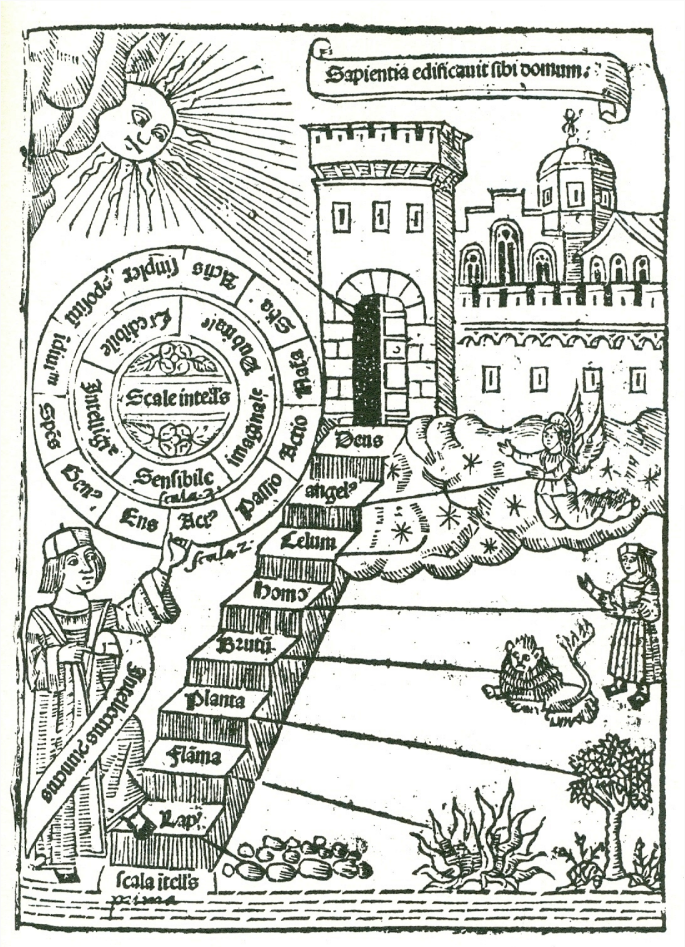
The recurrent laryngeal nerve



The recurrent laryngeal nerve corresponds to the fourth vagus nerve, and turns around the sixth arterial arch which is active in the fetus and is located in the chest.

Evolution as diversification

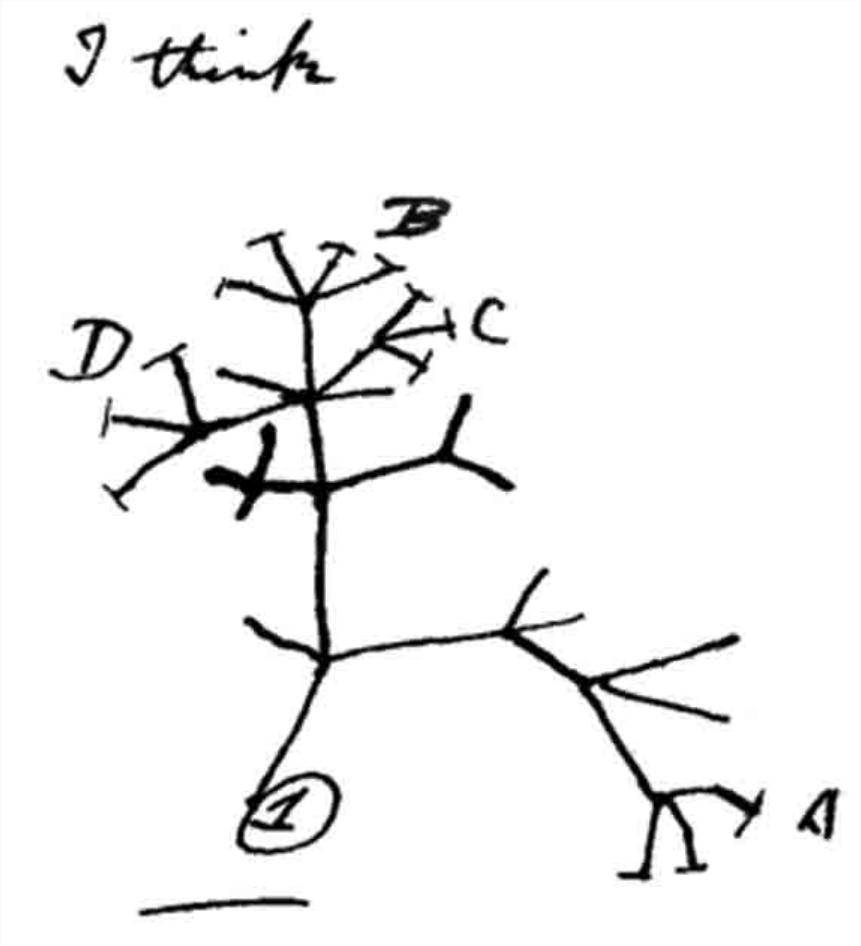
The Scala naturæ



R. Llull

Evolution as diversification

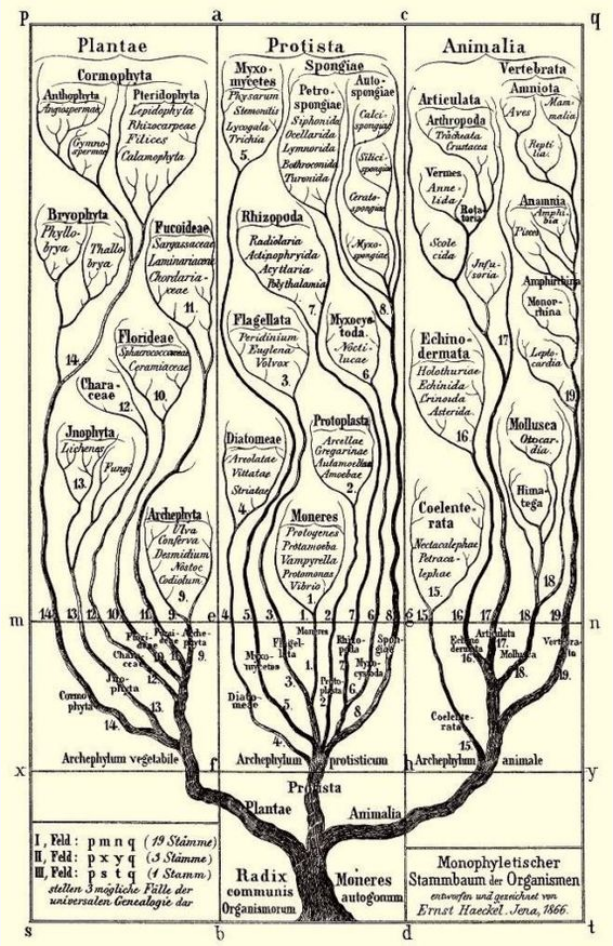
The tree of life



Ch. Darwin, 1837

Evolution as diversification

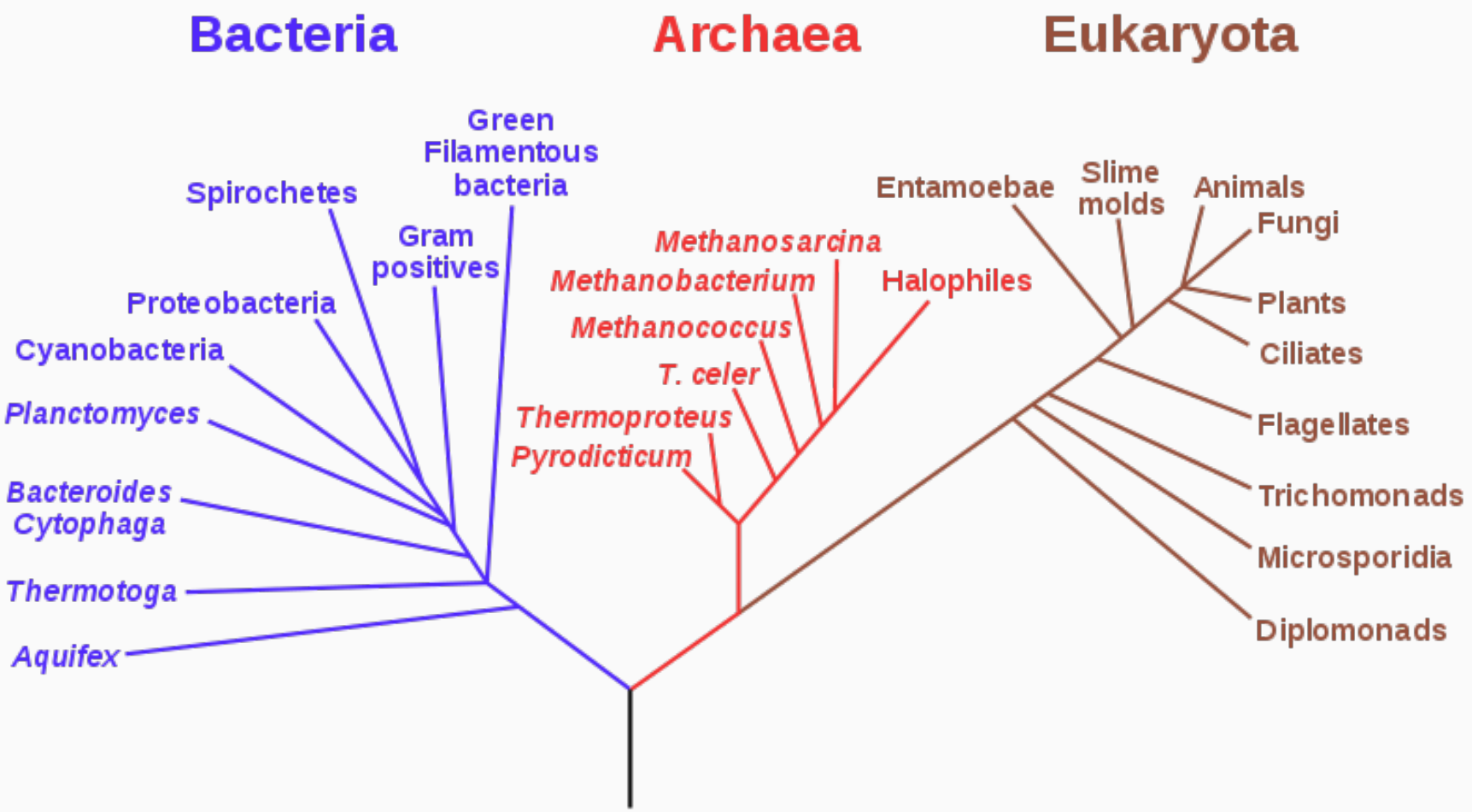
The tree of life



E. Haeckel

Evolution as diversification

The tree of life



From Wikipedia

Success probability

- In hindsight, each tree branch appears as the result of a highly improbable process directed towards the present state
- Looking from the root, there are so many viable choices that the probability of getting "somewhere" is close to one
- And anyway almost 99% of the species which existed are now extinct...: Most roads led to nowhere!

The mechanisms of evolution

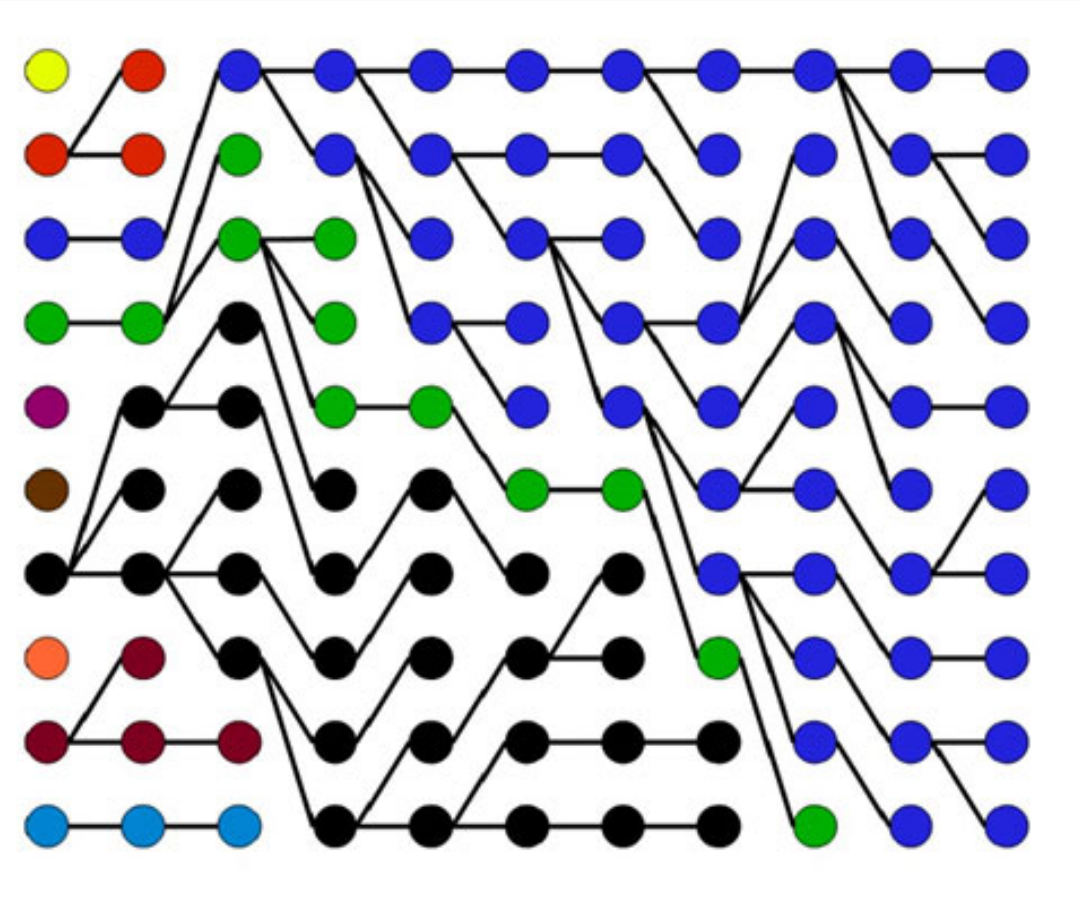
Reproduction: Similar begets similar

Selection: "Survival of the fittest" (Spencer)

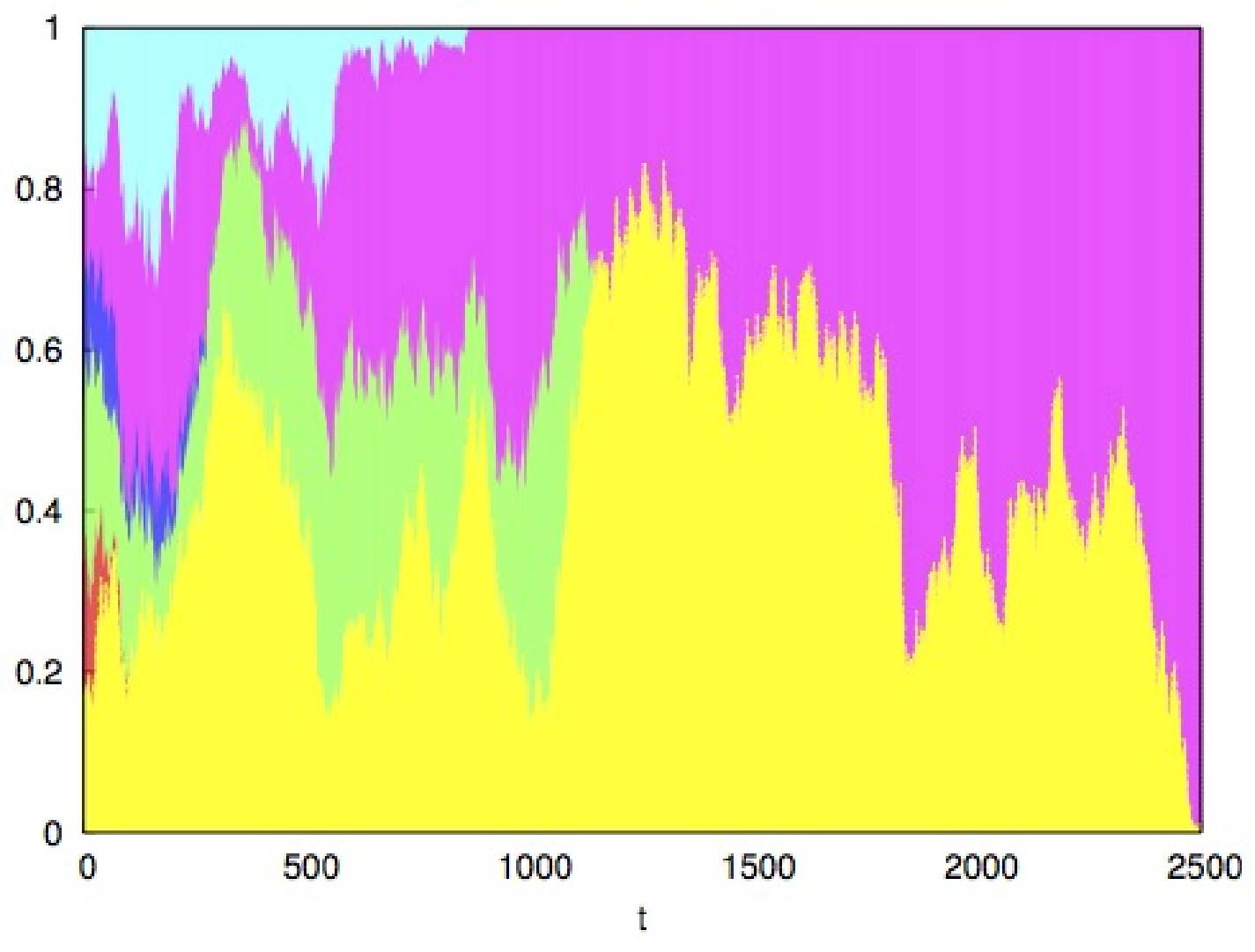
Mutation: Selection acts on a population which remains heterogeneous

Describing the evolutionary process requires a probabilistic approach

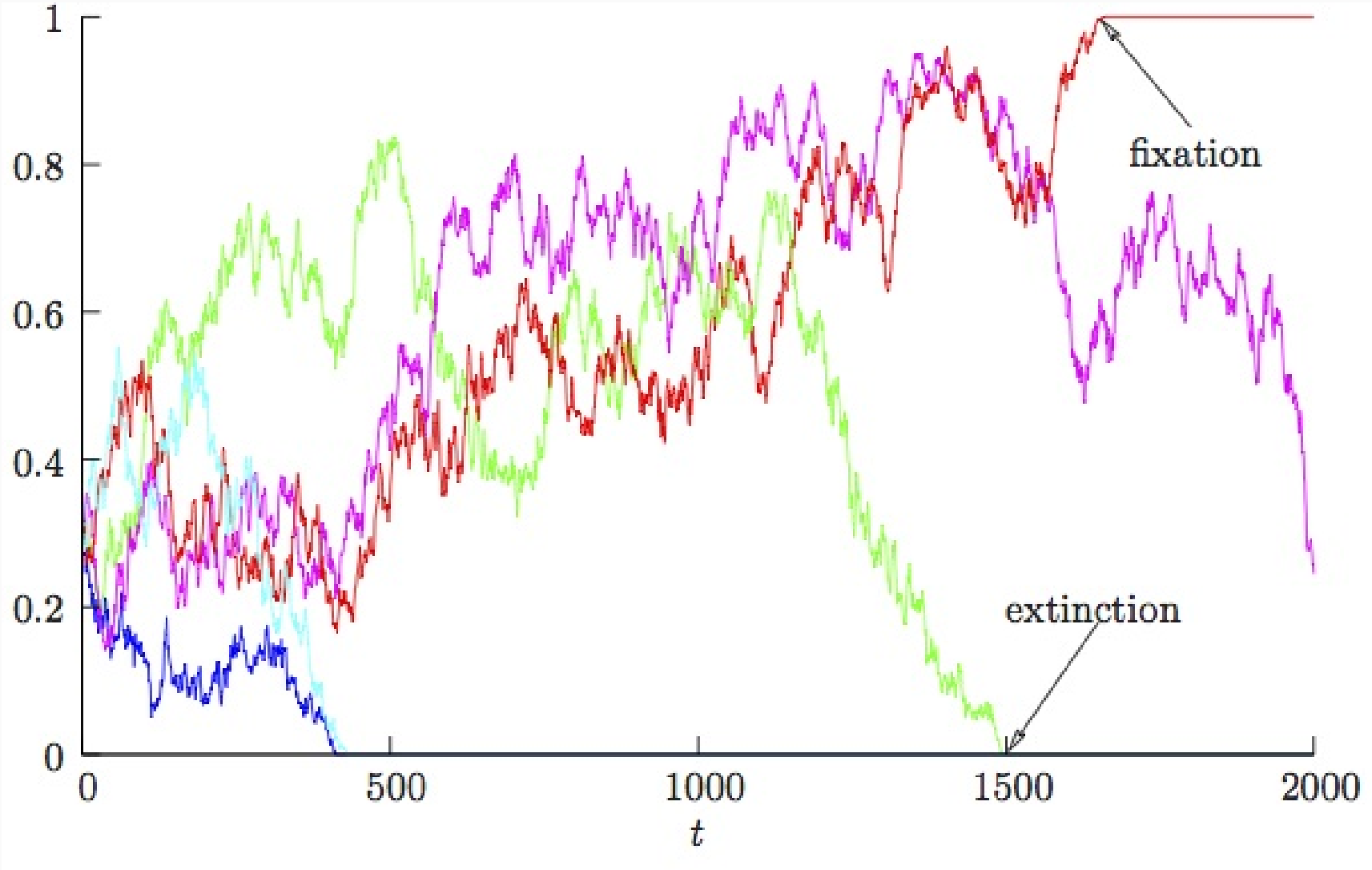
The Wright-Fisher model: The neutral case



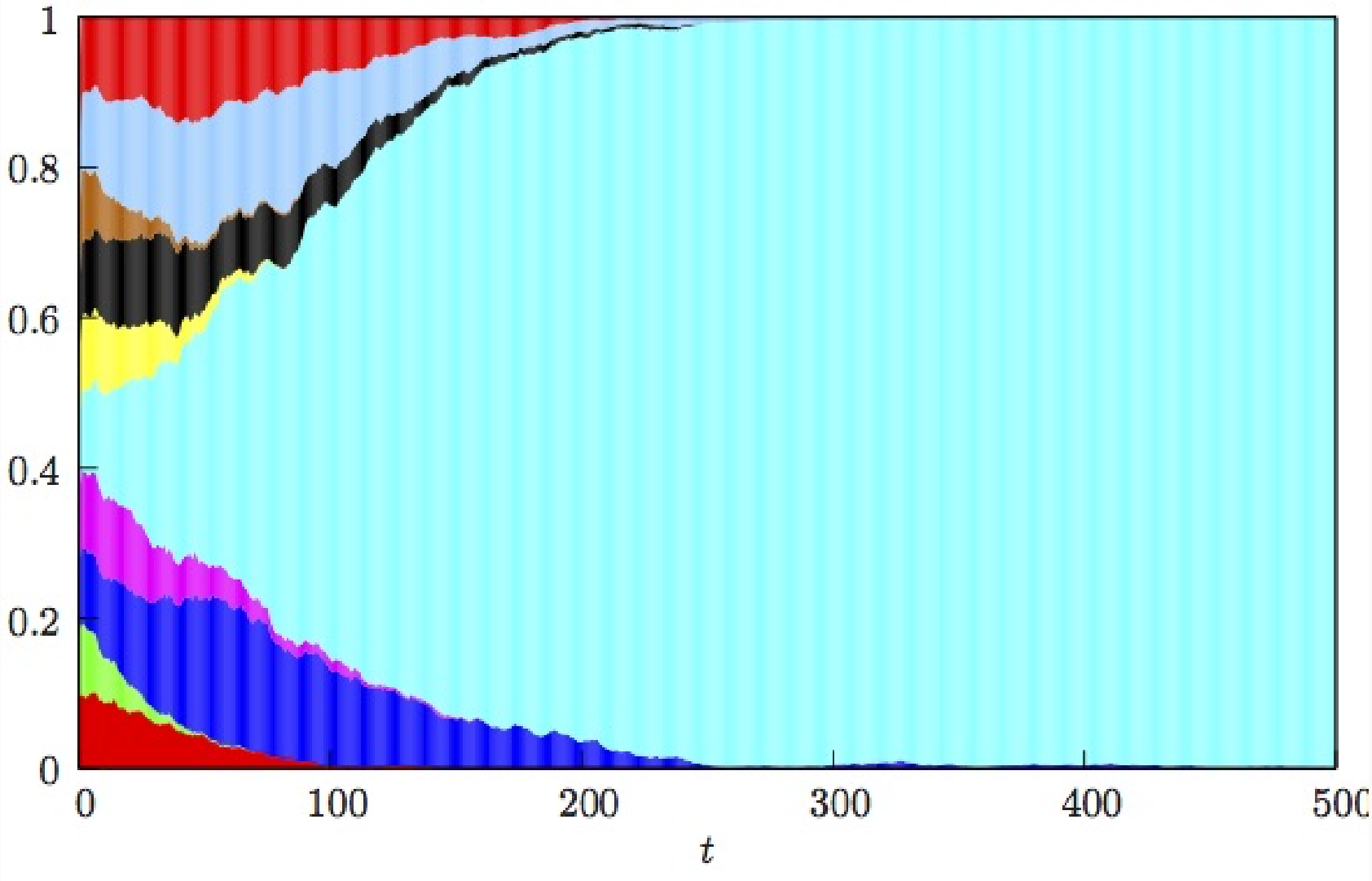
The Wright-Fisher model: The neutral case



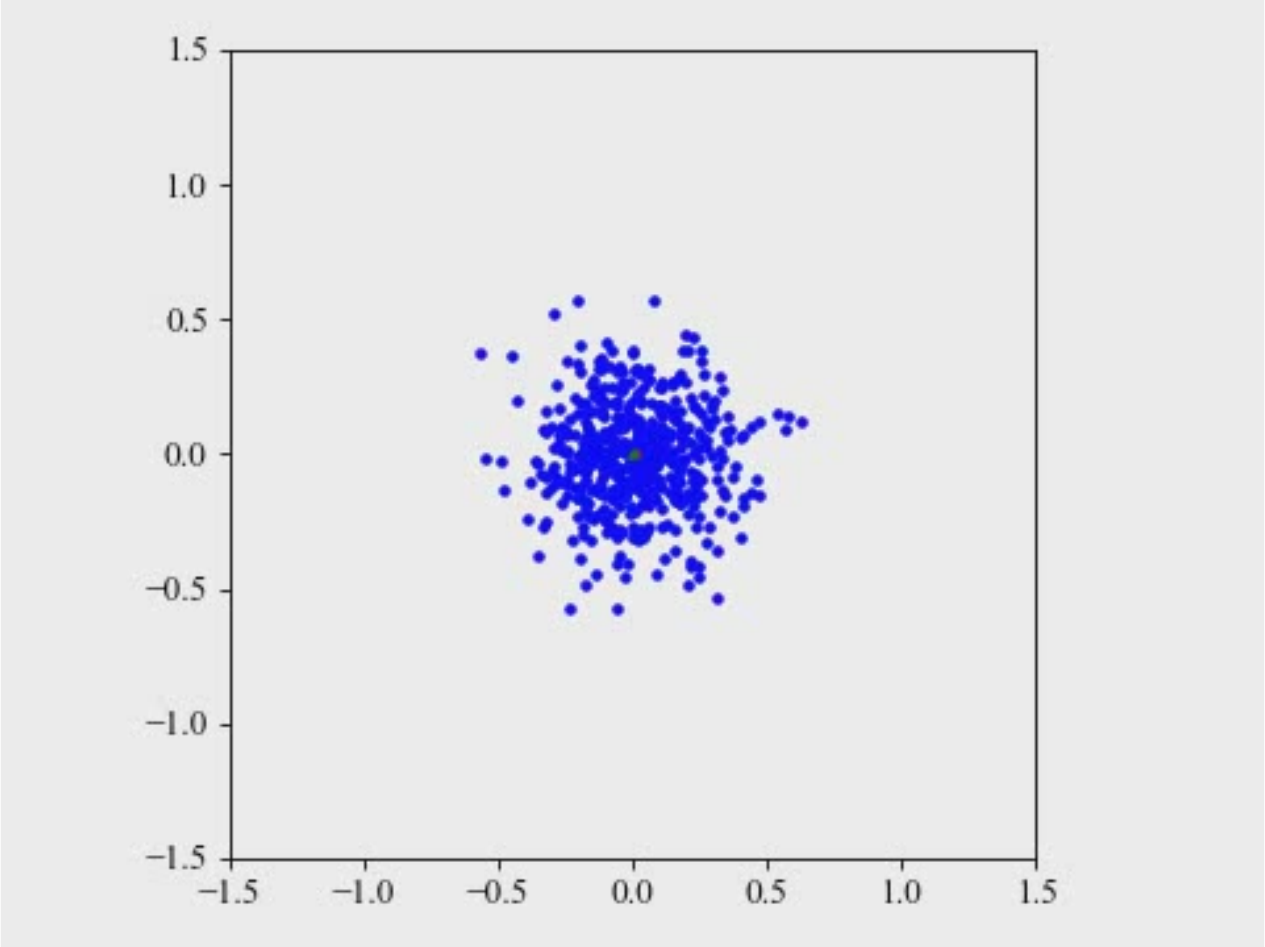
The Wright-Fisher model: The neutral case



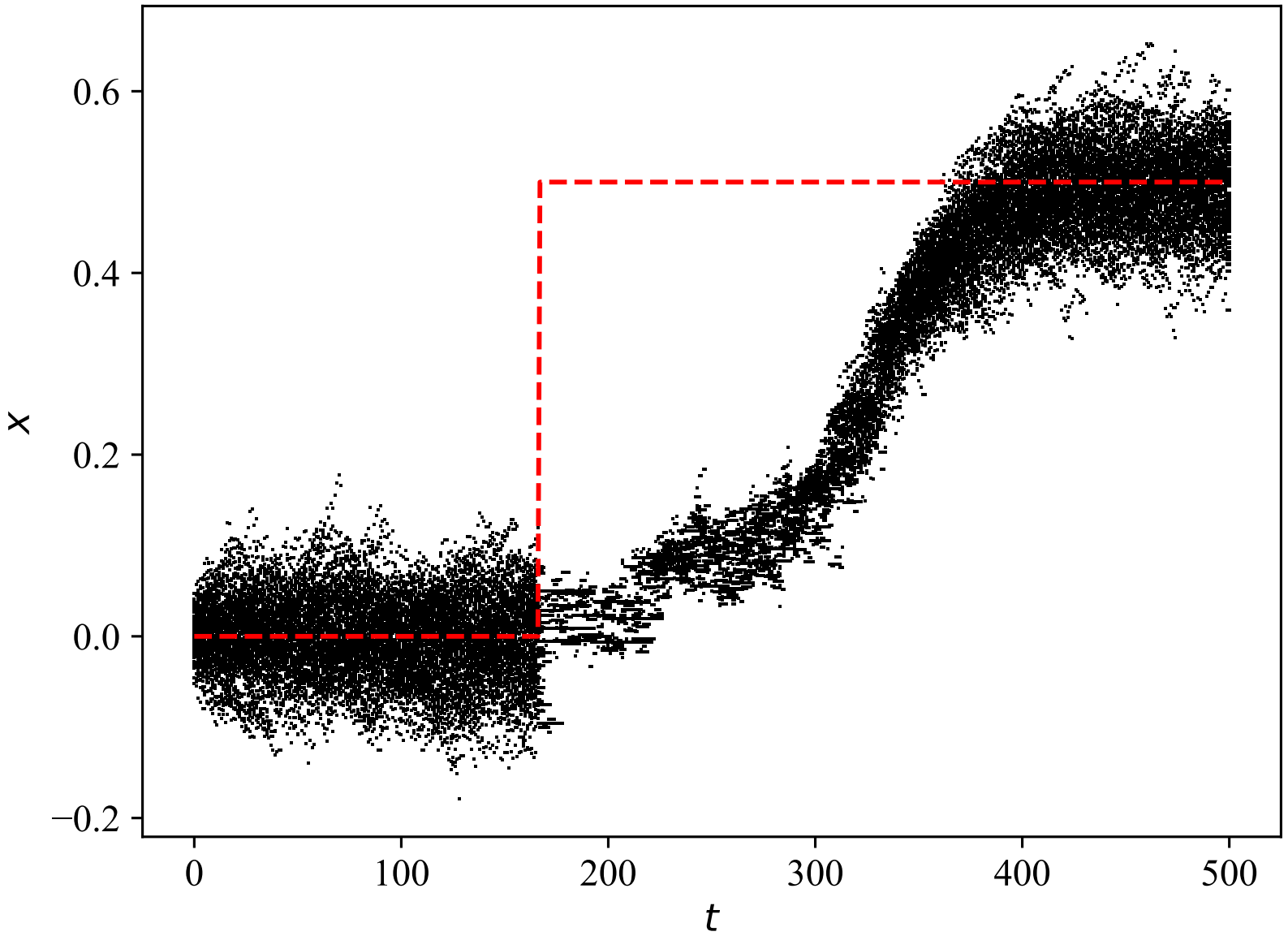
The Wright-Fisher model: The case with selection



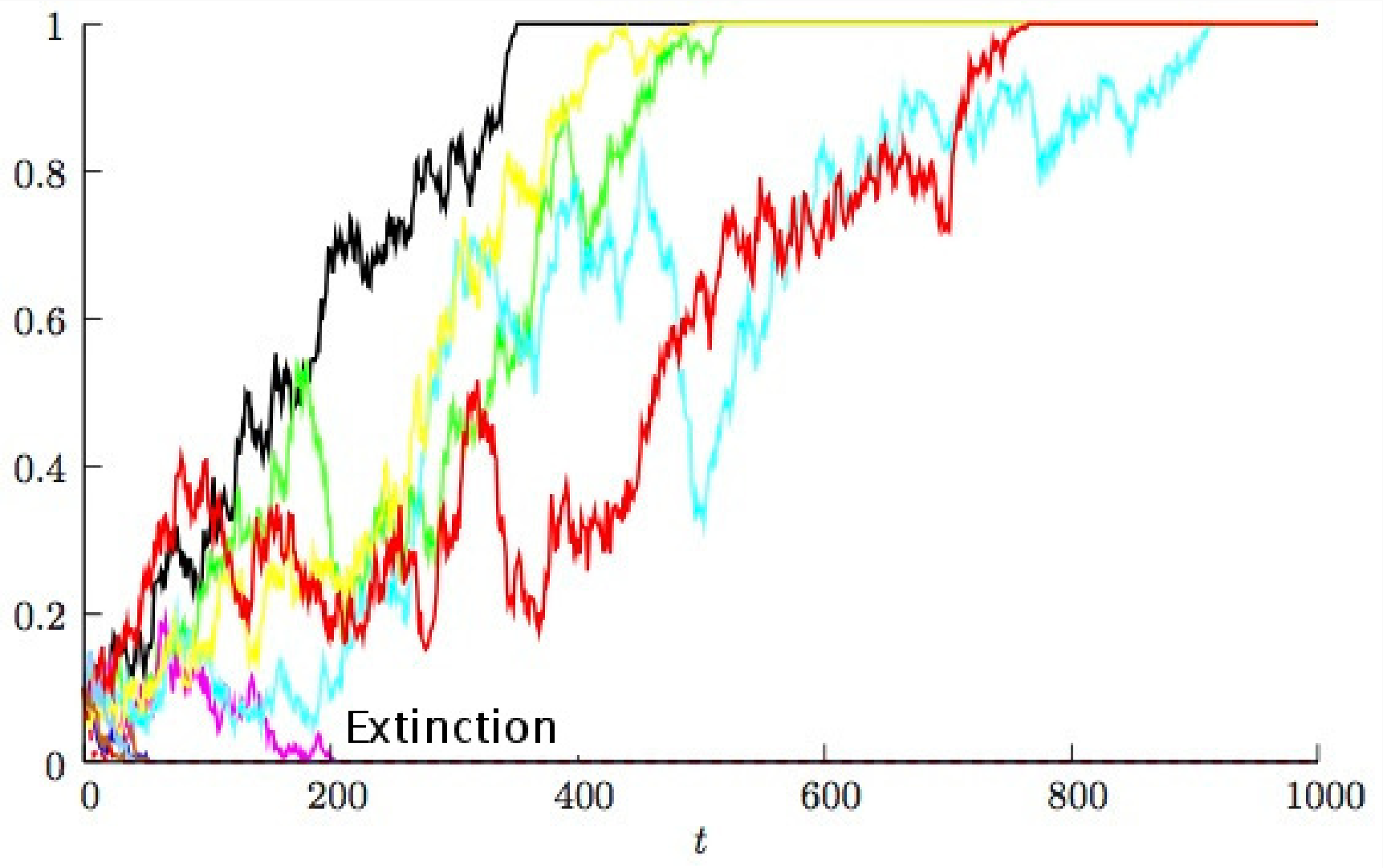
Selecting the improbable



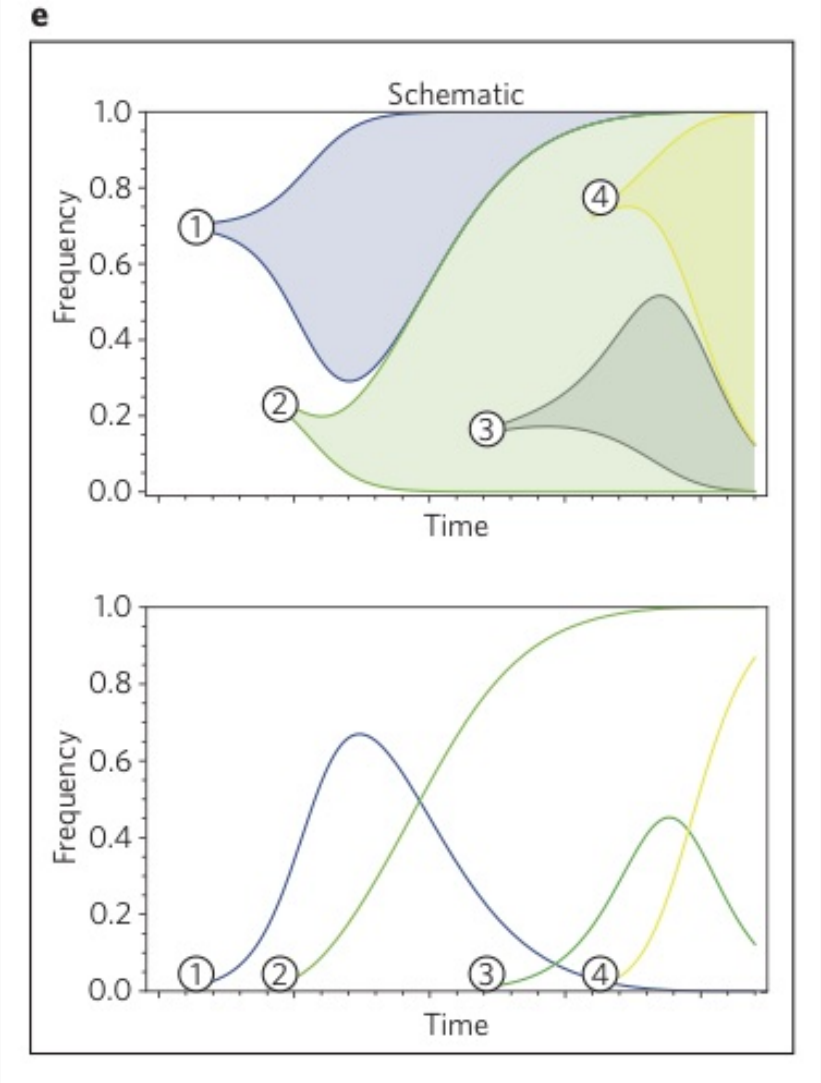
Selecting the improbable



Failures of selection

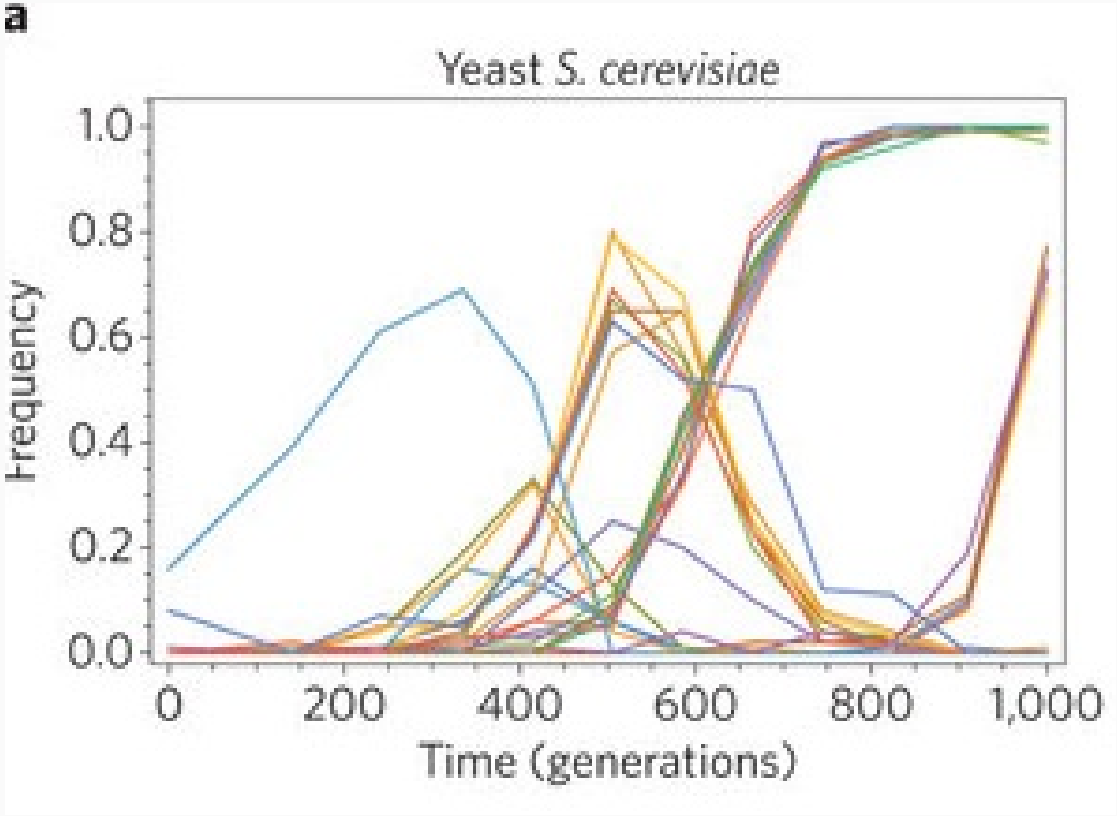


Wright-Fisher model with selection and mutations



A. Nourmohammad et al., 2013

Wright-Fisher model with selection and mutations



Yeast cells under clonal evolution for 1,000 generations. Several sets of mutations first increase in frequency but are eventually outcompeted by another lineage.

M. Lässig et al., 2017

Can we predict evolution?

- Details of evolution cannot be predicted
- Some inferences can however be made
- However some aspects can be predicted with present-day techniques
- An example: The choice of influenza vaccines

Angraecum sesquipedale and Xanthopan morganii praedicta

Darwin's (and Wallace's) prediction on the existence of an impollinating insect

'I have just received such a Box full from Mr Bateman with the astounding Angraecum sesquipedalia [sic] with a nectary a foot long. Good Heavens what insect can suck it'

'Do you know its marvelous nectary 11 1/2 inches [29.2 cm] long, with nectar only at the extremity. What a proboscis the moth that sucks it, must have! It is a very pretty case.'

Darwin, 1862

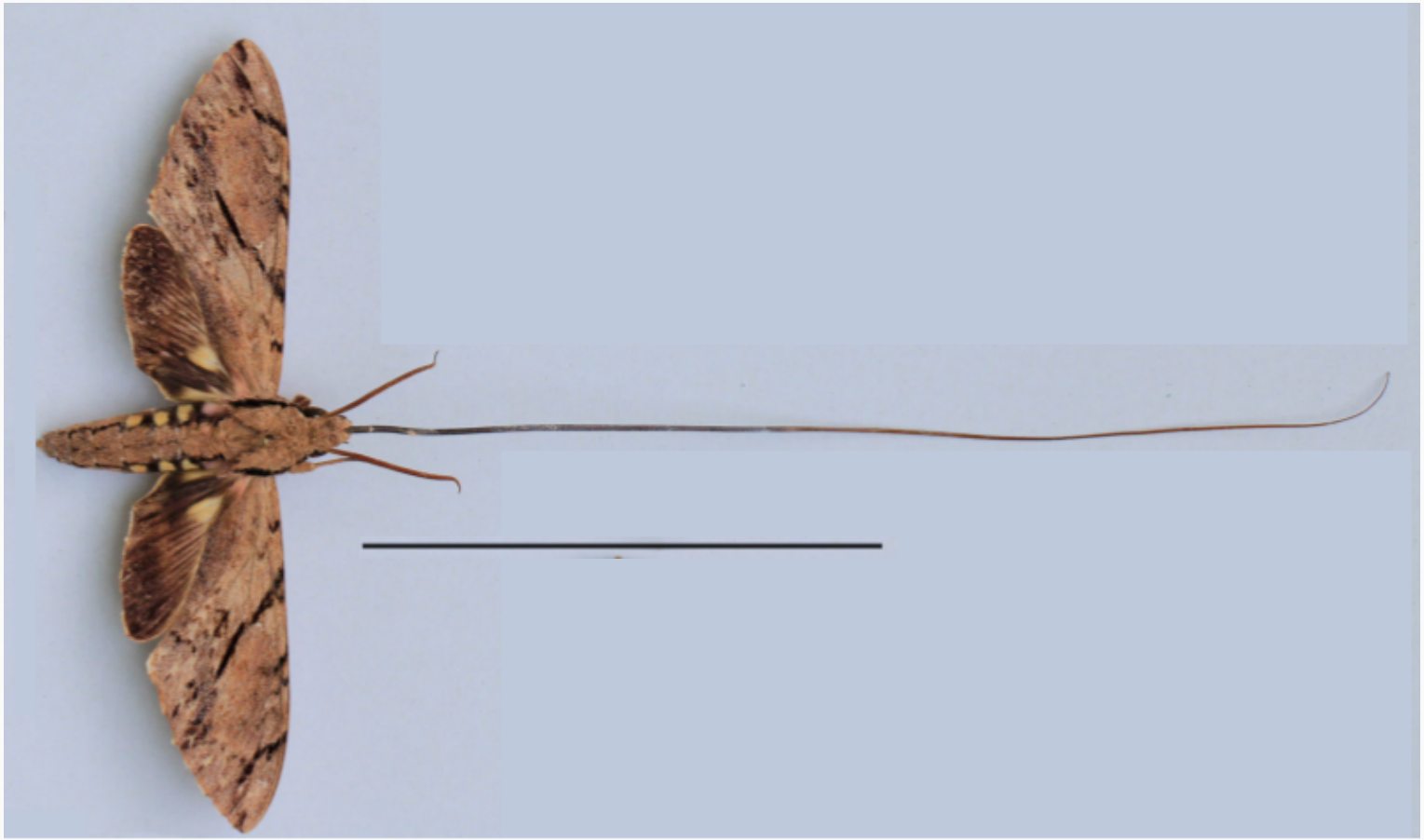
Angraecum sesquipedale and Xanthopan morganii praedicta

Xanthopan morganii praedicta was discovered in 1903, but only in 1992 it was shown sucking A. sesquipedale's nectar.

Arditti et al., 2012

Angraecum sesquipedale and Xanthopan morganii praedicta

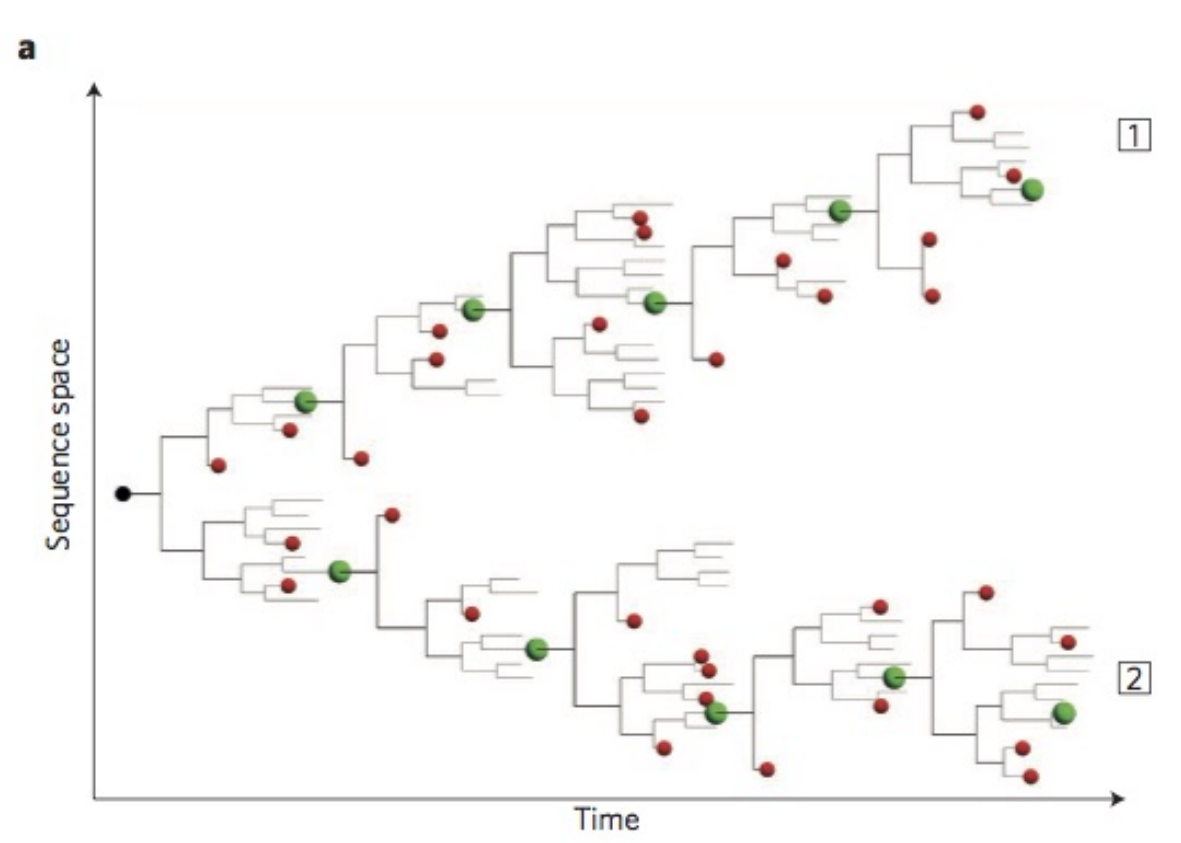
X. morganii praedicta's giant proboscis



Bar: 10cm

Arditti et al., 2012

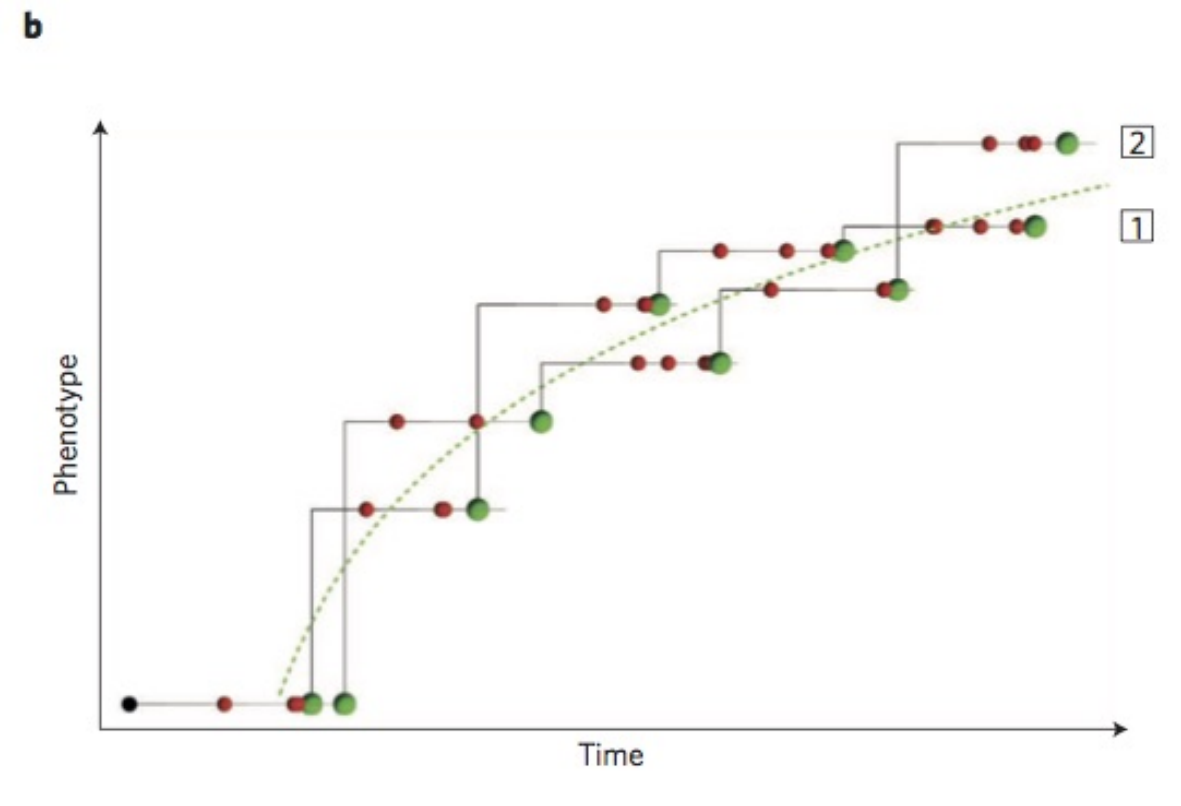
Evolution in genotypic space



The evolution in genotypic space exhibits a large number of paths with equal probability. This process is only partially constrained by selection (red points). Genotypic evolution is neither reproducible nor predictable.

Lässig et al. 2017

Evolution in phenotypic space

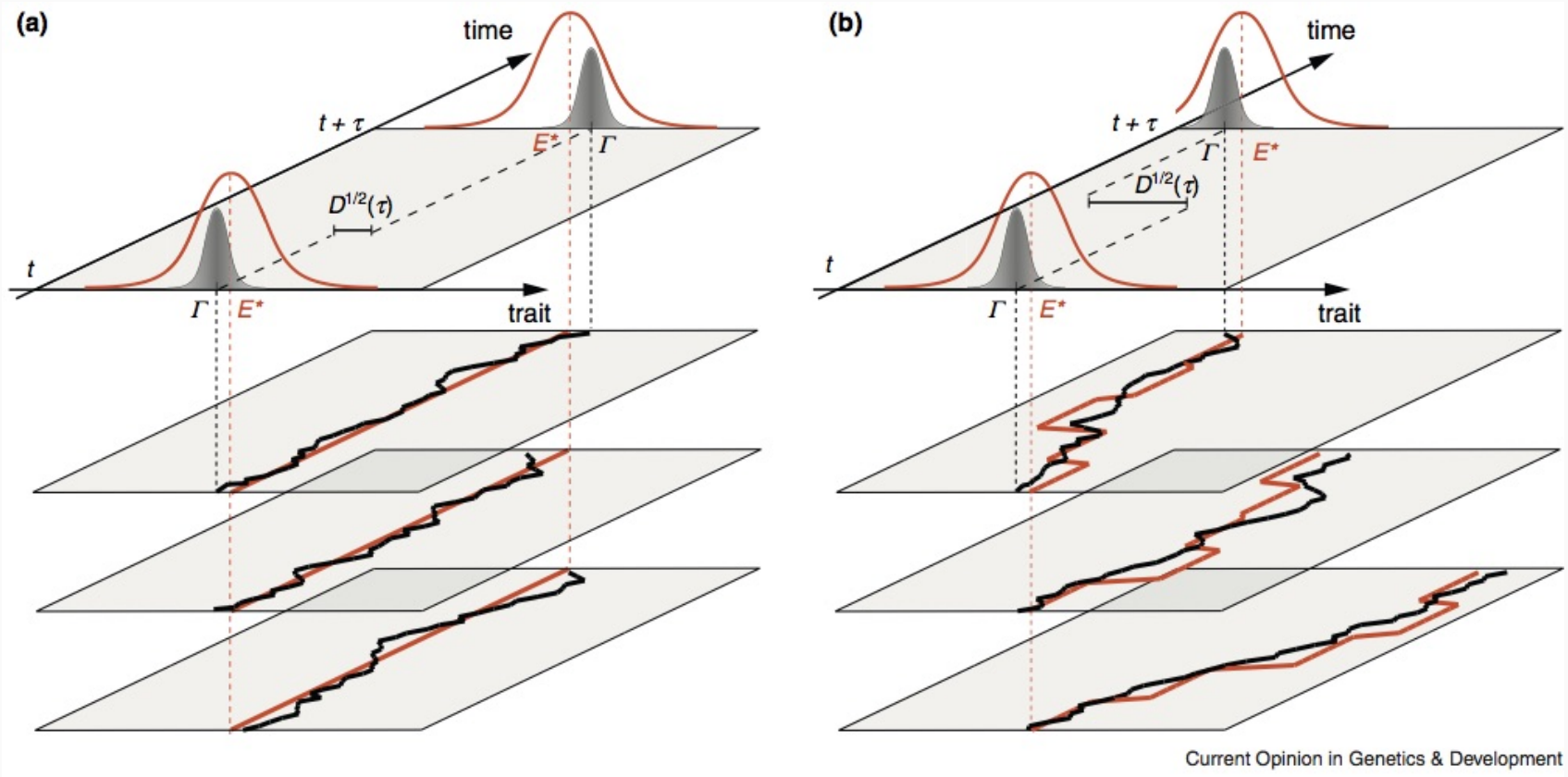


The evolution in phenotypic space is more predictable because the number of options is smaller and the options can be distinguished and ranked.

Lässig et al. 2017

Evolution of quantitative traits

Distribution of a quantitative trait in several populations



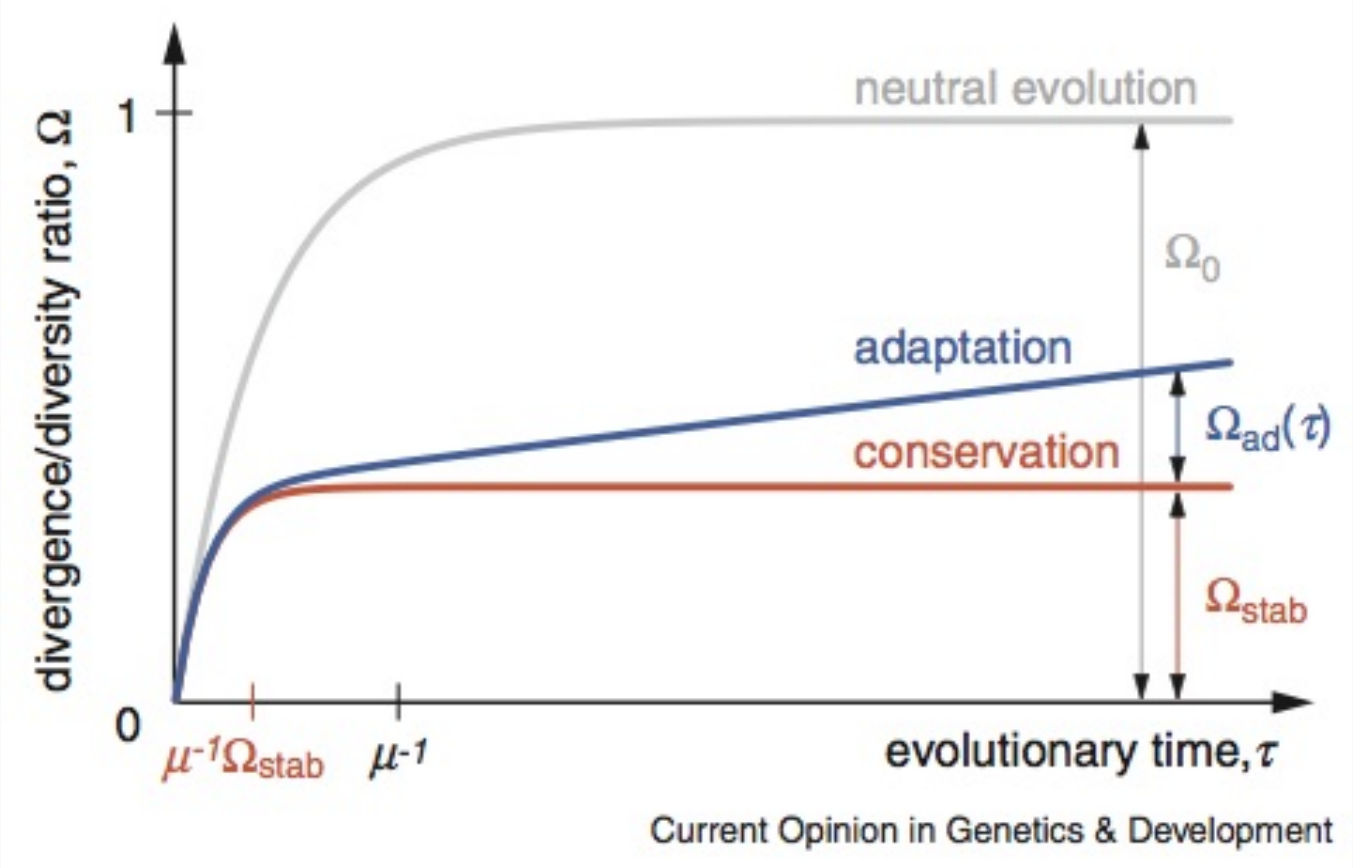
(a) Stabilizing selection (constant optimum)

(b) Adapting evolution (variable optimum)

A. Nourmohammad et al., 2013

Evolution of quantitative traits

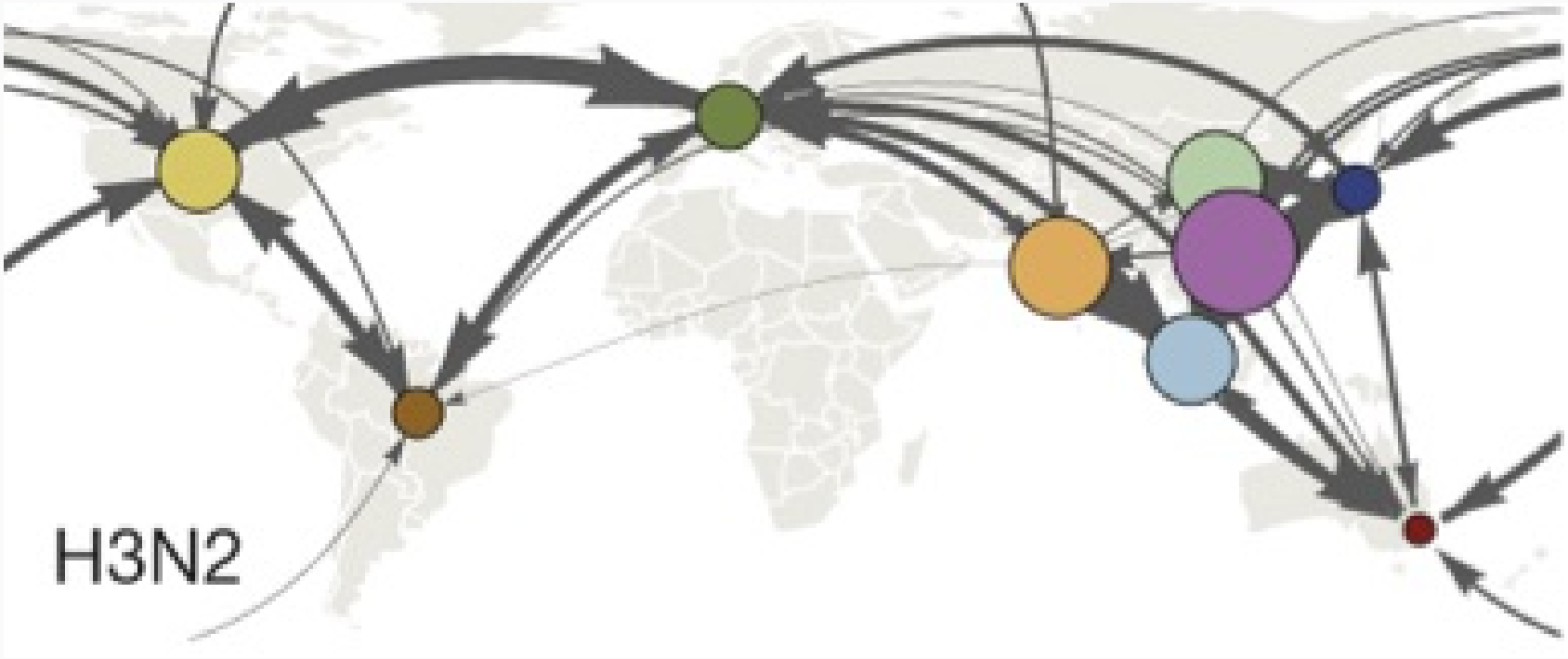
Evolution of a quantitative trait in different modes



The evolution pattern allows to identify the selection mode

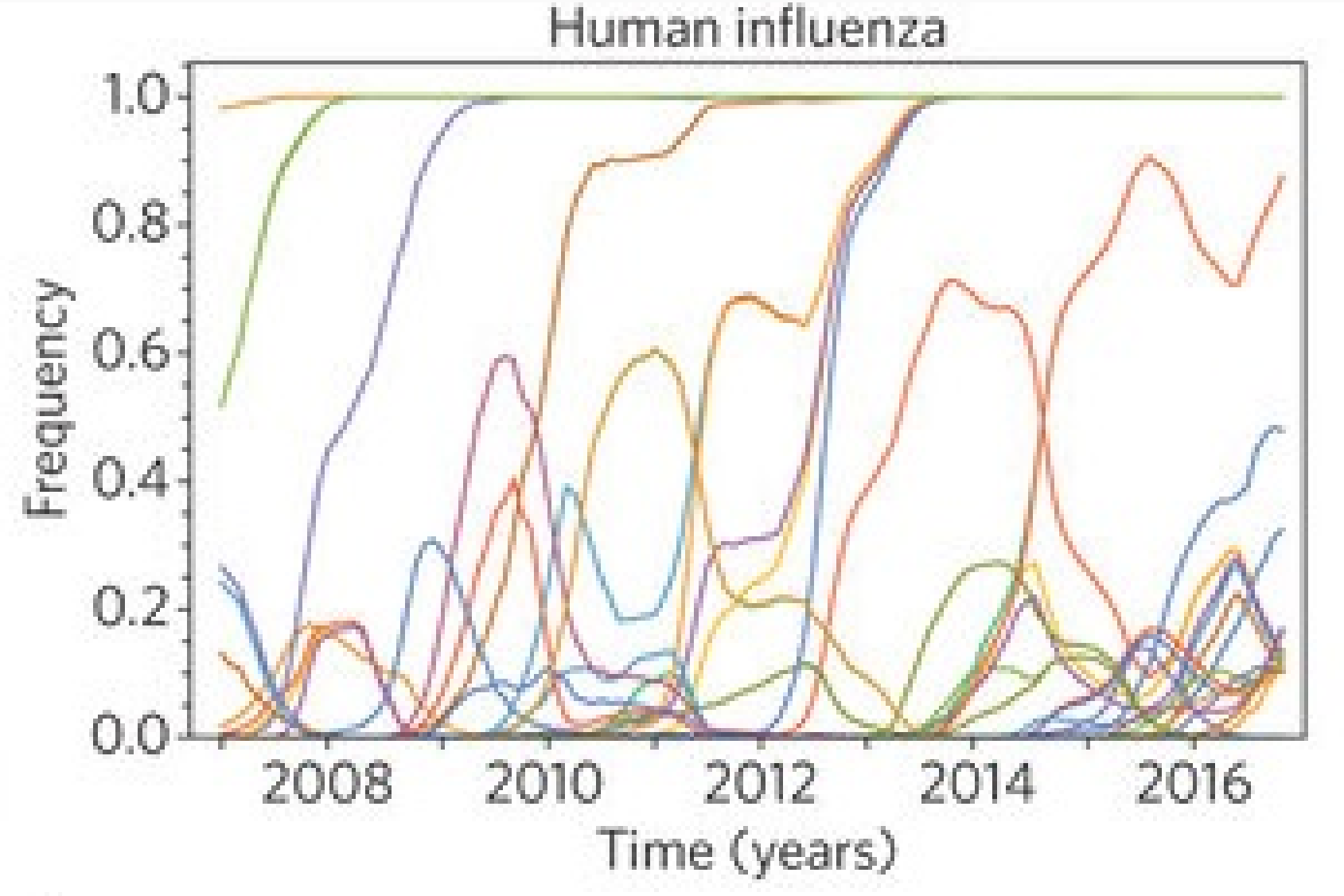
A. Nourmohammad et al., 2013

The global circulation of influenza



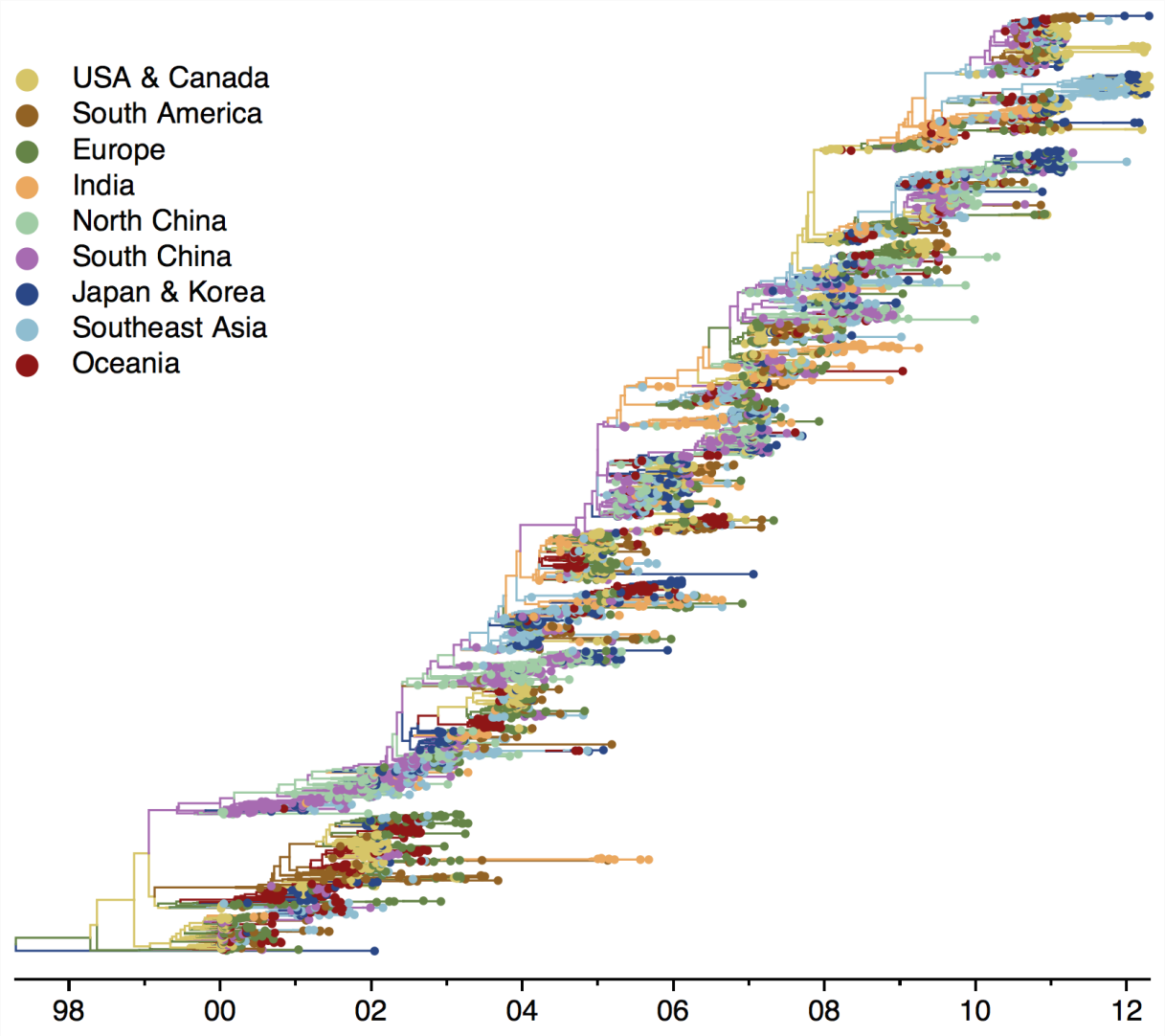
Bedford et al., 2015

The global circulation of influenza



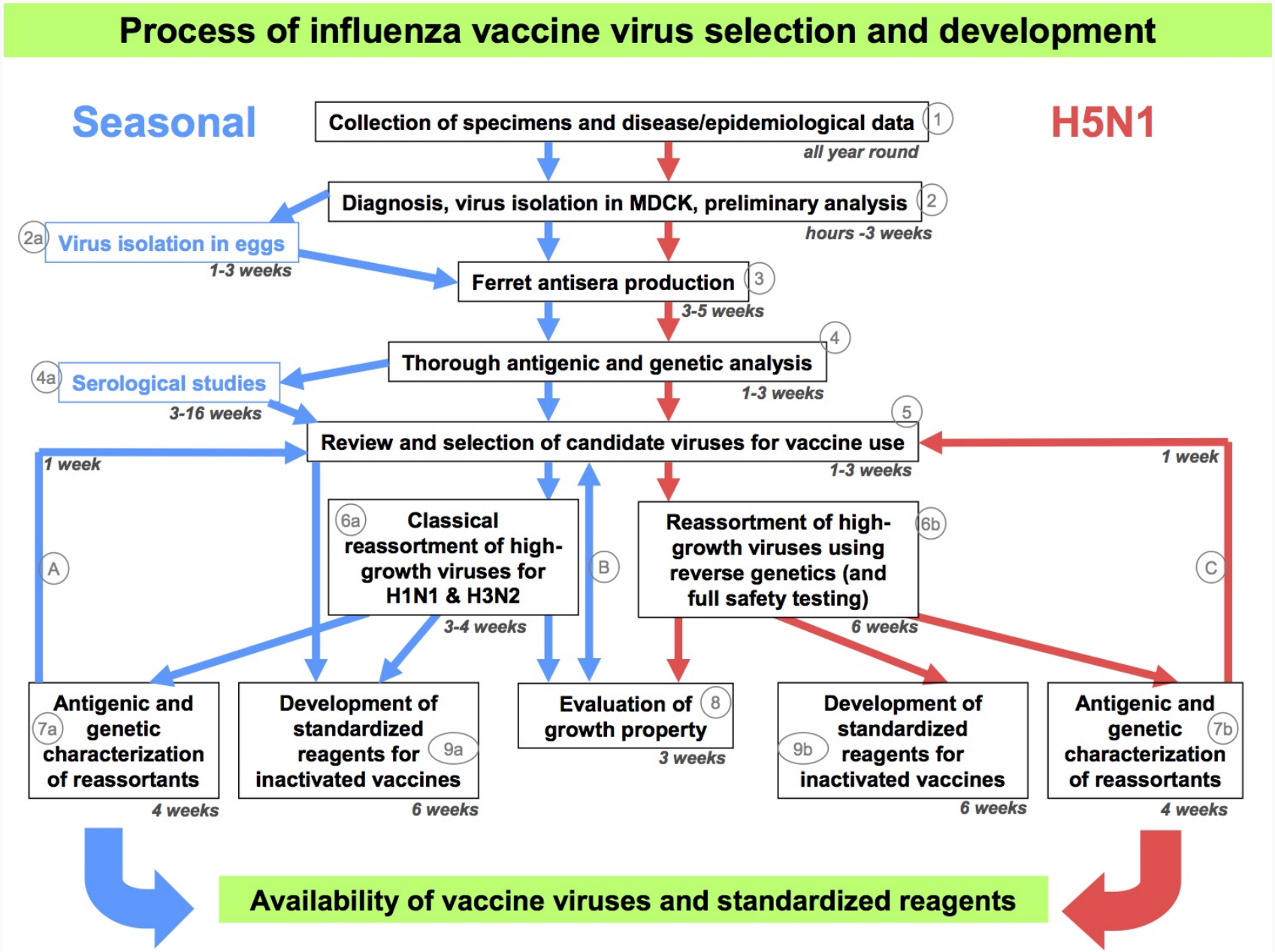
Lässig et al., 2017

The global genealogy of influenza



Bedford et al., 2015

The selection of influenza vaccines



Evolution and probability

- Nothing in biology makes sense except in the light of evolution (Dobzhansky)
- Nothing in evolution makes sense except in the light of probability
- The details of genotypic evolution are neither reproducible nor predictable
- The evolution of quantitative traits (e.g., antibody effectiveness, but also antibiotic resistance) can be predicted with present-day techniques

Thank you!

Further reading

- R. A. Fisher, The Genetical Theory of Natural Selection (Oxford: Clarendon Press, 1930)
- F. Jacob, Evolution and tinkering, Science **196** 1161–1166 (1977)
- J. Arditti et al., 'Good Heavens what insect can suck it' – Charles Darwin, Angraecum sesquipedale and Xanthopan morganii praedicta, Botanical Journal of the Linnean Society **169** 403–432 (2012)
- A. Nourmohammad et al., Universality and predictability in molecular quantitative genetics, Curr. Op. in Genetics & Development **23** 684–693 (2013)
- M. Lässig et al., Predicting evolution, Nature ecology & evolution **1** 0077 (2017)
- T. Bedford et al., Global circulation patterns of seasonal influenza viruses vary with antigenic drift, Nature **523** 217–220 (2015)
- www.who.int/entity/influenza/vaccines/virus/recommendations/2017_18_north/en/index.html