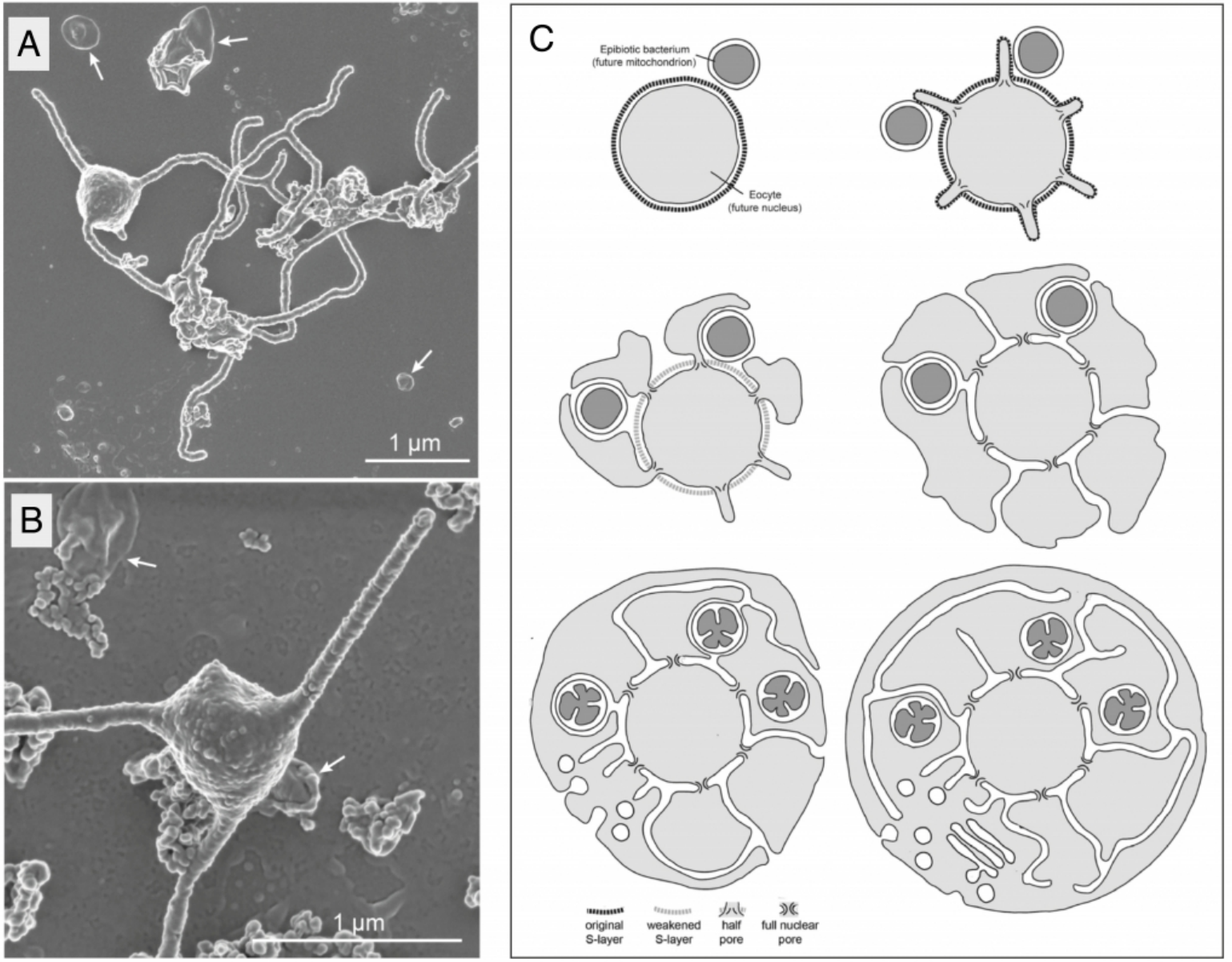
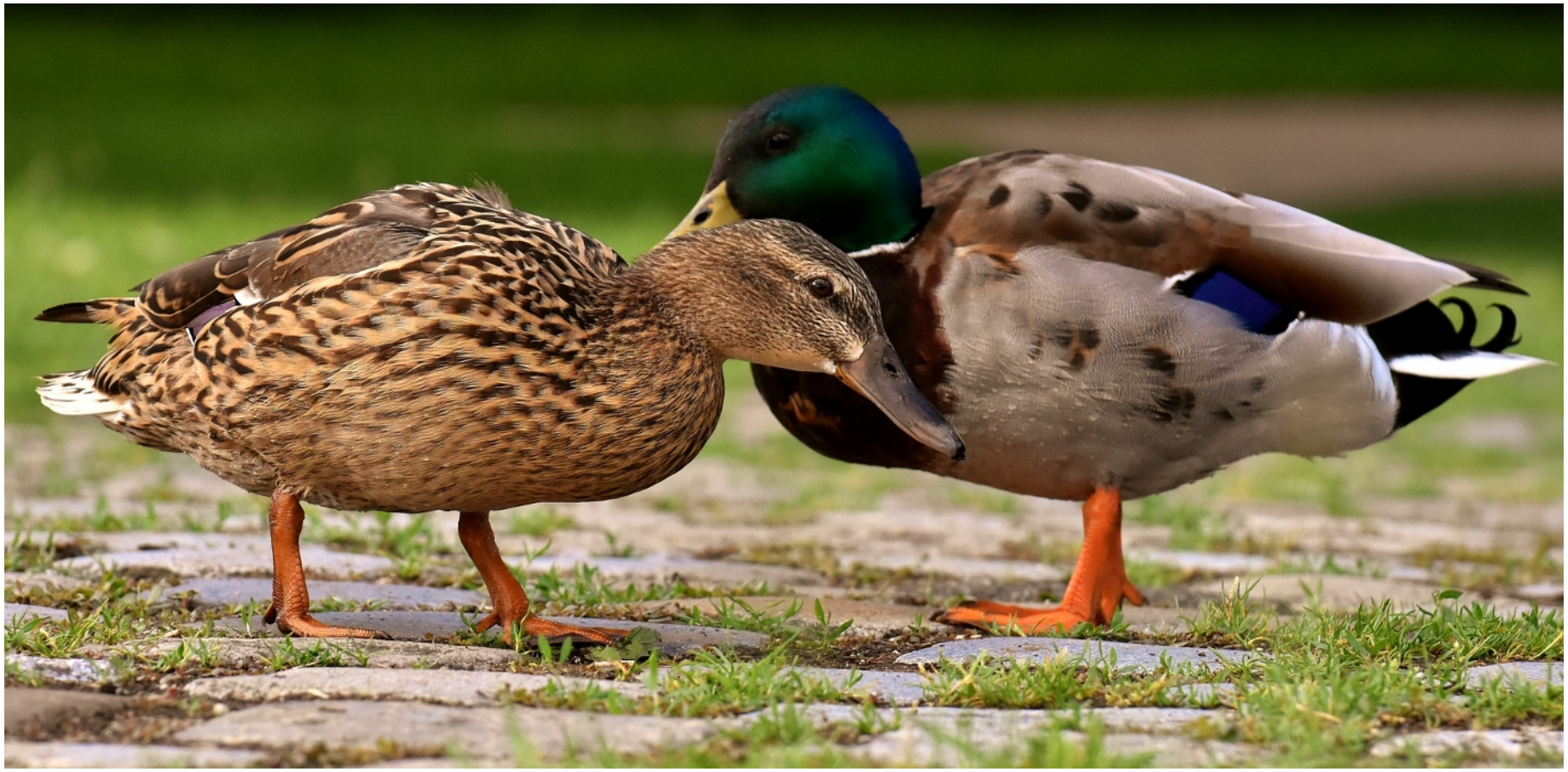
“Inside-out” model for eukaryogenesis



igure 3 of Imachi, Nobu et al. 2019

https://prelights.biologists.com/highlights/isolation-of-an-archaeon-at-the-prokaryote-eukaryote-interface/

Evolution (II)



V. Courtier

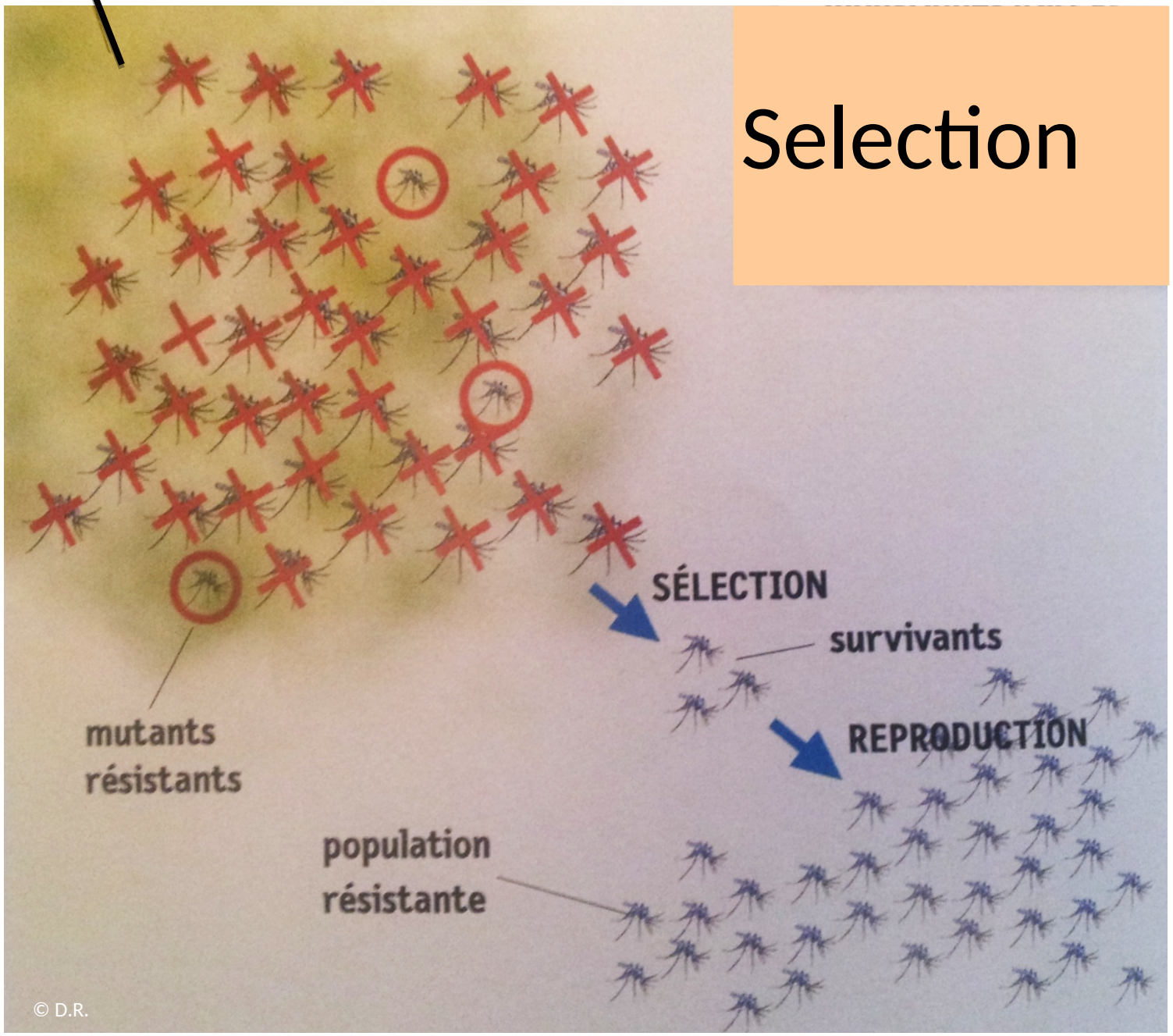
2026

”Another curious aspect of the theory of evolution is that everybody thinks he understands it. I mean philosophers, social scientists, and so on. While in fact very few people understand it, actually, as it stands, even as it stood when Darwin expressed it, and even less as we now may be able to understand it in biology.”

Jacques Monod, 1975, On the molecular theory of evolution.

The theory of evolution

Insecticide



Selection

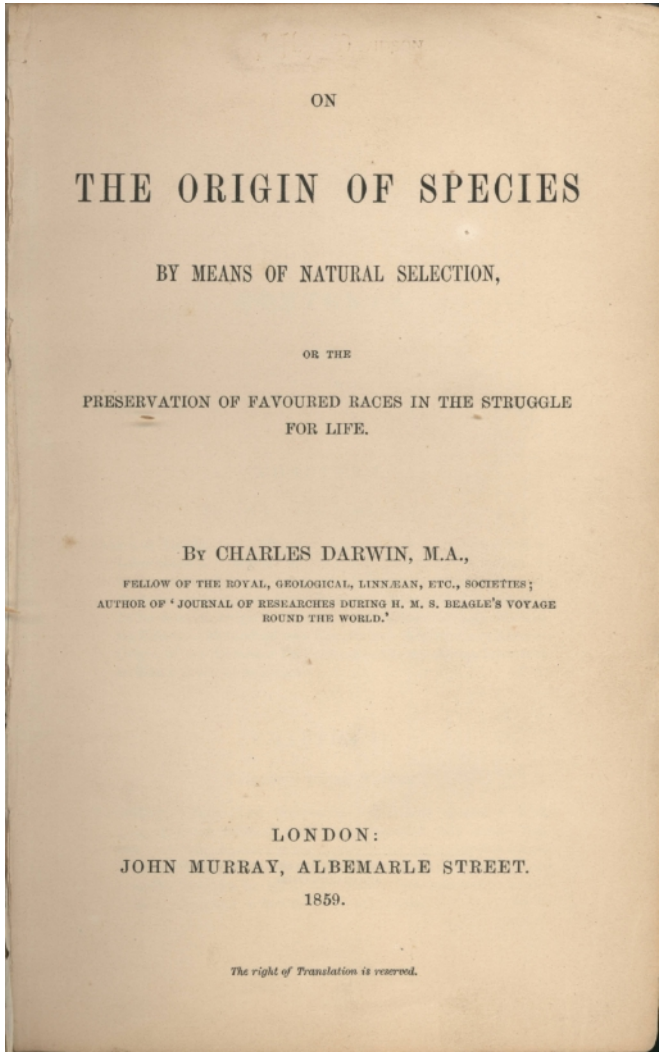
"Places not more than fifty or a hundred miles apart often have species of insects and birds at the one, which are not found at the others. There must be some boundary which determines the range of each species; some external peculiarity to mark the line which each one does not pass."

"In all works on Natural History, we constantly find details of the marvellous adaptation of animals to their food, their habits, and the localities in which they are found. But naturalists are now beginning to look beyond this, and to see that there must be some other principle regulating the infinitely varied forms of animal life."

Alfred R. Wallace



Charles Darwin
1859
« The origin of species »



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

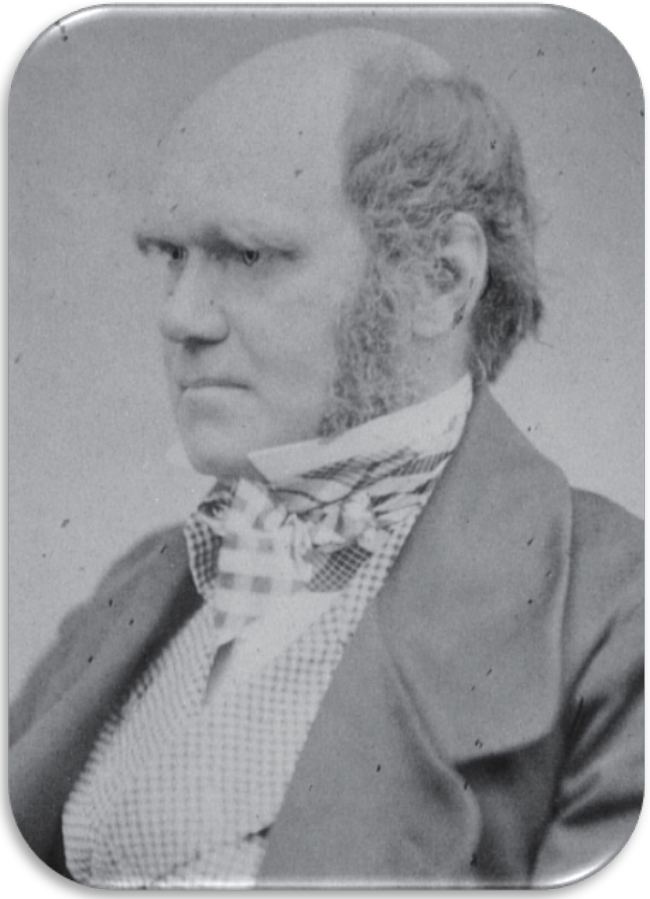
By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.





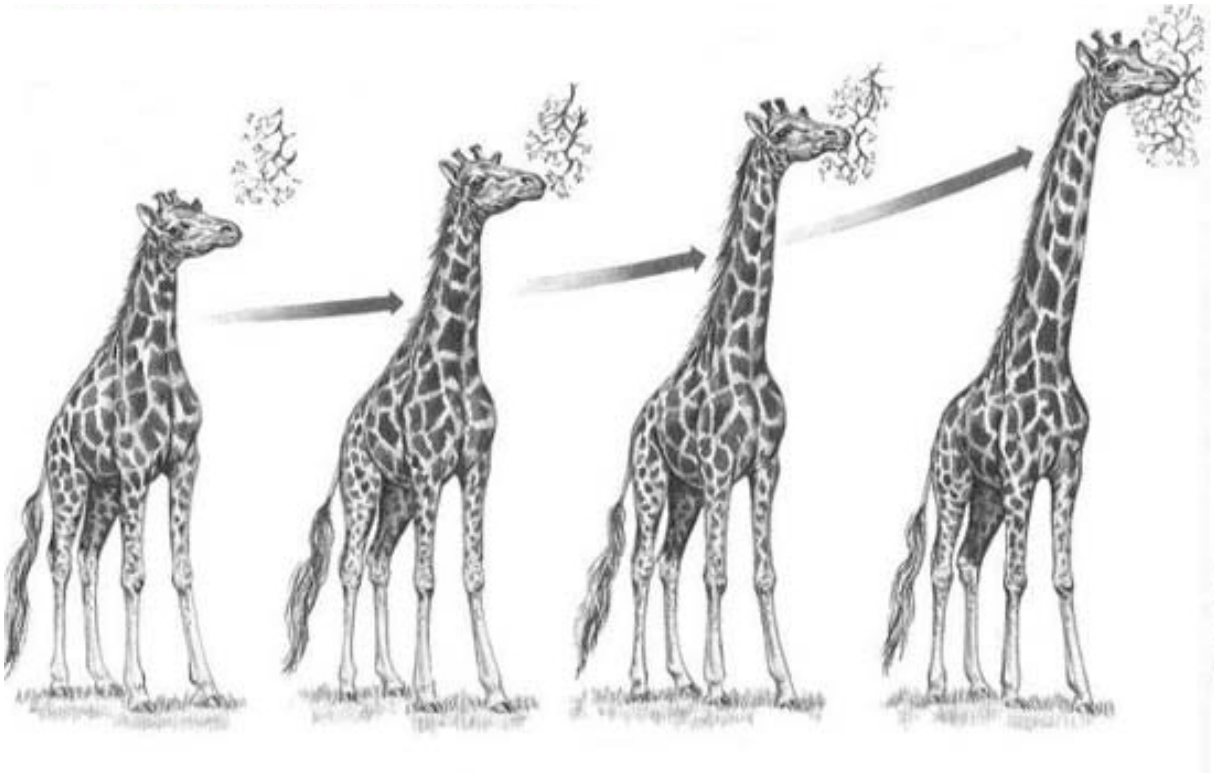
"I could never have approached the completeness of his book—its vast accumulation of evidence, its overwhelming argument, and its admirable tone and spirit. I really feel thankful that it has not been left to me to give the theory to the public."

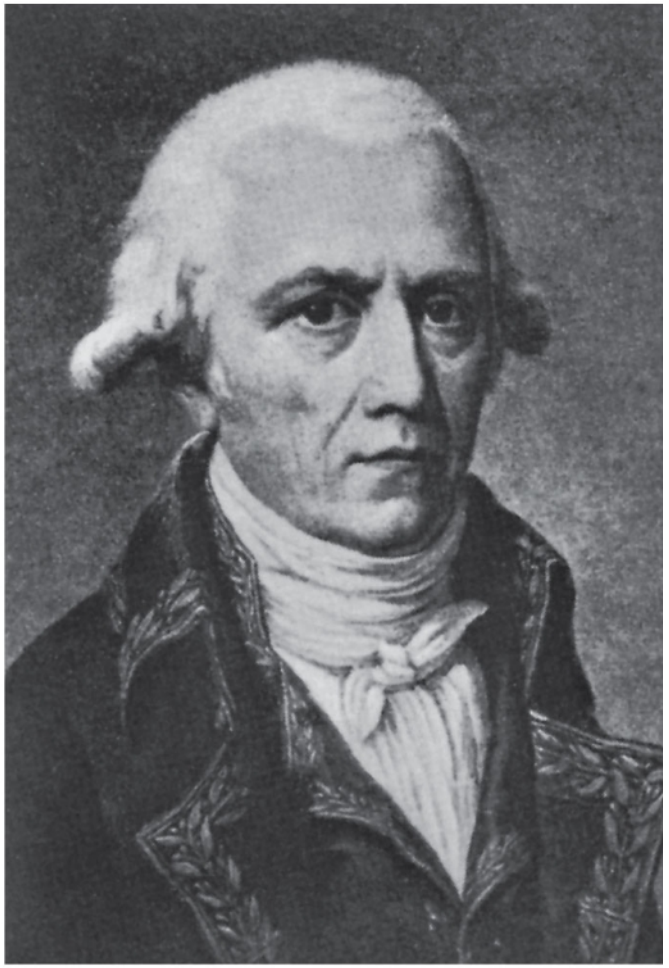
Letter of Alfred R. Wallace to a friend, H.W. Bates



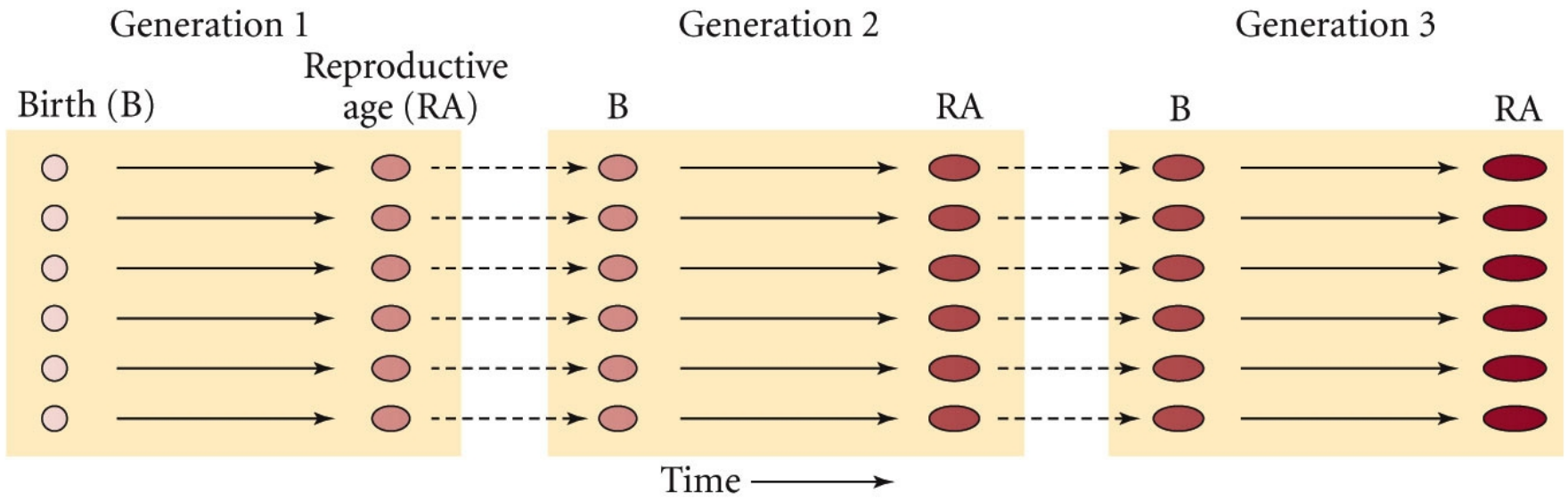
Jean-Baptiste Lamarck (1744-1829)

Hérédité des caractères acquis

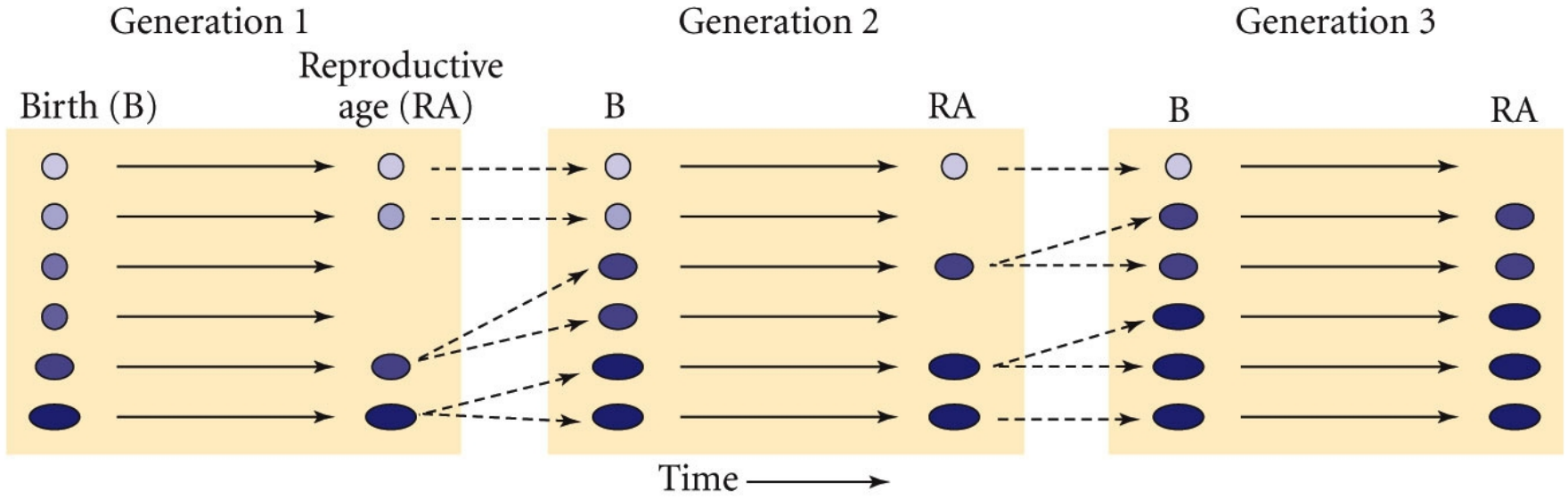




Transformational evolution



Variational evolution



Les trois piliers de l'évolution

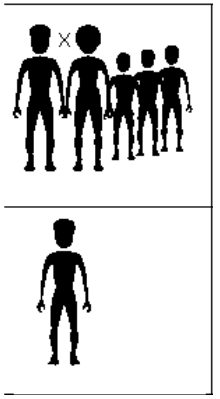
Variation

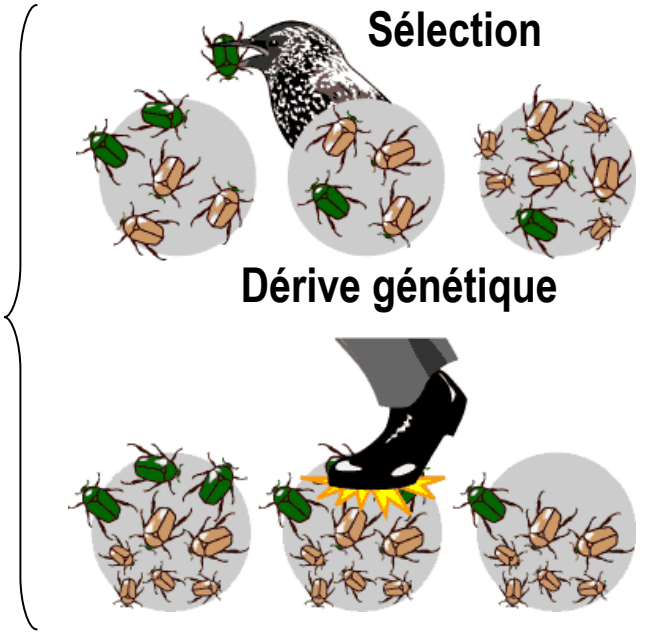
Mutations de l'ADN

Transmission



Reproduction différentielle



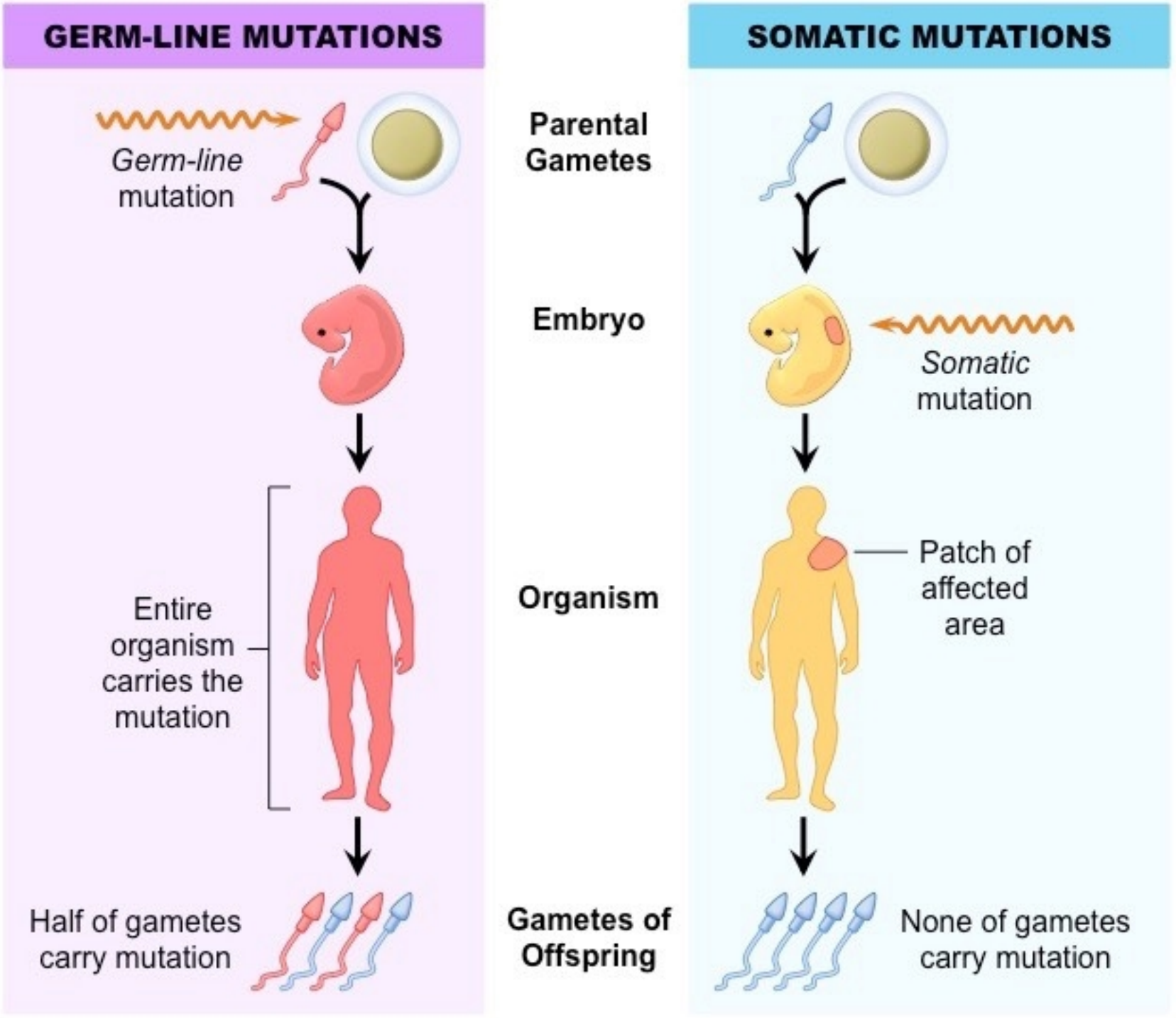


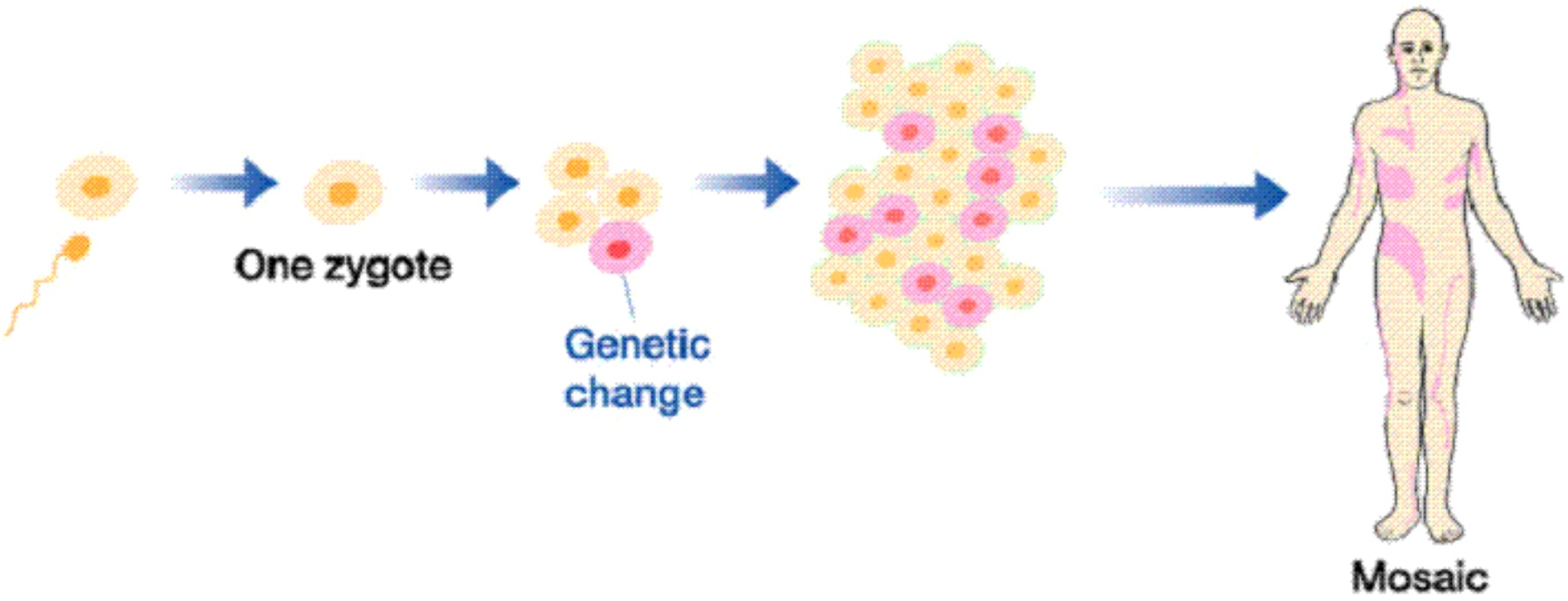
Les 4 forces évolutives

Mutation
Sélection
Dérive
Migration

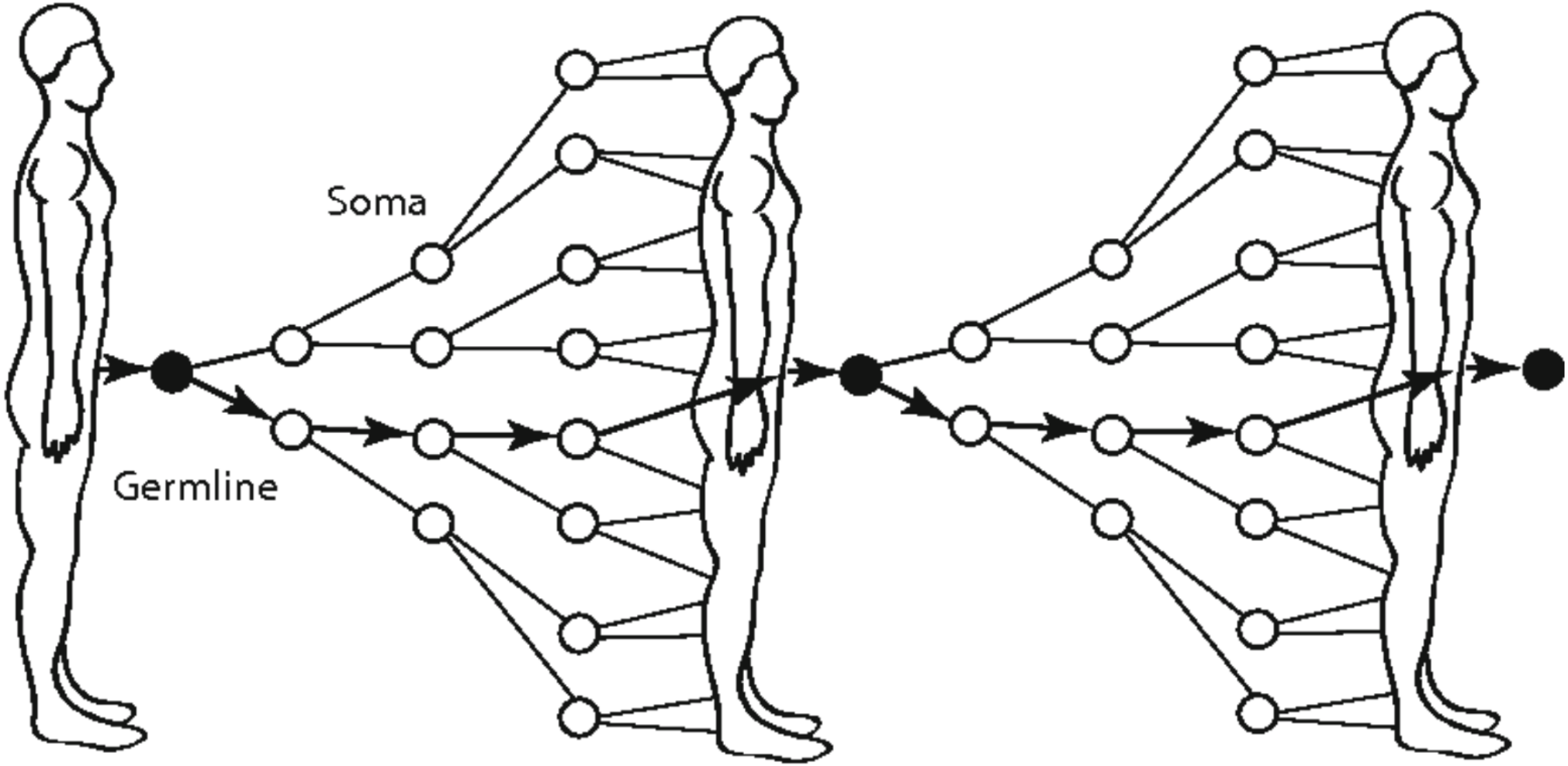
Lignée germinale

Lignée somatique



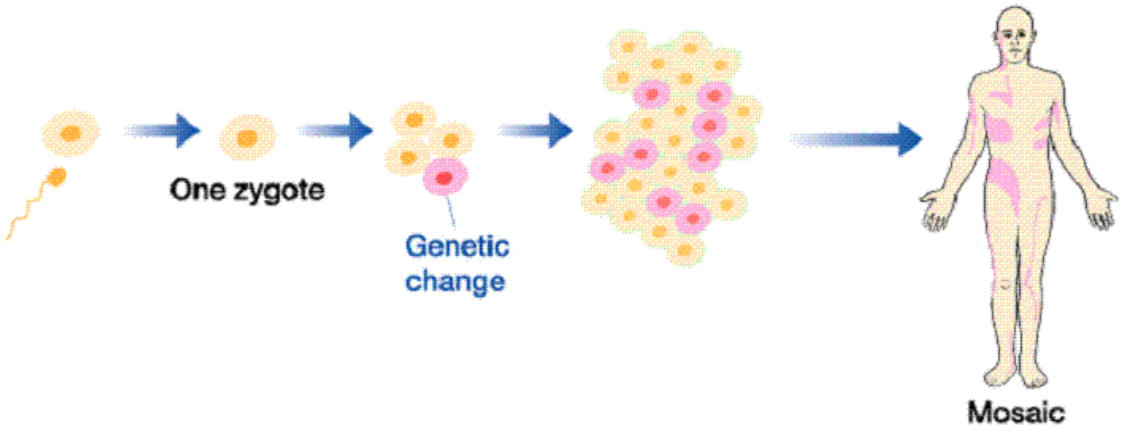

One zygote
Genetic change
Mosaic

August Weismann’s germplast theory (1892)



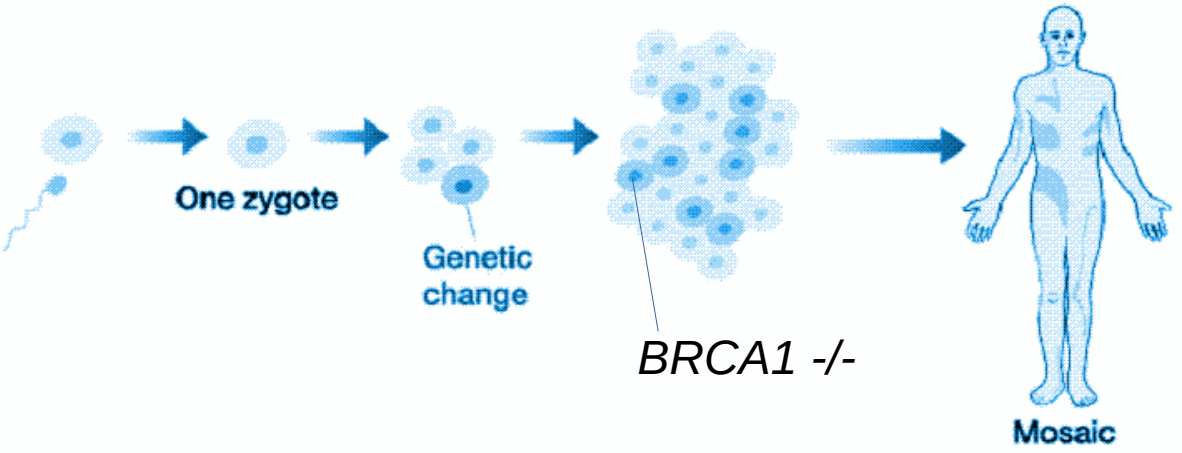
Changes acquired during an organism's life cannot affect its offspring

woman
BRCA1 +/+



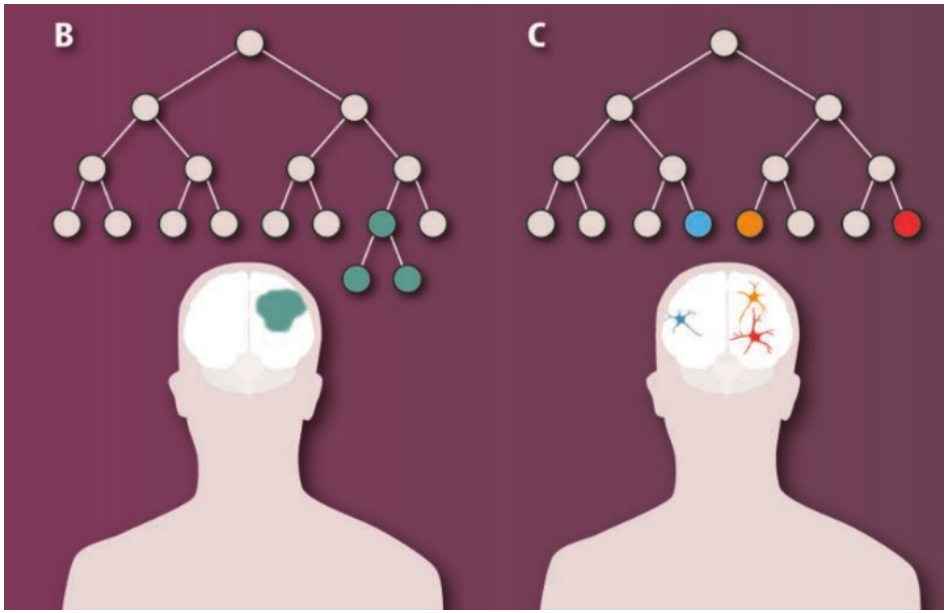
10% chance to develop breast cancer

woman
BRCA1 +/-



45% chance to develop breast cancer before 70 years old
Cancer cells will be *BRCA1 -/-*

Somatic transposition in human brain



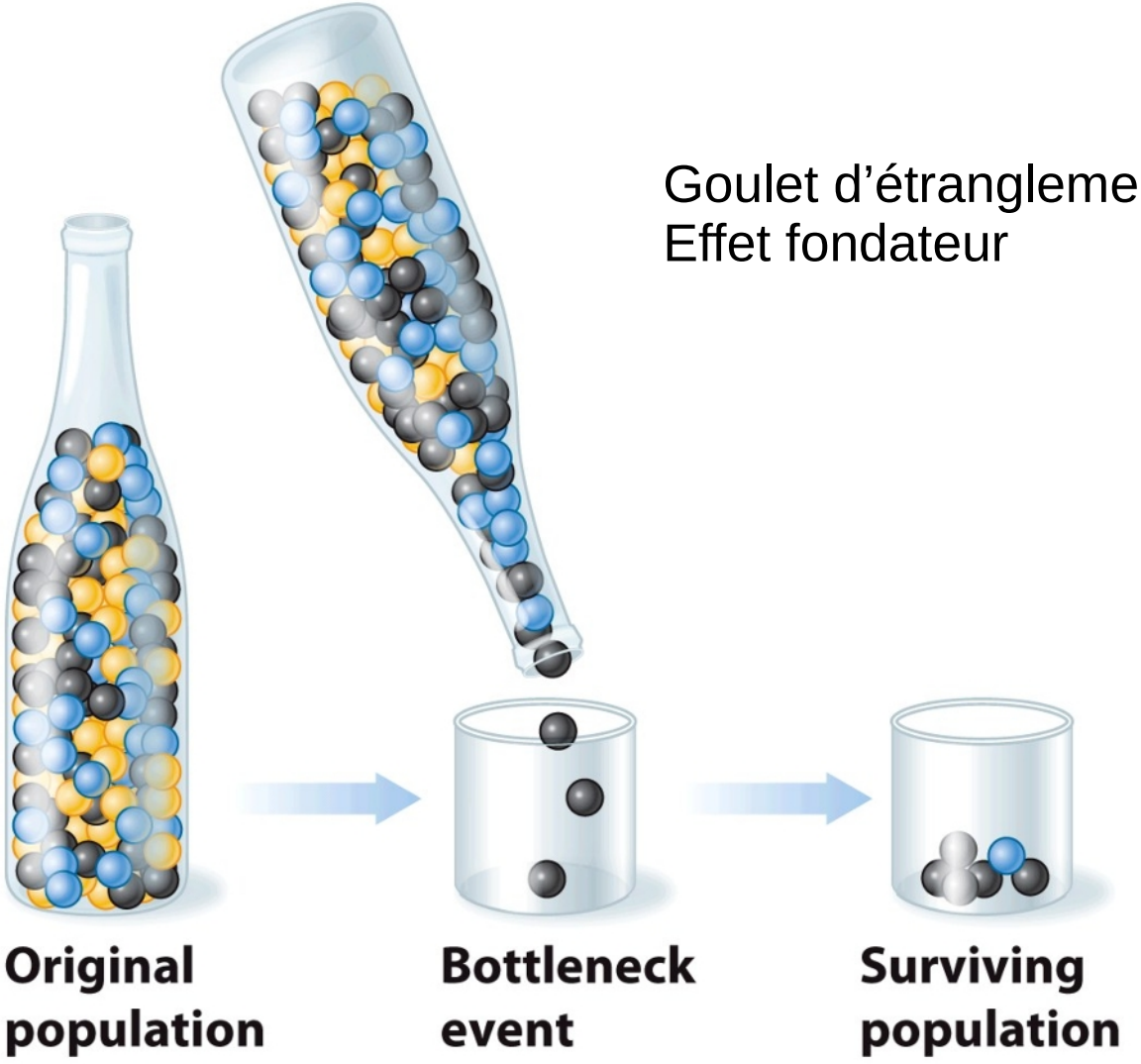
In three individuals:

in the hippocampus and caudate nucleus
7,743 somatic L1 insertions, 13,692 somatic Alu insertions and 1,350 SVA insertions

Baillie 2011 Nature

Dérive génétique

Fluctuation de la fréquence des allèles au fil des générations dans une population d'effectif limité, liée à l'effet d'échantillonnage, indépendamment des mutations, de la sélection et des migrations.



Goulet d’étranglement
Effet fondateur

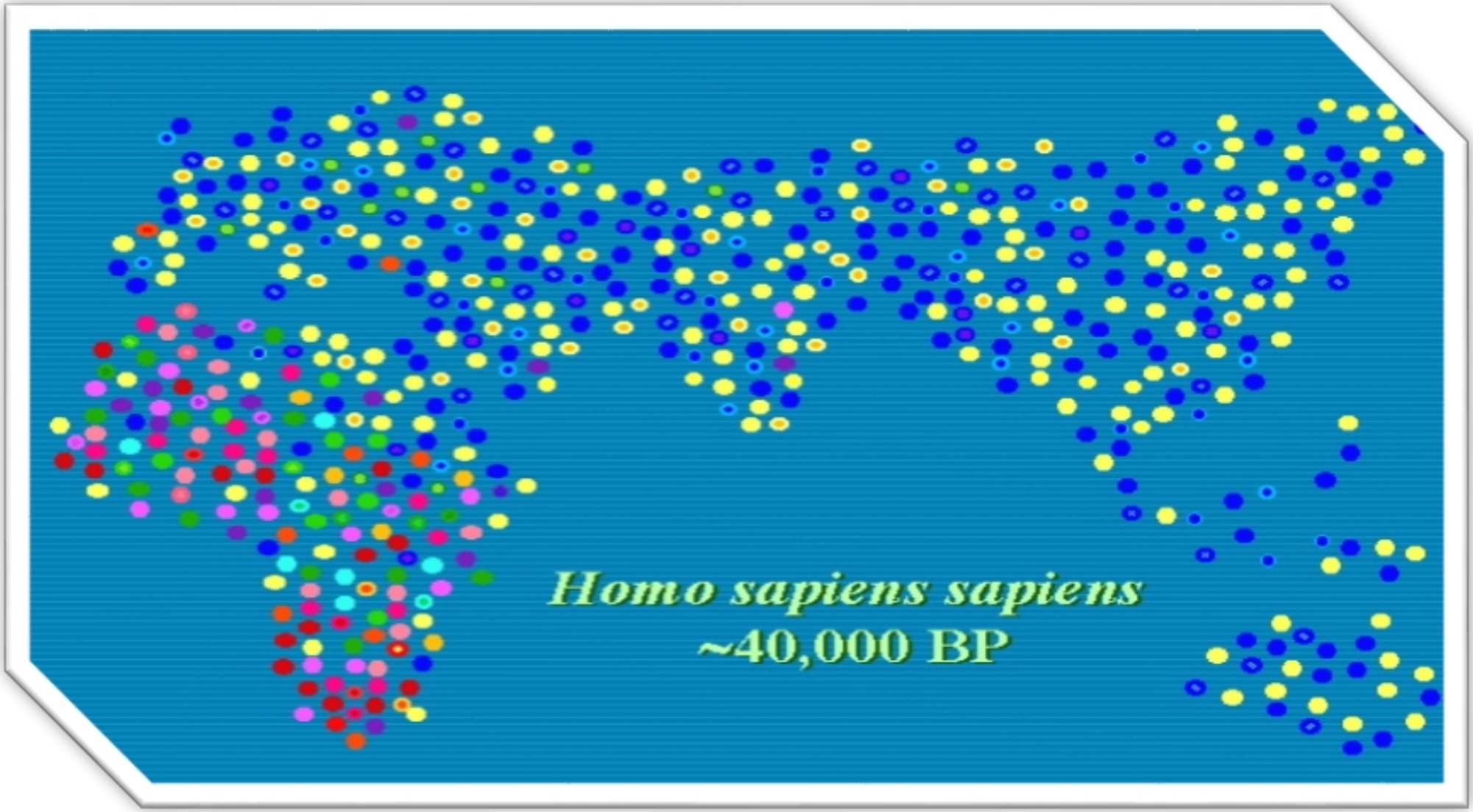
Goulet d'étranglement sur l'atoll de Pingelap (Pacifique)



- 1775 : un typhon a tué toute la population sauf 30 survivants
- 250 personnes actuellement descendants de ces 30 survivants
- 10% de la population souffre d'achromatopsie



Diversité génétique dans l'espèce humaine



Afrique:
Plus grande diversité génétique

Besides evolution

Causes of phenotypic differences ?

Genetic



Epigenetic



Environment



Stochasticity



Transmitted

Determistic

Interactions

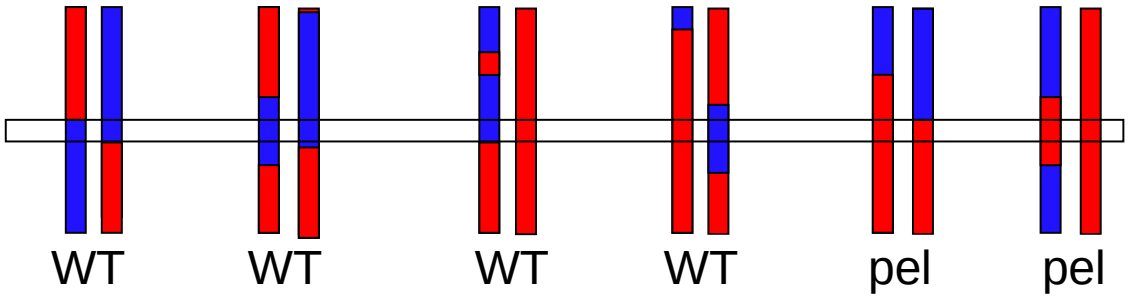


Wild-type



Peloric

Linaria vulgaris



Cubas 1999 Nature

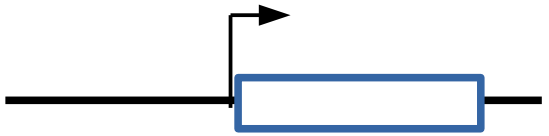
An epimutation



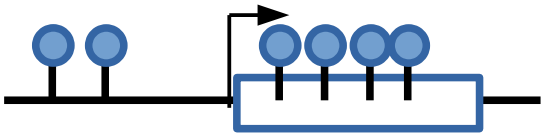
Wild-type



Peloric



CYCLOIDEA



CYCLOIDEA

Methylated DNA

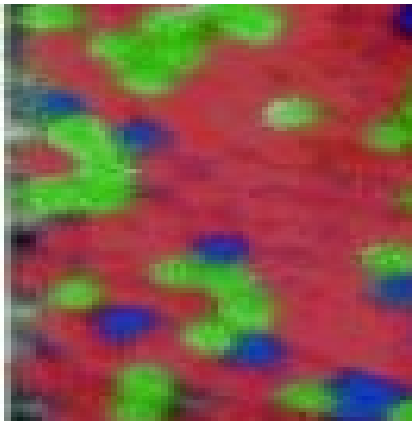
Presence of CYCLOIDEA proteins

Absence of CYCLOIDEA proteins

Developmental noise

Differences between left and right sides of the body



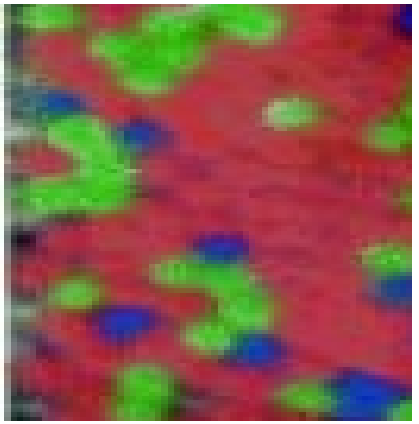



ear shape, neuron connectivity, olfactory receptor gene expression, X inactivation pattern, organ cell number and size...

Developmental noise

Differences between left and right sides of the body






ear shape, neuron connectivity, olfactory receptor gene expression, X inactivation pattern, organ cell number and size...

Differences between twins

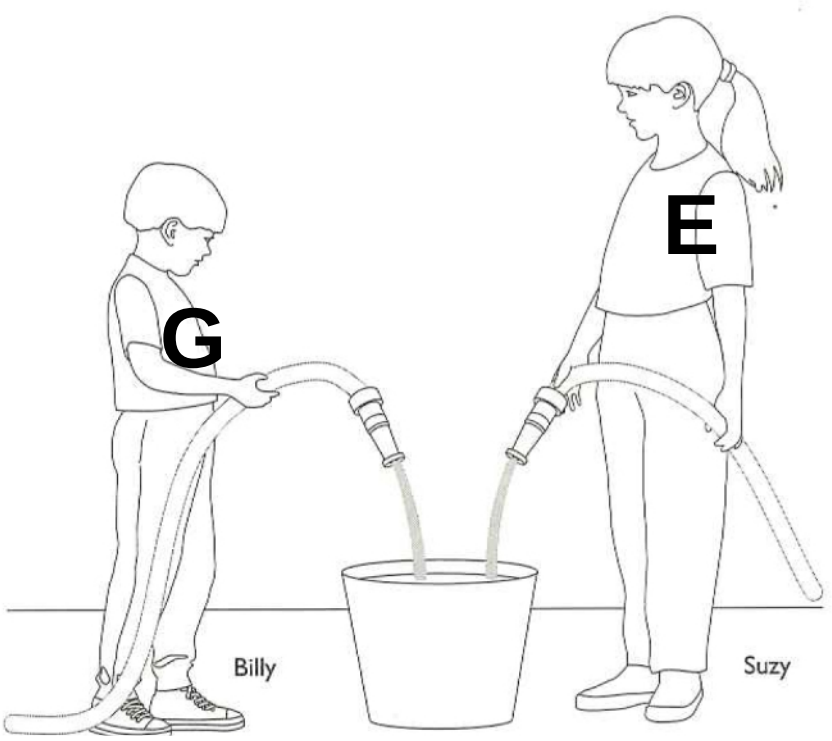
immune system cells, gait, arms crossing, voice, heart beat, brain waves...

Some can be attributed to variation in the number of determinant molecules

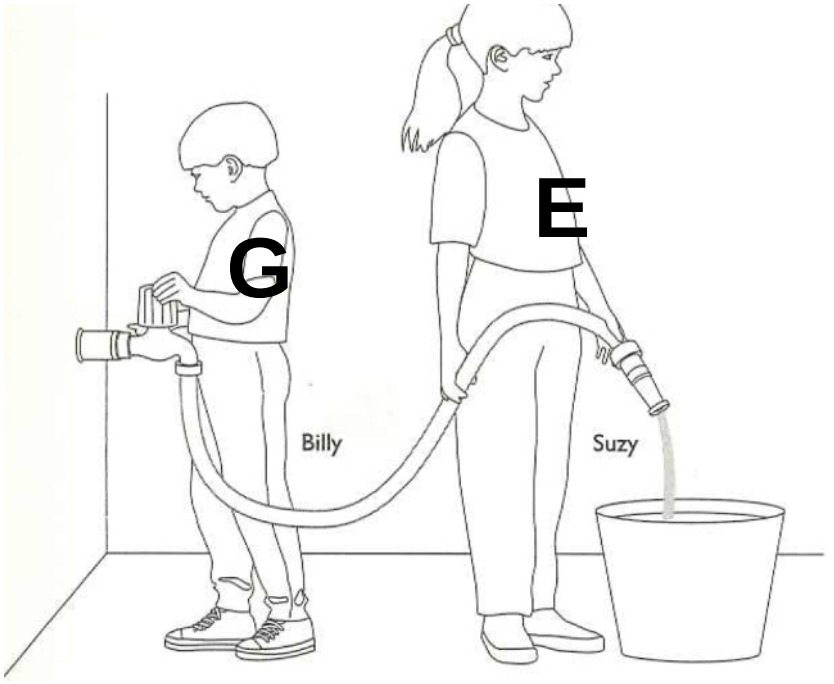
During terminal differentiation of mouse 3T3-L1 pre-adipocytes, individual TF abundance differs dramatically (from ~250 to >300,000 copies per nucleus) and the dynamic range can vary up to fivefold during differentiation.

Simicevic 2013 Nature

Contributions of the genotype (G) and the environment (E) to phenotypic variation



GxE



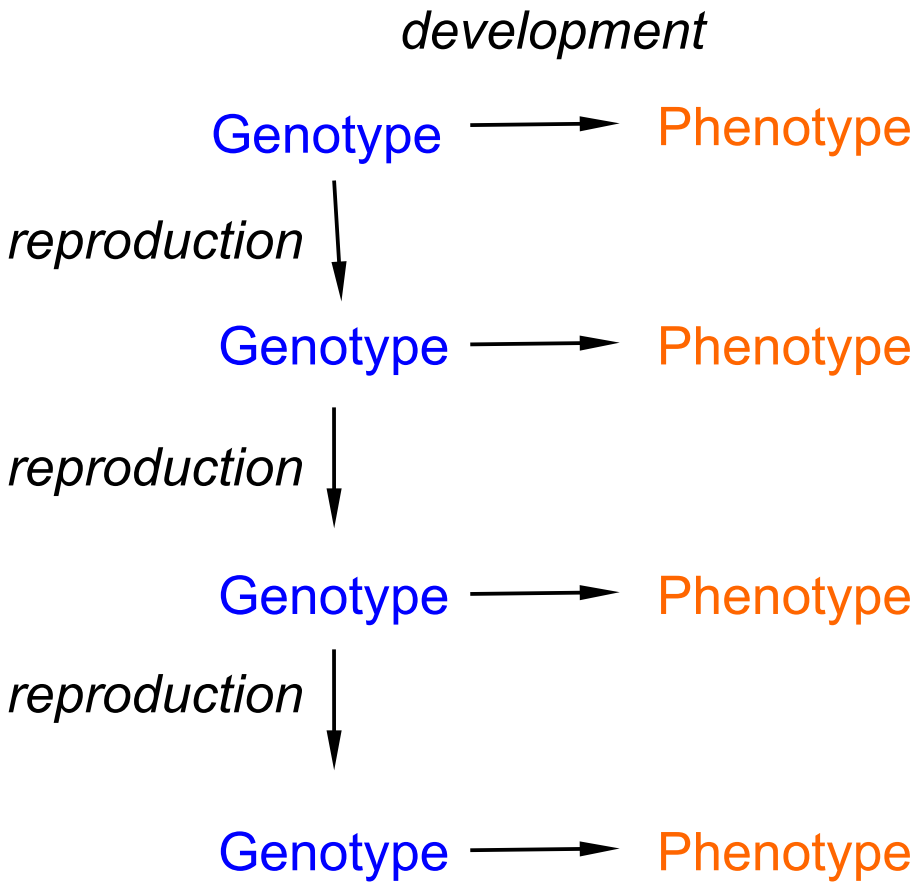
From Fox Keller (2010)

The Siamese cat
An example of GxE

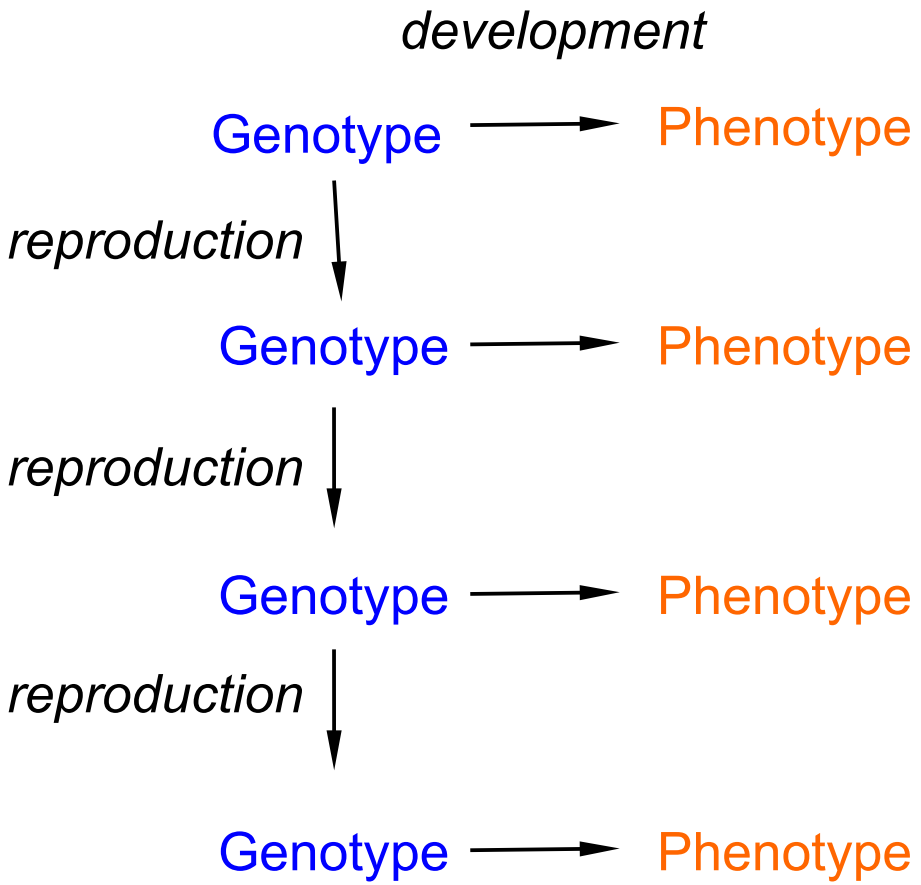




Mutation in *tyrosinase*
Heat-sensitive enzyme
No production of melanin in warm body parts


development
Genotype
Phenotype
reproduction
Genotype
Phenotype
reproduction
Genotype
Phenotype
reproduction
Genotype
Phenotype

A simplistic view



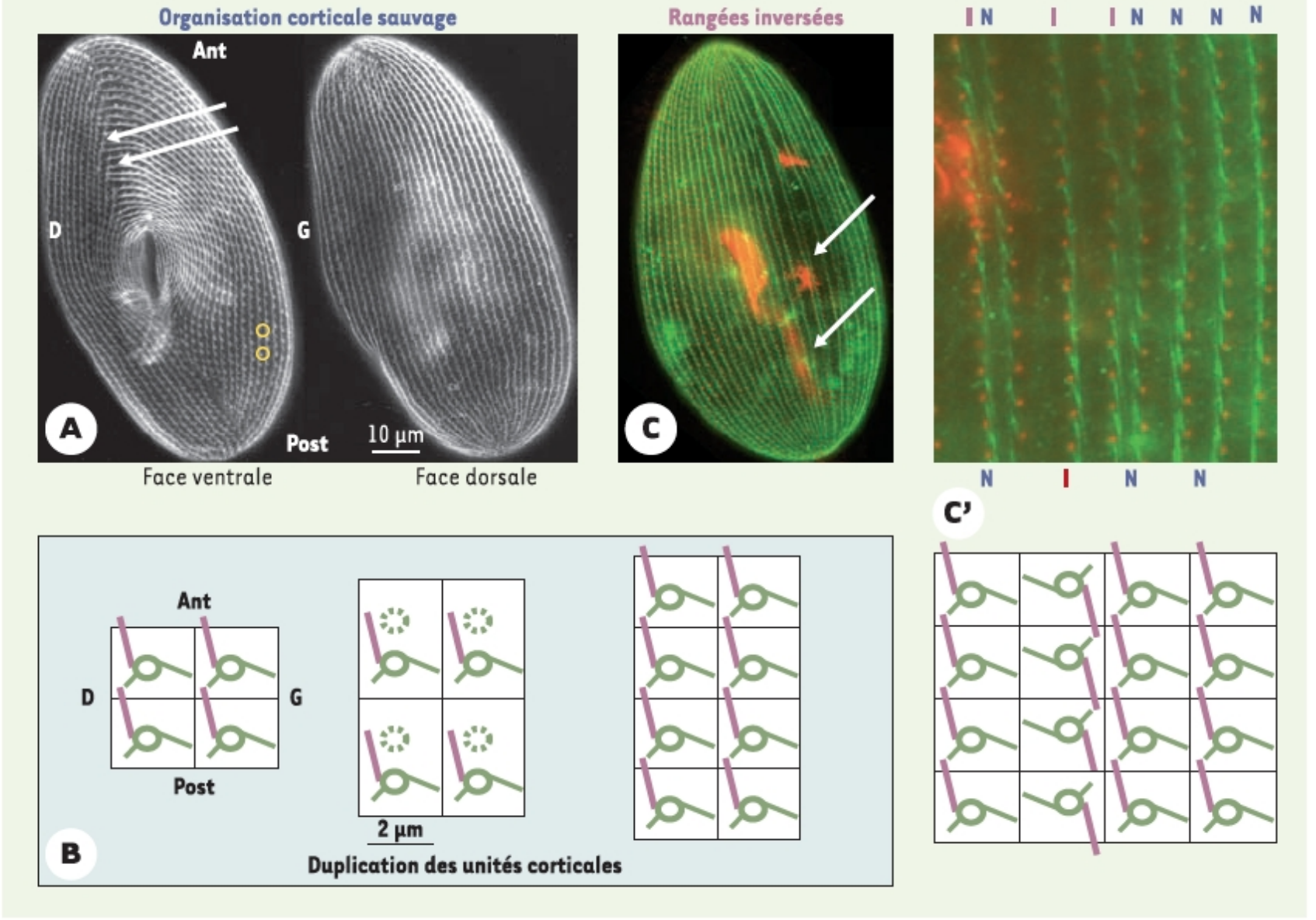
Heritable traits are not always due to genes

The genotype does not determine entirely the phenotype

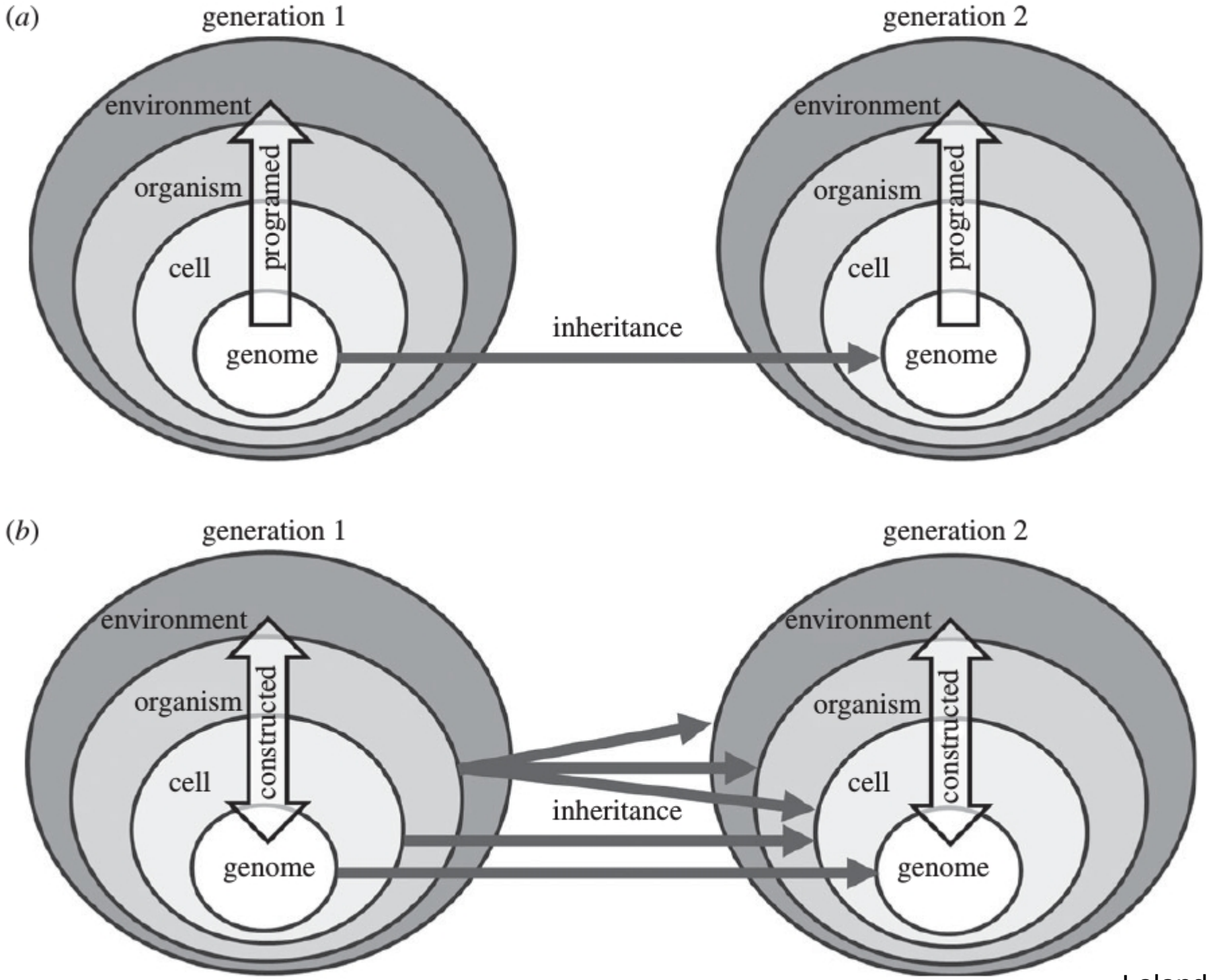
The genotype cannot replicate by itself

Genotype and phenotype imply variation

Cortical heredity in *Paramecium*



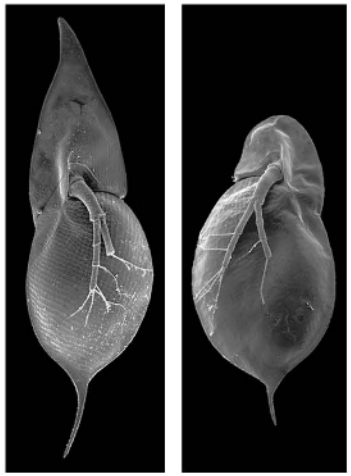
Meyer & Beisson M/S 2005


(a)
generation 1
generation 2
environment
organism
cell
genome
programed
inheritance
environment
organism
cell
genome
programed
(b)
generation 1
generation 2
environment
organism
cell
genome
constructed
inheritance
environment
organism
cell
genome
constructed

Laland 2015

Plasticity: one genotype → several phenotypes

Daphnia



with helmet | without helmet

Nemoria arizonaria caterillars



spring: caterpillars feed on catkins



summer: caterpillars feed on leaves

Water crowfoot plant



leaves growing above water | leaves growing below water

Desert locusts



solitary



gregarious

Commodore butterfly



winter



summer

Commodore butterly: Michael Wild, CC-BY-SA-3.0 (winter), Svdmolen, CC-BY-SA-3.0 (summer)

Daphnia: Agrawal *et al* (1999)

Nemoria arizonaria caterillars: Sadava *et al* (2014)

Water crowfoot plant: J R Crellin, CC BY-NC-ND 3.0

Complexifications of the relationship between genotype and phenotype

Interaction between genes

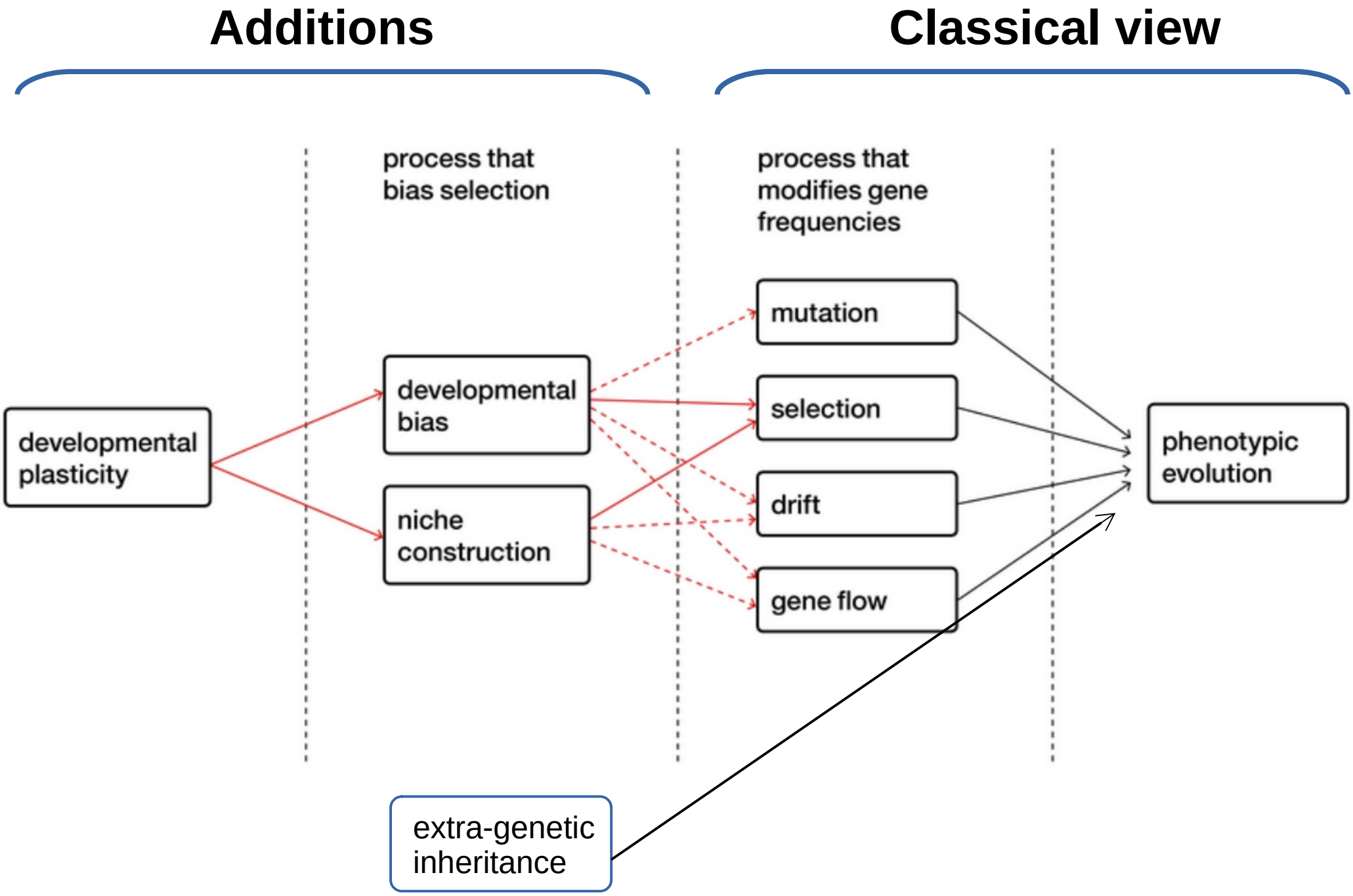
GxE

Plasticity

Epigenetics

Noise

Extended evolutionary synthesis



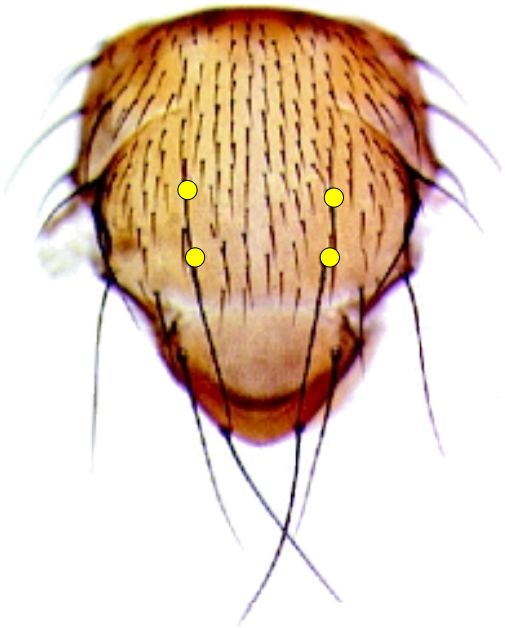
Niche construction

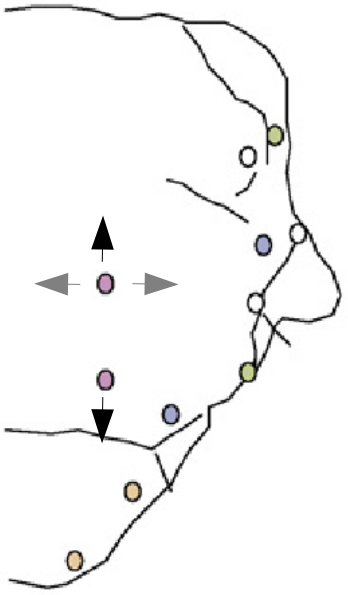


Developmental Bias

Standing variation

D. melanogaster

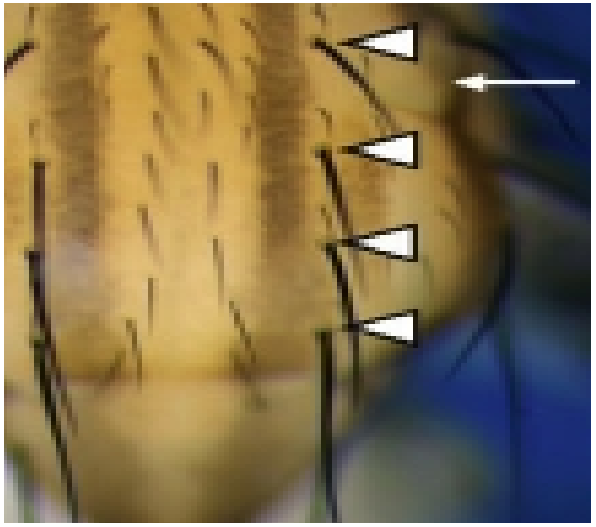




variation
no variation

Natural evolution

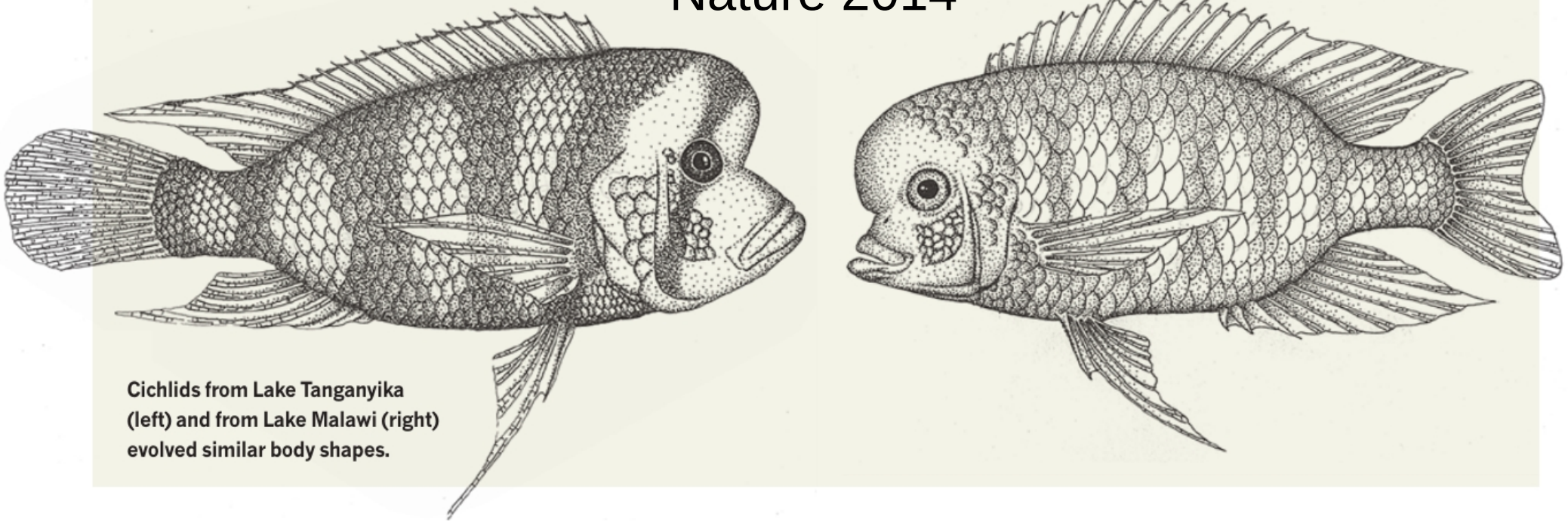
D. quadrilineata



Marcellini et al 2006 PloS Biol

Garcia-Vázquez 1988 J. Heredity

Nature 2014



Cichlids from Lake Tanganyika (left) and from Lake Malawi (right) evolved similar body shapes.

Does evolutionary theory need a rethink?

Researchers are divided over what processes should be considered fundamental.

POINT

Yes, urgently

Without an extended evolutionary framework, the theory neglects key processes, say Kevin Laland *and colleagues.*

COUNTERPOINT

No, all is well

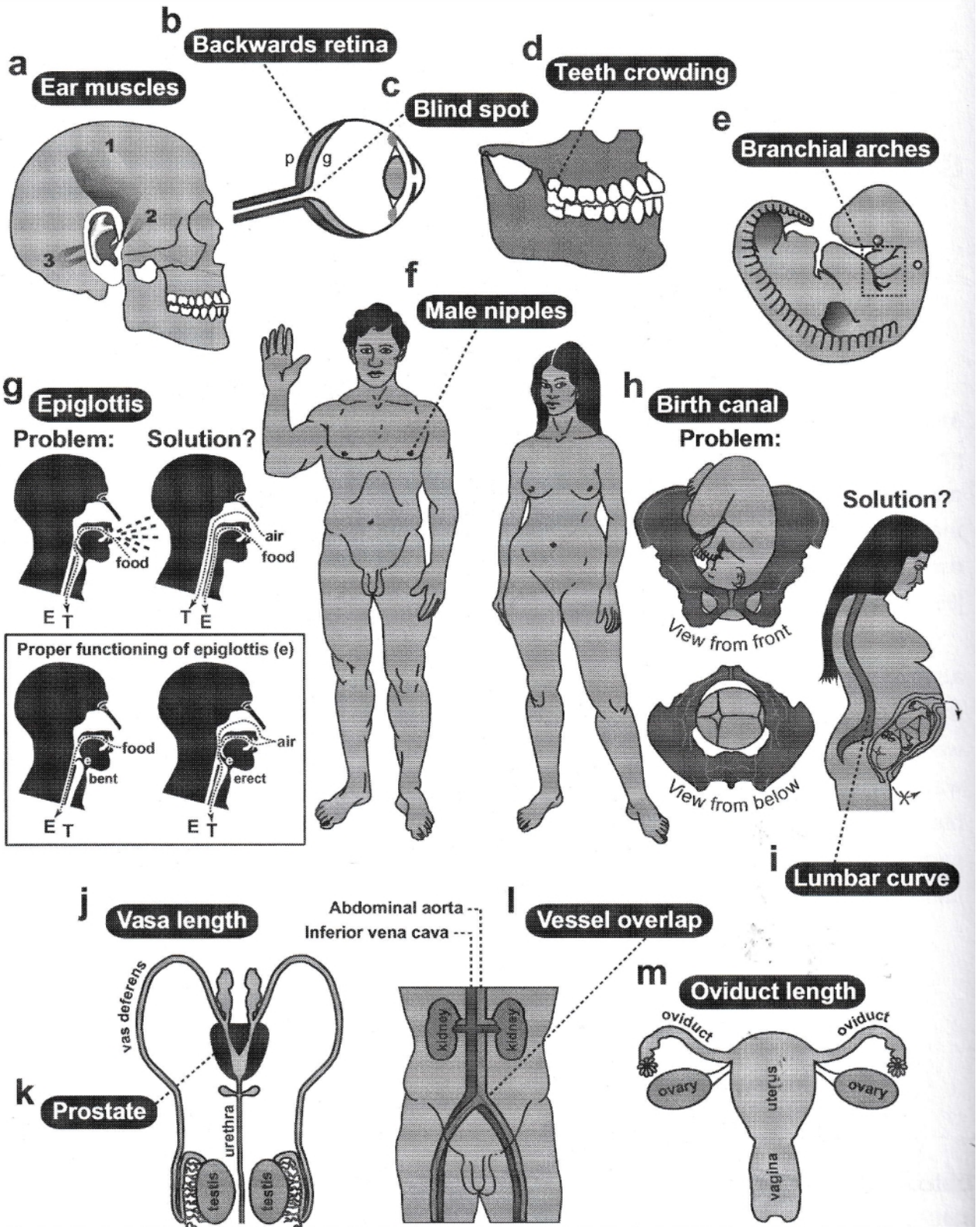
Theory accommodates evidence through relentless synthesis, say Gregory A. Wray, Hopi E. Hoekstra *and colleagues.*

Remarkable cases of evolution



Hypertrichosis. Rare condition, here : Supatra Susphan of Thailand.
Not a true atavism

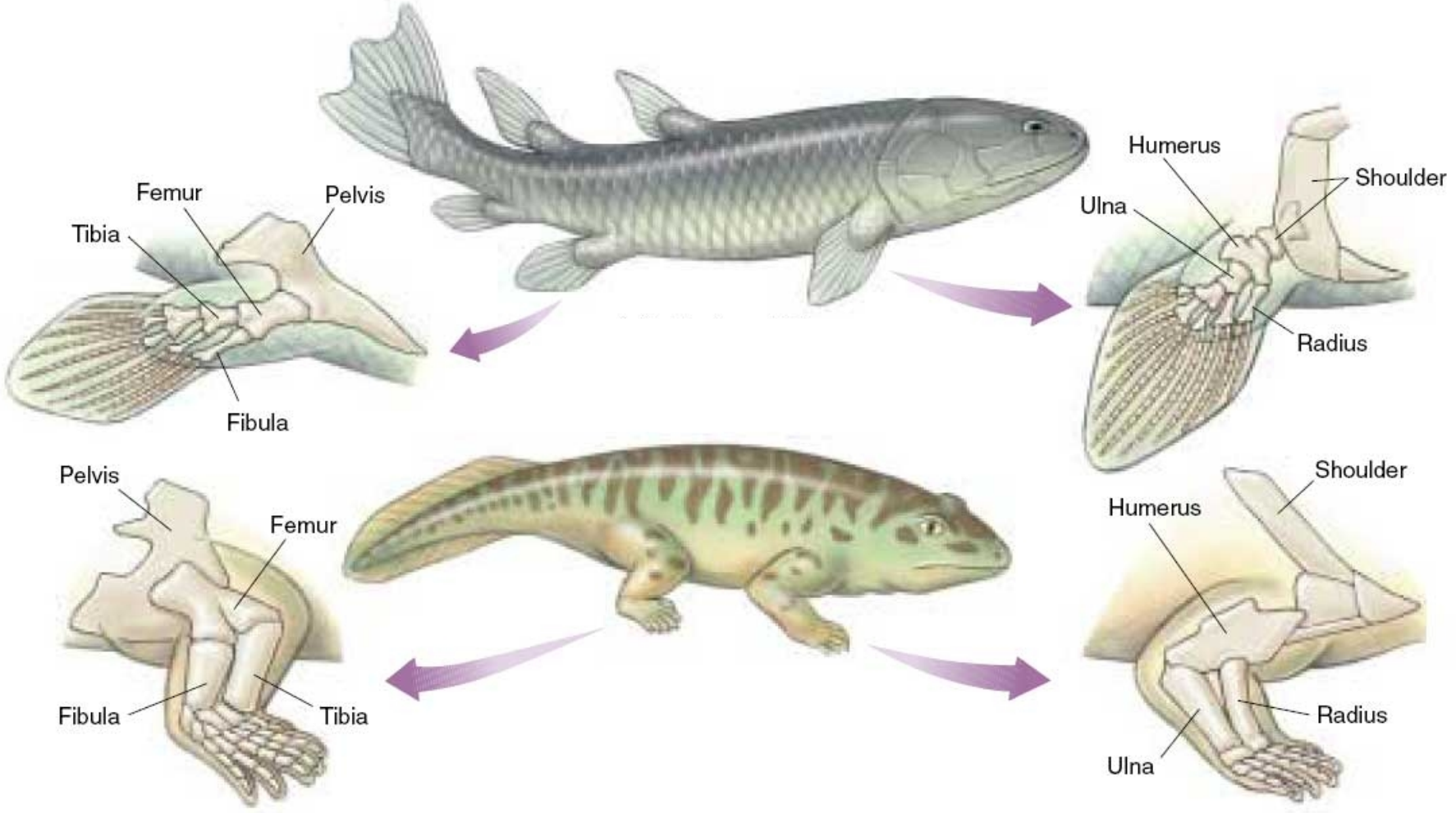
Genetic basis not identified yet



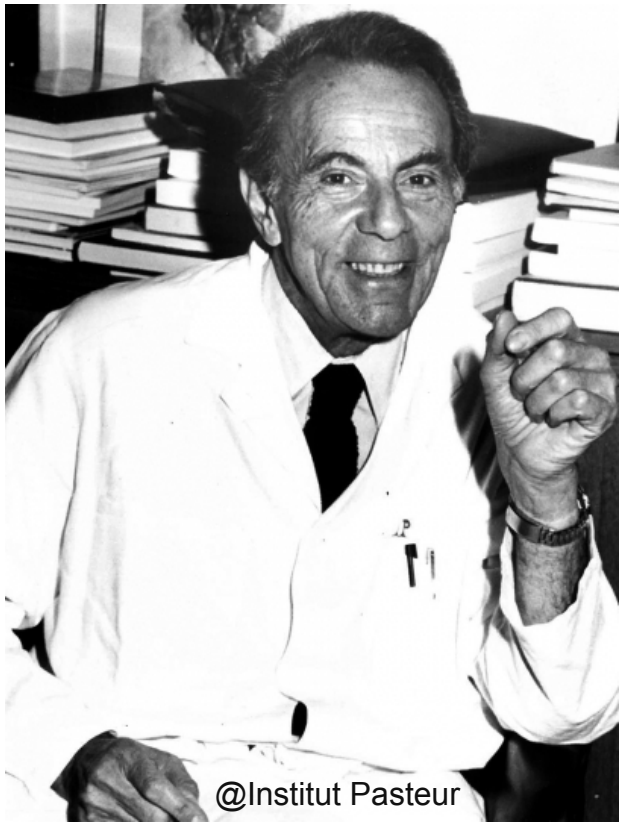
Useless or detrimental traits in humans

Exaptation

Evolution d'un trait de caractère vers une nouvelle fonction



10 June 1977, Volume 196, Number 4295 **SCIENCE**



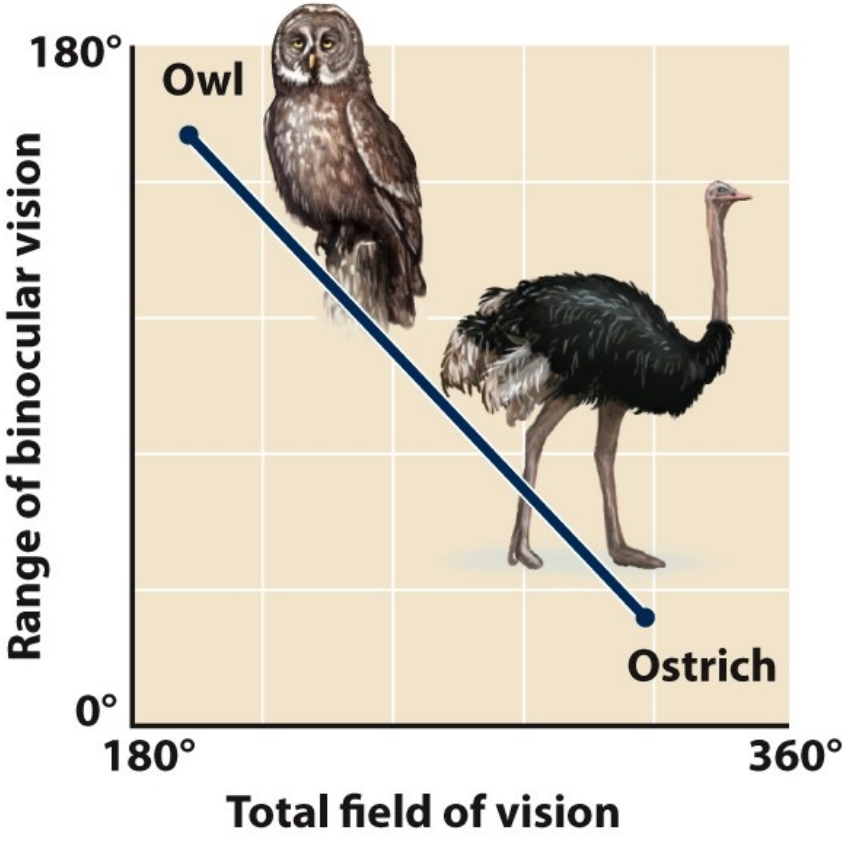
Evolution and Tinkering

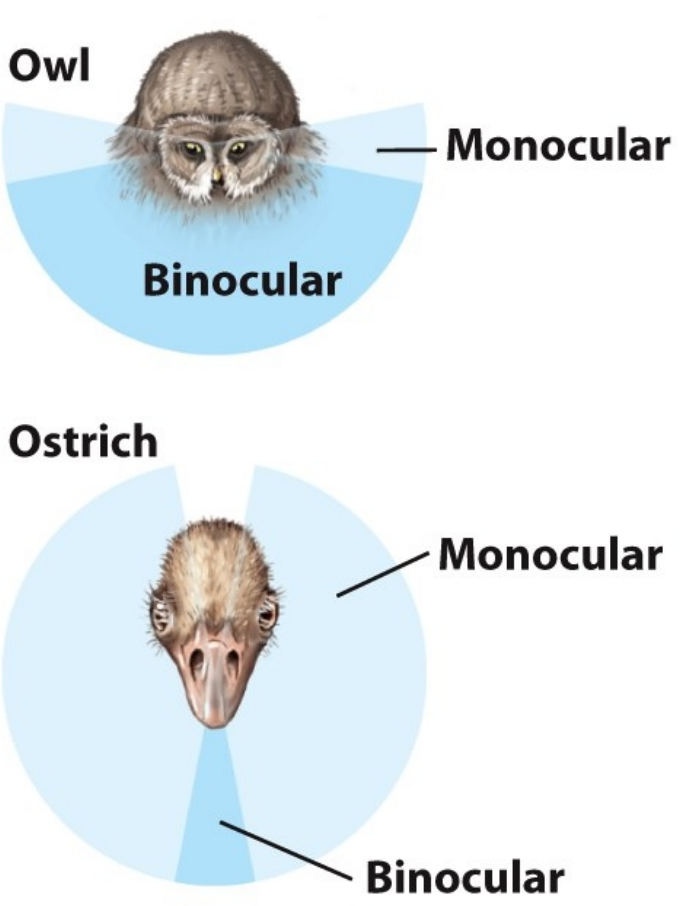
François Jacob

« La sélection naturelle ne fonctionne pas comme un ingénieur. Elle fonctionne comme un bricoleur. »

« L'évolution ne tire pas ses nouveautés du néant. Elle travaille sur ce qui existe déjà. […] La sélection naturelle opère à la manière non d'un ingénieur, mais d'un bricoleur; un bricoleur qui ne sait pas encore ce qu'il va produire, mais récupère tout ce qui lui tombe sous la main. »
(François Jacob, Le Jeu des possibles, 1981)

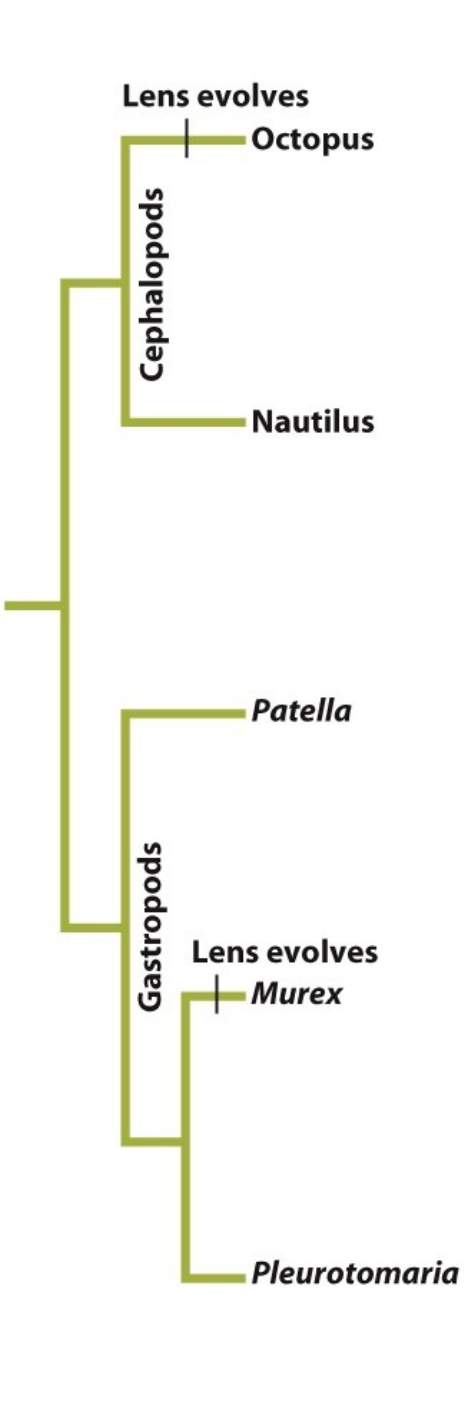
Compromis évolutifs (“trade-offs”)

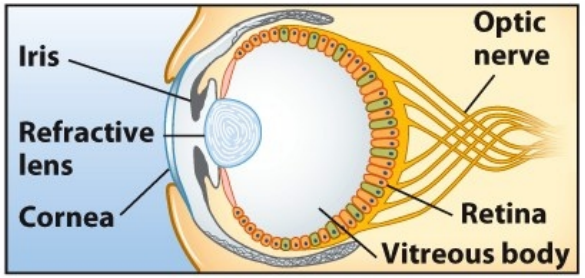






Adaptation par changements graduels







Lentille, iris, cornée..

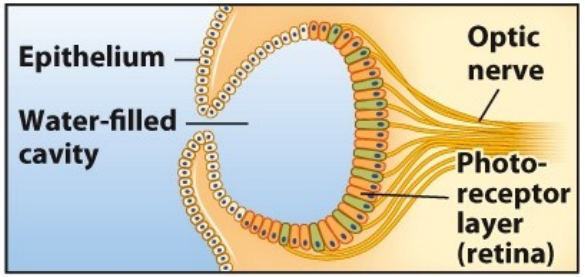
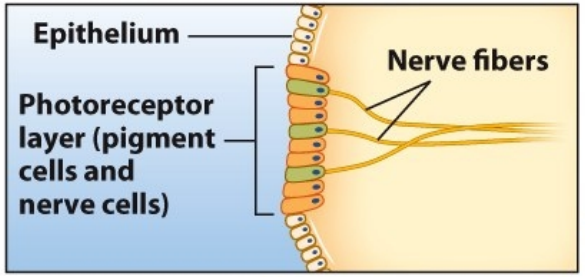


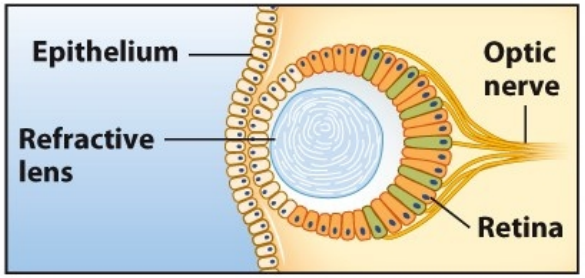


Image précise



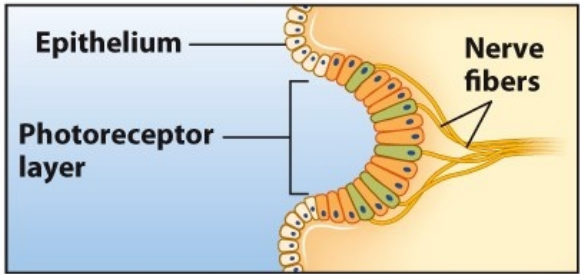


Détection de la lumière





Lentille



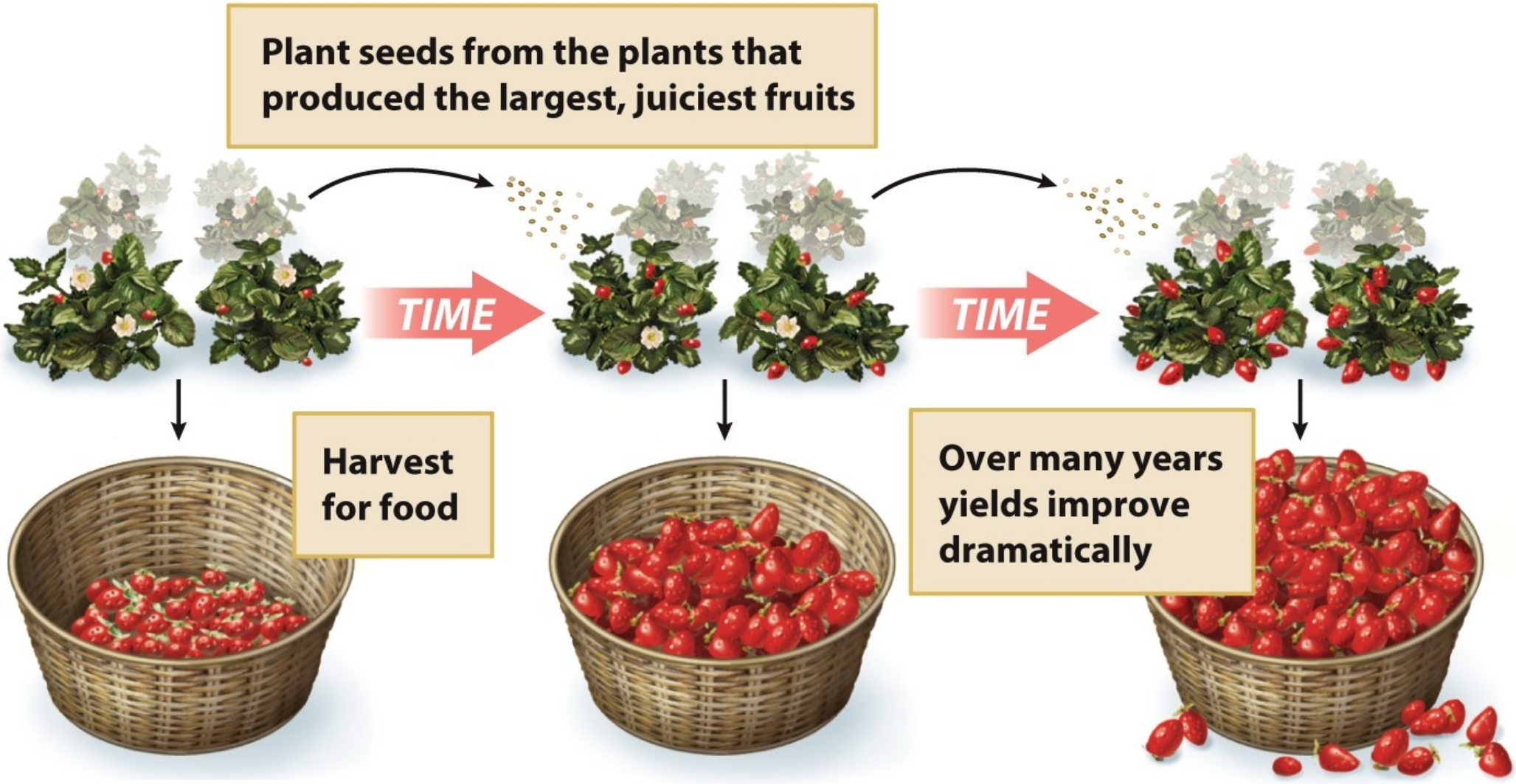


Détection de la lumière et de sa direction

Domestication



Domestication



Evolution de *Crepis sancta*



En 5-12 générations

Cheptou et al 2008

La couleur noire des loups de Yellowstone vient des chiens



© Alexis Rockman

© Doug Smith - Wikipedia

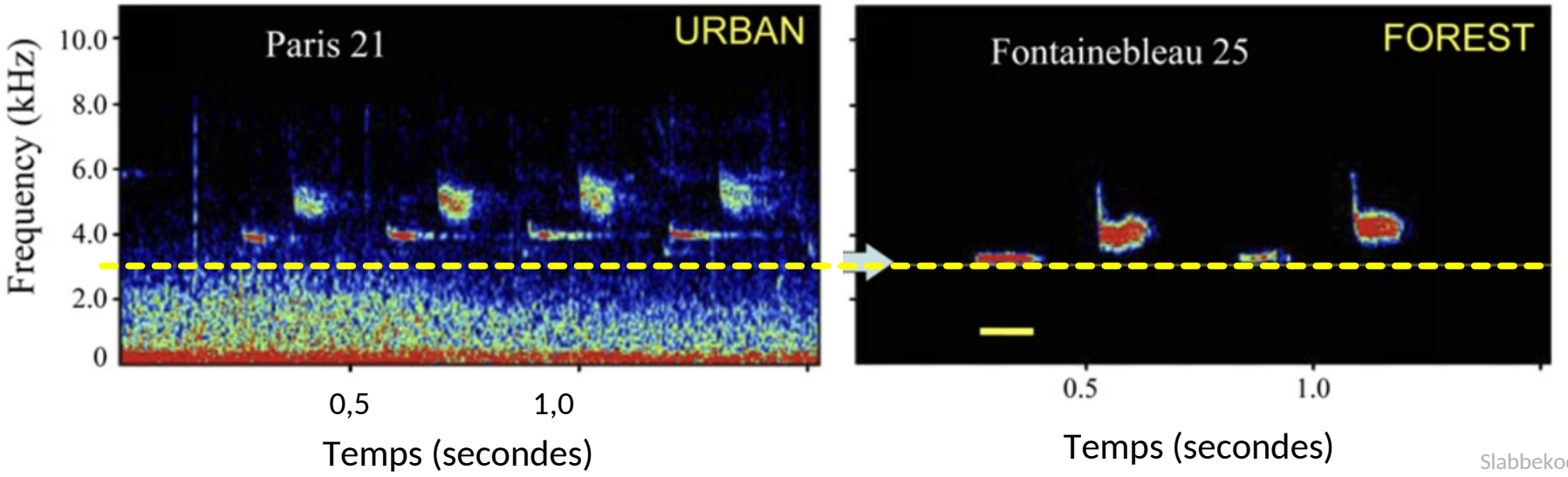
Anderson et al. 2009 Nature

Adaptation de la mésange charbonnière au bruit des villes



Sous la Tour Eiffel

Forêt de Fontainebleau

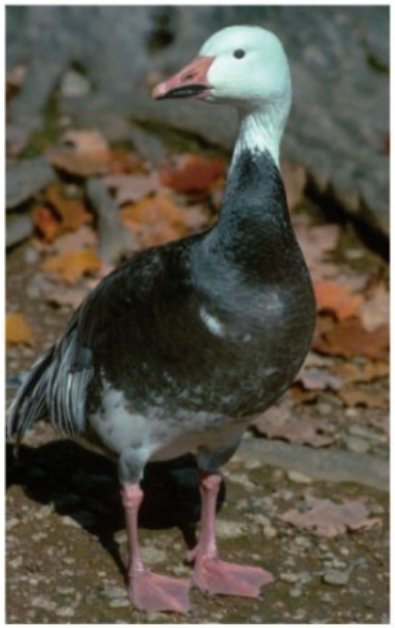


Slabbekoorn et al. 2016 Curr Biol

https://www.newscientist.com/article/dn10720-urban-songbirds-raise-their-voices-to-be-heard/

A few questions about evolution

Pourquoi autant de variabilité phénotypique intra-espèce ?













(C)





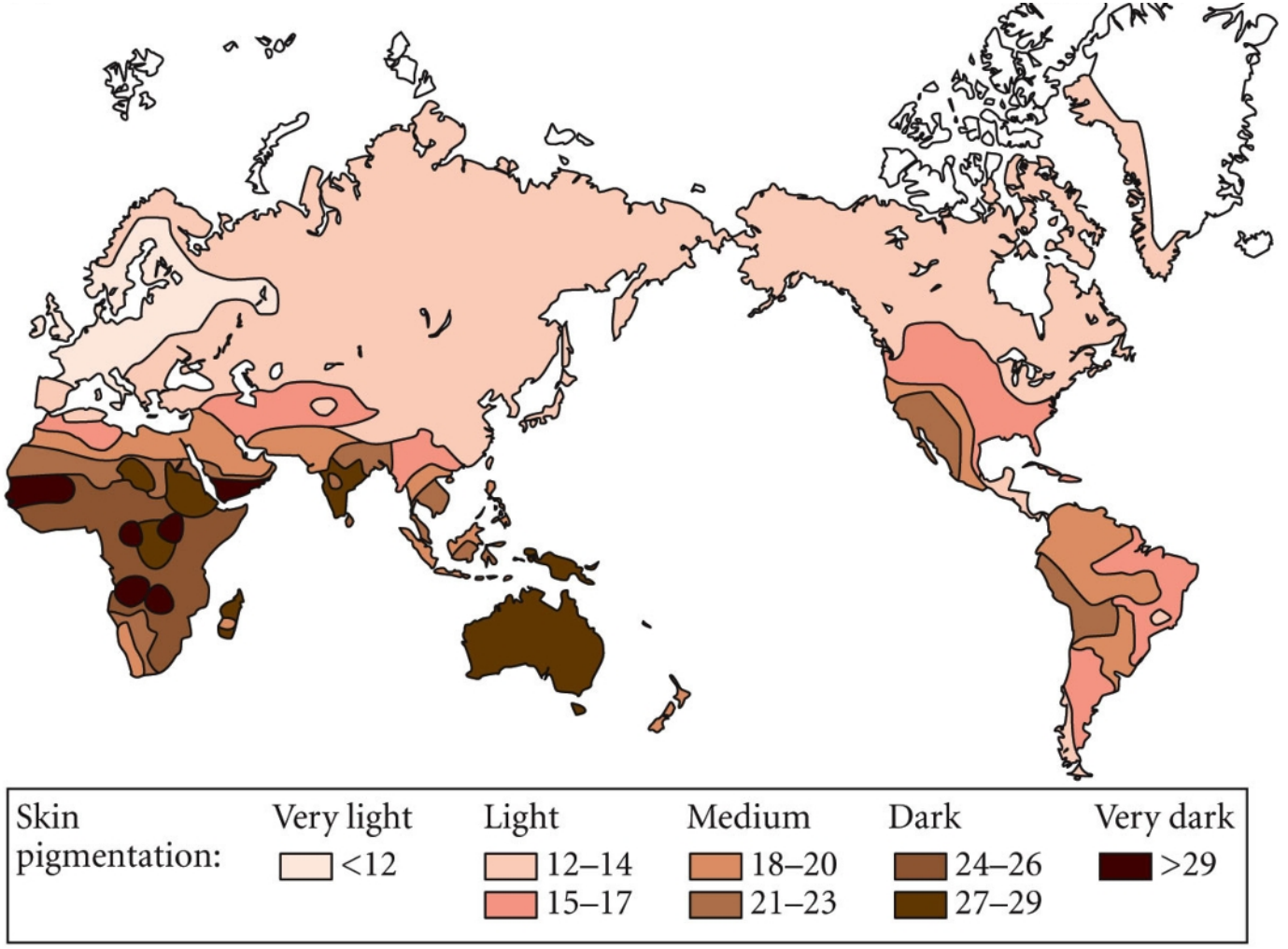








Sélection hétérogène dans l'espace: pigmentation de la peau humaine



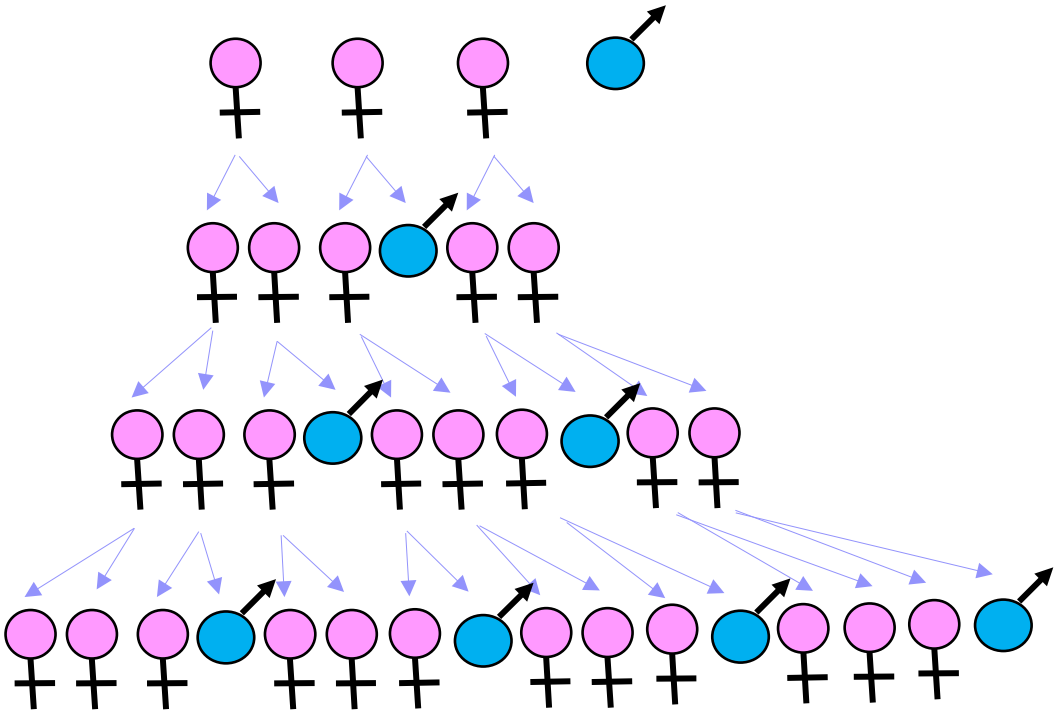
Sélection dépendante de la fréquence (gauchers)



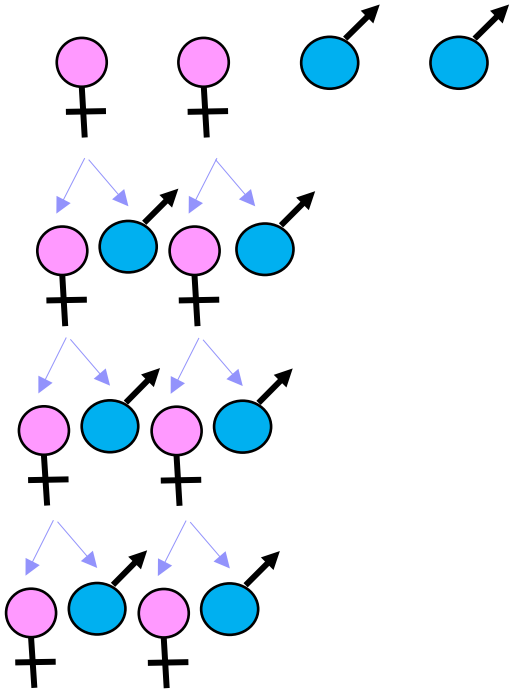


Sélection dépendante de la fréquence
Sex ratio

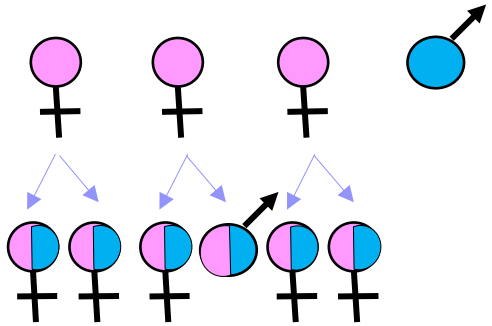
Sex-ratio 3/4



Sex-ratio 1/2

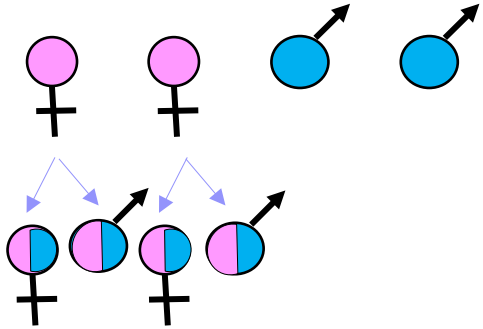


Sex-ratio 3/4



Un gène dans un mâle laisse **plus de copies** que dans une femelle

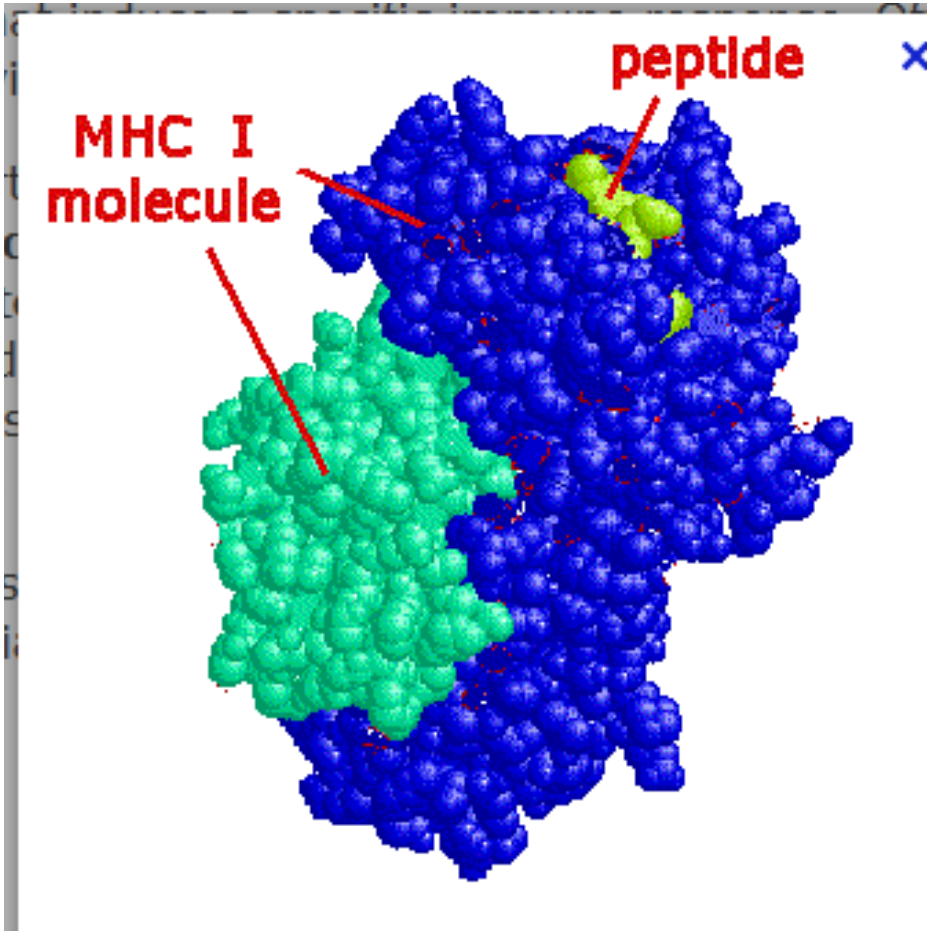
Sex-ratio 1/2



Un gène dans un mâle laisse **autant de copies** que dans une femelle

Un allèle faisant davantage du sexe rare augmentera en fréquence.
A l'équilibre, le sex ratio est ½ .

Sélection dépendante de la fréquence
(hôtes-parasites: système immunitaire effectivement très polymorphe, notamment chez l'homme)



Pourquoi les oiseaux chantent ?



Quatre niveaux de causalité

Causes proximales

- Quelles sont les causes immédiates du comportement ?
- Comment le comportement s'est mis en place au cours de l'ontogenèse ?

- Comment le comportement s'est-il mis en place au cours de la phylogenèse ?
- Quelle est sa valeur sélective ?

Causes ultimes

Pourquoi les oiseaux chantent ?



<u>Comment ?</u>

= causes proximales= explications mécanistes

Le pinson chante:

- Parce que l'air traverse le syrinx
- Modifications de taux hormonaux au printemps
- Apprentissage par les parents

<u>Pourquoi ?</u>

= causes ultimes

= explications évolutives

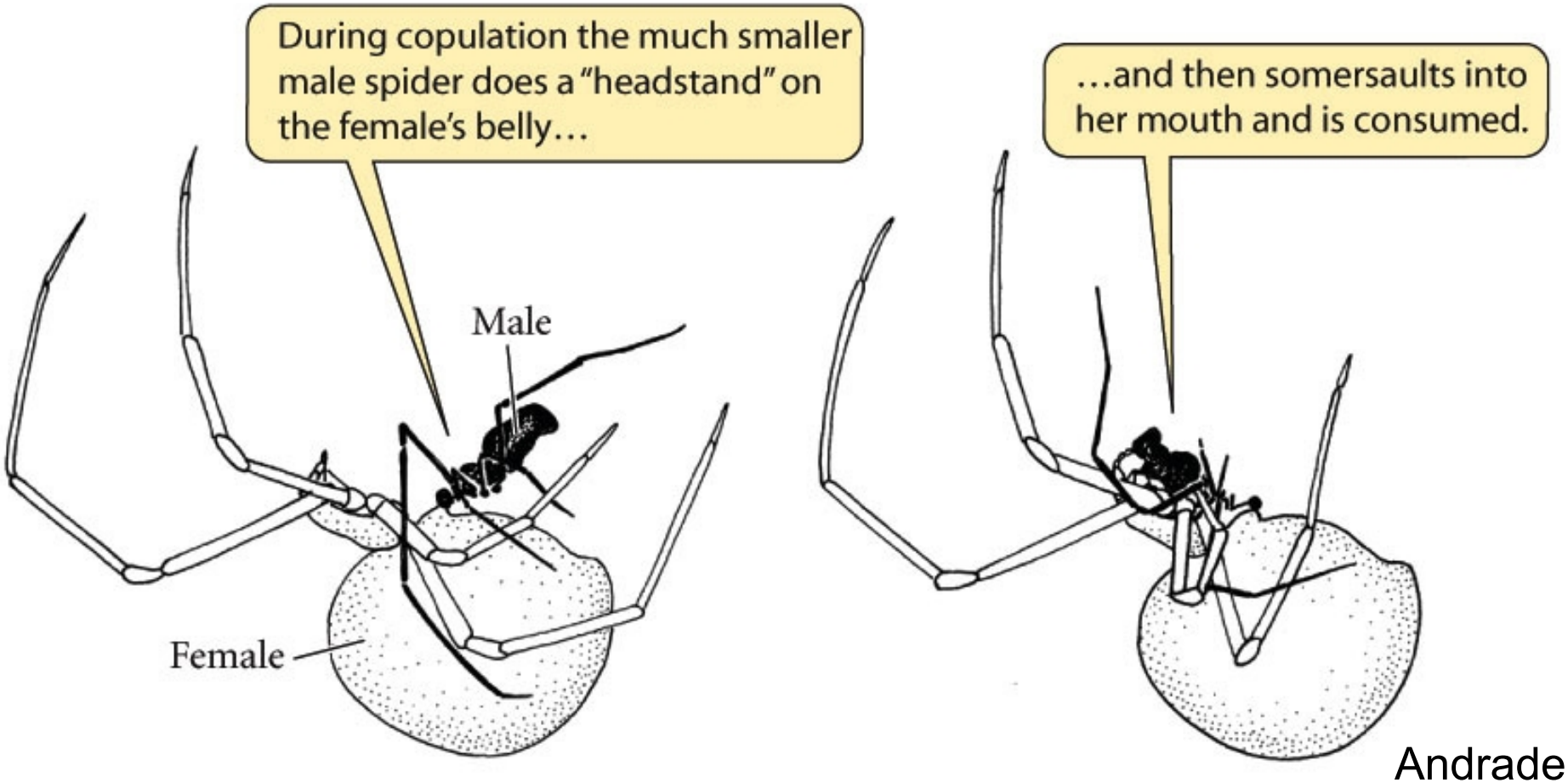
Reproduction

Compétition

Prédation

Pourquoi les mâles araignées se font manger chez certaines espèces ?

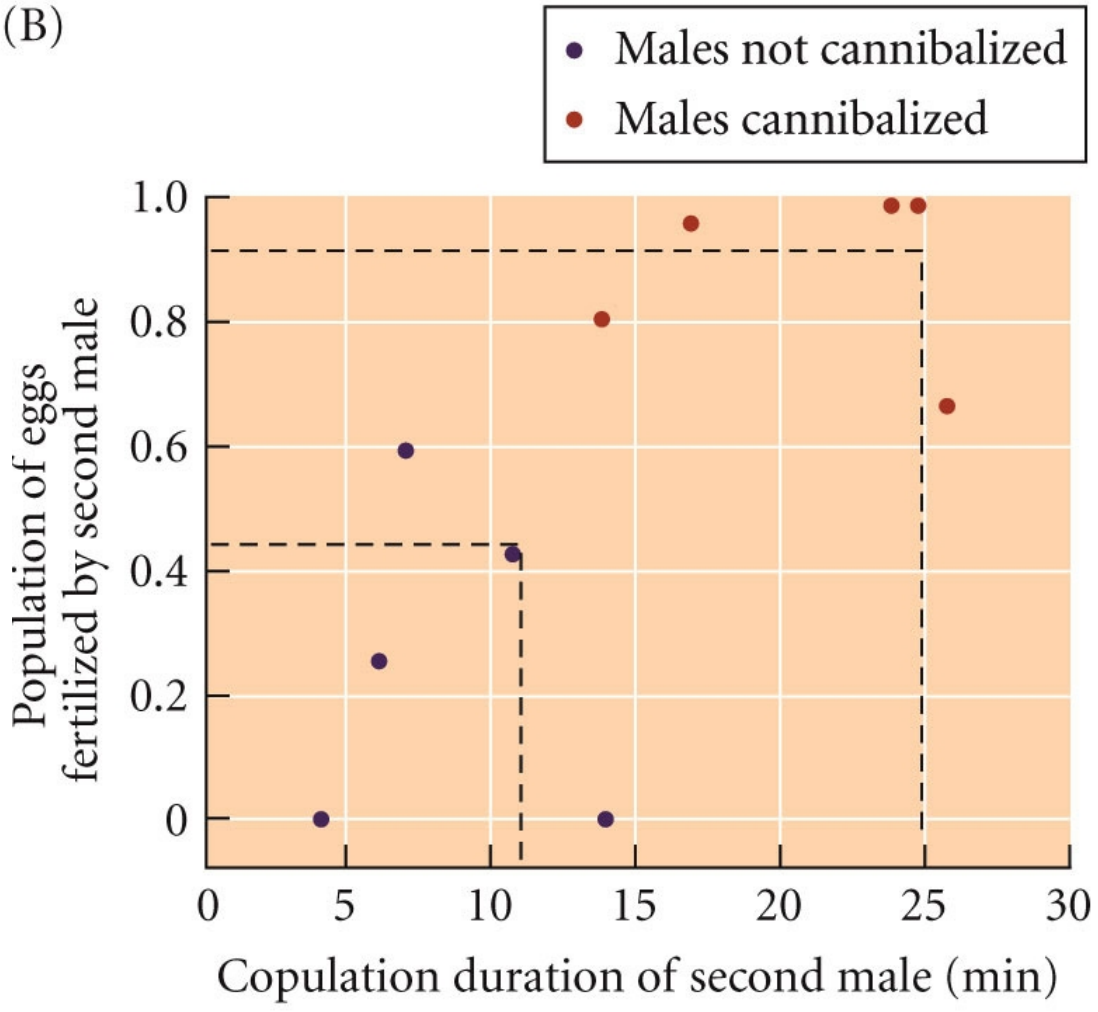
Cannibalisme des mâles par les femelles araignées
Latrodectus hasselti (Veuve noire à dos rouge)



Andrade 1996

Les mâles qui se laissent manger laissent plus de descendants (copulation plus longue)





Pourquoi les lions mâles tuent parfois tous les petits de la troupe ?

Infanticide chez les lions



- Quand un nouveau lion ou groupe de lions conquiert une troupe, il tue tous les lionceaux (infanticide)



Facteurs proximaux : odeur inconnue des lionceaux

Facteurs ultimes : lionnes fécondables au bout de 9 mois au lieu de 25 mois

Pas pour le bien de l’espèce

Maladies qui ont décimé des populations



Cryphonectria sur les chataîgniers



Maladies du blé et de la pomme de terre

Pas pour le bien de l'espèce



La sélection naturelle ne fonctionne pas “pour perpétuer l’espèce”

- La sélection fait augmenter en fréquence les allèles des individus qui laissent plus de descendants que les autres (survie + reproduction)

- Même si c’est aux dépends de la persistence de l’espèce

La reproduction sexuée

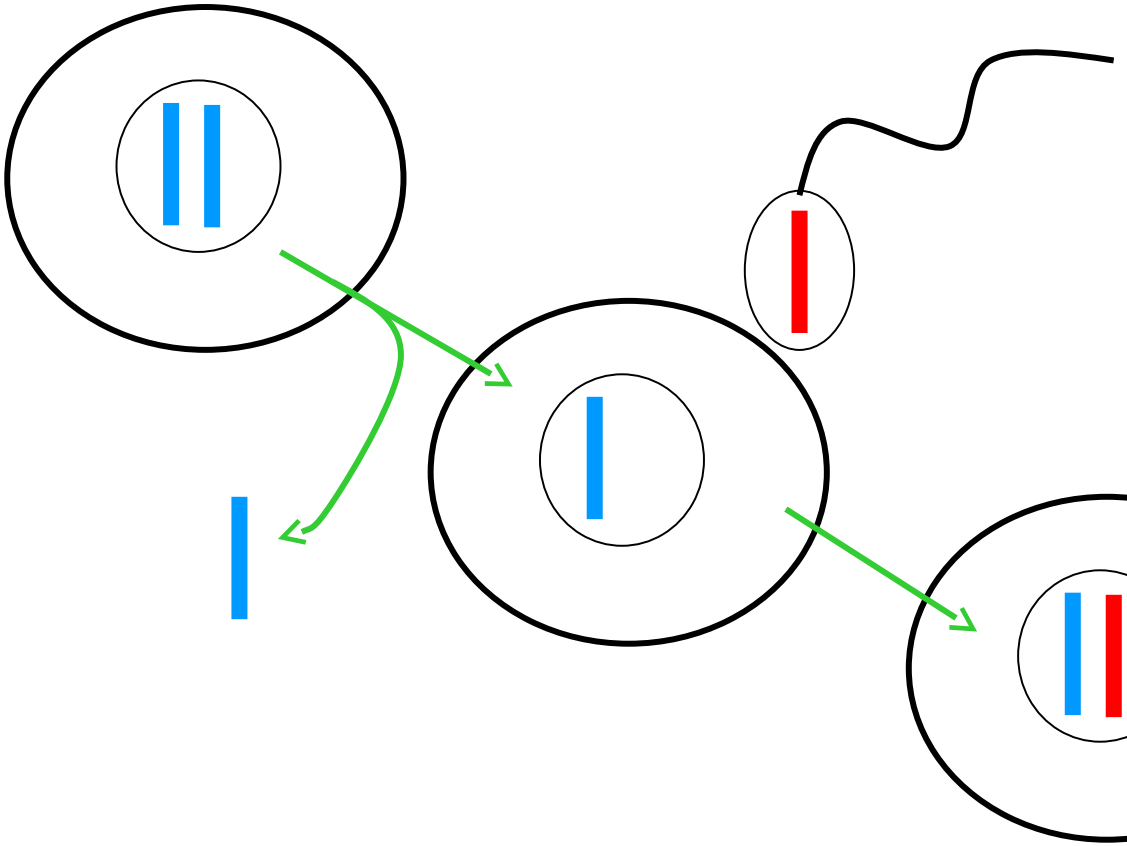
Comment expliquer l'existence d'individus différenciés en mâles et femelles ?

Comment la sélection a-t-elle pu favoriser l'existence d'individus différents qui doivent se rencontrer pour se reproduire, alors qu'il pourrait sembler plus simple et plus efficace d'avoir simplement des individus hermaphrodites capables de s'autoféconder ?

Le « coût de la méiose »



John Maynard Smith





Autres désavantages de la reproduction avec sexes séparés

- Coût physiologique de la méiose et de la production de gamètes non utilisés

- Coût pour trouver un partenaire (parade, attirent les prédateurs, nectar, etc.

- Risque de maladie sexuellement transmissible.









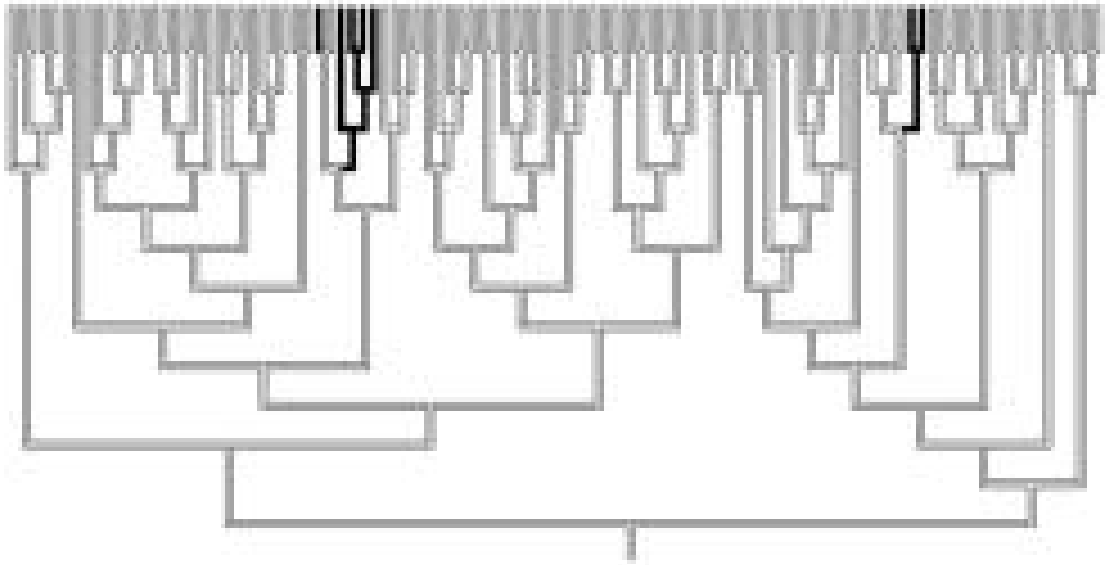
D’autres coûts…





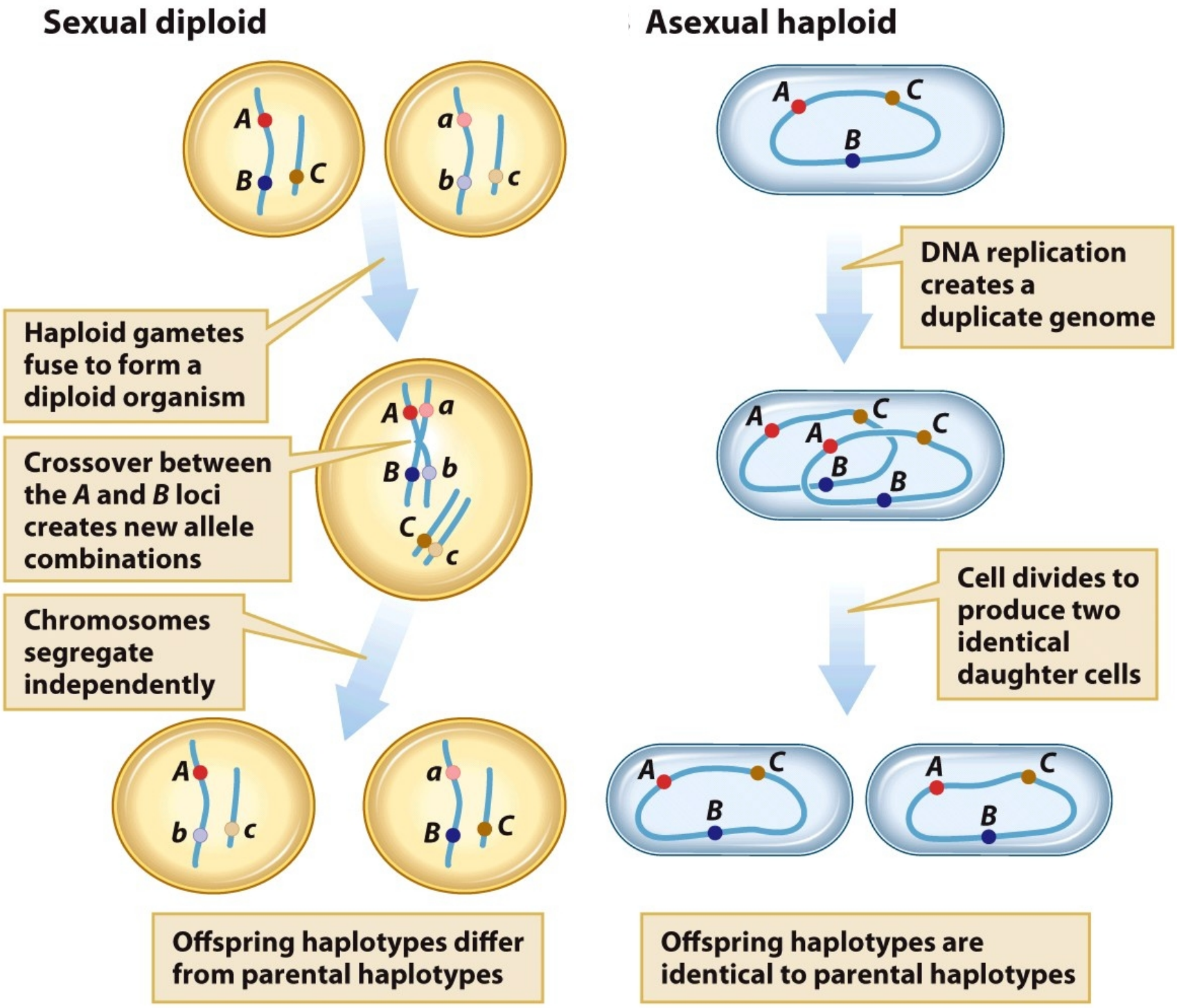
Punaises de lit

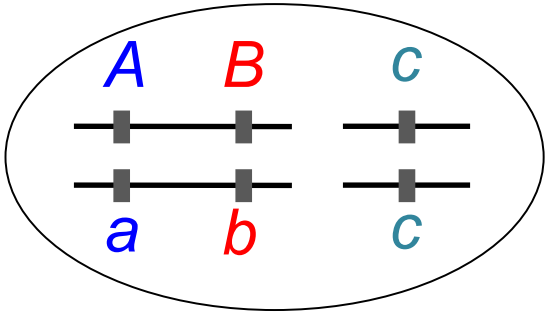
Les espèces asexuées sont toutes « récentes »

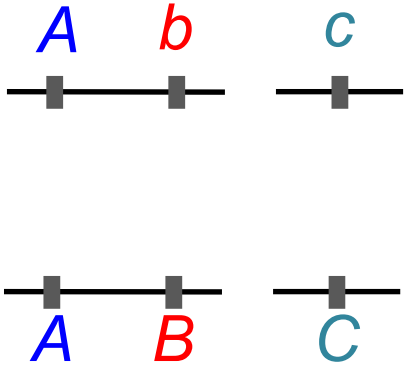


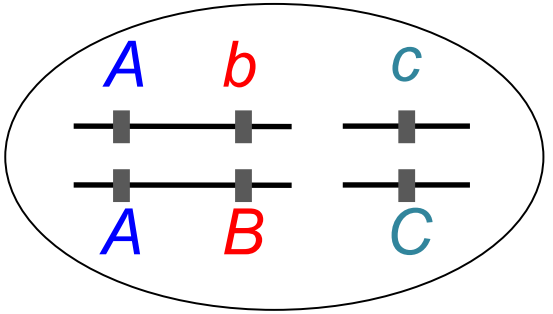


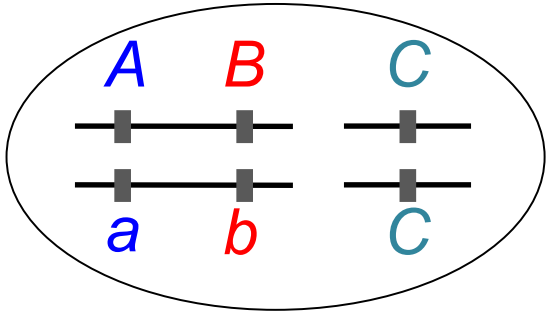



Sexual diploid
A
B
C
a
b
c
Haploid gametes fuse to form a diploid organism
Crossover between the A and B loci creates new allele combinations
Chromosomes segregate independently
Offspring haplotypes differ from parental haplotypes
Asexual haploid
DNA replication creates a duplicate genome
Cell divides to produce two identical daughter cells
Offspring haplotypes are identical to parental haplotypes

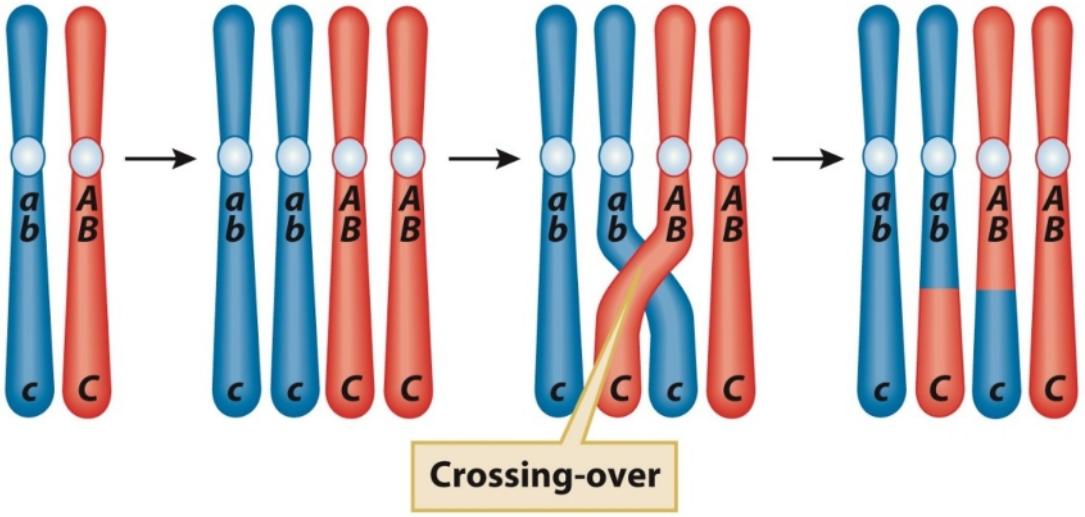


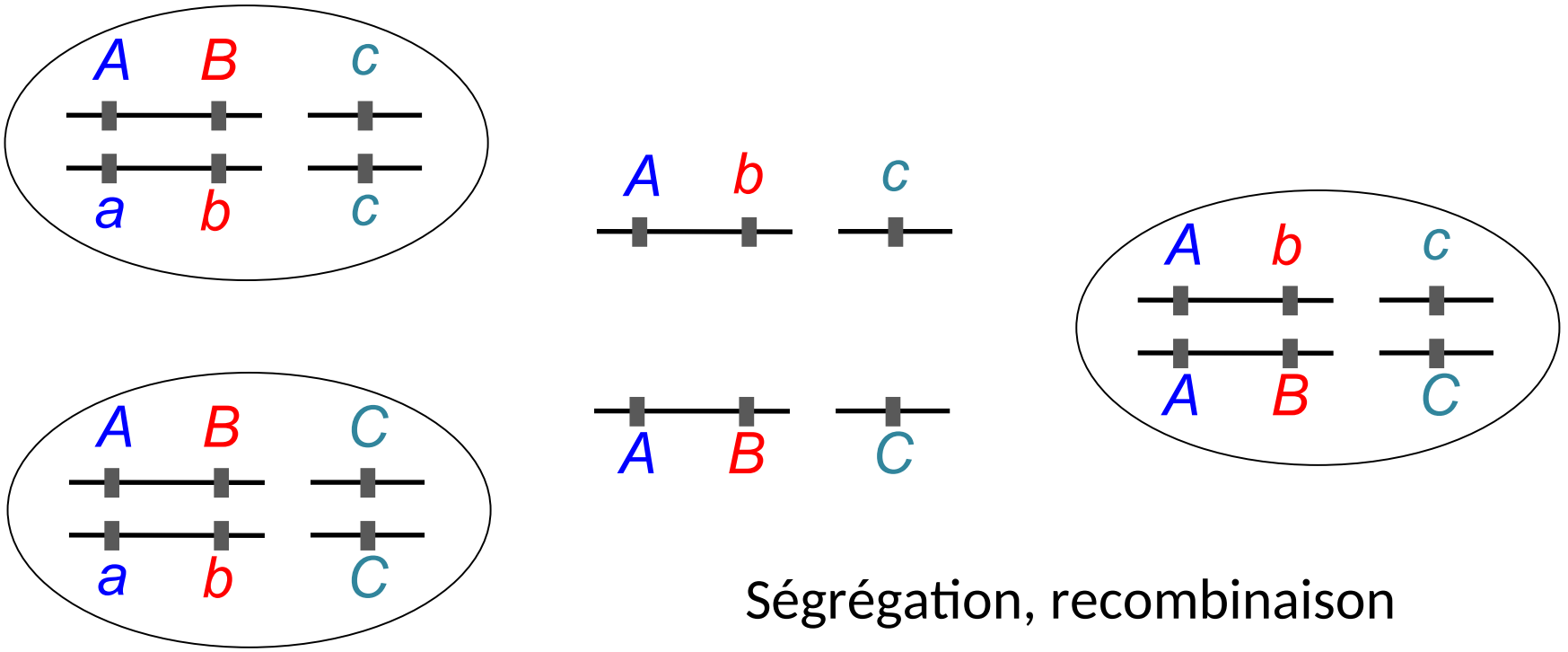






Ségrégation, recombinaison



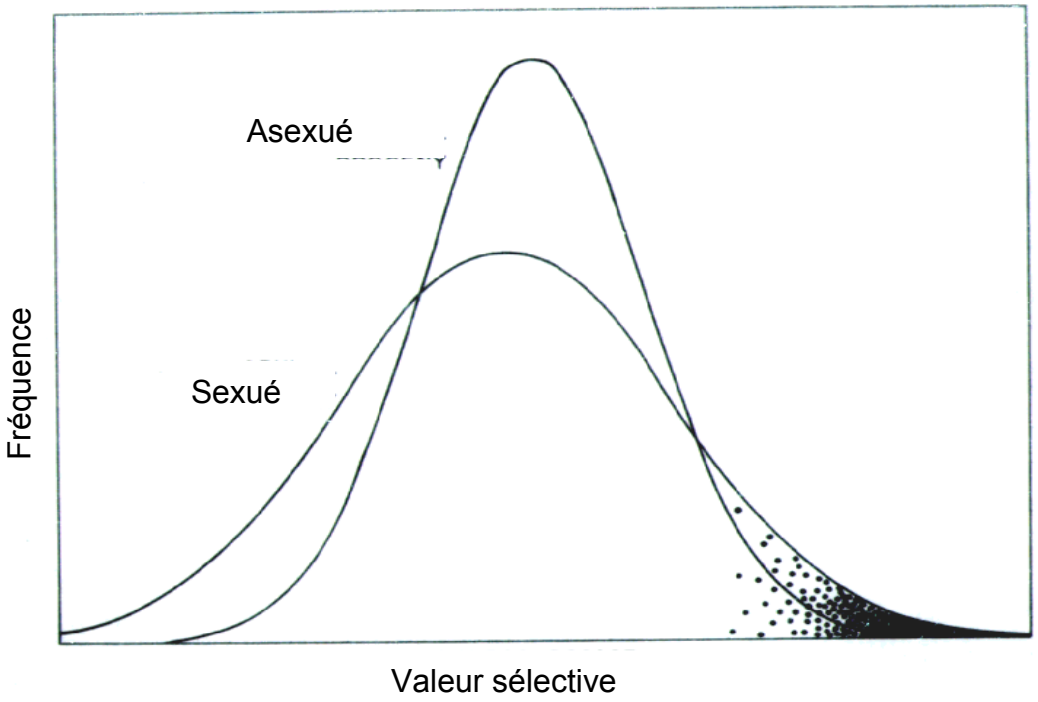


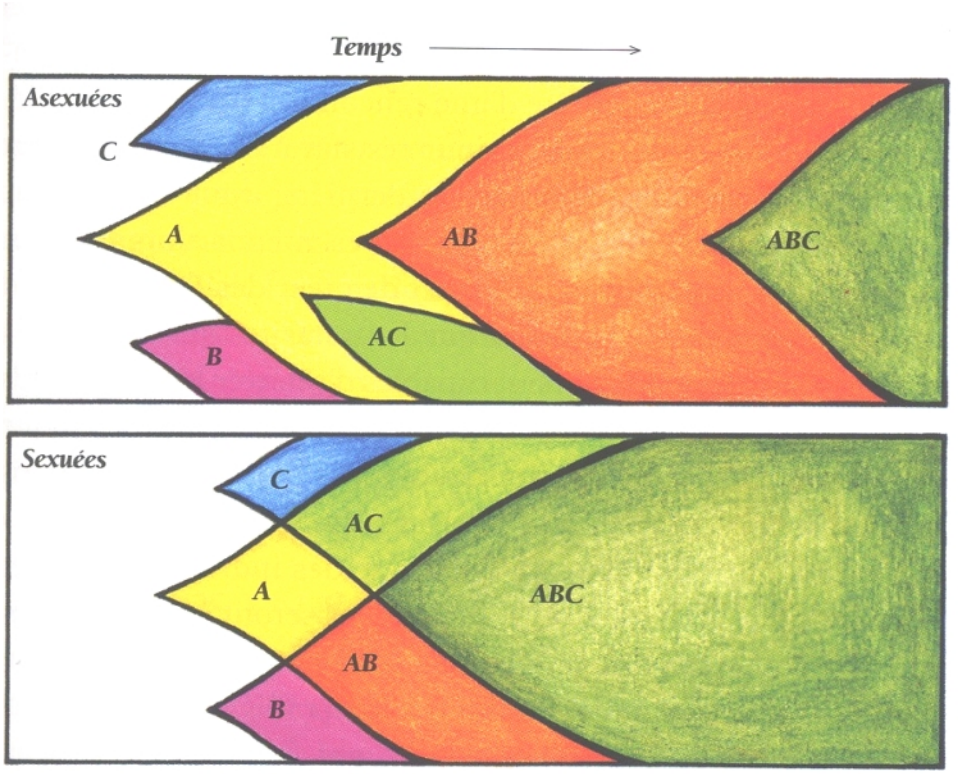
Ségrégation, recombinaison

La reproduction sexuée casse les associations génétiques

Pourquoi la reproduction sexuée ?

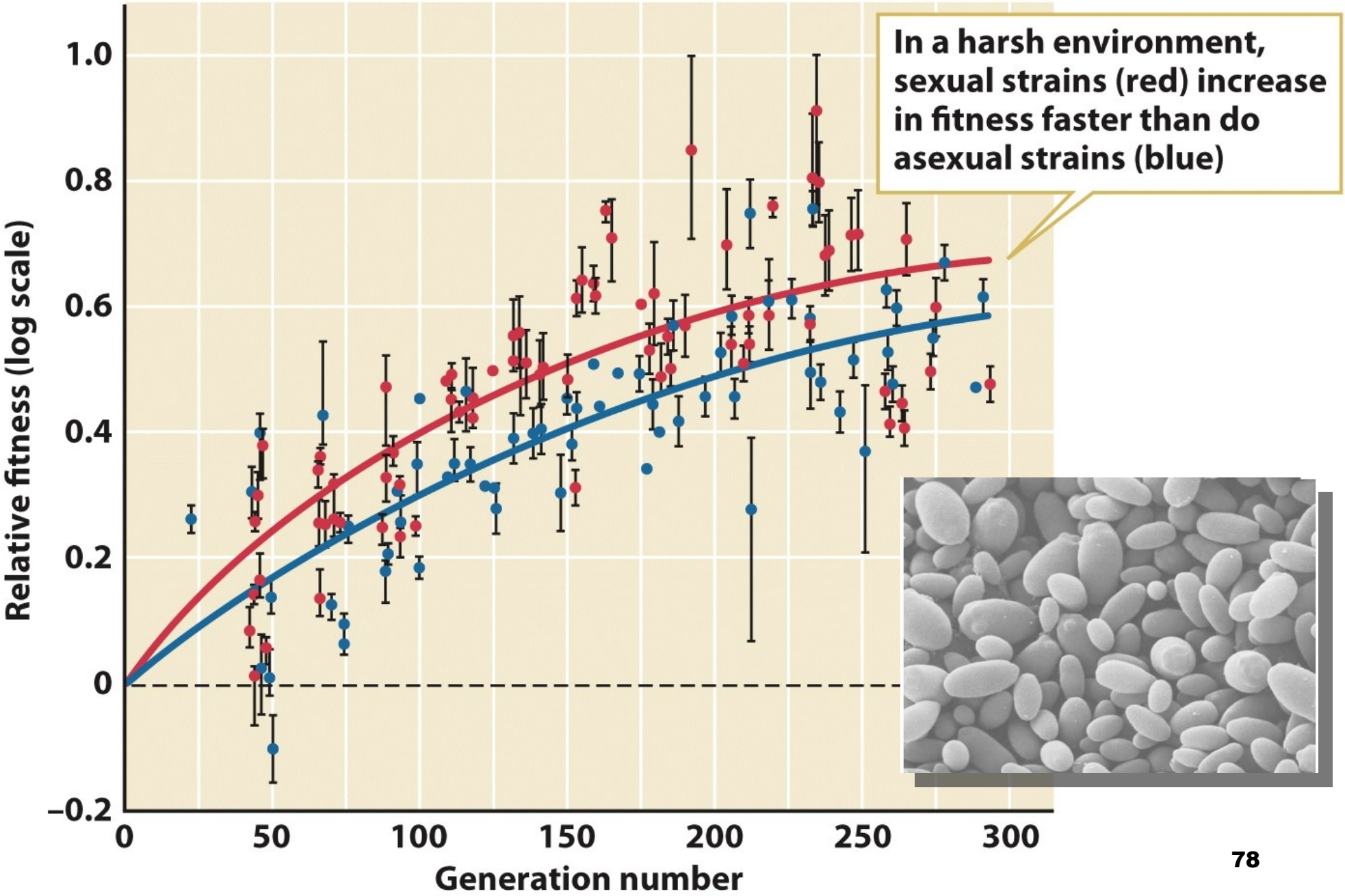
Réponse classique :
Génère de la diversité en redistribuant les combinaisons génétiques …





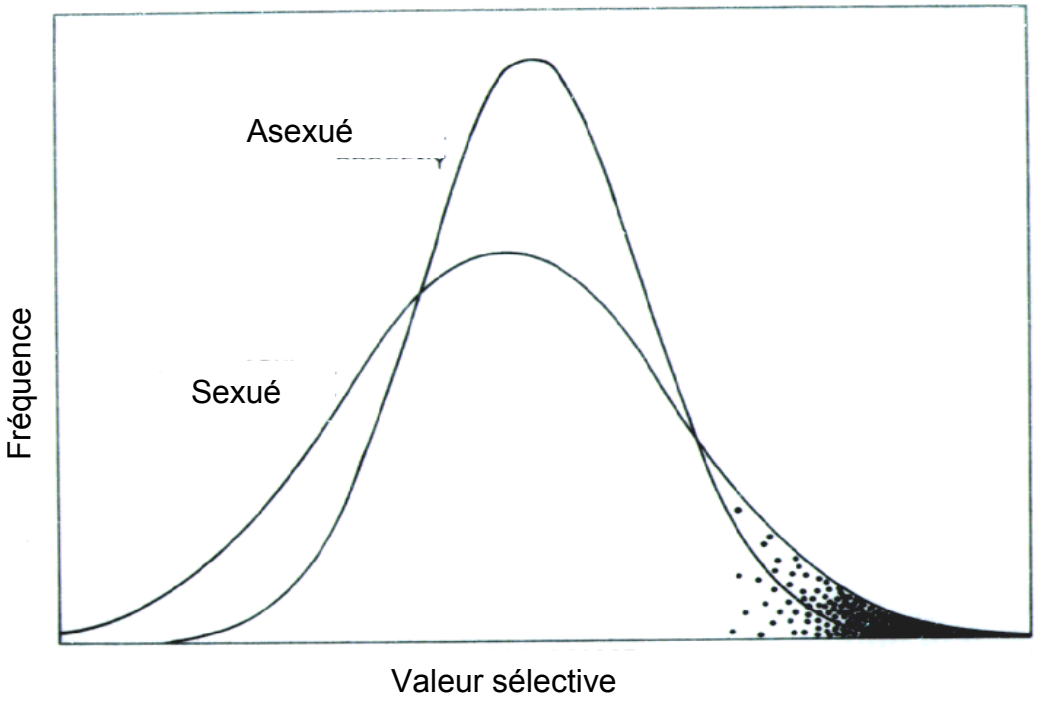
Effectivement, une plus grande variation est créée au cours de la reproduction sexuée

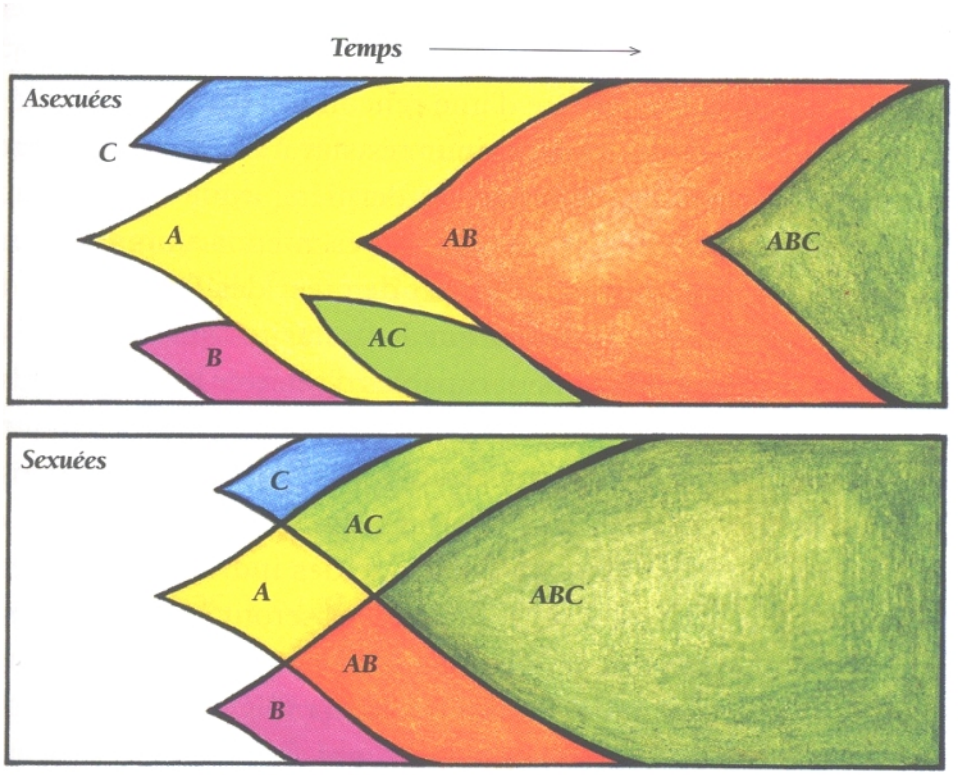
Relative fitness in asexual versus sexual populations in yeast



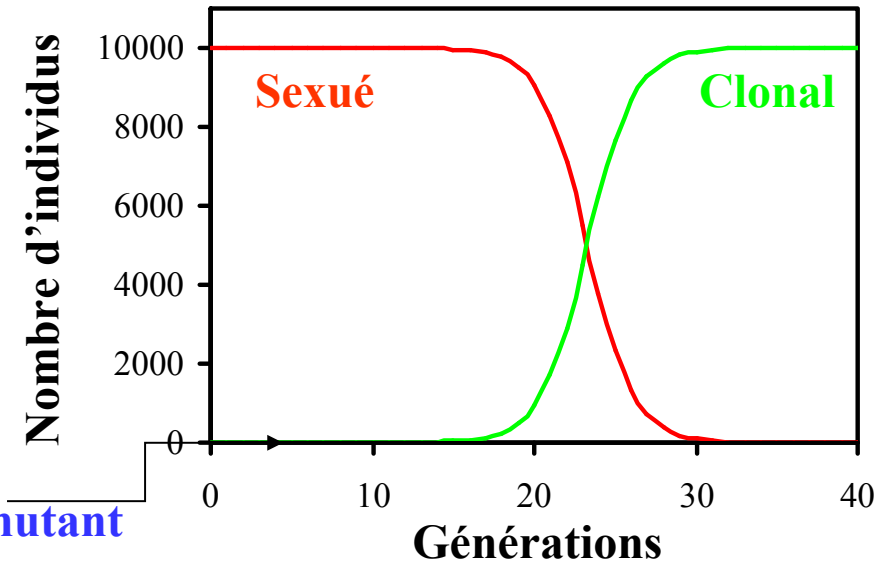
Pourquoi la reproduction sexuée ?

Réponse classique :
Génère de la diversité en redistribuant les combinaisons génétiques …





Modèles : Il faut que la sélection change au moins toutes les 5 générations pour permettre de maintenir la reproduction sexuée.



Apparition d'un mutant clonal

Les femelles clonales envahissent les populations bien avant que l'avantage de la diversité génétique ne puisse intervenir!

Echange de matériel génétique entre bactéries



Les pathogènes : un environnement qui change vite







«Now, here, you see, it takes all the running you can do, to keep in the same place»

L’hypothèse de la reine rouge explique le maintien de la reproduction sexuée

Potamopyrgus antipodarum, escargot d’eau douce de Nouvelle Zélande

On trouve :

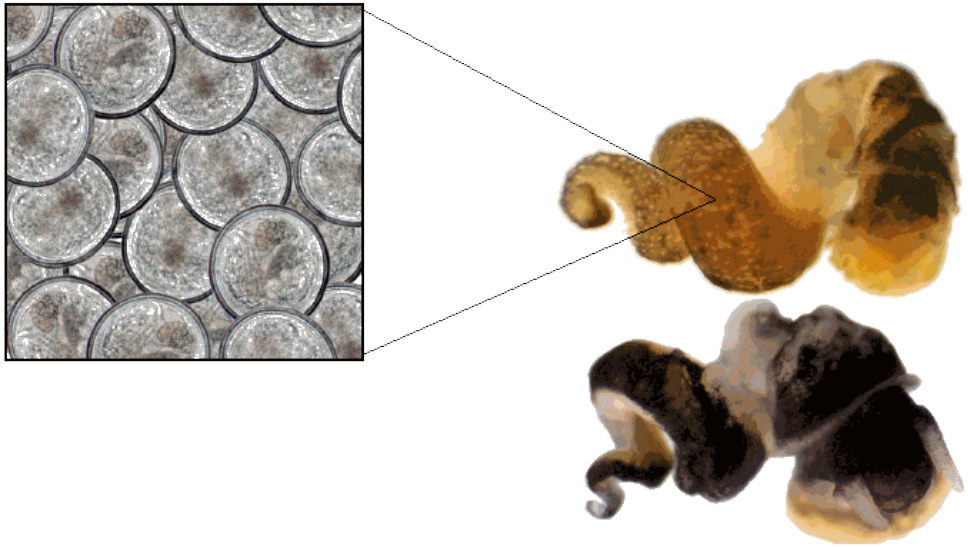
- des populations de mâles et femelles sexuées
- des populations de femelles asexuées (parthénogénétiques)





L’hypothèse de la reine rouge explique le maintien de la reproduction sexuée

Plus de femelles sexuées et de mâles
dans les lacs où la fréquence des parasites est élevée





Evolution de la reproduction sexuée avec sexes séparés

Différentes explications

Double coût du sexe et autres désavantages de la reproduction sexuée

Création de nouvelles combinaisons génétiques

Hypothèse de la reine rouge

Conclusions

Théorie de l'évolution : 3 piliers, 4 forces

Bricolage de l'évolution

Evolution toujours en cours aujourd'hui pour toutes les espèces

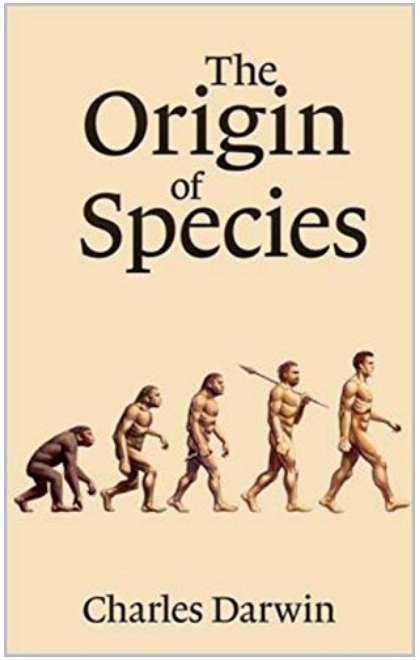
Les causes ultimes et proximales

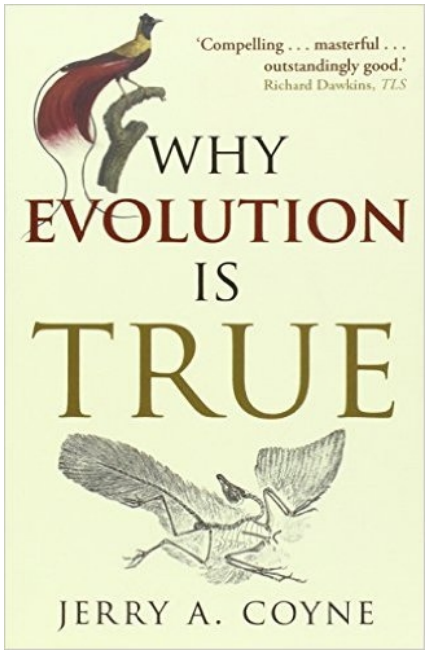
Causes de la diversité intraspécifique

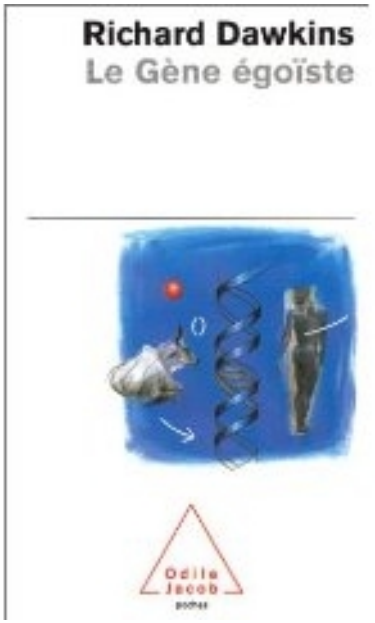
La sélection naturelle ne fonctionne pas pour perpétuer l'espèce

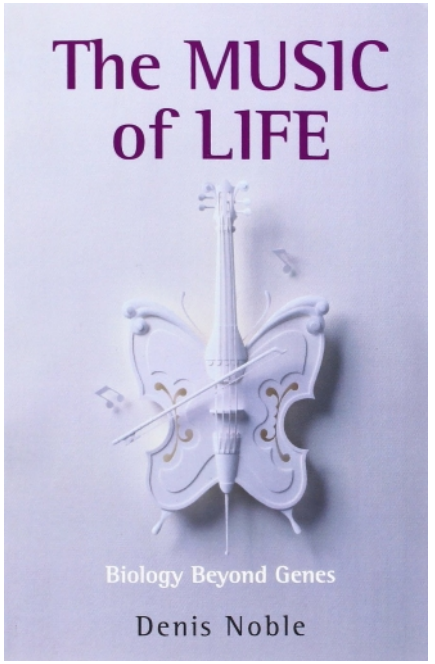
Hypothèse de la reine rouge - l'évolution ne s'arrête jamais

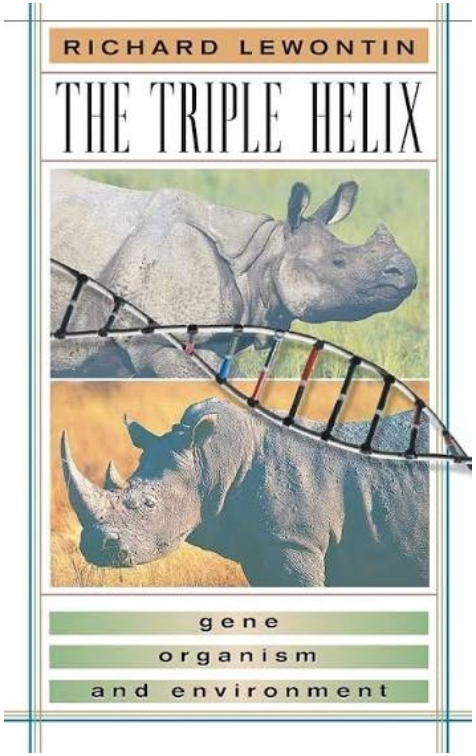
La reproduction sexuée permet le réassortiment des allèles et la persistance face aux pathogènes

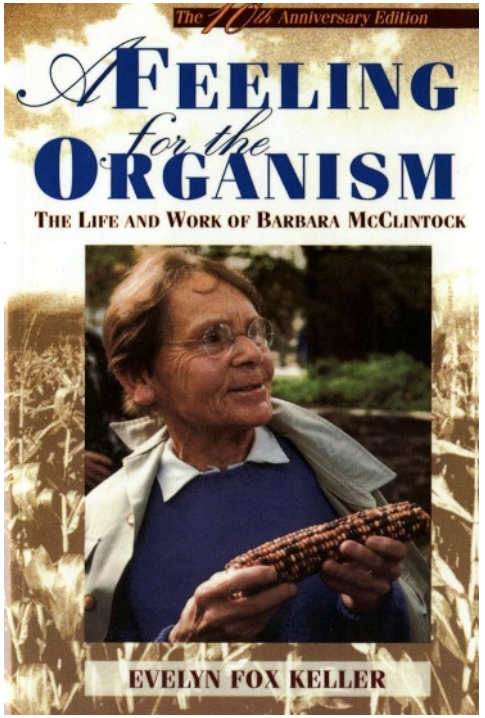

The Origin of Species
Charles Darwin

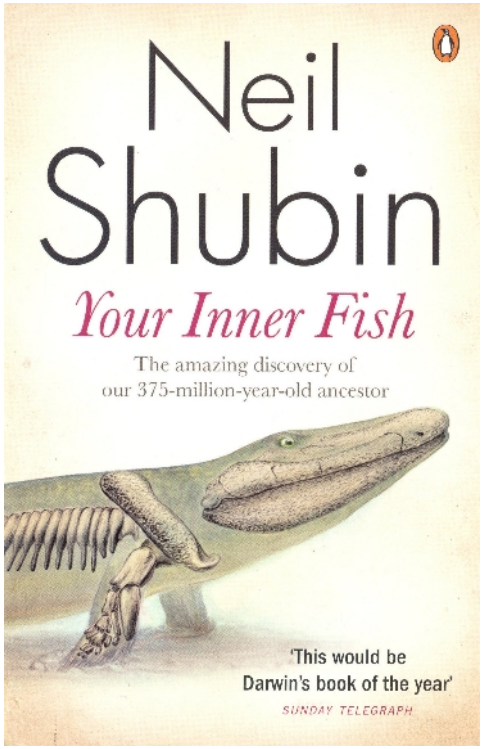

'Compelling . . . masterful . . . outstandingly good.'
Richard Dawkins, TLS
WHY EVOLUTION IS TRUE
JERRY A. COYNE


Richard Dawkins
Le Gène égoïste
Odile Jacob


The MUSIC of LIFE
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The amazing discovery of our 375-million-year-old ancestor
'This would be Darwin's book of the year'
SUNDAY TELEGRAPH


Michel Raymond
Cro-Magnon toi-même !
Petit guide darwinien de la vie quotidienne