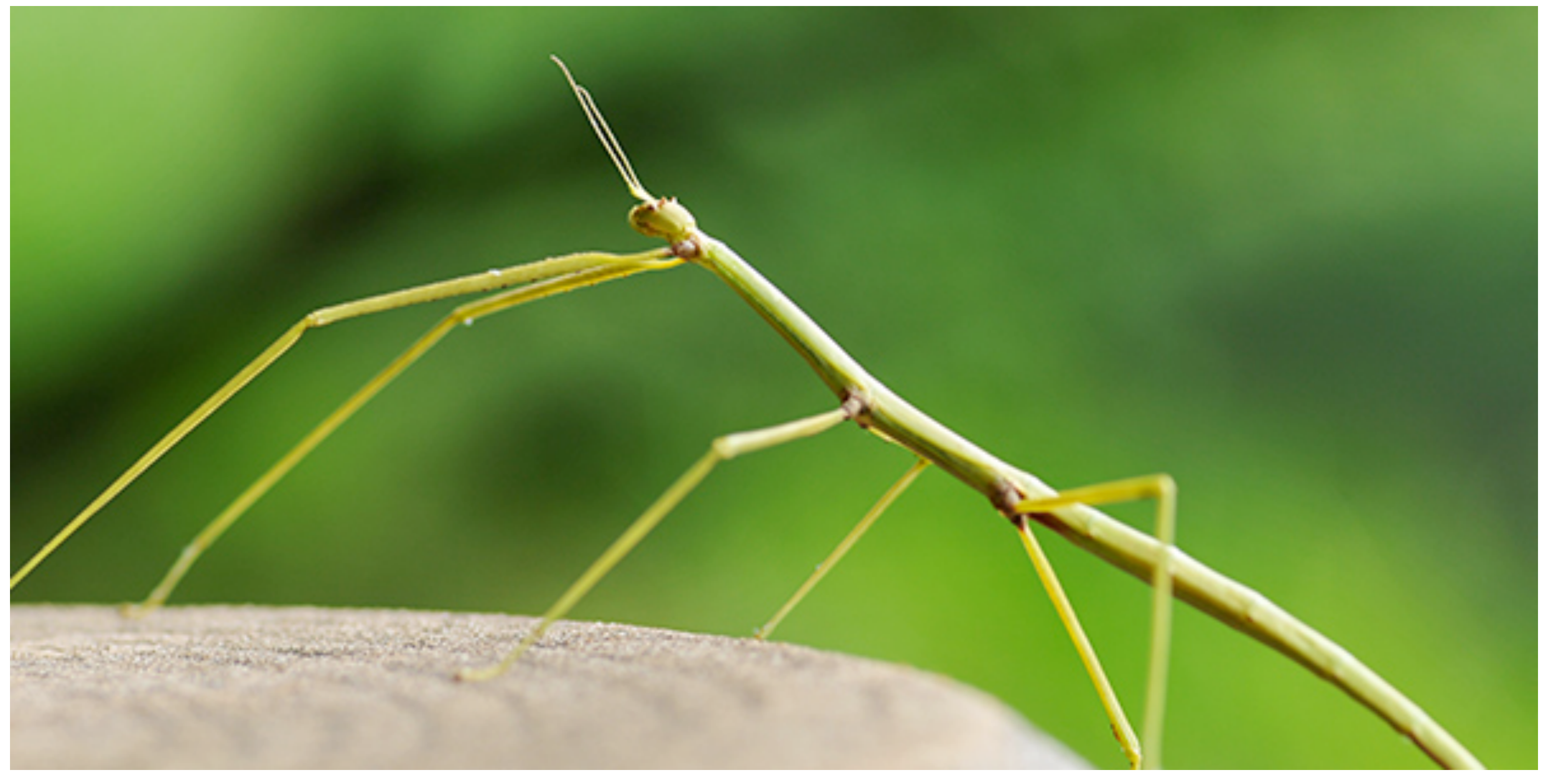
Part II - Sexual reproduction

Sexual reproduction is near universal in multi-cellular organisms

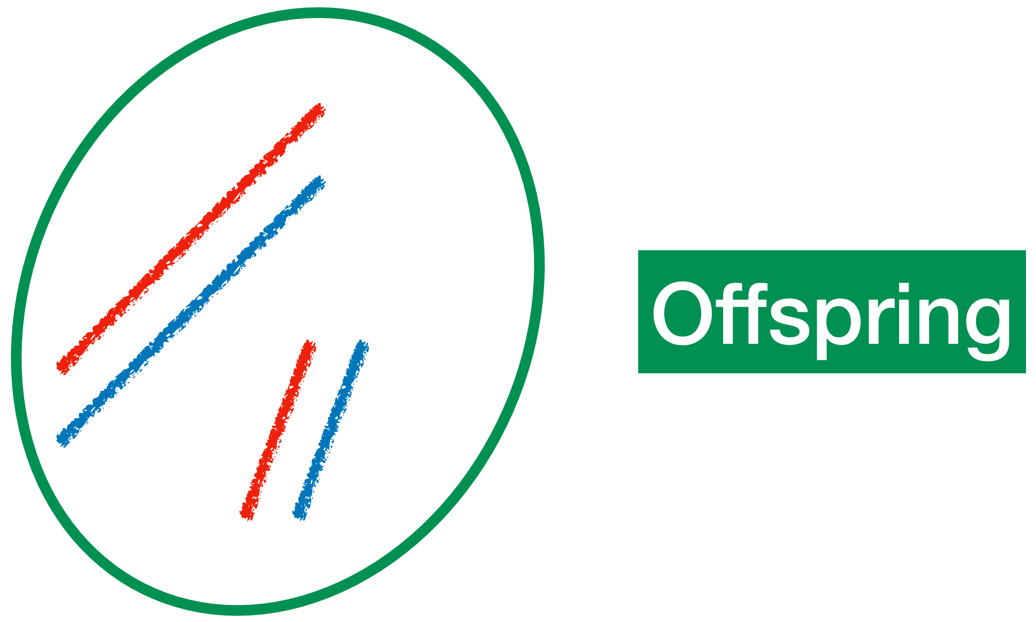
Very few ancestral asexual lineages



What is sexual reproduction?

and what are sexes?

- Production of new organisms by the combination of genetic material of two individuals.



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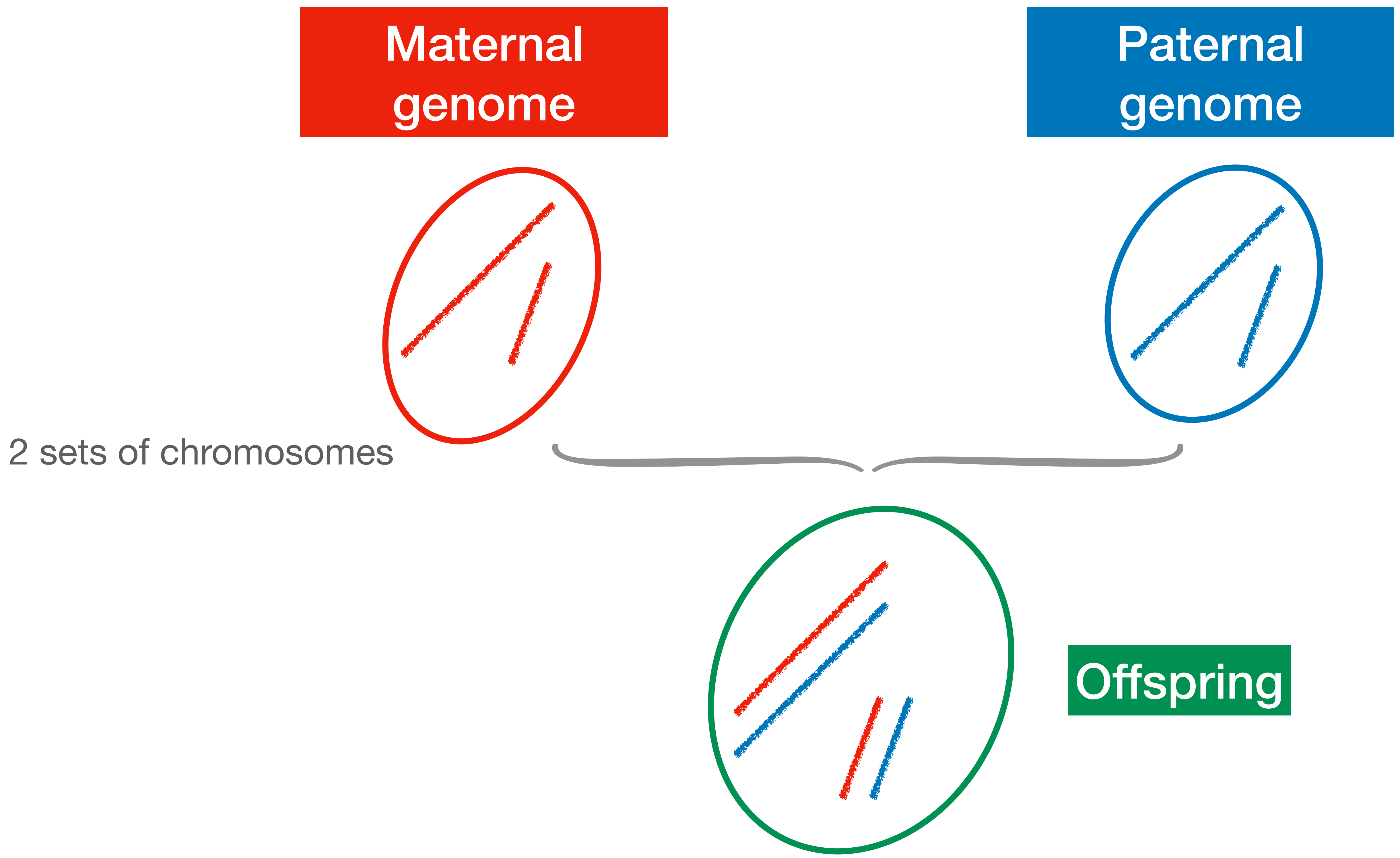

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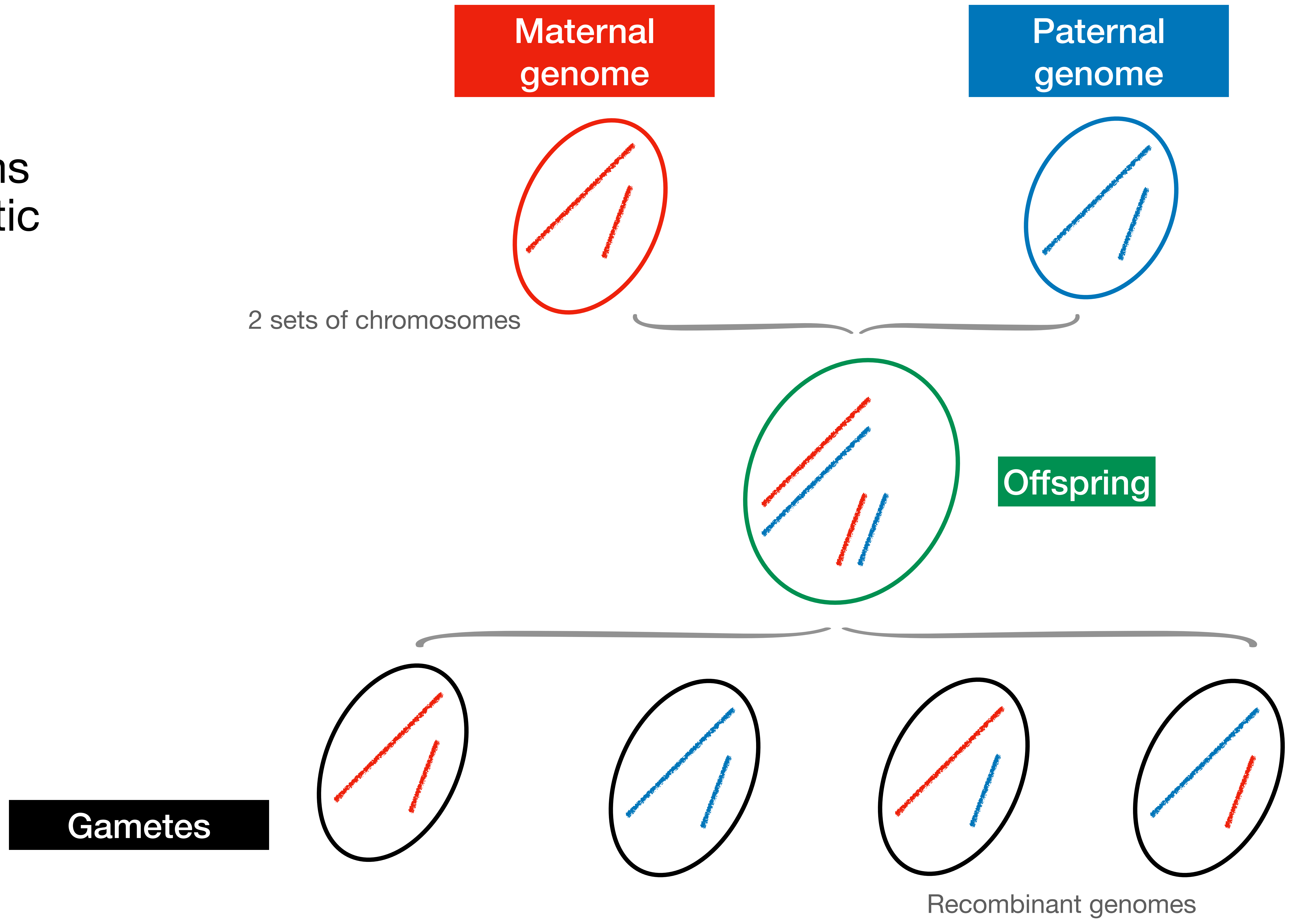

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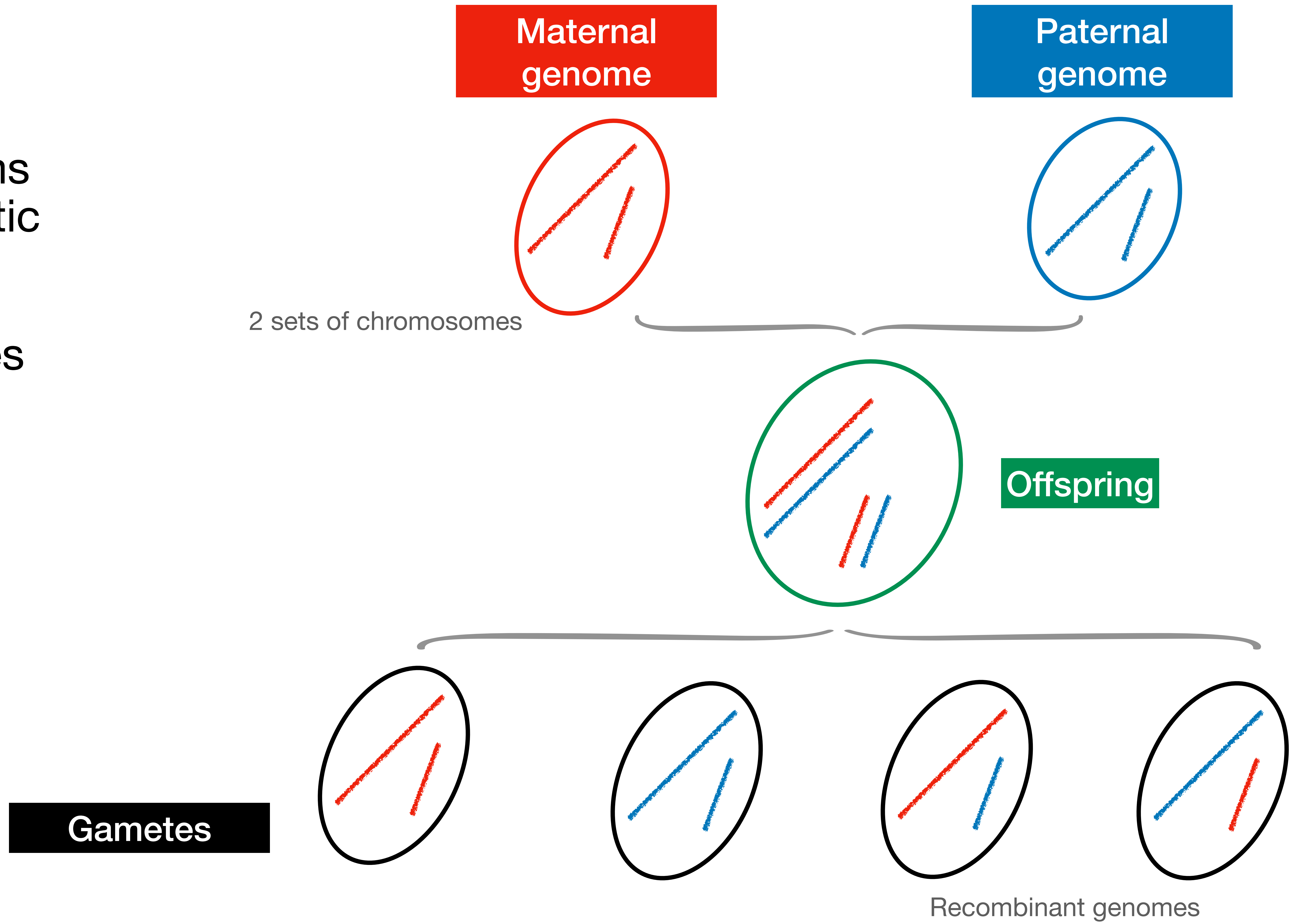

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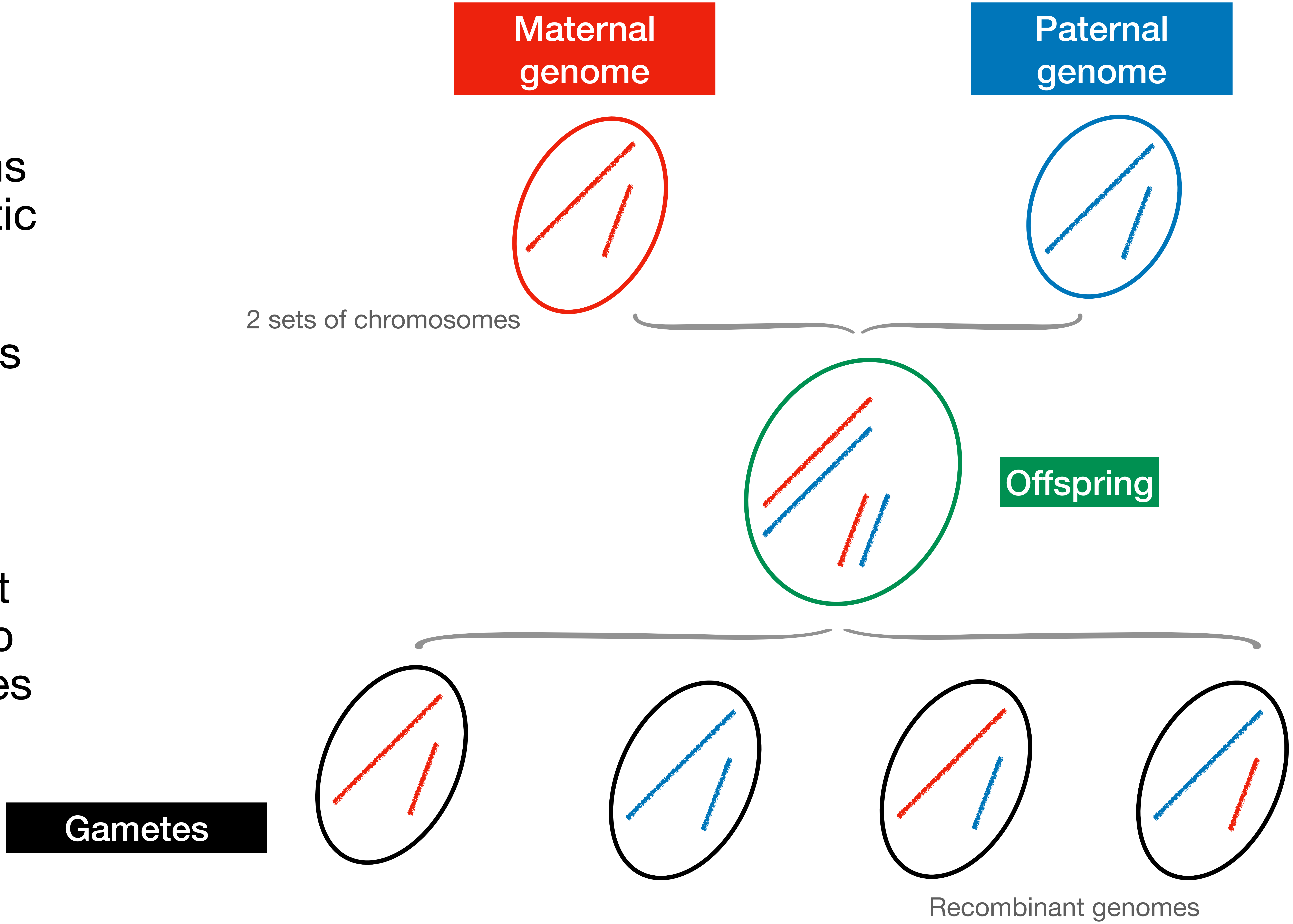
- Production of new organisms by the combination of genetic material of two individuals.
- Sexes are defined as classes of individuals that are incompatible for sexual reproduction.
- Typically 2 sexes: males that produce many minute cheap gametes (sperm) and females that fewer produce large expensive ones (eggs).



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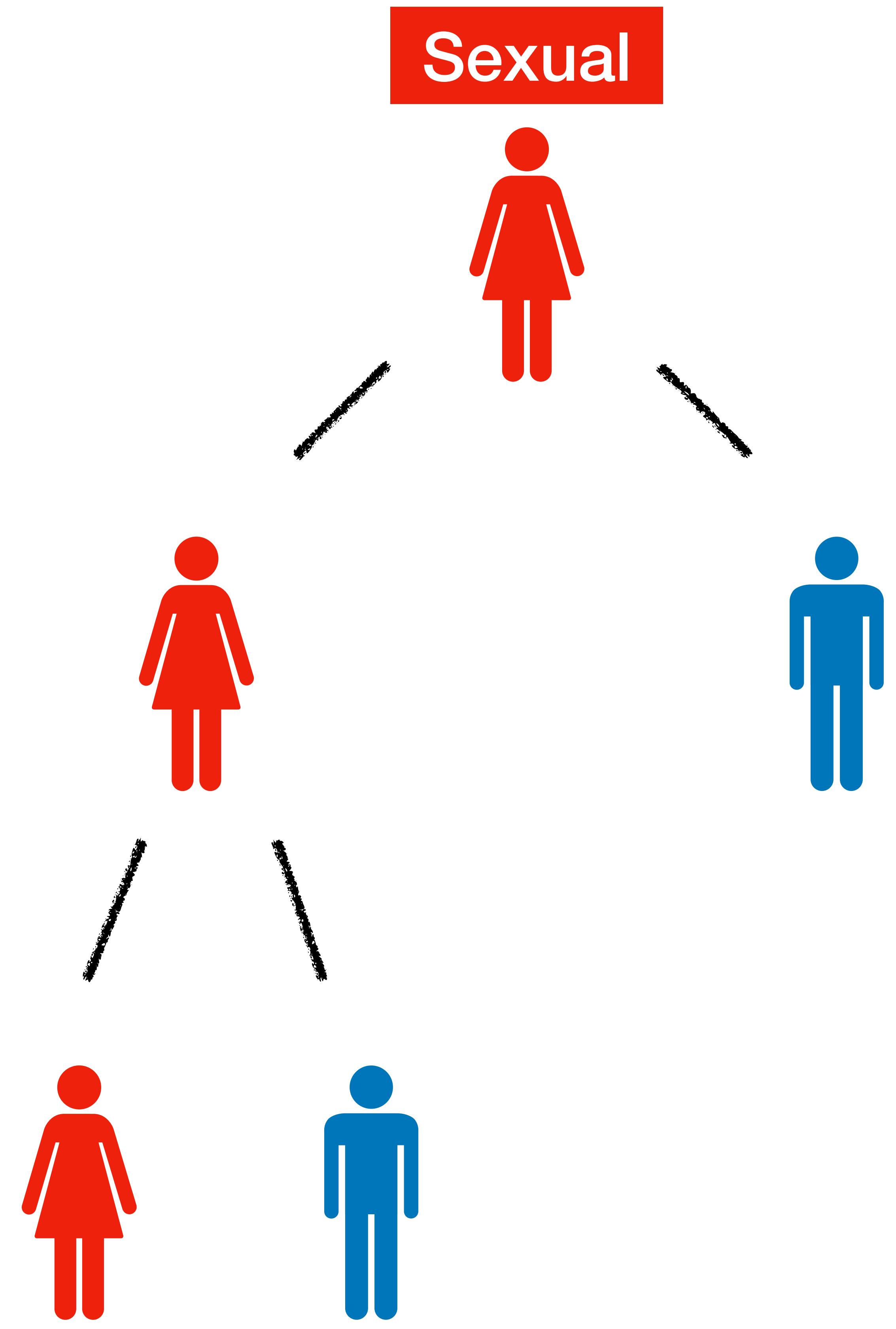
- Human man record claim: 888 offspring Ismael the Bloodthirsty, emperor of Morocco (1672-1727)

The demographic cost of sex

- For every daughter a sexual female makes, an asexual makes two.



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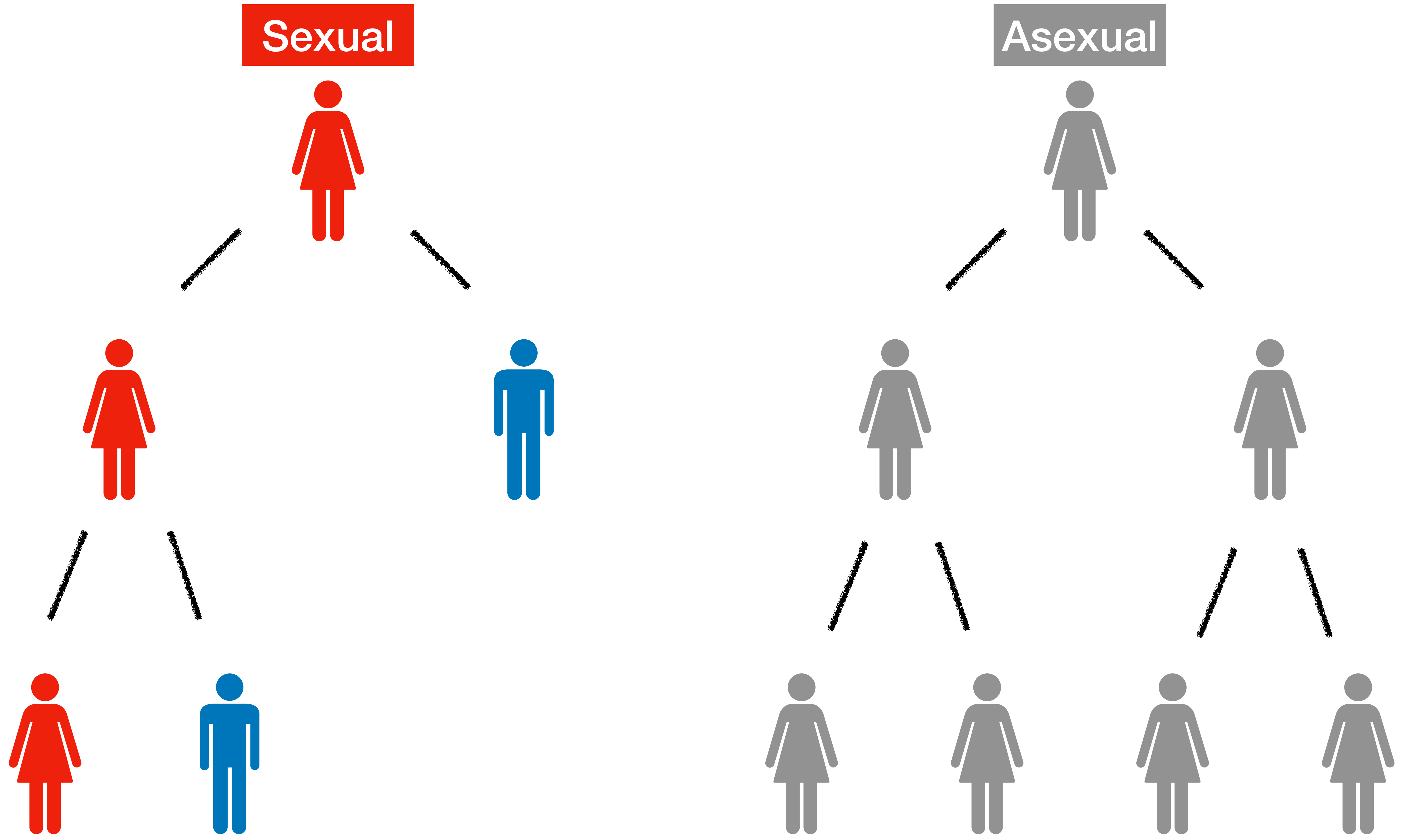

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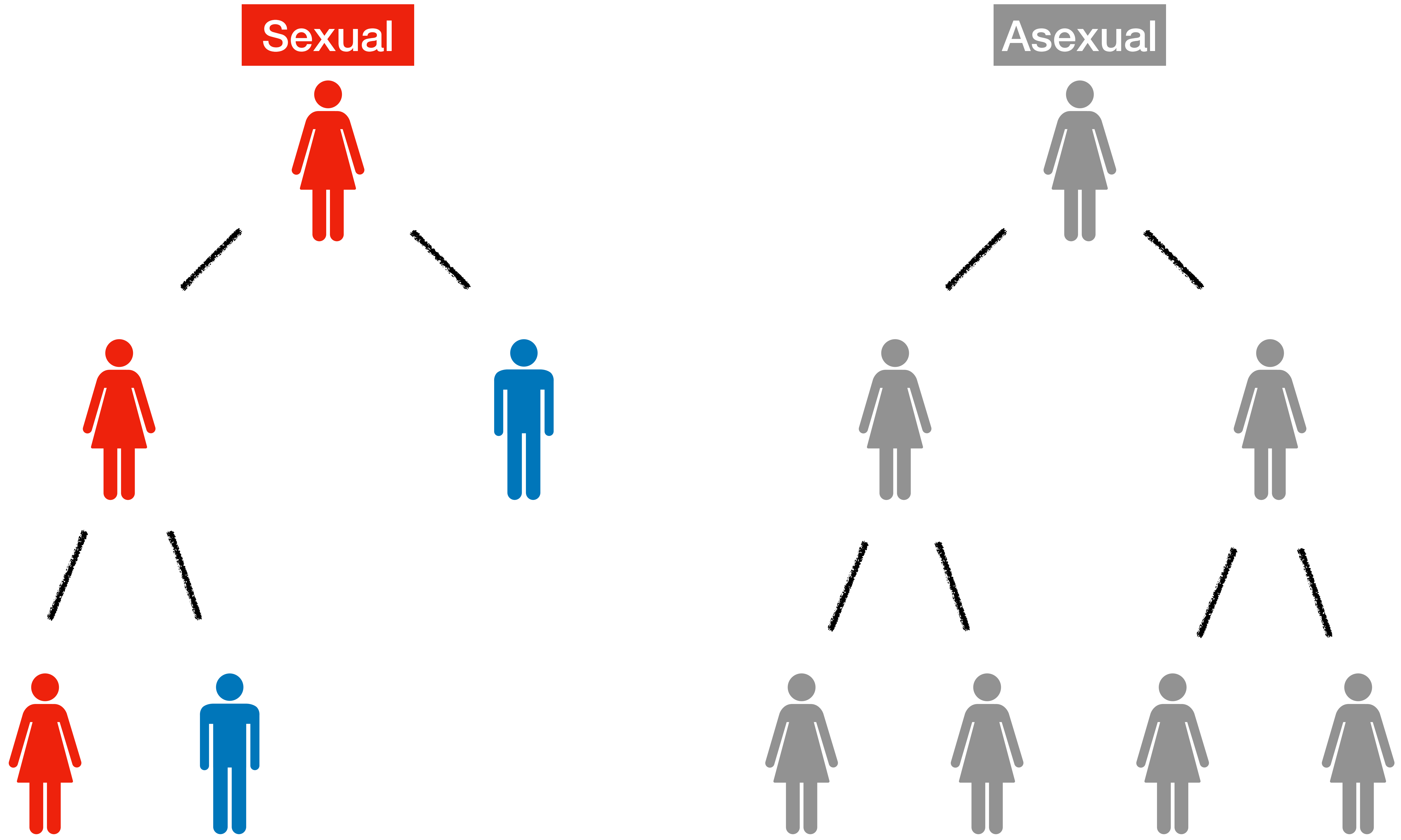
- For every daughter a sexual female makes, an asexual makes two.
- Asexuals have a huge demographic advantage and should easily outcompete sexual.



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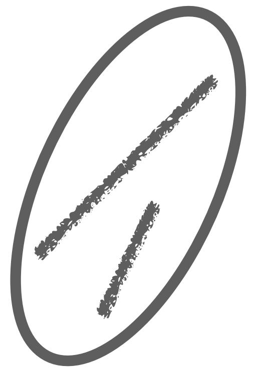

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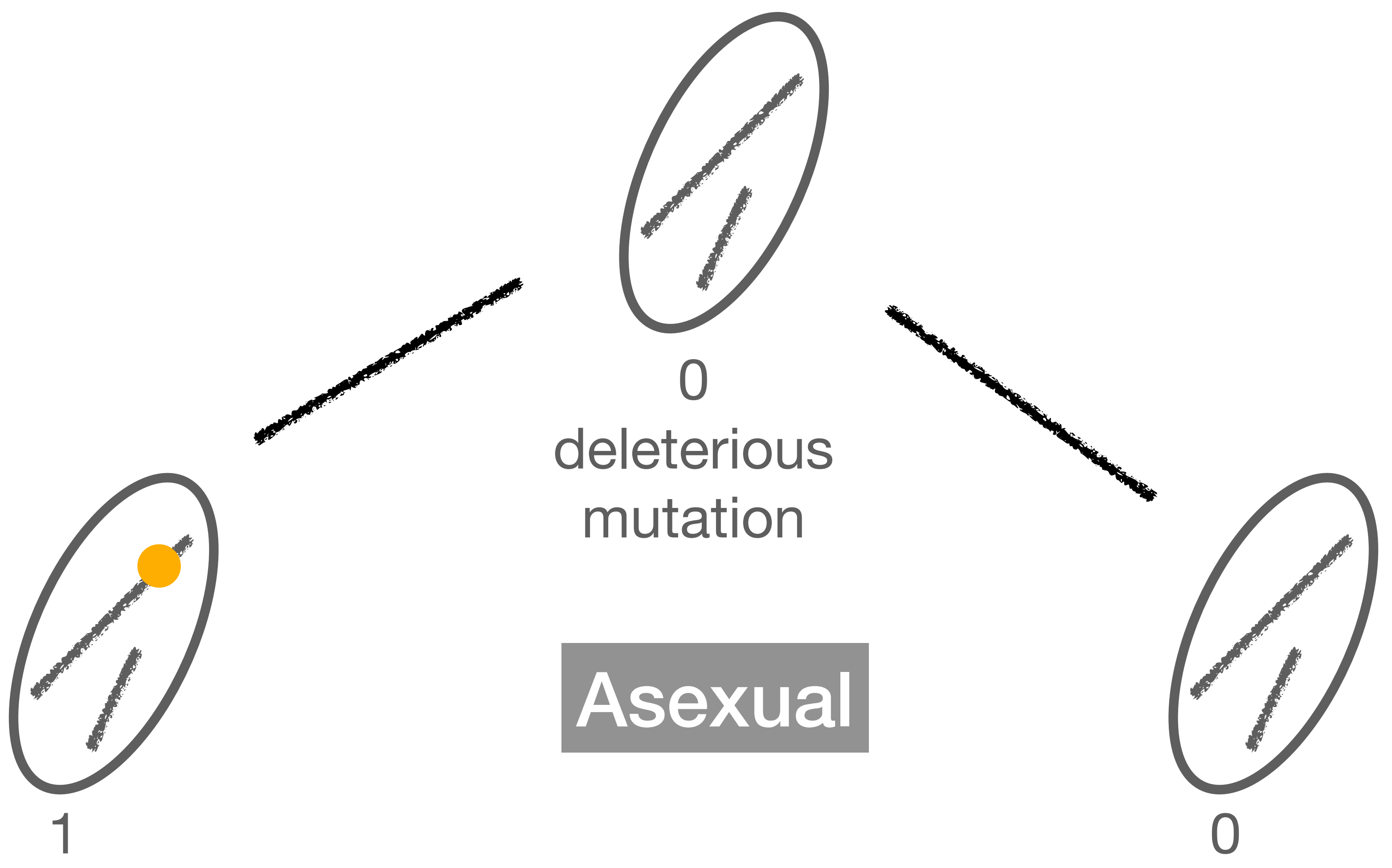

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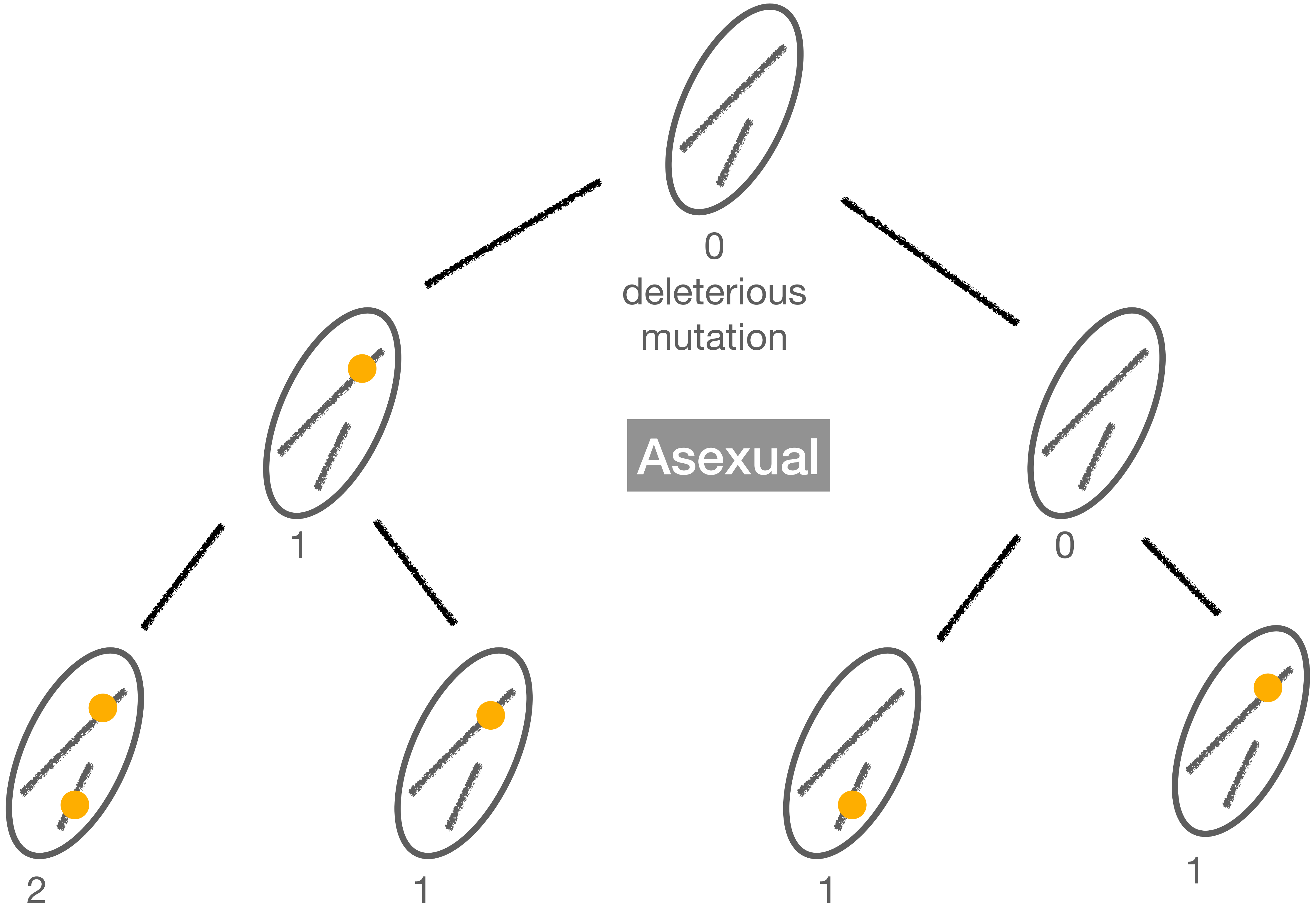

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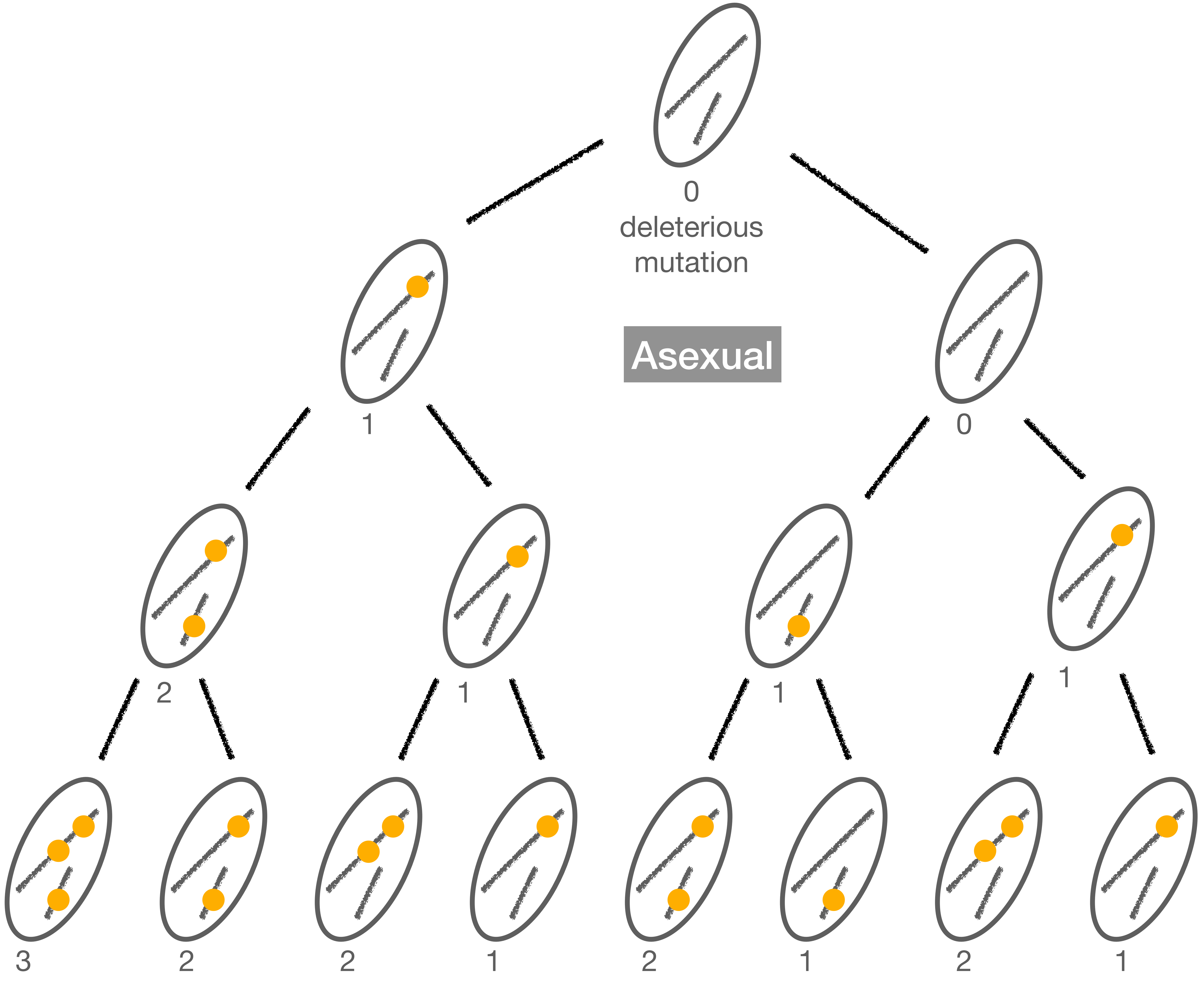

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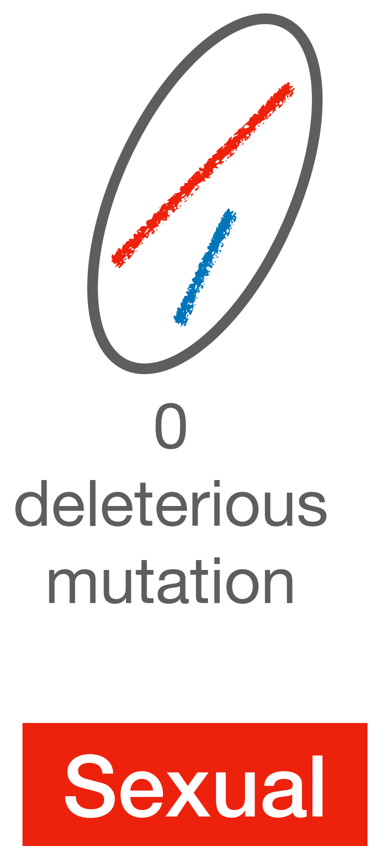

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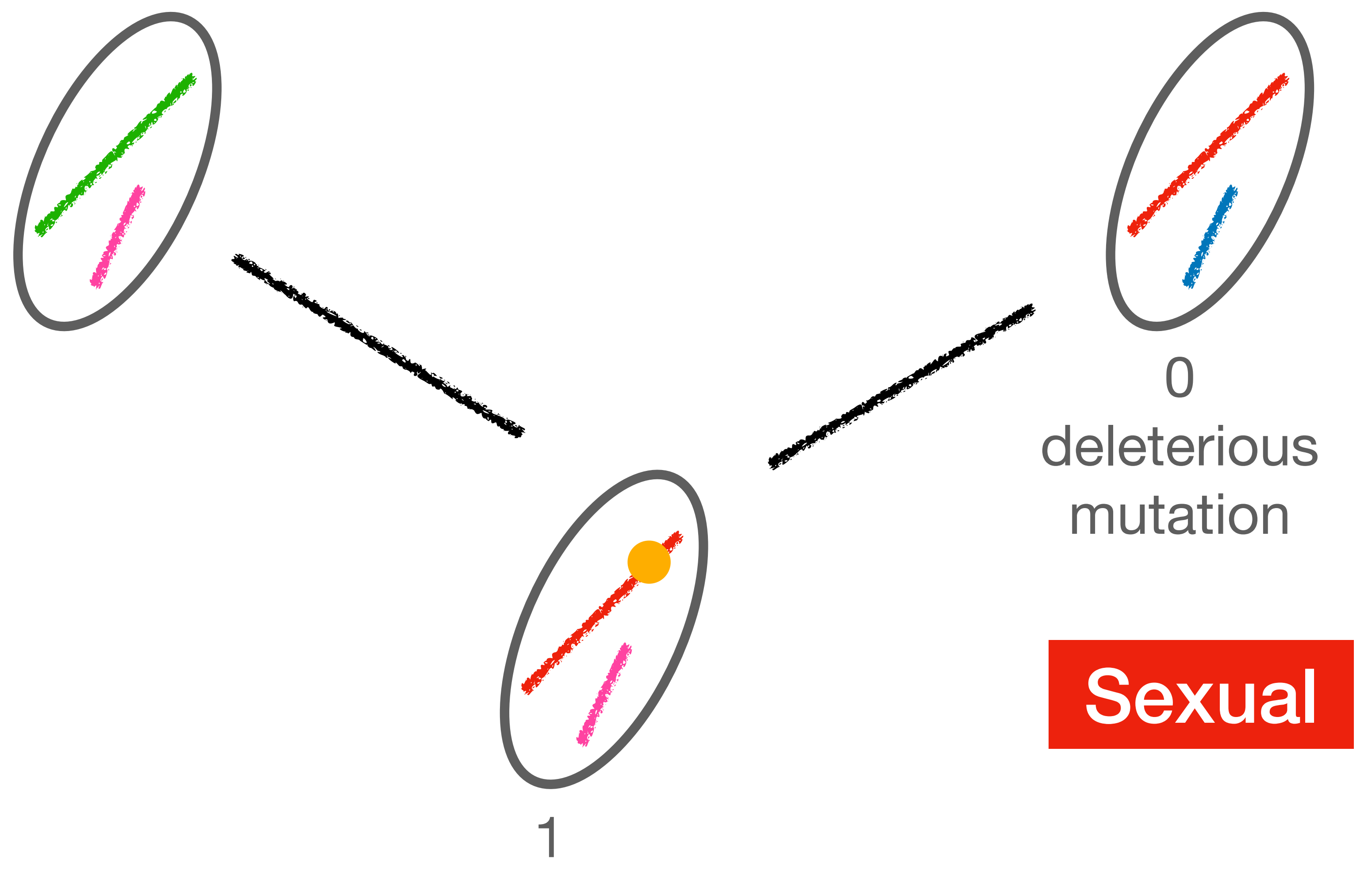

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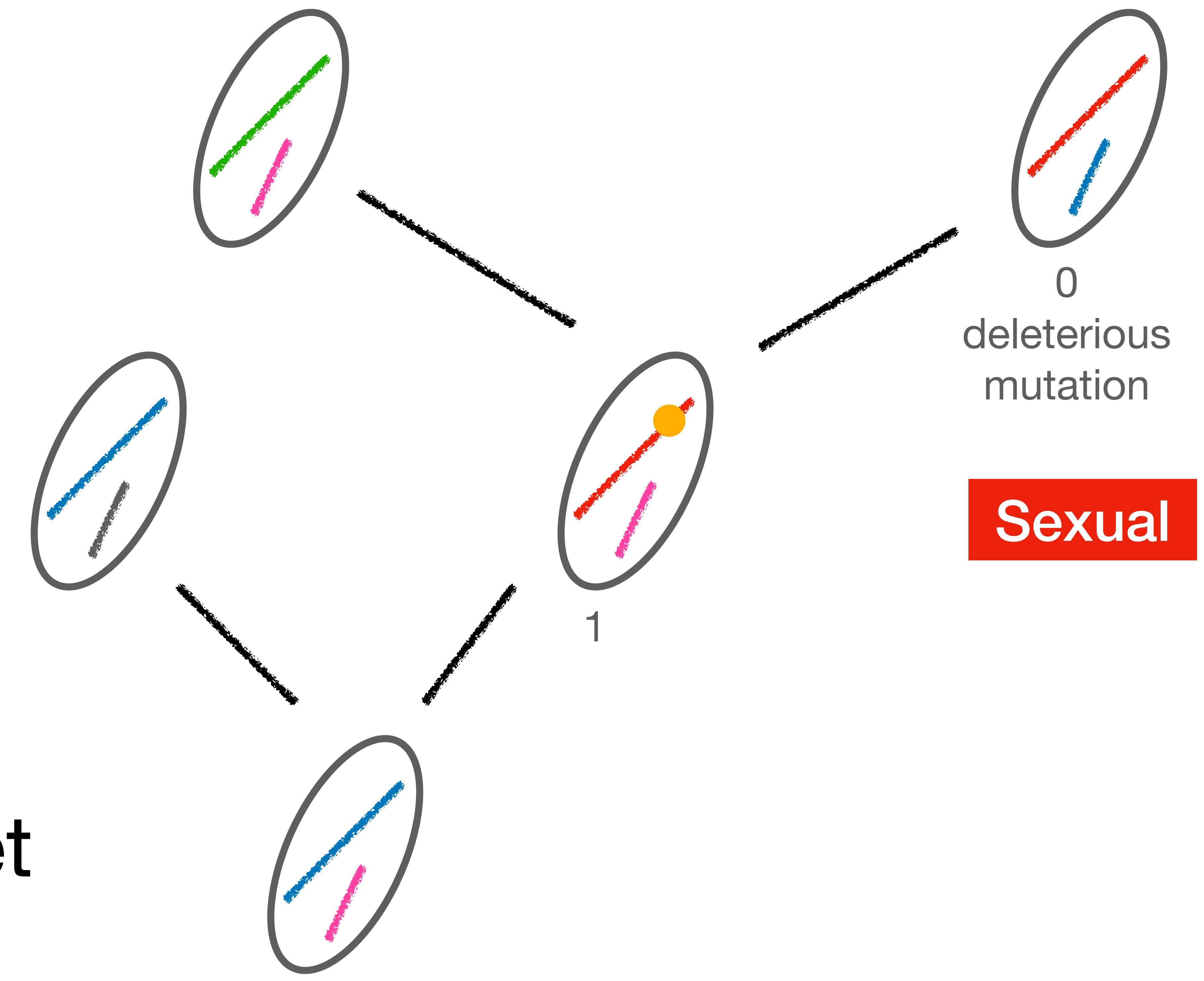

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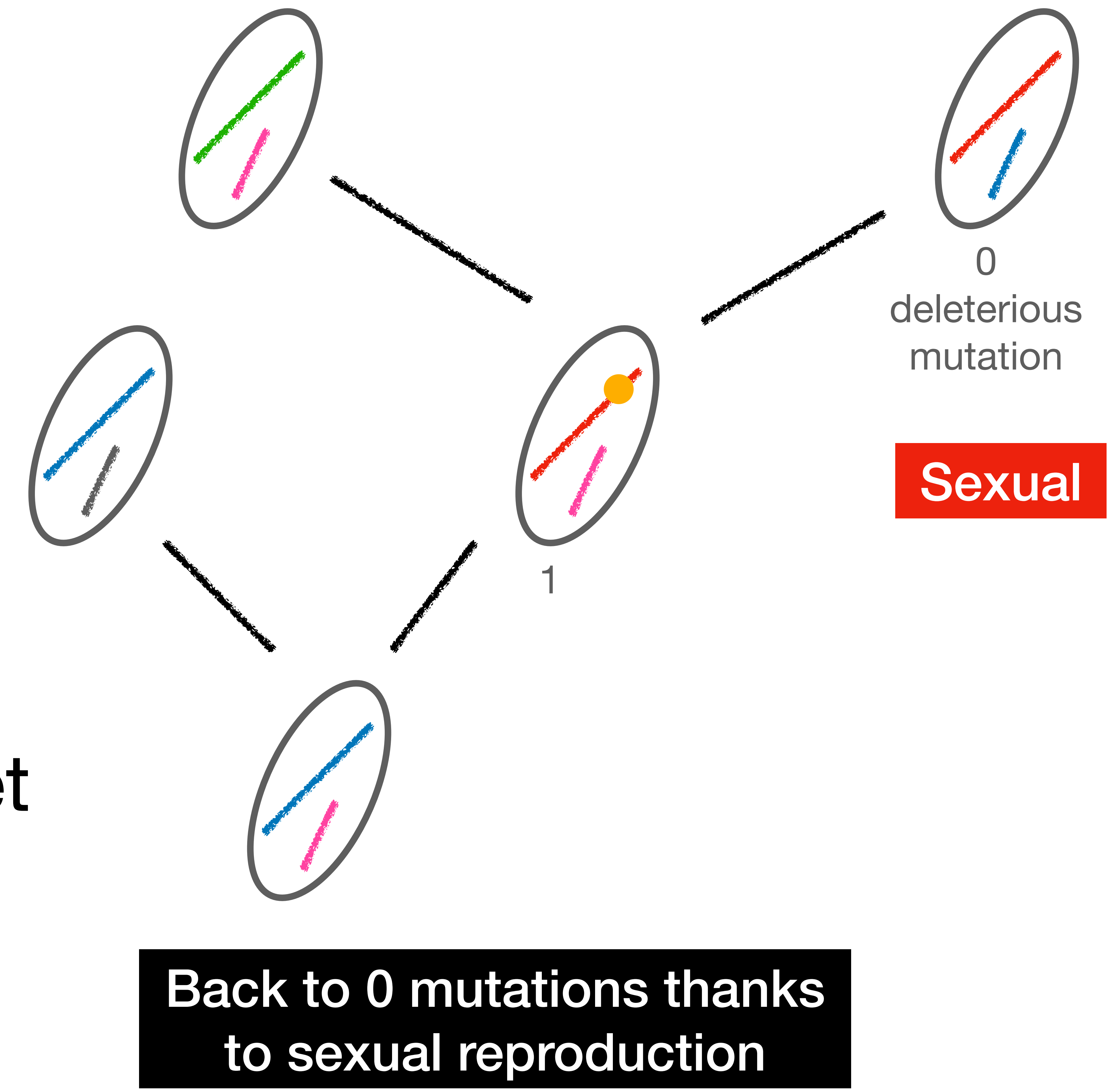

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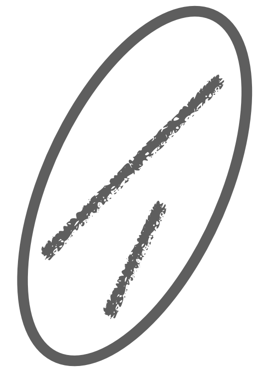

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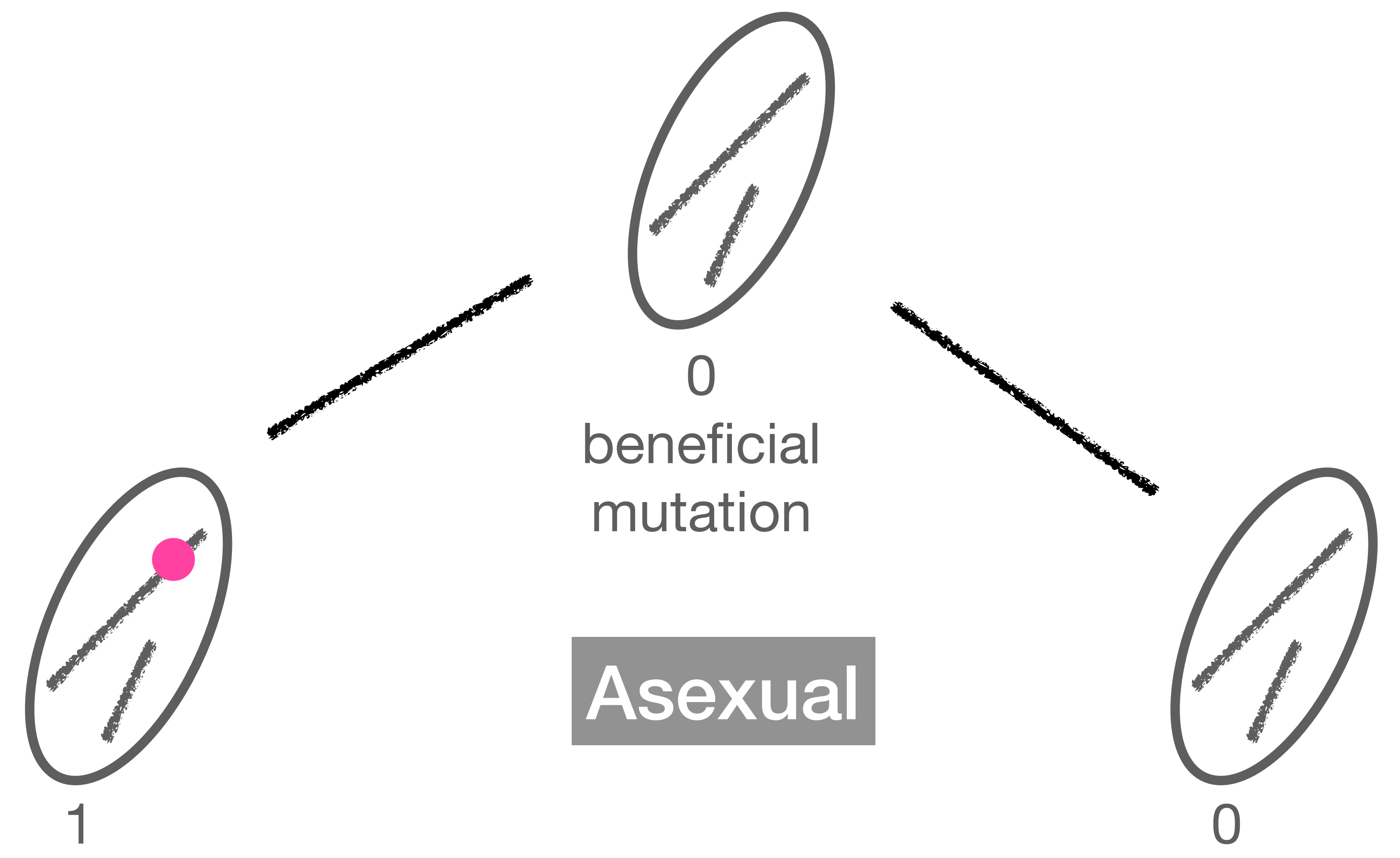

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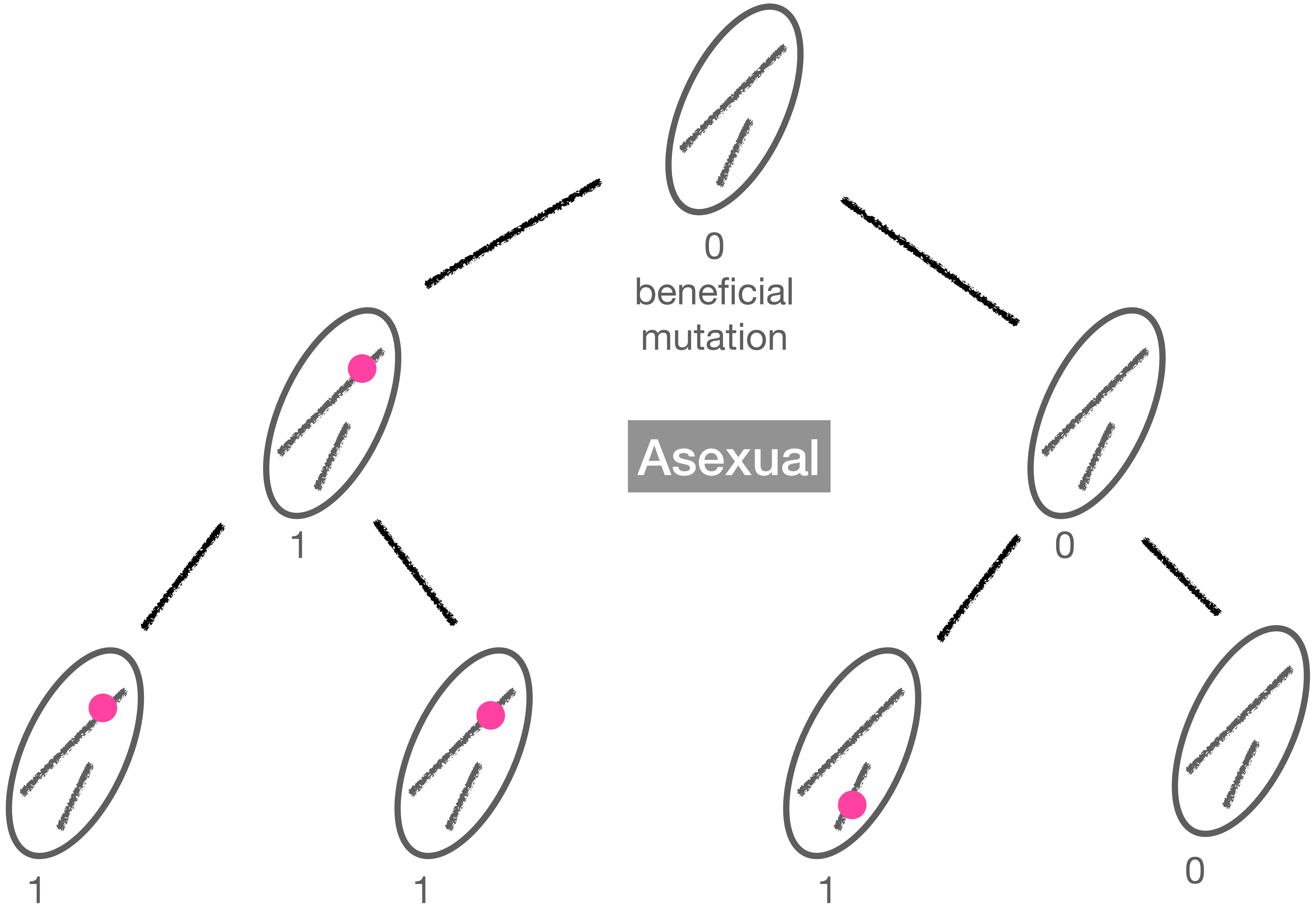

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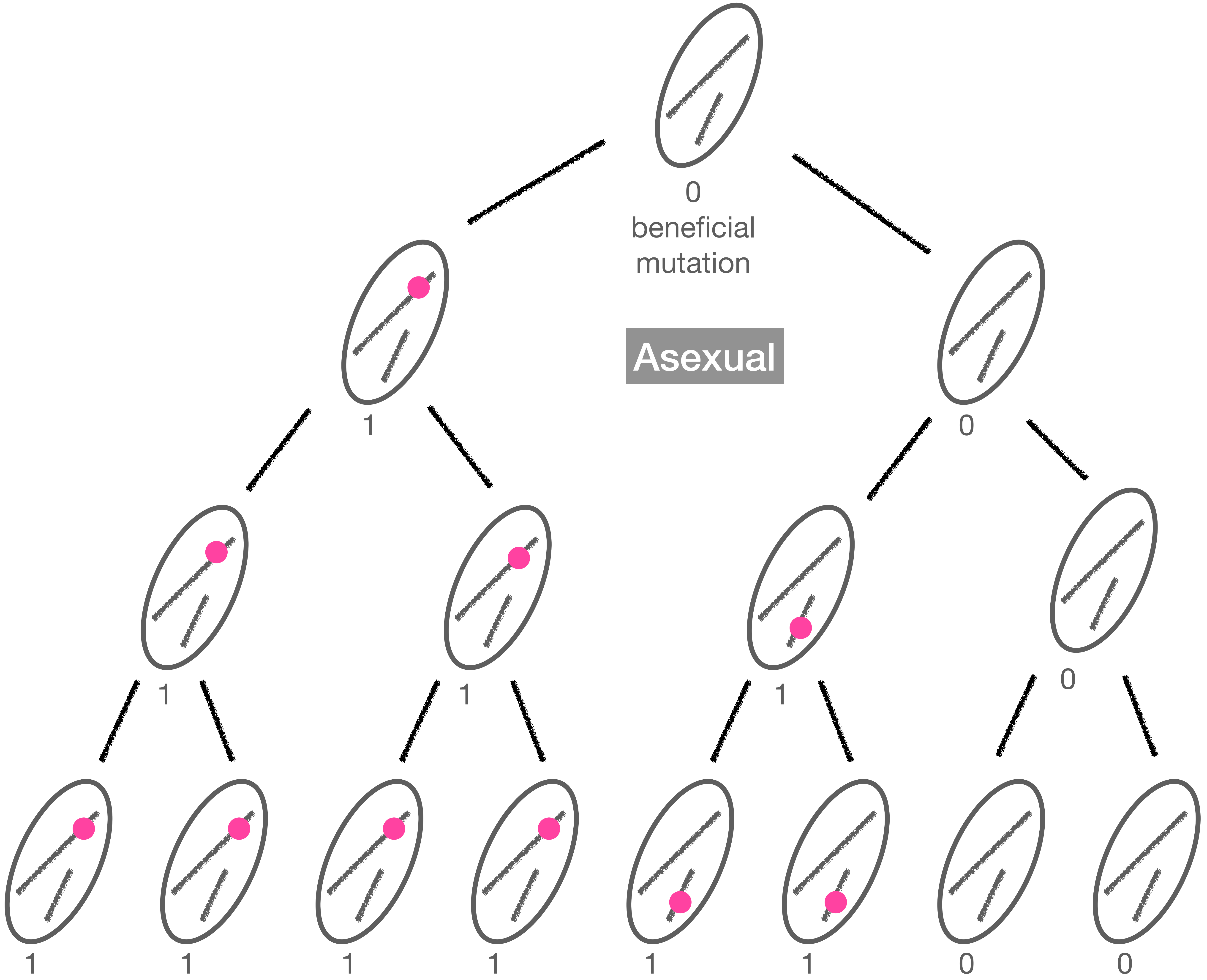

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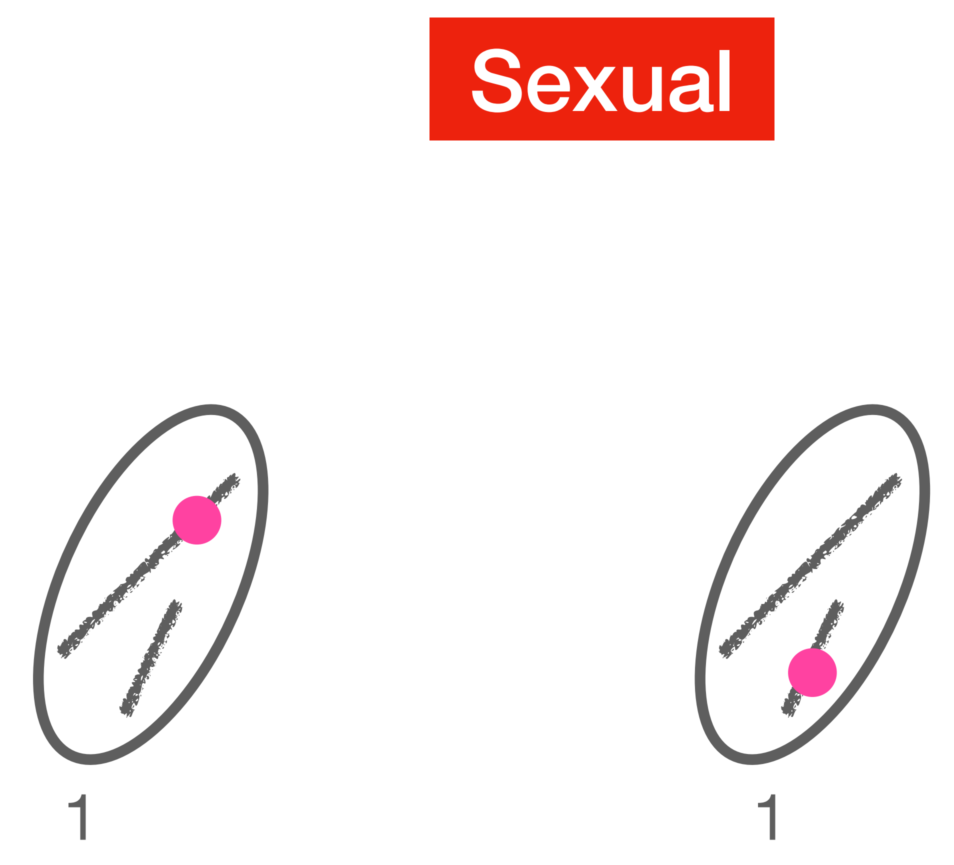

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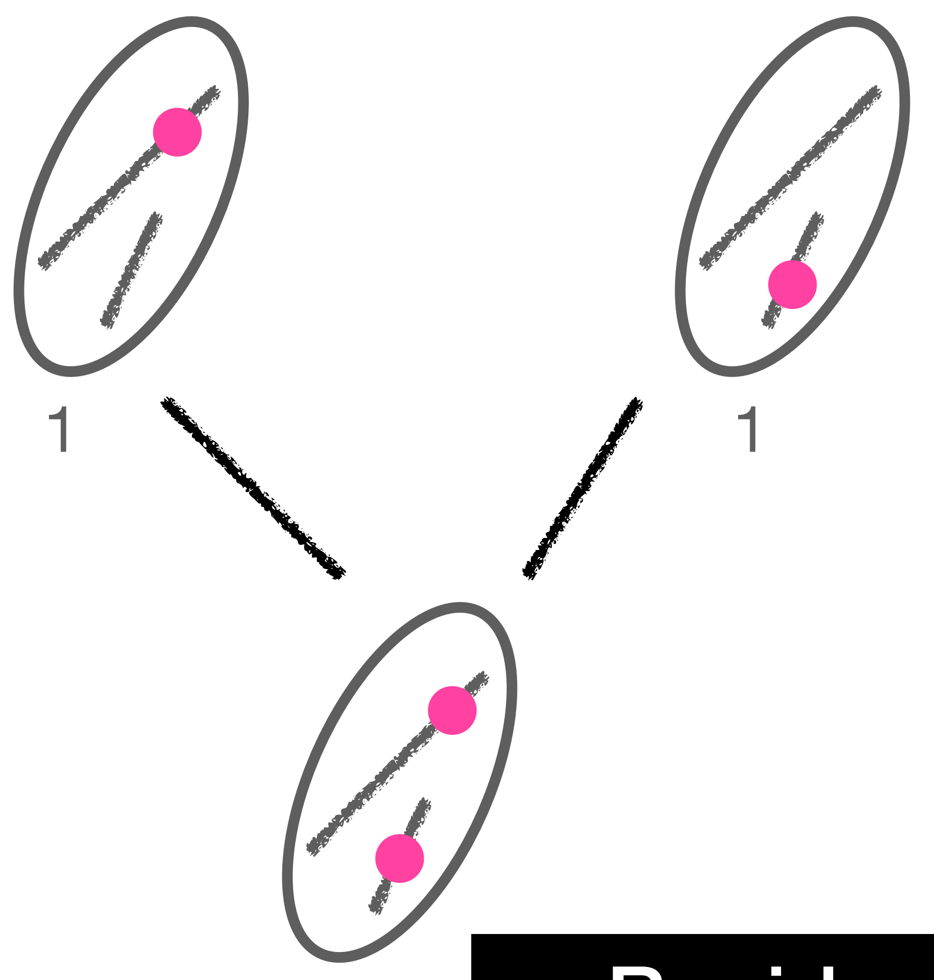
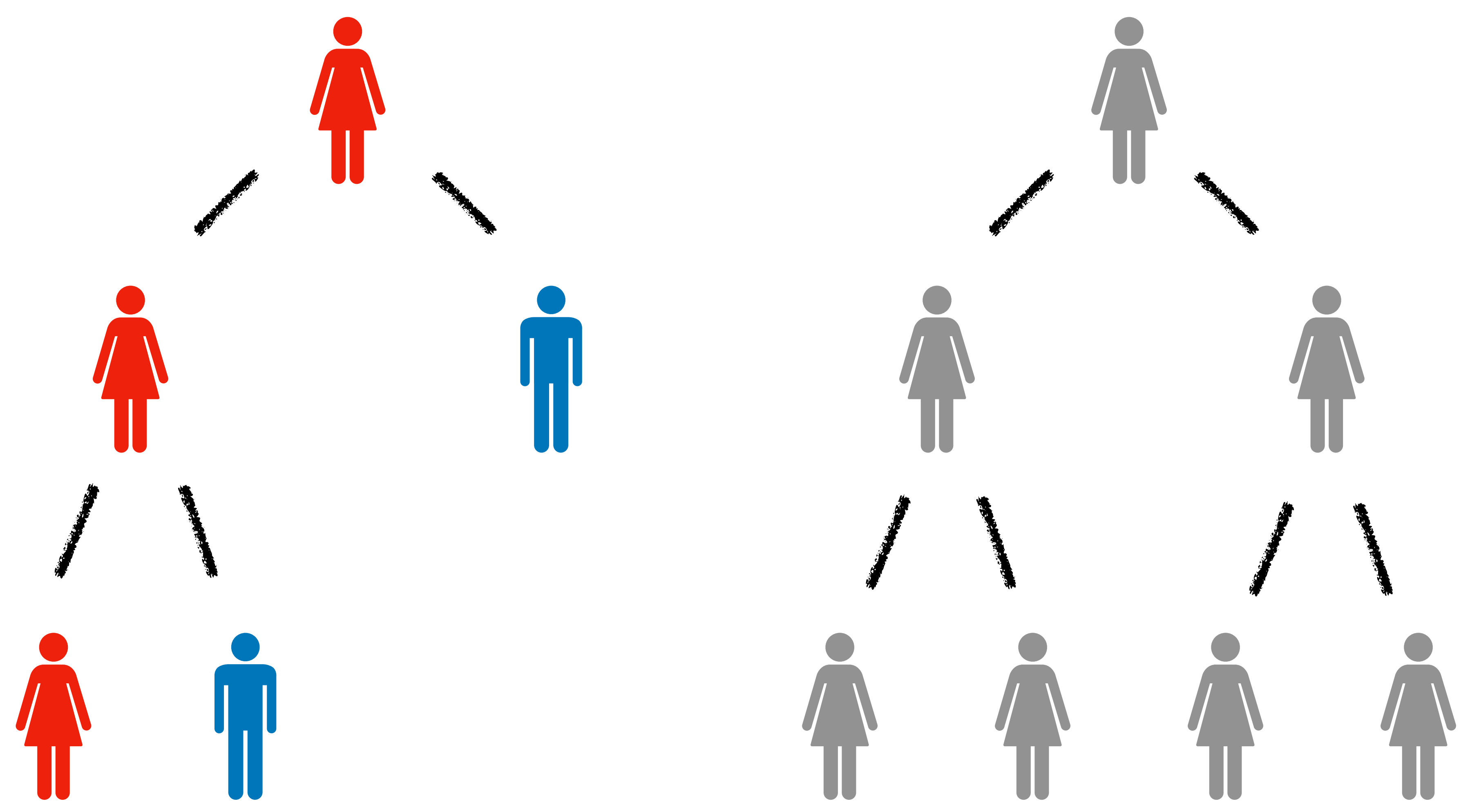
Sexual

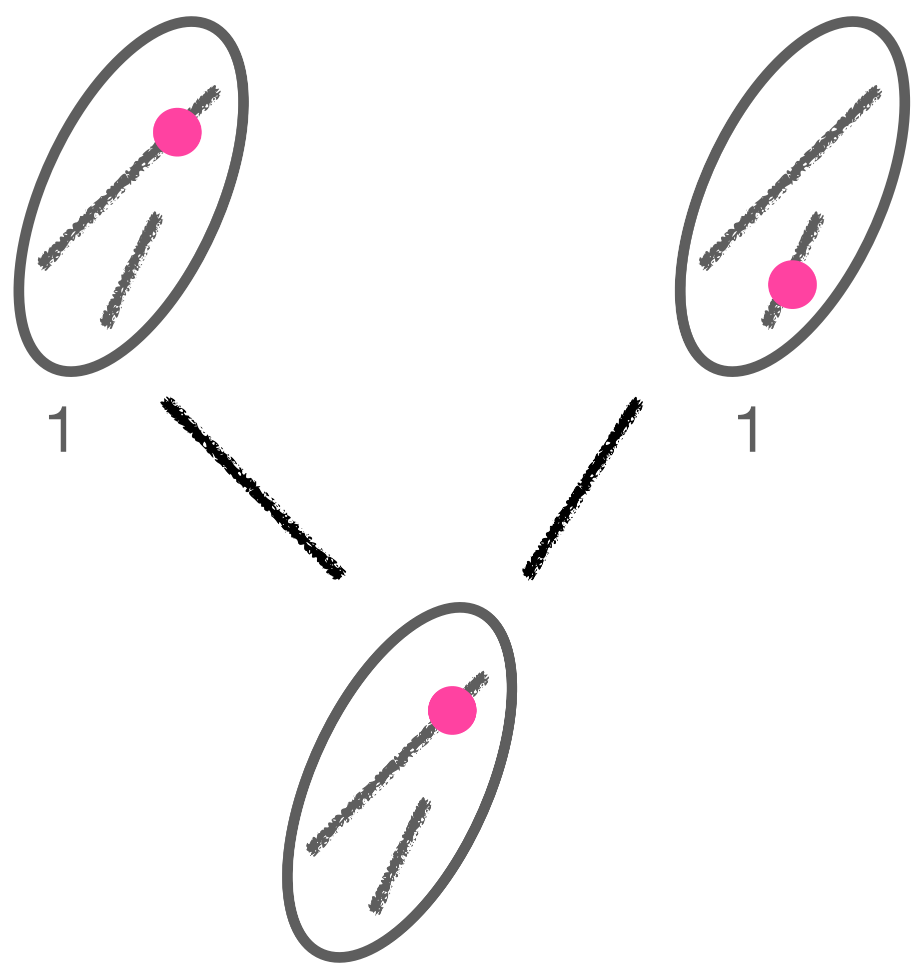


Rapid combinations of advantageous genes

Summary



- Sex = production of new organisms by the combination of genetic information of two individuals.
- Males = many small gametes (sperm). Females = fewer larger gametes (egg).
- Population growth is female limited.
- Two-fold demographic cost of sex.
- Asexuals accumulate more deleterious mutations and adapt less efficiently than sexual.



The maintenance of sex

The problem

How to overcome the twofold cost?

- Rapid demographic advantage versus slow evolutionary cost of asexuality

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Fecundity

$$f(k) \propto (1 - s)^k$$

Number of deleterious mutations

Effect of single mutation

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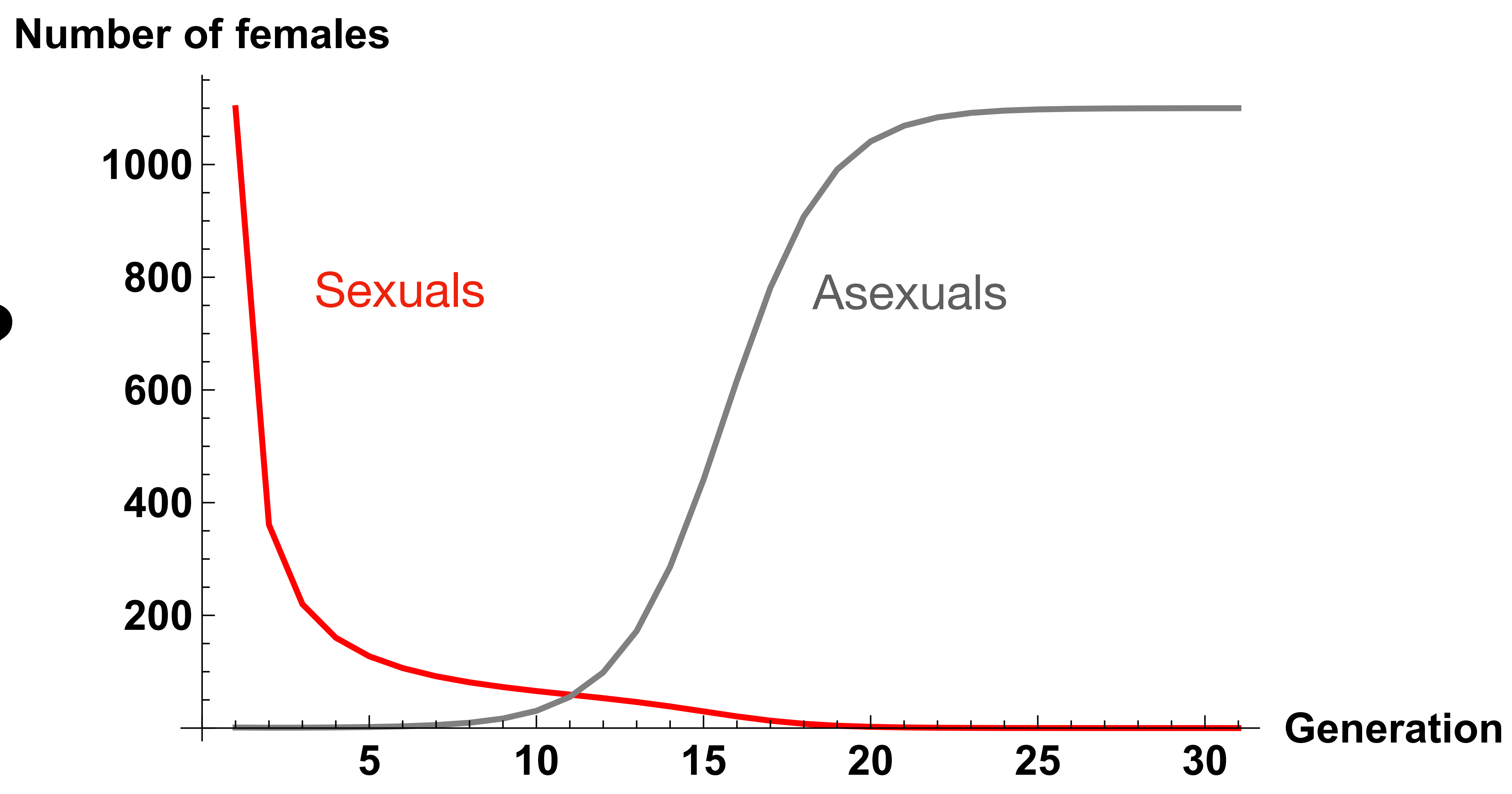

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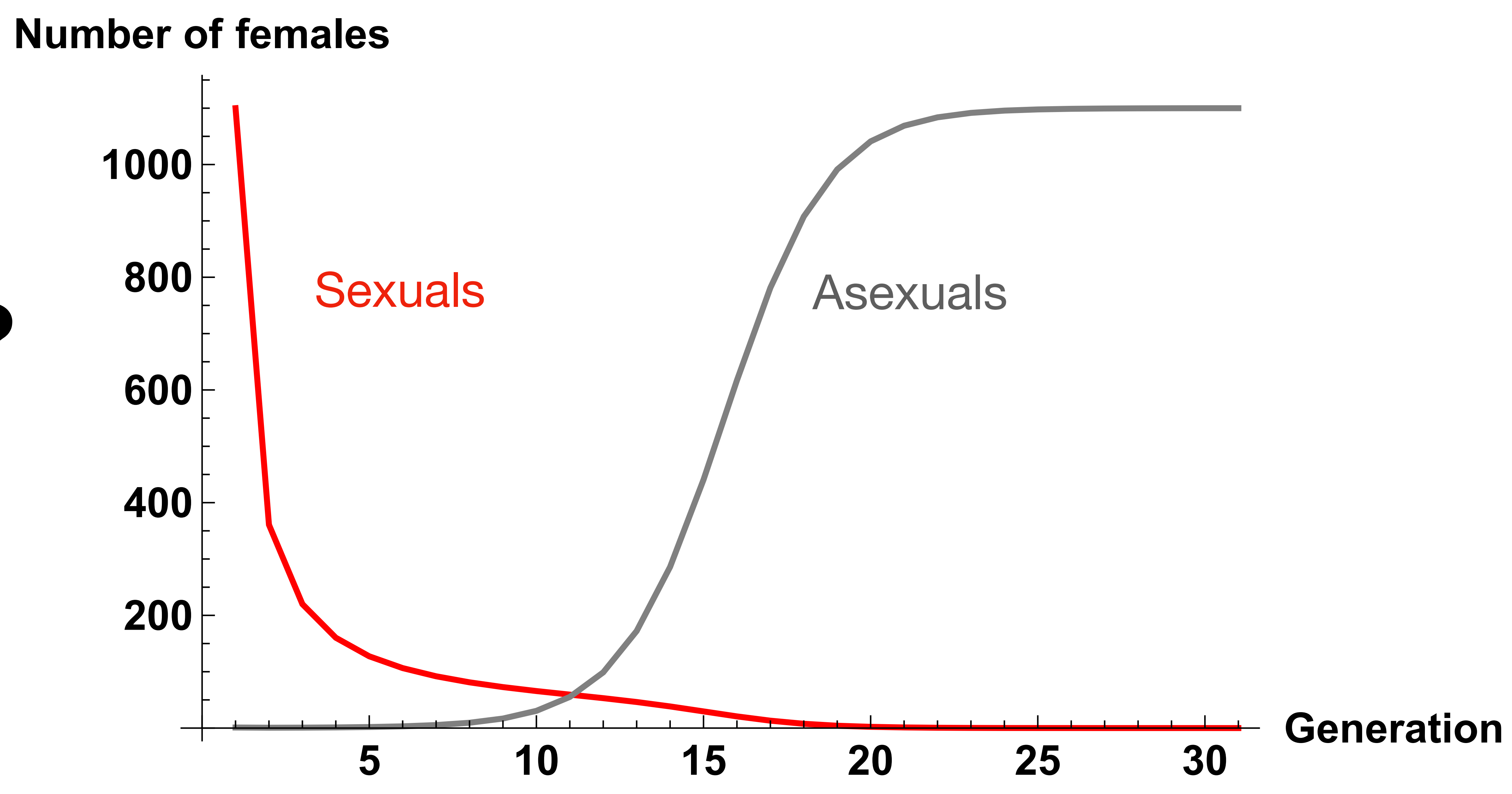

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condition for maintenance of sex due to deleterious mutations

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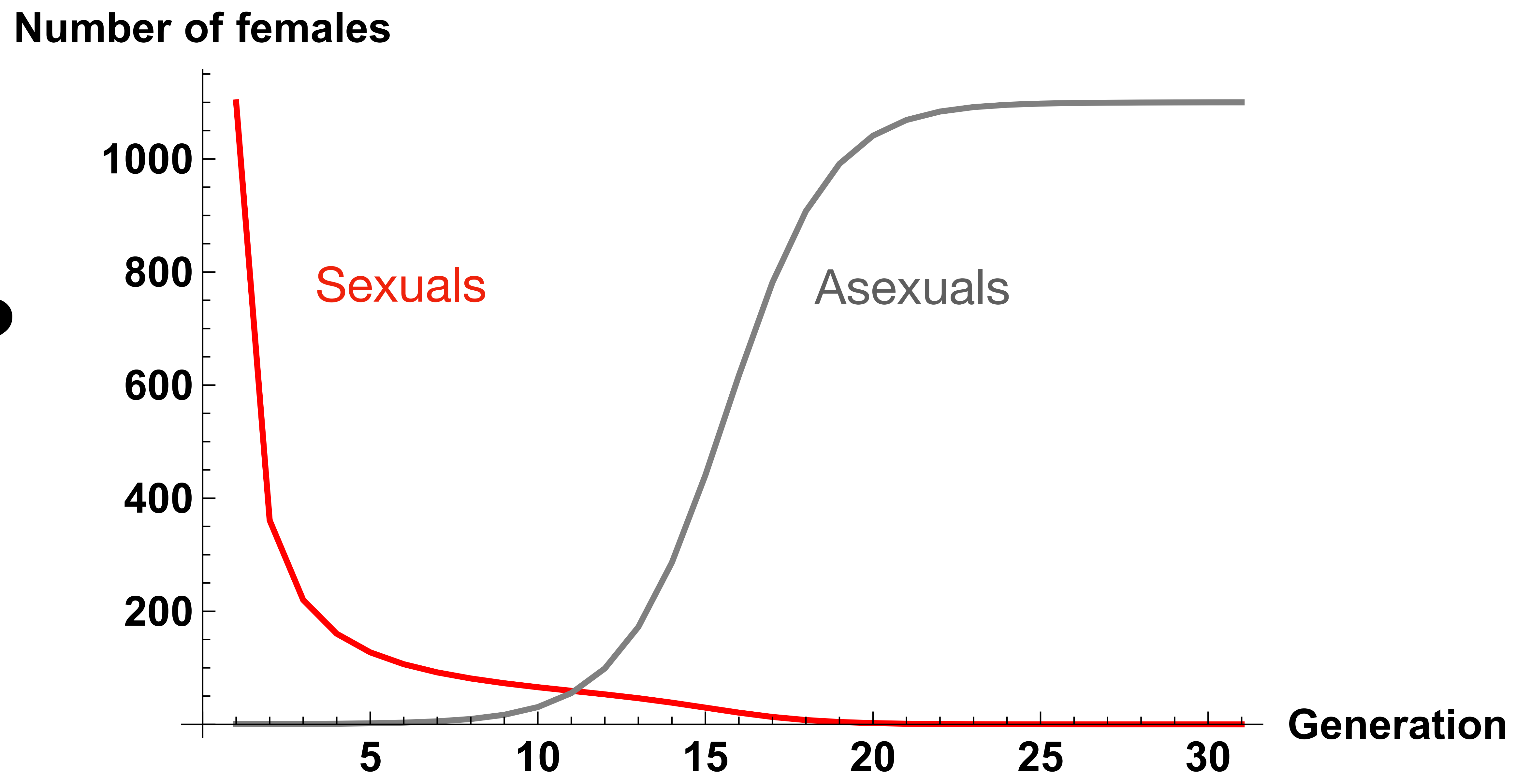

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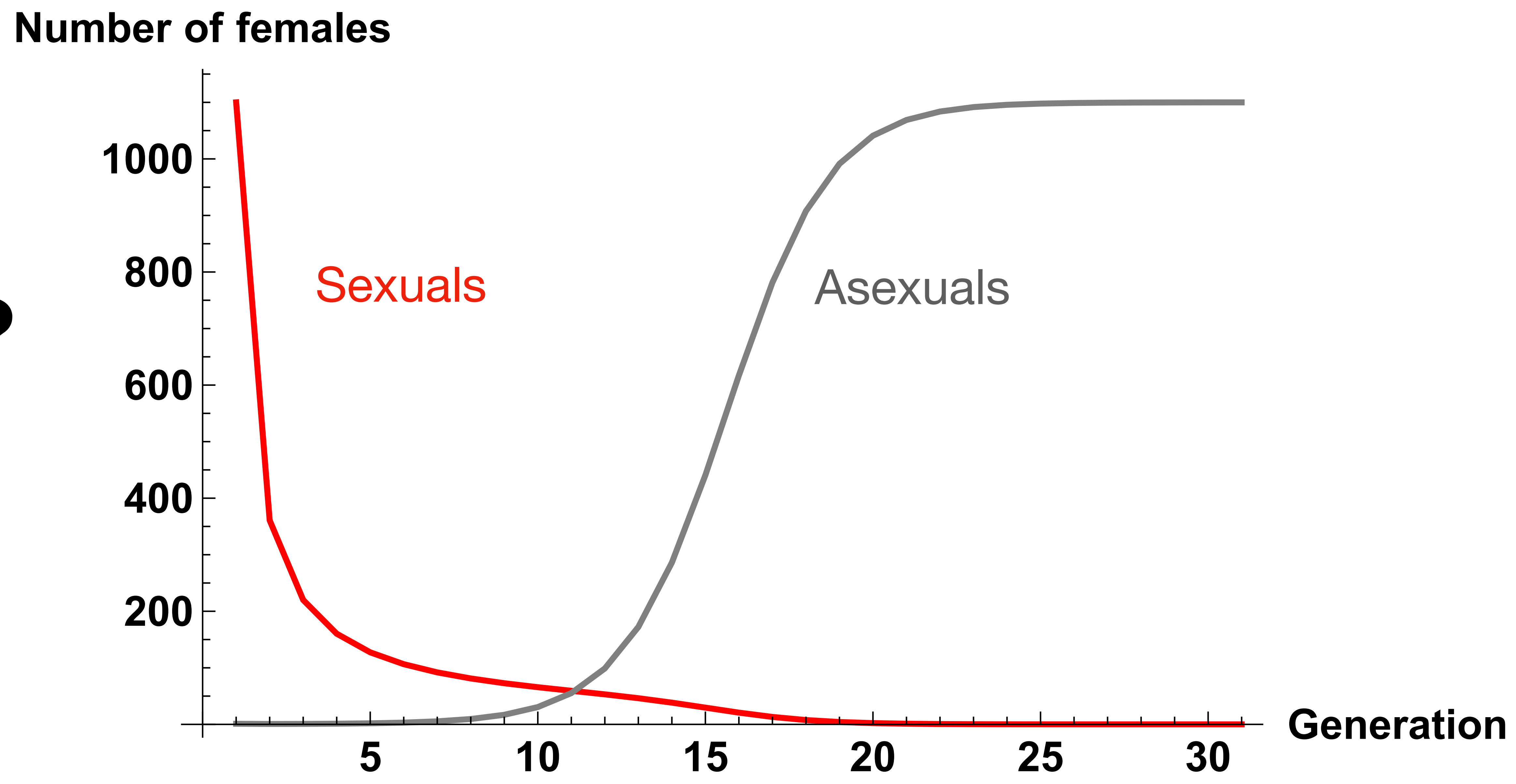

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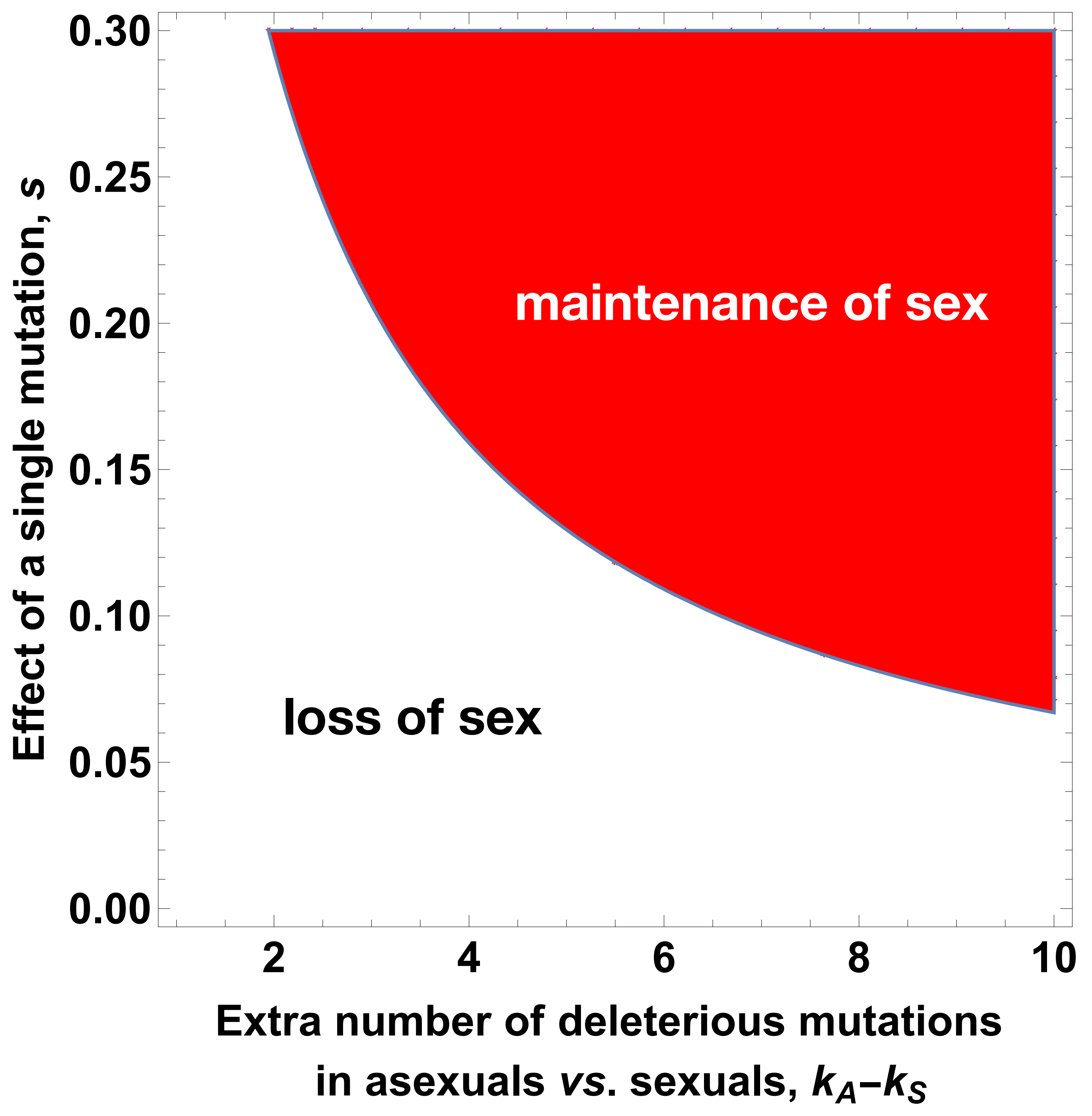

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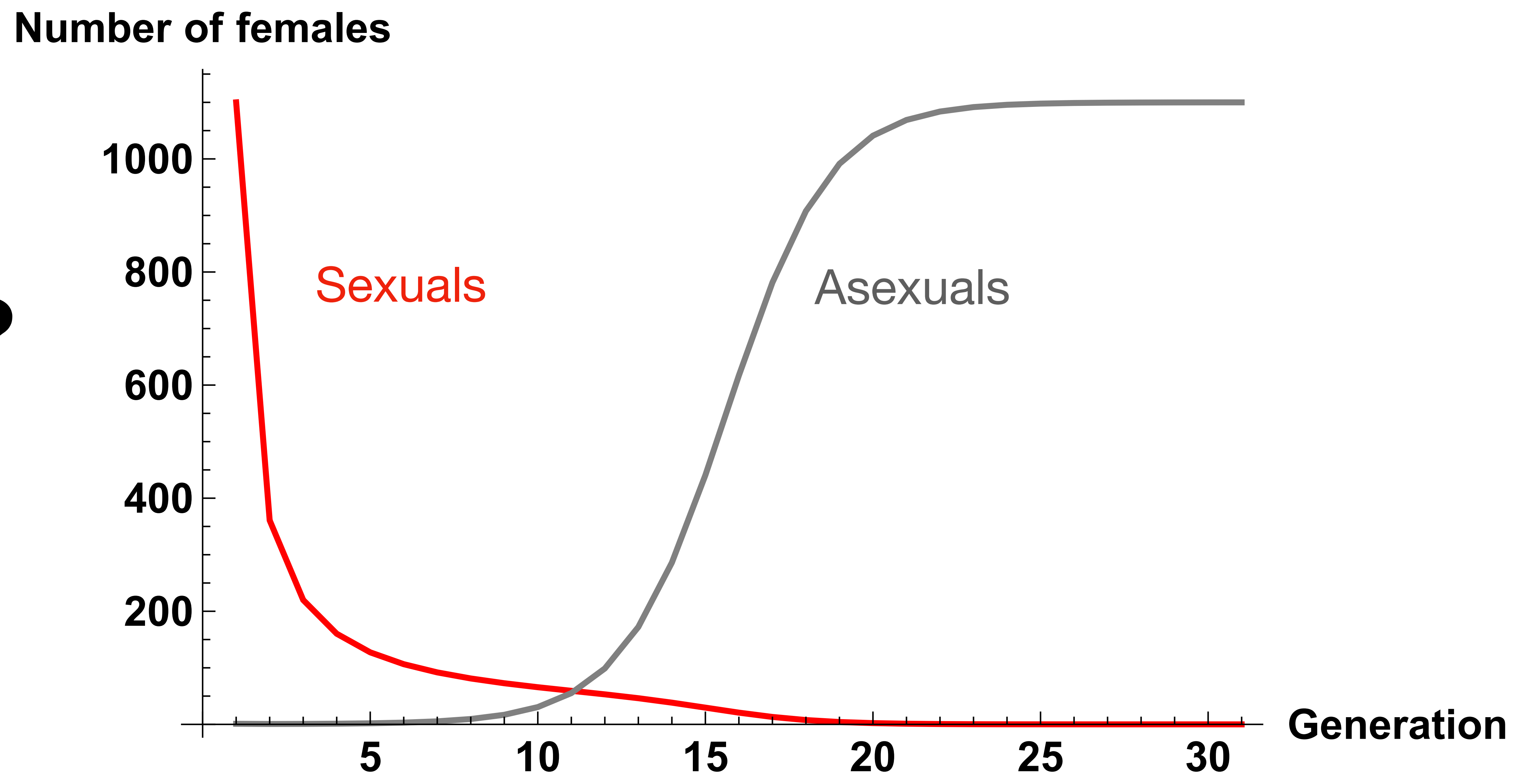
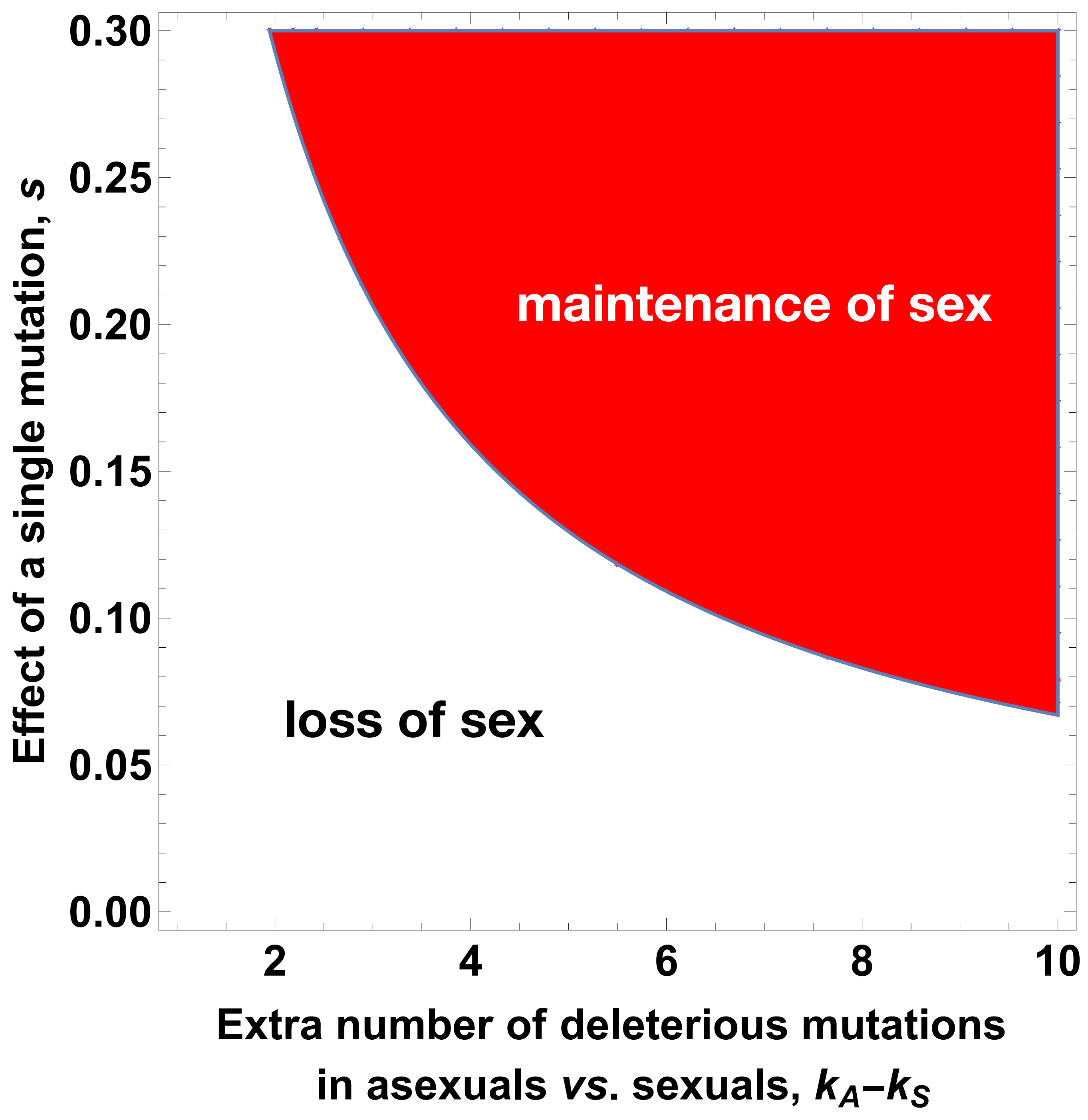


- Rapid demographic advantage versus slow evolutionary cost of asexuality

Assuming an asexual is initially equivalent to a sexual, deleterious mutations must accumulate impossibly fast or have unrealistically large fitness effects for sexuality to be maintained.



Can strong epistasis rescue sexuals?

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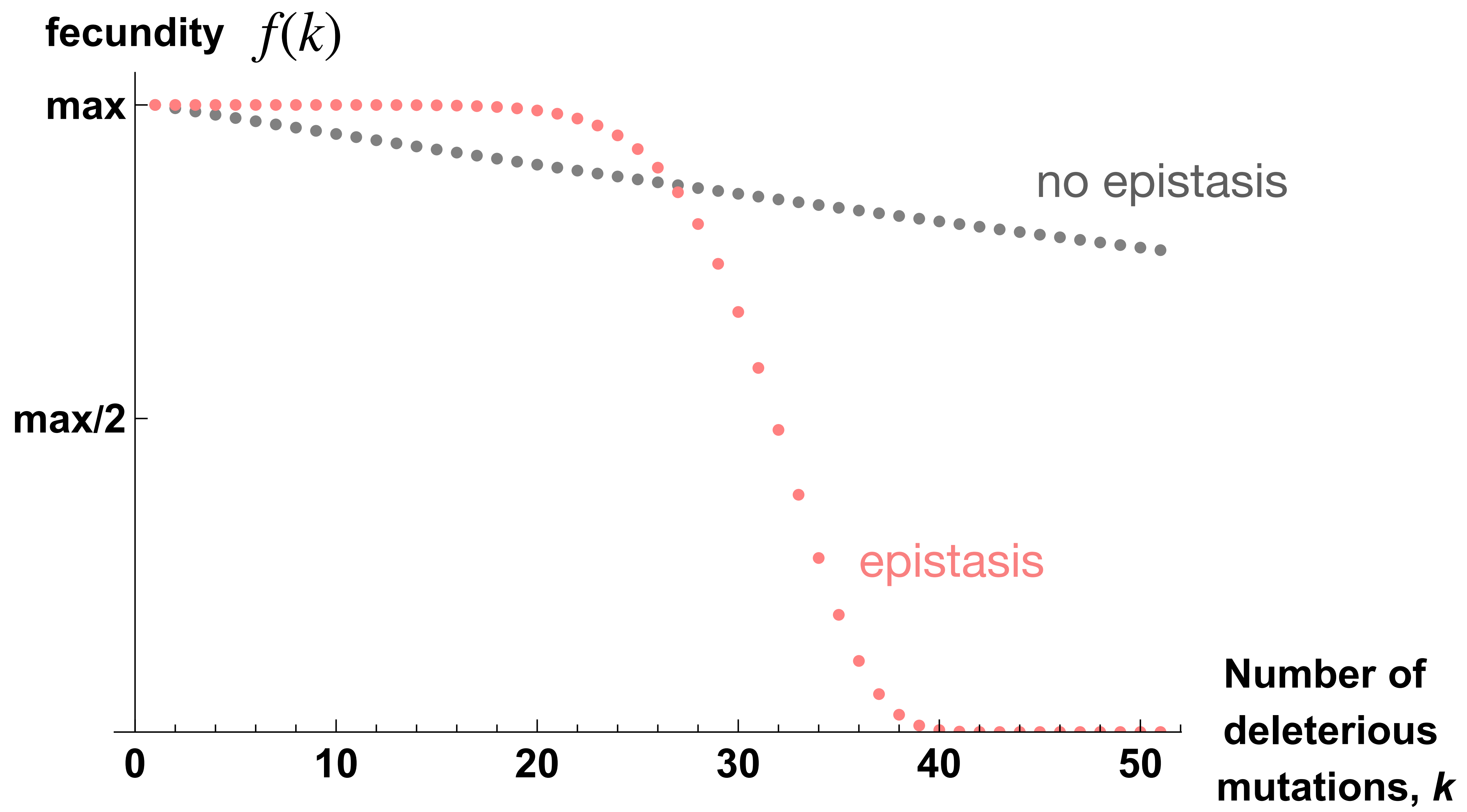

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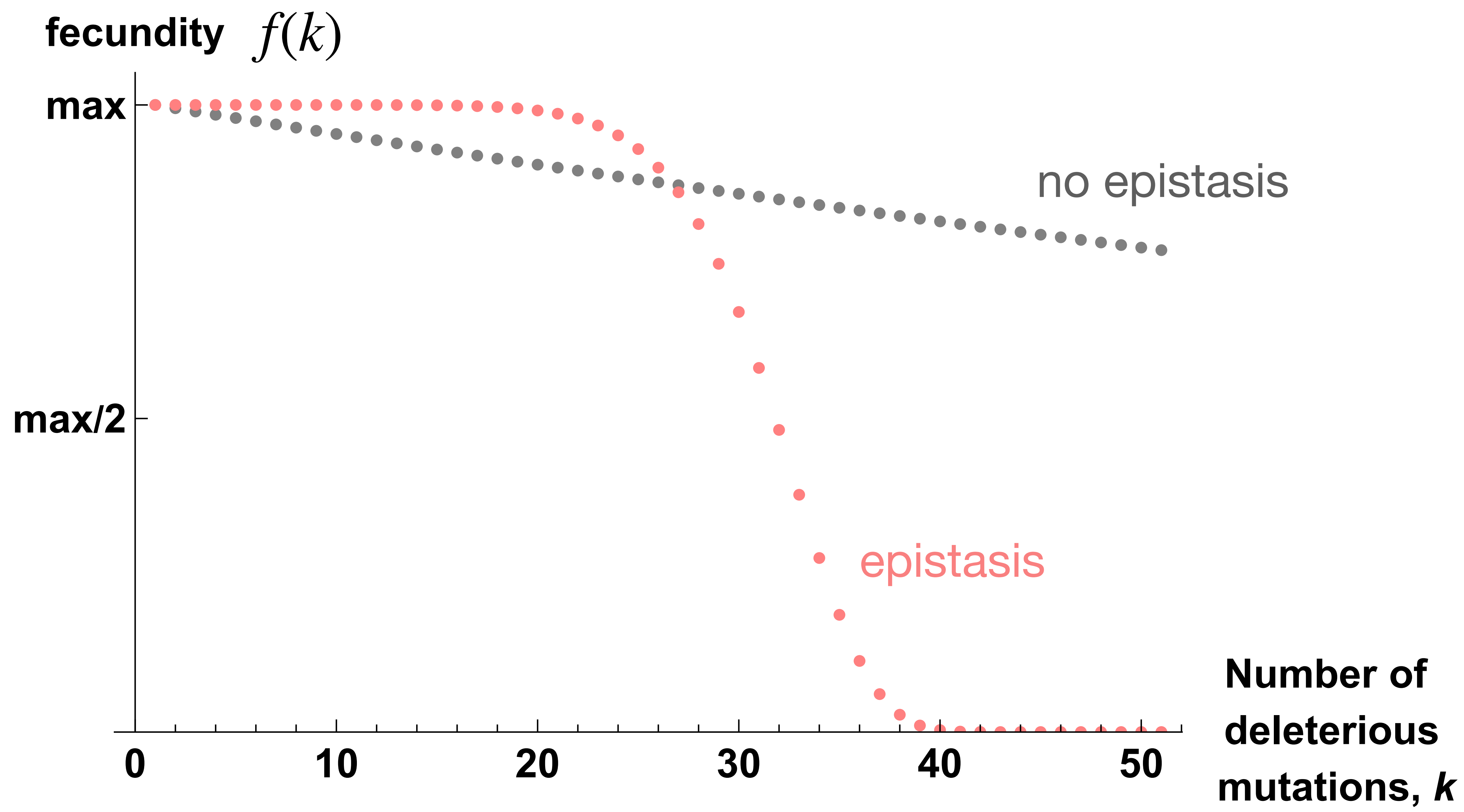

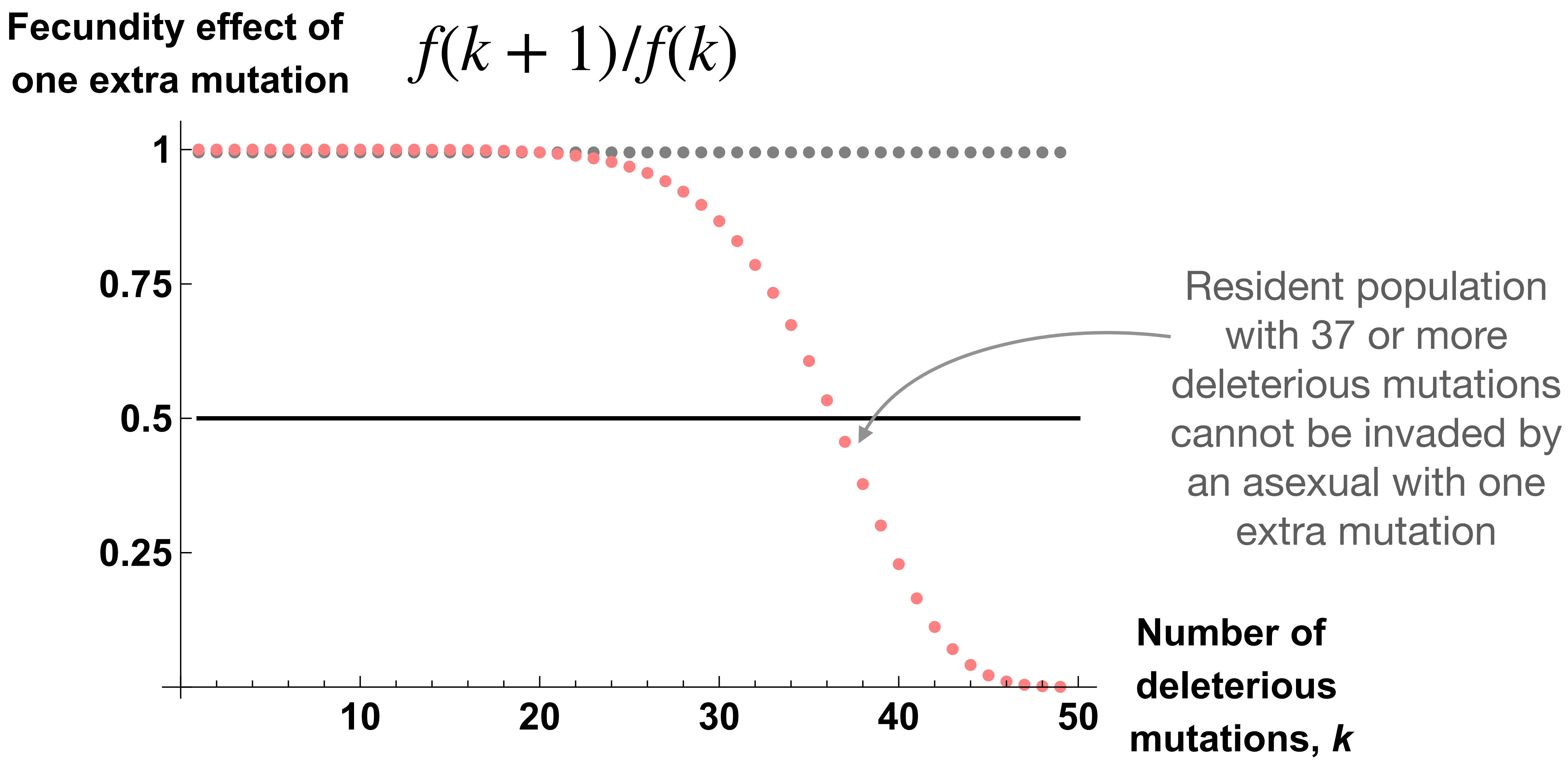

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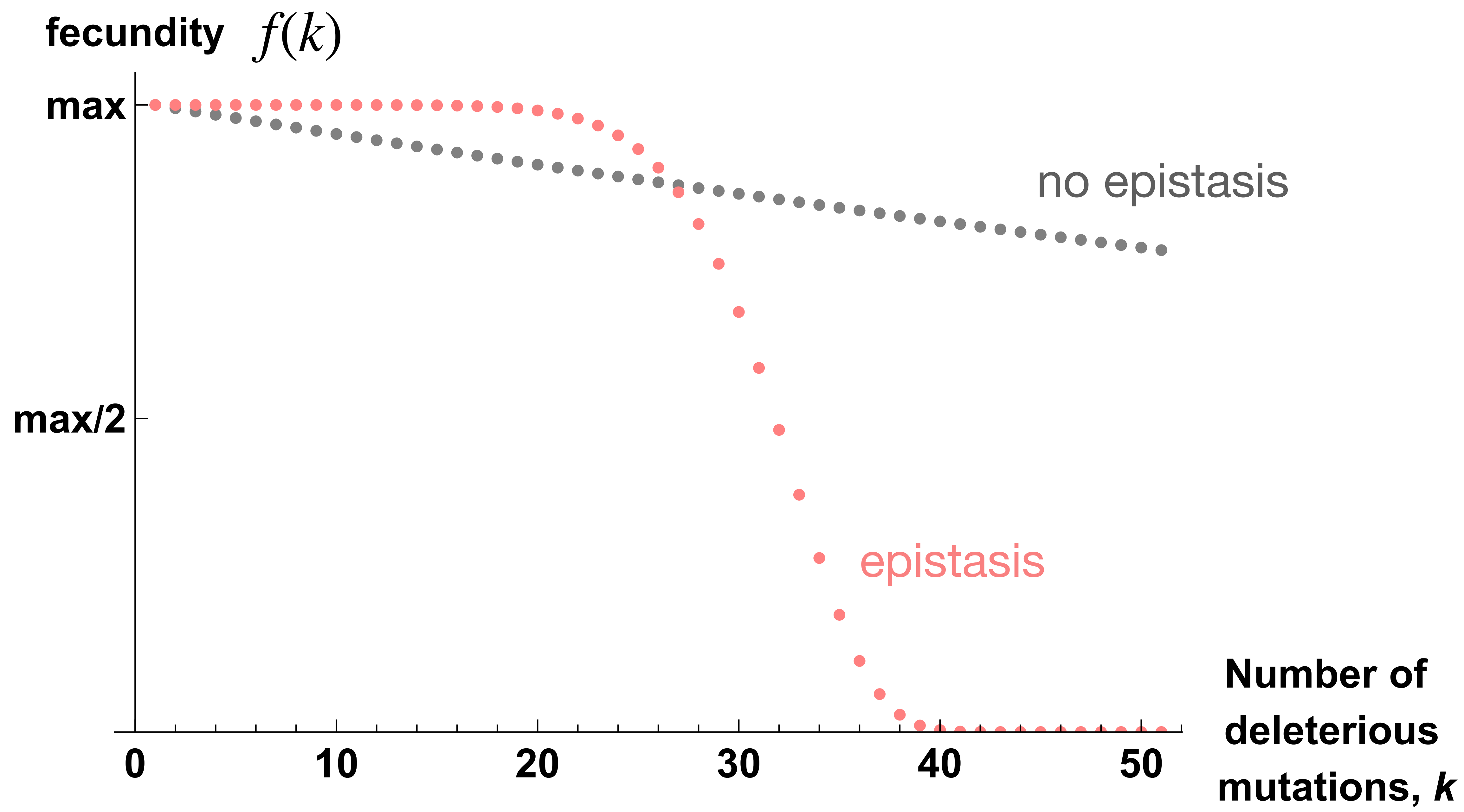
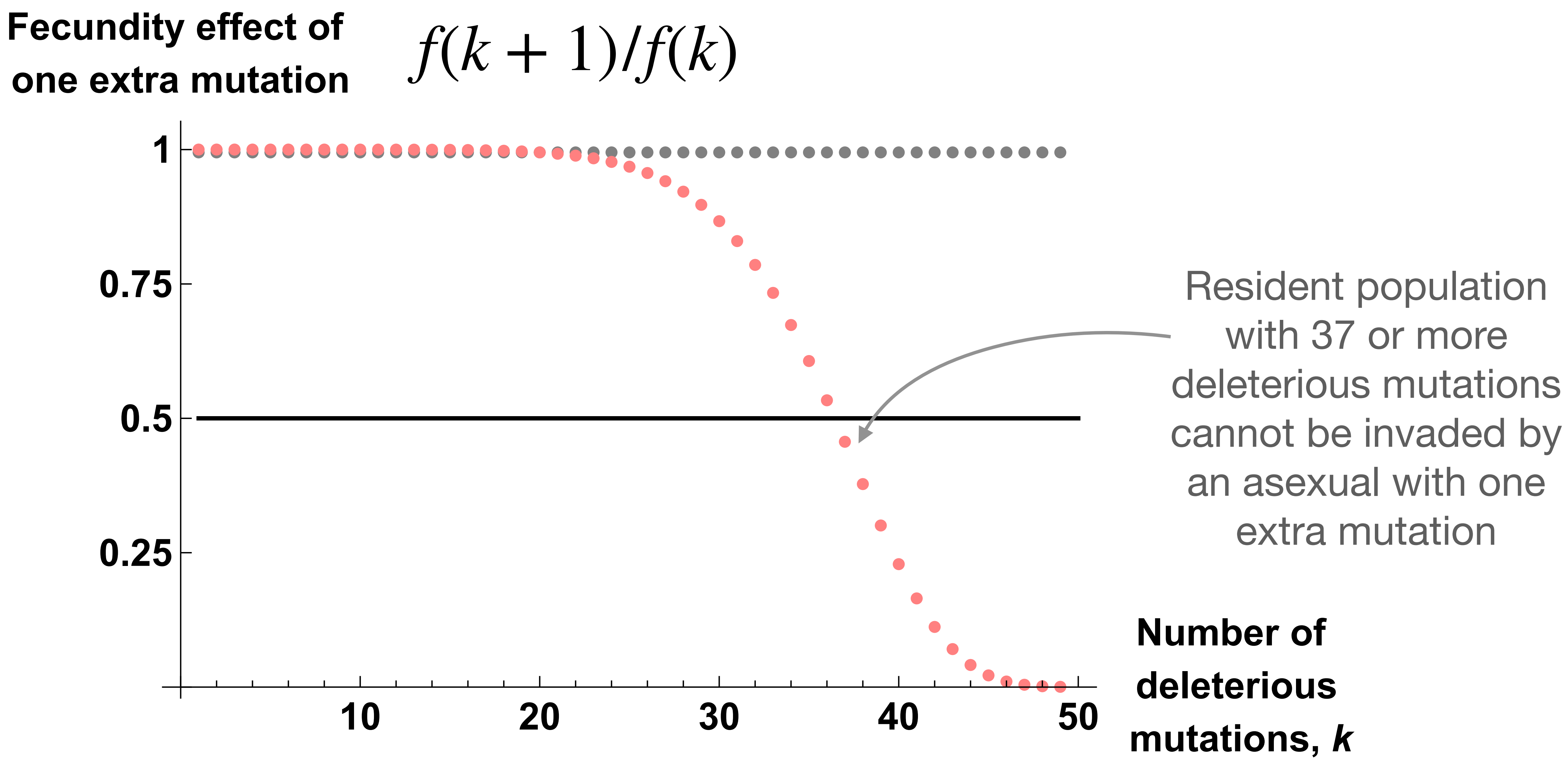


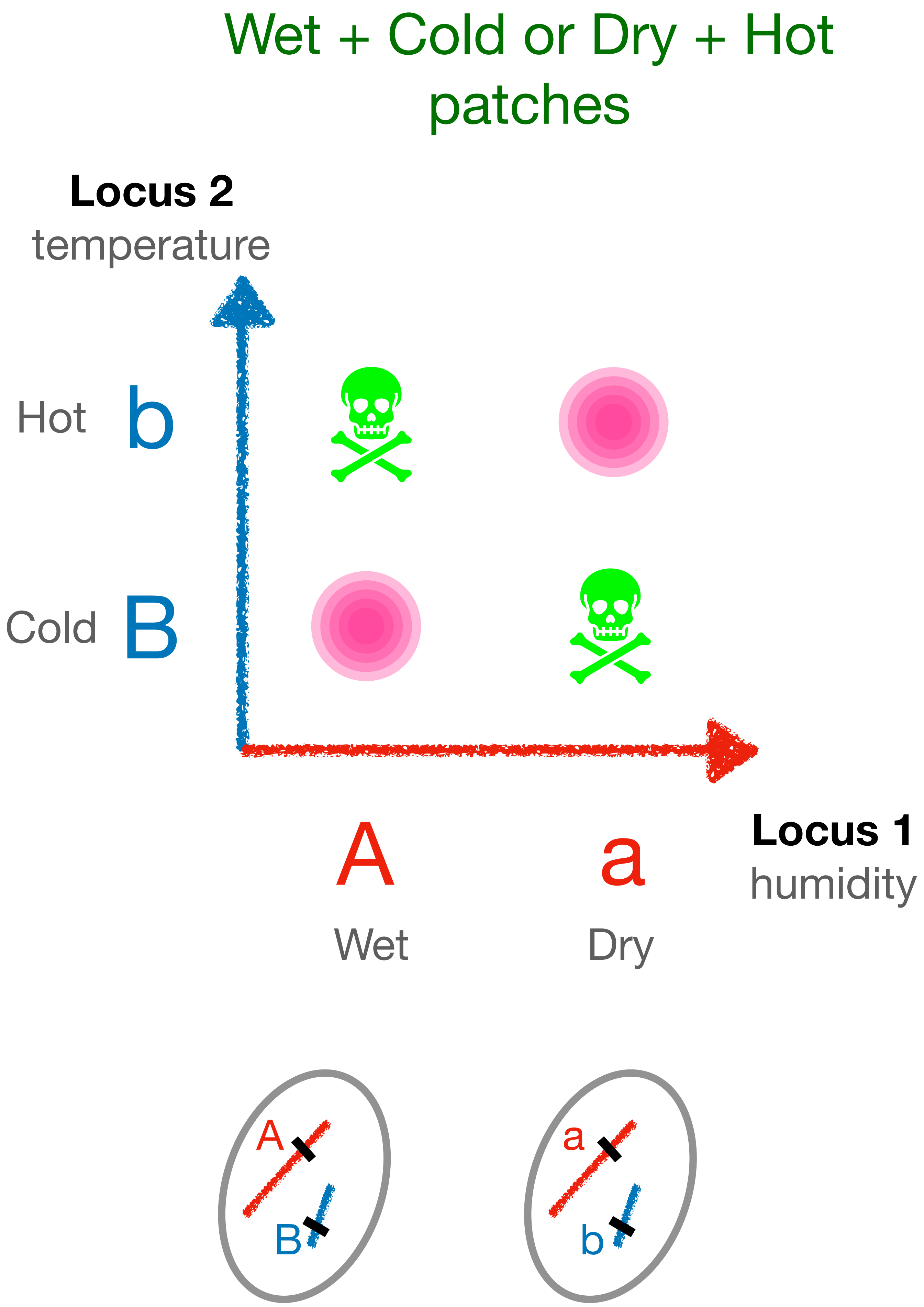


- Works if sexual population already quite loaded with mutations
- See exercise sheet 3

Fluctuating epistasis

Fluctuating epistasis

- Environment favours specific allelic associations



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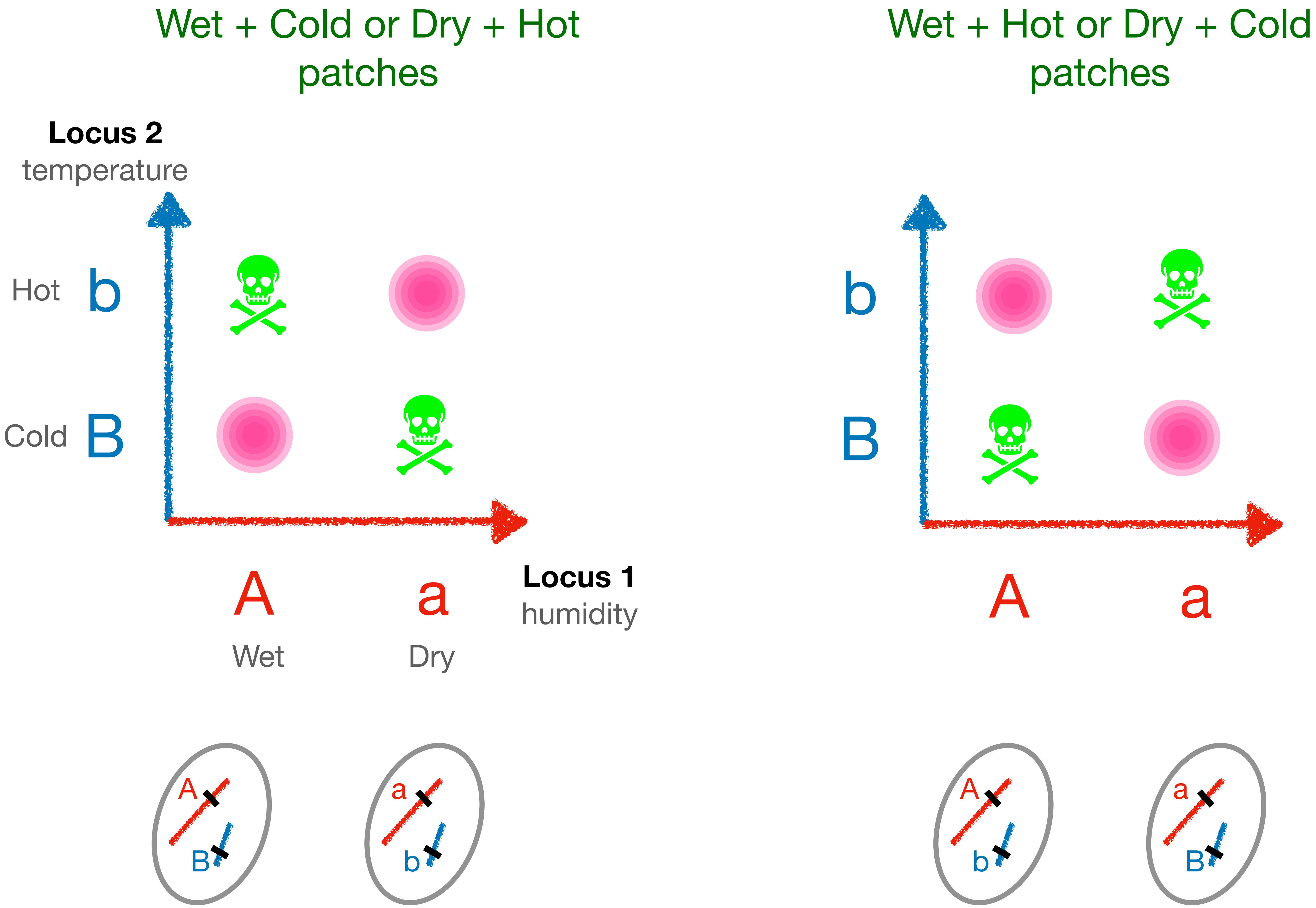
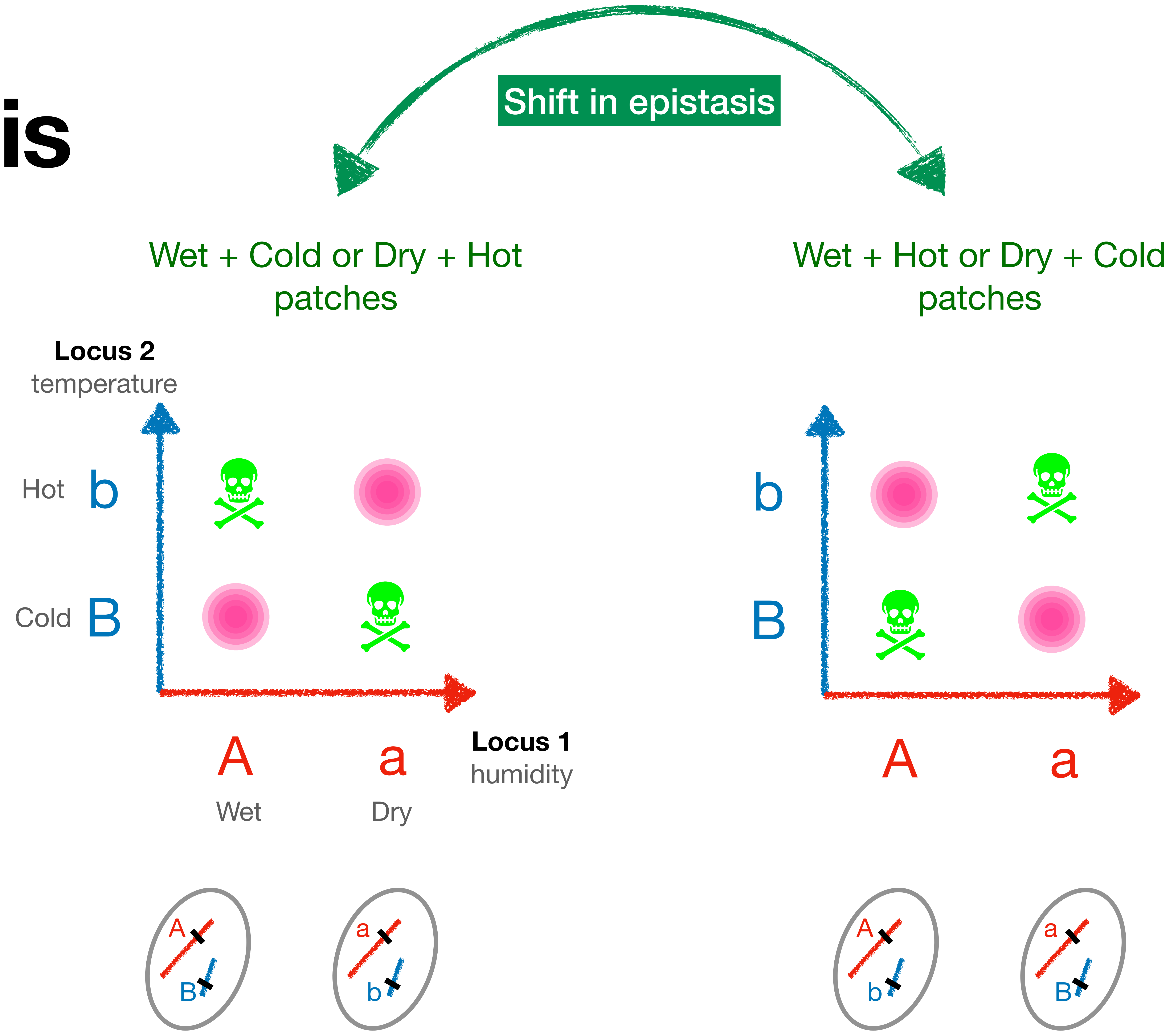


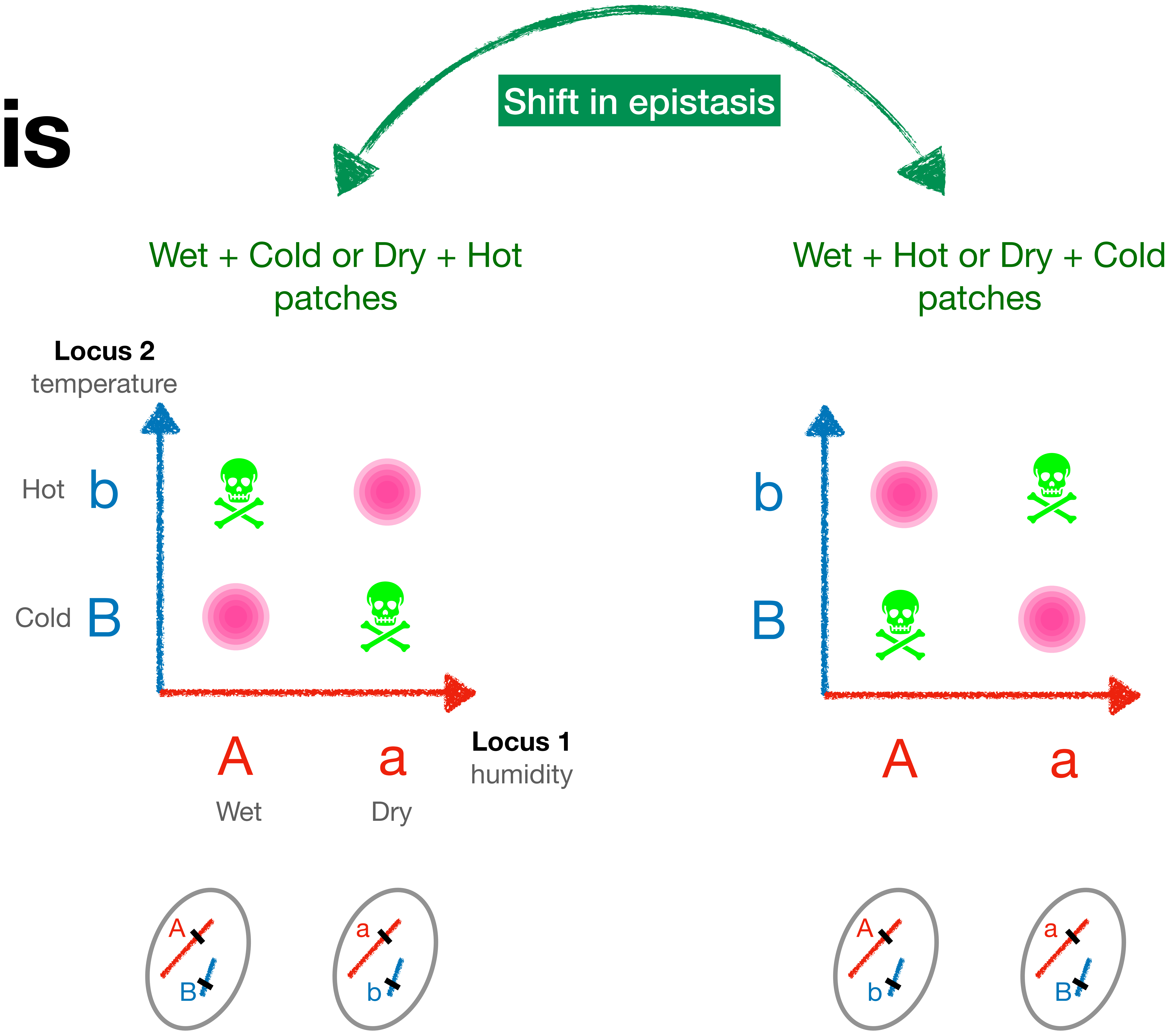
Fluctuating epistasis

- Environment favours specific allelic associations
- The environment fluctuates in time, favouring different associations at different times



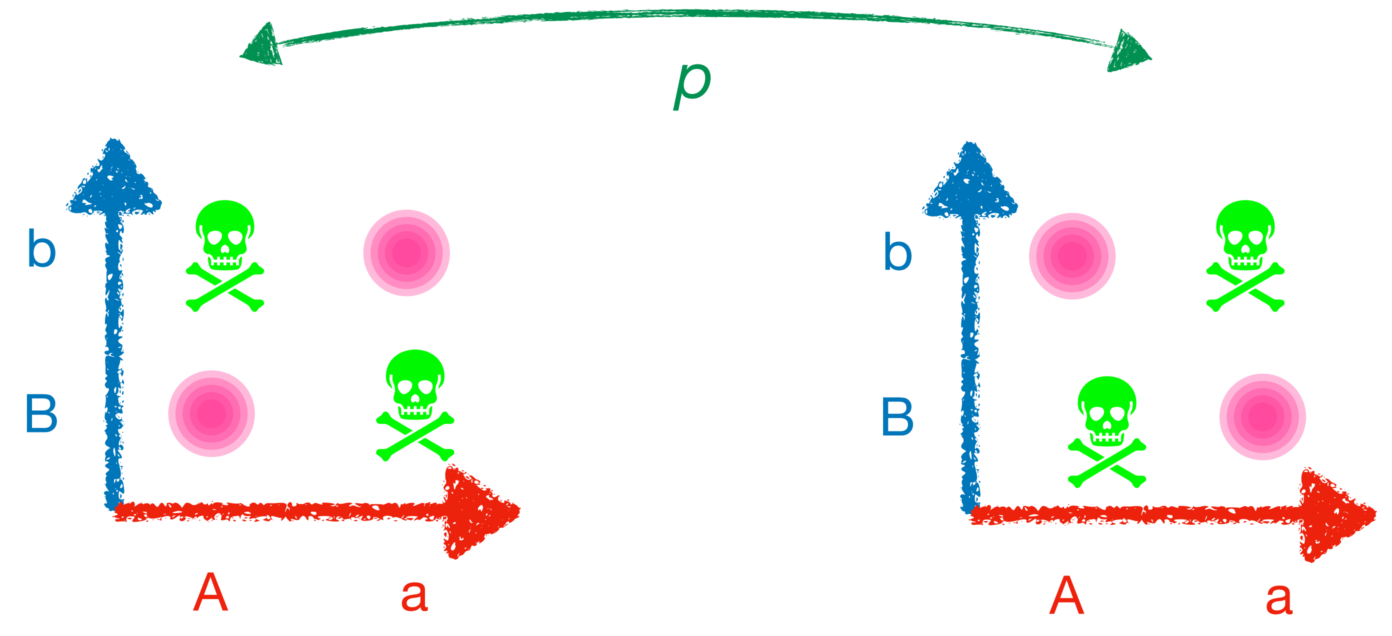
Fluctuating epistasis

- Environment favours specific allelic associations
- The environment fluctuates in time, favouring different associations at different times
- Asexuals should lose out as the allelic associations of an asexual lineage are fixed



Fluctuating epistasis

Example



- Population with two types of habitats, each favouring a specific combination of alleles.

- Combination changes at each generation with probability *p.*

- Start with a population of sexuals. Introduce asexuals through mutation.

Fluctuating epistasis

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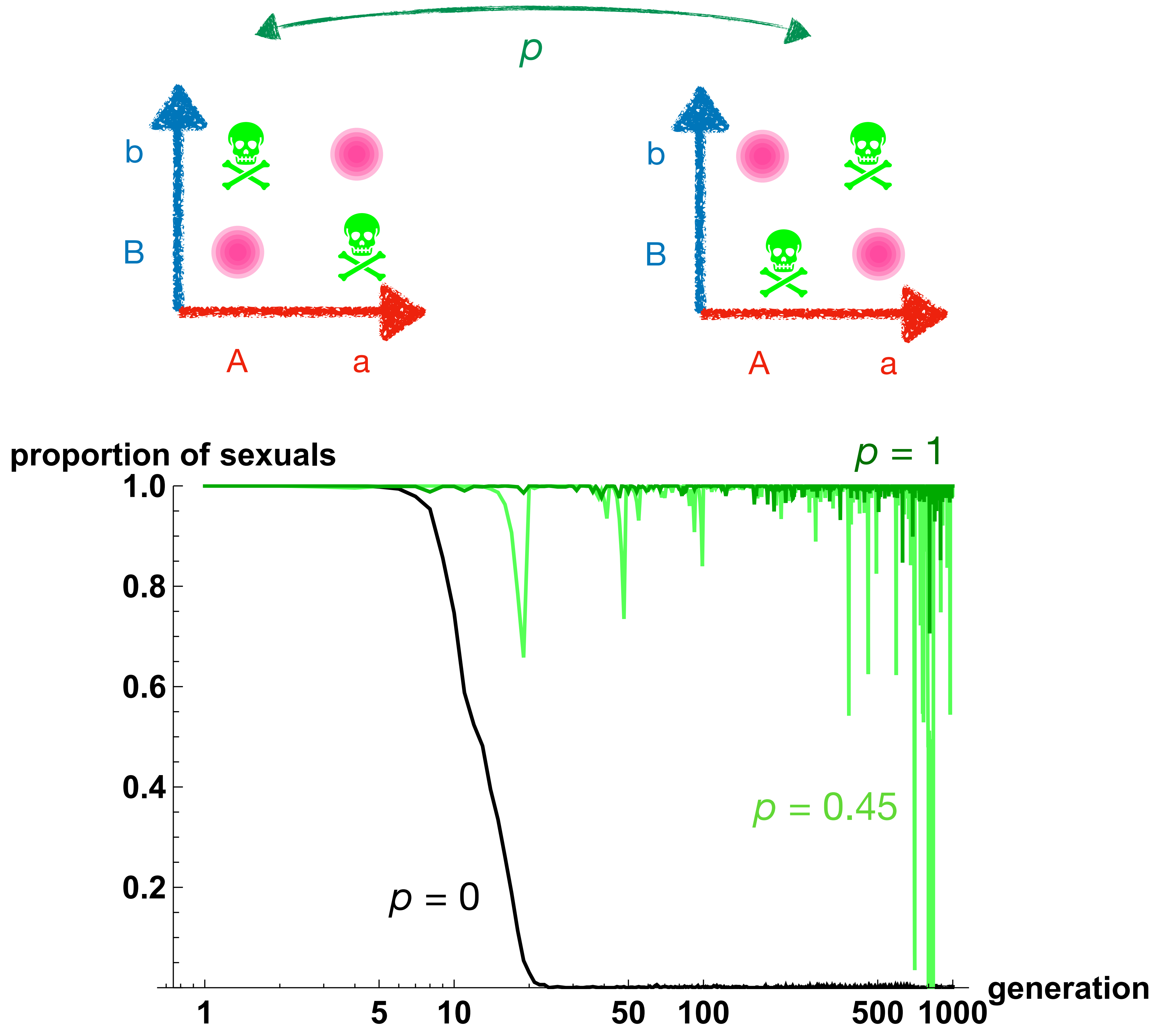

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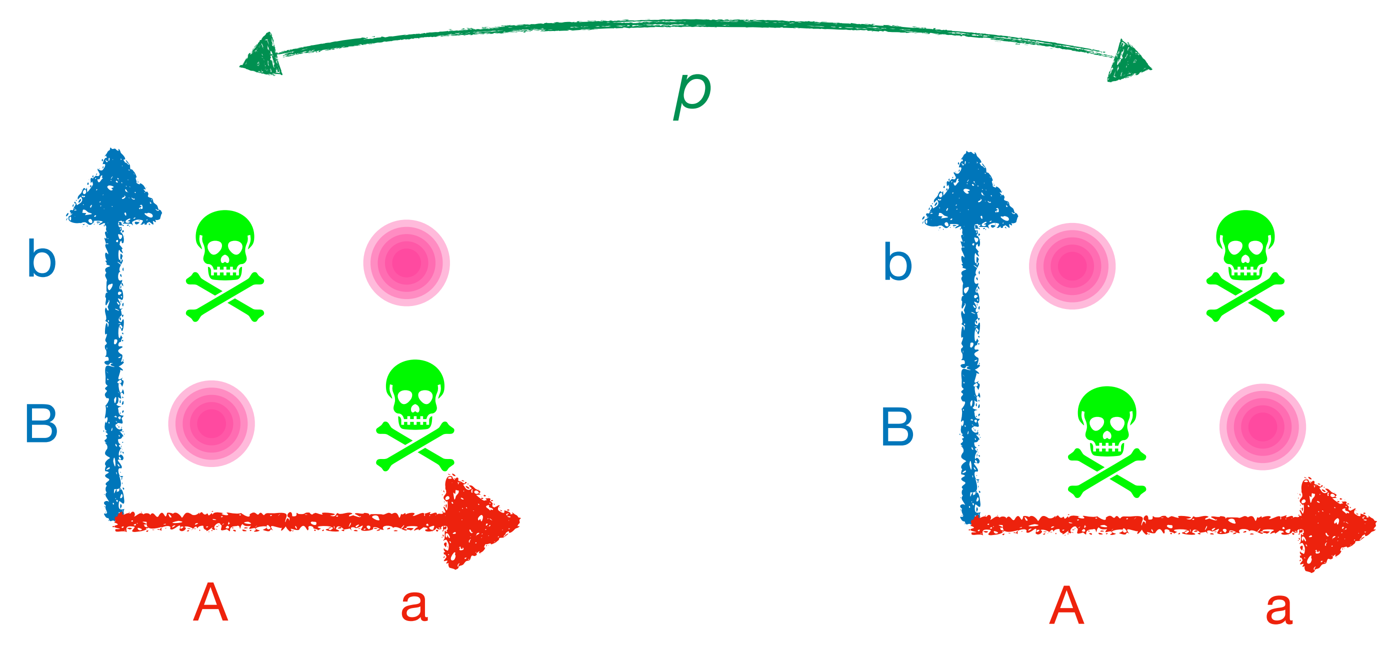
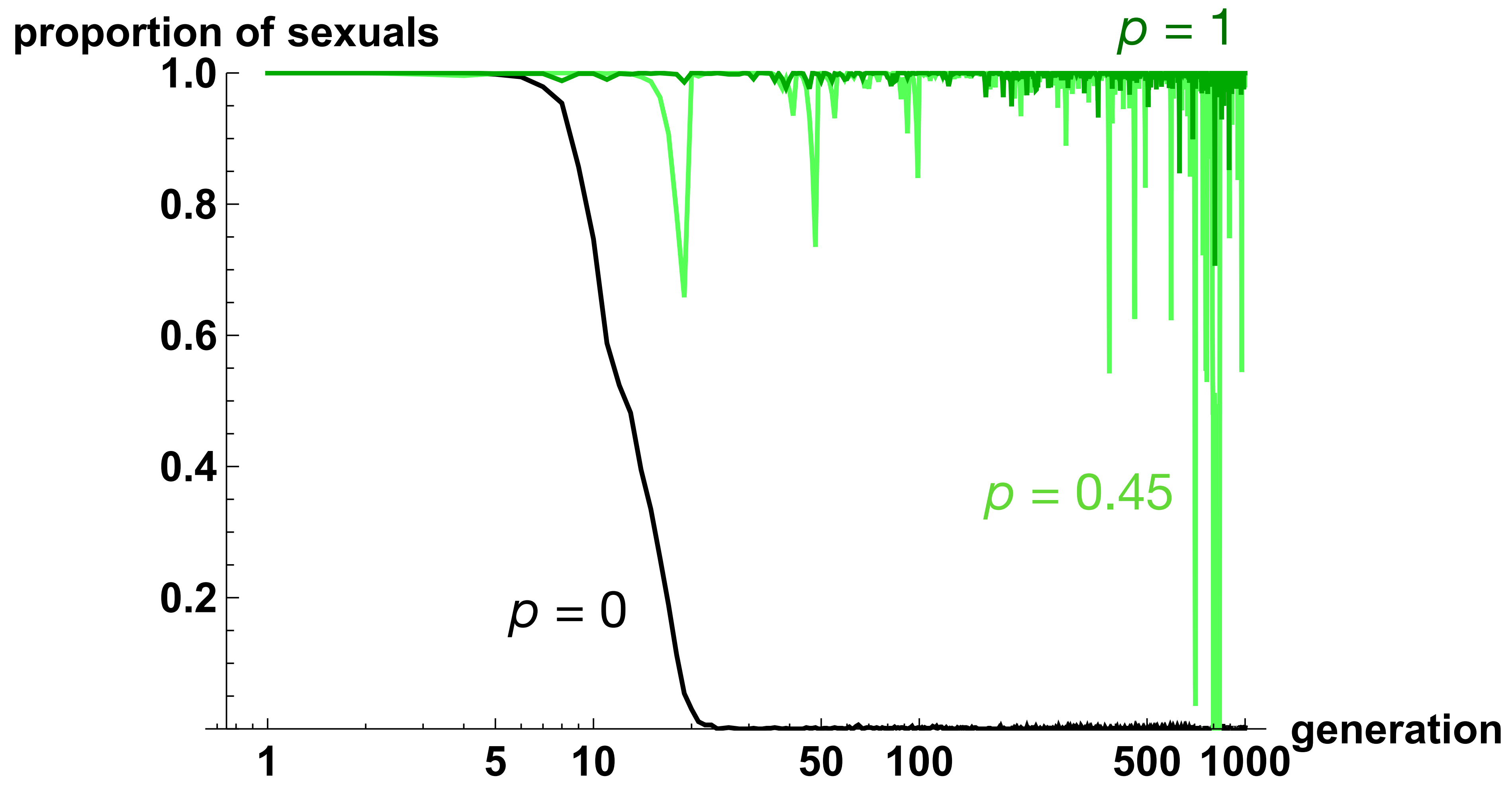
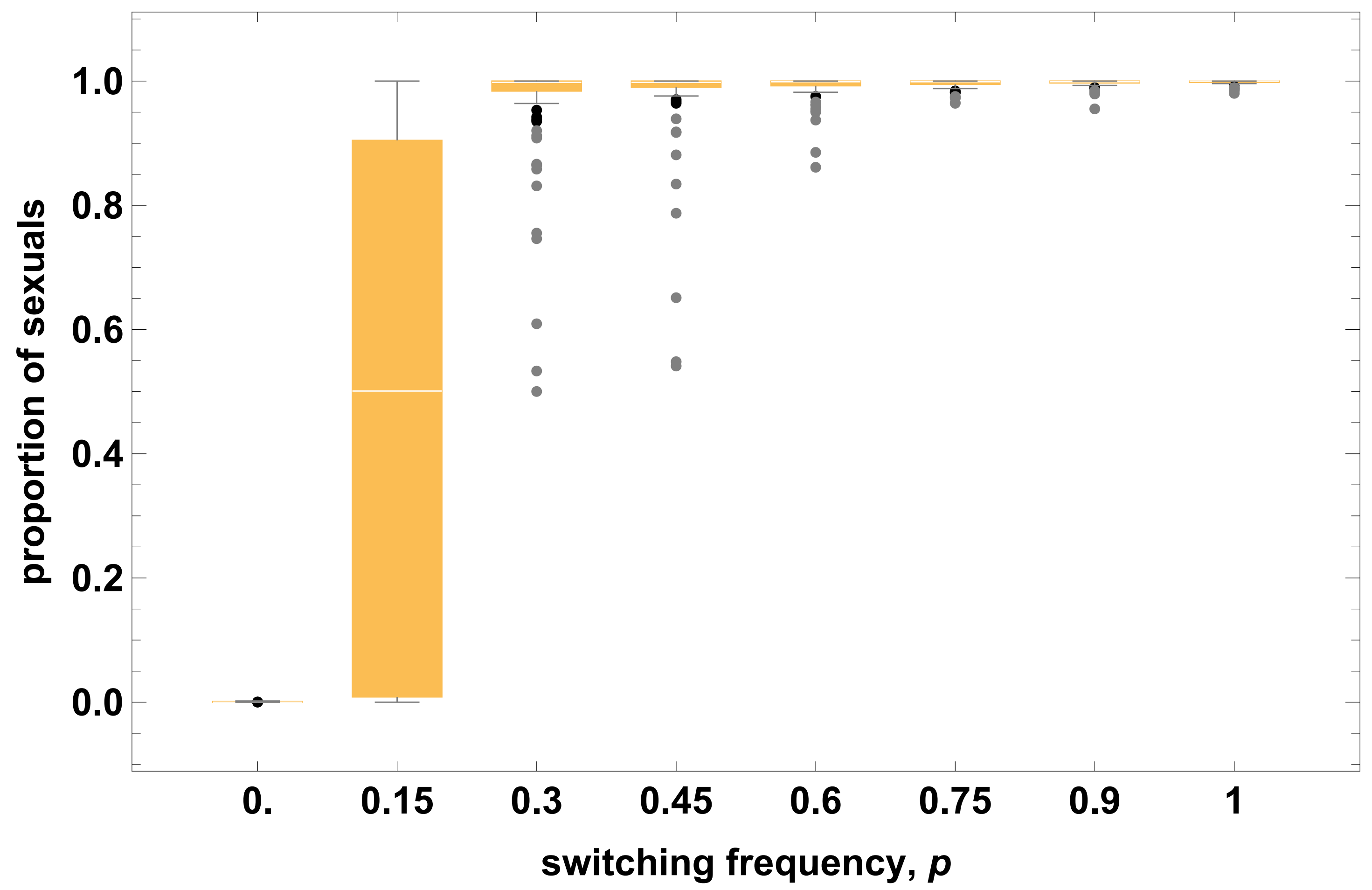


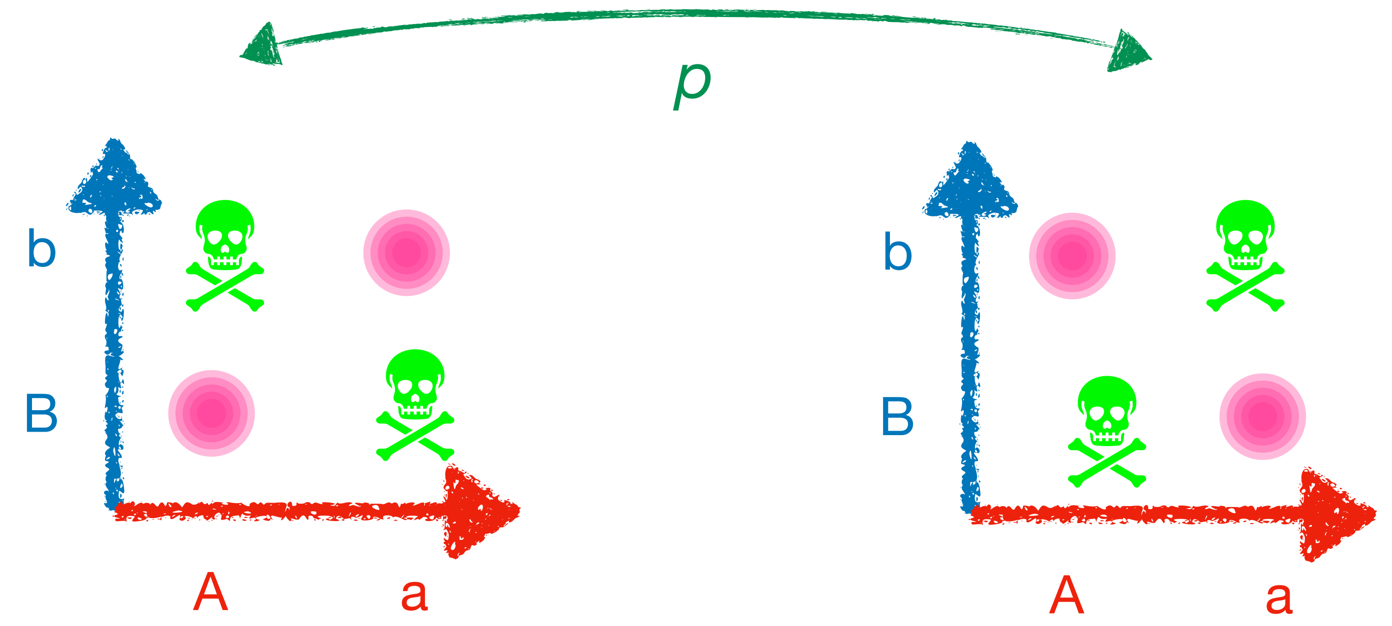


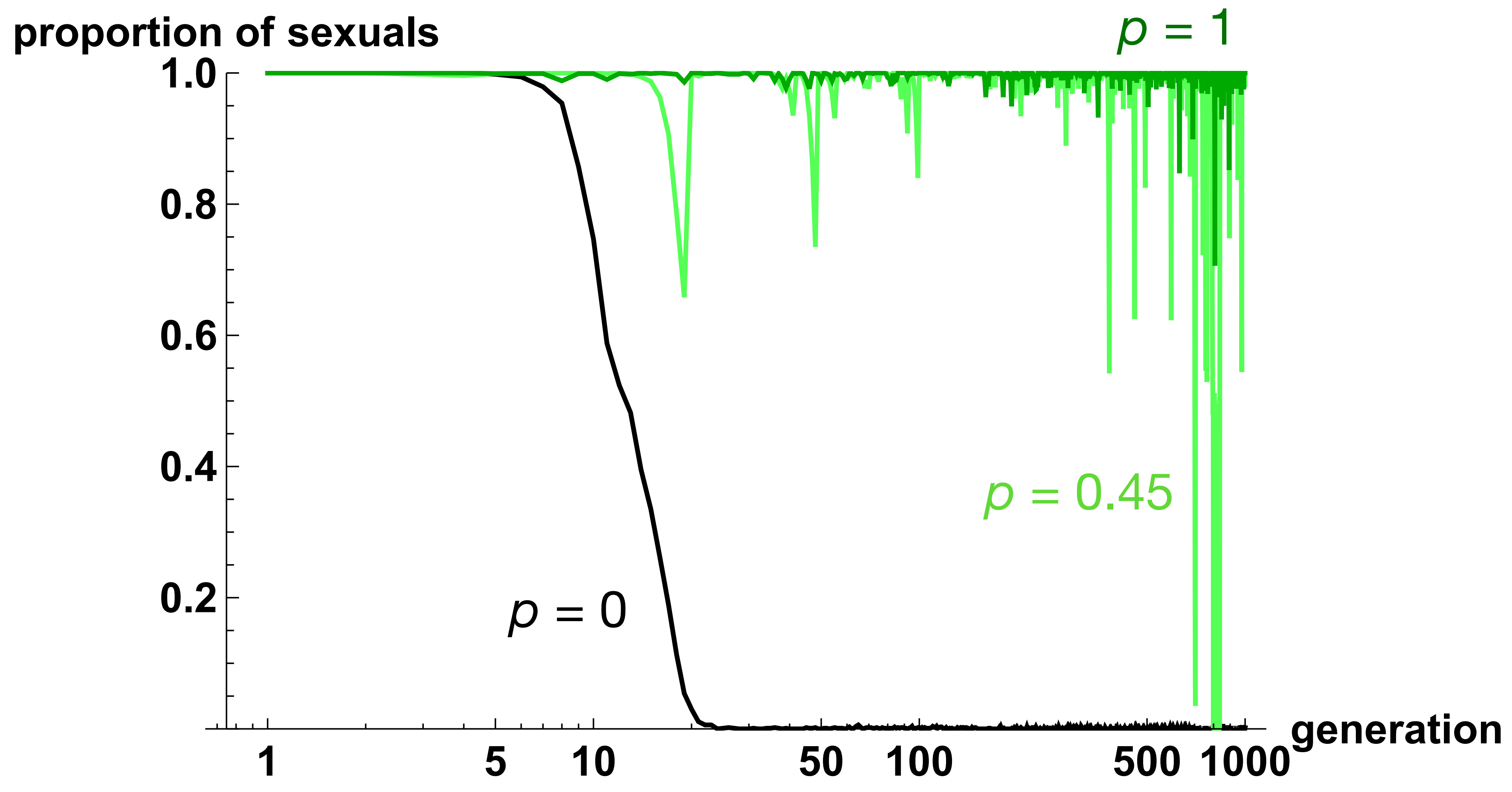


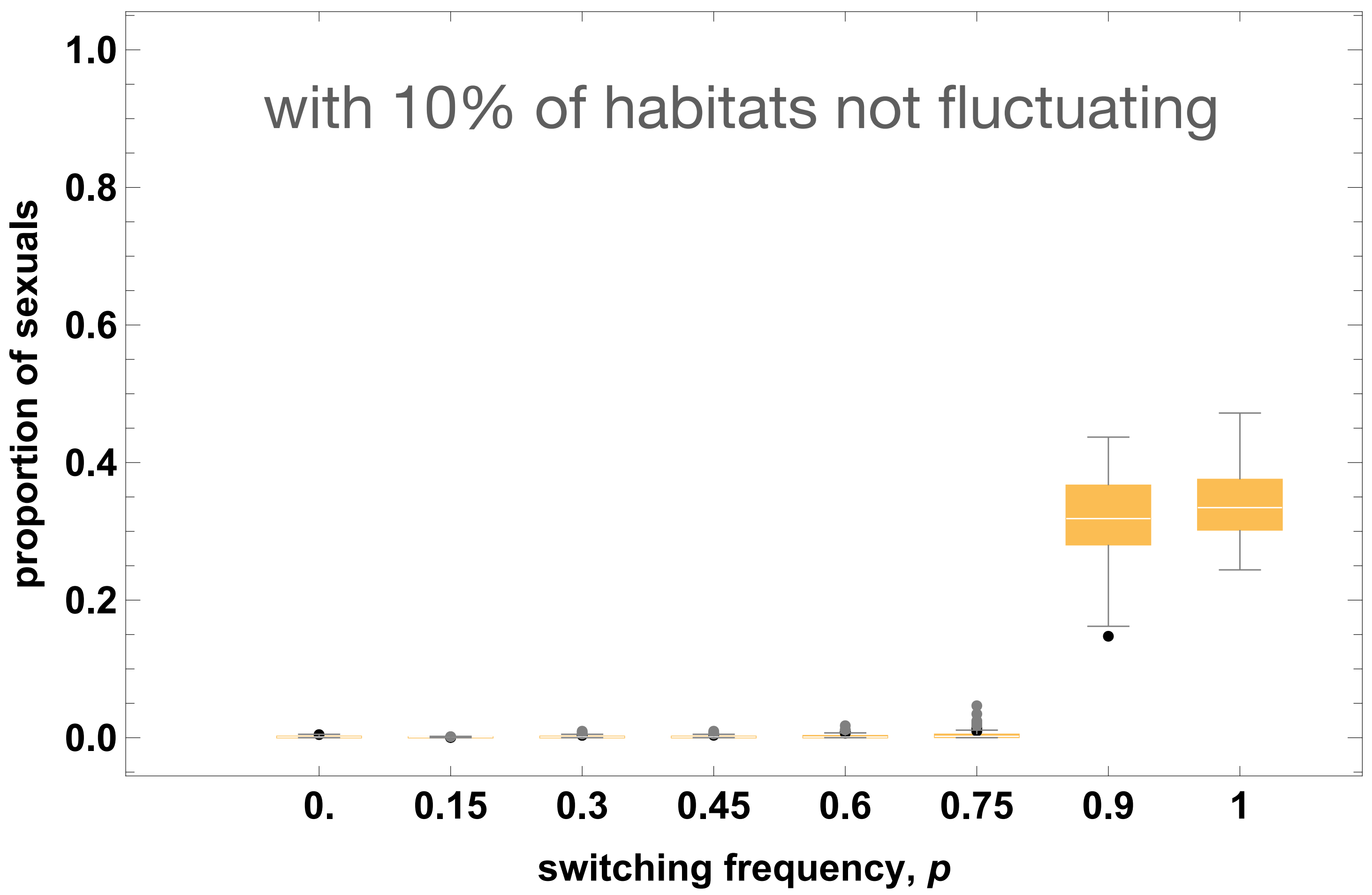
Fluctuating epistasis

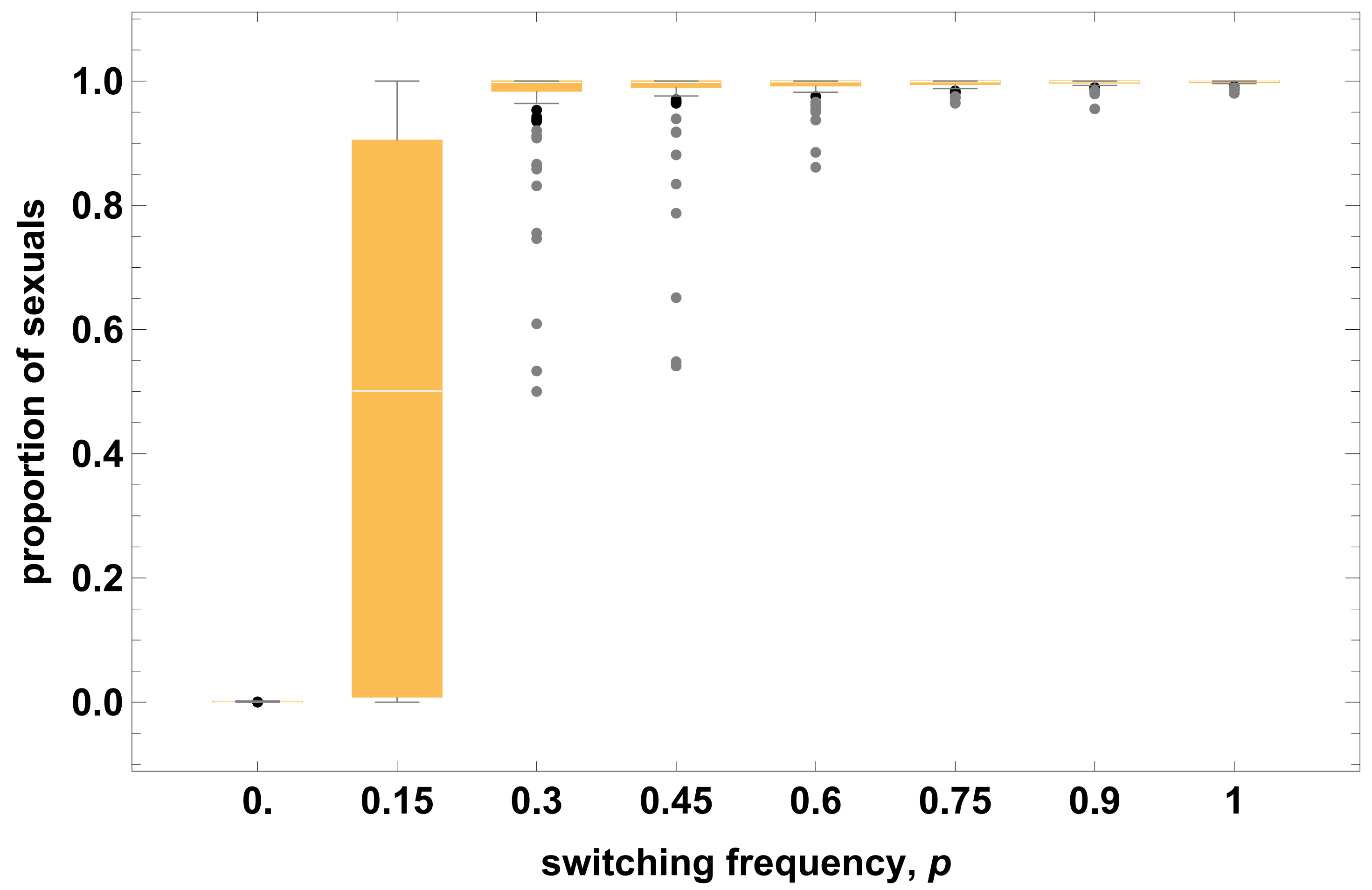
But…

- Environmental and genetic assumptions seem unrealistic.
- Allowing for refugia makes it much more difficult to maintain sexual reproduction:









An ecological model of fluctuating epistasis

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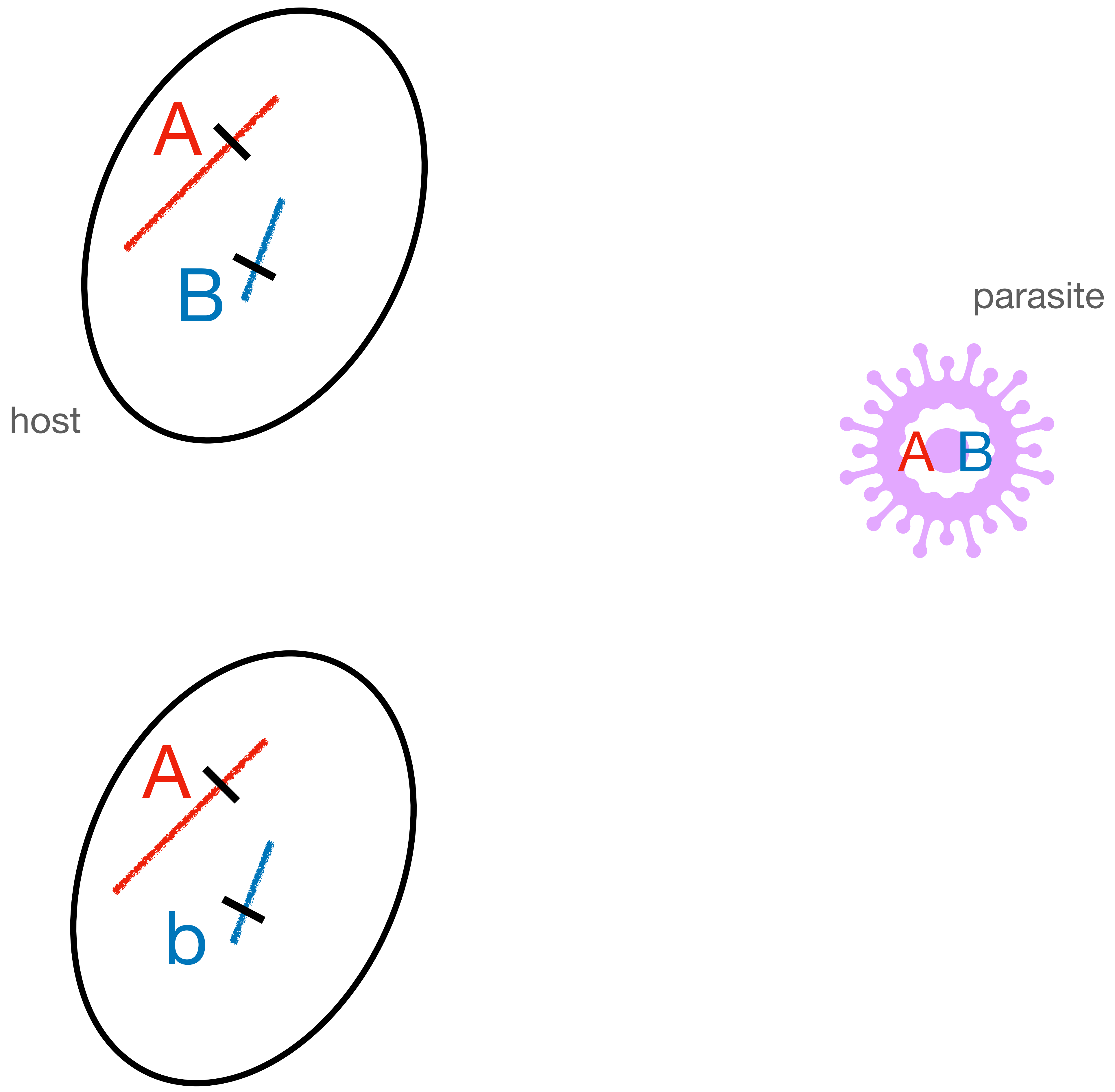
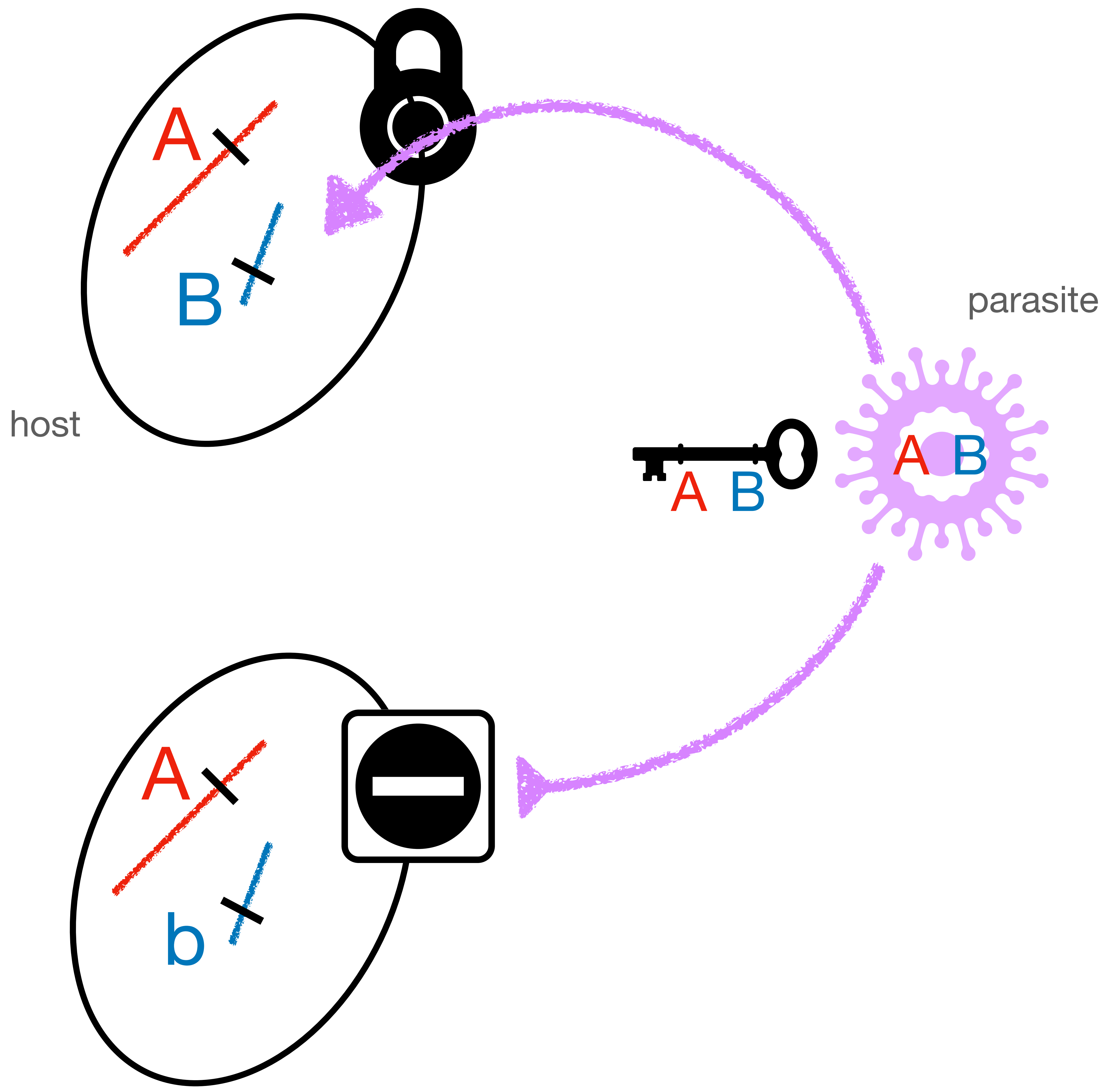
- Coevolution of host and parasites.



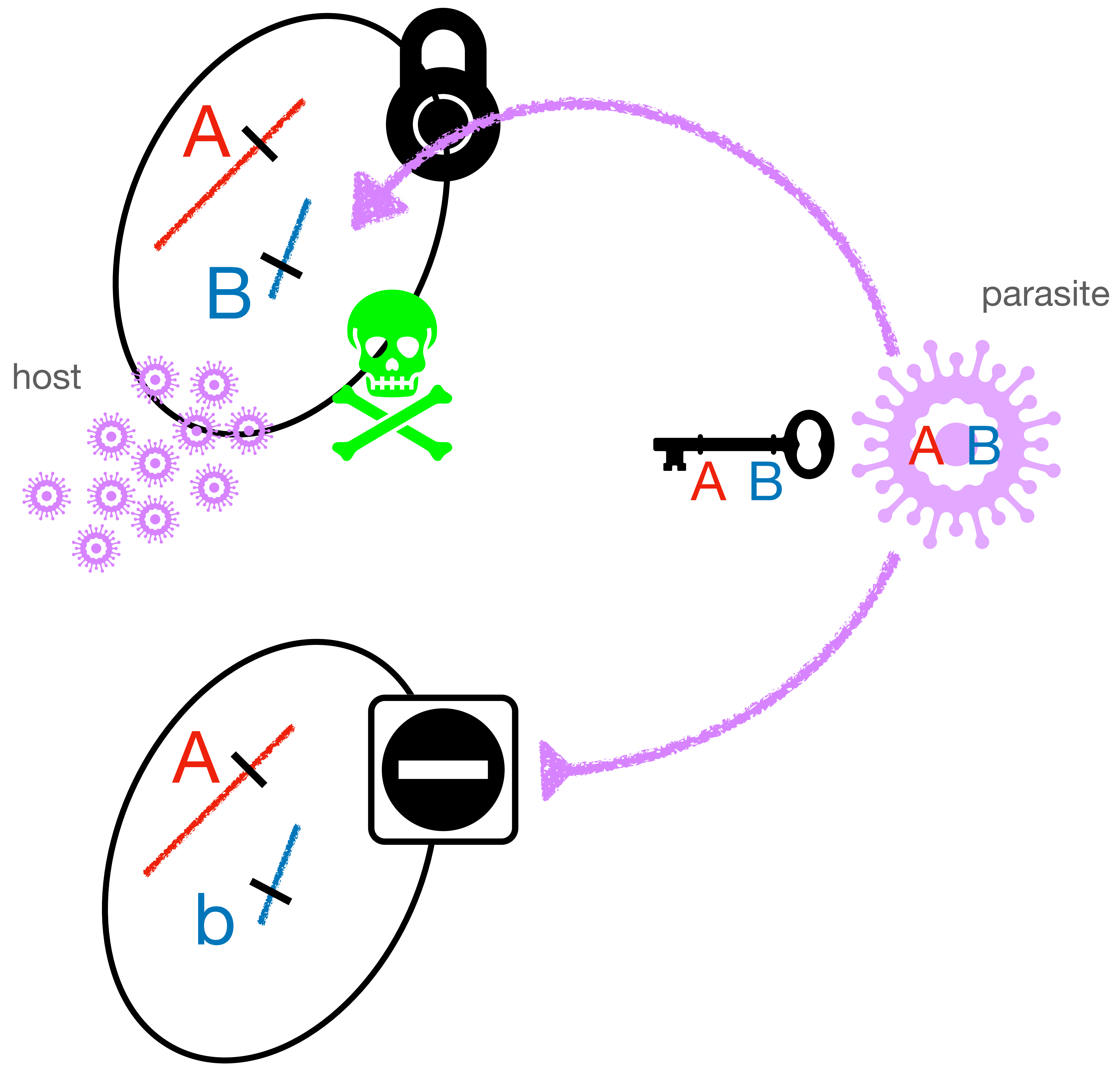
An ecological model of fluctuating epistasis

- Coevolution of host and parasites.
- Lock and key system where parasites can only target host with matching genotype.



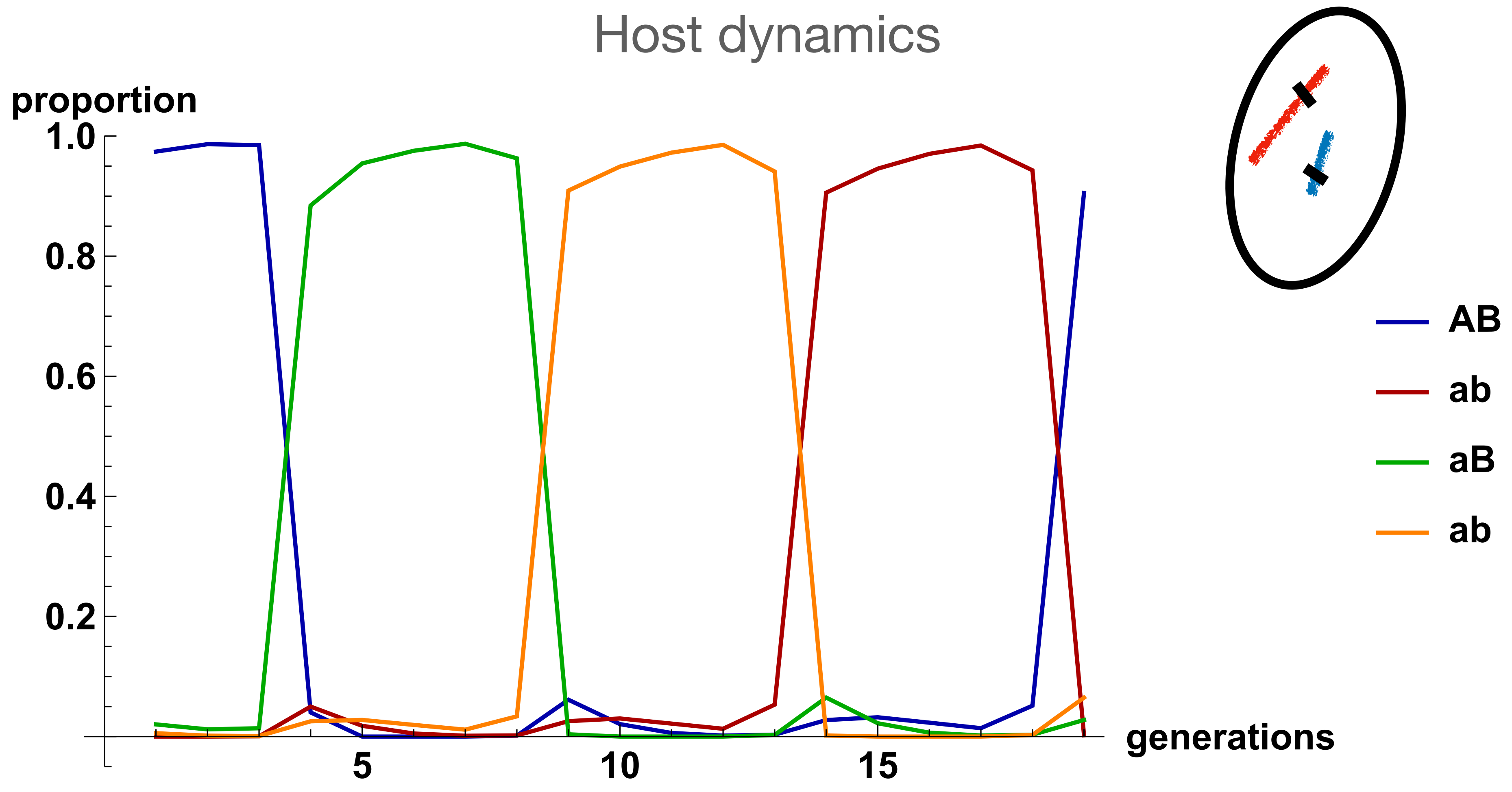
An ecological model of fluctuating epistasis

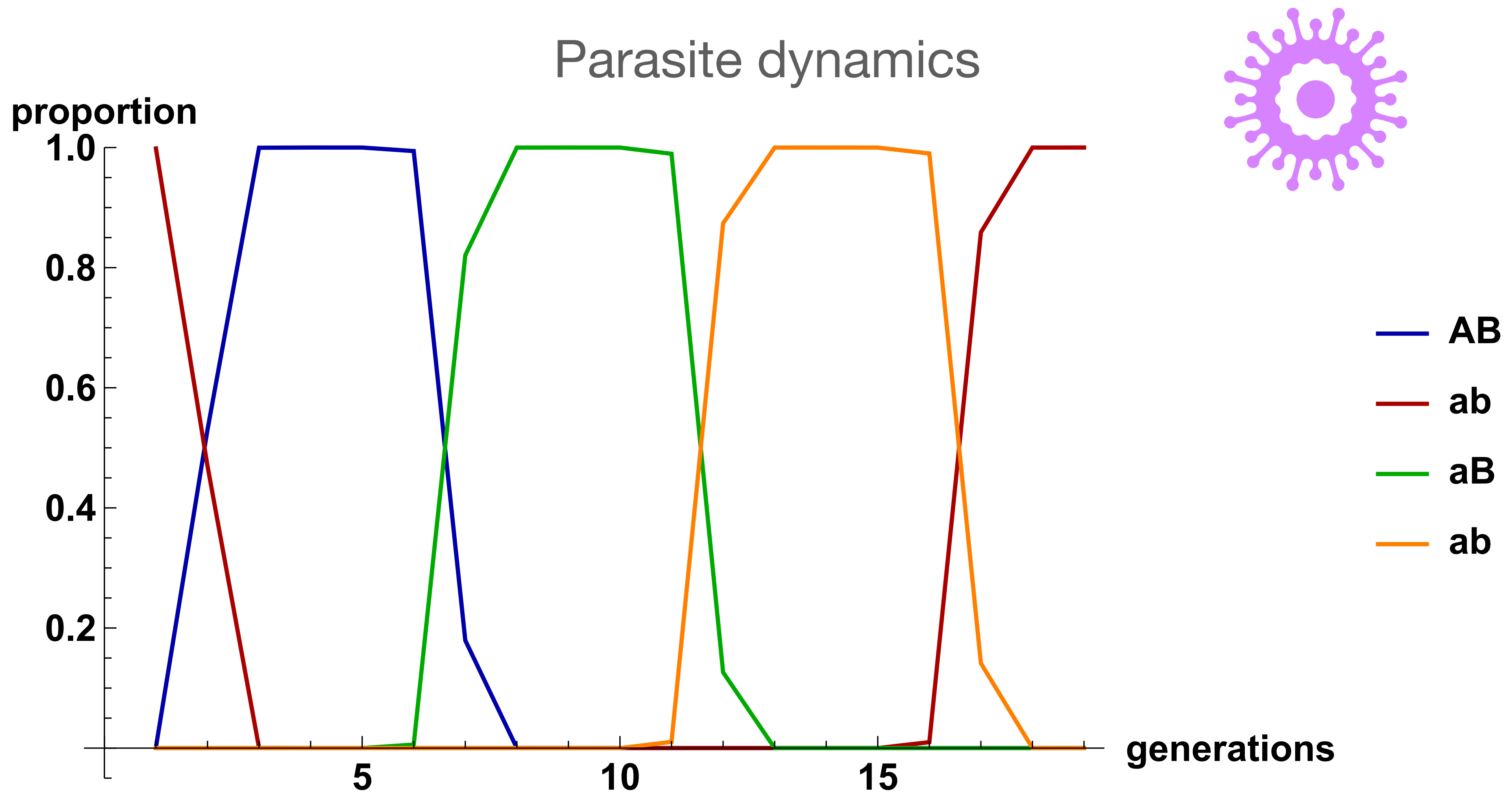
- Coevolution of host and parasites.
- Lock and key system where parasites can only target host with matching genotype.
- Selection on parasites to match most common host, selection on host to evade most common parasite.
- Creates fluctuating epistasis in host.



An ecological model of fluctuating epistasis

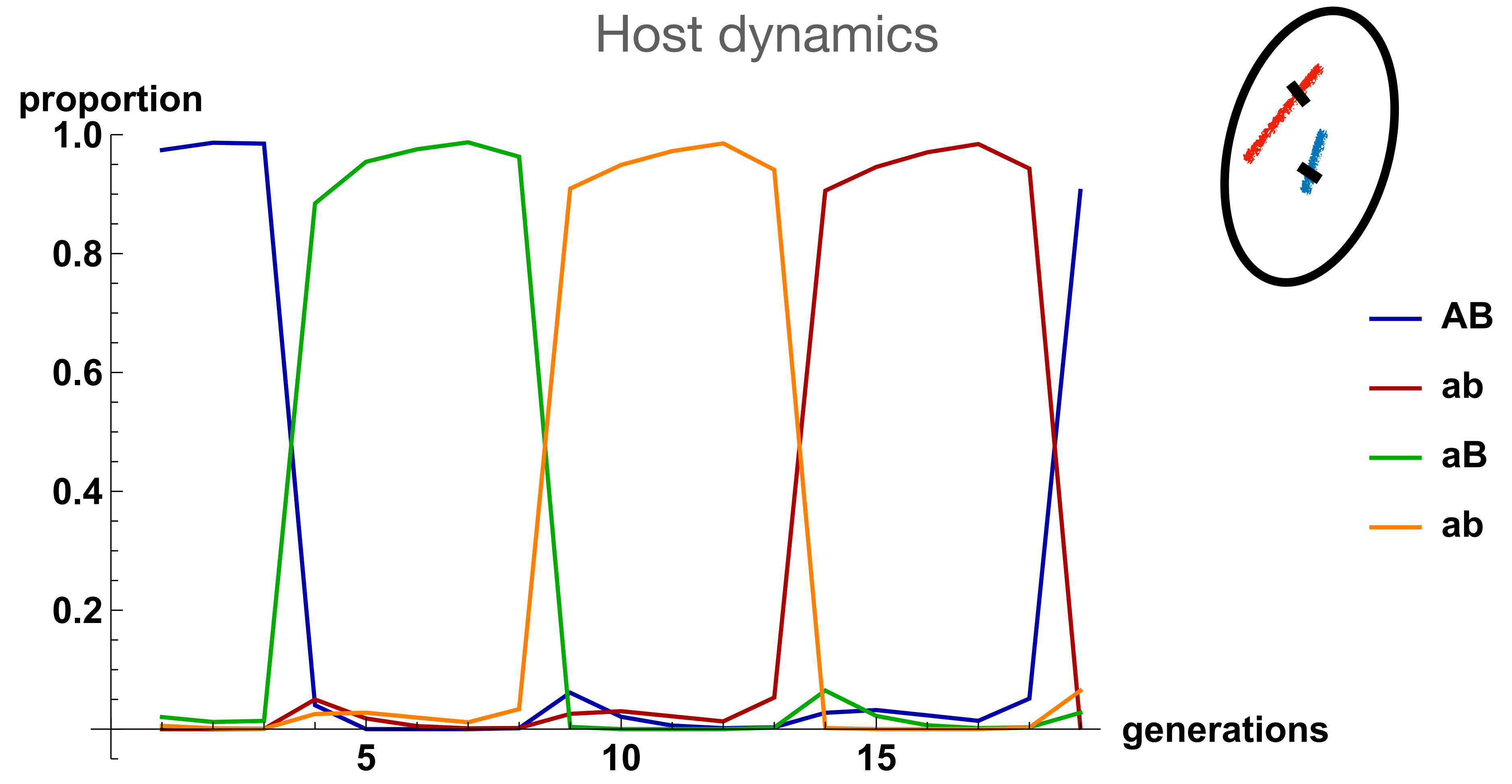
Red queen dynamics

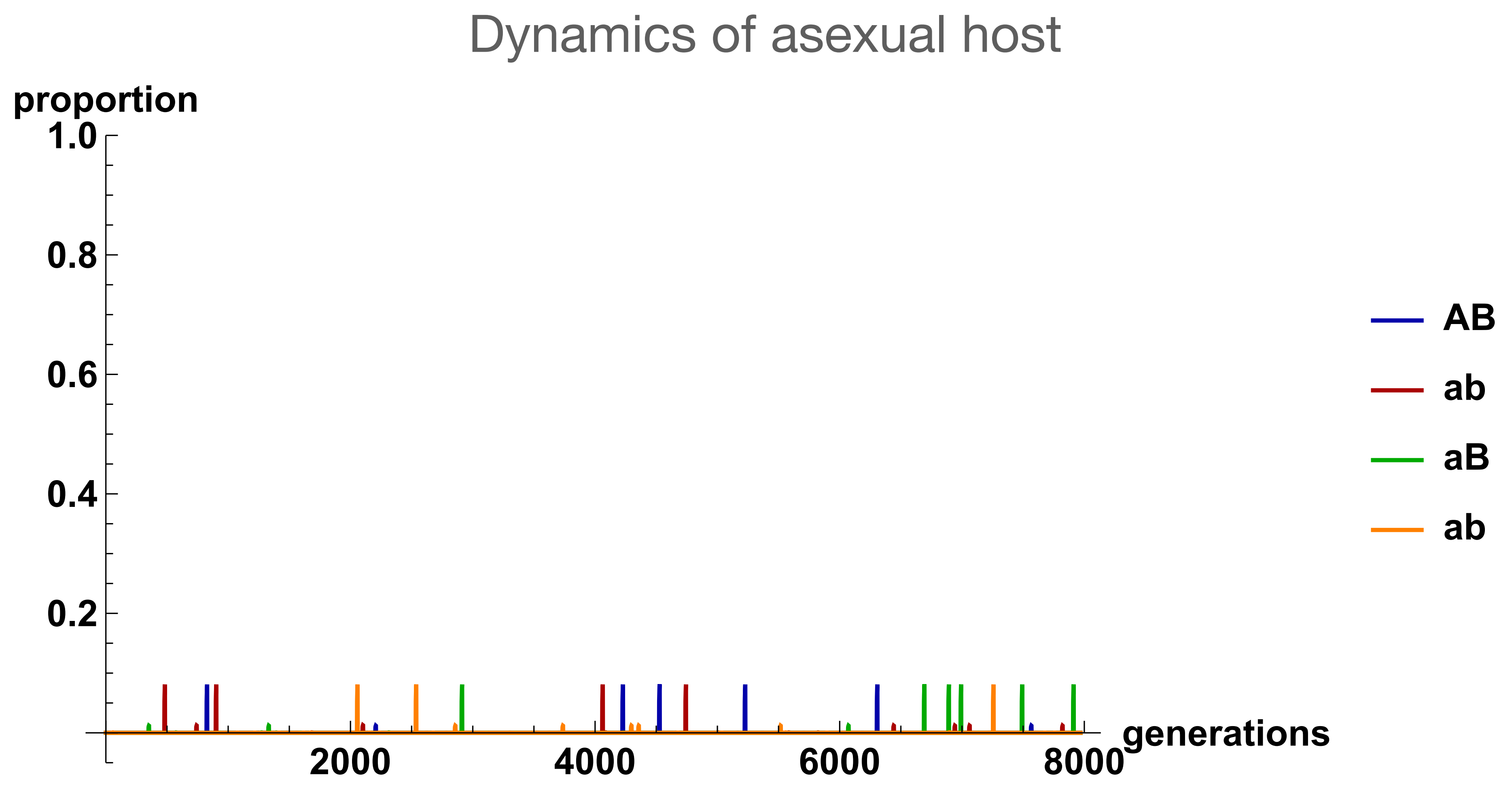


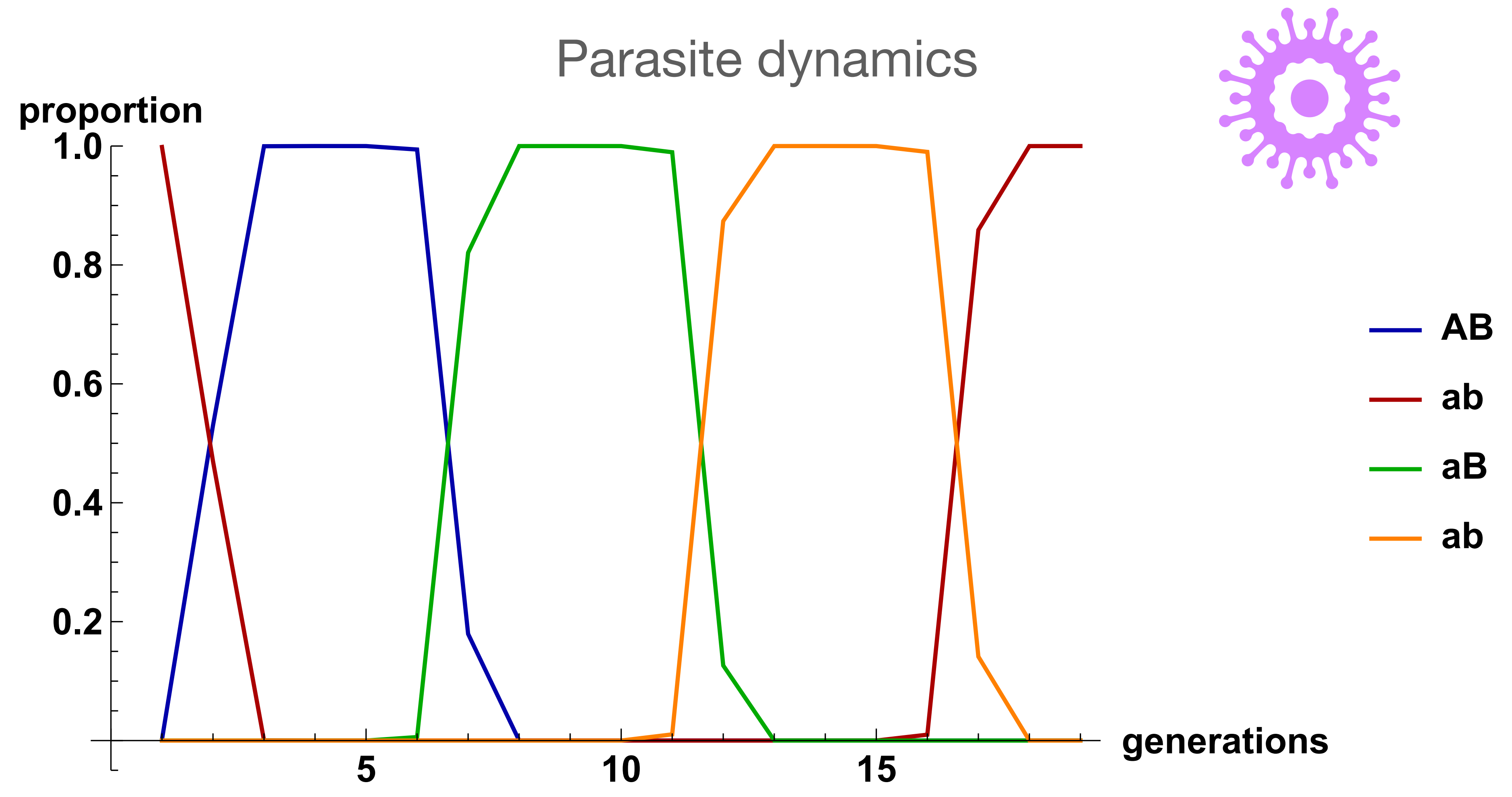


An ecological model of fluctuating epistasis

Red queen dynamics



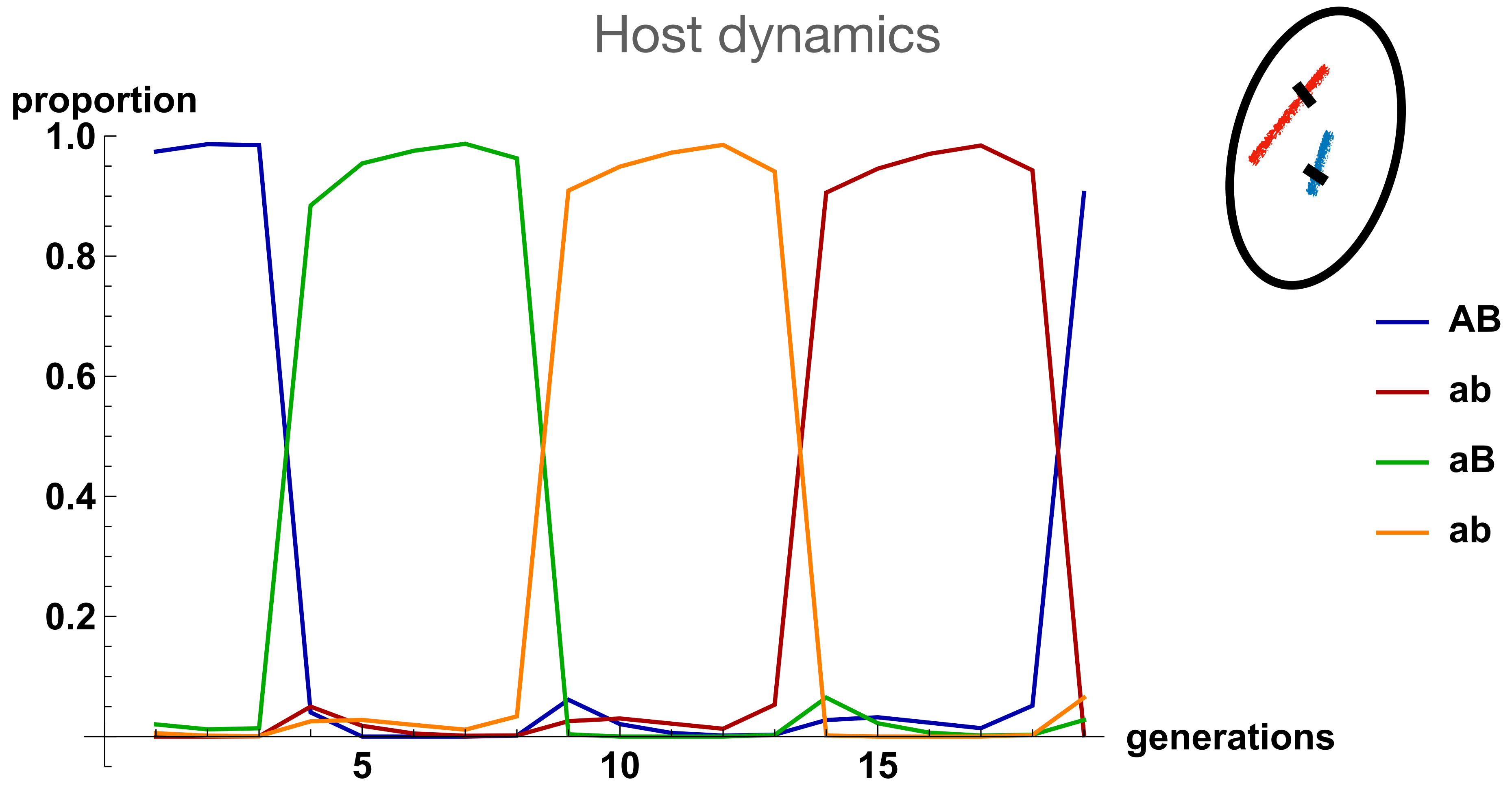


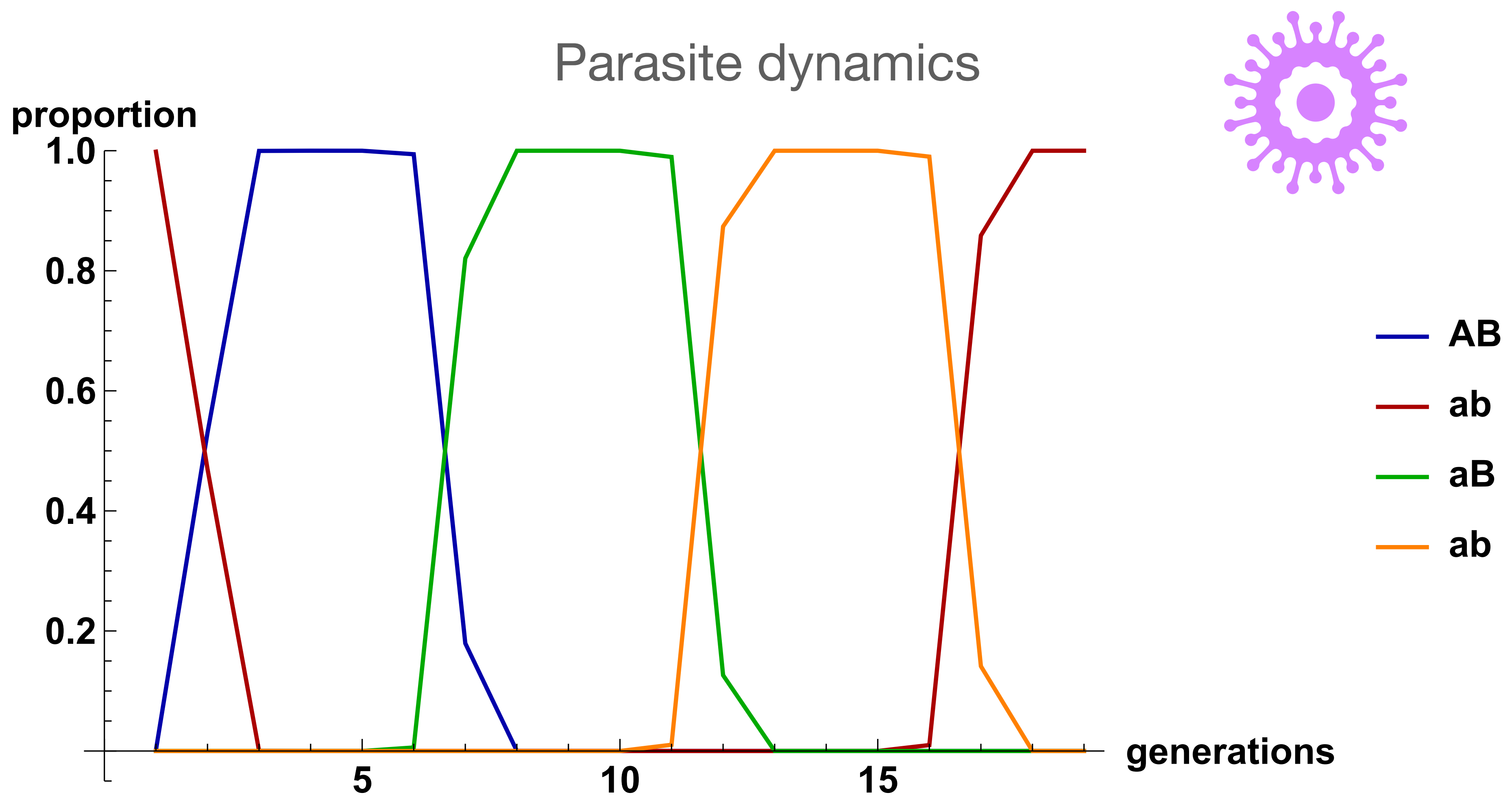


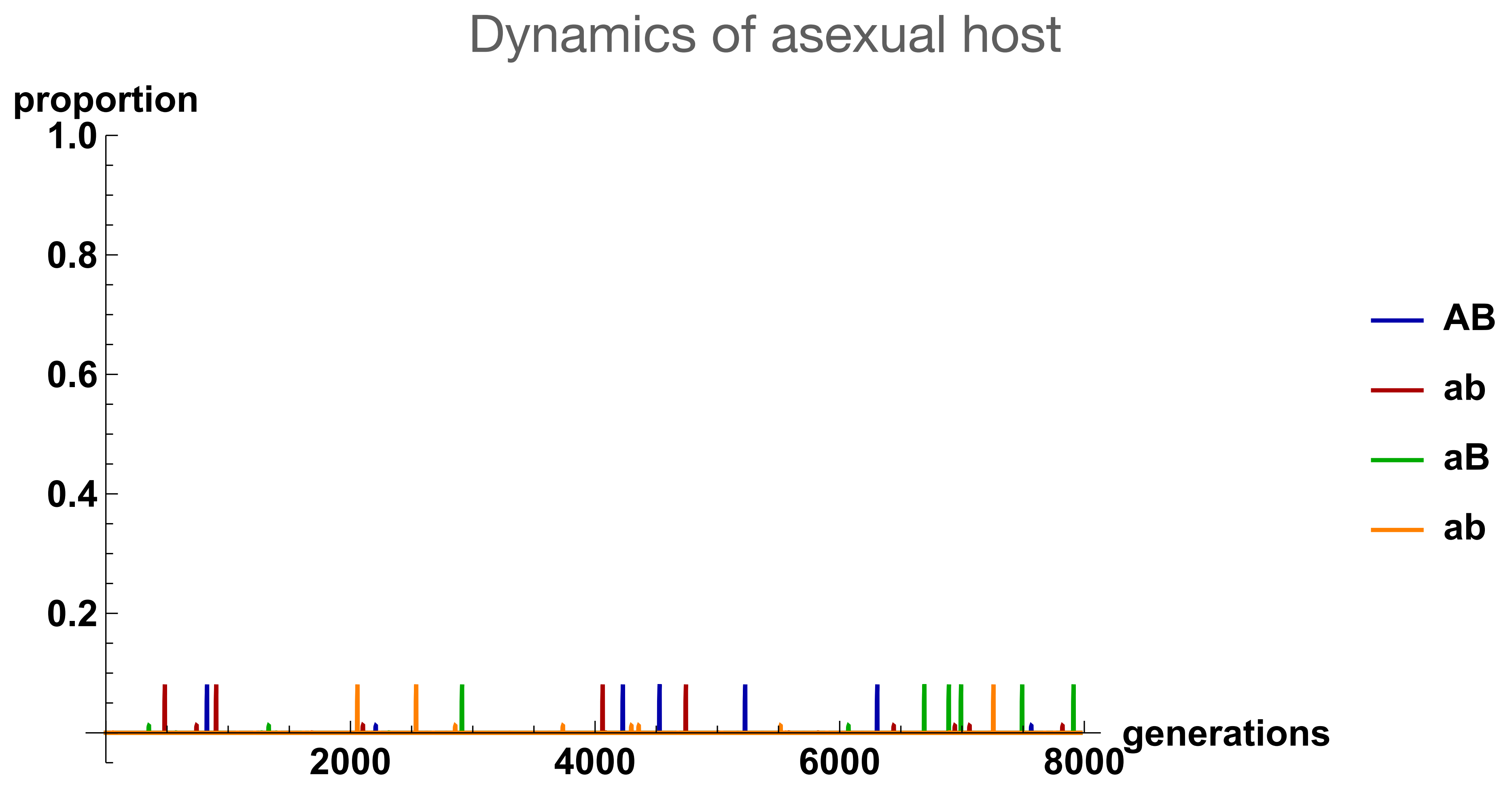
Red queen dynamics can trigger fluctuating epistasis, favouring sexual reproduction.

An ecological model of fluctuating epistasis

But…

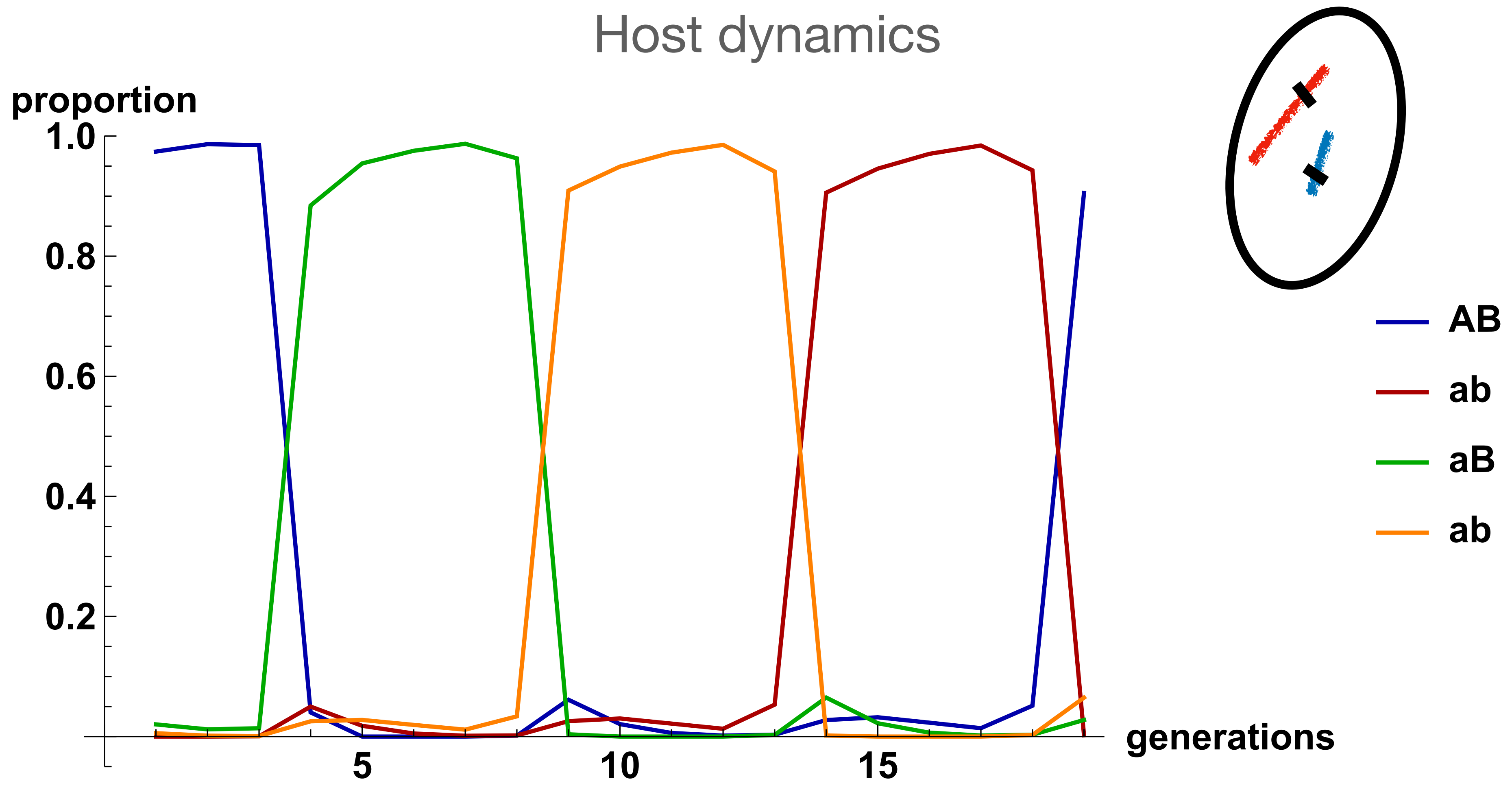


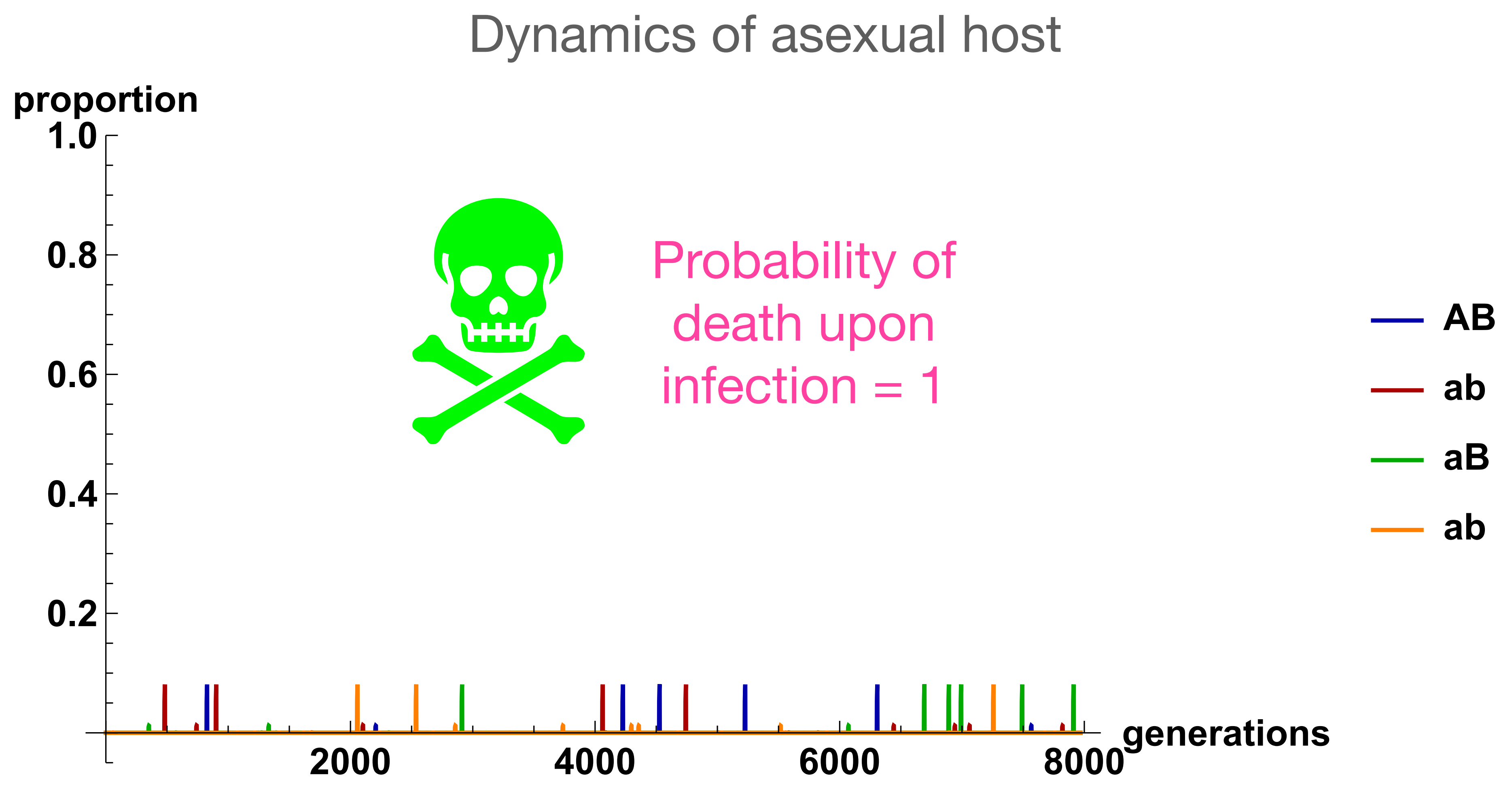


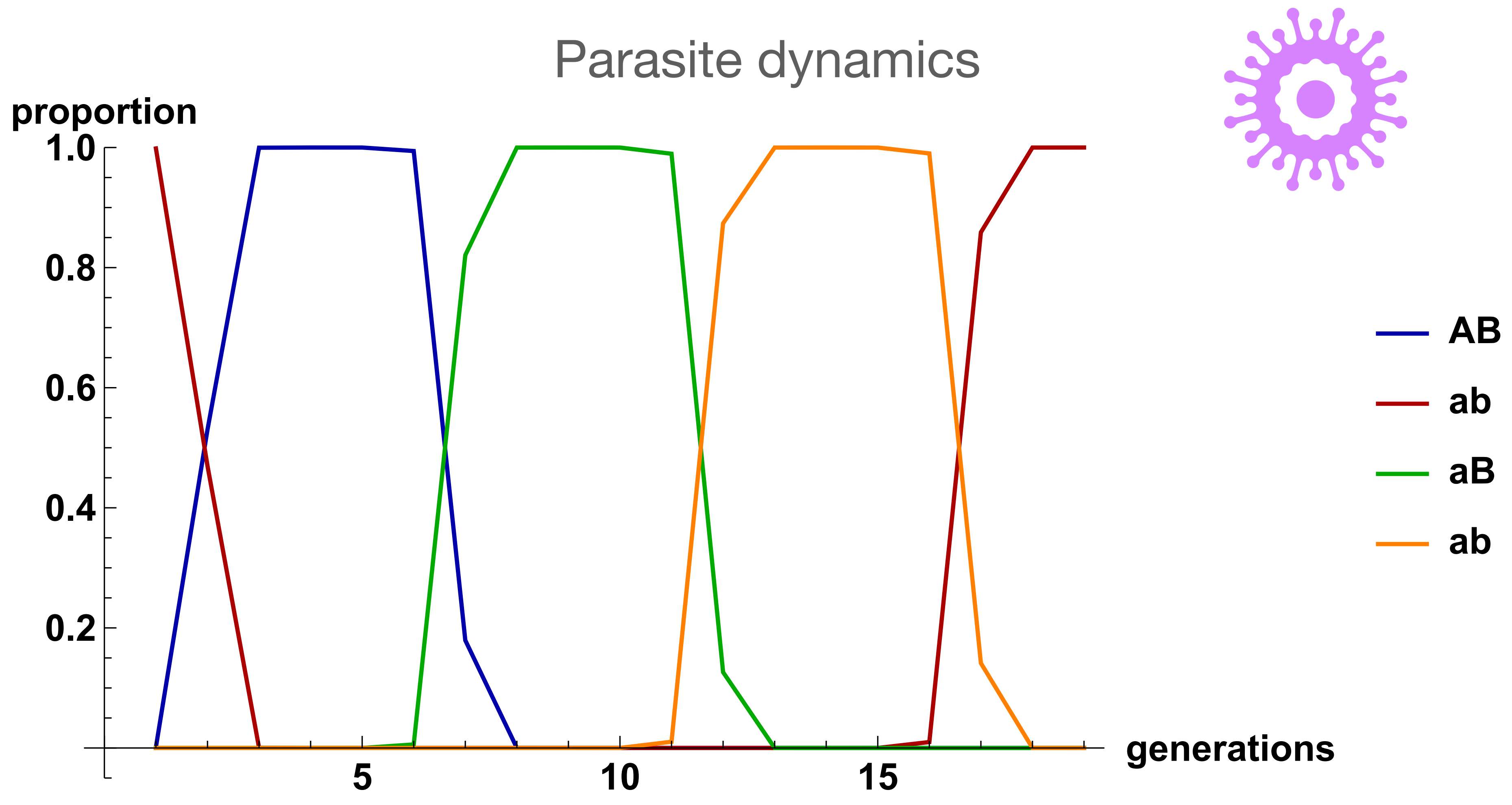


An ecological model of fluctuating epistasis

But…

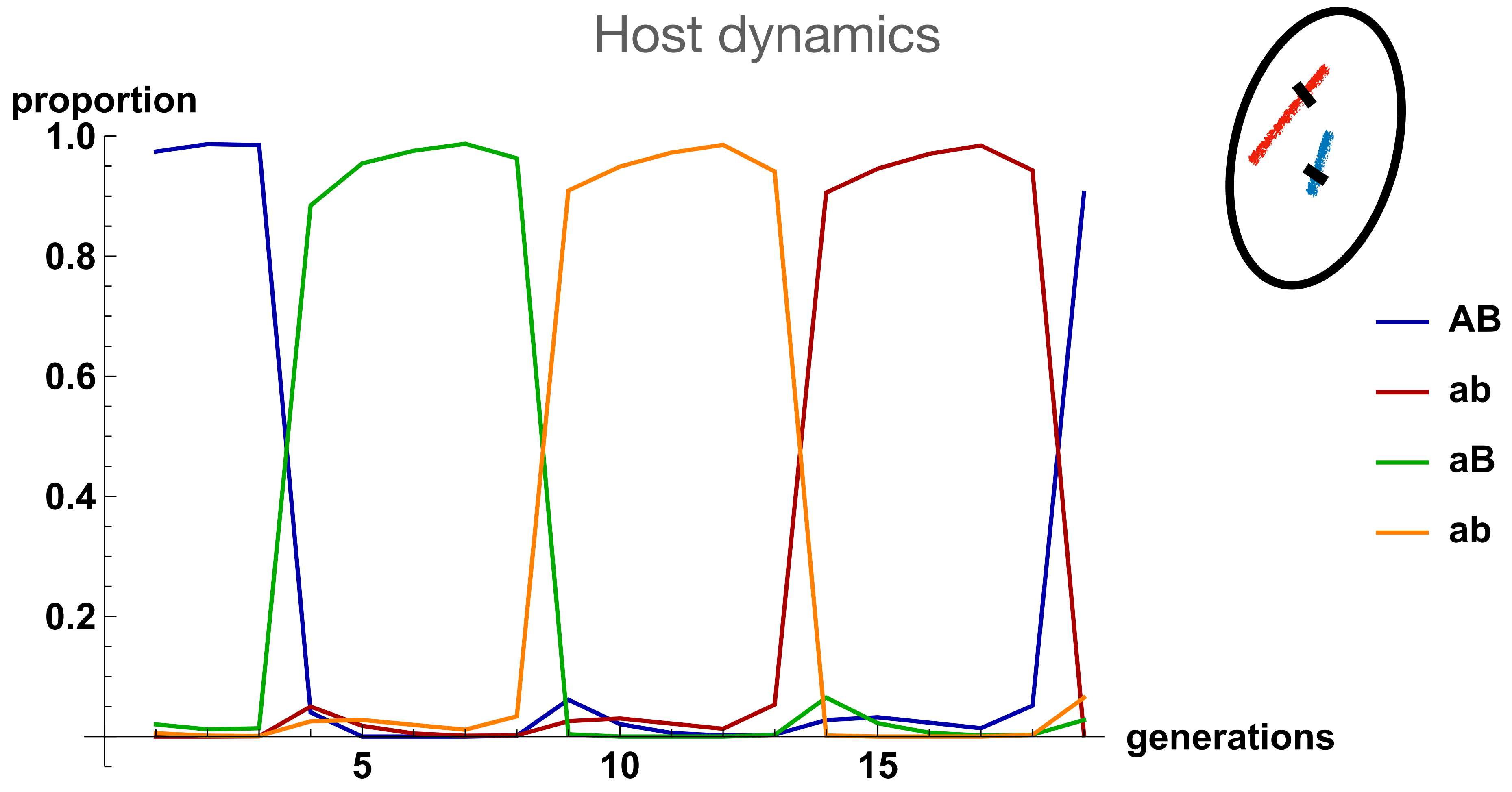


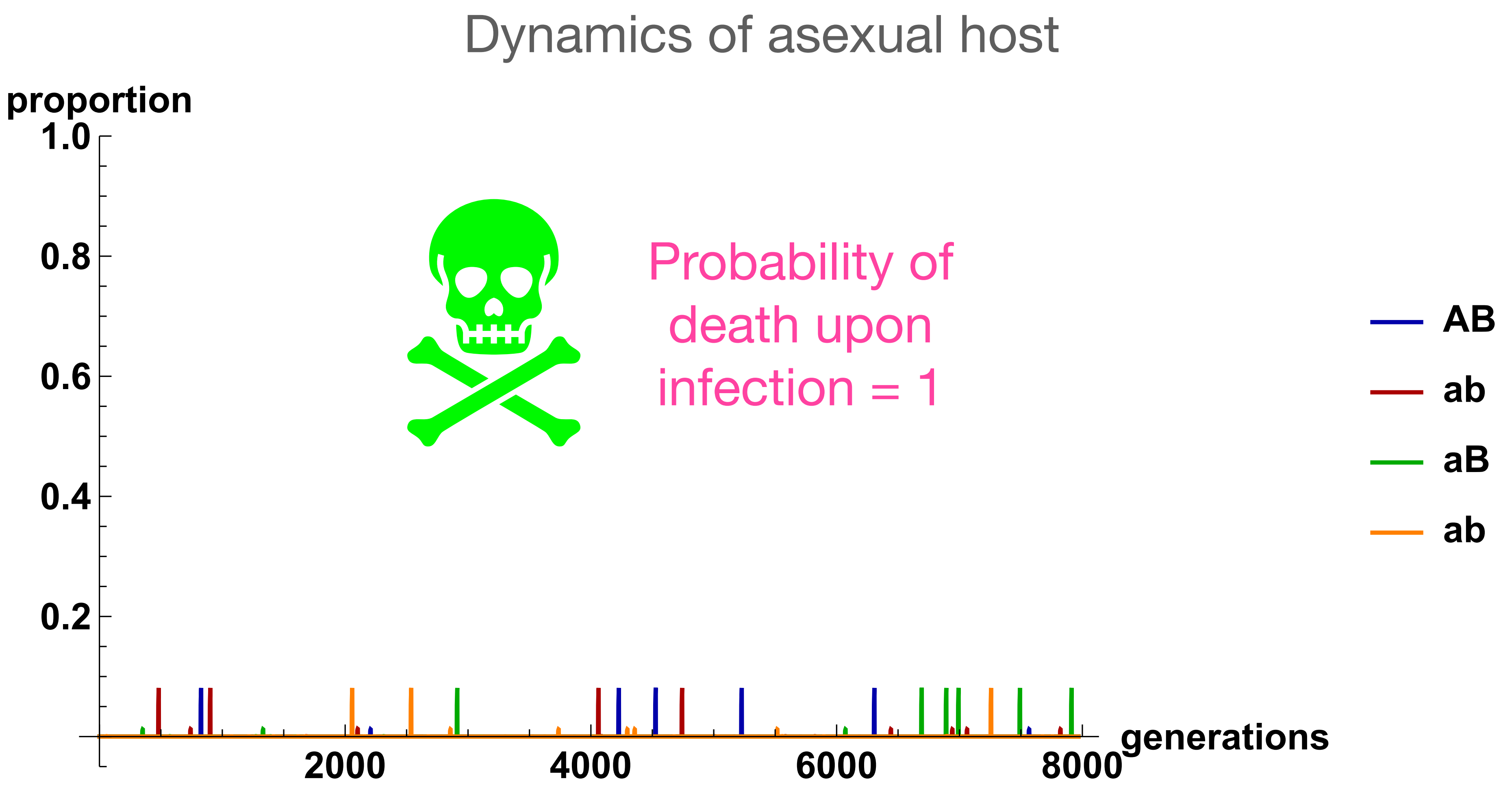


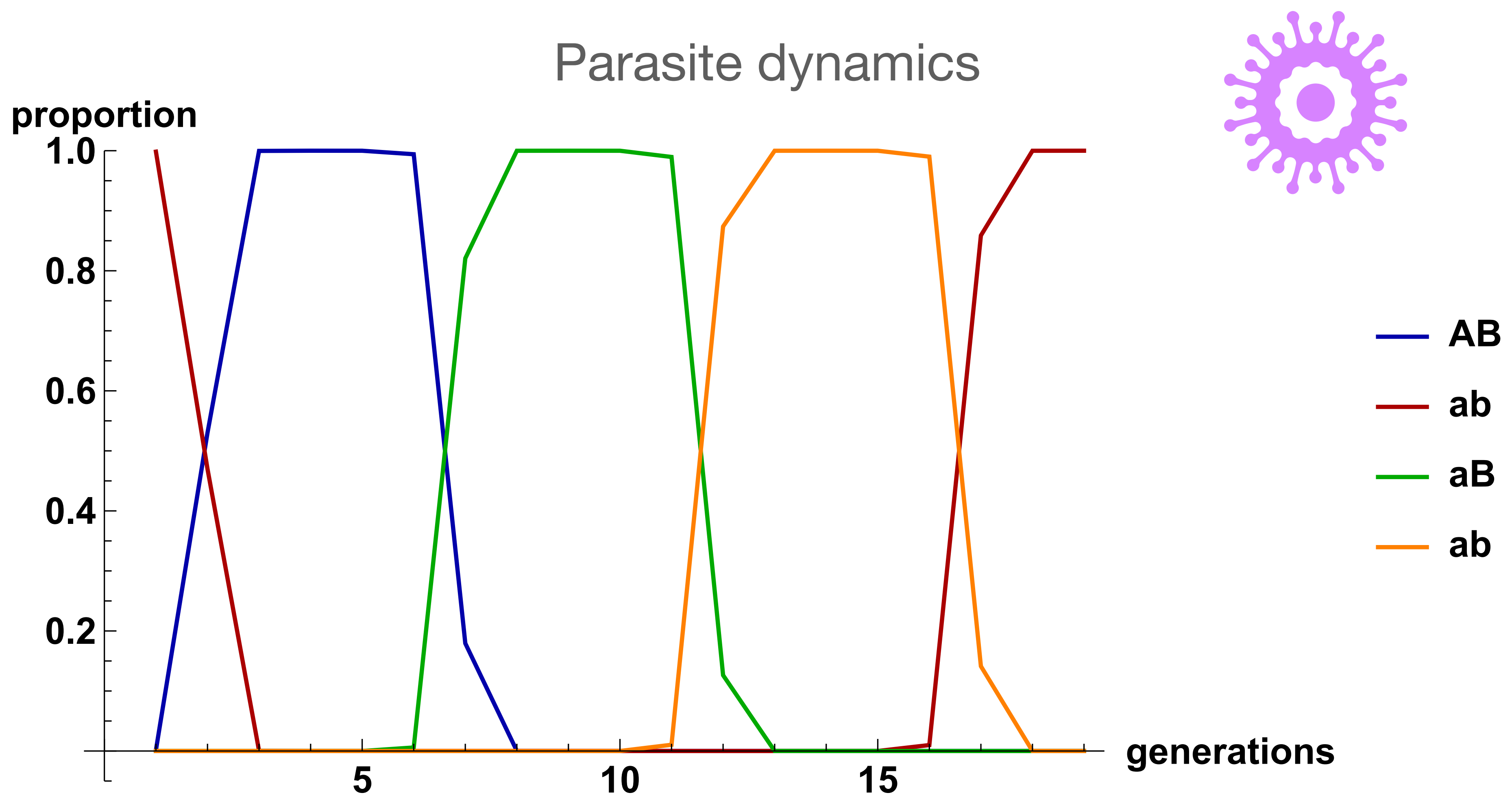


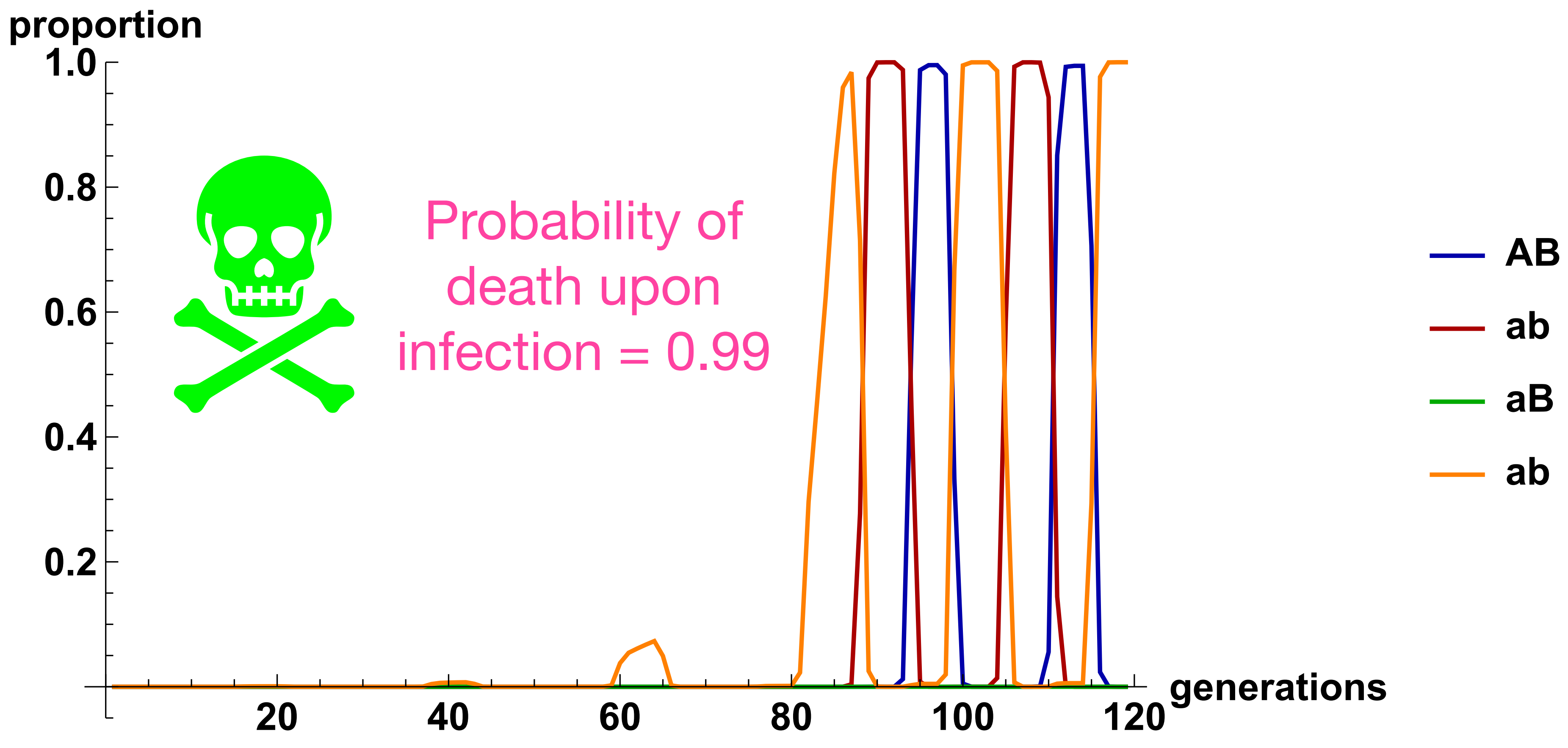
An ecological model of fluctuating epistasis

But…

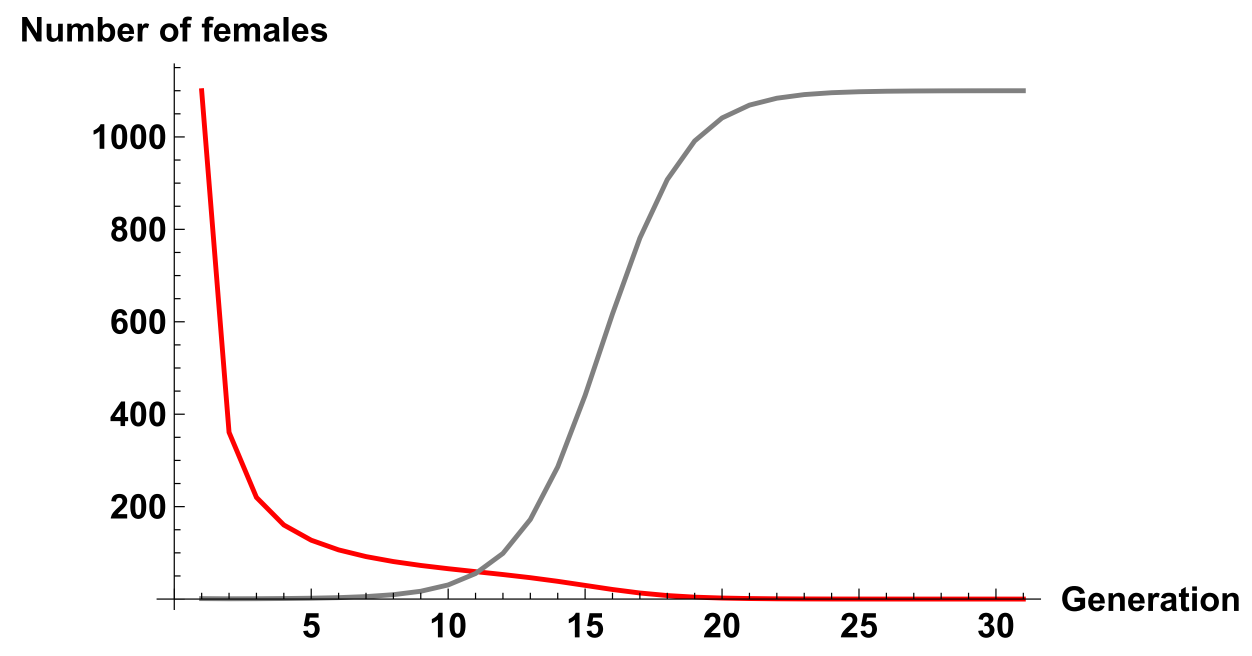


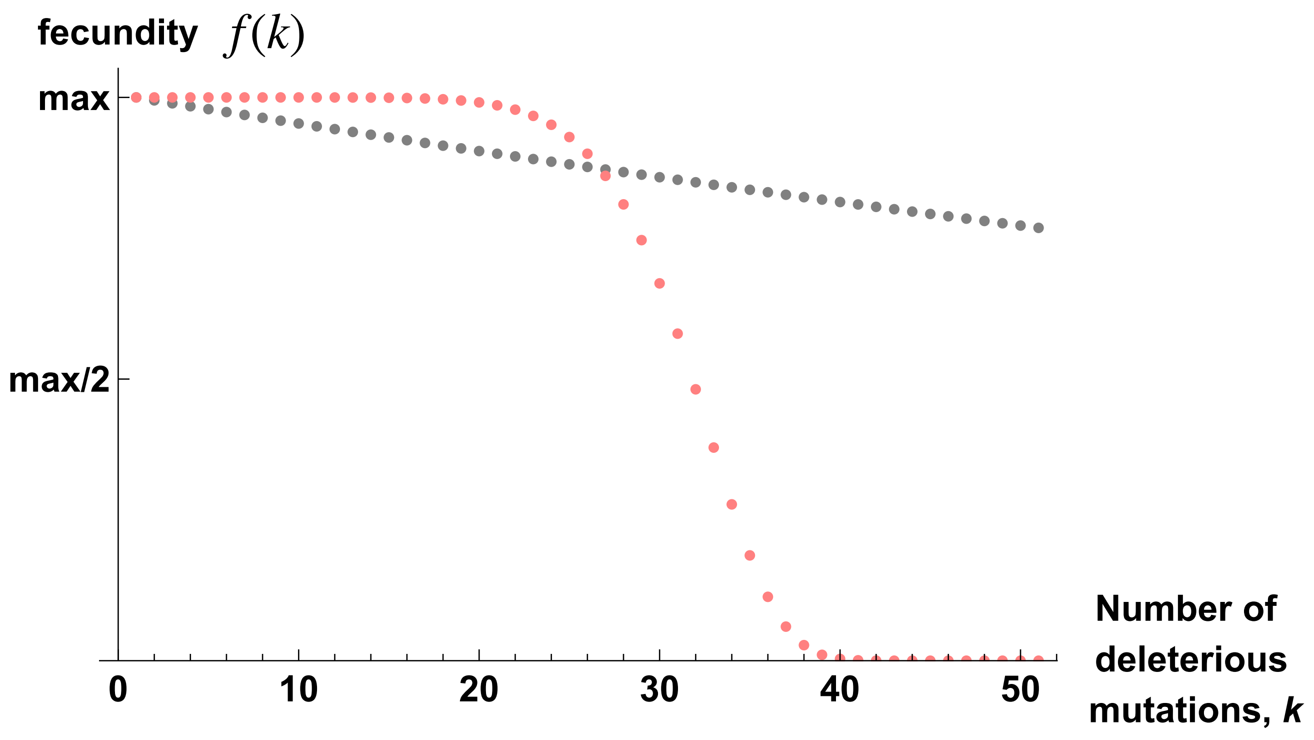






Summary





- Maintenance of sex is not straightforward: rapid demographic advantage versus slow evolutionary cost of asexuality.
- Strong epistasis can mitigate demographic advantage as fitness decreases rapidly with new mutations.
- Fluctuating epistasis also disadvantages asexuals who cannot easily create novel allelic combinations.
- Ecological interactions can lead to red queen dynamics and fluctuating epistasis, favouring sexual reproduction.
- But existing models do not fully answer the question.