Genotype-phenotype map of complex traits

Lecture

Dominance, linkage, pleiotropy

Dominance

Linkage and Pleiotropy

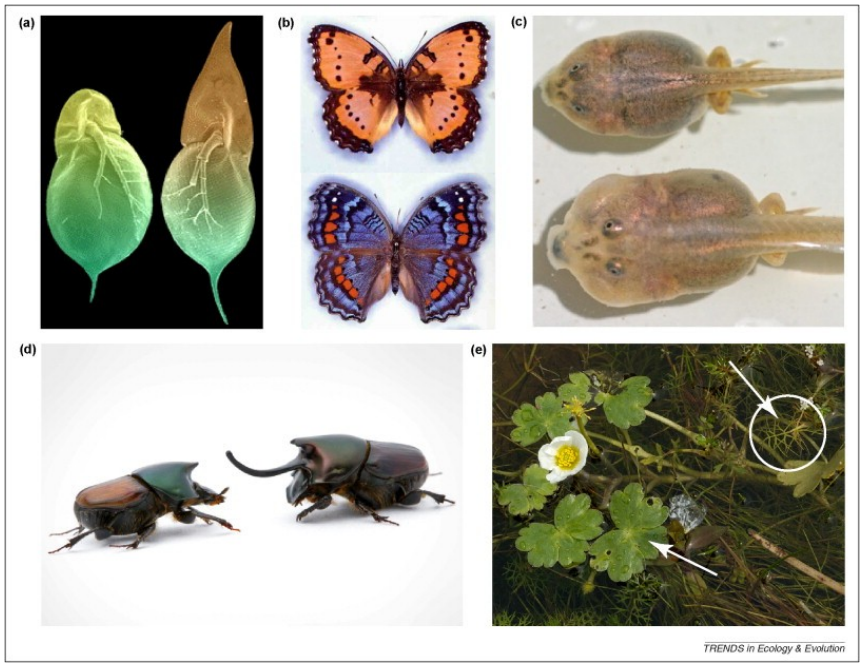
Epistasis

Phenotypic plasticity

= environment-dependent phenotype expression

(a single genotype can express multiple phenotypes
as response to environmental variation)

Phenotype expression can vary with
→ abiotic environment
→ resource availability
→ presence or absence of predators
→ ...

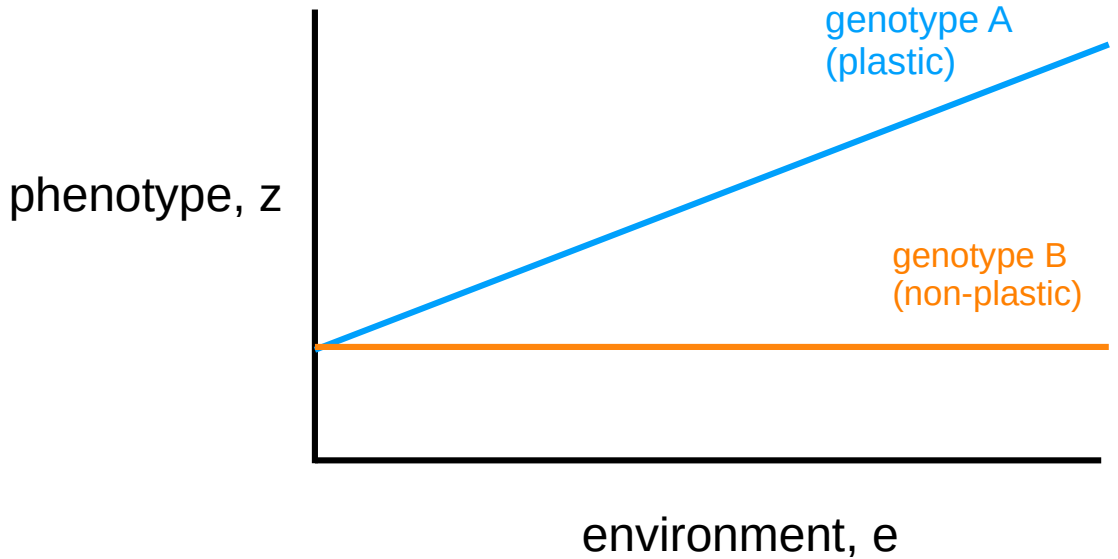


Pfennig et al. (2010), TREE, 25: 459-467

Phenotypic plasticity

= best illustrated by a *reaction norm*

A reaction norm plots
the expressed phenotypes
of a single genotype
across a range of environments

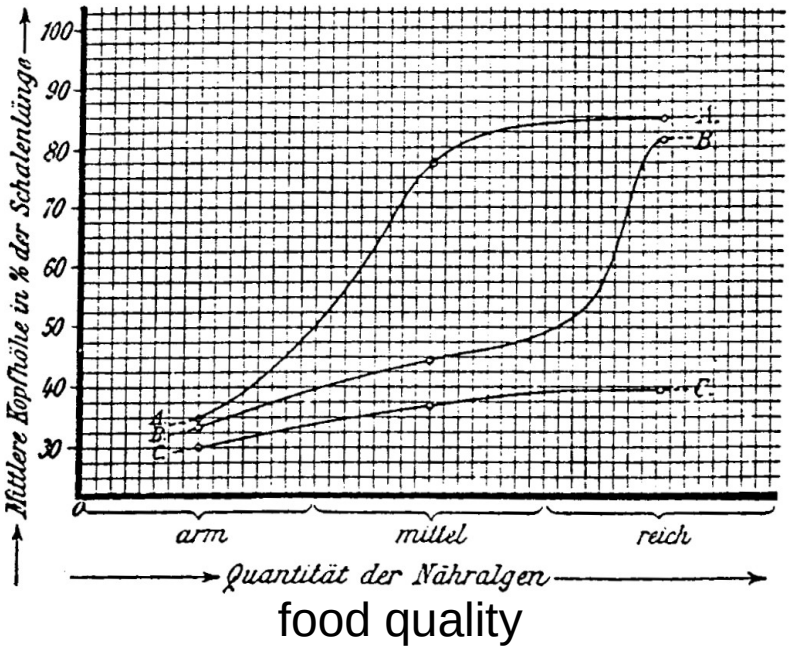


Phenotypic plasticity

= best illustrated by a *reaction norm*

→ an old concept !

Head hight in Daphnia



"*The genotype of a quantitative trait is its inherited reaction norm*" (Woltareck 1909)

Woltereck (1909) Verhandlungen der deutschen zoologischen Gesellschaft, 19: 110–173

Phenotypic plasticity

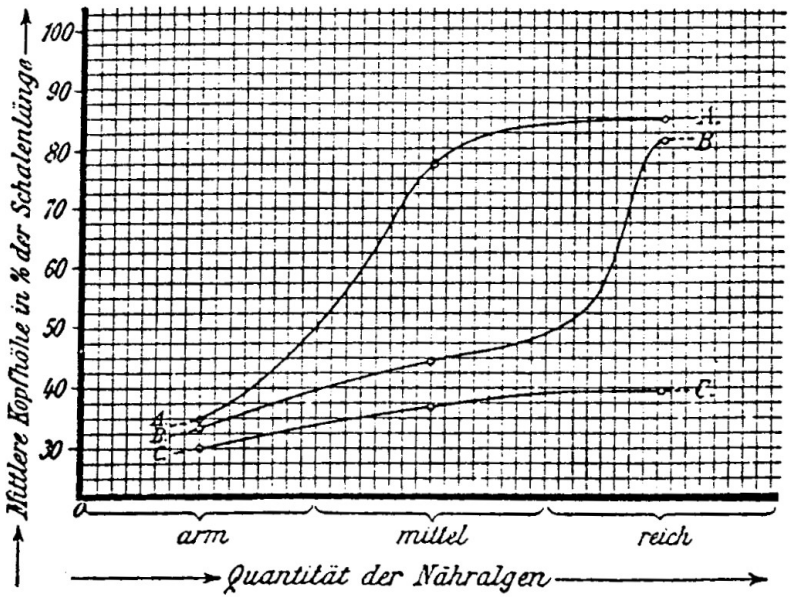
= best illustrated by a *reaction norm*

→ an old concept !

→ initially mostly ignored
in Europe and N. America

→ an important conceptual tool
in Soviet Union

→ „rediscovered“ after WW II
in the „west“



Sarkar (1999) Biology and Philosophy, 14: 235–252

Phenotypic plasticity

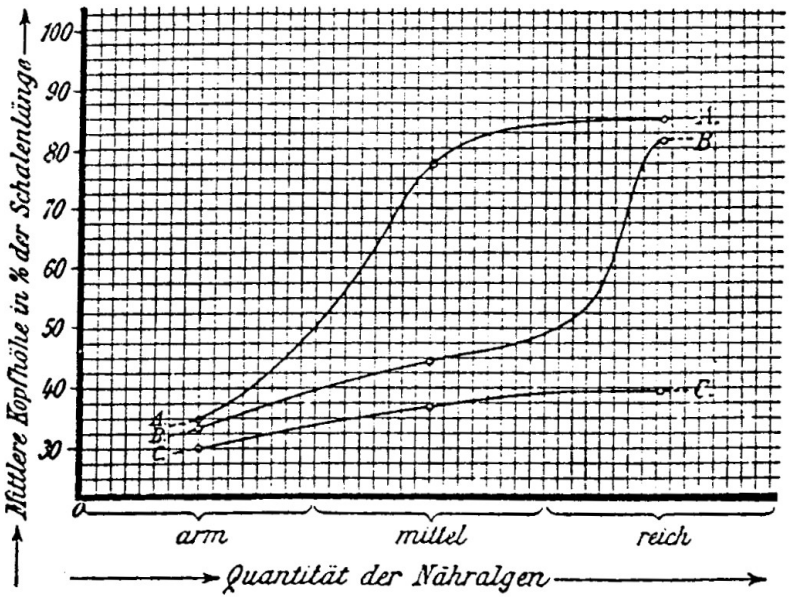
= best illustrated by a *reaction norm*

„*The ability of a genotype to change its phenotype was once considered rather a nuisance – making it difficult to define a genotype.*“

(Bradshaw 2006, New Phytologist 170: 644-648)

„*How populations and species respond to modified environmental conditions is critical to their persistence*“

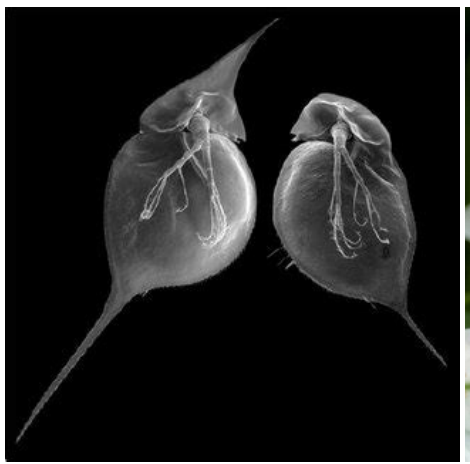
(Fox et al. 2019, Phil. Trans. R. Soc. B 374: 20180174)



Kinds of plasticity

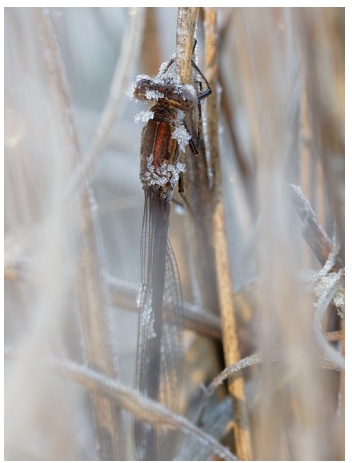
active response

„active plastic responses require a specific signal perception-transduction system allowing plants to respond by changing their development.“



passive response

„Many phenotypic responses to environmental stress, however, may be the consequence of passive reductions in growth due to resource limitation“



Van Kleunen & Fischer (2005) New Phytologist 166: 49-60)

Kinds of plasticity

labile plasticity

„Physiological and behavioural characters typically display reversible development producing labile phenotypes that change continually during an individual lifetime“

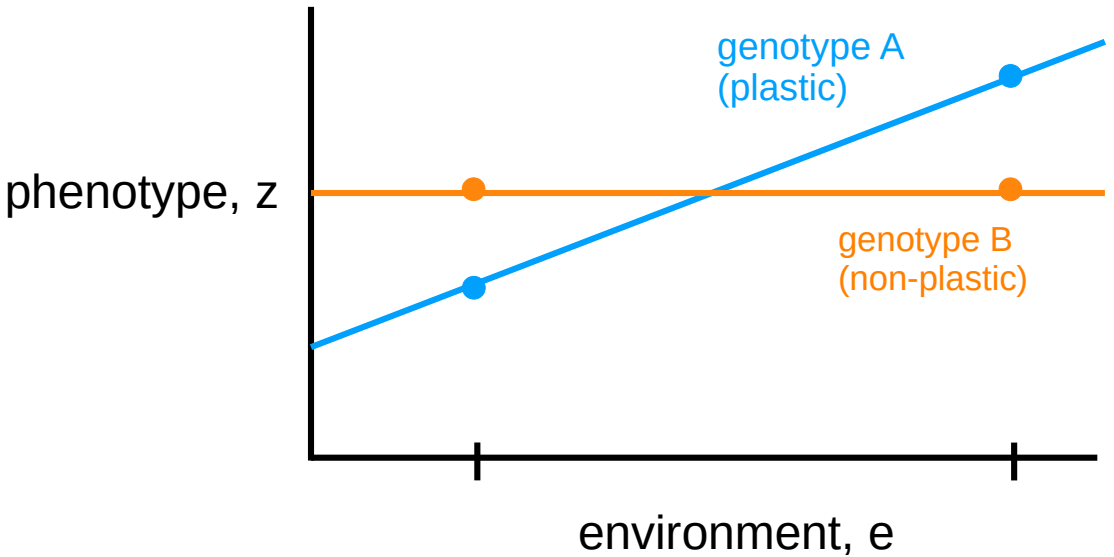
developmental plasticity

„During a brief critical stage of early development, the environment experienced by an individual influences its subsequent development. …

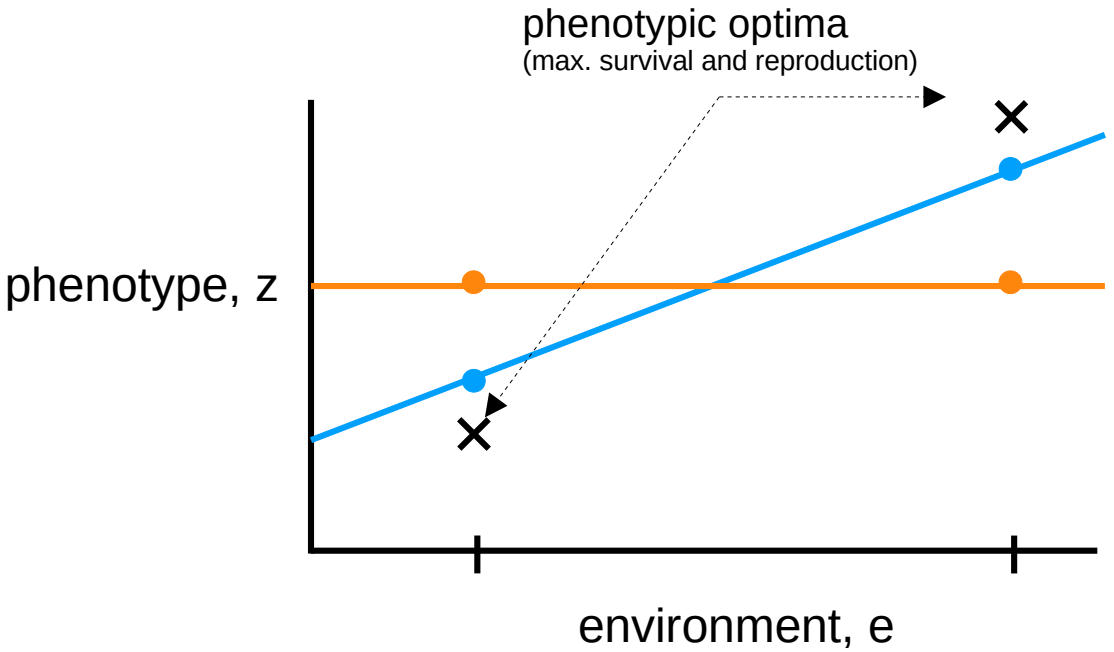
(also called fixed or one-shot plasticity)

Lande (2015) Molecular Ecology 24: 2038-2045

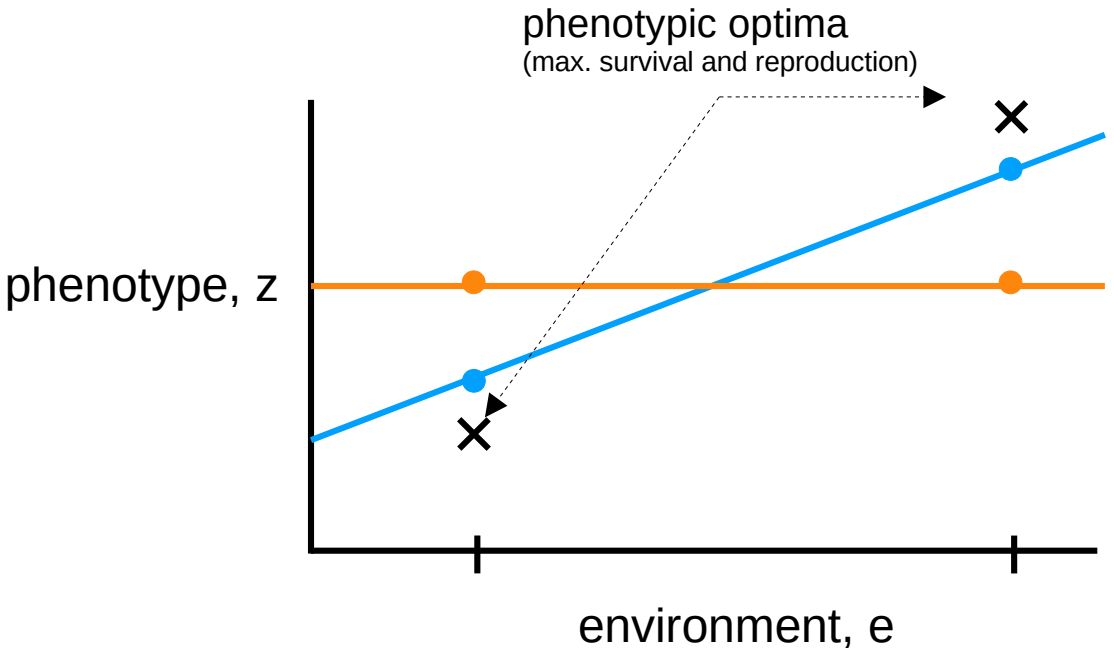
Fitness consequences of plasticity



Fitness consequences of plasticity

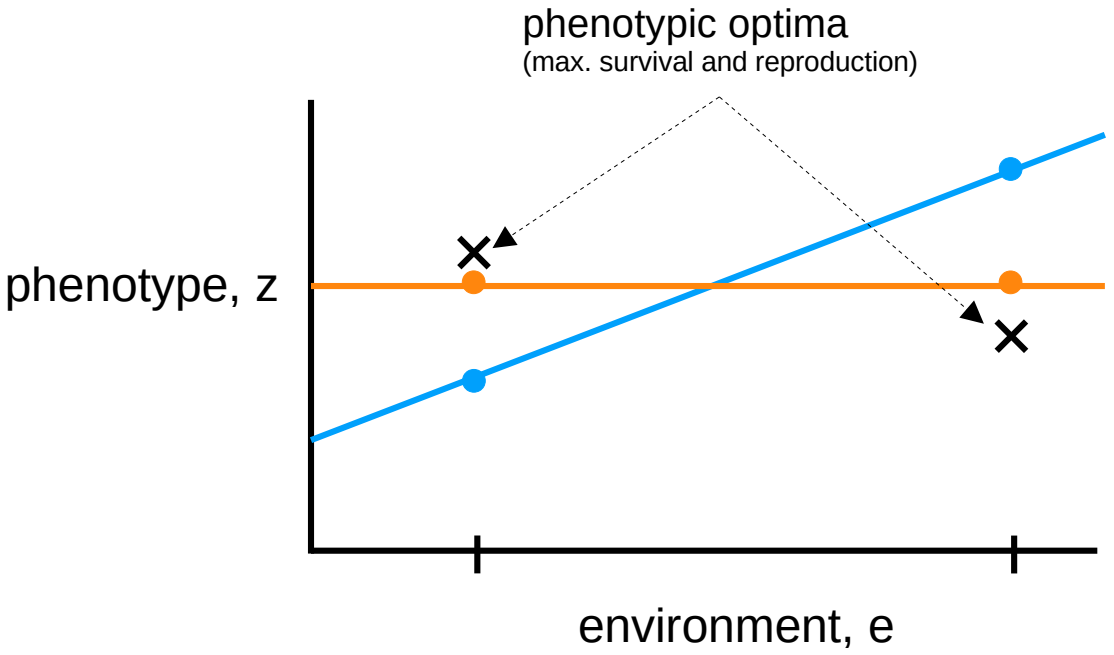


Fitness consequences of plasticity

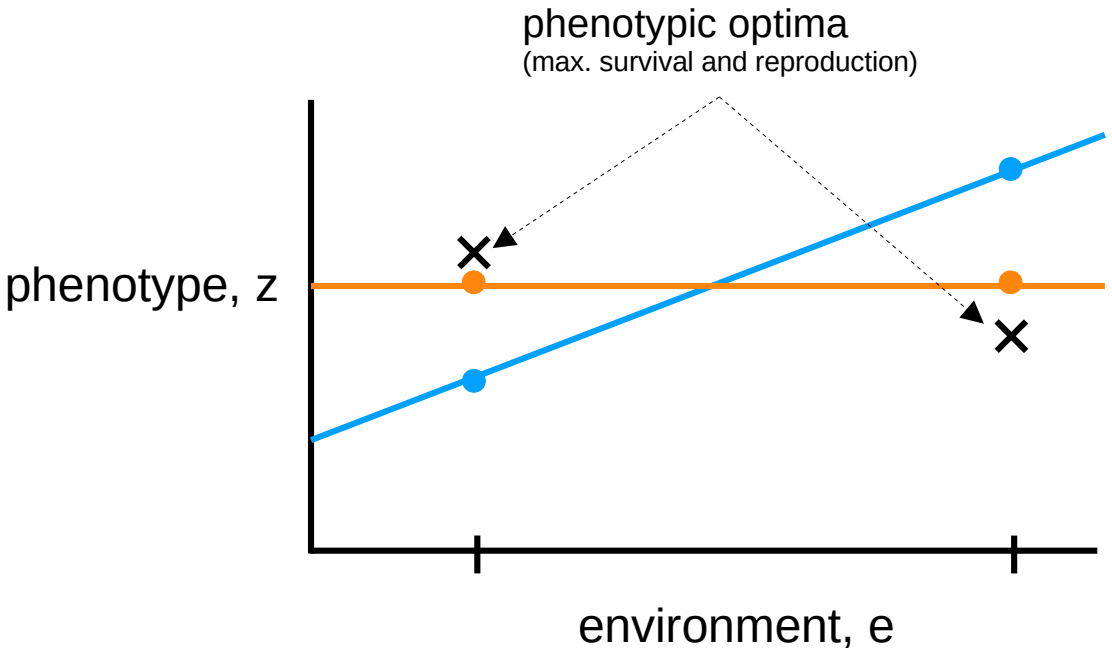


→ adaptive plasticity

Fitness consequences of plasticity



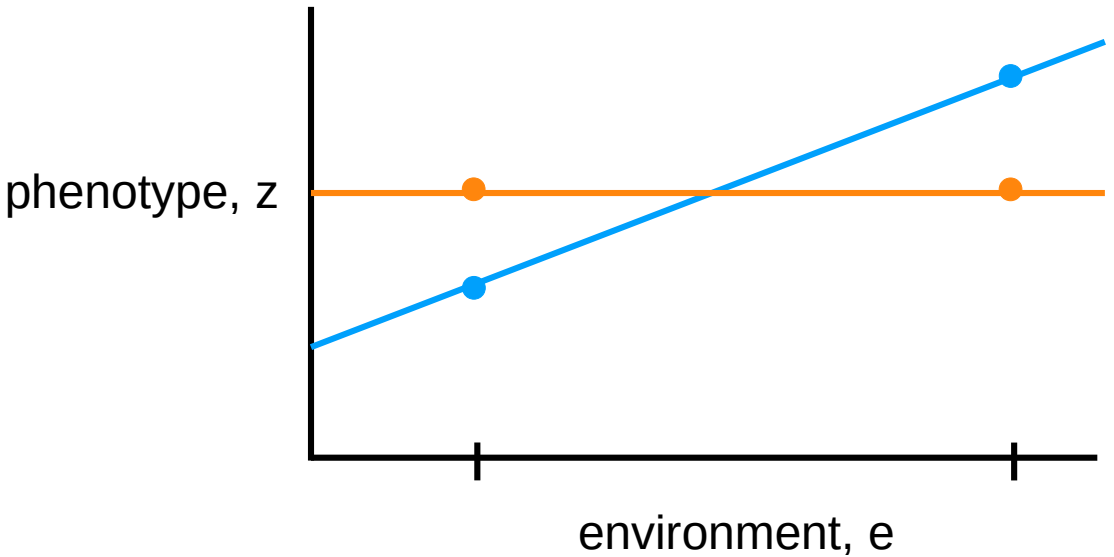
Fitness consequences of plasticity



→ maladaptive plasticity

often:
- passive (unavoidable) response
- in novel environments
- arises from genetic correlations

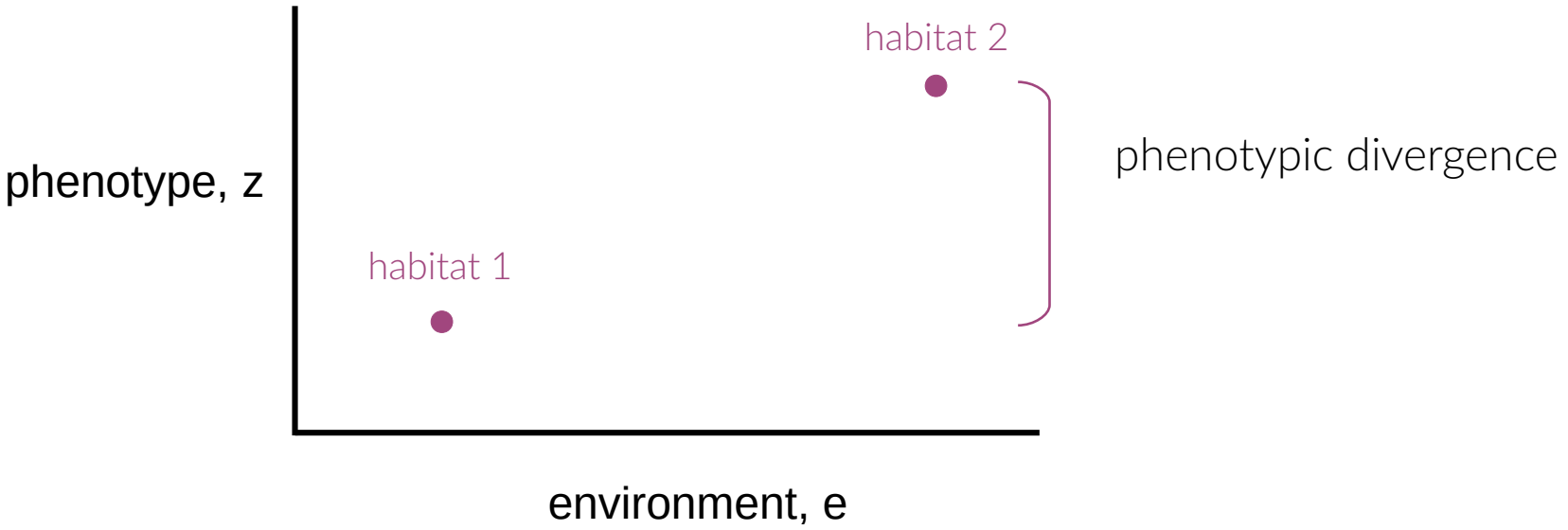
Fitness consequences of plasticity



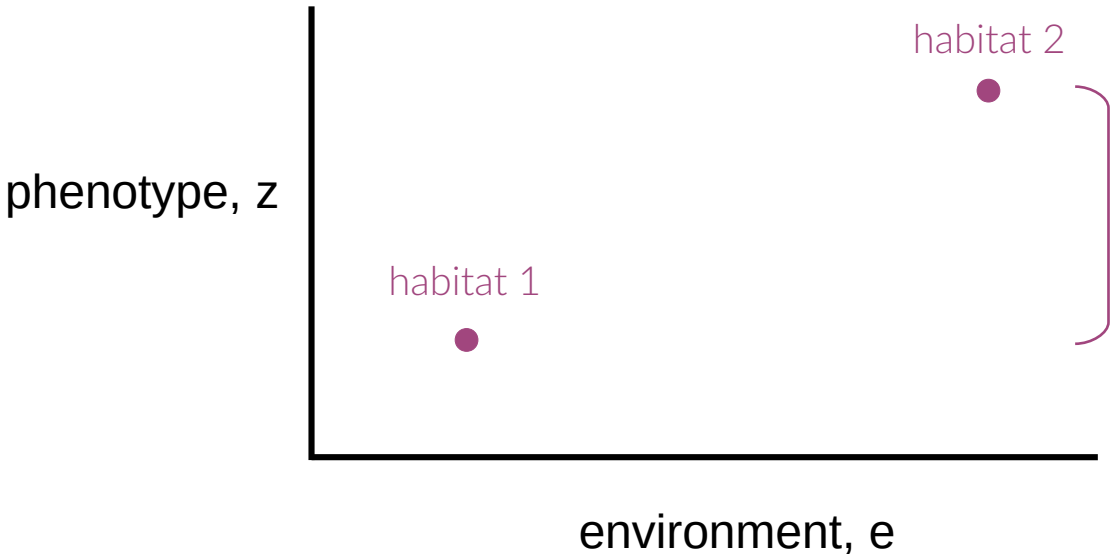
→ neutral
(non-adaptive)

No selection
→ no phenotypic optima

Plasticity: A “problem” for biologists



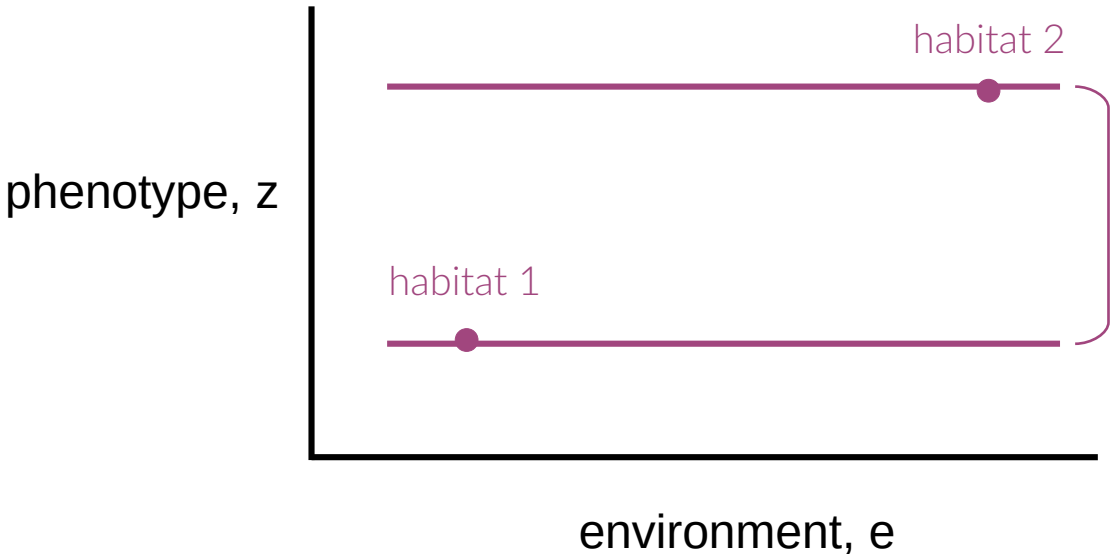
Plasticity: A “problem” for biologists



phenotypic divergence

→ what is the reason ?

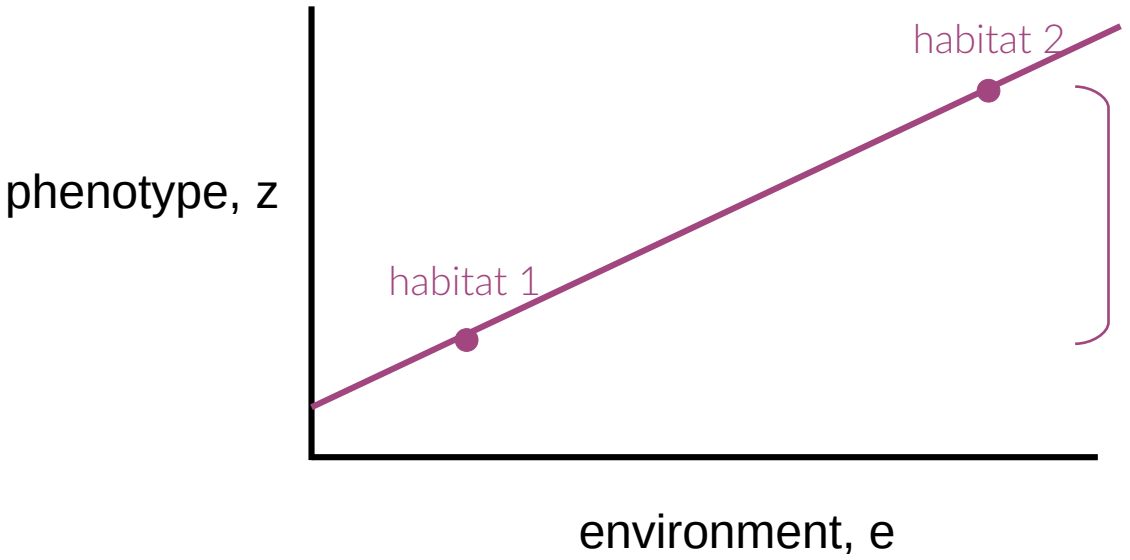
Plasticity: A “problem” for biologists



phenotypic divergence

1) genetic divergence ?

Plasticity: A “problem” for biologists



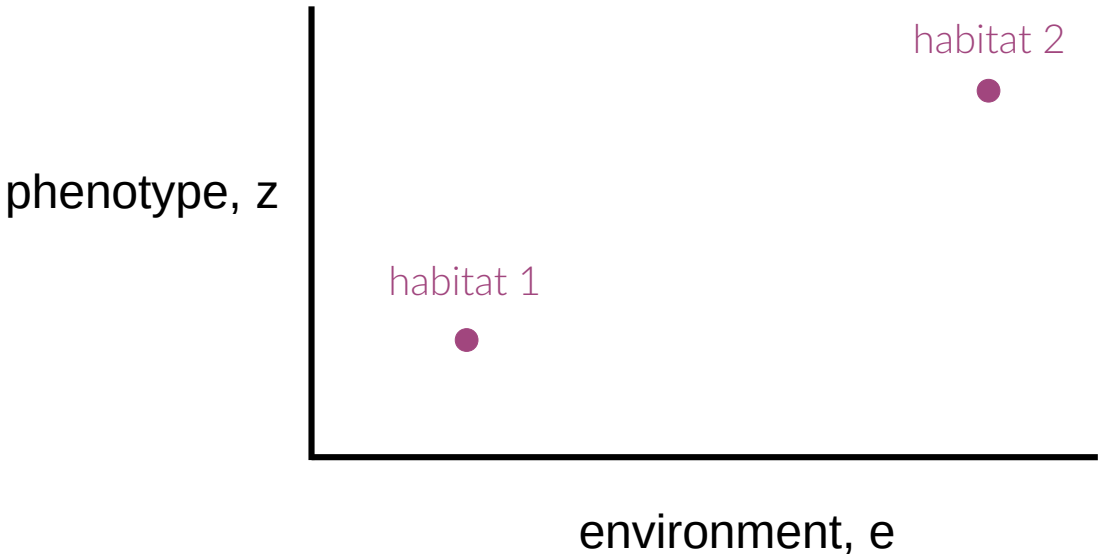
phenotypic divergence

1) genetic divergence ?

or

2) plastic divergence ?

Plasticity: A “problem” for biologists

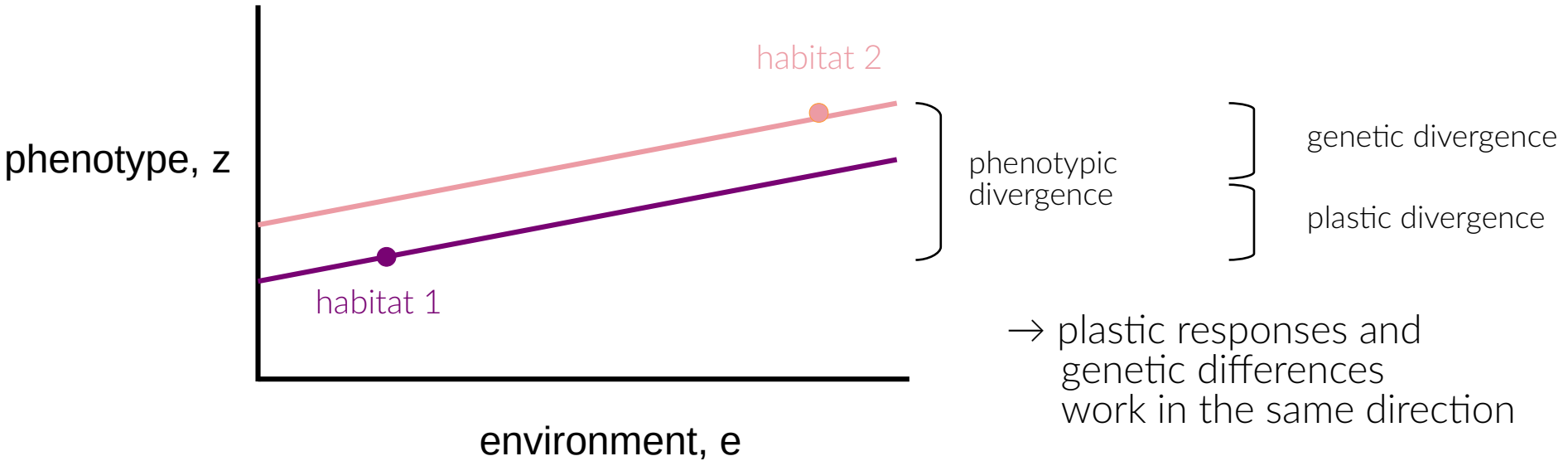


→ phenotypic plasticity blurs the link between genotype and phenotype

→ nature or nurture?

Plasticity: A “problem” for biologists

→ most often, they shape phenotype expression in concert



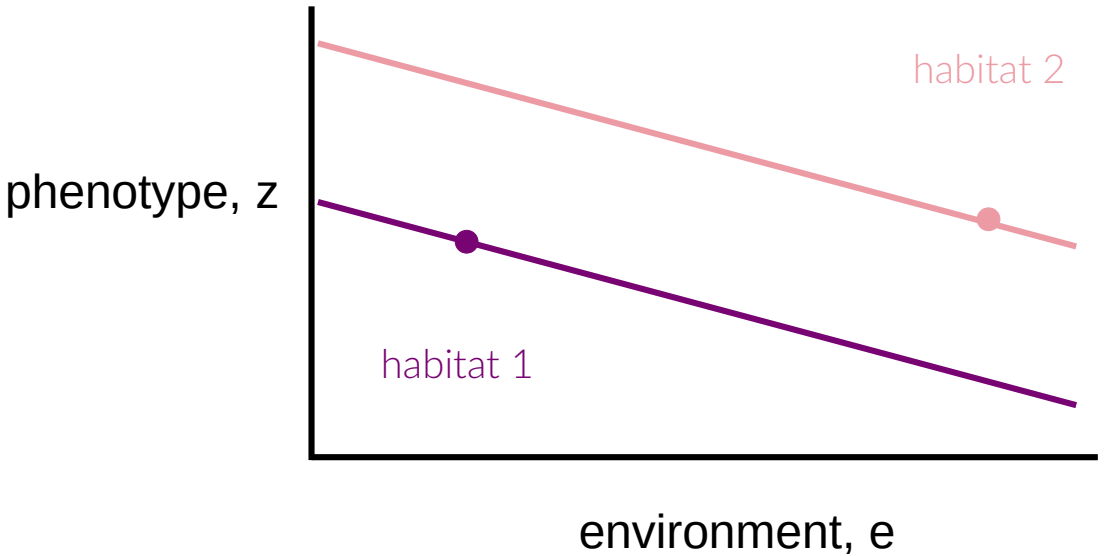
→ plastic responses and genetic differences work in the same direction

= *co-gradient variation*

Conover et al. (2009) Annals of the New York Academy of Sciences 1168: 100-129

Plasticity: A “problem” for biologists

→ most often, they shape phenotype expression in concert



phenotypic divergence

genetic divergence

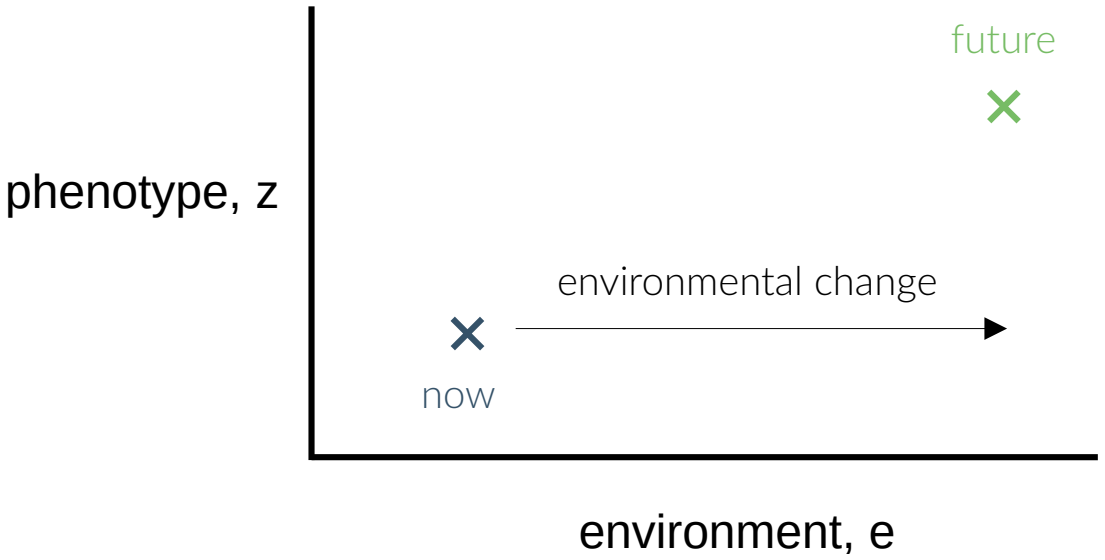
plastic divergence

→ plastic responses and genetic differences work in <u>opposite</u> direction

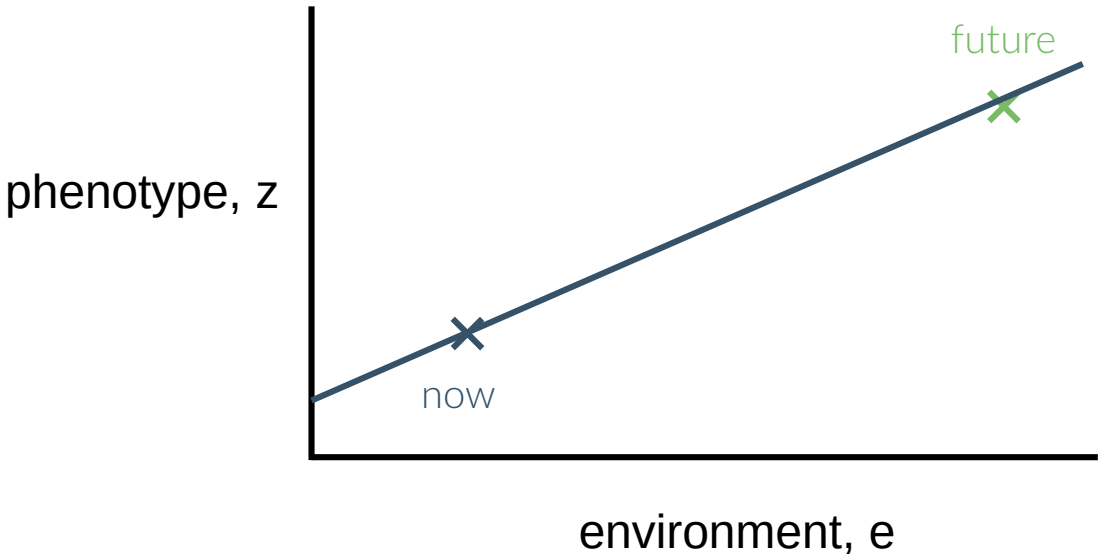
= *counter-gradient variation*

Conover et al. (2009) Annals of the New York Academy of Sciences 1168: 100-129

Plasticity feeds back on genetic evolution



Plasticity feeds back on genetic evolution



With (perfectly) adaptive plasticity genetic change is redundant.

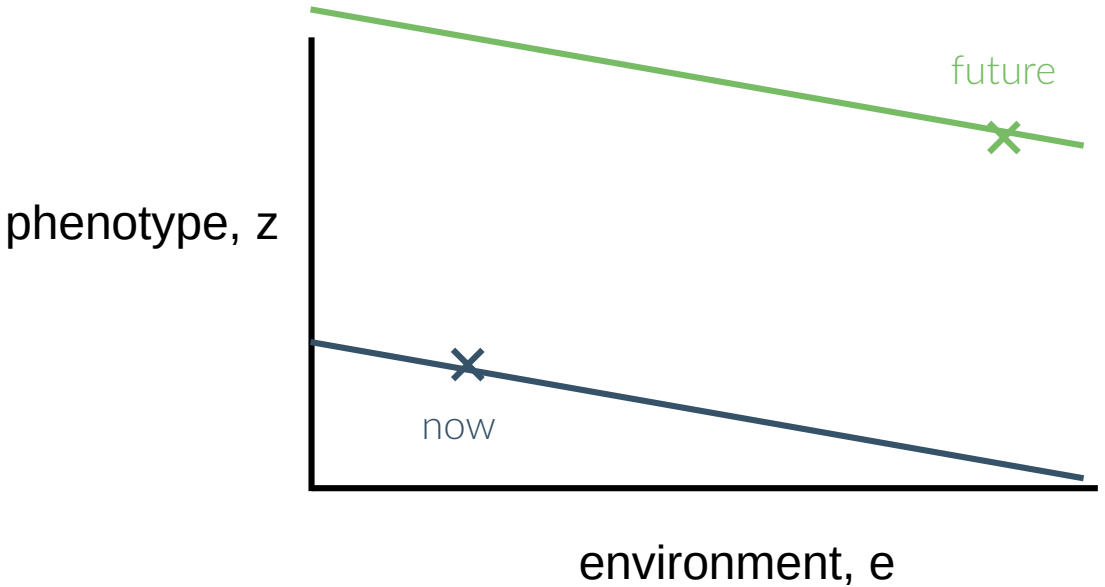
→ adaptive plasticity limits genetic adaptations

→ because they are alternative solutions to the same problem

Chevin et al. (2019), PLoS Biology 8:e1000357

Plasticity feeds back on genetic evolution

→ because they are alternative solutions to the same problem

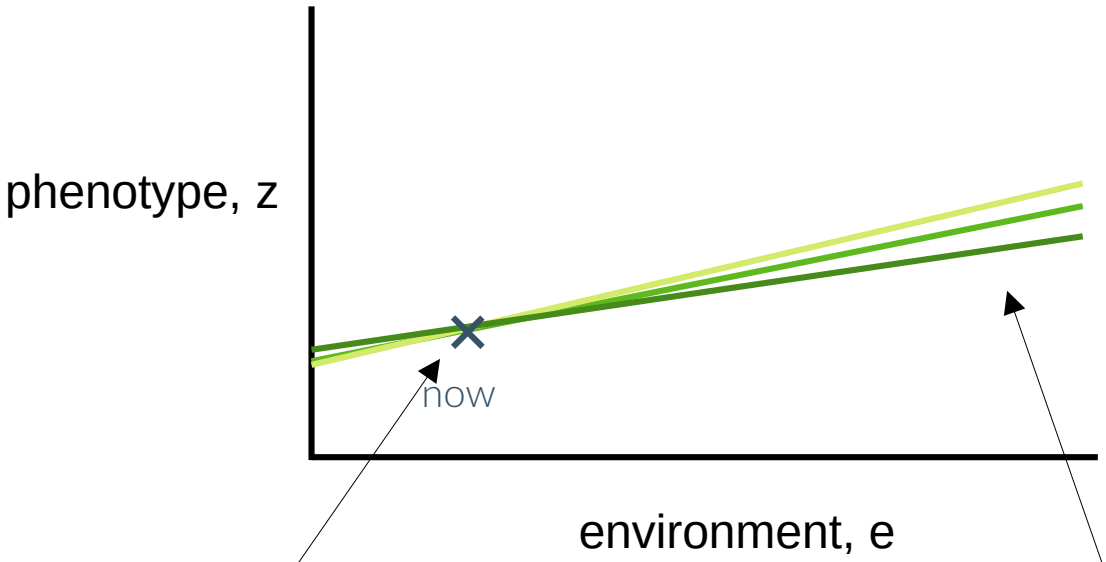


With maladaptive plasticity large genetic changes are necessary to adapt

→ genetic compensation

Ghalambor et al. (2015), Nature 525: 372-375
Koch & Guillaume (2020), Molecular Ecology 29: 3938–3953

Phenotypic plasticity can evolve



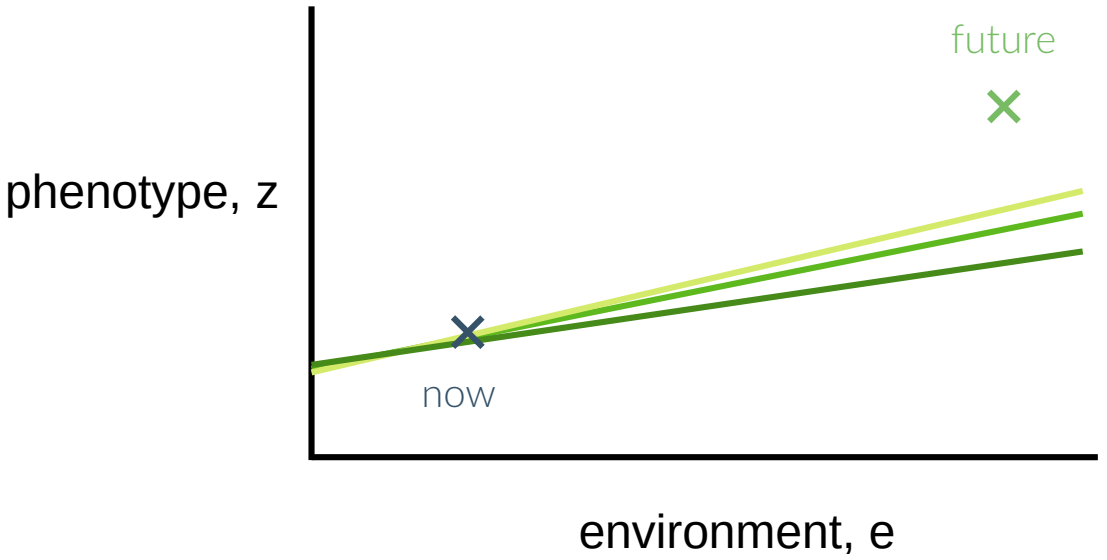
Genetic variance in plasticity (GxE interaction)

= precondition for evolution of plasticity

Small phenotypic variance in mean environment (*canalization*) from stabilizing selection

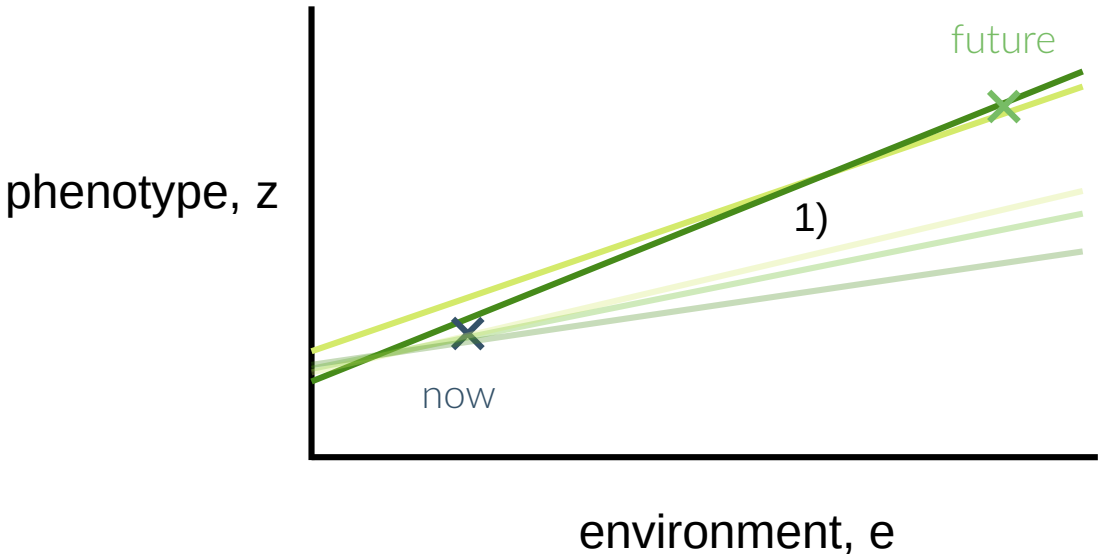
… but large (*cryptic) variation* under novel conditions

Phenotypic plasticity can evolve



Plasticity evolution occurs in 2 steps:

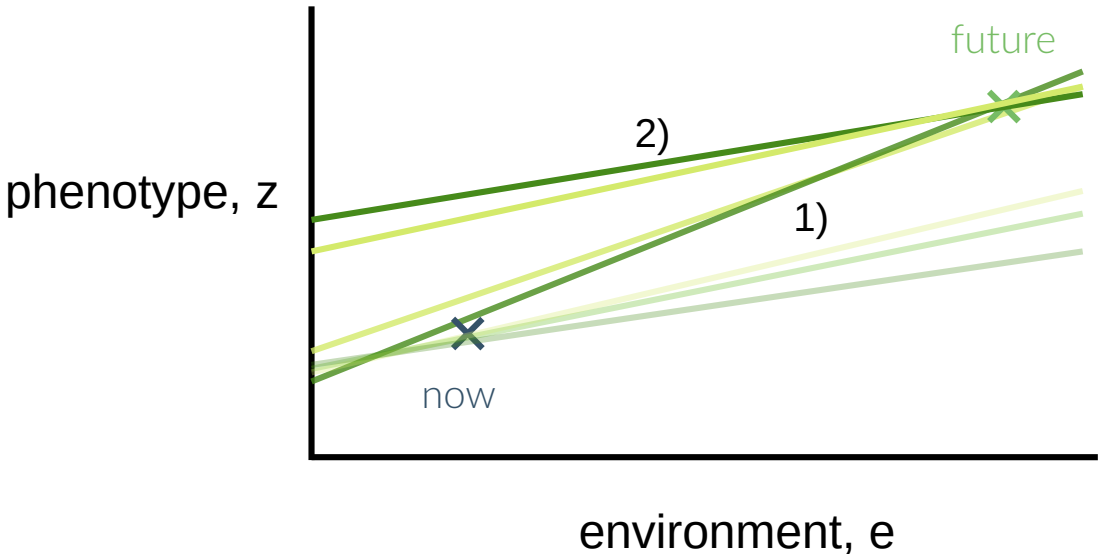
Phenotypic plasticity can evolve



Plasticity evolution occurs in 2 steps:

1) evolution of larger plasticity

Phenotypic plasticity can evolve

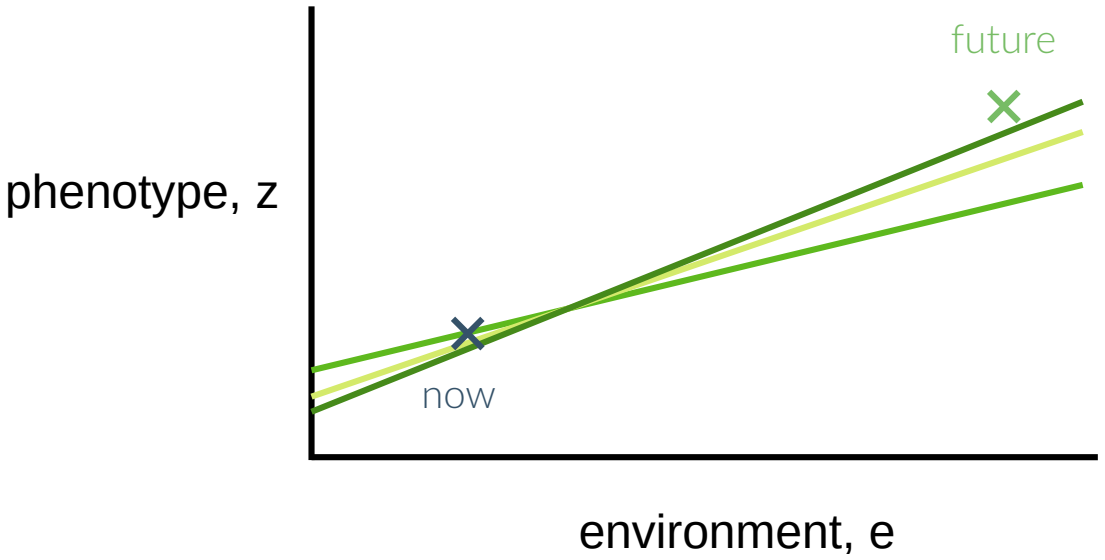


Plasticity evolution occurs in 2 steps:

1) evolution of larger plasticity

2) genetic assimilation
(return to smaller plasticity)

Phenotypic plasticity can evolve



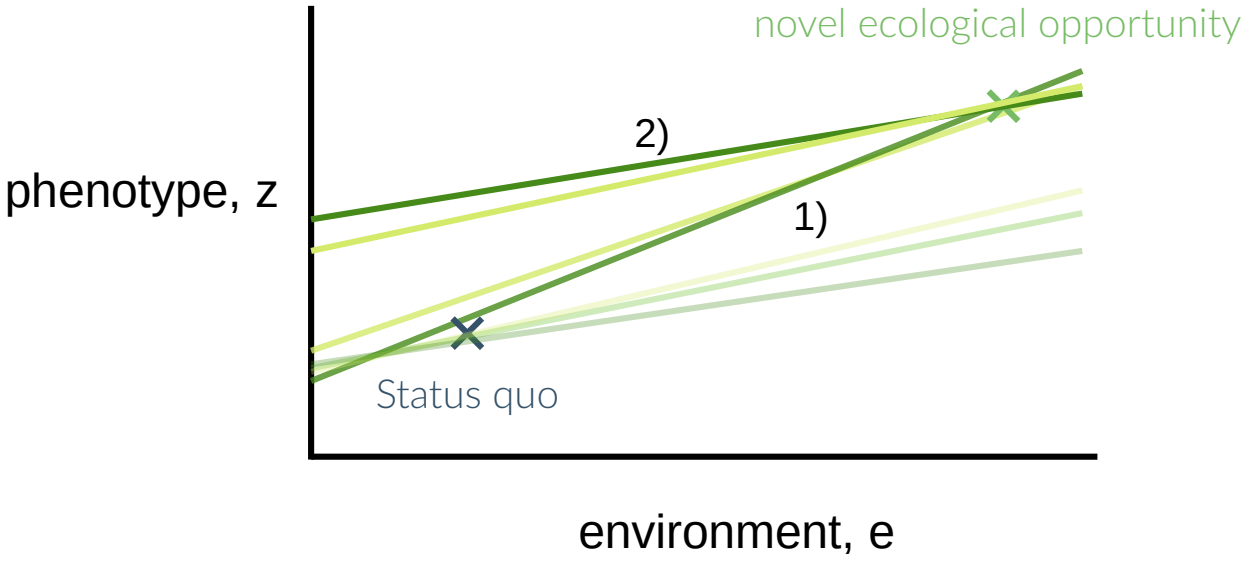
But ...

plasticity rarely evolves
to be perfect
because of

- costs of plasticity
- limited cue reliability
- time lag in phenotypic response
- ...

DeWitt et al. (1998), TREE 13: 77-81

Phenotypic plasticity can evolve



→ Plasticity might benefit genetic diversity and speciation

"*genes are probably more often followers than leaders in evolutionary change*"

(Mary Jane West-Eberhard)

West-Eberhard (2005), PNAS 102: 6543-6549

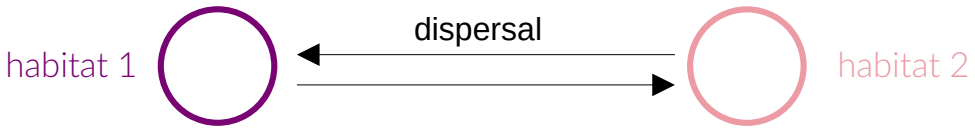
Exercise

Exercise: The evolution of local adaptation in face of phenotypic plasticity

Largely following
Schmid & Guillaume (2017), Heredity 119: 214–225

You could also check out a shiny app:
https://maxschmid.shinyapps.io/plasticityandpopulationdifferentiation/

Exercise: The evolution of local adaptation in face of phenotypic plasticity



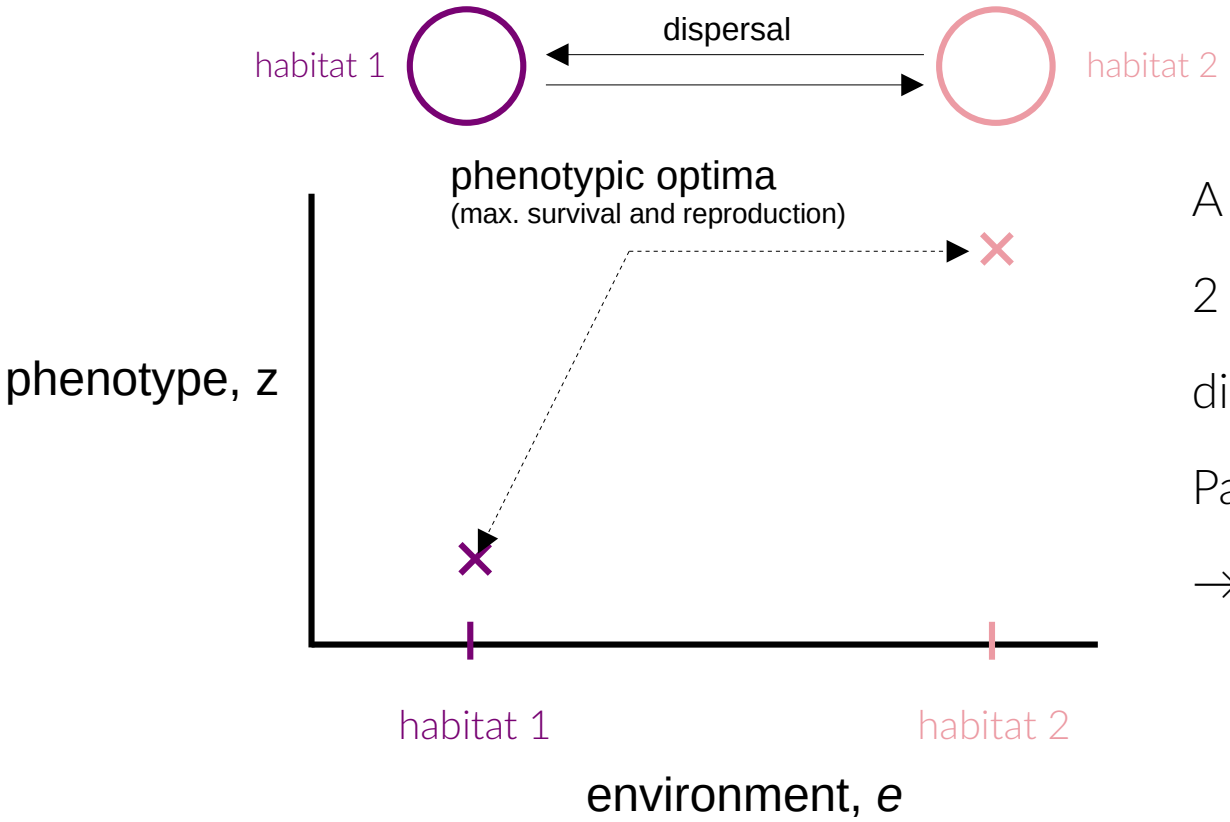
A single species

2 patches

dispersal between patches

Patches differ in environmental factor

Exercise: The evolution of local adaptation in face of phenotypic plasticity



A single species

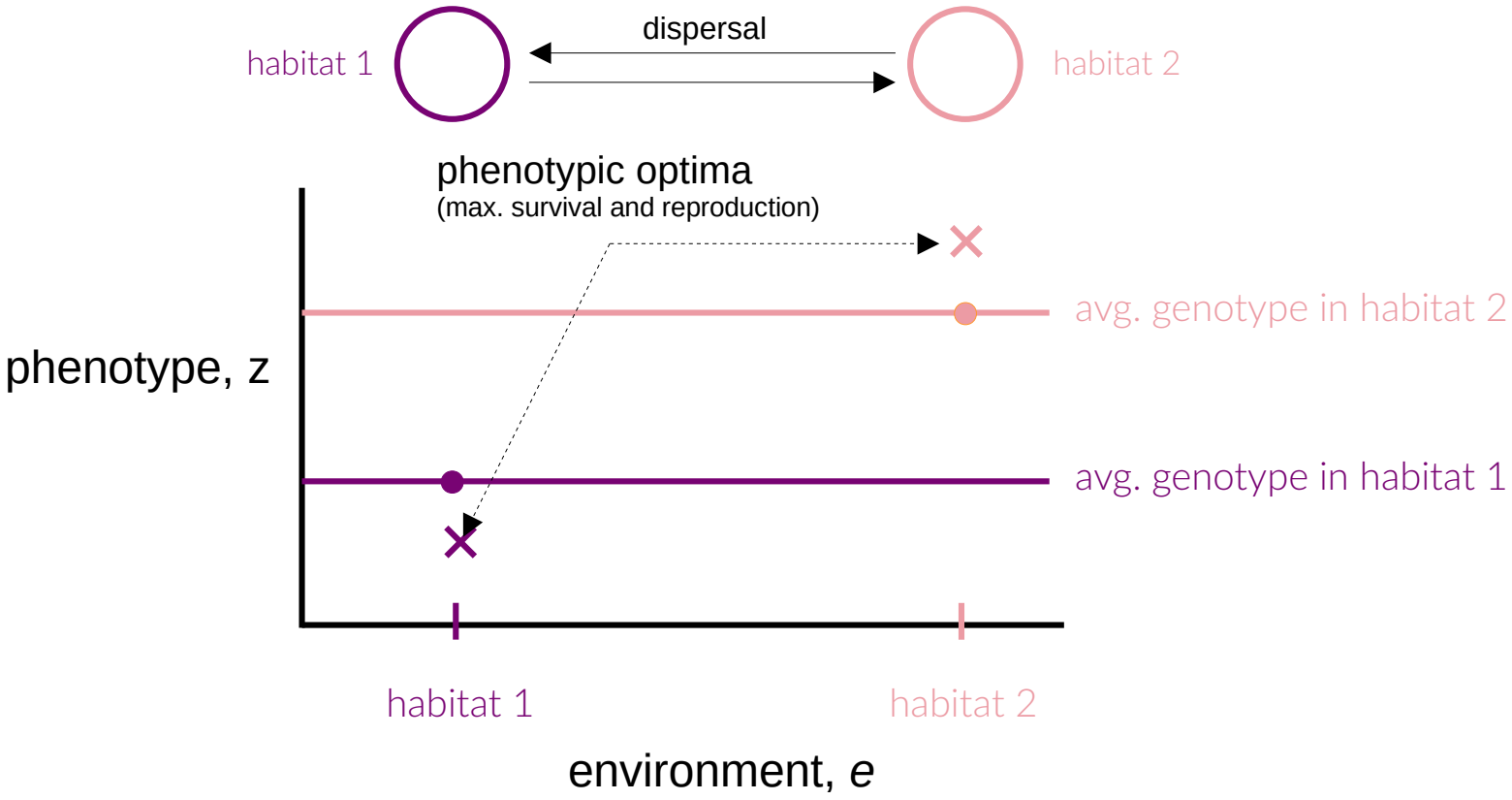
2 patches

dispersal between patches

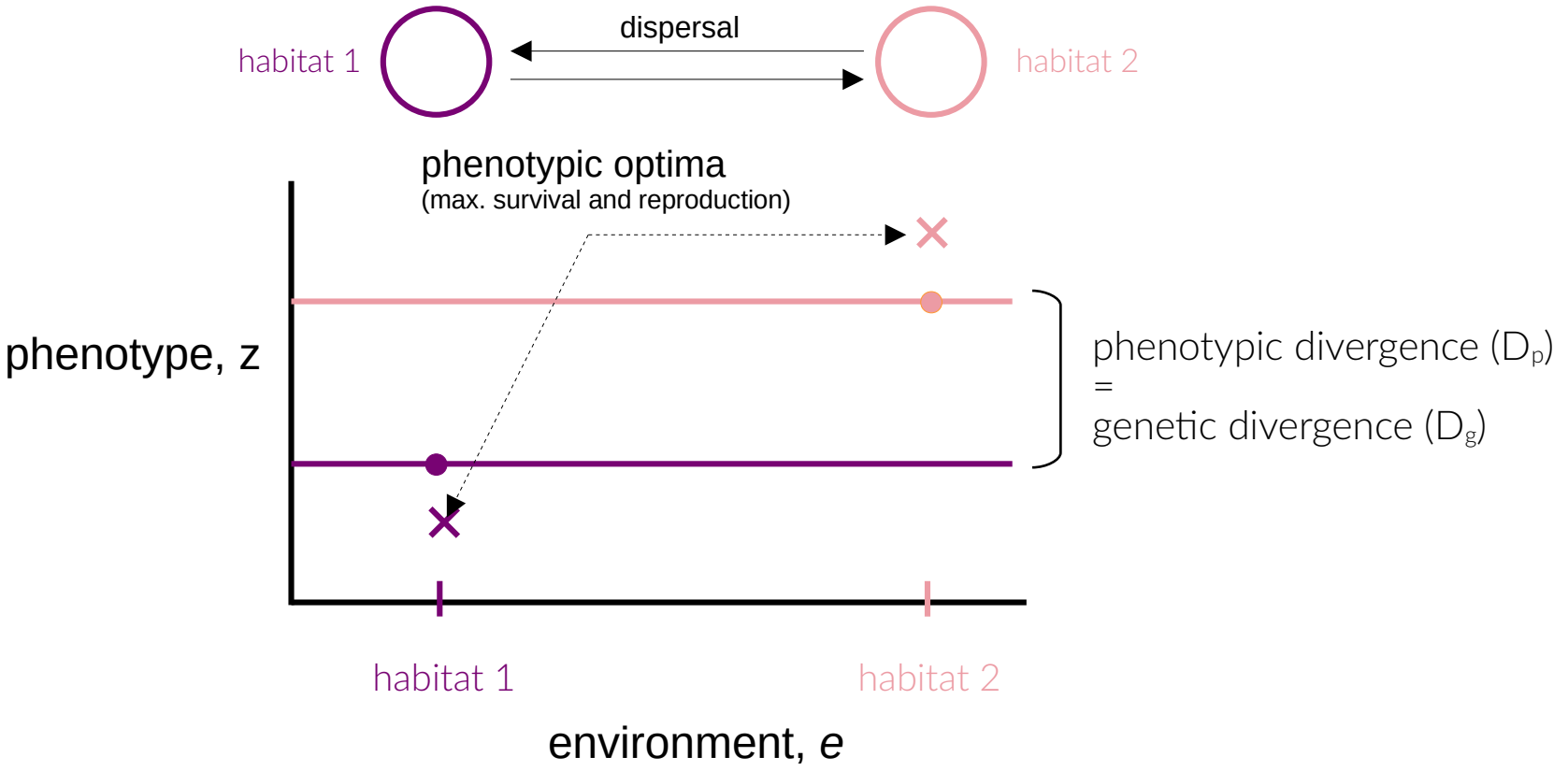
Patches differ in environmental factor

→ divergent selection
(favoring phenotypic divergence)

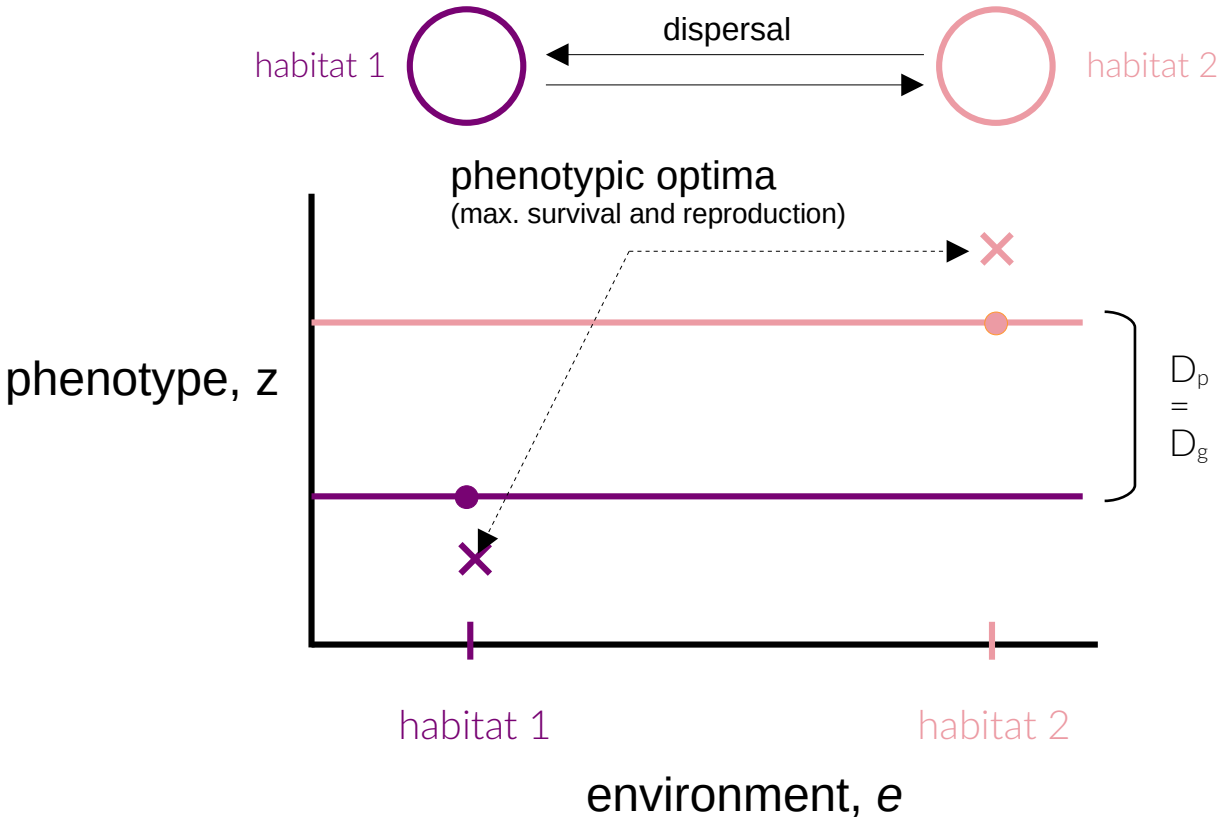
Exercise: The evolution of local adaptation in face of phenotypic plasticity



Exercise: The evolution of local adaptation in face of phenotypic plasticity



Exercise: The evolution of local adaptation in face of phenotypic plasticity

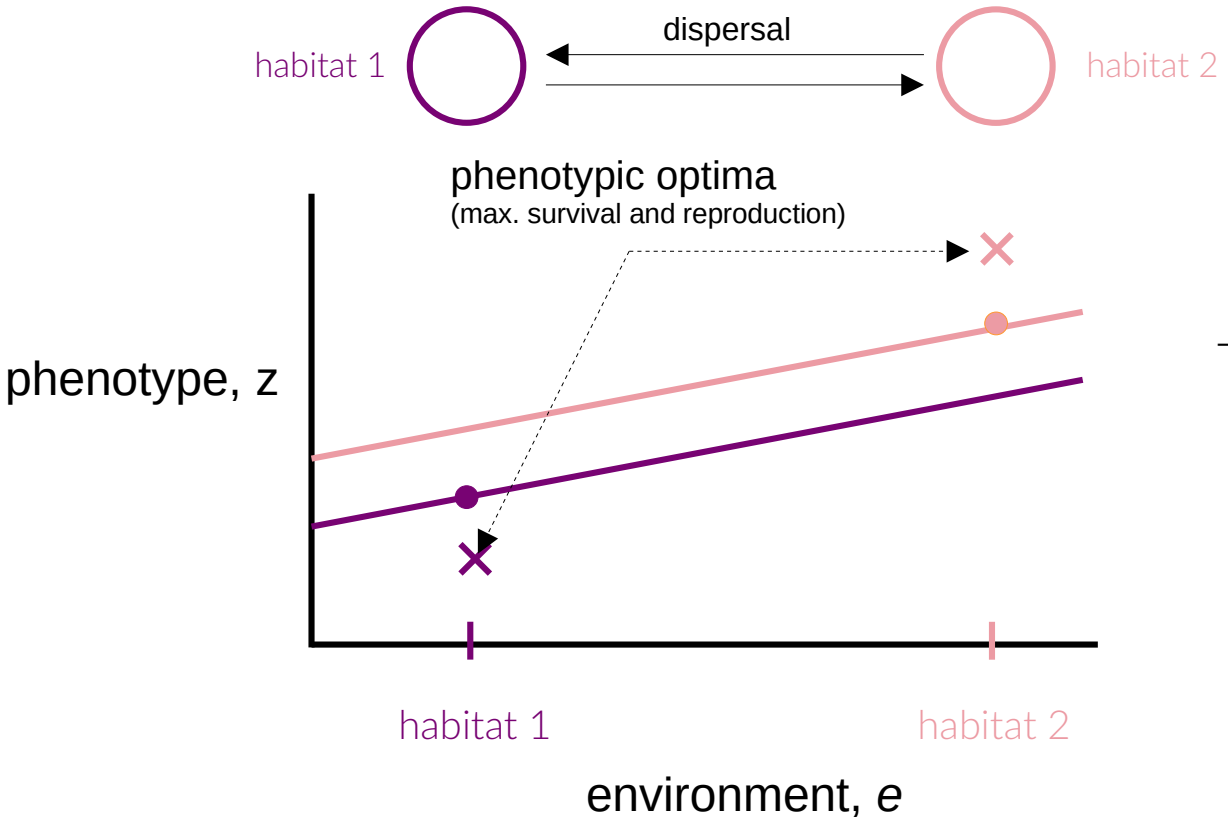


Local adaptation
(= genetic divergence)

declines with
- dispersal
- selection strength
- ...

→ varies with the balance between gene flow and selection

Exercise: The evolution of local adaptation in face of phenotypic plasticity



→ What is the effect of phenotypic plasticity?