The evolution of conditional dispersal under different life cycles

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in collaboration with Florence Débarre

October 2017 – Toulouse

Ecology and evolutionary biology, deterministic and stochastic models

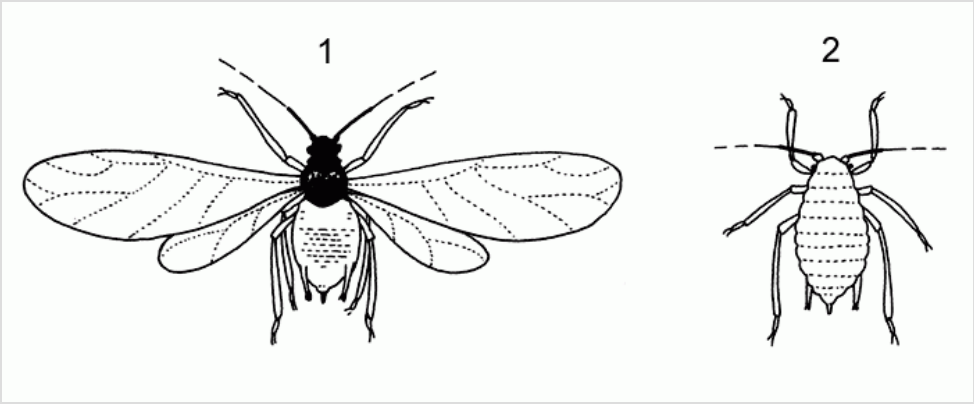
What is dispersal?

Dispersal =

- Any movement of individuals or propagules contributing to gene flow
- Reproducing away from birth place

- (zool.) movement between successive breeding sites
- (bota.) movement of seeds or pollen

Variability of dispersal *in natura*



Koppert

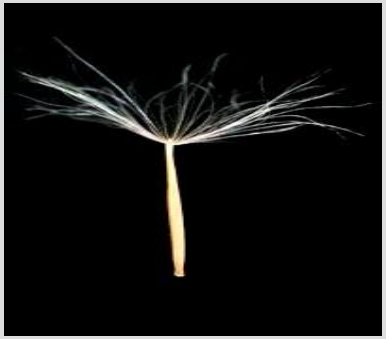


Photo : P. Goujon

Photo : S. Amn

Heritability of dispersal

Heredity (2008) 100, 39–46

www.nature.com/hdy

ORIGINAL ARTICLE

Heritability of dispersal rate and other life history traits in the Glanville fritillary butterfly

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JOURNAL OF Evolutionary Biology
eseb European Society for Evolutionary Biology
doi: 10.1111/j.1420-9101.2011.02281.x

Heritability of short-scale natal dispersal in a large-scale foraging bird, the wandering albatross

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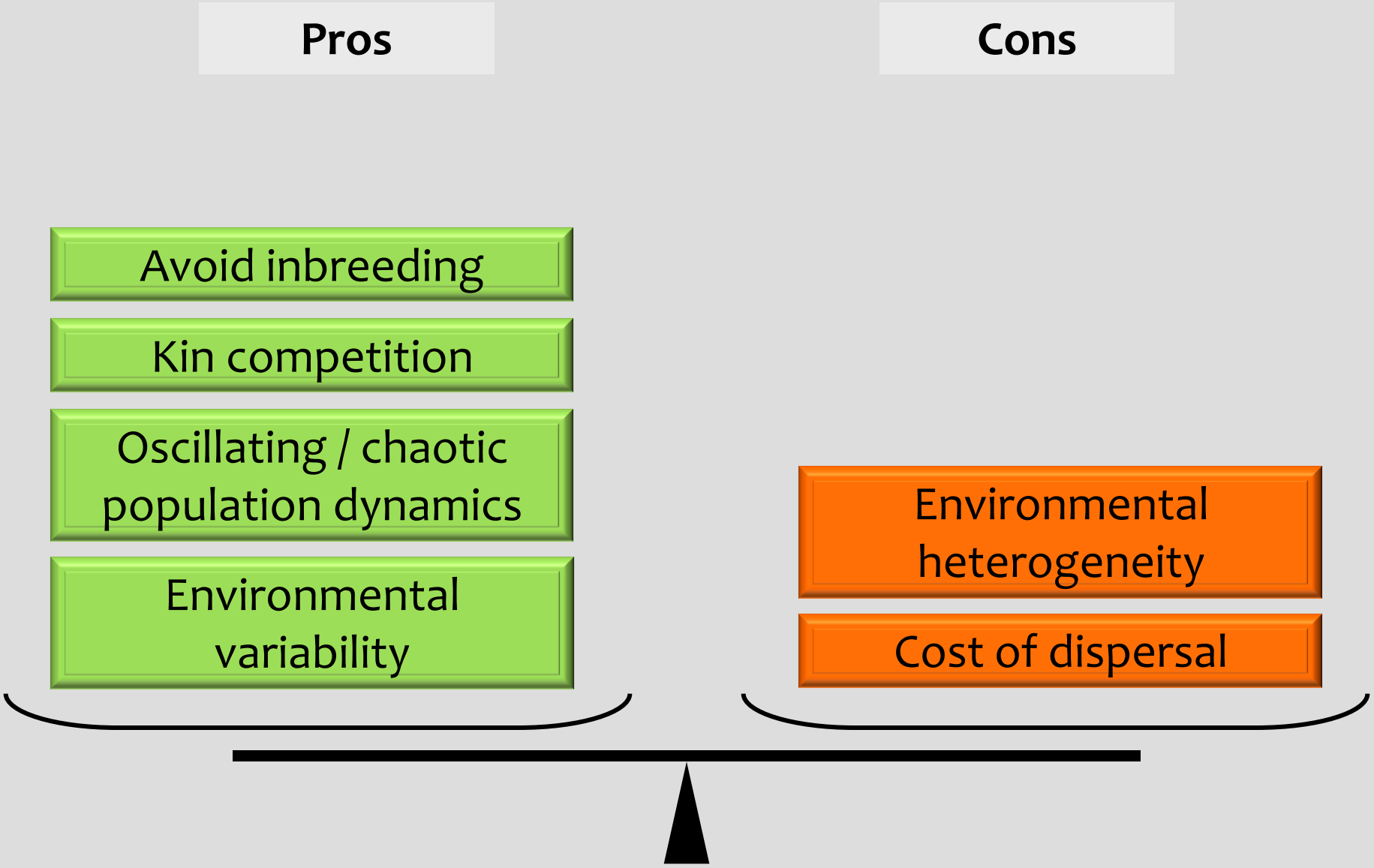
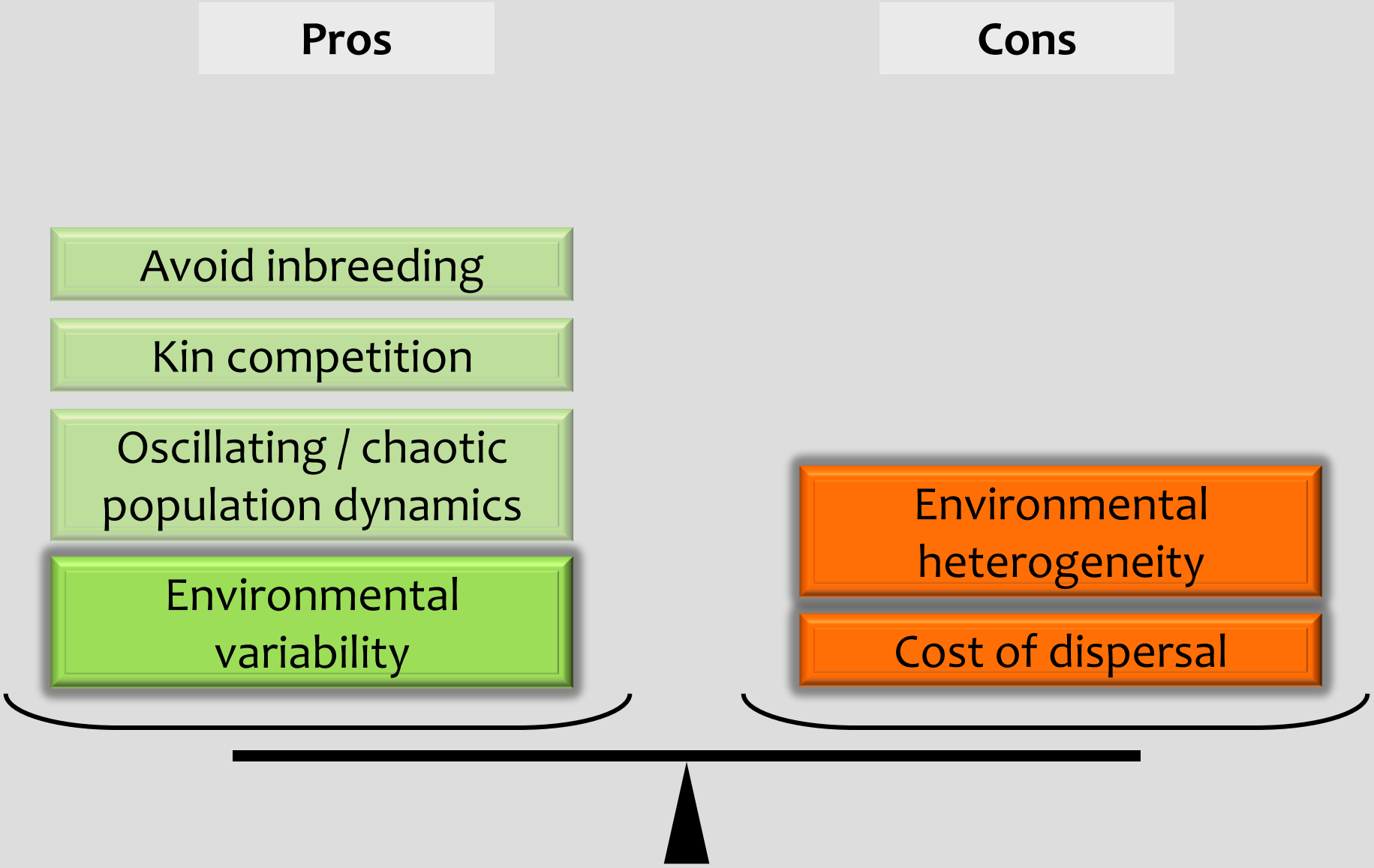
Selective pressures on dispersal



Selective pressures on dispersal



Heterogeneity and variability

- Environments are temporally variable

  organisms experience temporally variable habitats

  geometric average -> sensitivity to "lows"

  selects for more dispersal

- Environments are spatially heterogeneous

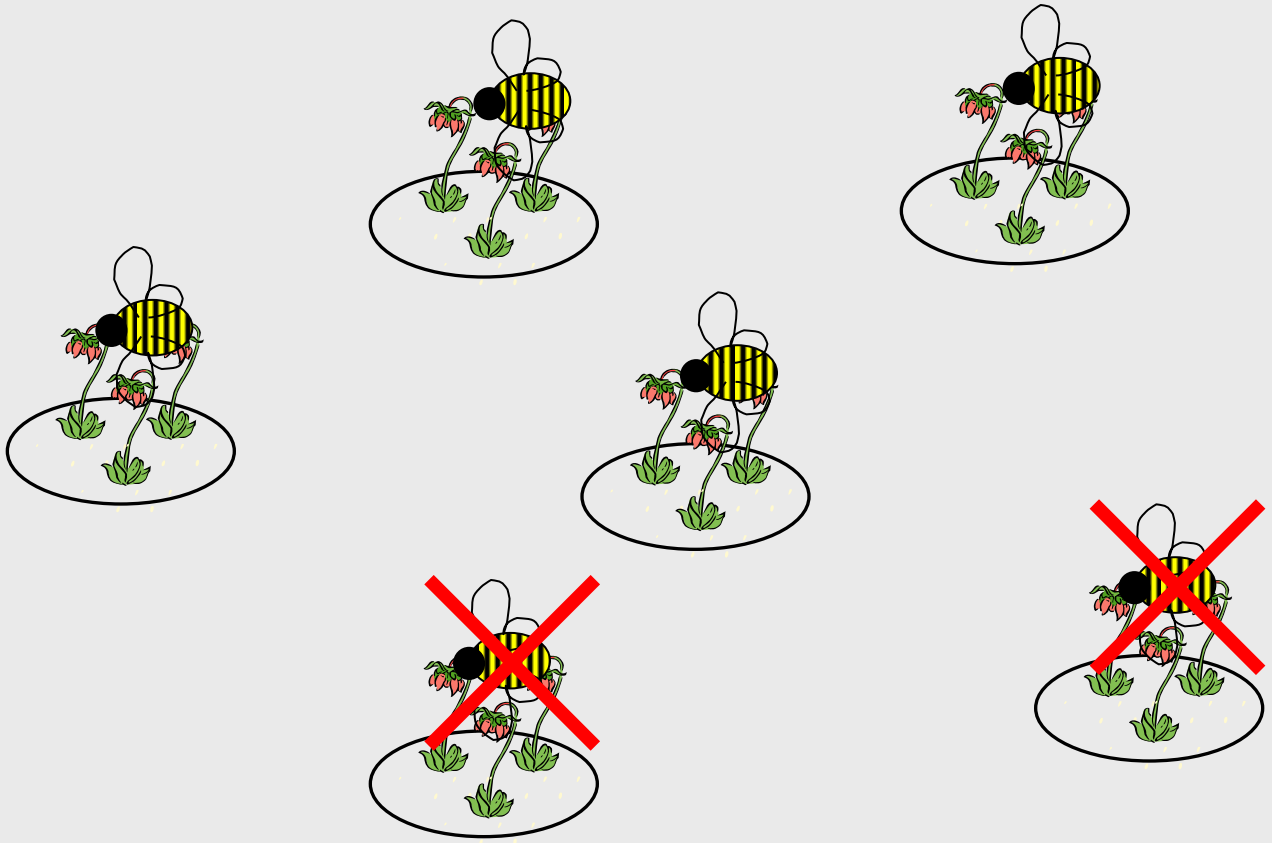
  dispersing allows for different habitats among siblings

  dispersal bias from good to bad habitats

  selects for less dispersal

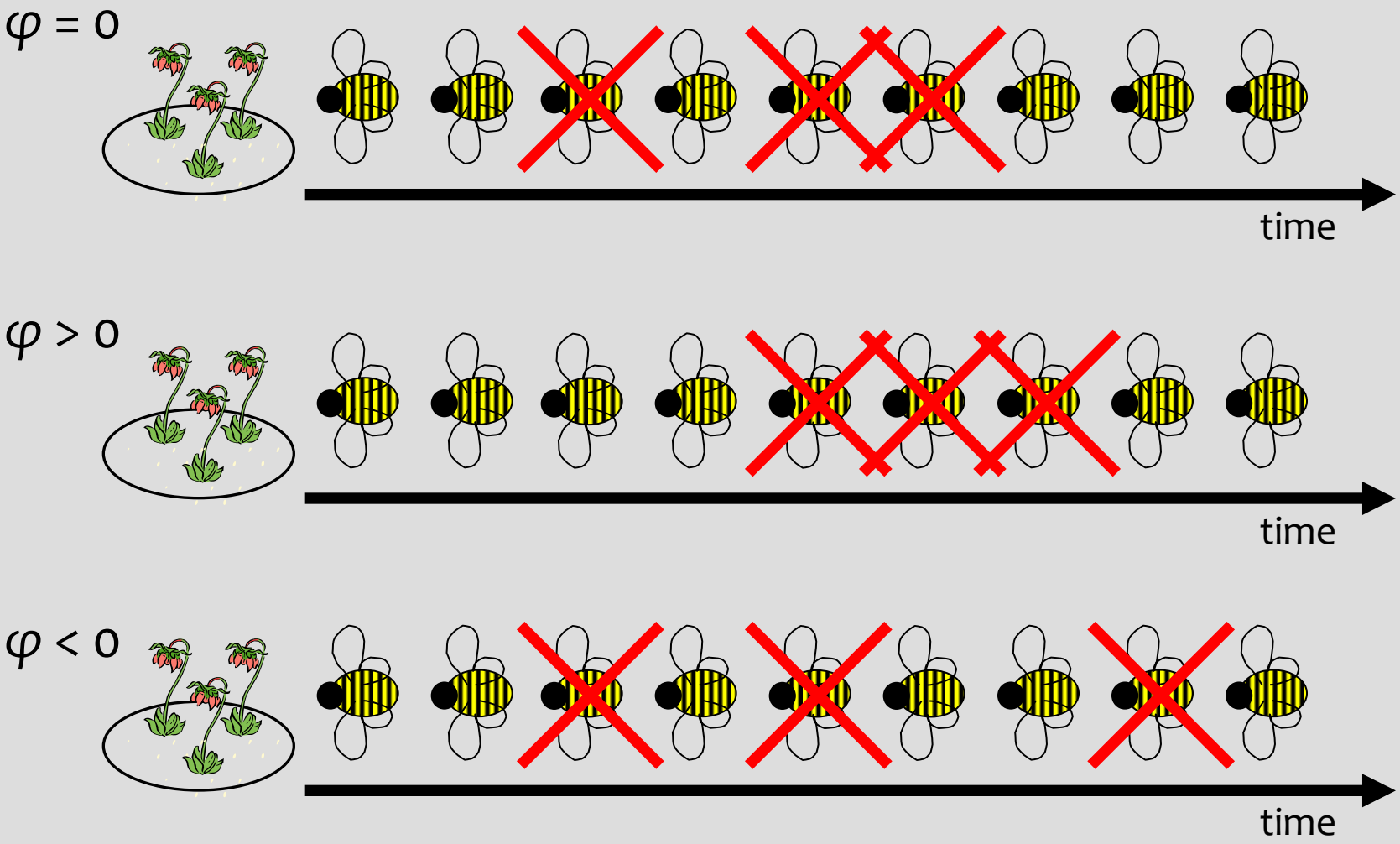
Measuring heterogeneity

First-order measure: proportion of type 1 patch, ρ



Measuring variability

temporal autocorrelation in patch state, φ



Questions / Outline

1. How can we model the evolution of dispersal in uncertain heterogeneous environments?

2. What happens when dispersal is informed by patch quality?

Adaptive dynamics

Assumptions:

– phenotypic gambit

"The phenotypic gambit is to examine the evolutionary basis of a character as if the very simplest genetic system controlled it: as if there were a haploid locus at which each distinct strategy was represented by a distinct allele, as if the payoff rule gave the number of offspring for each allele, and as if enough mutation occurred to allow each strategy the chance to invade." A. Grafen, *in* Krebs & Davies 1984

– rare mutations of small effects

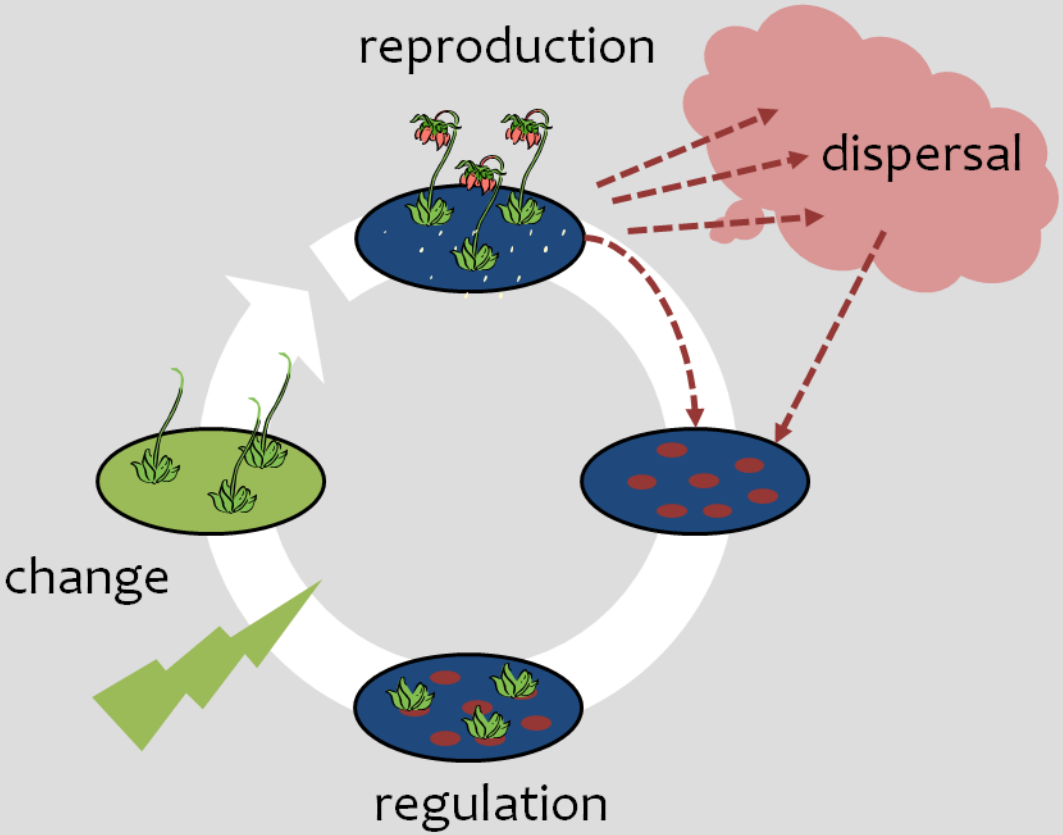
Tools:

– expression for fitness (using matrices)

– selection gradient → convergence stability

– Hessian of mutant fitness → evolutionary stability

How does environmental state change?



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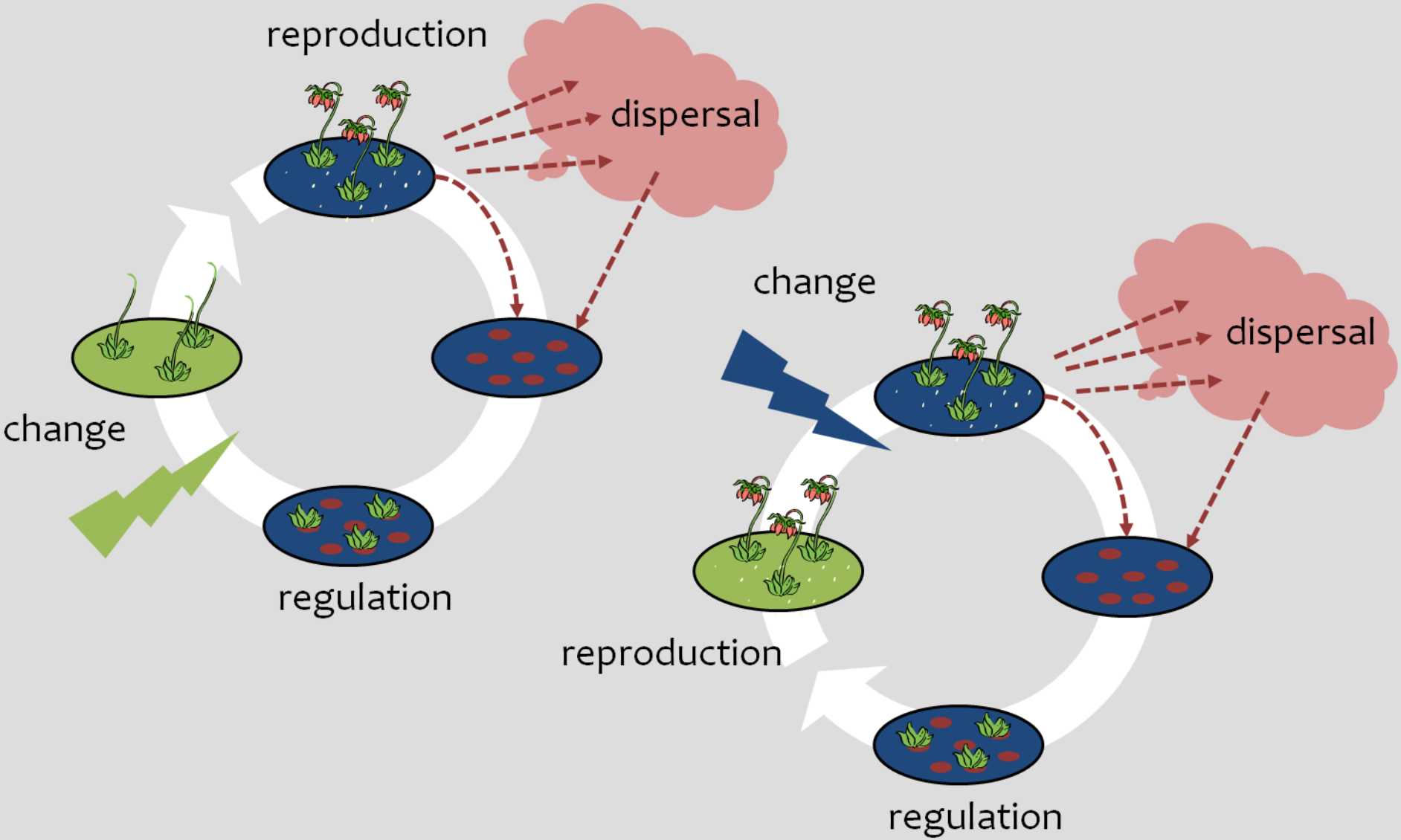
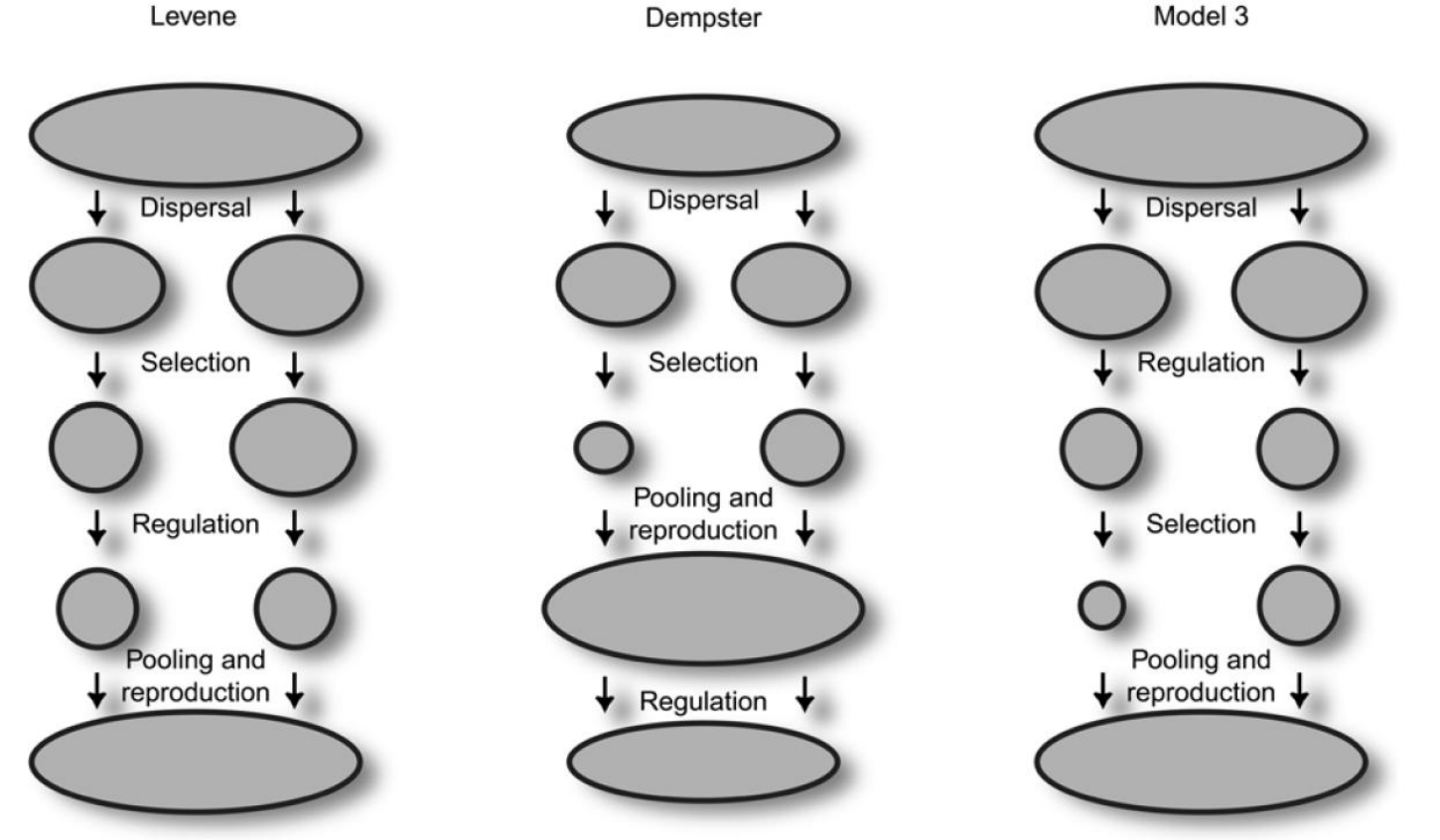


Life cycles

Looking at the evolution of local adaptation…



Ravigné *et al.*, 2004

Life cycles

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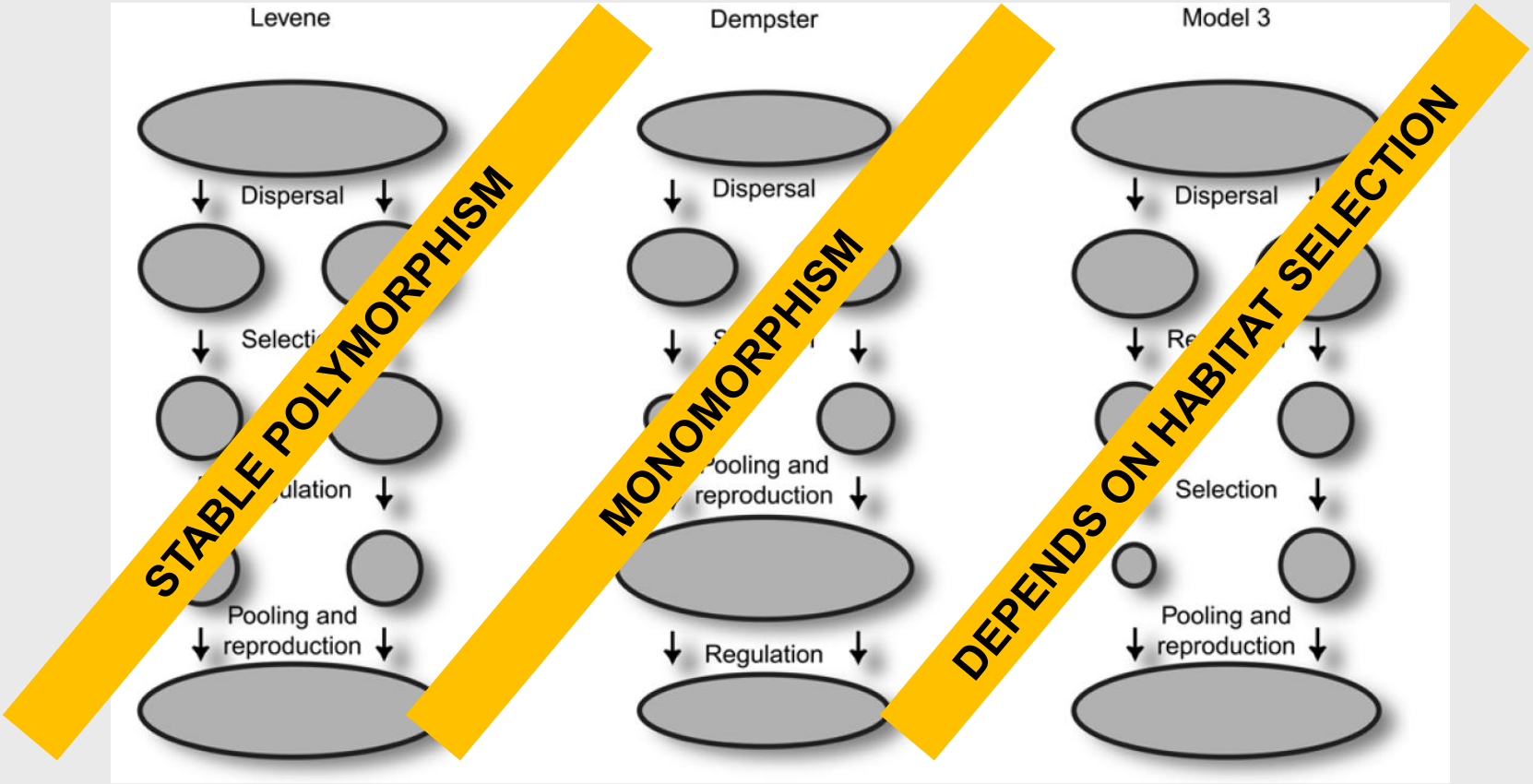


Ravigné *et al.*, 2004

A general model

Massol (2013)

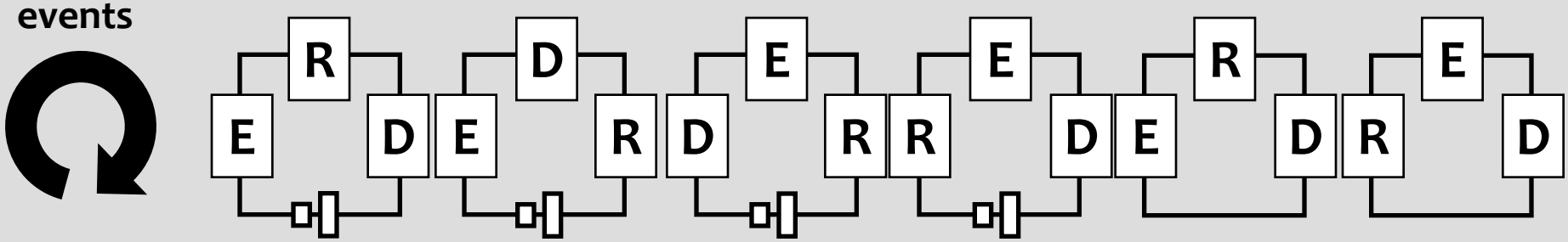
Ingredients:

- 2 patch types (1 & 2; affect fecundity through f_1 and f_2), infinity of patches
- 4 life cycle events: reproduction, dispersal, regulation & environmental change
- discrete, non-overlapping generations
- reproduction: result of local adaptation, not limiting
- regulation: local (but large populations)
- dispersal: global (no limitation by distance)

Classification of life cycles

extended from Massol (2013)

Order of events



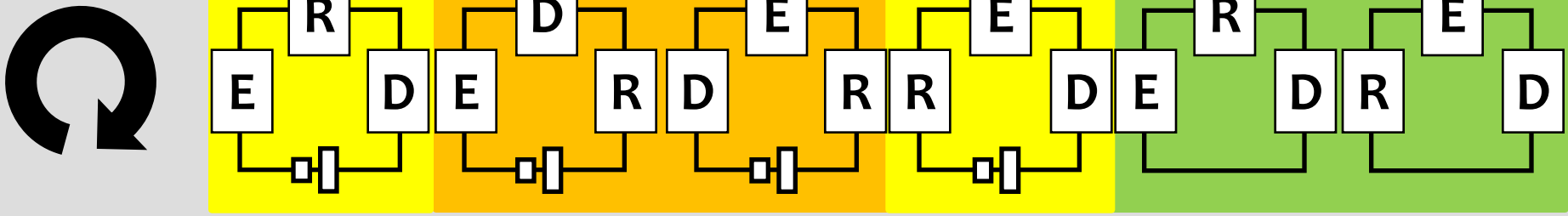
Ravigné *et al.*'s classification	***Ravigné type 3***	***Levene soft selection regime***	***Ravigné type 3***	***Dempster hard selection regime***
Modelling complexity	***Simple life cycles***	***Complex life cycles***		***Simple life cycles***

Classification of life cycles

extended from Massol (2013)

When dispersal is unconditional

Order of events



Ravigné *et al.*'s classification	***Ravigné* type 3**	***Levene* soft selection regime**	***Ravigné* type 3**	***Dempster* hard selection regime**

Classes of equivalence for fitness correspond to Ravigné *et al.*'s

Mathematical justification:

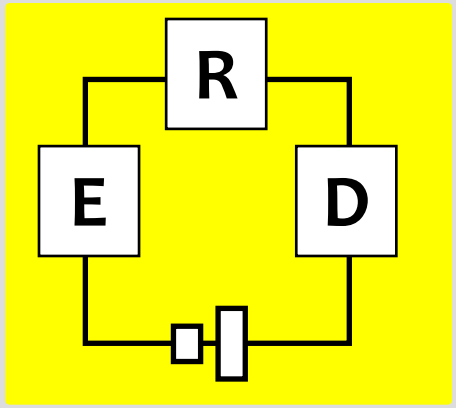
- **E** always commutes with regulation.
- With unconditional dispersal, **E** also commutes with dispersal.

Evolution of dispersal

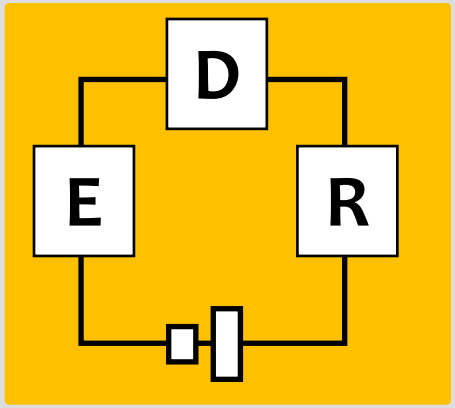
Massol & Débarre (2015)

Order of events

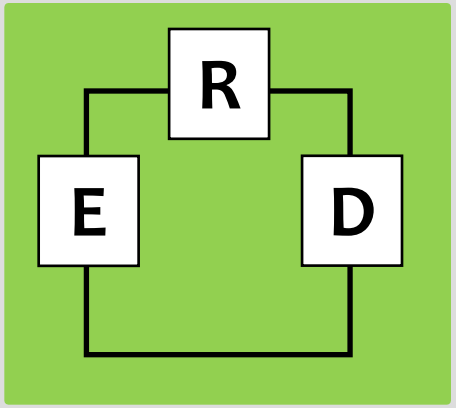
Ravigné *et al.*'s classification



Ravigné



Levene

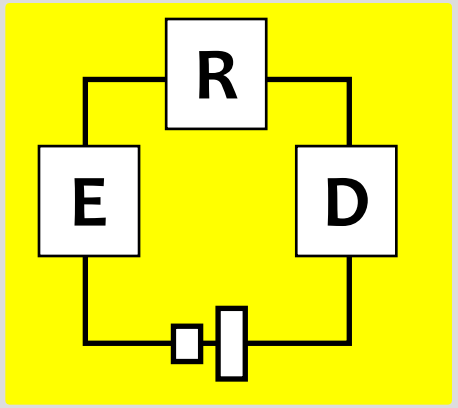


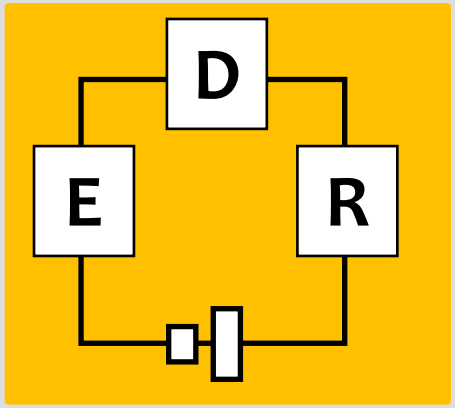
Dempster

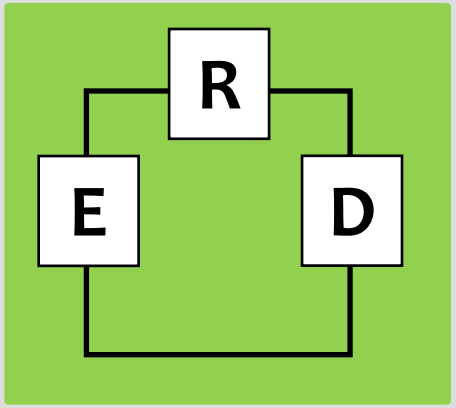
Evolution of dispersal

Massol & Débarre (2015)

Order of events







Ravigné *et al.*'s classification

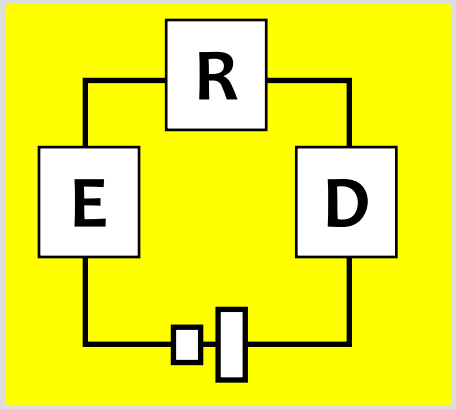
Ravigné | *Levene* | *Dempster*

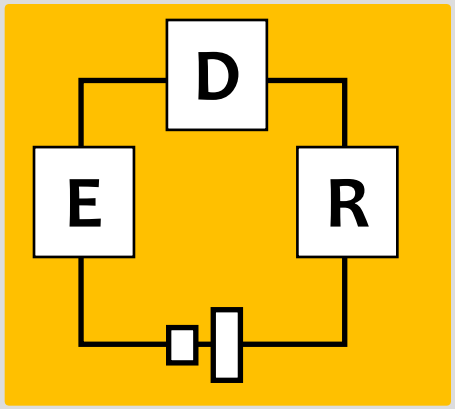
evolution towards philopatry

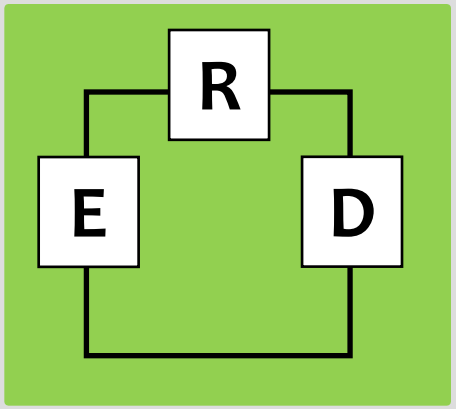
Evolution of dispersal

Massol & Débarre (2015)

Order of events

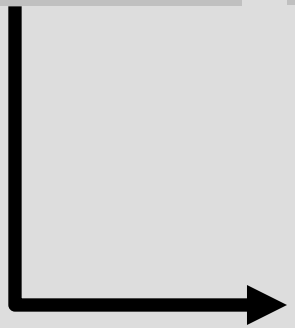


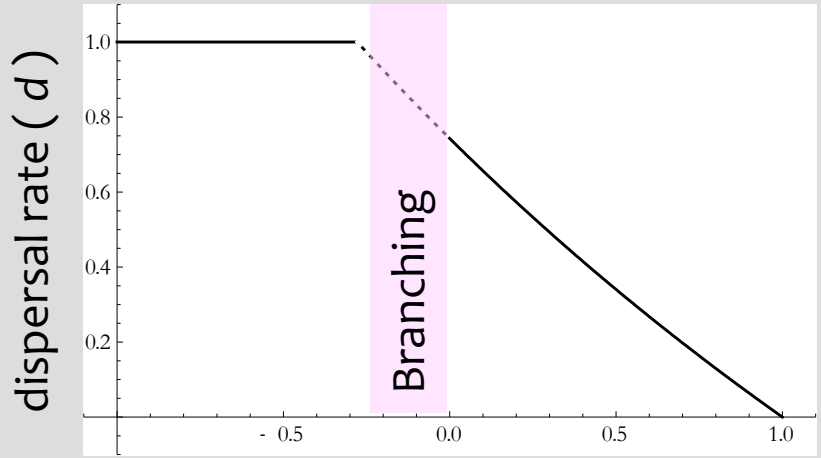




Ravigné *et al.*'s classification

Ravigné | ***Levene*** | ***Dempster***

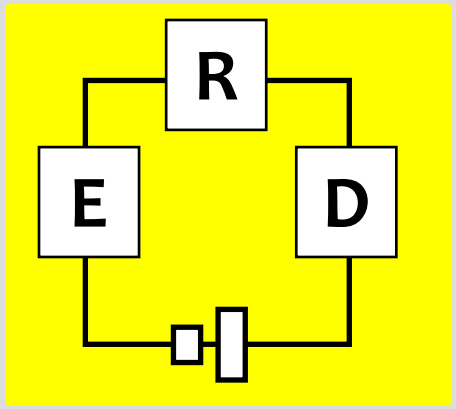


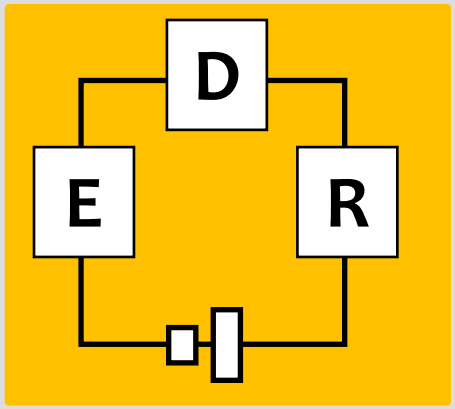


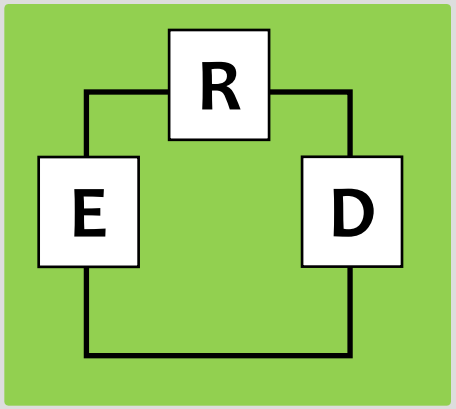
Evolution of dispersal

Massol & Débarre (2015)

Order of events

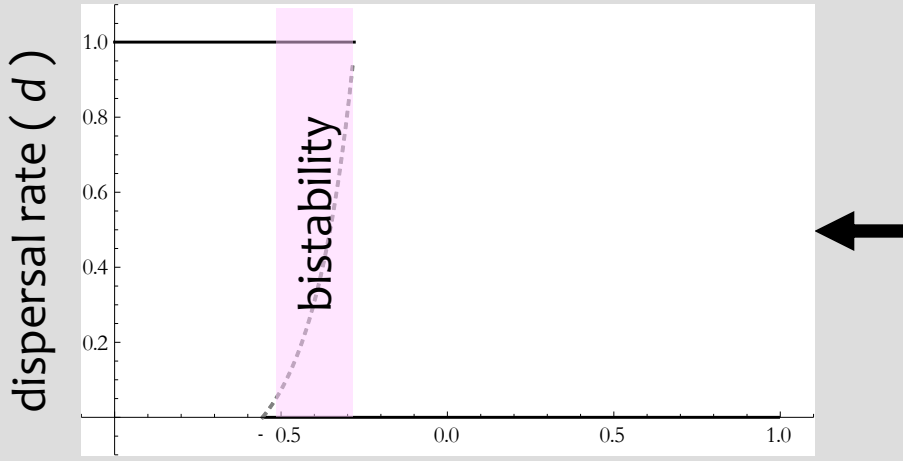






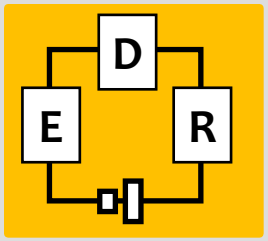
Ravigné *et al.*'s classification

Ravigné | ***Levene*** | ***Dempster***



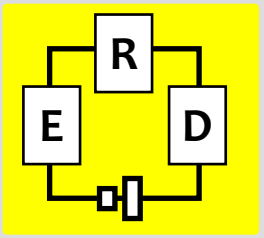
Evolution of dispersal

Massol & Débarre (2015)



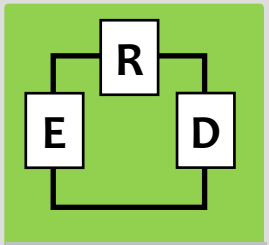
Levene

Evolution towards total philopatry



Ravigné

Intermediate dispersal rates are possible
Branching happens for negatively autocorrelated environments



Dempster

Either total philopatry or total dispersal
Bistability can happen

Informed dispersal and life cycles

- Conditioning dispersal decision on patch "quality" may decrease the indirect cost of dispersing

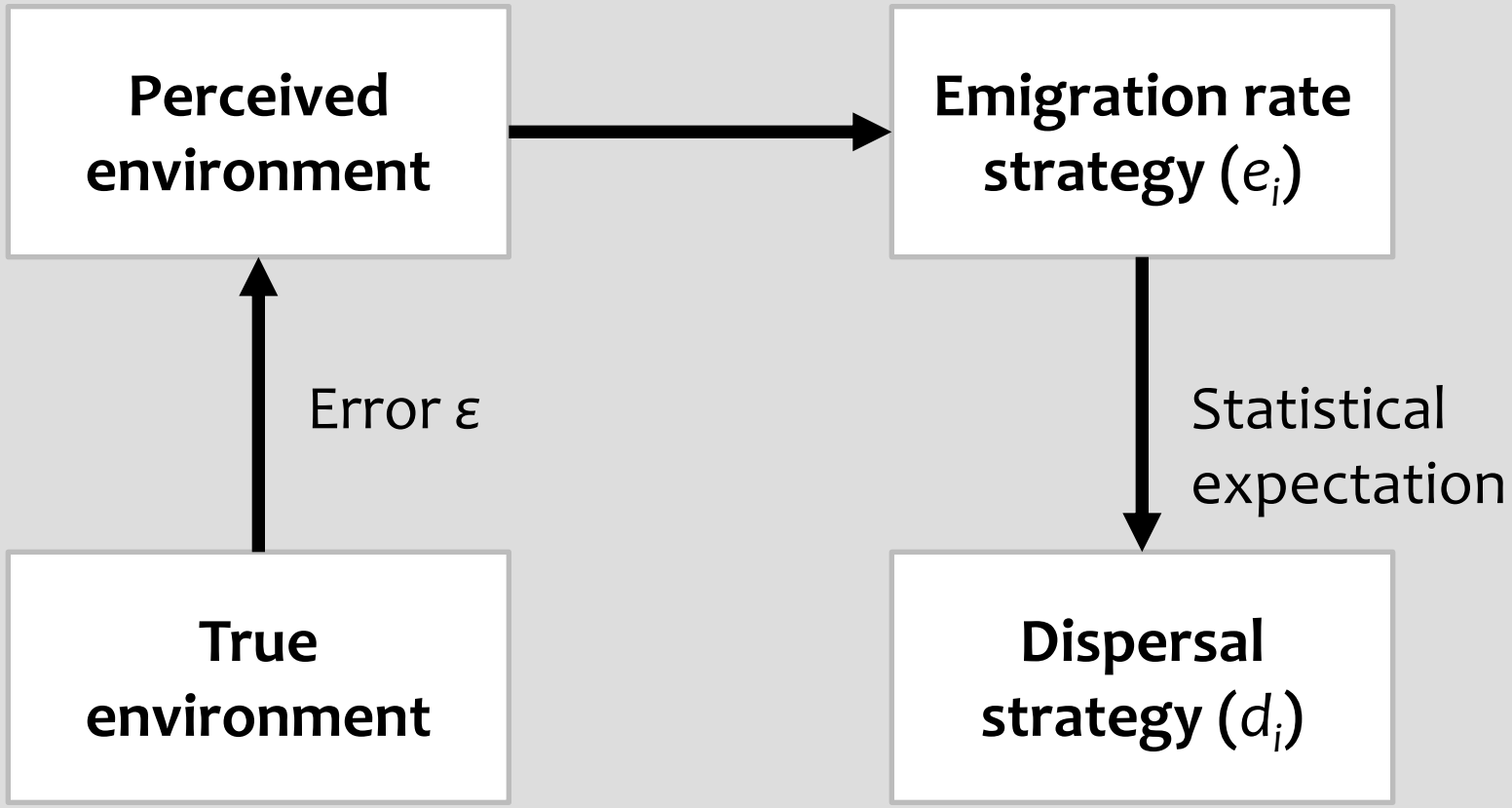
- First theoretical argument using two-patch models (McPeek & Holt 1992)

- With almost static environments and bad cues, dispersal is not conditioned on current perceived patch quality (McNamara & Dall 2011)

  → bang-bang dispersal (all or nothing), with no polymorphism (informed dispersal *vs.* polymorphism)

Informed dispersal

after McNamara & Dall (2011)

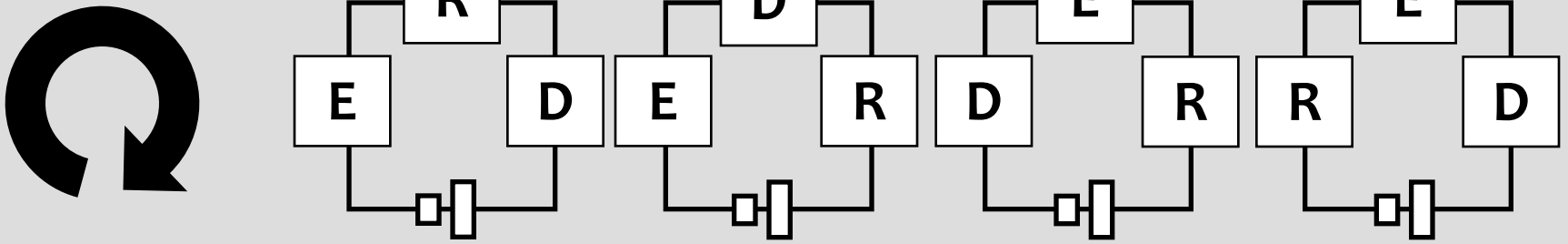


$$d_1 = \varepsilon e_2 + (1-\varepsilon) e_1$$

$$d_2 = \varepsilon e_1 + (1-\varepsilon) e_2$$

Classification of life cycles

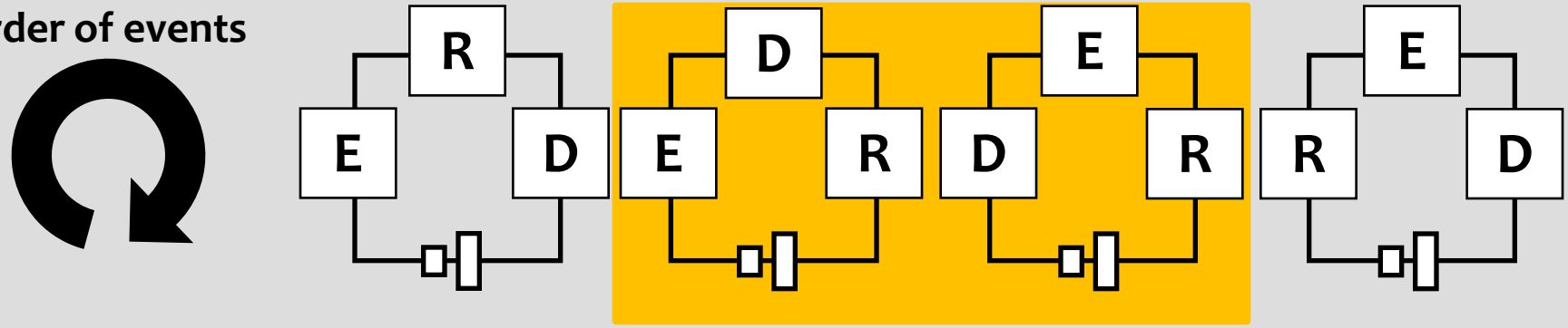
Order of events



Ravigné *et al.*'s classification	Ravigné	Levene	Ravigné

Information & life cycles

Order of events



Ravigné *et al.*'s classification

Ravigné

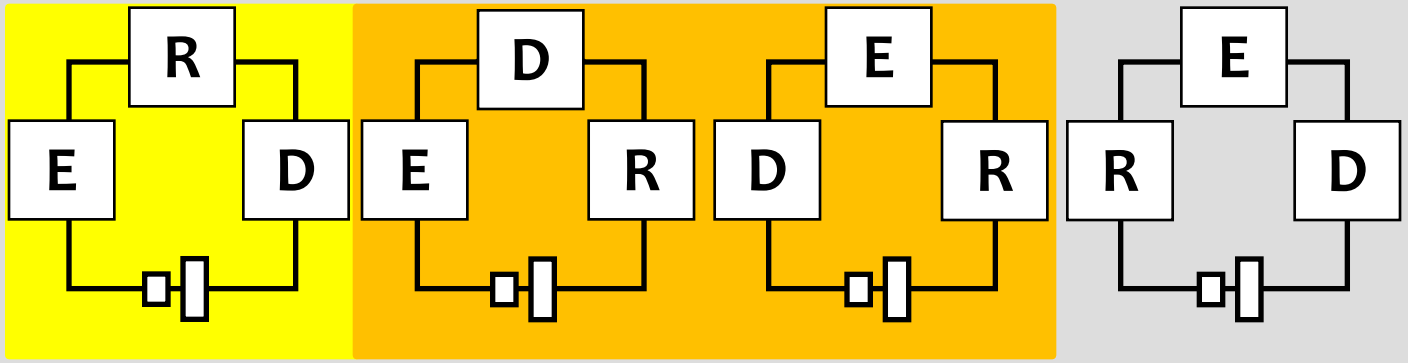
Levene

Ravigné

evolution towards philopatry

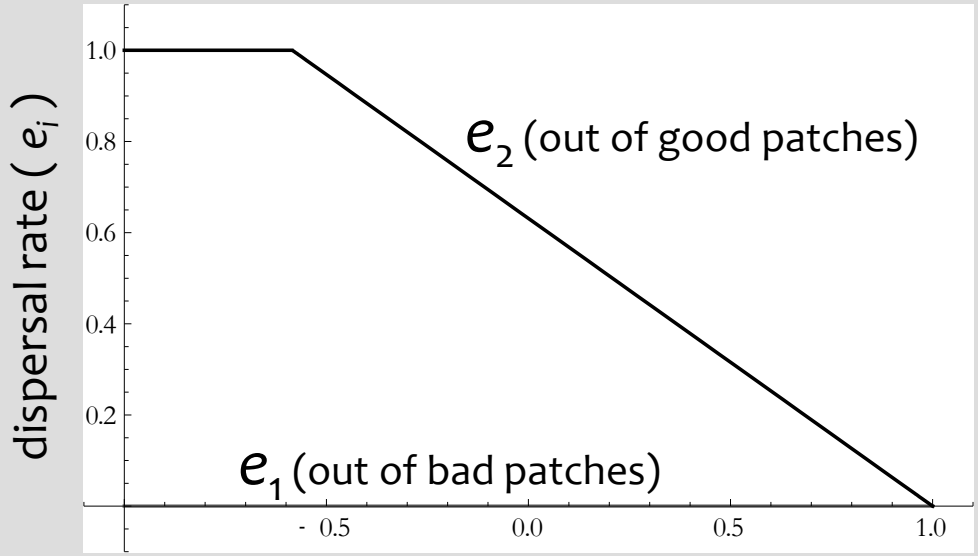
Information & life cycles

Order of events



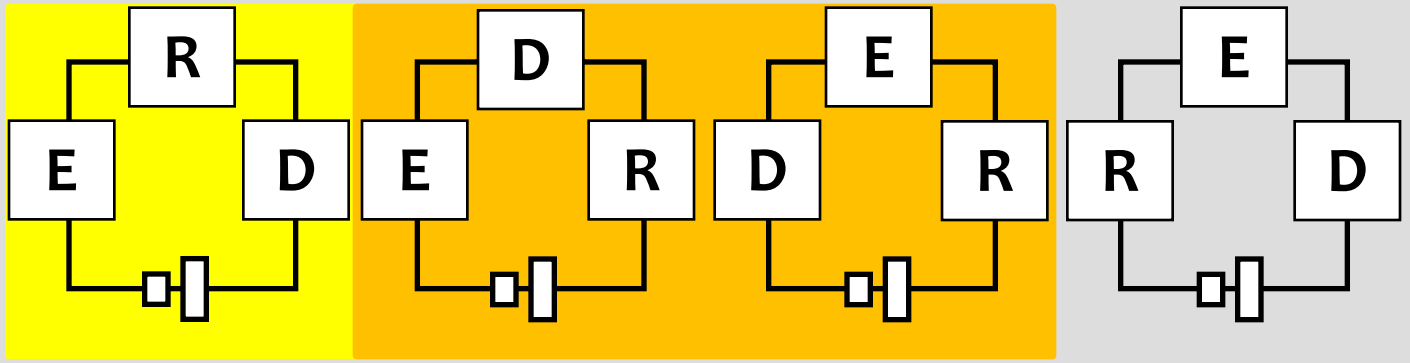
Ravigné *et al.*'s classification	Ravigné	Levene	Ravigné

Results with perfect cue



Information & life cycles

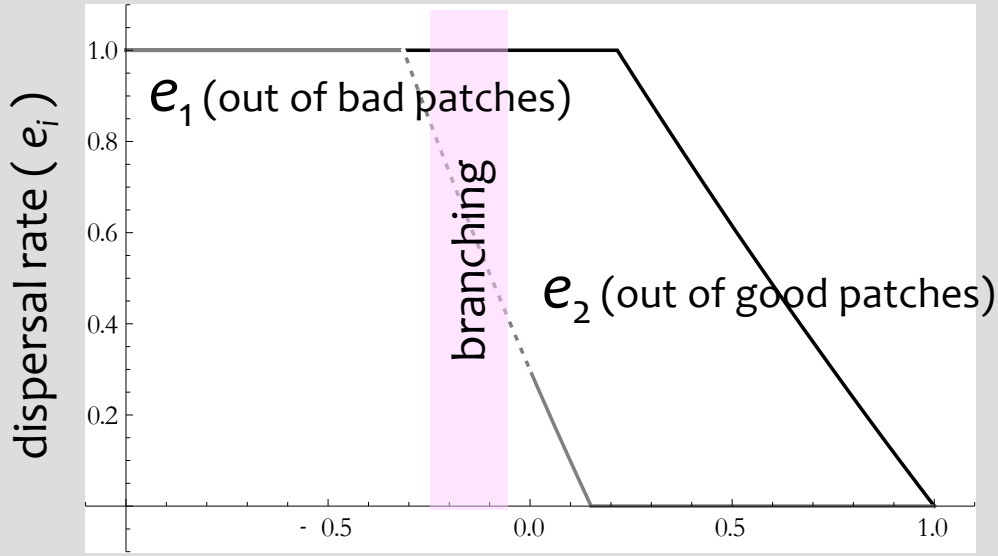
Order of events



Ravigné *et al.*'s classification

Ravigné | Levene | Ravigné

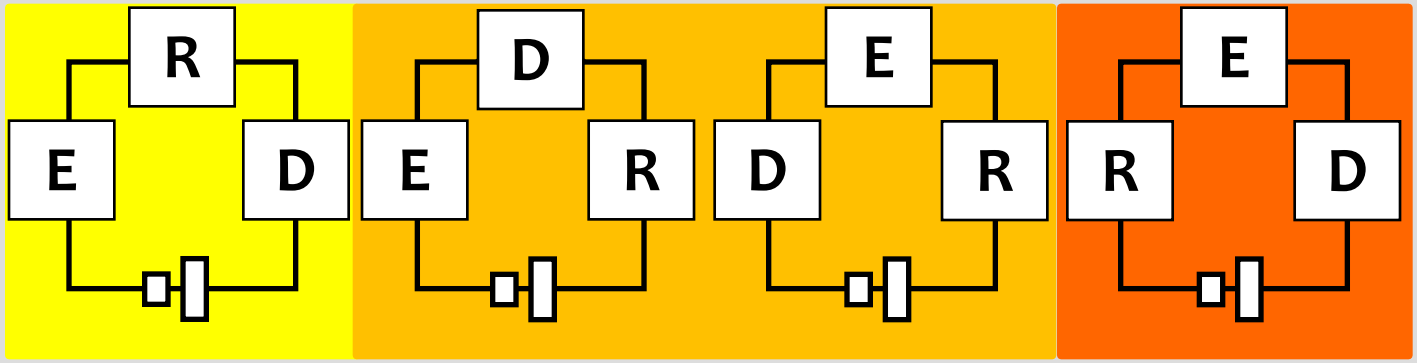
Results with imperfect cue



Information & life cycles

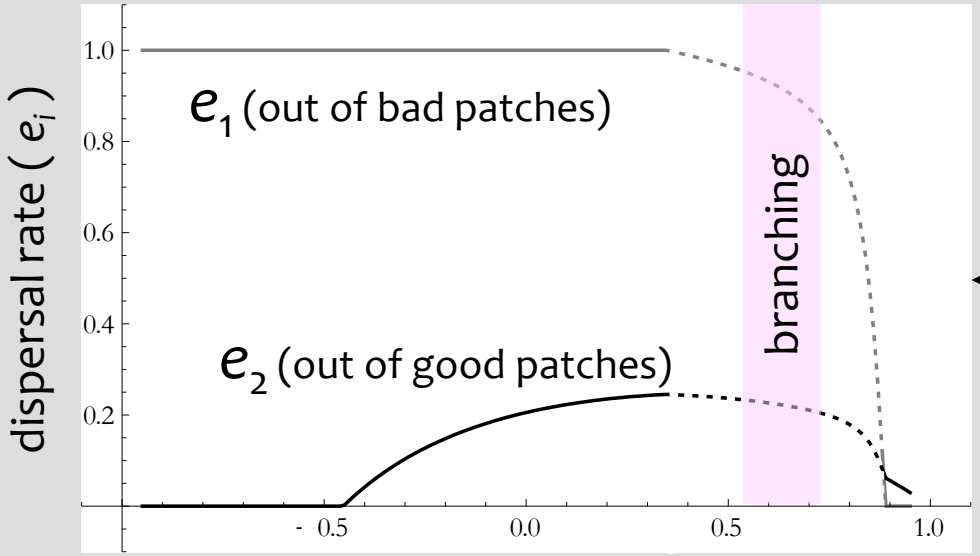
Massol & Débarre (in prep)

Order of events



Ravigné *et al.*'s classification

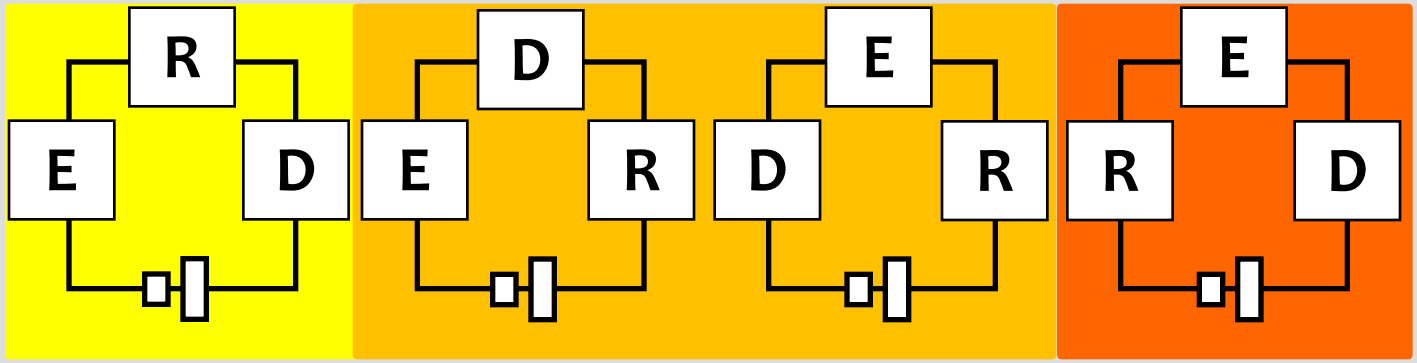
Ravigné | **Levene** | **Ravigné**



Results with perfect cue

Information & life cycles

Order of events



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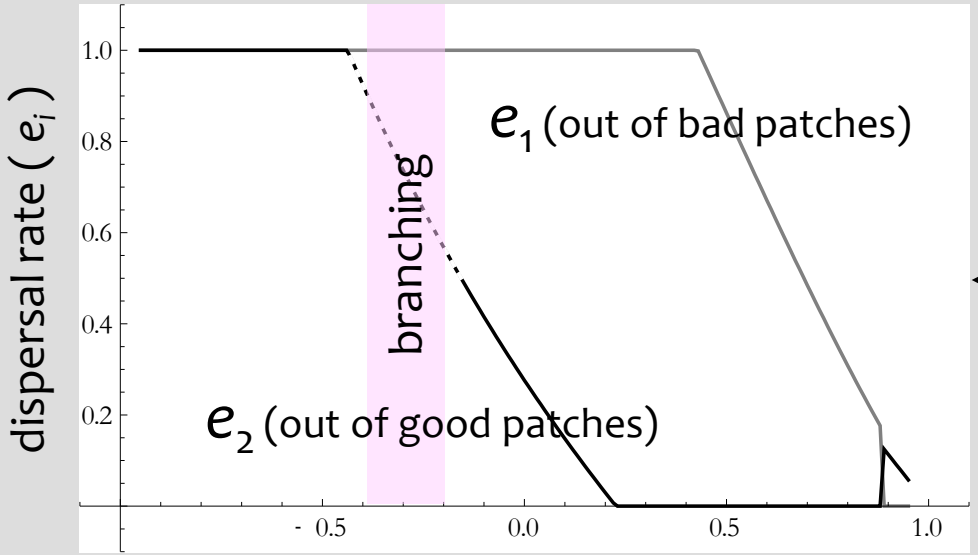
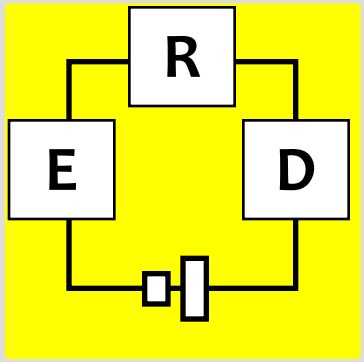
Ravigné | Levene | Ravigné



Results with imperfect cue

Making sense of all of that…



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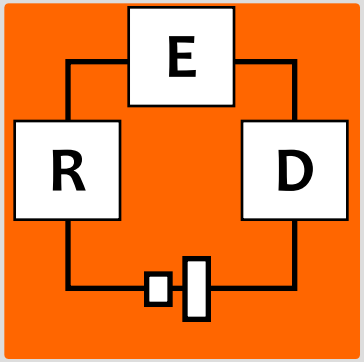
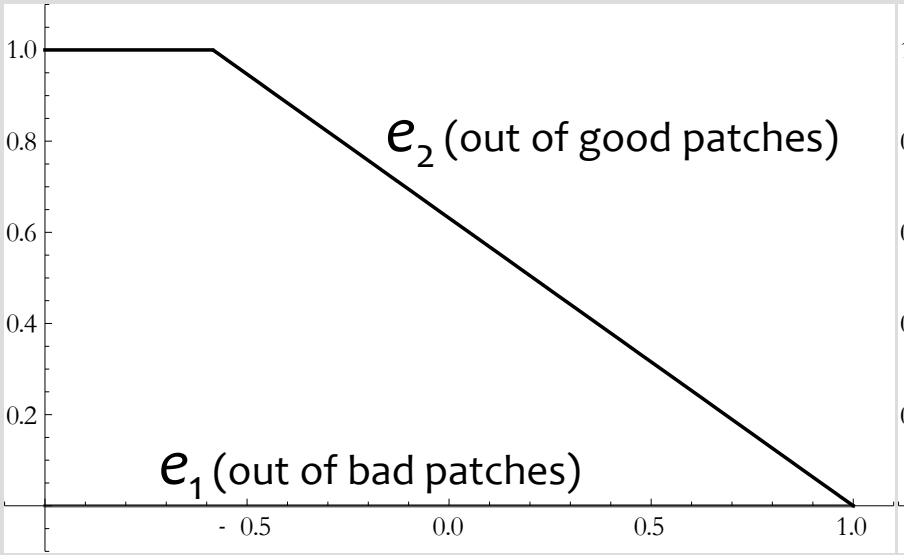
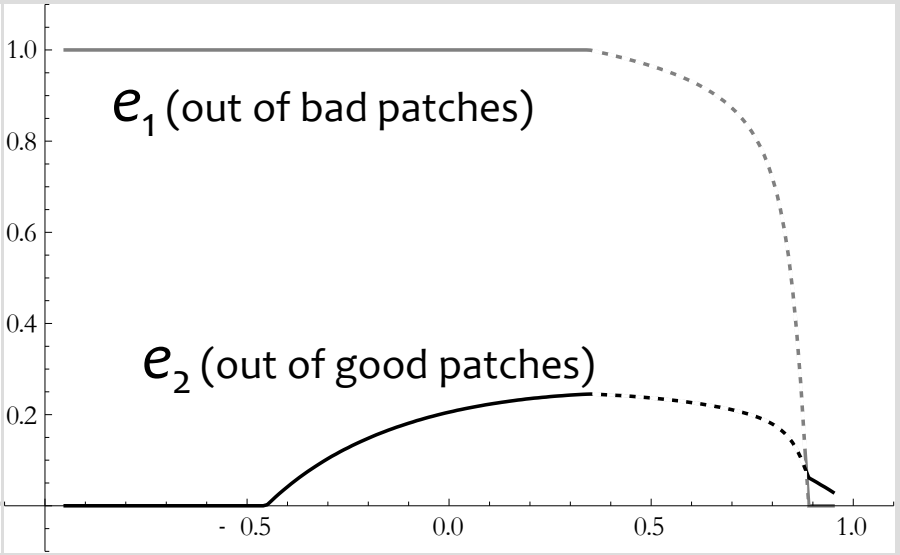


be regulated where it's easy…

… & go find a better place to reproduce





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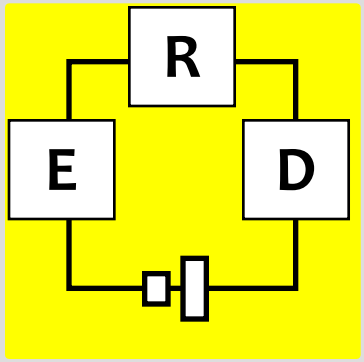

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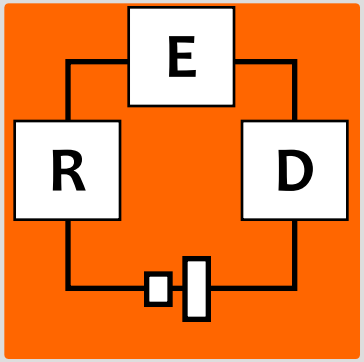

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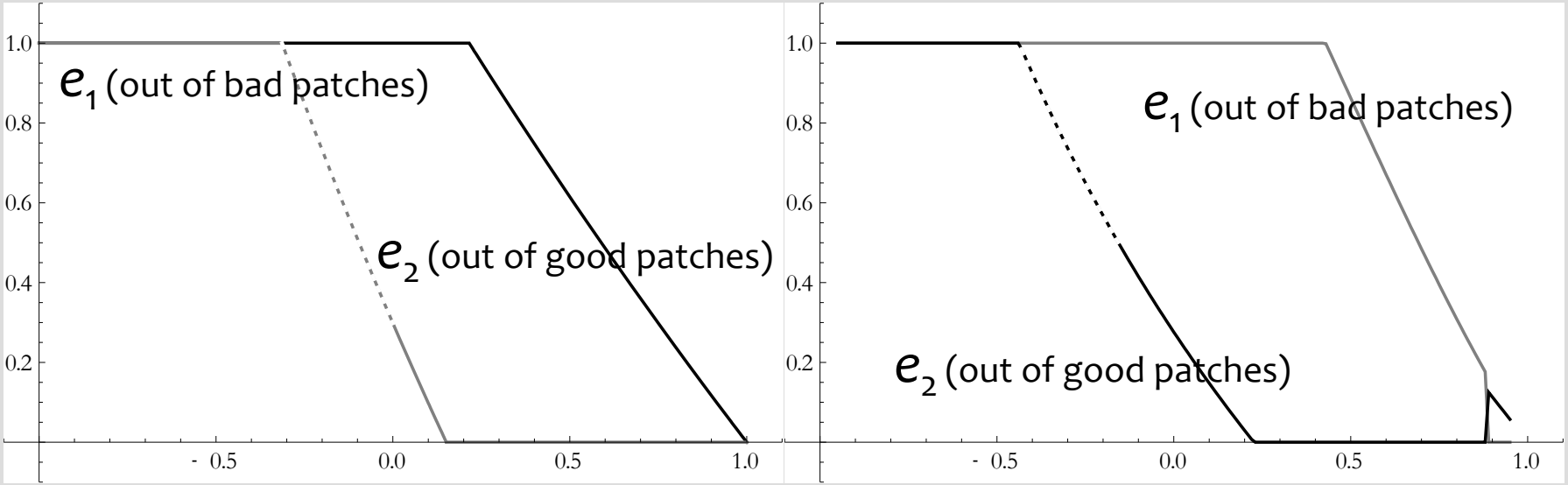
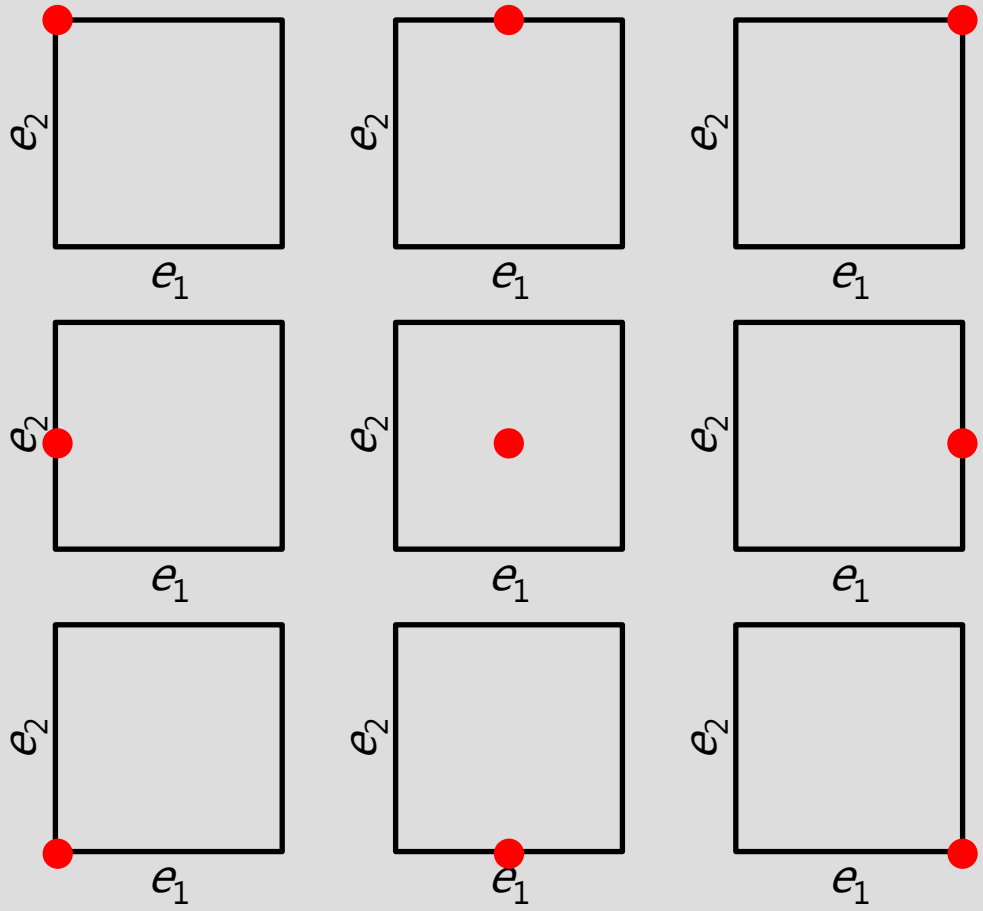
… & go find a better place to reproduce

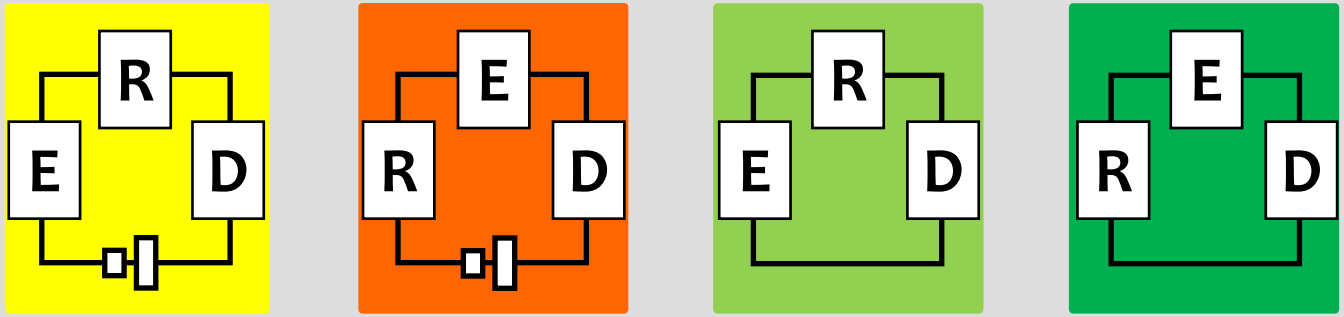


Evolutionary outcomes



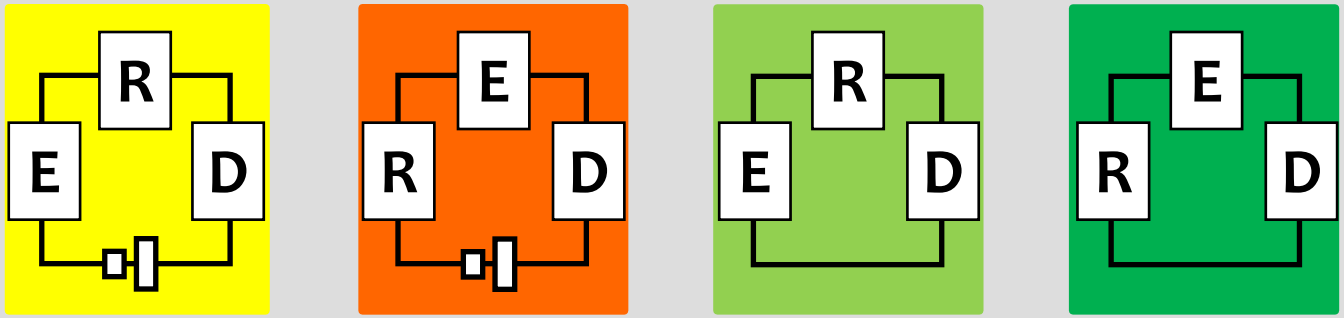
with a ★ = branching point

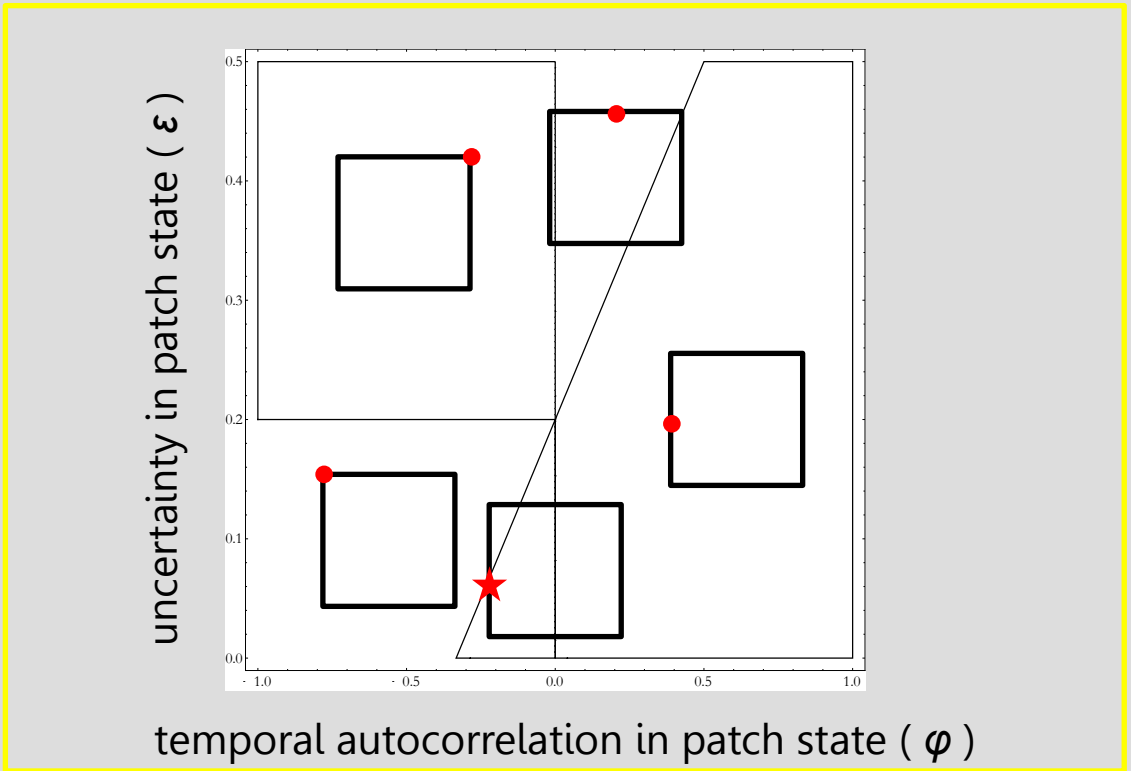
Evolutionary outcomes



Evolutionary outcomes

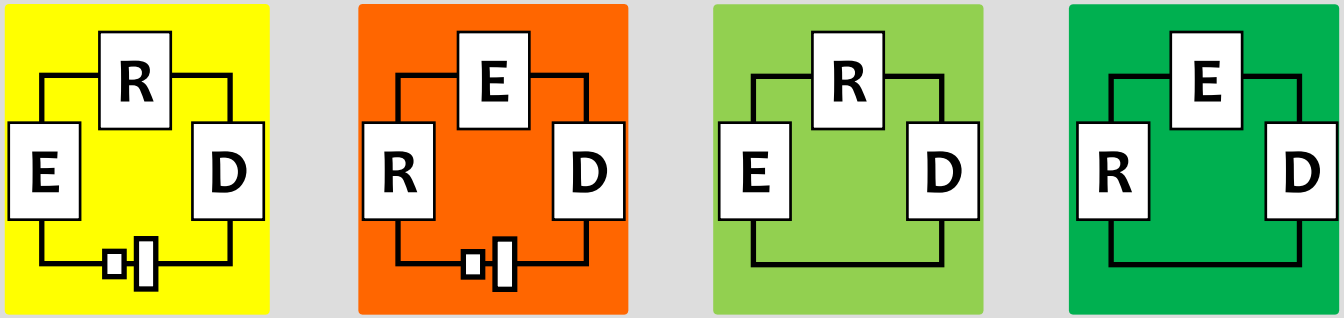
at $c = 0$

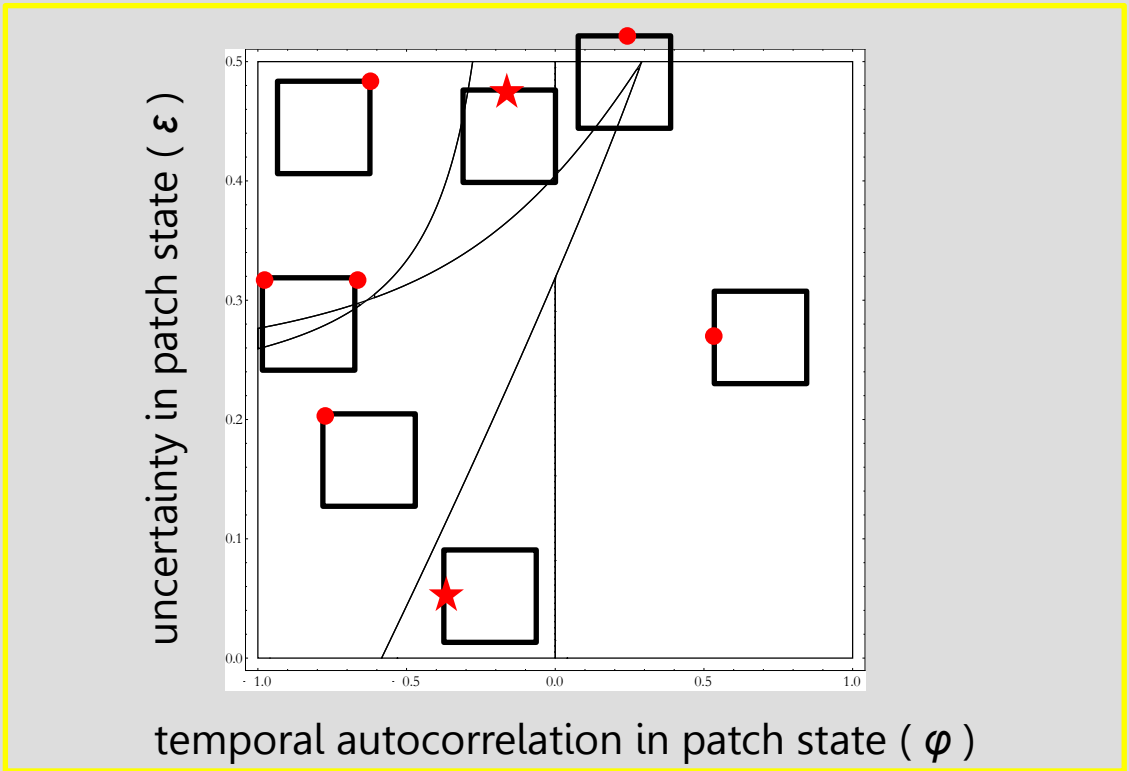




Evolutionary outcomes

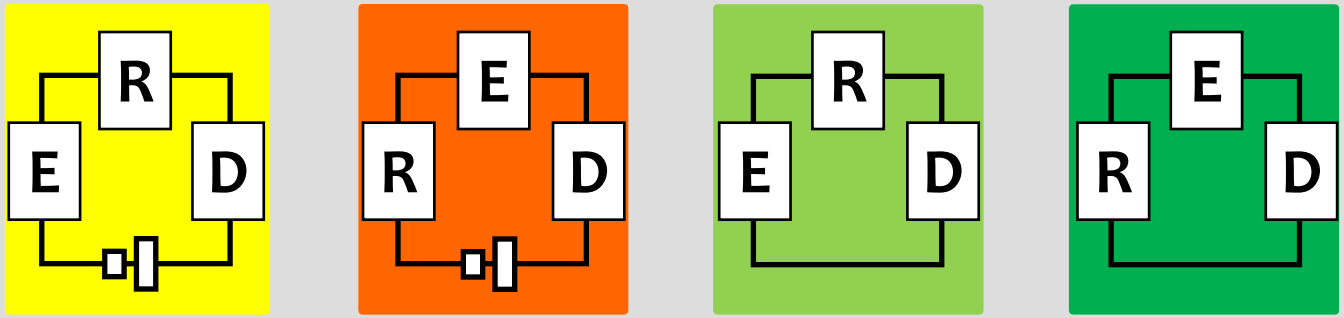
at c = 0.1

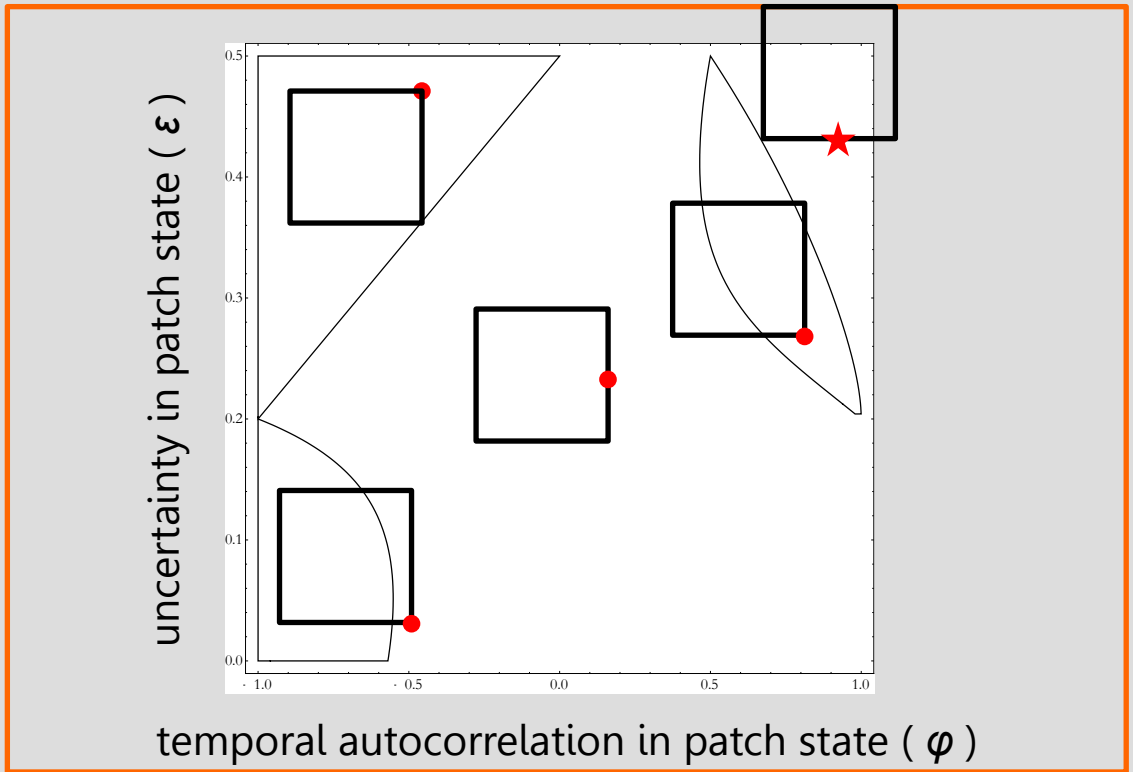




Evolutionary outcomes

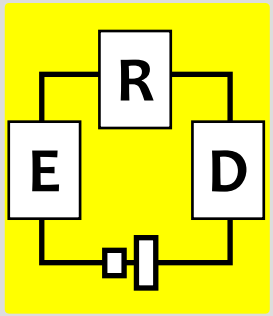
at $c = 0$

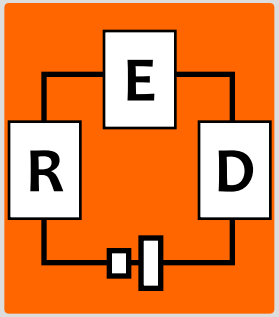


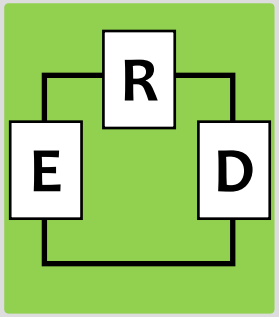


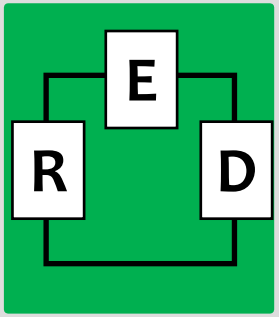
Evolutionary outcomes

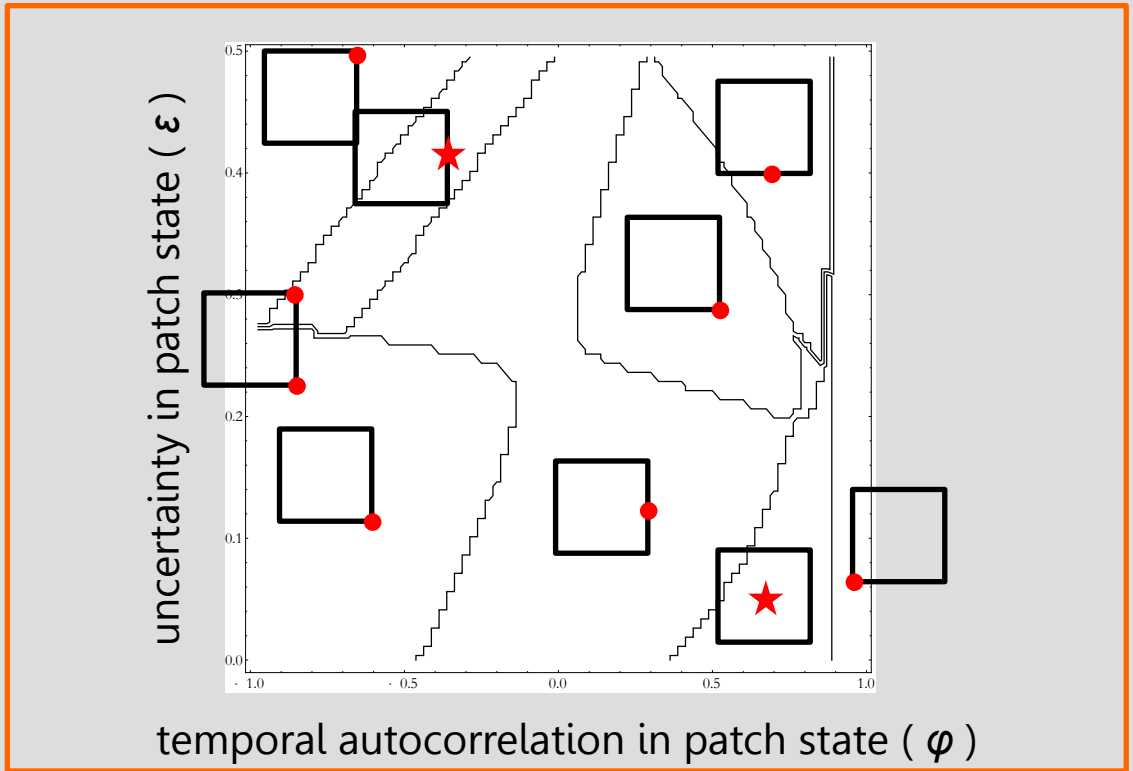
at c = 0.1





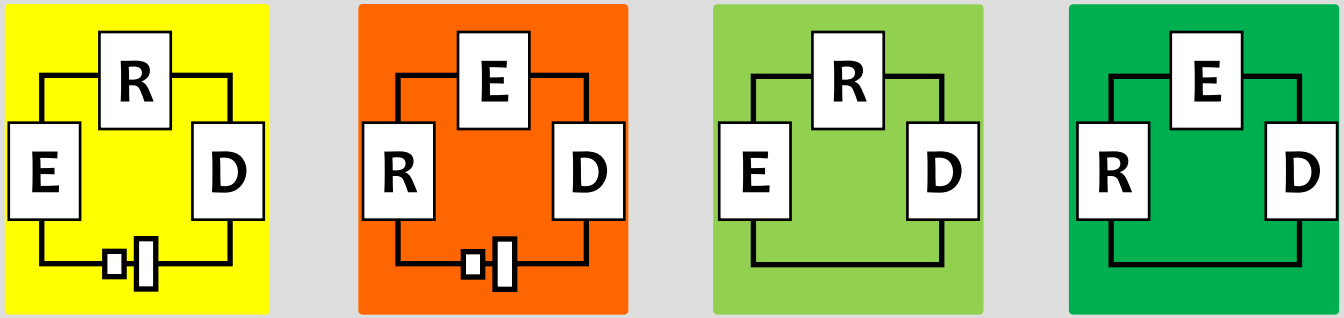


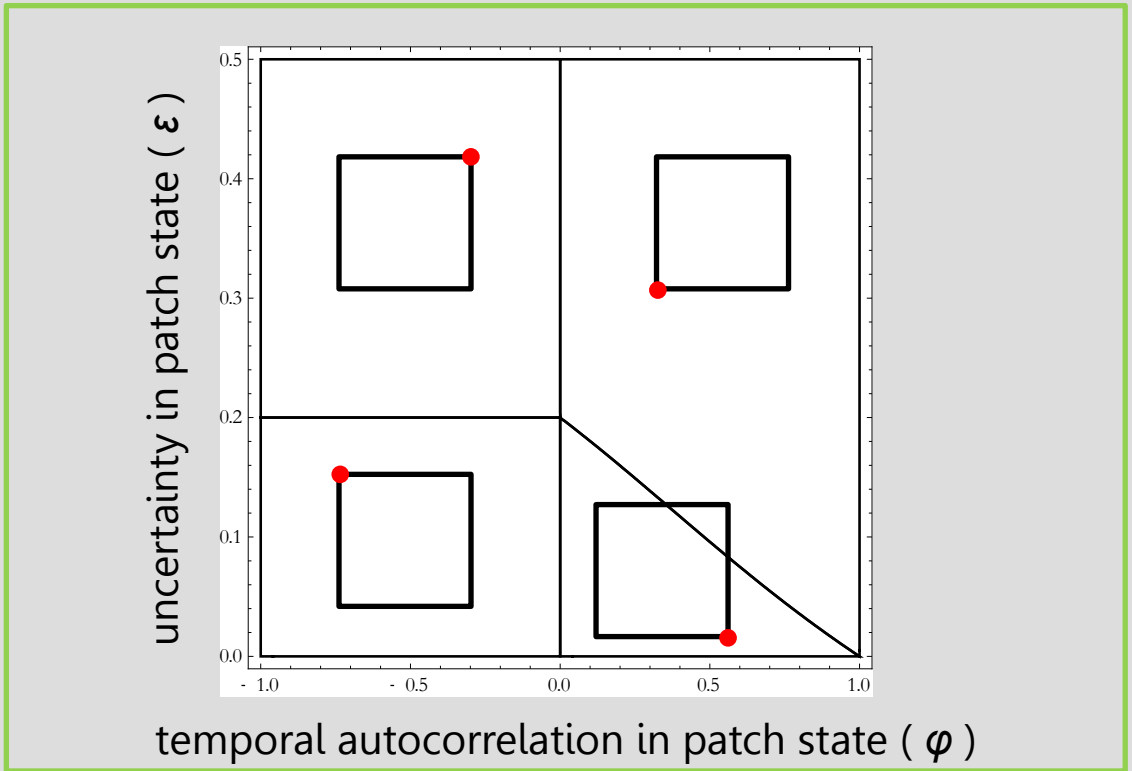




Evolutionary outcomes

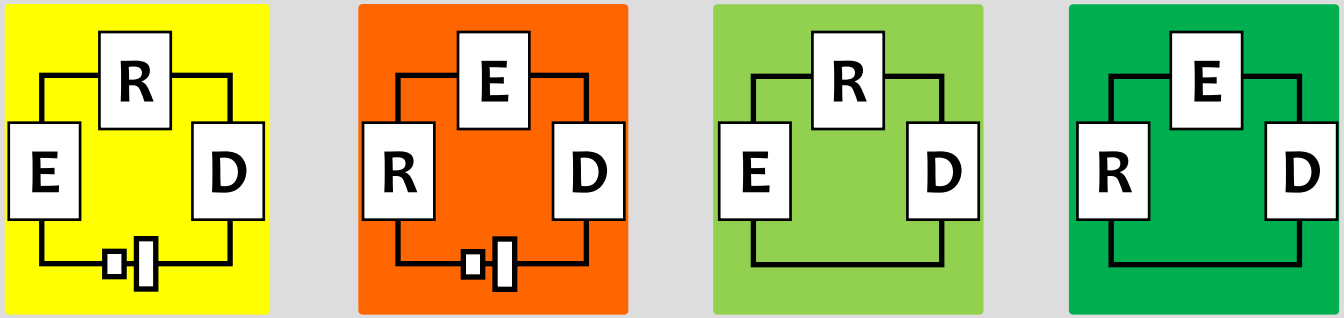
at $c = 0$

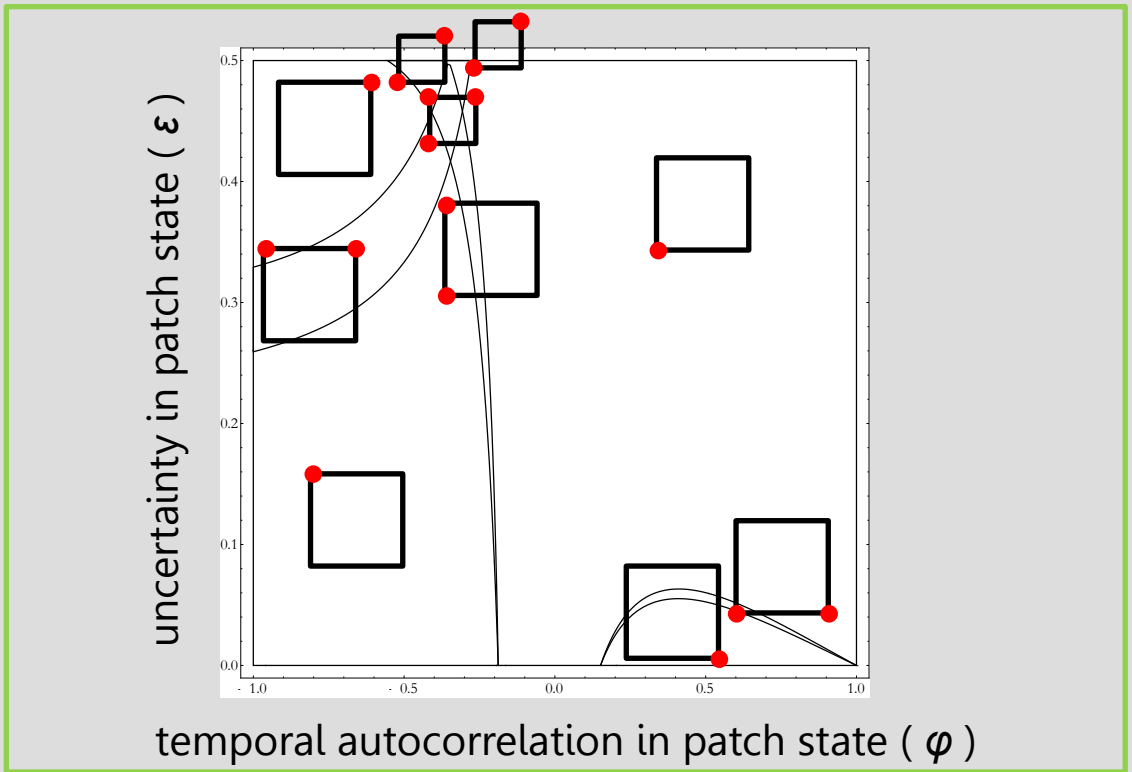




Evolutionary outcomes

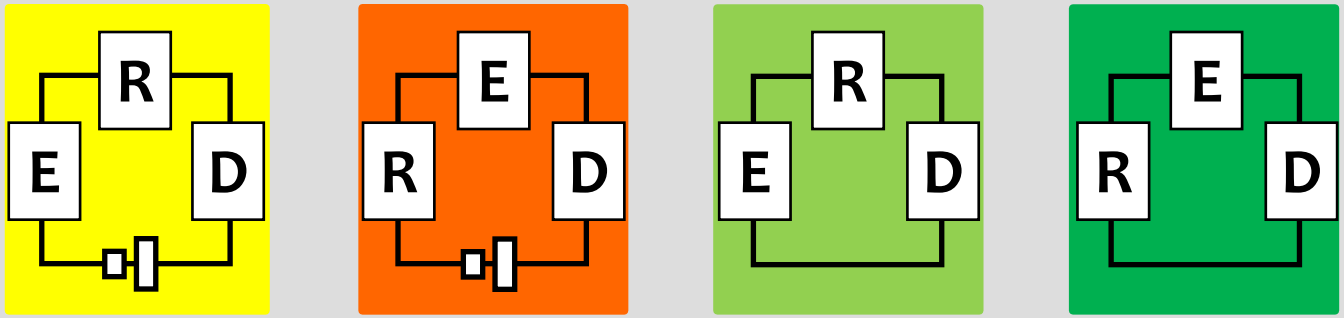
at $c = 0.1$

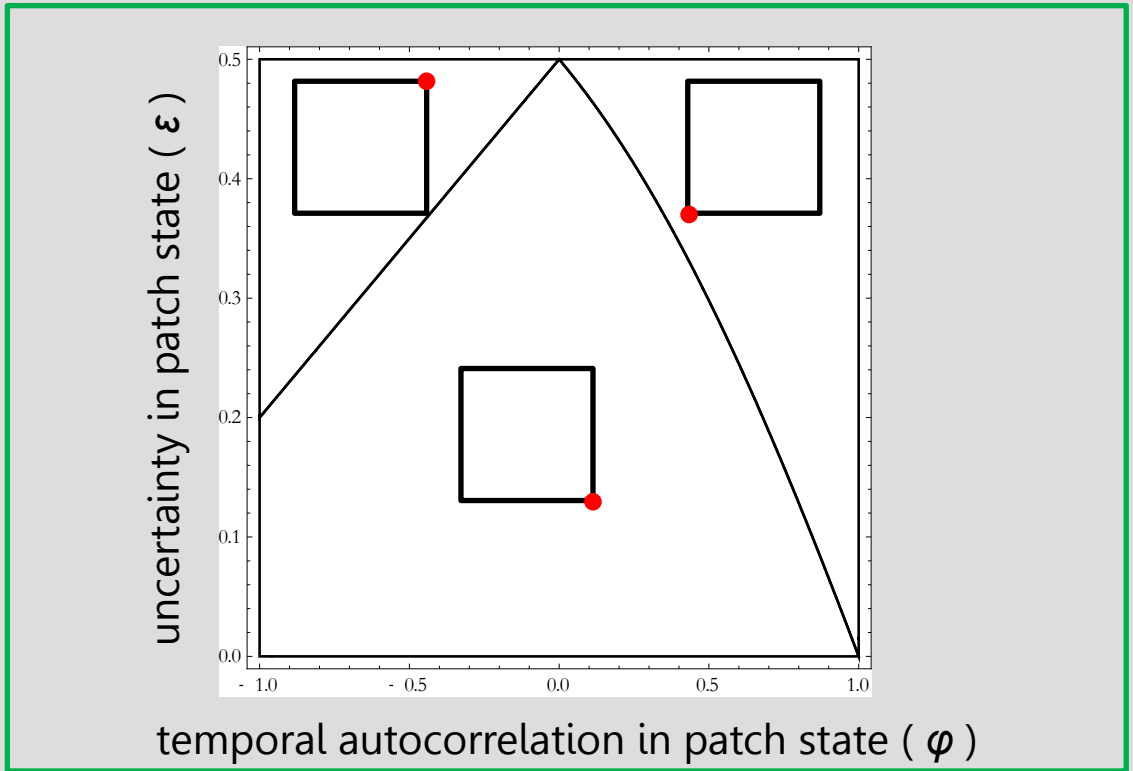




Evolutionary outcomes

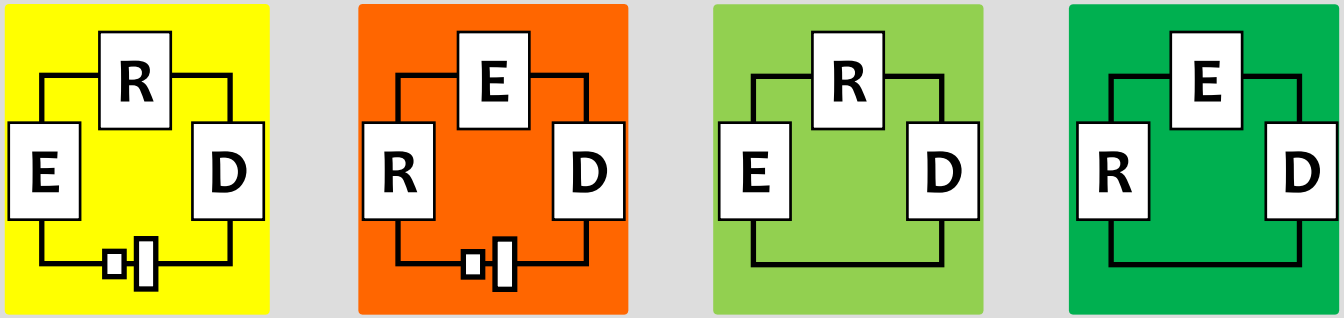
at $c = 0$

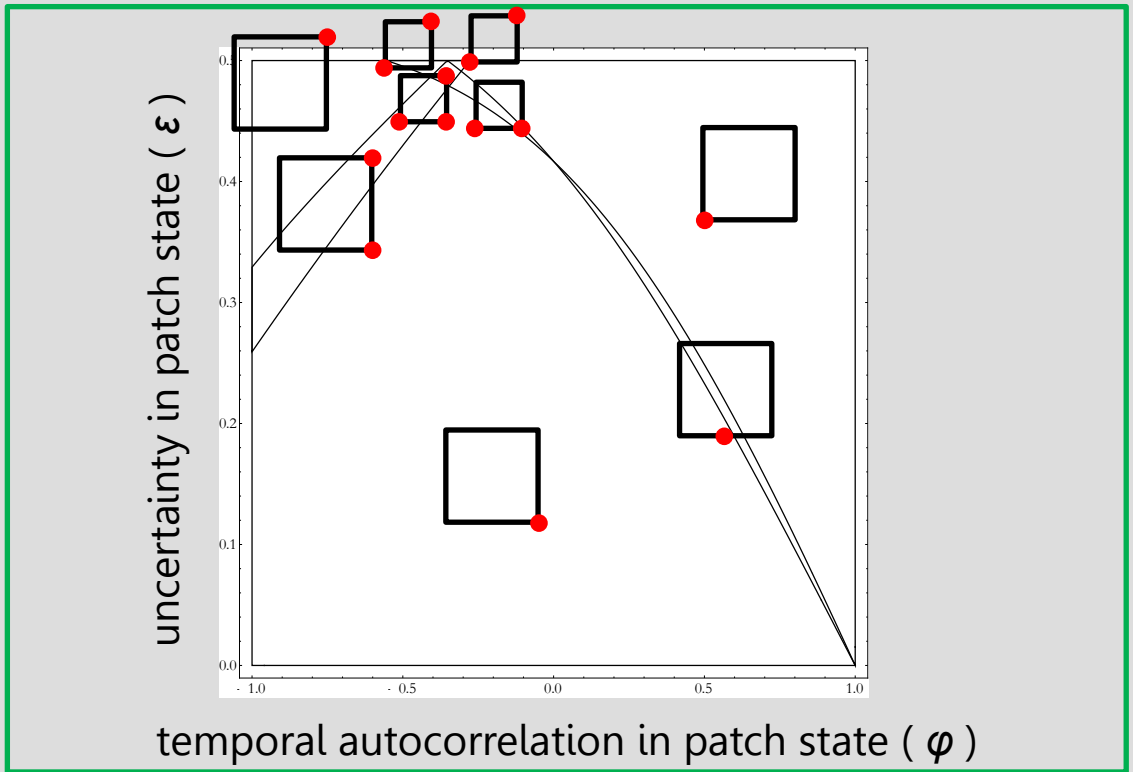




Evolutionary outcomes

at $c = 0.1$





Informed dispersal and life cycles

Observations:

- informed dispersal follows different rationales with different life cycles
- disruptive selection can happen in an informed dispersal model
- bang-bang dispersal strategies can happen under any life cycle
- bistability can occur under any life cycle

Take-home messages

1. Environmental variability can affect the evolution of dispersal in a variety of ways

2. Informed dispersal and dispersal polymorphisms are not mutually exclusive

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Usual suspects: