

# Multi-rate and multi-regime



**Trunk – crown anoles:**

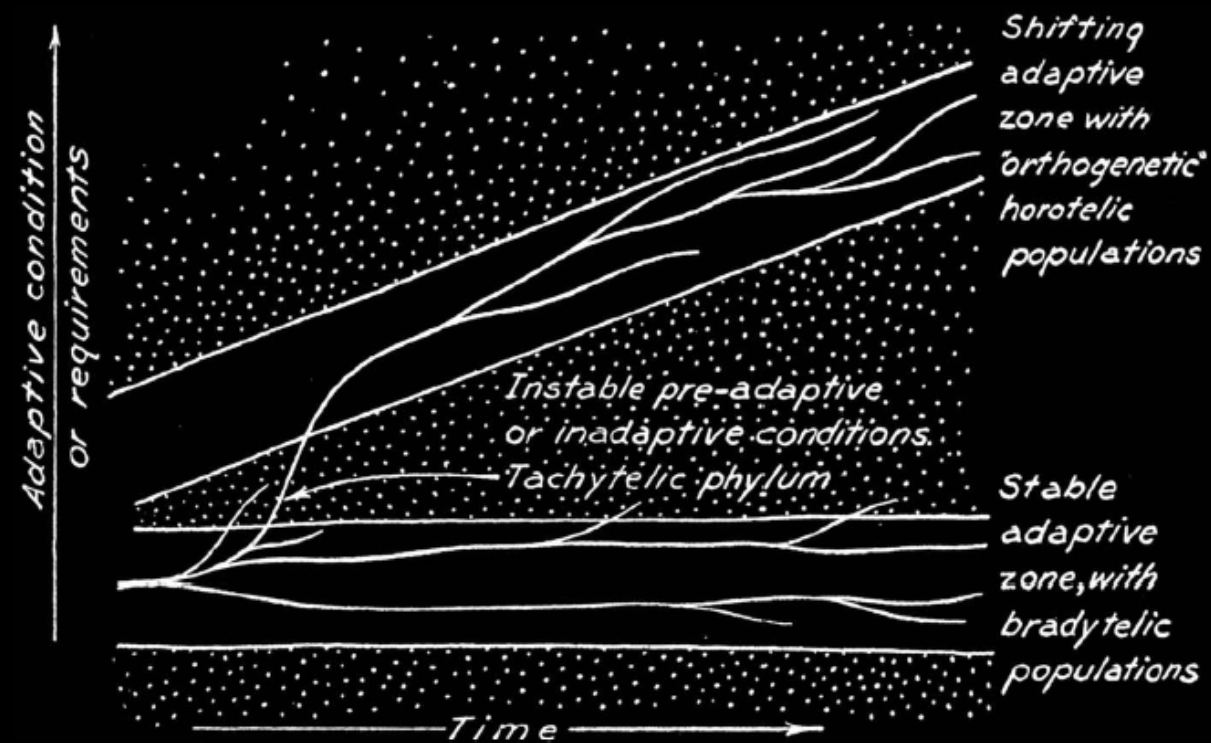
*A. allisoni* (Cuba) and *A. chlorocyanus* (Hispaniola)



**Twig anoles:**

*A. valencienni* (Jamaica) and *A. insolitus* (Hispaniola)

# Adaptive Radiation



Simpson 1953

**Ways to enter a new adaptive zone,  
according to Simpson:**

# Ways to enter a new adaptive zone, according to Simpson:

1. Dispersal into new geographic area

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1. Dispersal into new geographic area
2. Evolution of a key trait

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1. Dispersal into new geographic area
2. Evolution of a key trait
3. Mass extinction of competitors

# Ways to enter a new adaptive zone, according to Simpson:

Can we detect jumps into new adaptive zones?  
new geographic area  
key trait

3. Mass extinction of competitors

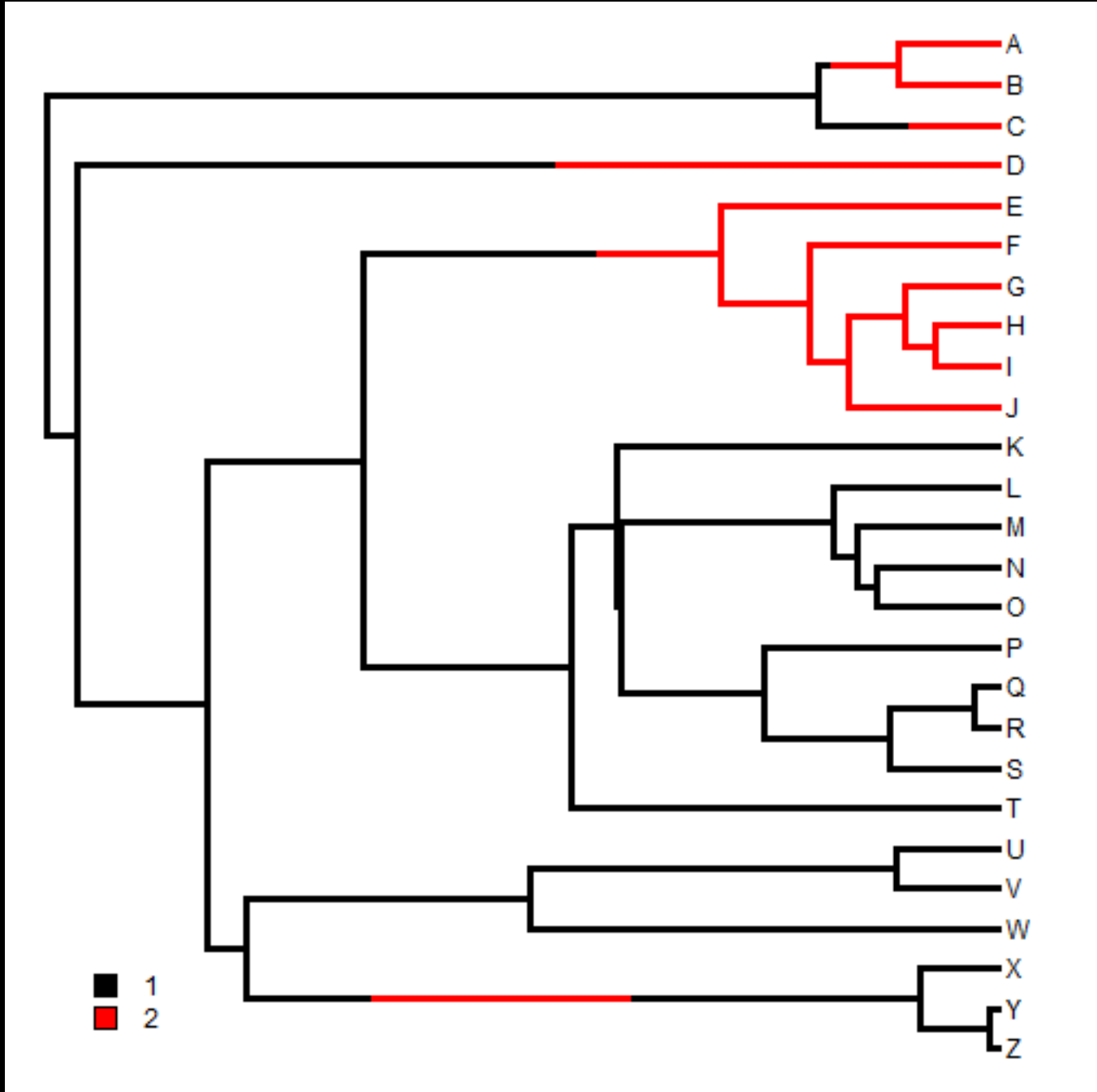
# Ways to enter a new adaptive zone, according to Simpson:

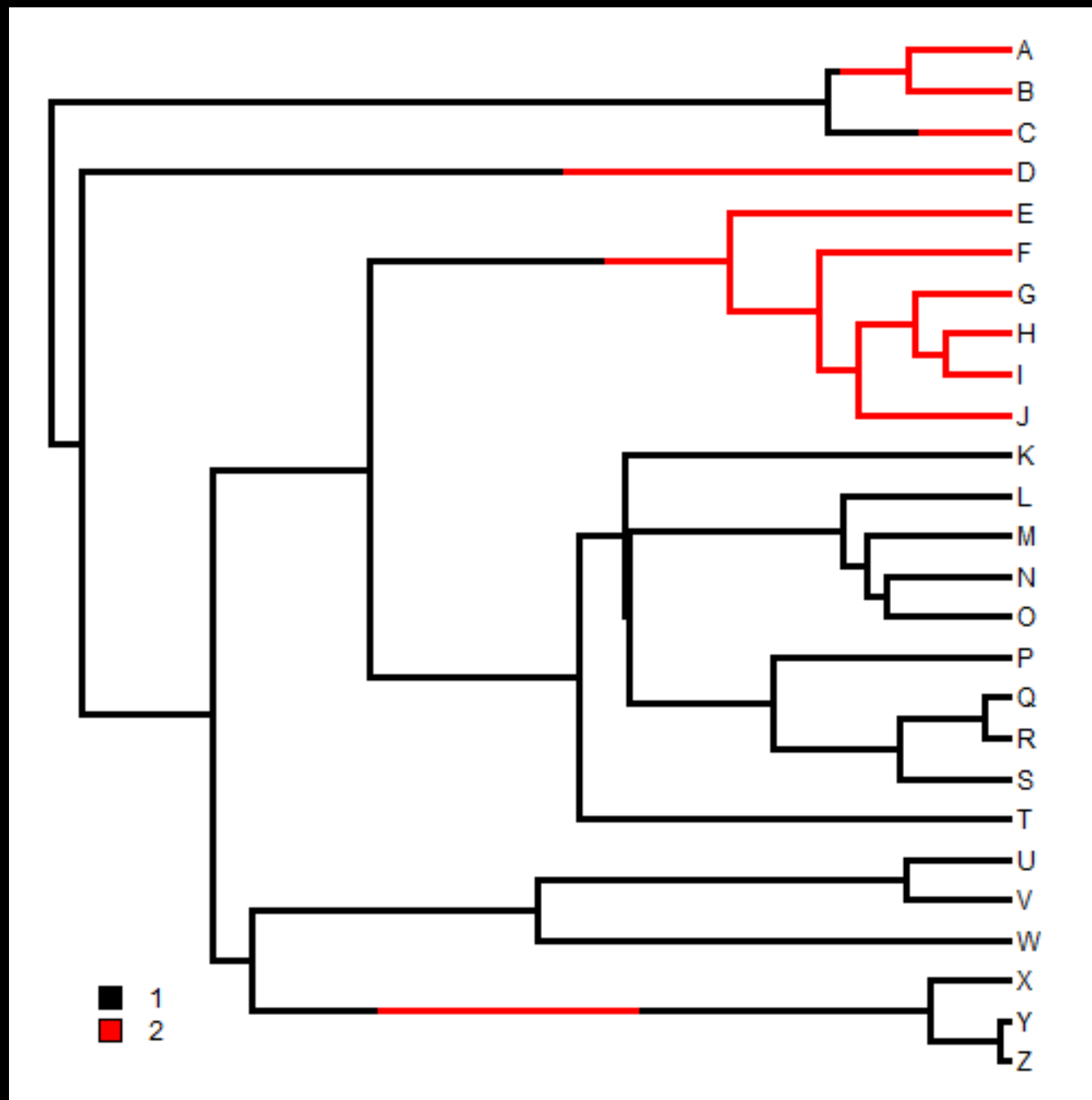
Can we detect  
jumps into new  
adaptive zones?

Do adaptive zones  
constrain  
evolutionary  
change?

3. Mass extinction of competitors







Is the **rate of evolution** different between state 1 and state 2?

Compare the fit of a single-rate model  
to a multi-rate model

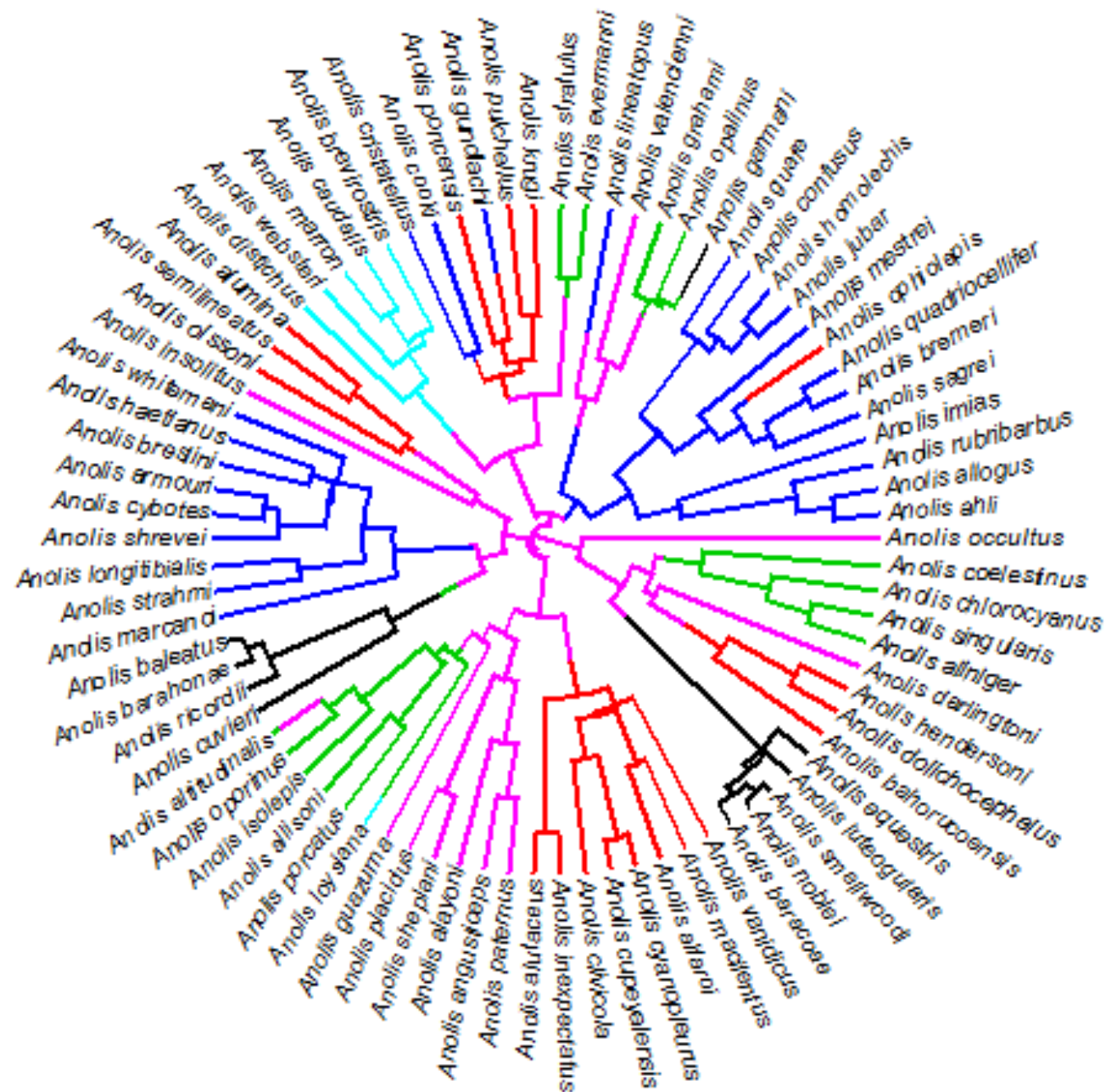
Model 1

$$\sigma^2$$

Model 2

$$\begin{matrix} \sigma_1^2 \\ \sigma_2^2 \end{matrix}$$





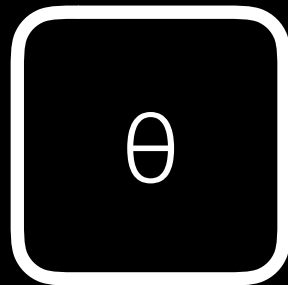
Is the **evolutionary regime** different between state 1 and state 2 (and so on)?



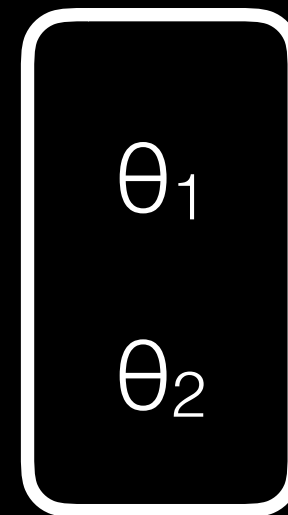


Compare the fit of a single-regime model  
to a multi-regime model

Model 1



Model 2



More complicated tools



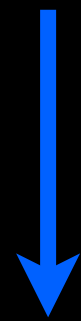
rijMCMC

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1)$

$k = 1$

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1)$

$k = 1$



split move

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_2 \alpha_2 \alpha_2 \alpha_2 \alpha_2)$

$k = 2$

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1)$   $k = 1$

↓ split move

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_2 \alpha_2 \alpha_2 \alpha_2 \alpha_2)$   $k = 2$

↓ split move

$(\alpha_3 \alpha_3 \alpha_3 \alpha_1 \alpha_1 \alpha_2 \alpha_2 \alpha_2 \alpha_2 \alpha_2)$   $k = 3$

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1)$   $k = 1$

↓ split move

$(\alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_2 \alpha_2 \alpha_2 \alpha_2 \alpha_2)$   $k = 2$

↓ split move

$(\alpha_3 \alpha_3 \alpha_3 \alpha_1 \alpha_1 \alpha_2 \alpha_2 \alpha_2 \alpha_2 \alpha_2)$   $k = 3$

↓ merge move

$(\alpha_3 \alpha_3 \alpha_3 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1 \alpha_1)$   $k = 2$

Through a series of **split** and **merge** moves

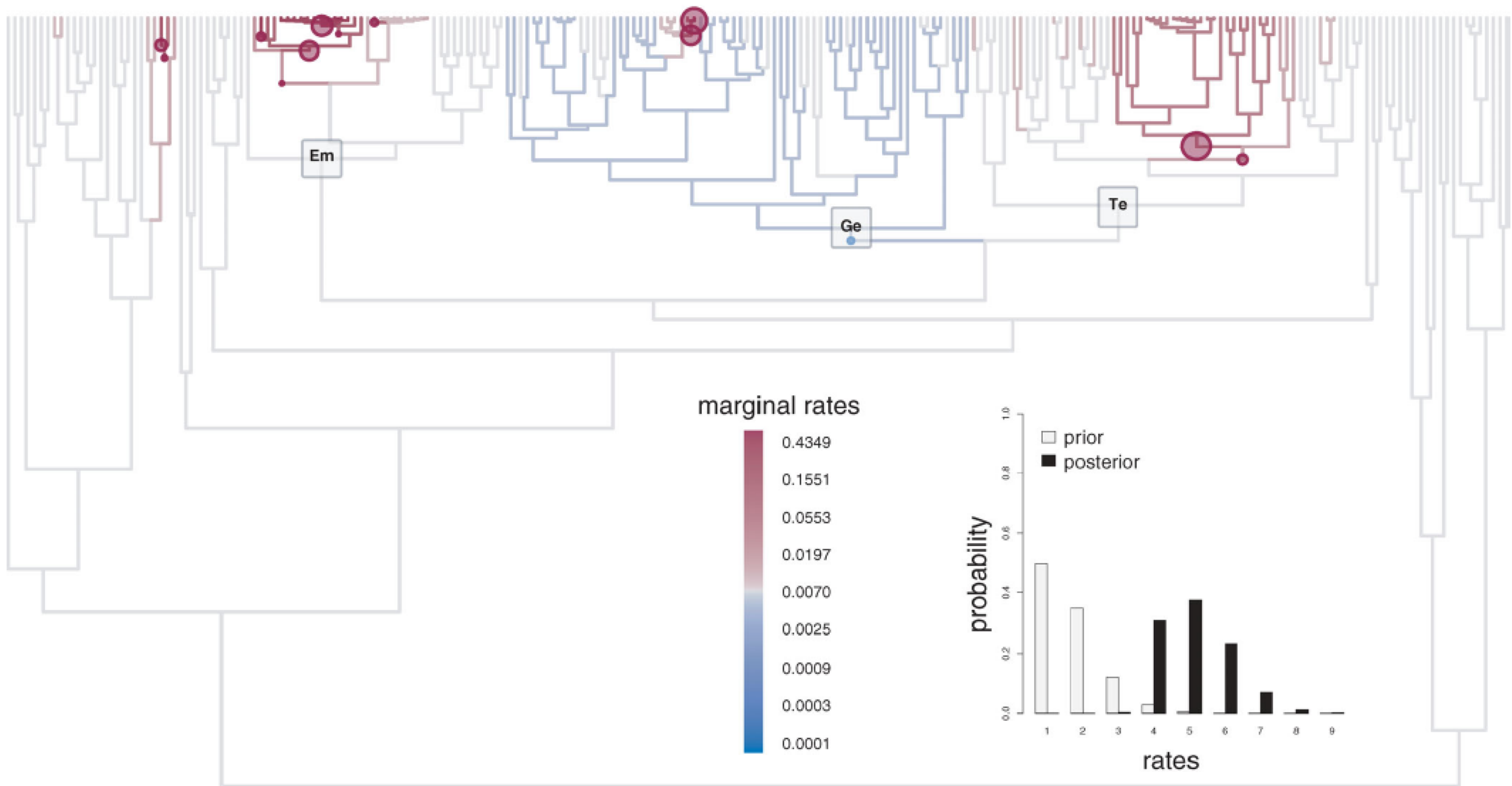
Through a series of **split** and **merge** moves

we can fit **multi-rate models** to comparative data

## **A NOVEL COMPARATIVE METHOD FOR IDENTIFYING SHIFTS IN THE RATE OF CHARACTER EVOLUTION ON TREES**

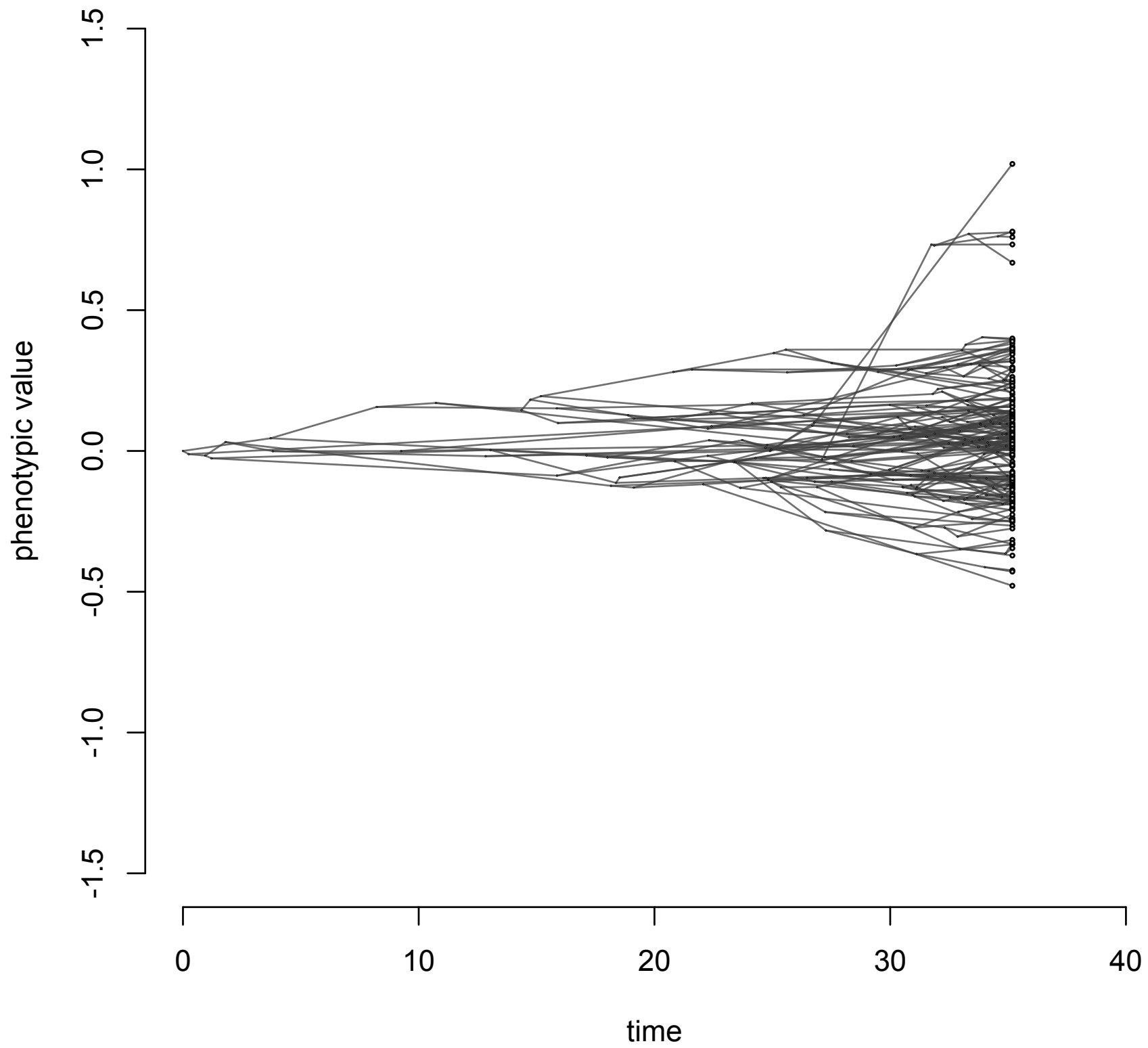
Jonathan M. Eastman,<sup>1,2</sup> Michael E. Alfaro,<sup>3,4</sup> Paul Joyce,<sup>5,6</sup> Andrew L. Hipp,<sup>7,8,9</sup> and Luke J. Harmon<sup>10,11</sup>





AUTEUR = changes in the *rate of evolution*  
along branches in a phylogeny

We modified AUTEUR to capture Simpson's idea of "jumps" into new adaptive zones



**simulated 'quantum' evolution**

## Simpsonian “Evolution by Jumps” in an Adaptive Radiation of *Anolis* Lizards

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AUTEUR "jump-bm"

*evolutionary jumps*  
along branches in a phylogeny

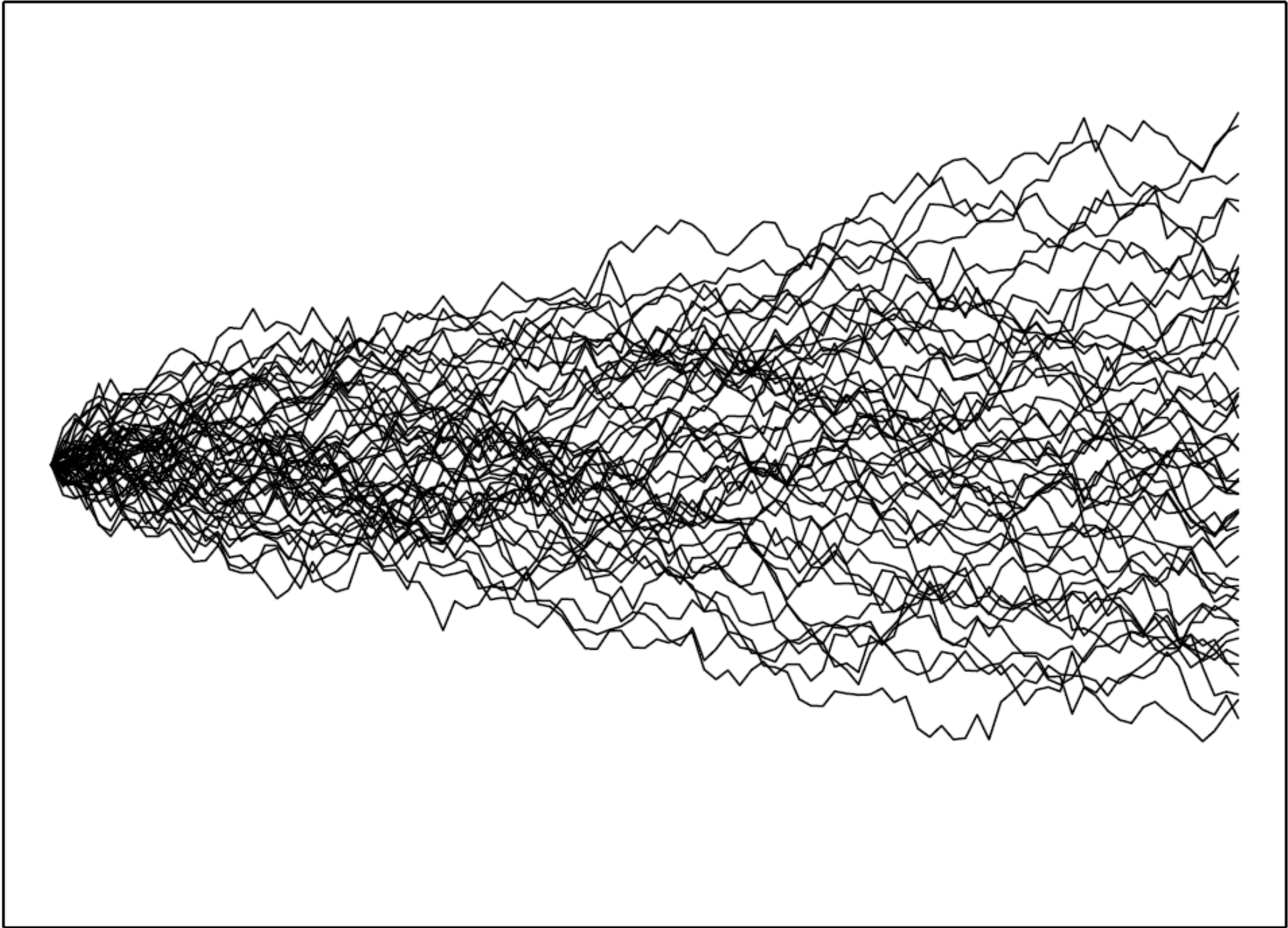
AUTEUR "rbm"

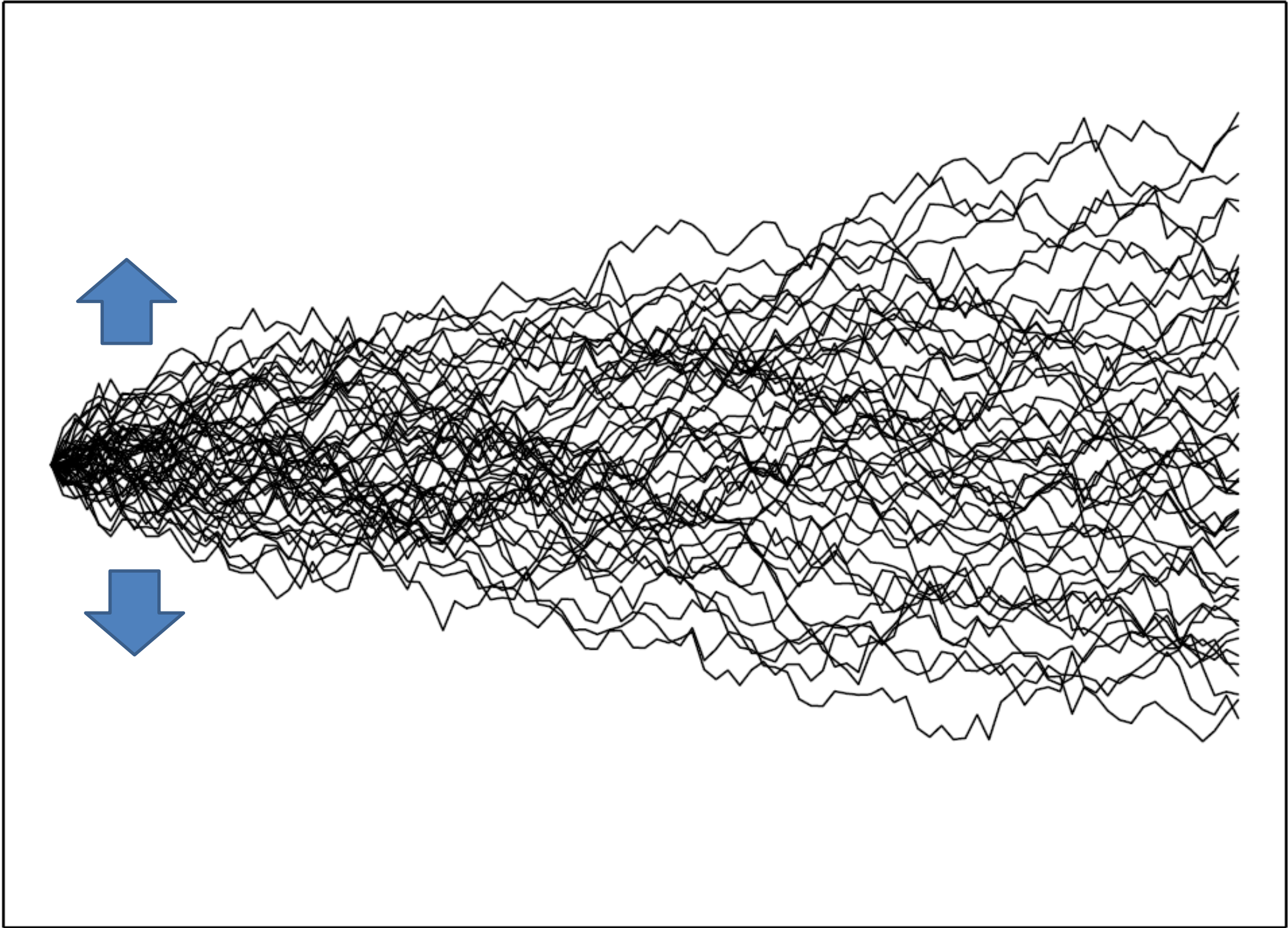
*evolutionary rate shifts*  
along branches in a phylogeny





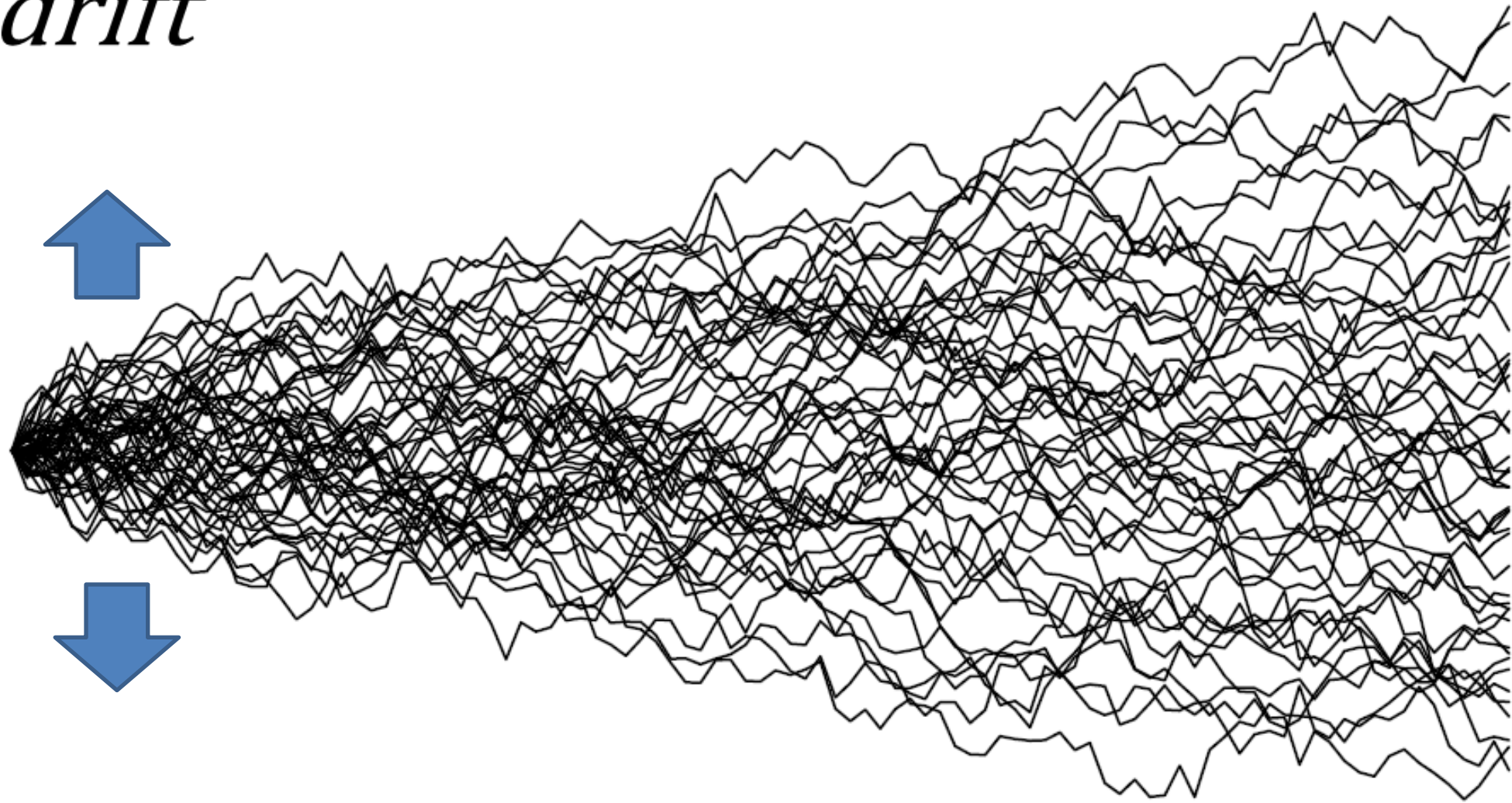
Do adaptive zones  
constrain  
evolutionary  
change?



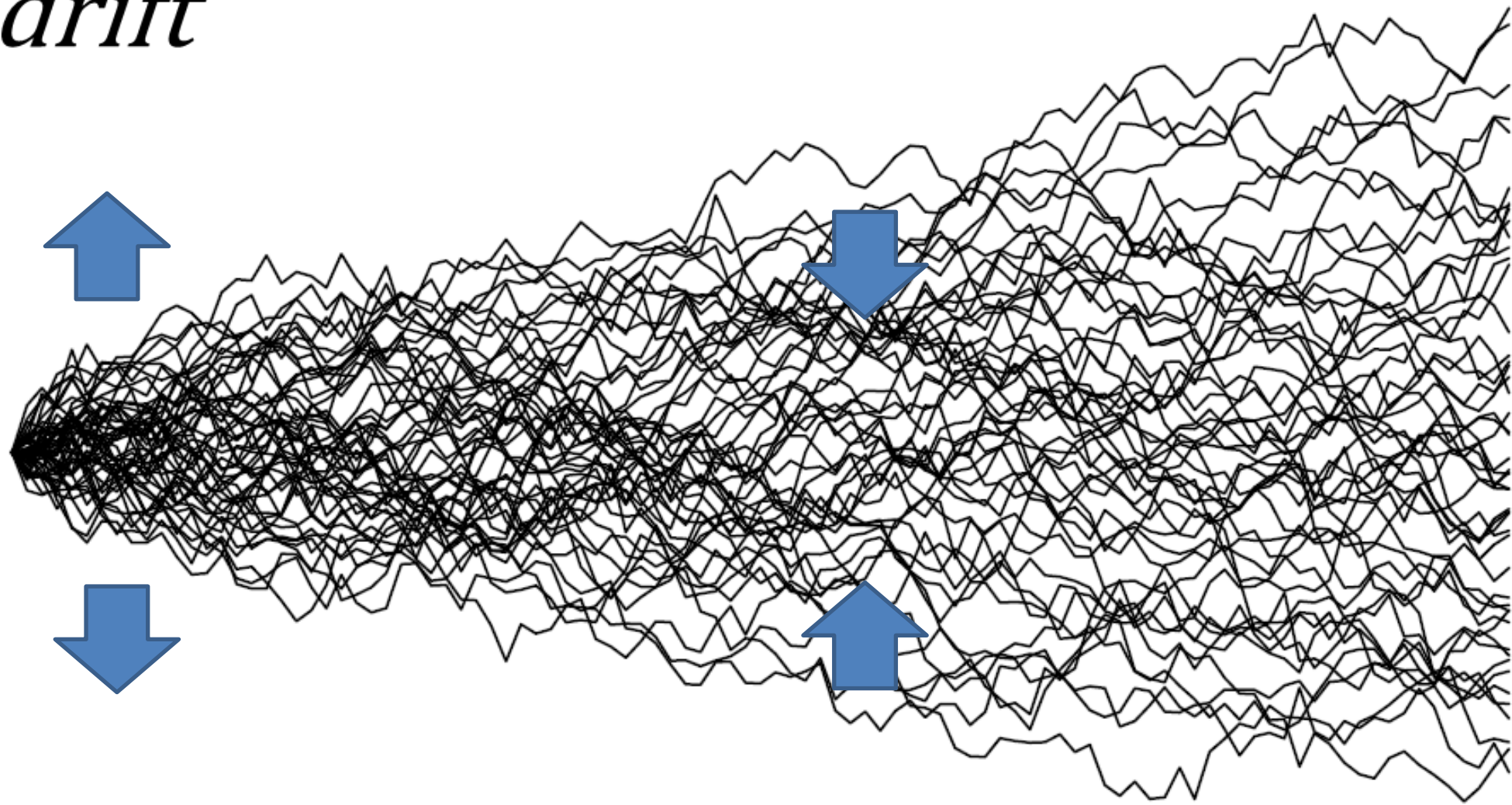




*drift*

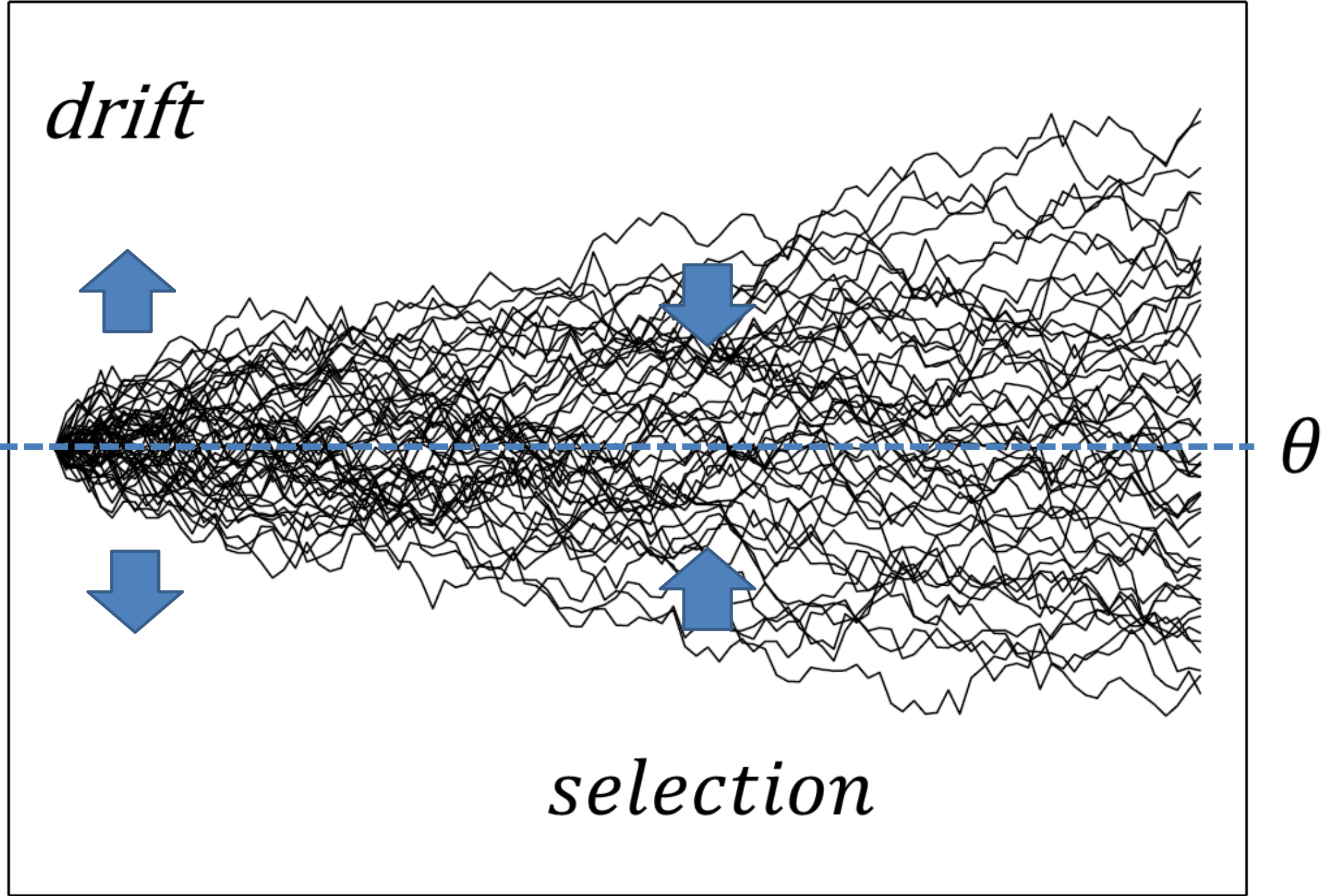


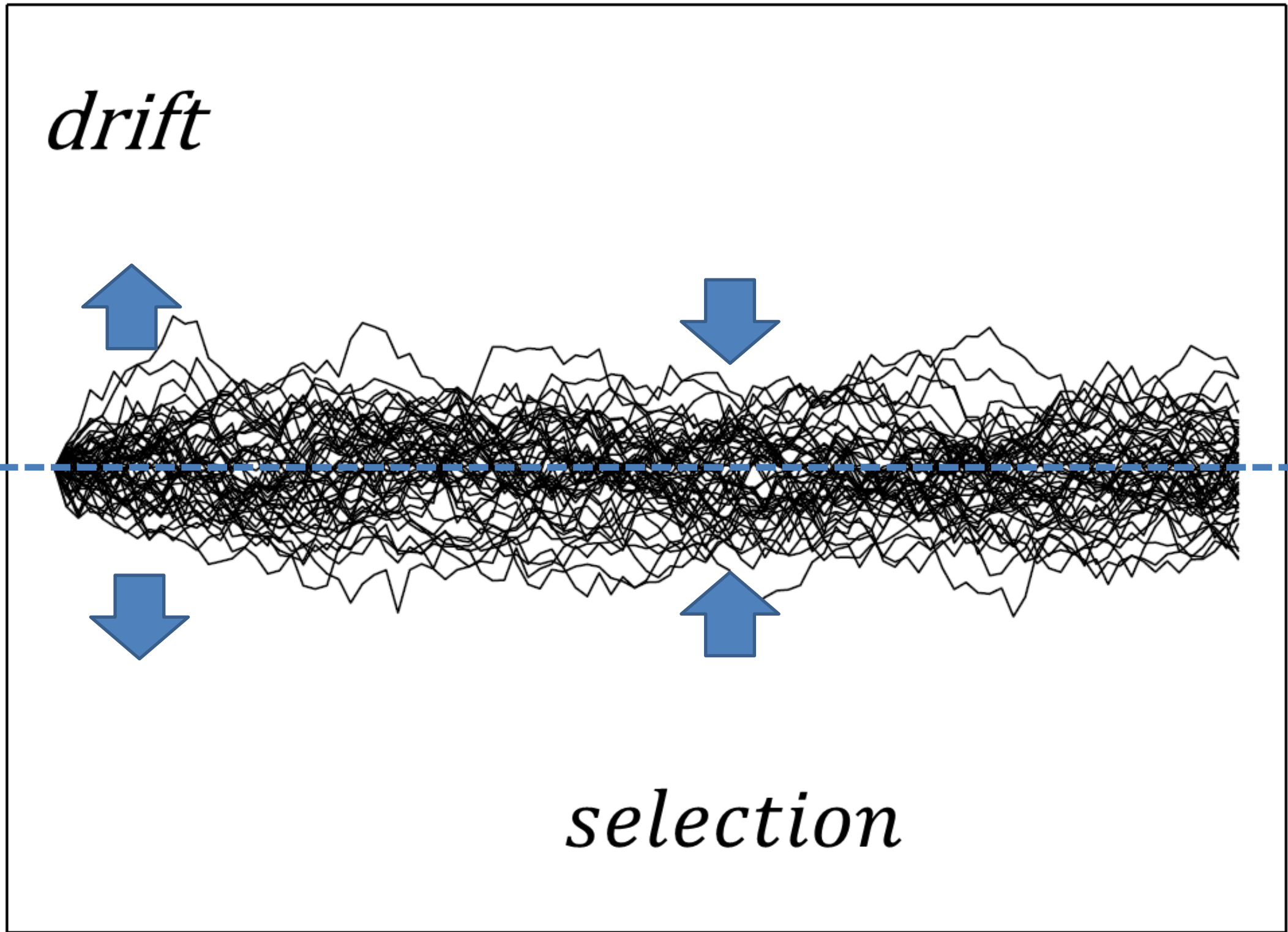
*drift*

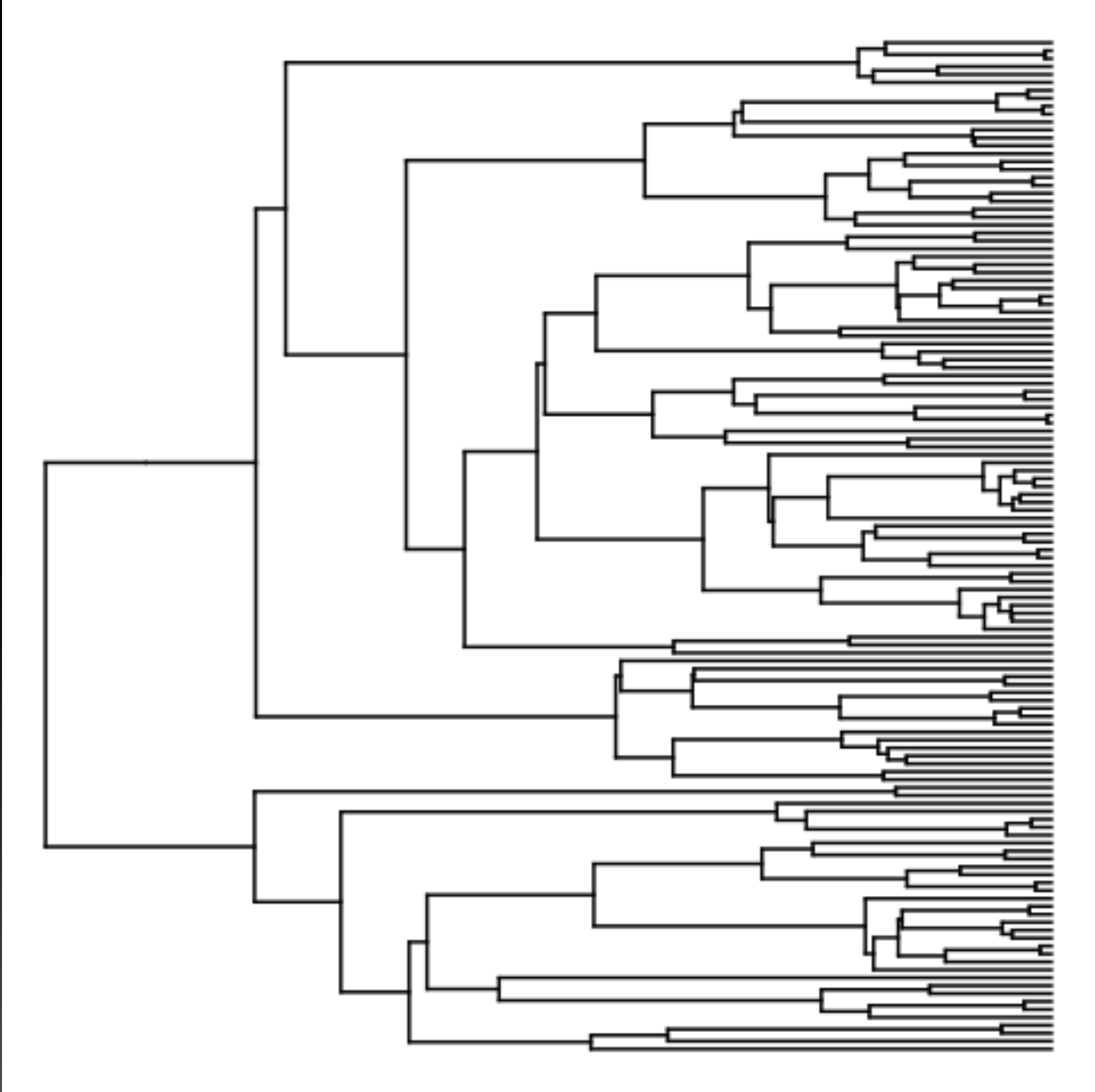


*selection*

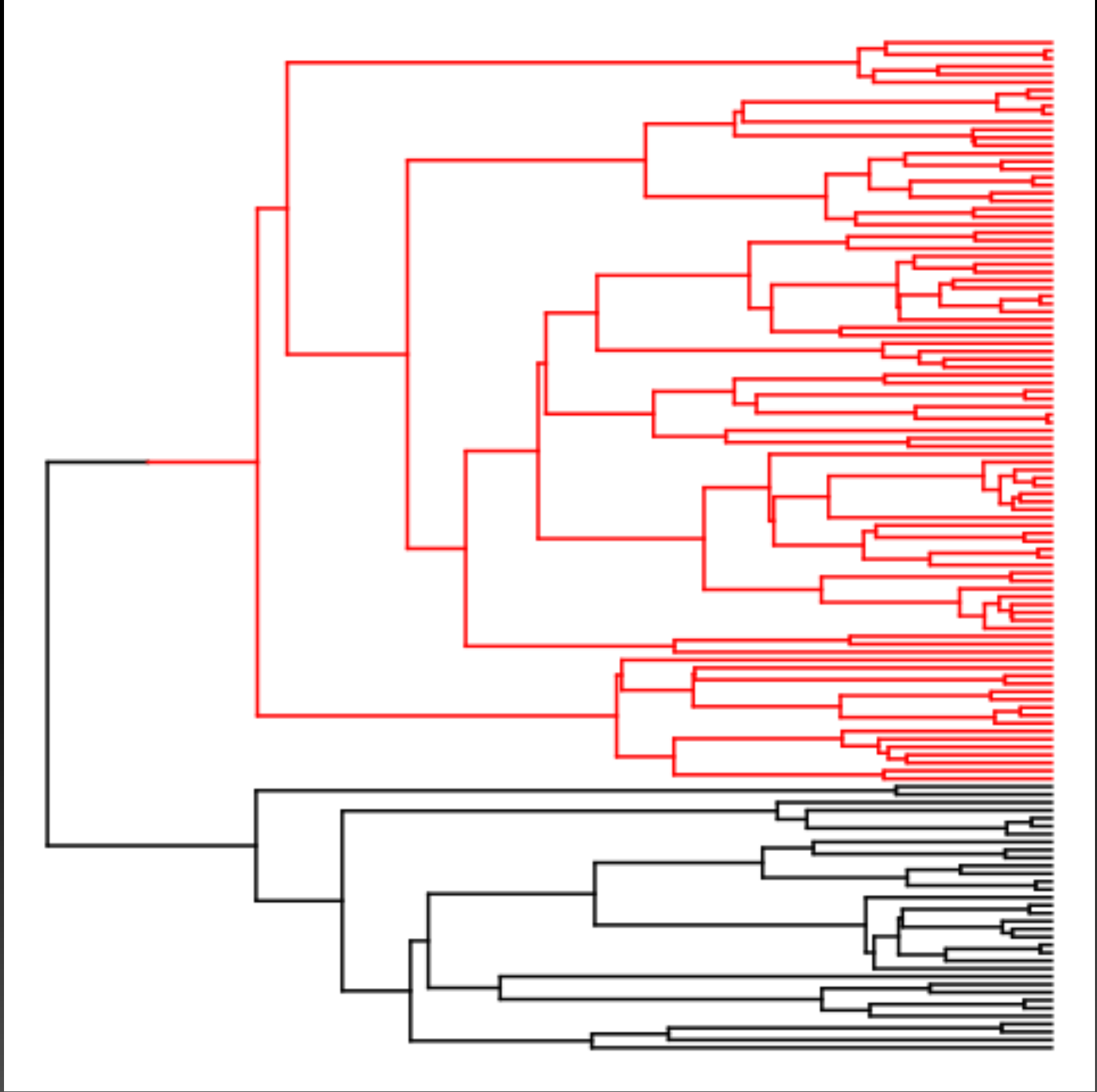


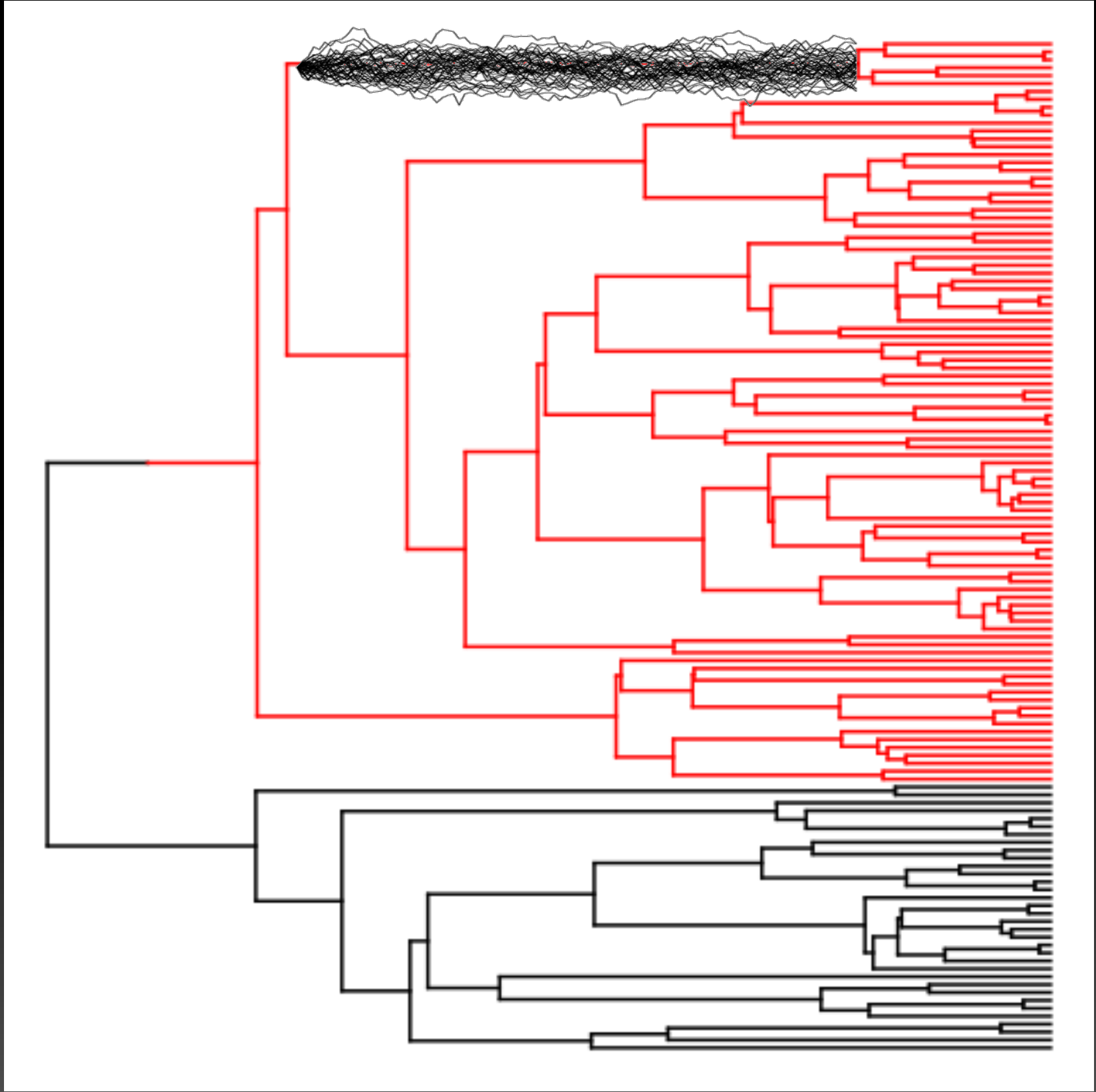




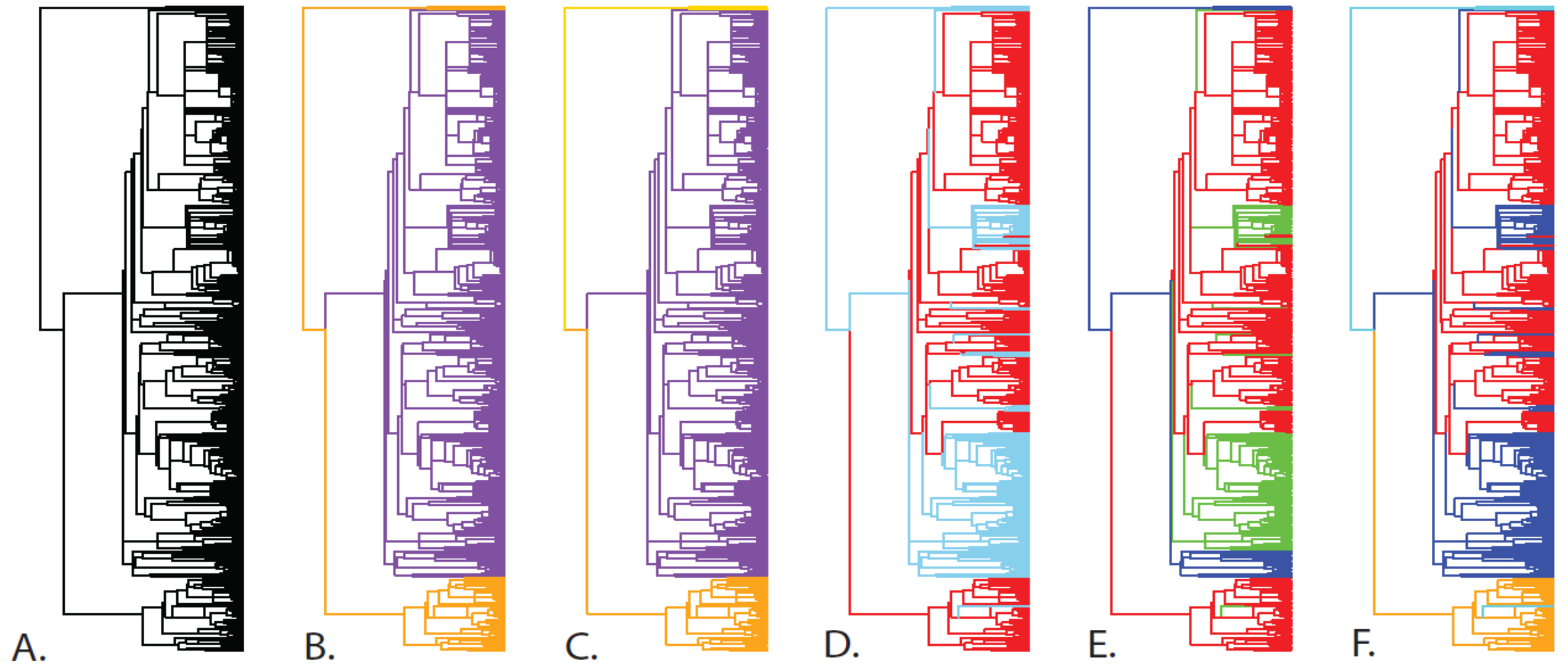


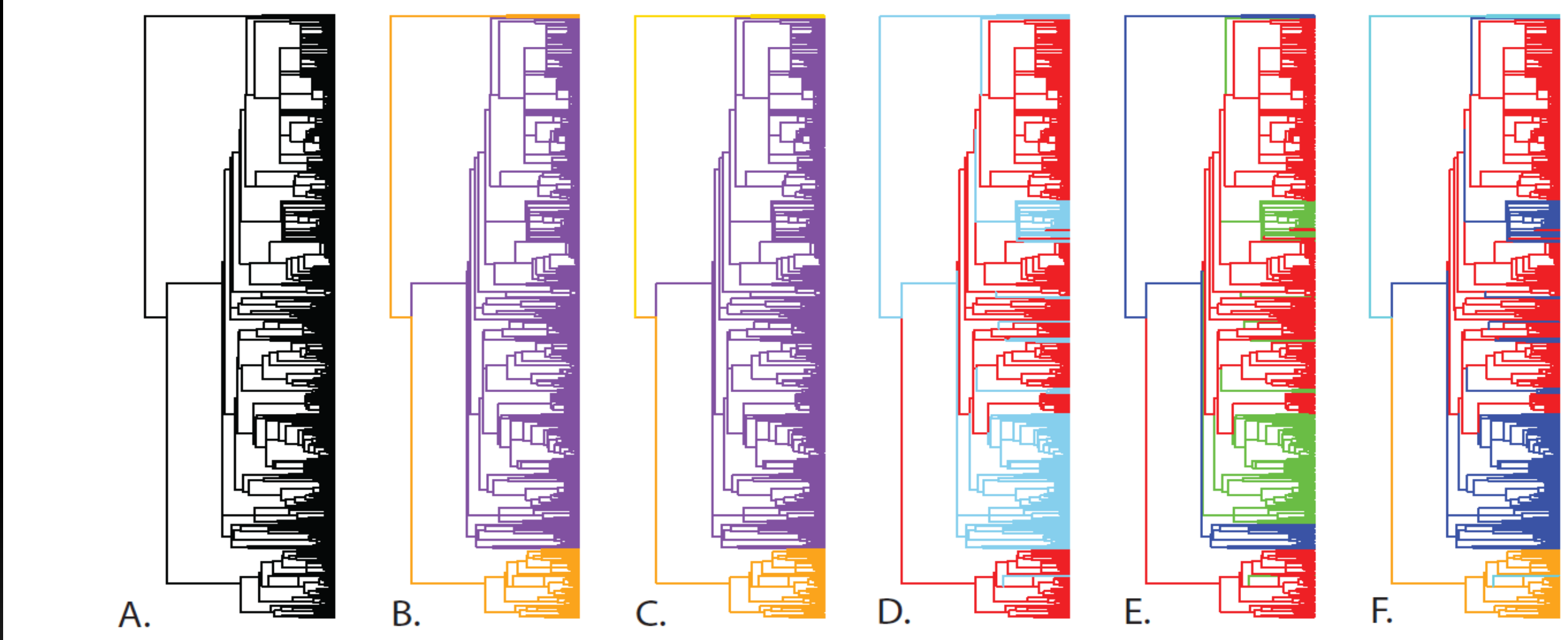




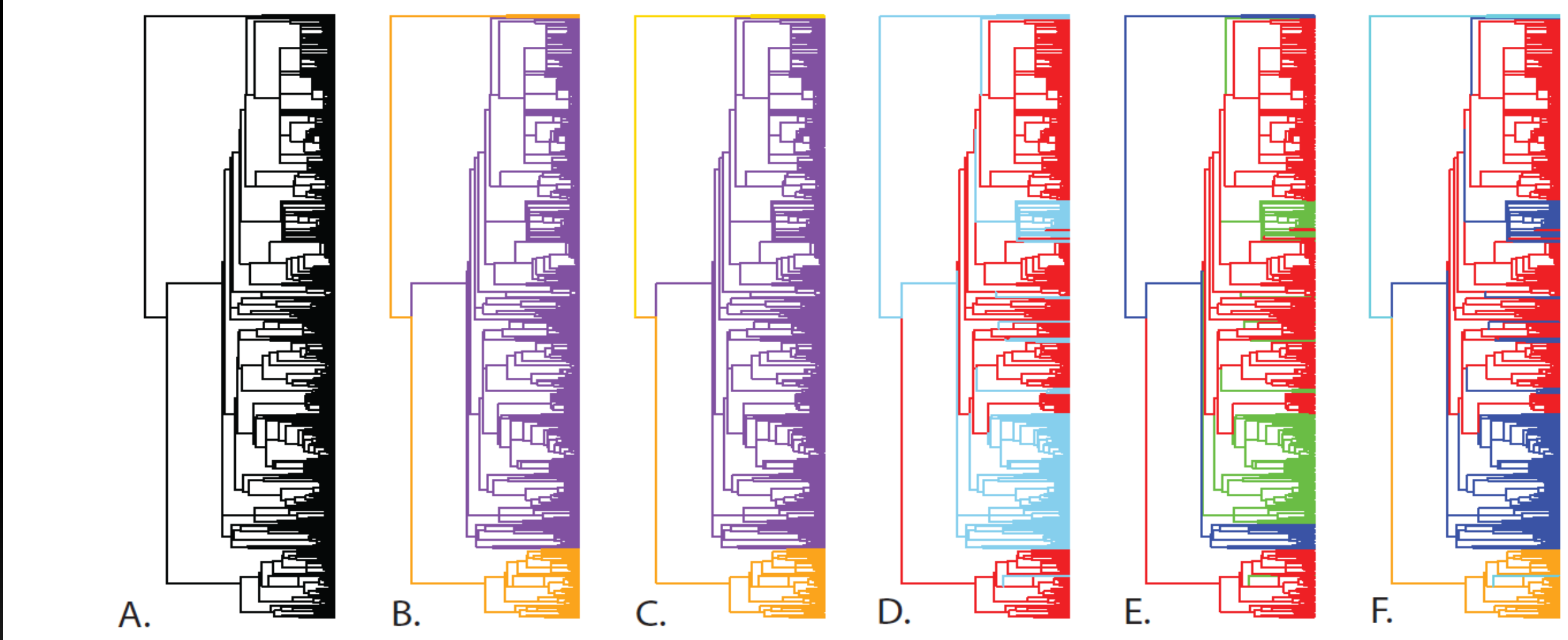


 bayou





# bayou



A.

B.

C.

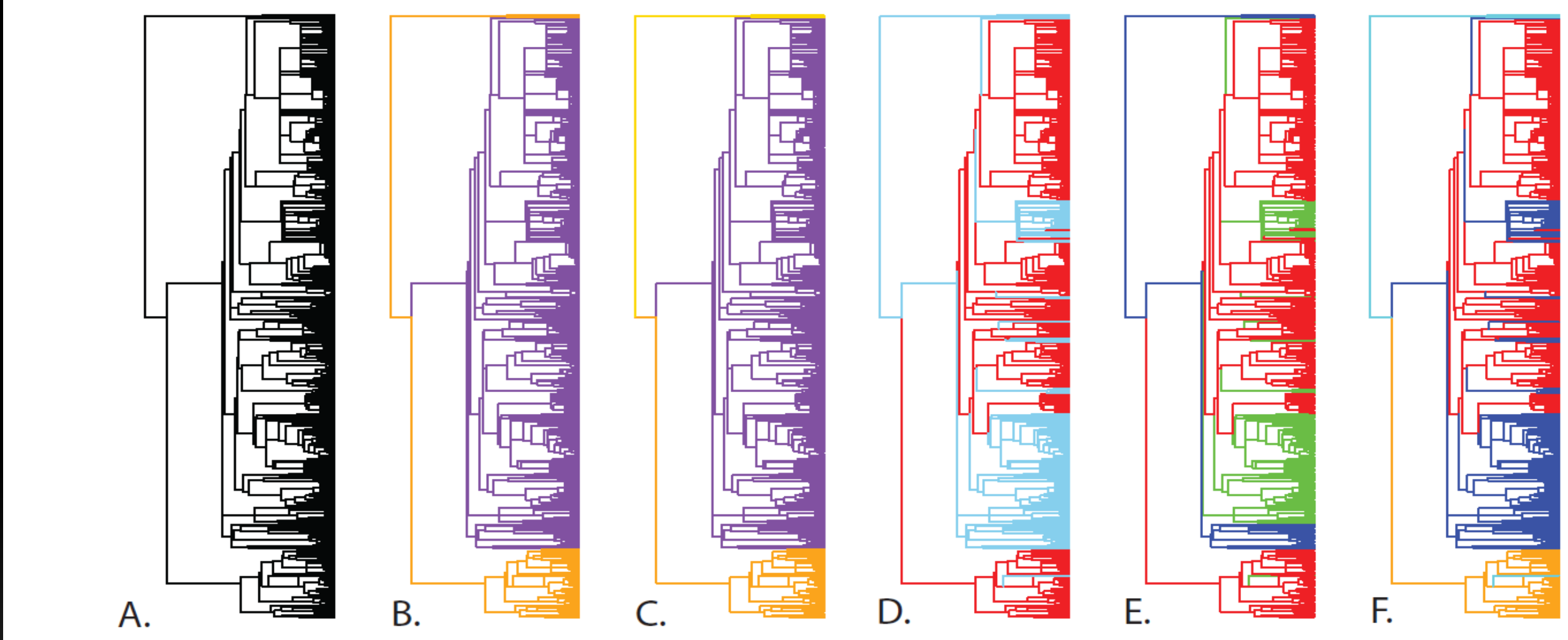
D.

E.

F.



# bayou



A.

B.

C.

D.

E.

F.





# Convergent evolution in anoles



## Trunk – crown anoles:

*A. allisoni* (Cuba) and *A. chlorocyanus* (Hispaniola)

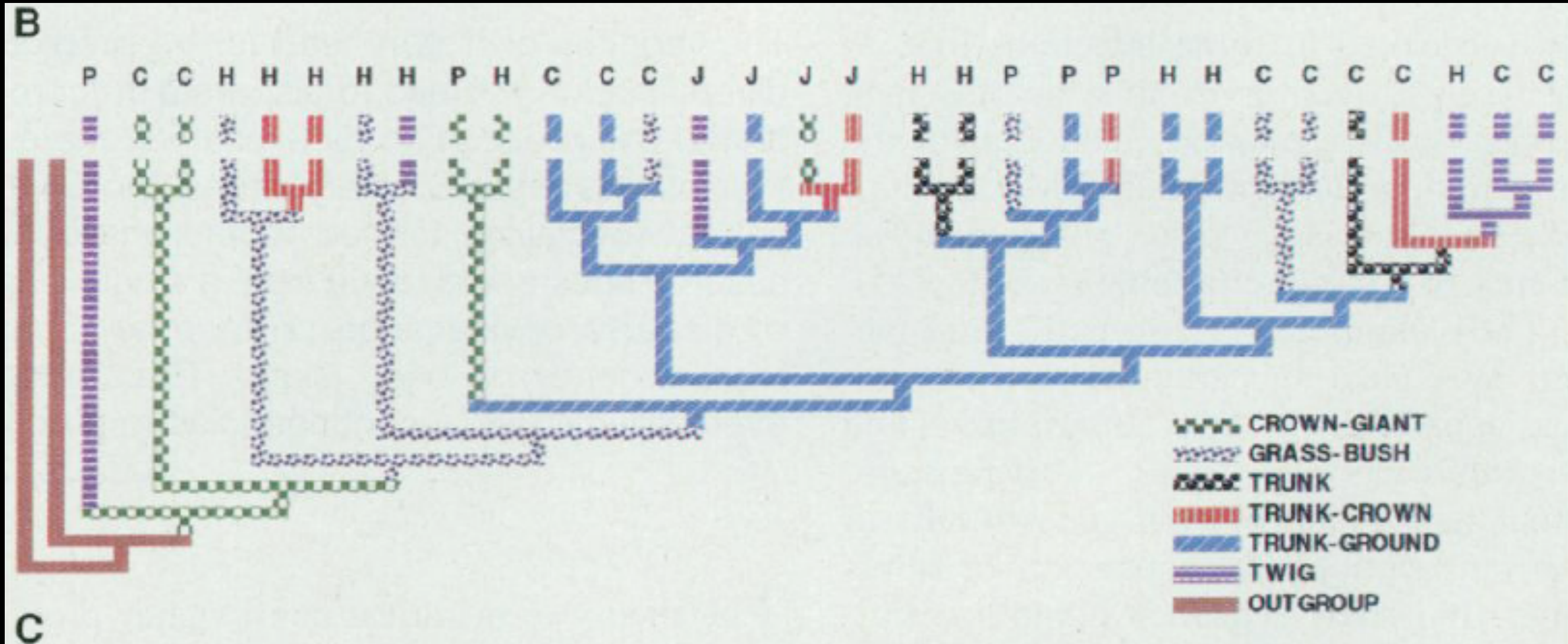


## Twig anoles:

*A. valencienni* (Jamaica) and *A. insolitus* (Hispaniola)



# Convergent evolution in anoles







changes in *adaptive zones*  
along branches in a phylogeny



changes in *adaptive zones*  
along branches in a phylogeny



Method

AUTEUR  
"rbm"

Auteur  
"jump-BM"

Auteur  
"jump-rbm"

BAYOU

Method	Base model
AUTEUR "rbm"	BM
Auteur "jump-BM"	BM
Auteur "jump-rbm"	BM
BAYOU	OU



Method	Base model	Addition
AUTEUR "rbm"	BM	Multiple rates
Auteur "jump-BM"	BM	Jumps
Auteur "jump-rbm"	BM	Multiple rates and jumps
BAYOU	OU	Multiple peaks

Method	Base model	Addition	Notes
AUTEUR "rbm"	BM	Multiple rates	Similar to BAMM
Auteur "jump-BM"	BM	Jumps	Levy walk
Auteur "jump-rbm"	BM	Multiple rates and jumps	Untested!
BAYOU	OU	Multiple peaks	Like Surface, but Bayesian