

Evolution in networks

Fernando Pedraza

31.03.23

fernando.pedraza@ieu.uzh.ch



In the light of evolution



“Seen in the light of evolution, biology is, perhaps, intellectually the most satisfying and inspiring science. Without that light it becomes a pile of sundry facts -- some of them interesting or curious but making no meaningful picture as a whole.”

Theodosius Dobzhansky

"... whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

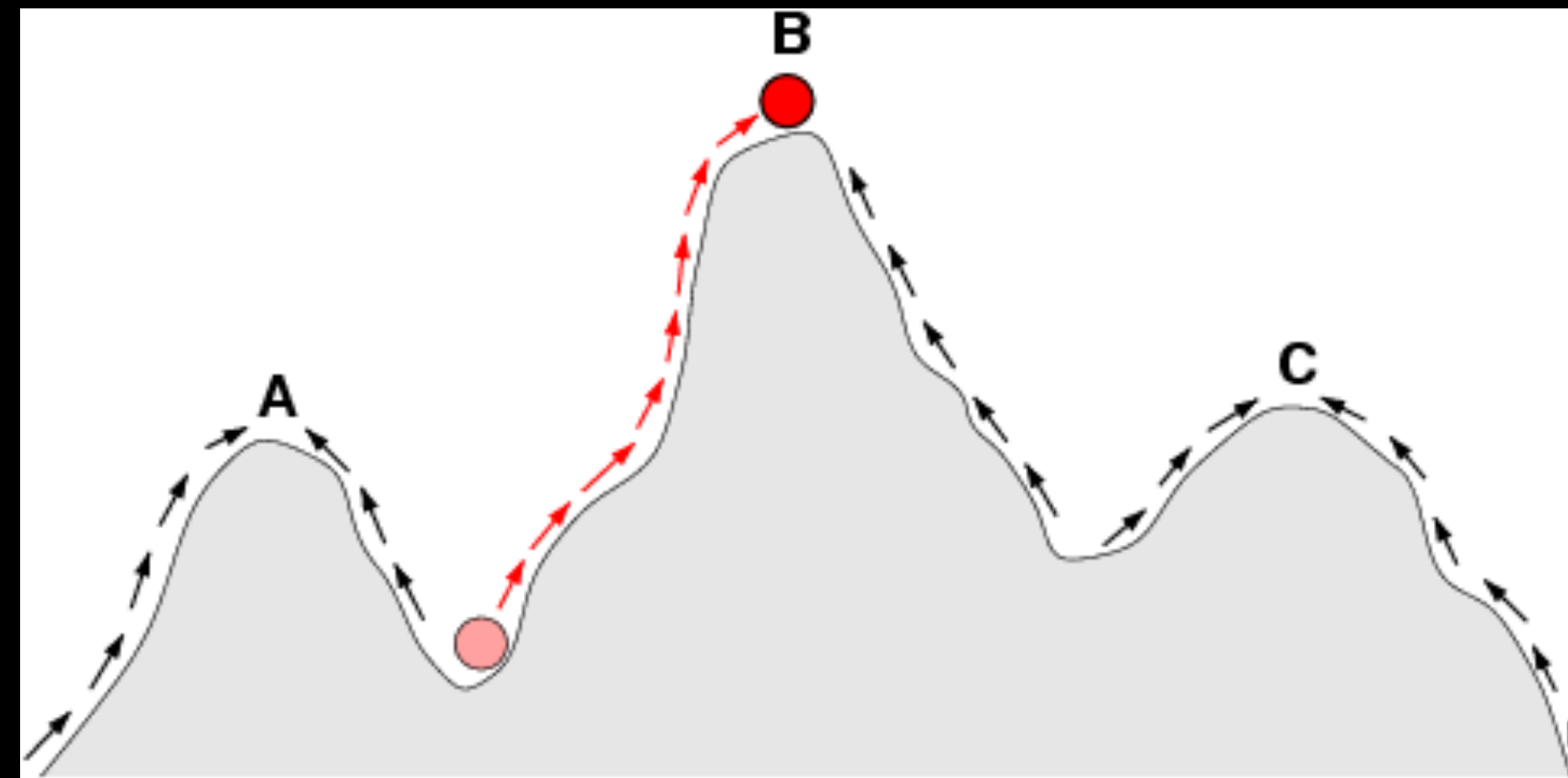
Charles Darwin, *The Origin of Species*



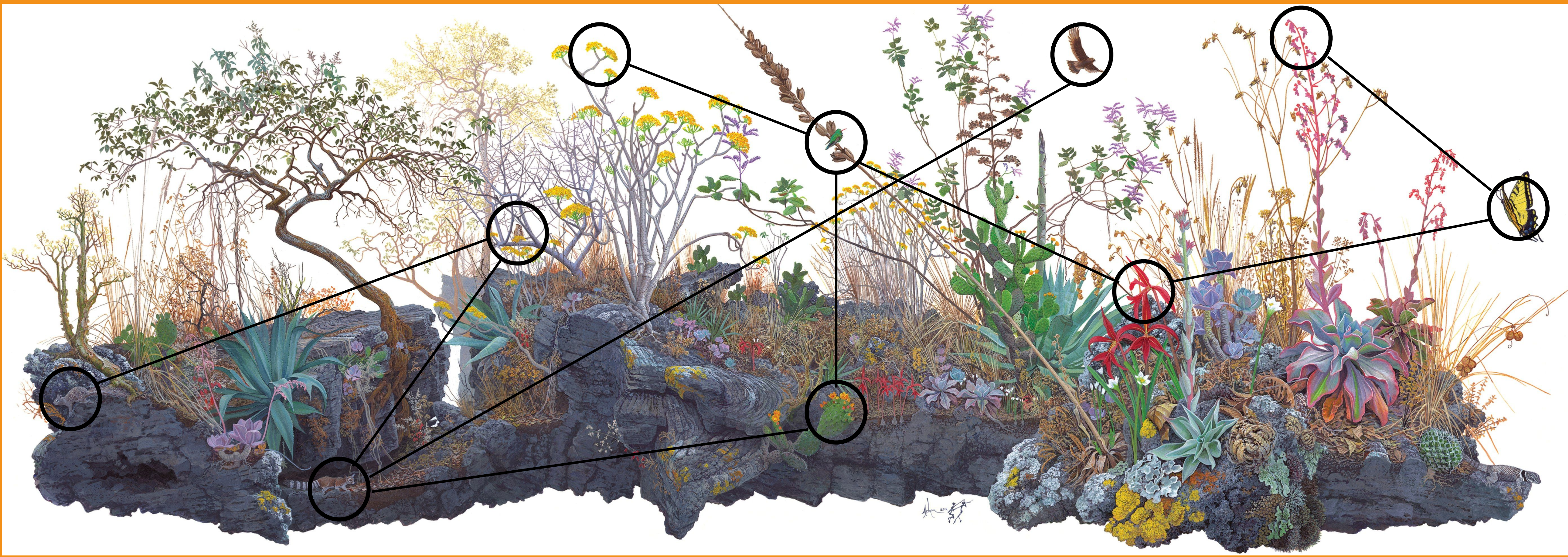
Art by Aslam Narváez

Evolution: a simple definition

Process that results in **changes** in the genetic material of a population over **time**. Evolution reflects the **adaptations** of organisms to their changing environments and can result in altered genes, novel traits, and new species.

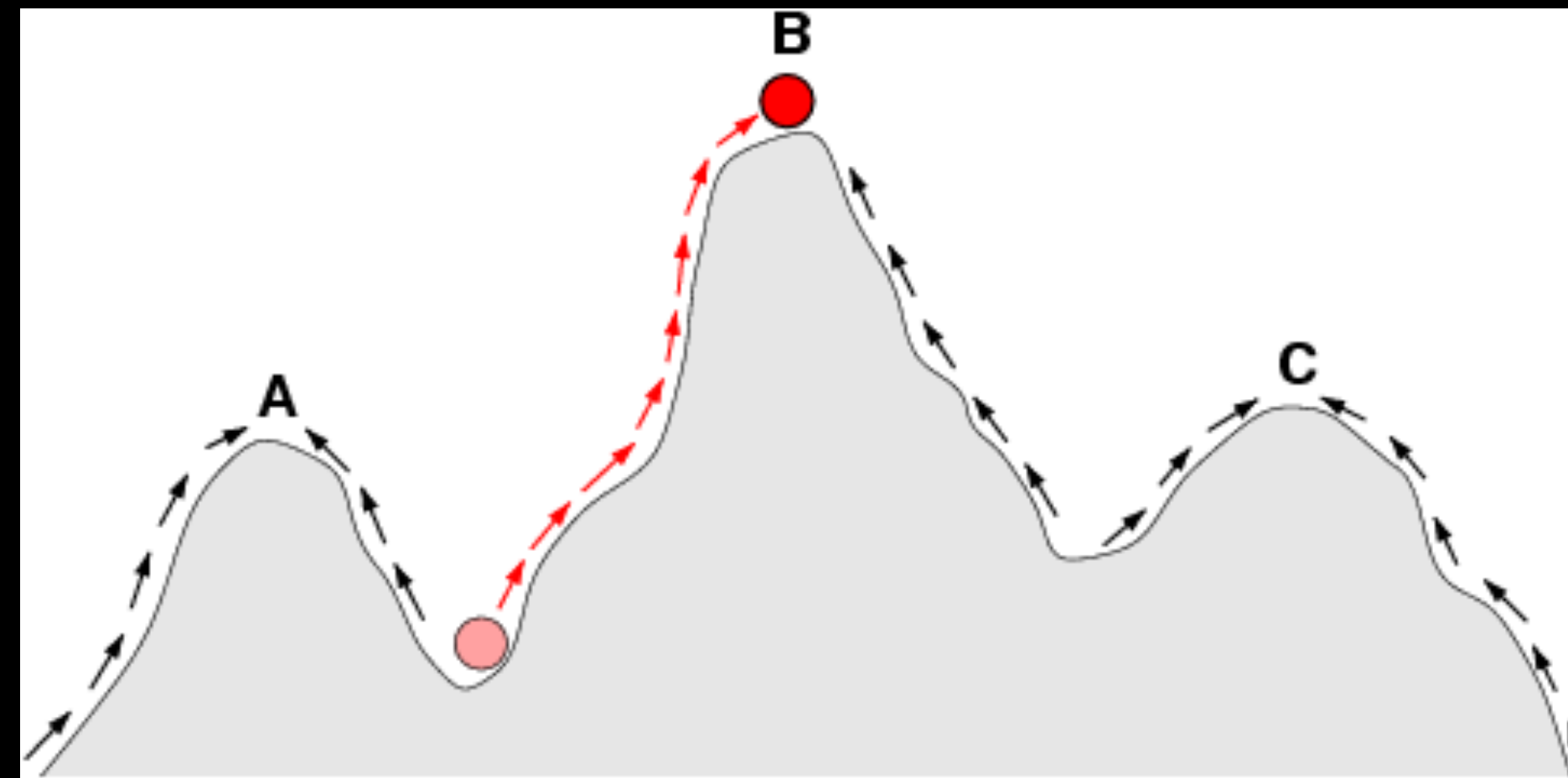






Coevolution: a simple definition

Process by which two or more species evolve in **tandem** by exerting **selection pressures** on each other.

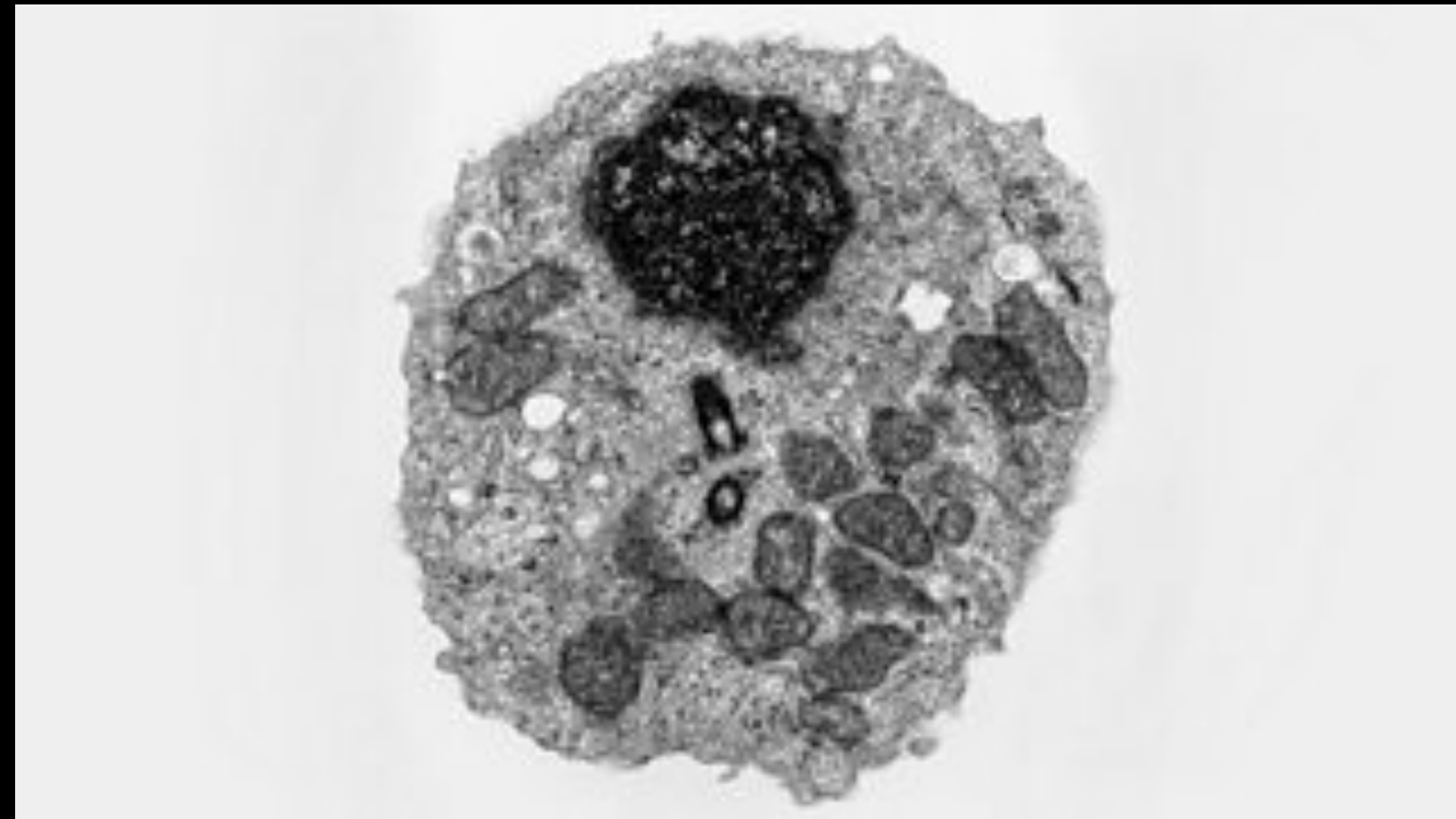


Butterflies and plants: a study in coevolution

“It is apparent that reciprocal selective responses have been greatly underrated as a factor in the origination of organic diversity.”

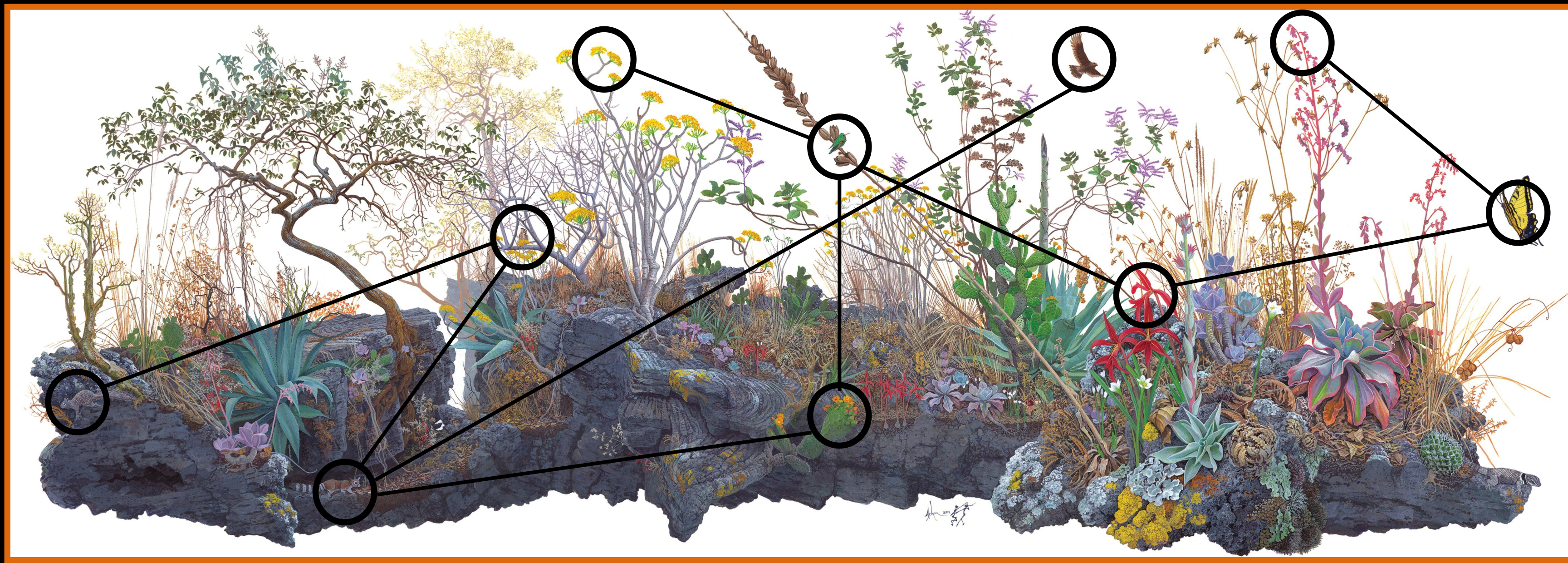


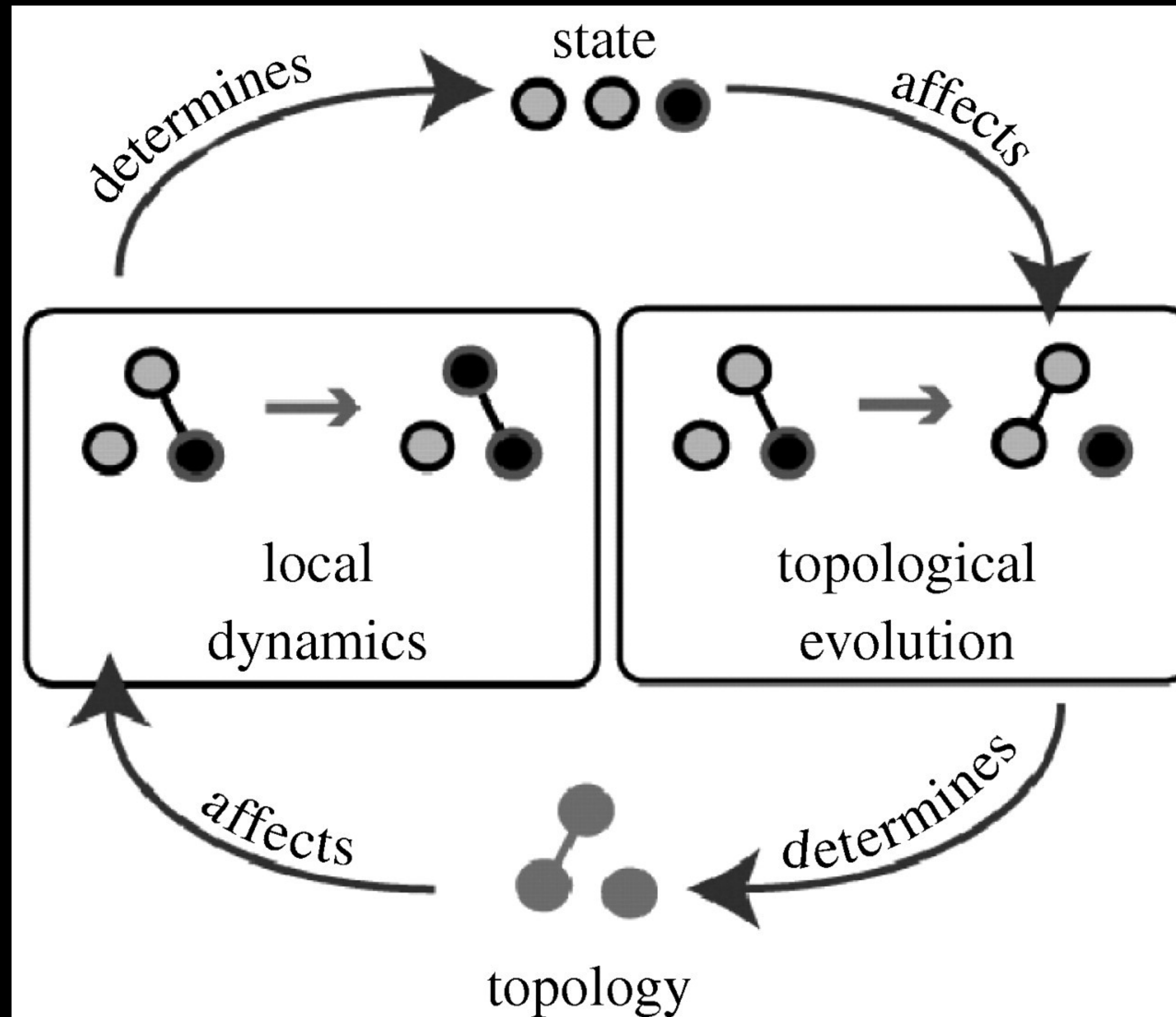
Much of evolution is coevolution



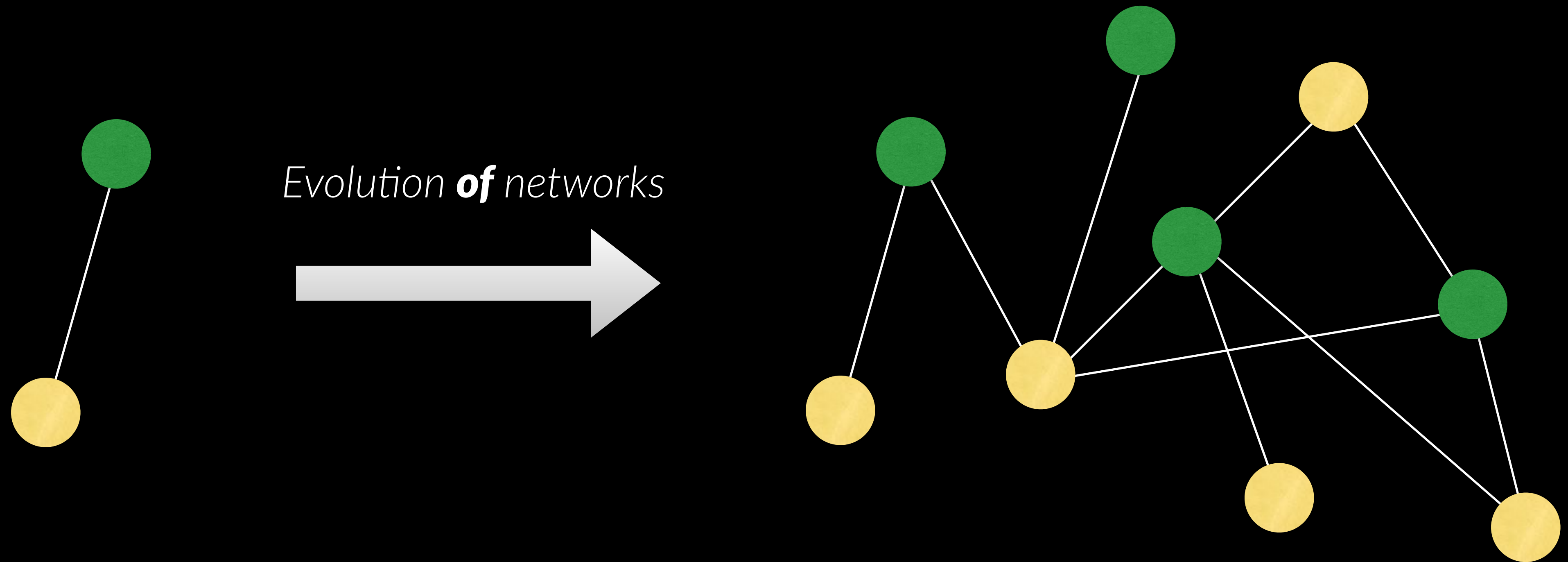
“There is now little question that coevolution has shaped many of the major events in the history of life.”

How do we frame ecological networks in the light of (co)evolution?

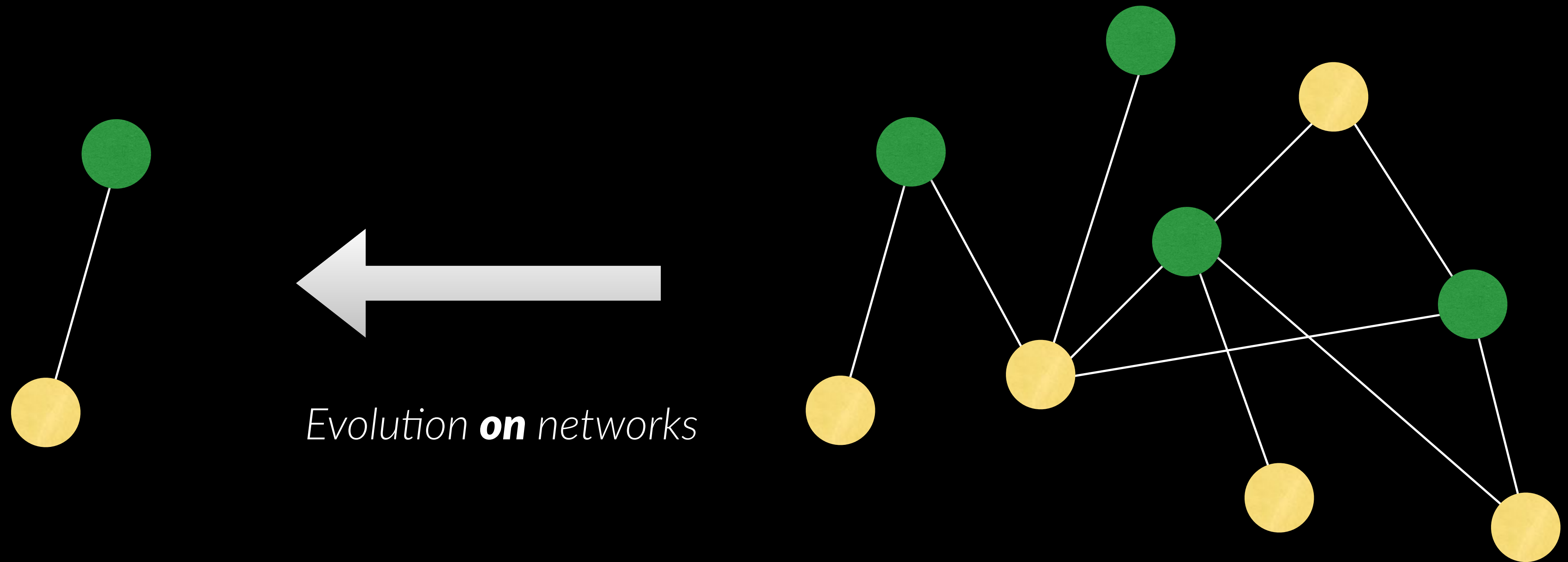




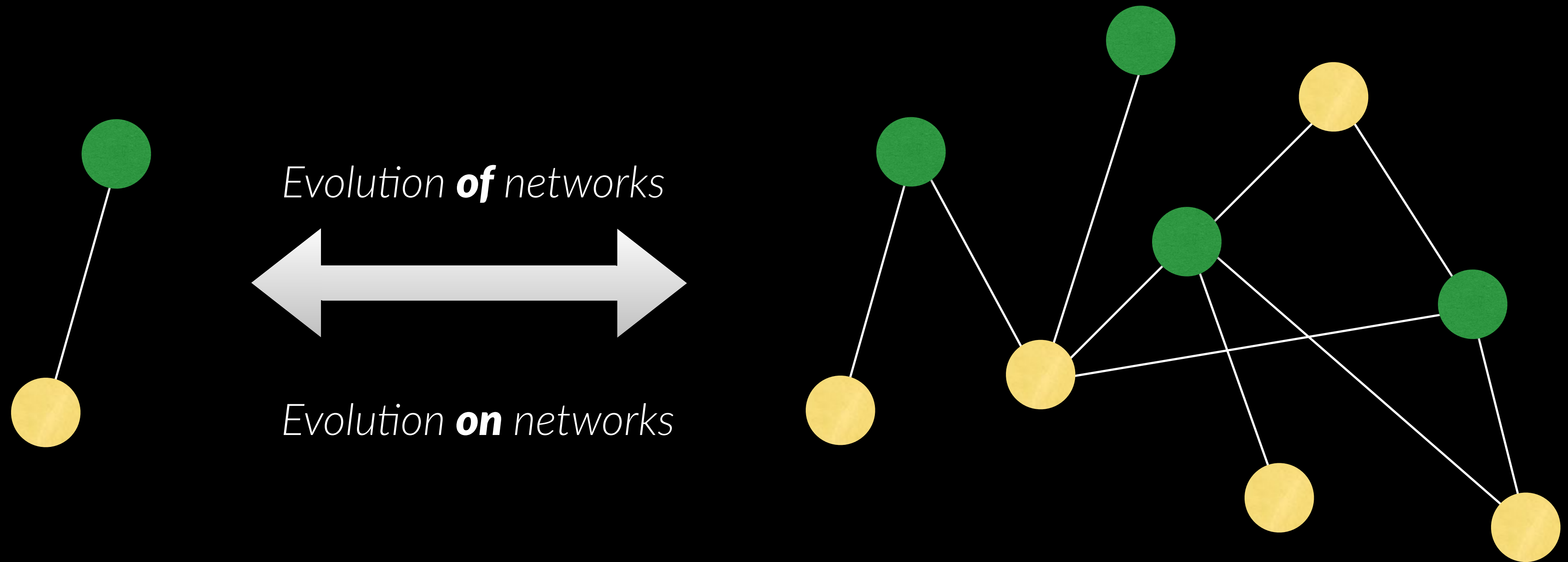
Evolution and networks: the chicken and egg problem



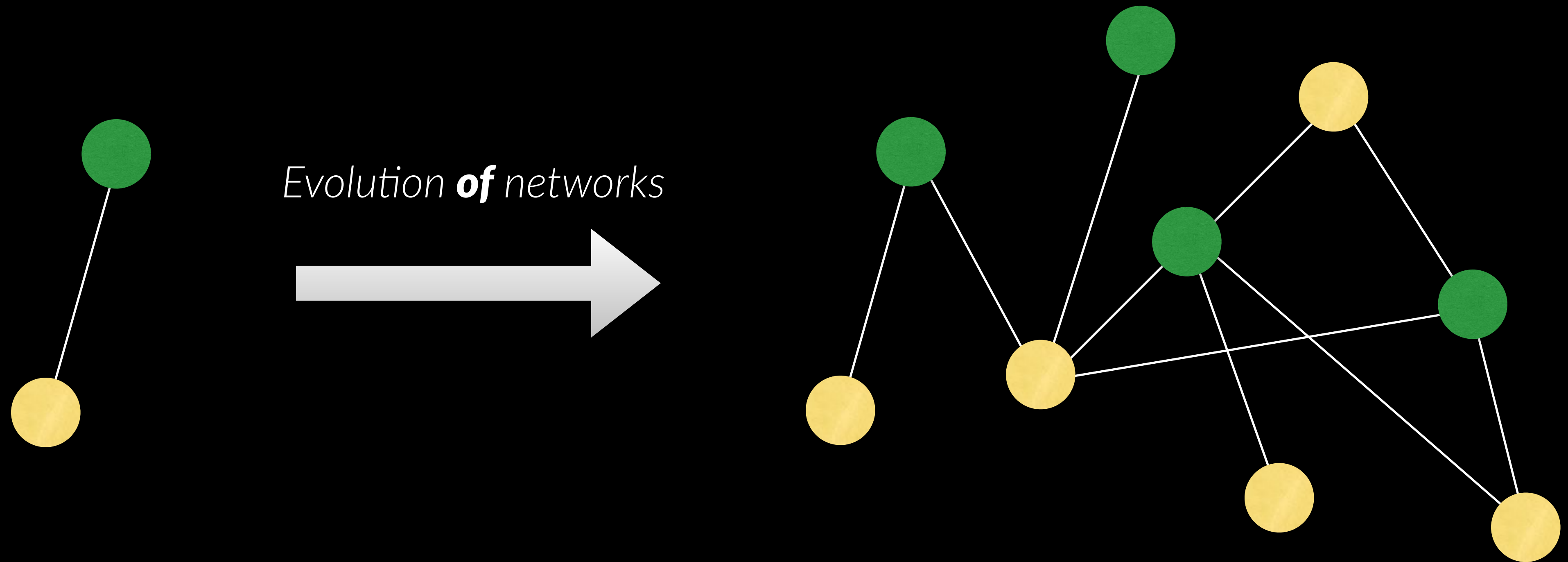
Evolution and networks: the chicken and egg problem



Evolution and networks: the chicken and egg problem



Evolution and networks: the chicken and egg problem



Evolution of networks

- *To what extent is network architecture associated with species phylogenetic relationship?*
- *What is the role of coevolution in driving changes in the structure of species interaction networks?*



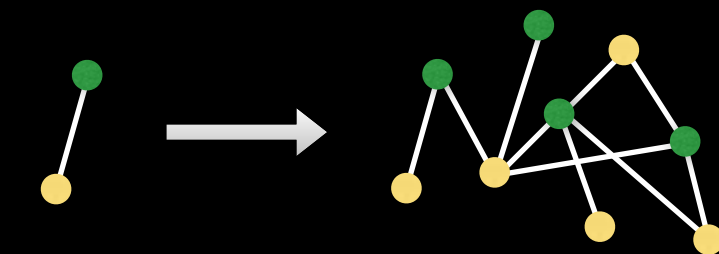
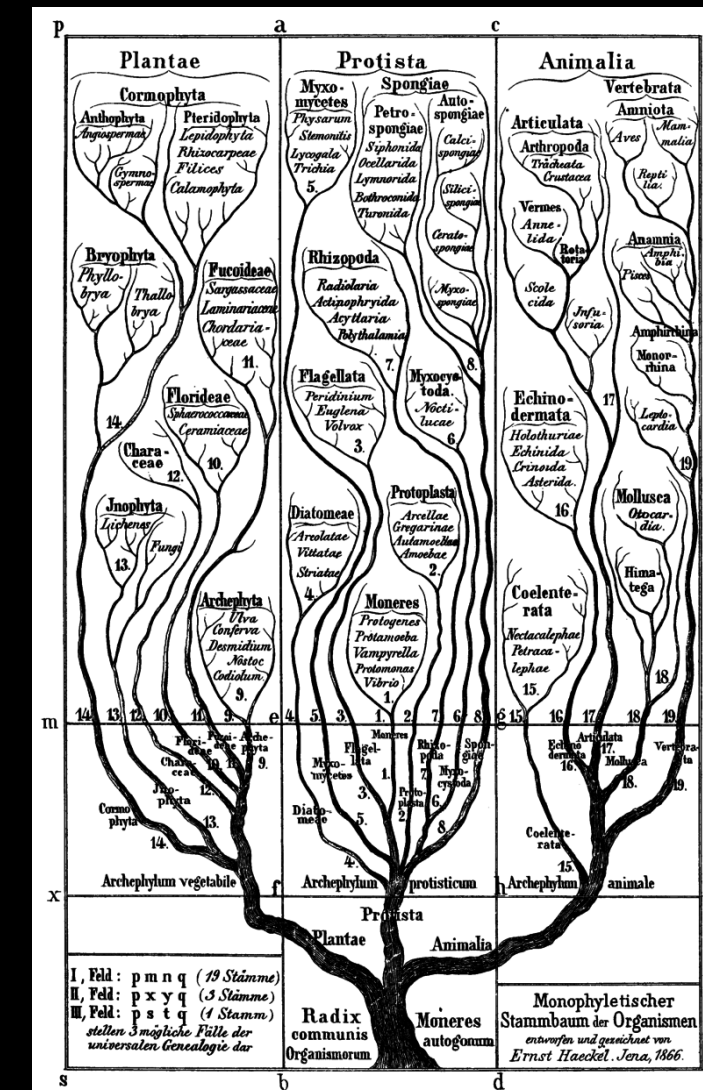
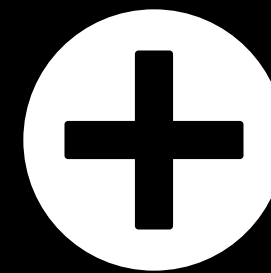
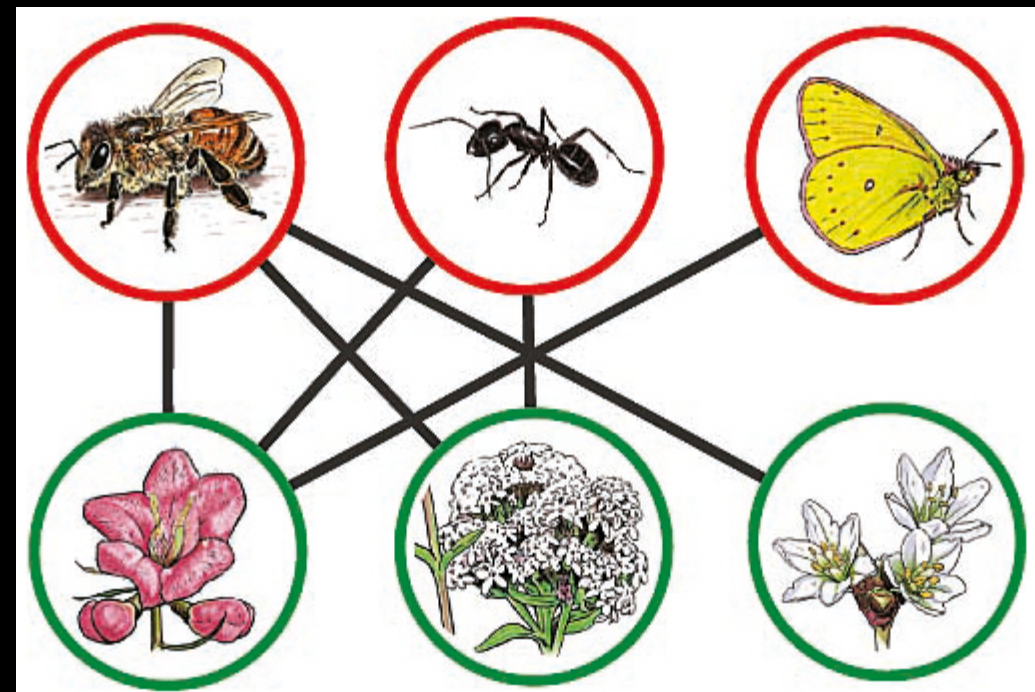
Evolution of networks

- *To what extent is network architecture associated with species phylogenetic relationship?*
- *What is the role of coevolution in driving changes in the structure of species interaction networks?*



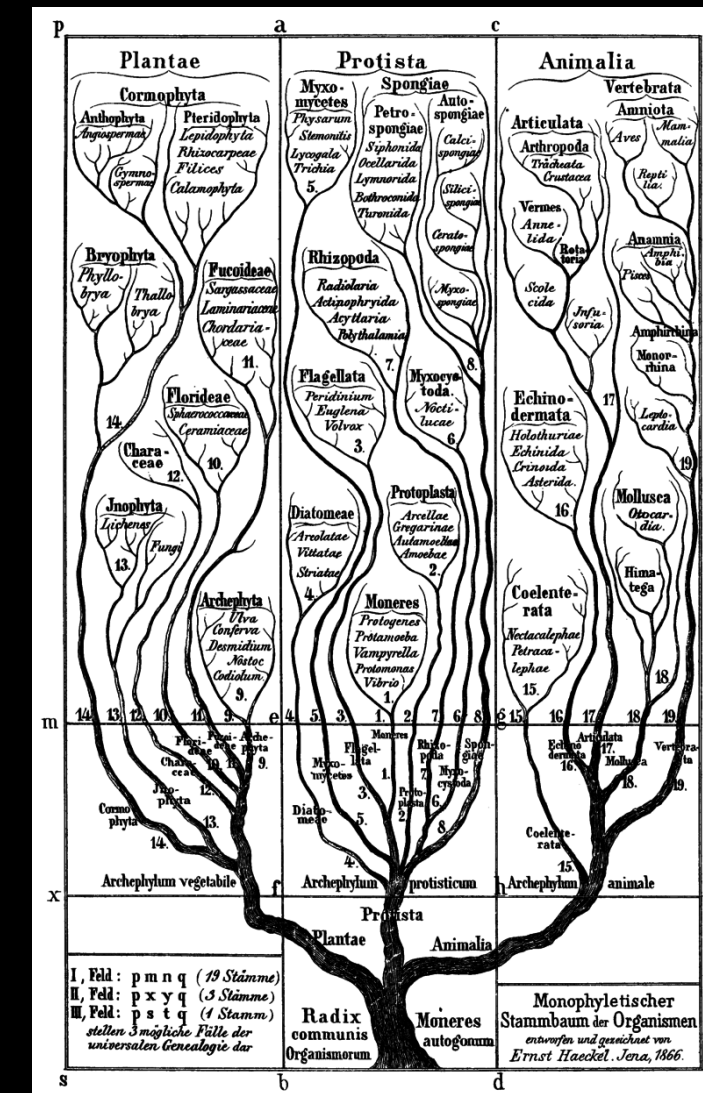
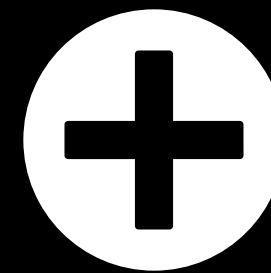
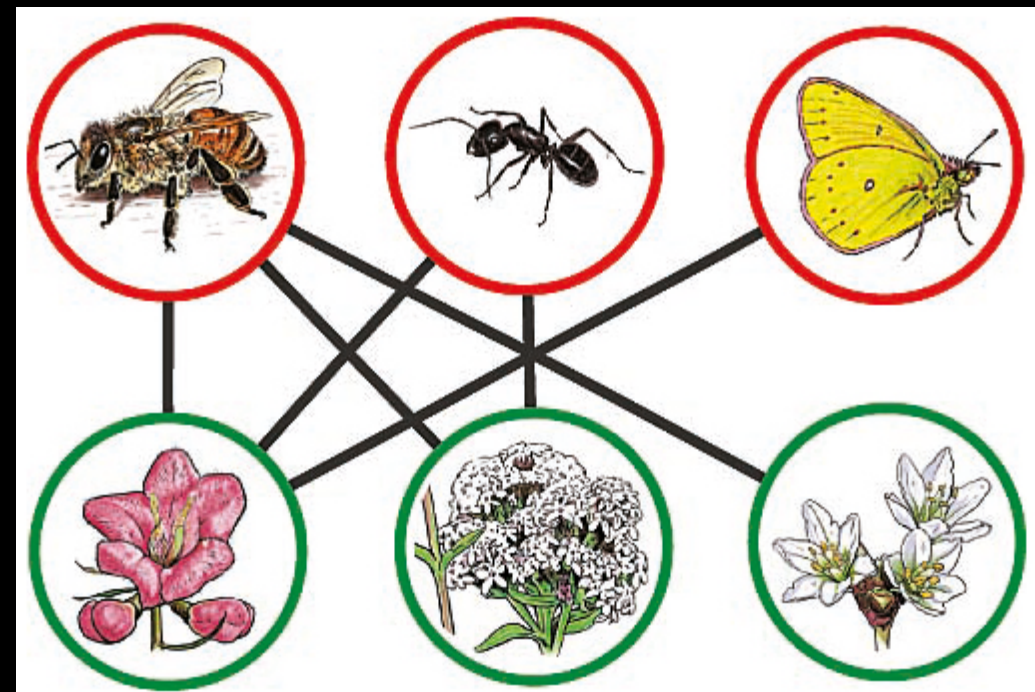
Evolution of networks

To what extent is network architecture associated with species phylogenetic relationship?

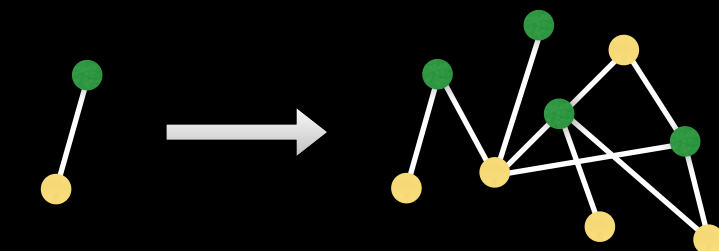


Evolution of networks

To what extent is network architecture associated with species phylogenetic relationship?

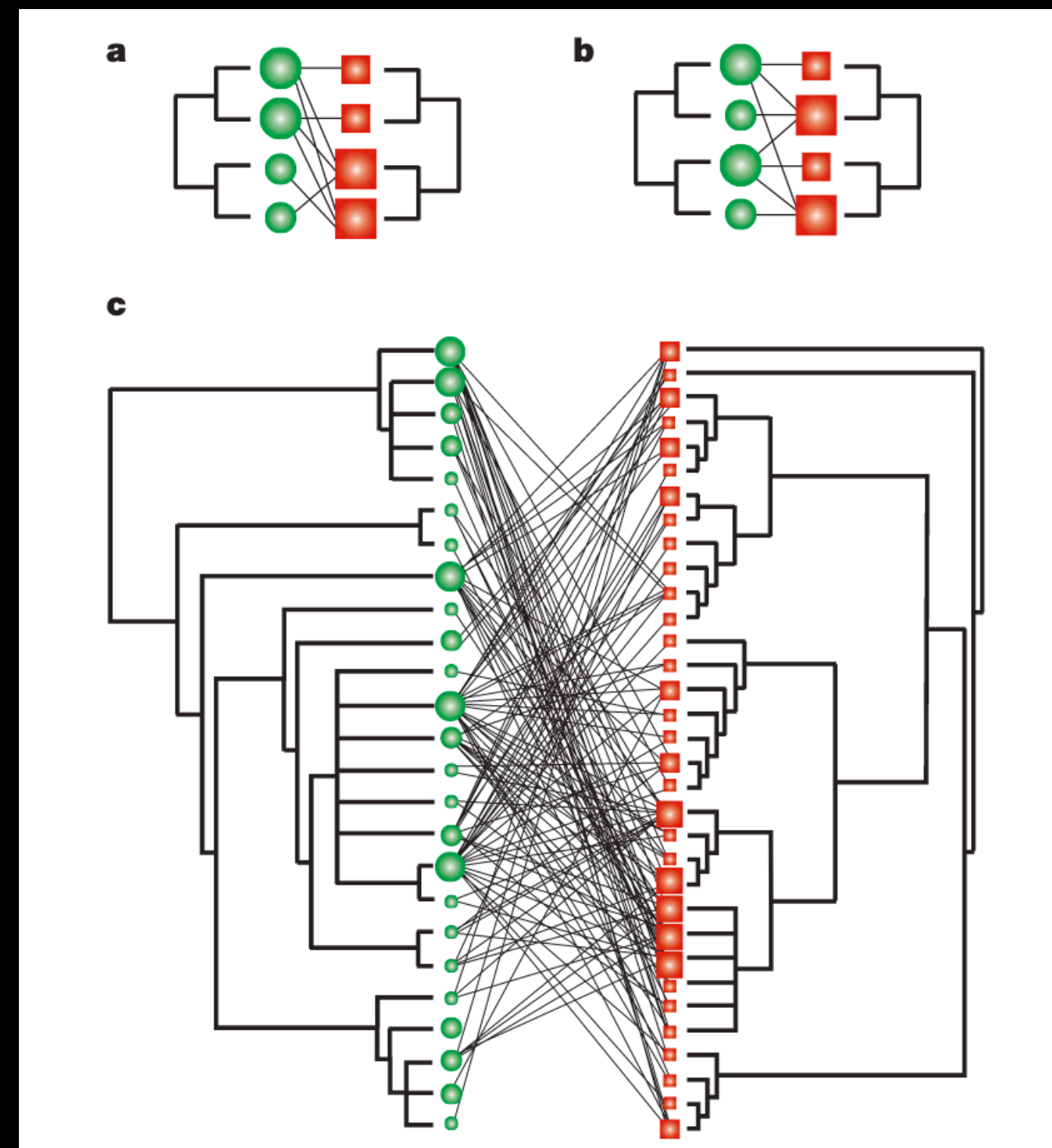


If patterns of interactions between species can be partly explained by phylogenetic relatedness, then this would suggest that network patterns are partially dependent on past evolutionary history.

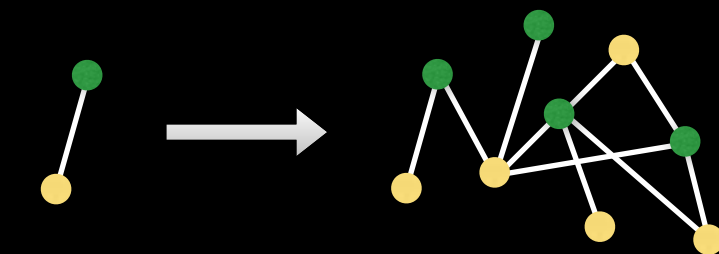


Evolution of networks

To what extent is network architecture associated with species phylogenetic relationship?

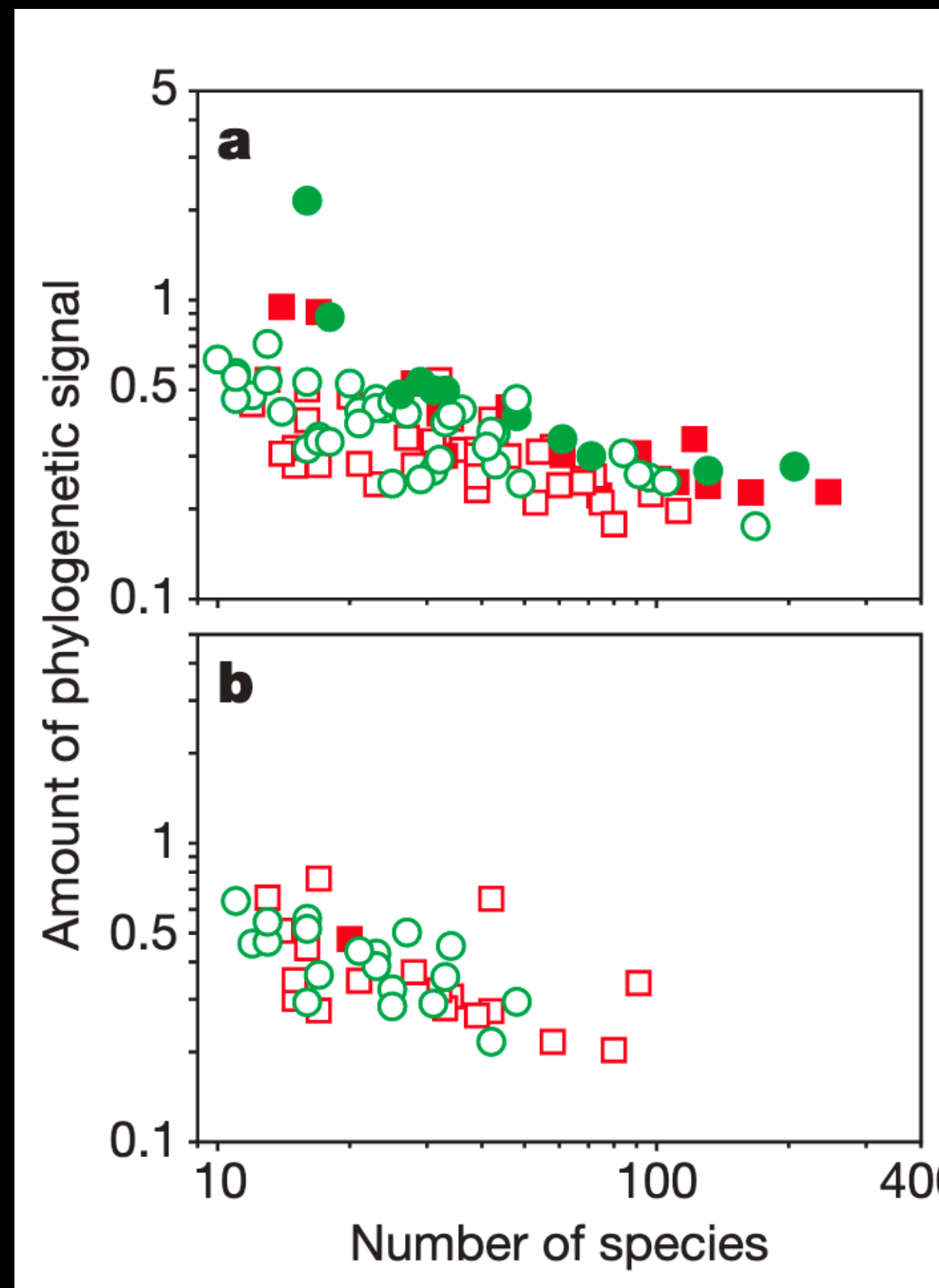


Rezende, Lavabre, Guimaraes, Jordano and Bascompte (2007). *Nature*, 448: 925-928



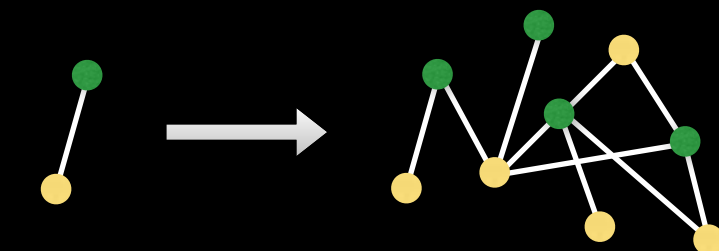
Evolution of networks

To what extent is network architecture associated with species phylogenetic relationship?



“Our results warrant the inclusion of evolutionary history into mechanistic models of network formation and maintenance”

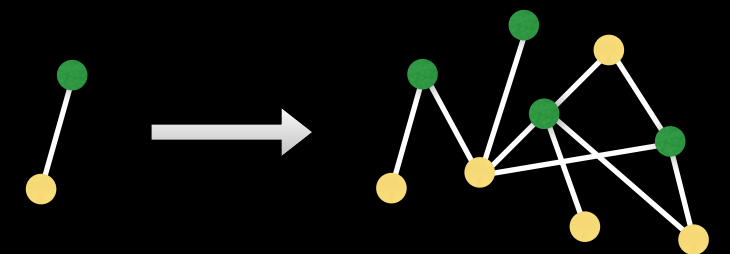
Rezende, Lavabre, Guimaraes, Jordano and Bascompte (2007). *Nature*, 448: 925-928



Evolution of networks

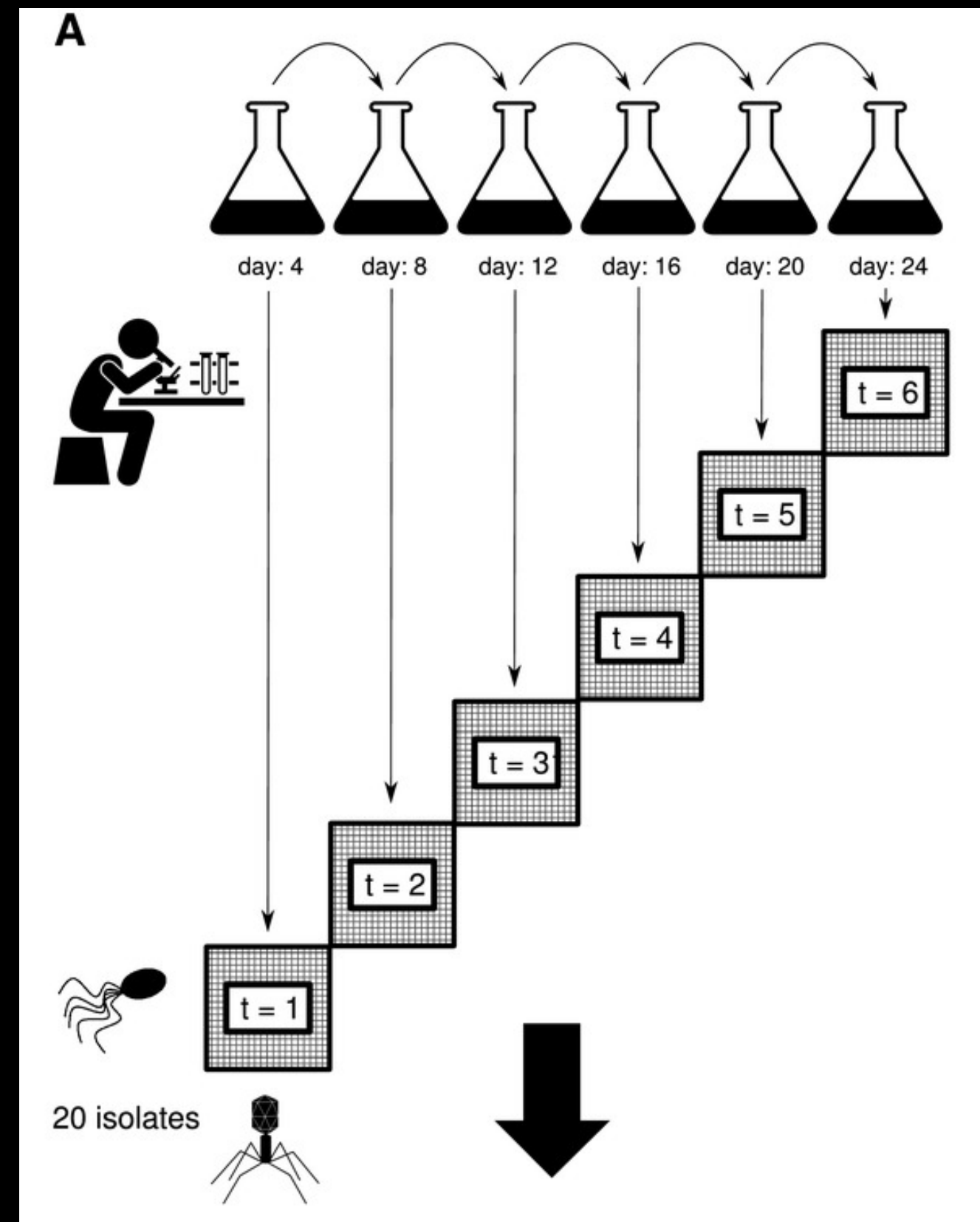
To what extent is network architecture associated with species phylogenetic relationship?

What is the role of coevolution in driving changes in the structure of species interaction networks?

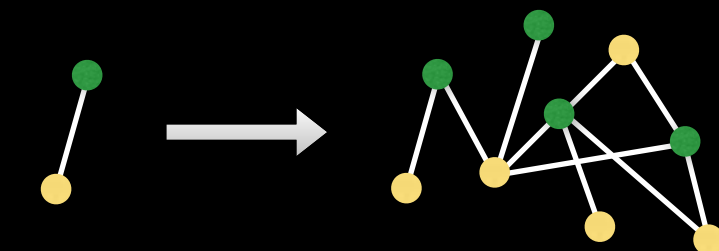


Evolution of networks

What is the role of coevolution in driving changes in the structure of species interaction networks?

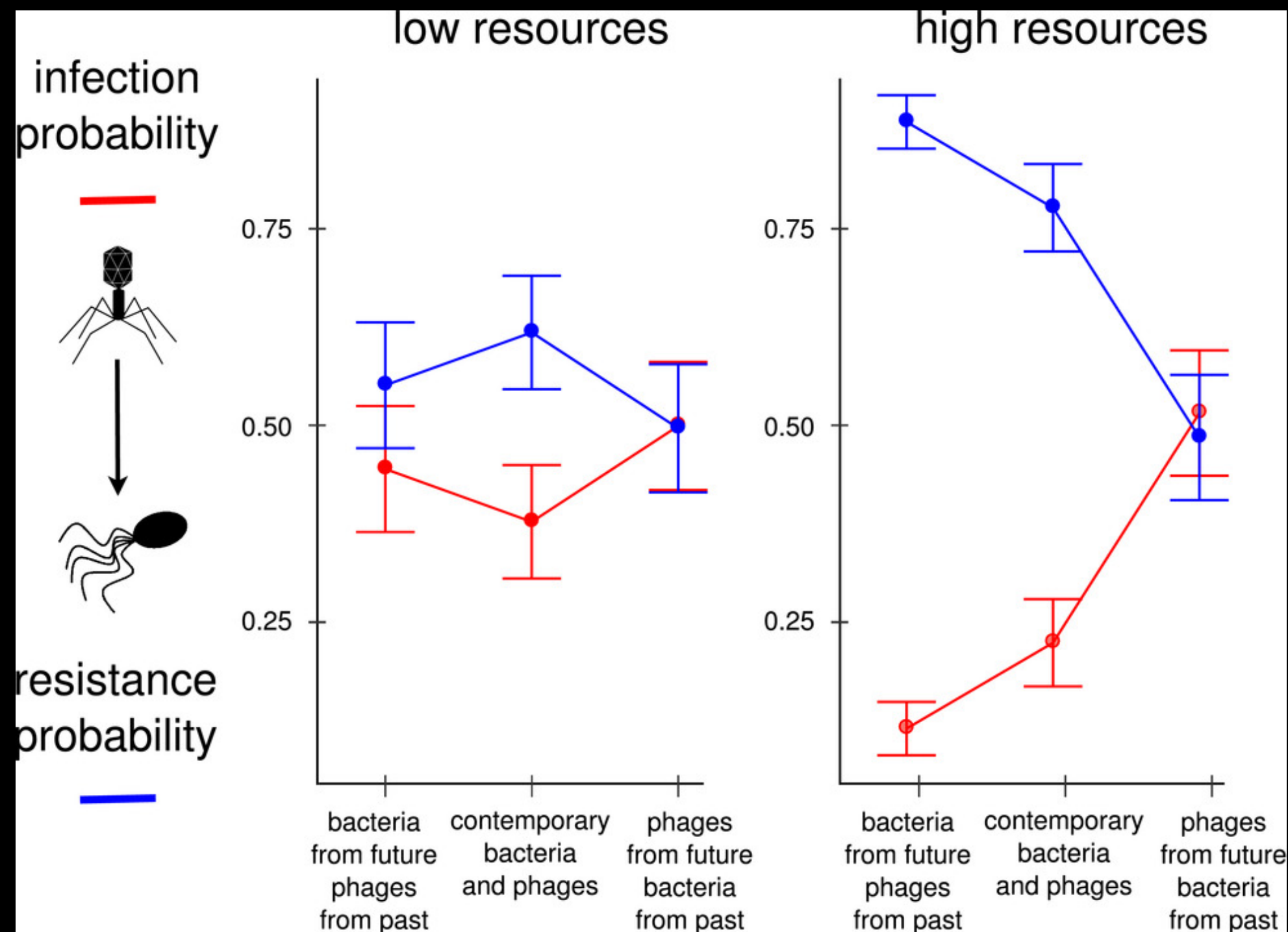


Fortuna, Barbour, Zaman, Hall, Buckling and Bascompte (2019). *Evolution*, 73: 1001-1011

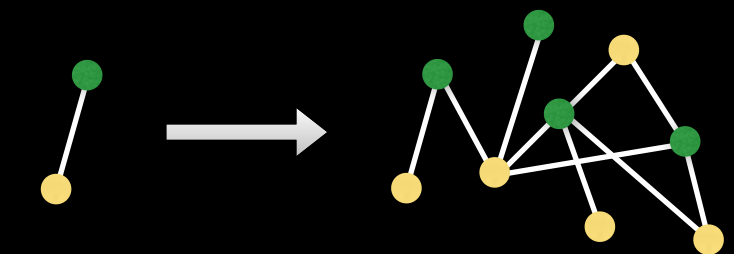


Evolution of networks

What is the role of coevolution in driving changes in the structure of species interaction networks?

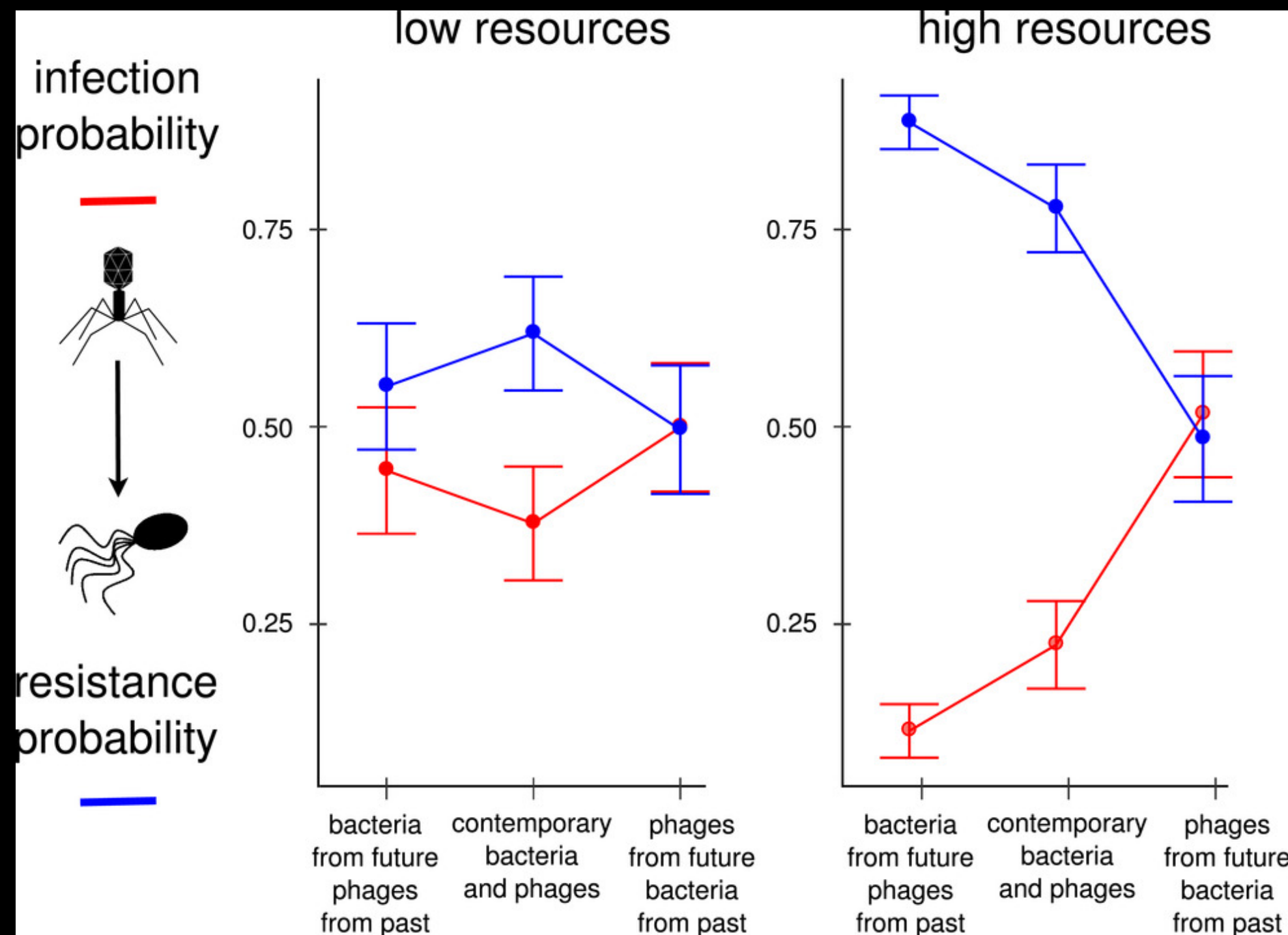


Under low resources, bacteria were more resistant to their contemporary than past and future phages, which is consistent with fluctuating dynamics

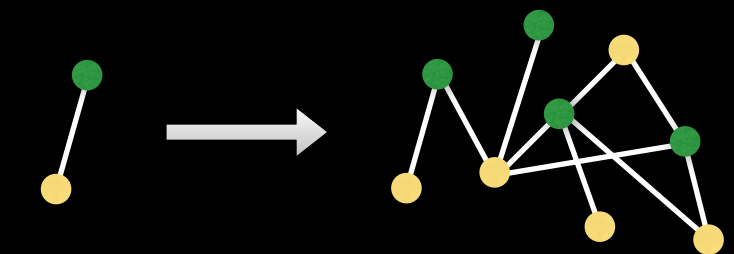


Evolution of networks

What is the role of coevolution in driving changes in the structure of species interaction networks?

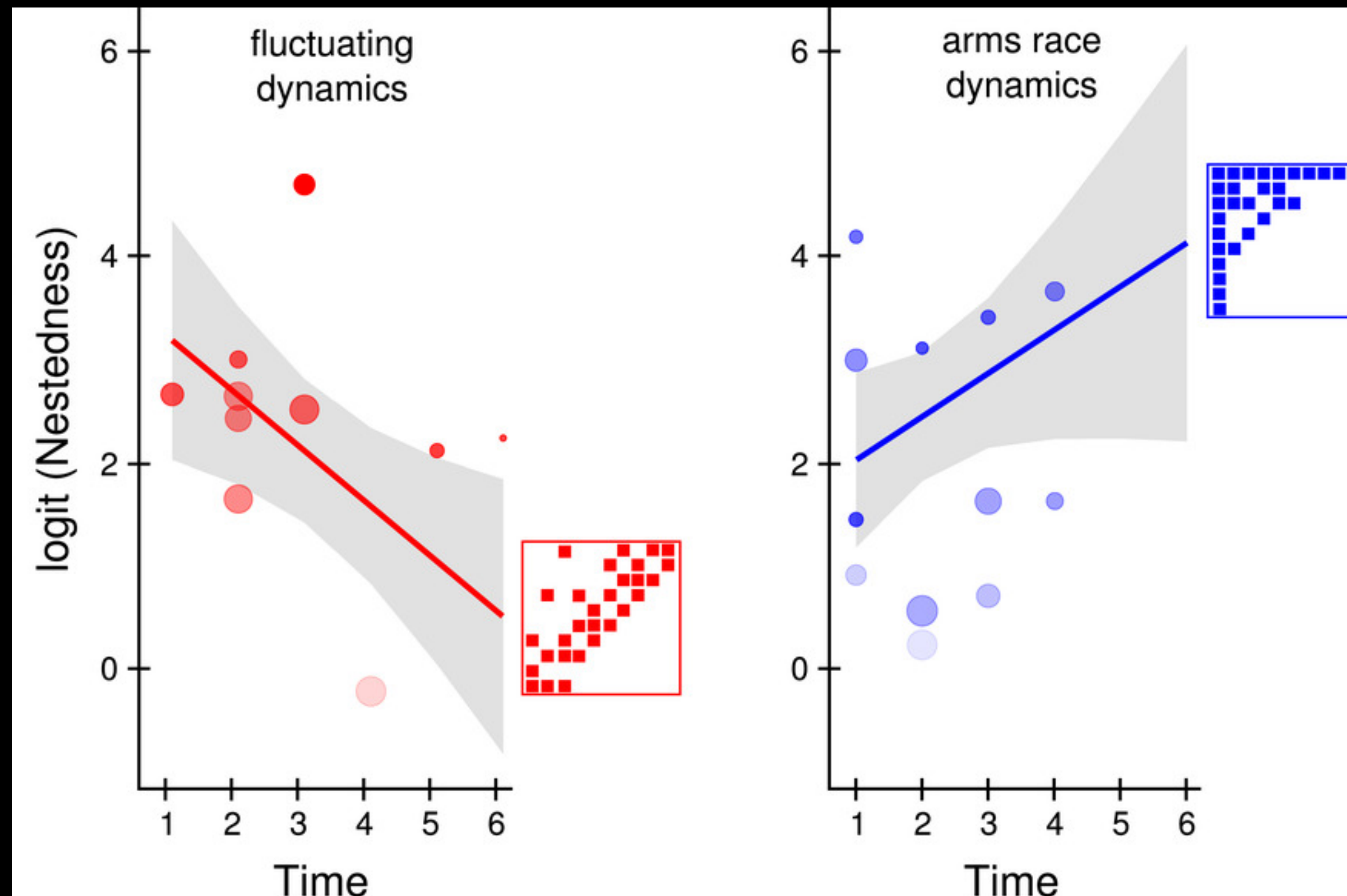


At high resources bacteria were more resistant to past phages and became less resistant to contemporary and future phages, which is a distinctive feature of arms race dynamics

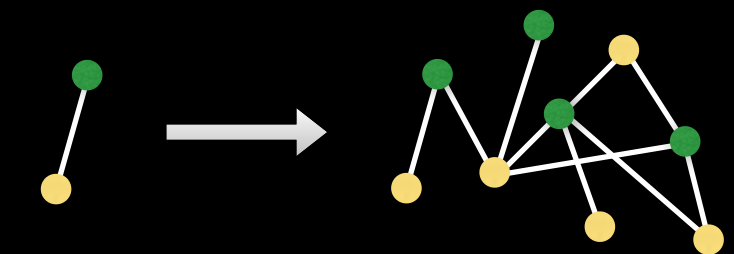


Evolution of networks

What is the role of coevolution in driving changes in the structure of species interaction networks?

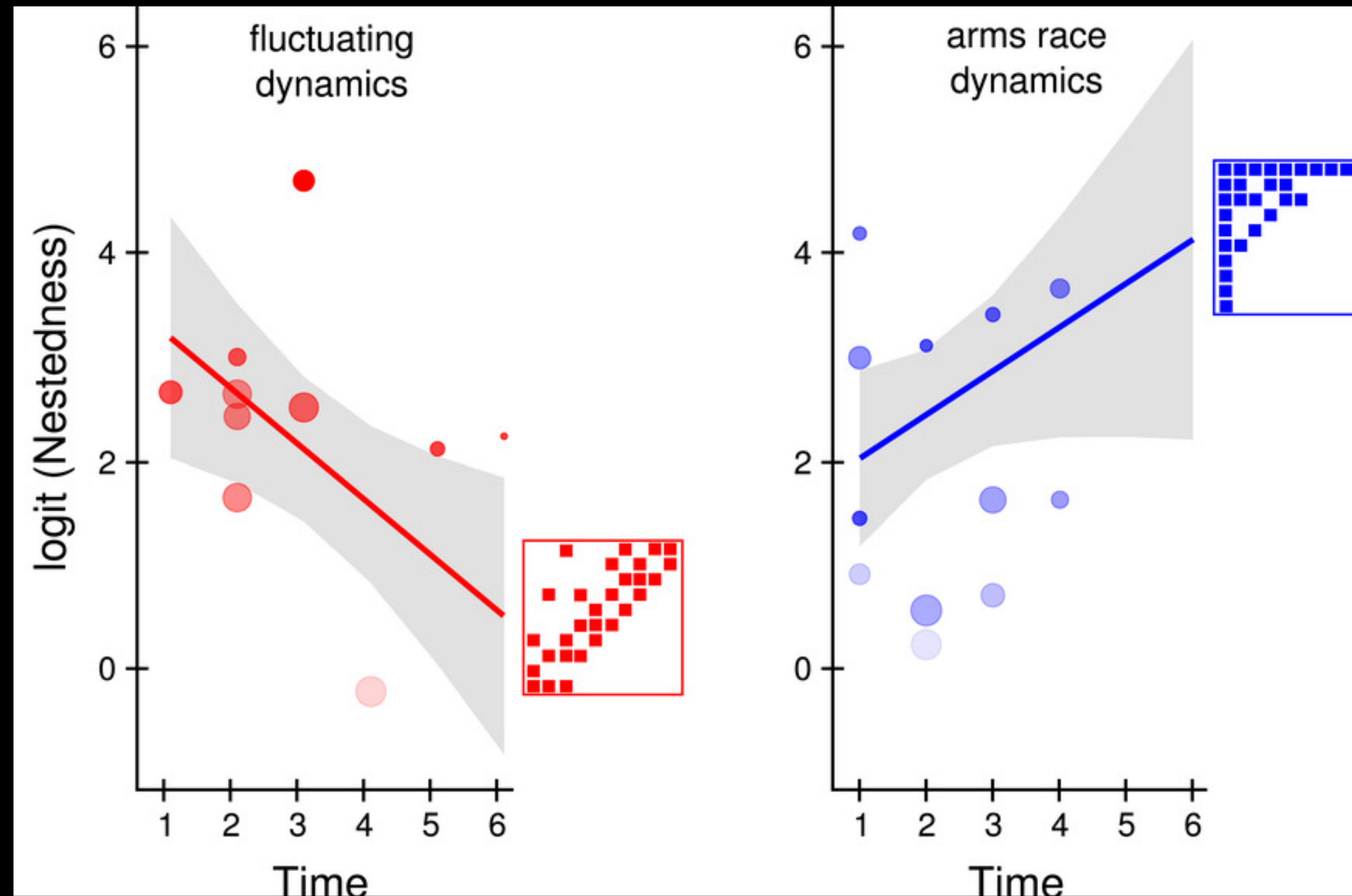


Interactions between coevolving bacteria and phages become less nested over time under fluctuating dynamics, and more nested under arms race dynamics.

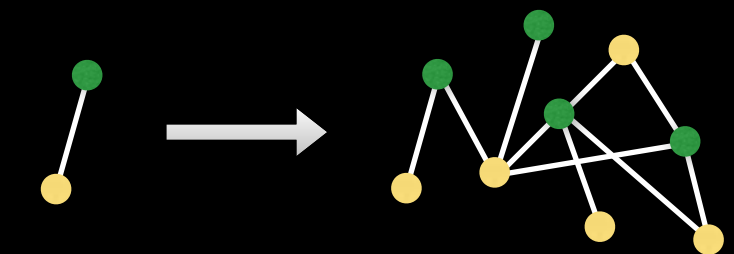


Evolution of networks

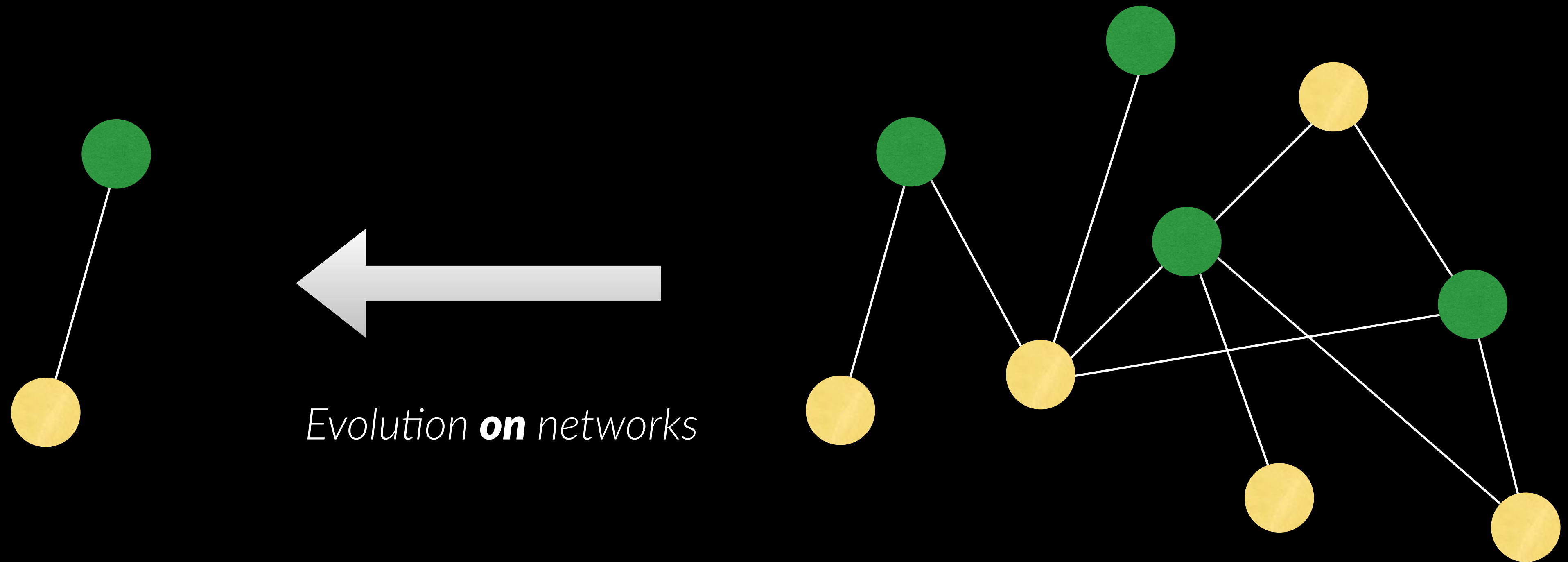
What is the role of coevolution in driving changes in the structure of species interaction networks?



The interaction pattern between bacteria and phages at the community level depends on the way coevolution unfolds.

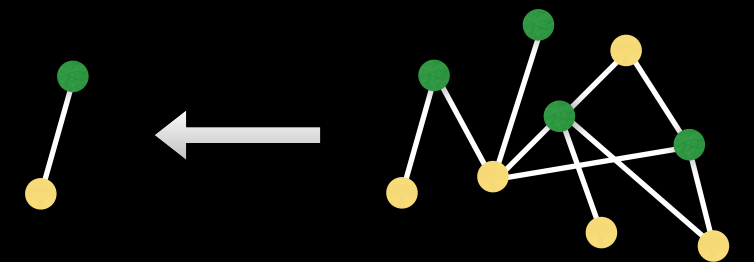


Evolution and networks: the chicken and egg problem



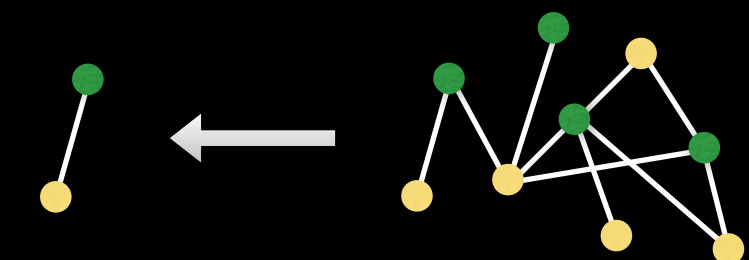
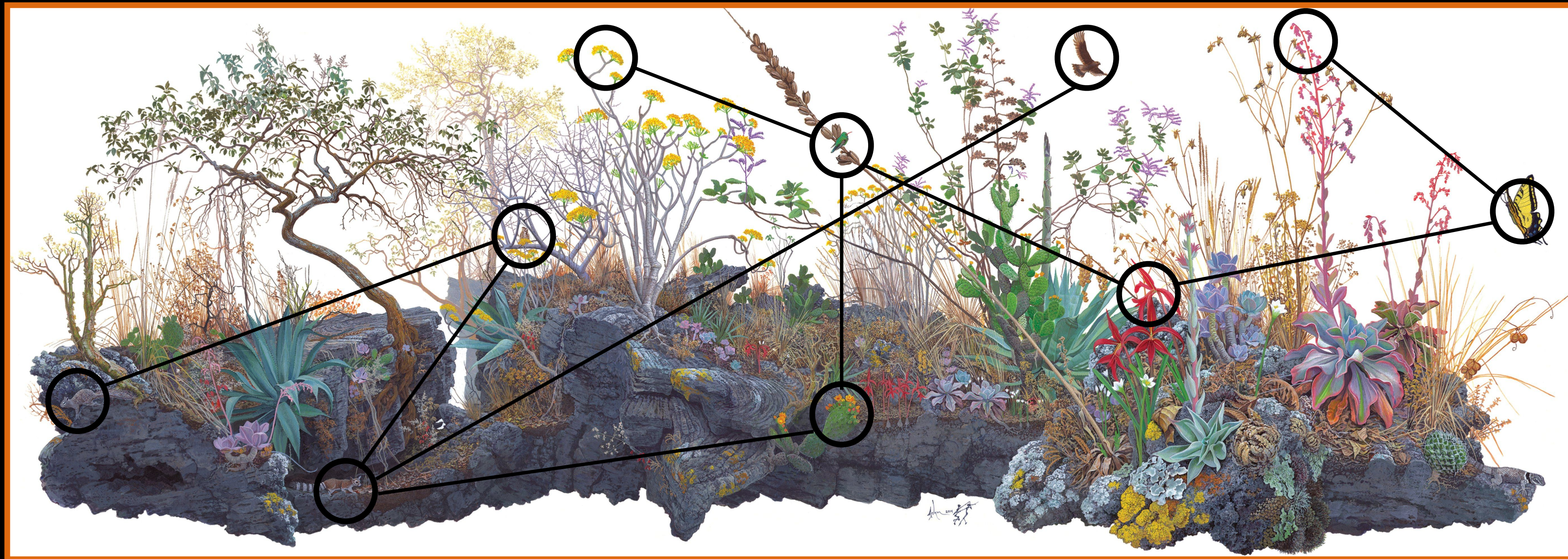
Evolution on networks

What are the evolutionary implications of network structure?



Evolution on networks

What are the evolutionary implications of network structure?

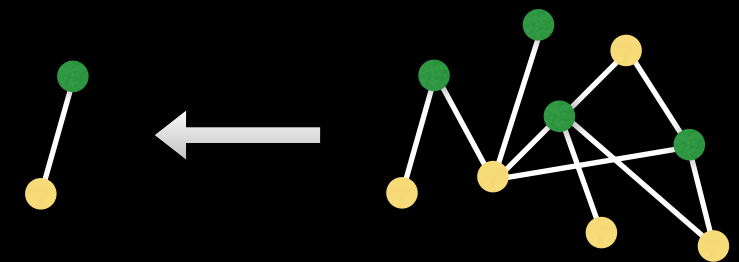


Evolution on networks: a framework to study coevolution in mutualistic networks

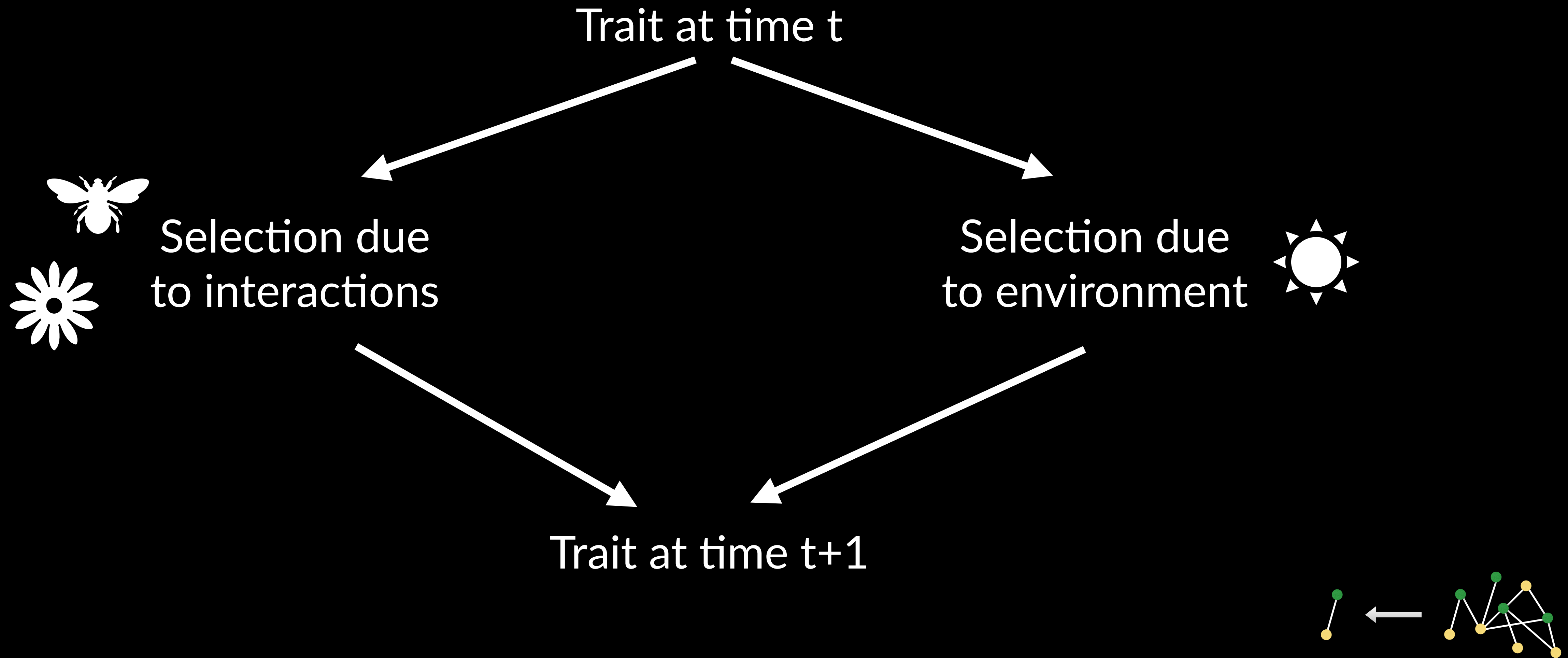
Trait at time t



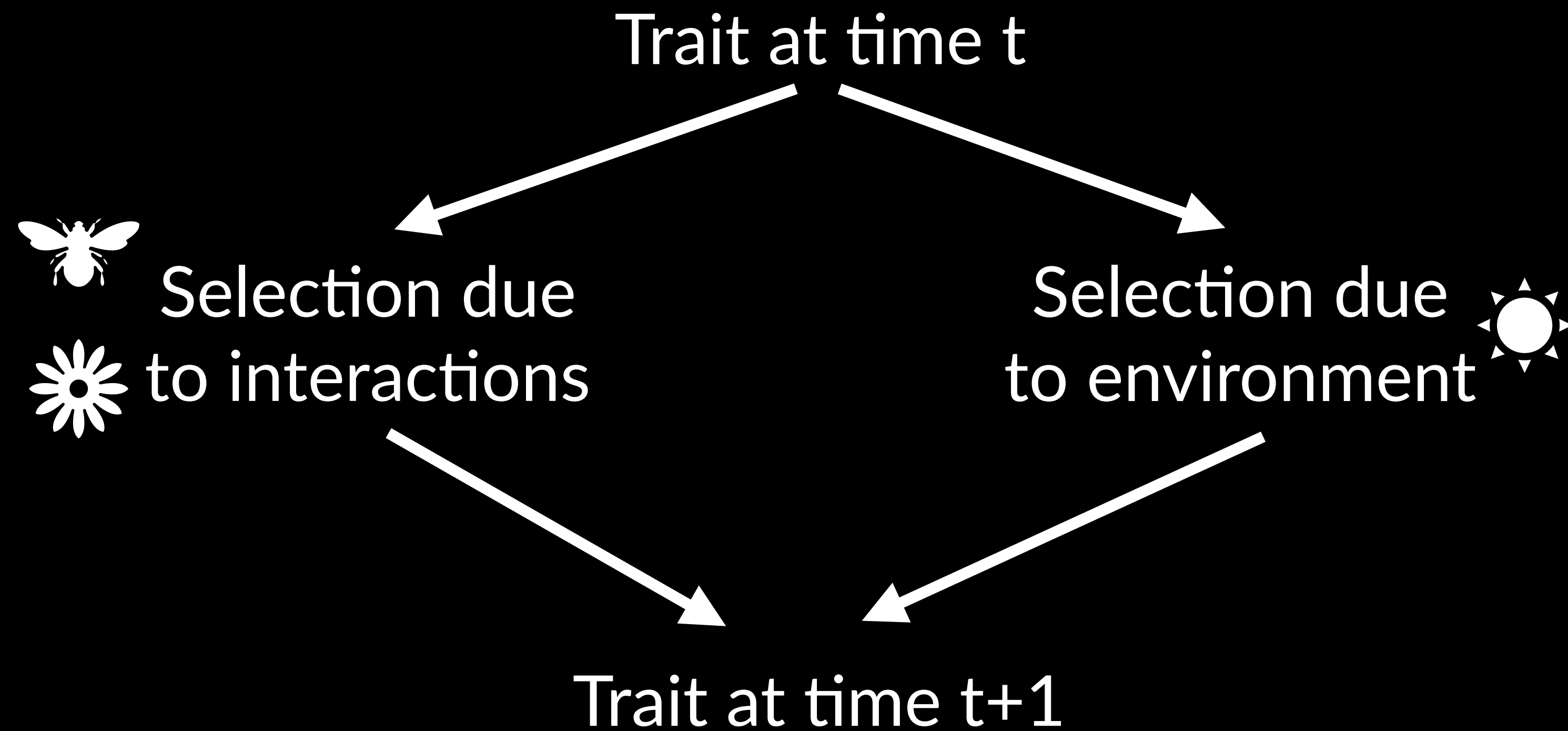
Trait at time $t+1$



Evolution on networks: a framework to study coevolution in mutualistic networks



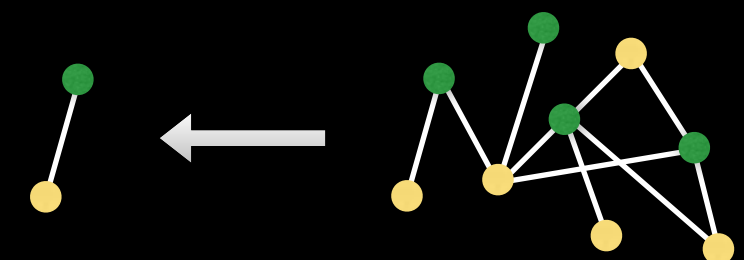
Evolution on networks: a framework to study coevolution in mutualistic networks



What does each force select for?

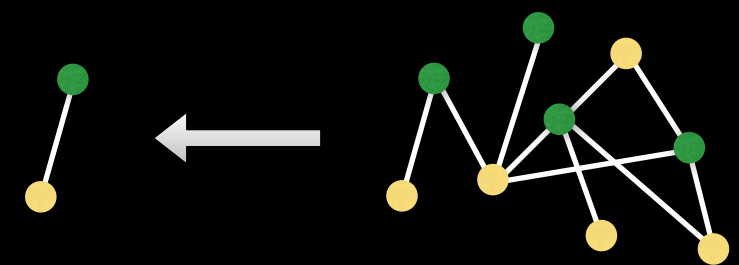
Which selective force is stronger?

How quickly will a trait change as a result of selection?



Evolution on networks: a framework to study coevolution in mutualistic networks

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$



Evolution on networks: a framework to study coevolution in mutualistic networks

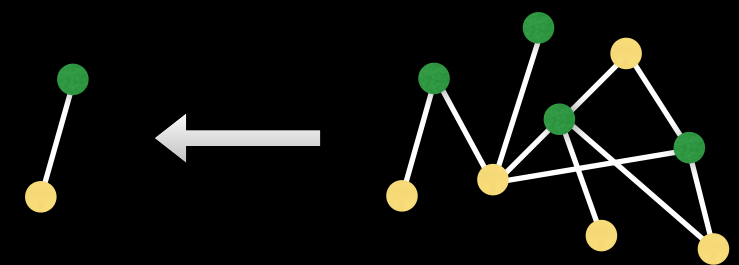
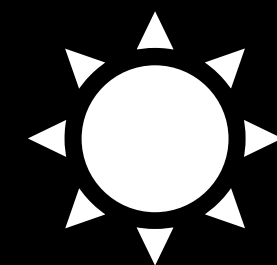
What does each force select for?

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\underbrace{\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right)}_{\text{Interactions}} + \underbrace{\left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right)}_{\text{Environment}} \right]$$

Interactions




Environment

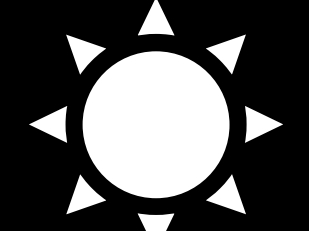


Evolution on networks: a framework to study coevolution in mutualistic networks

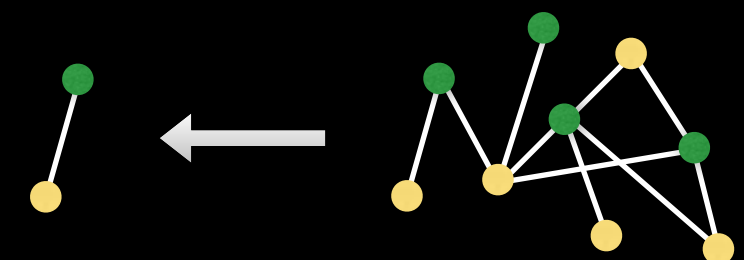
What does each force select for?

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \underbrace{\left(Z_j^{(t)} - Z_i^{(t)} \right)}_{\text{Interactions}} + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \underbrace{\left(\theta_i - Z_i^{(t)} \right)}_{\text{Environment}} \right]$$

Interactions 

Environment 

Which selective force is stronger?



Evolution on networks: a framework to study coevolution in mutualistic networks

How quickly will a trait change as a result of selection?

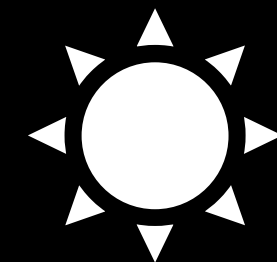
What does each force select for?

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$

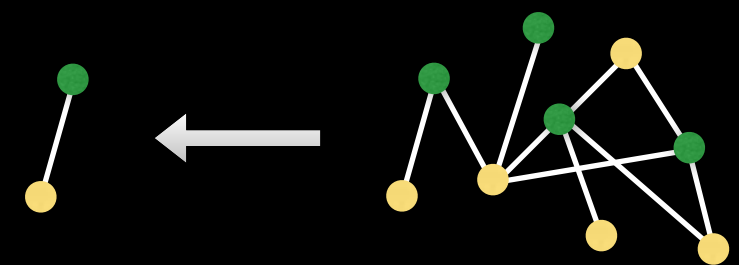
Interactions



Environment



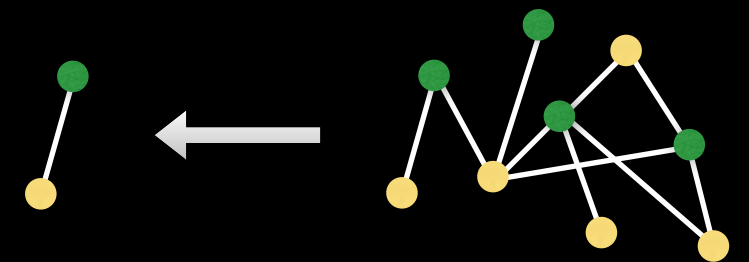
Which selective force is stronger?



Evolution on networks: a framework to study coevolution in mutualistic networks

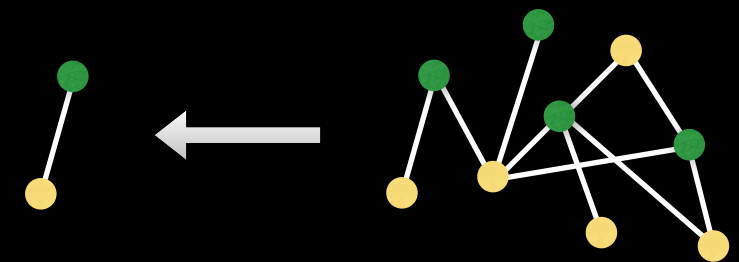
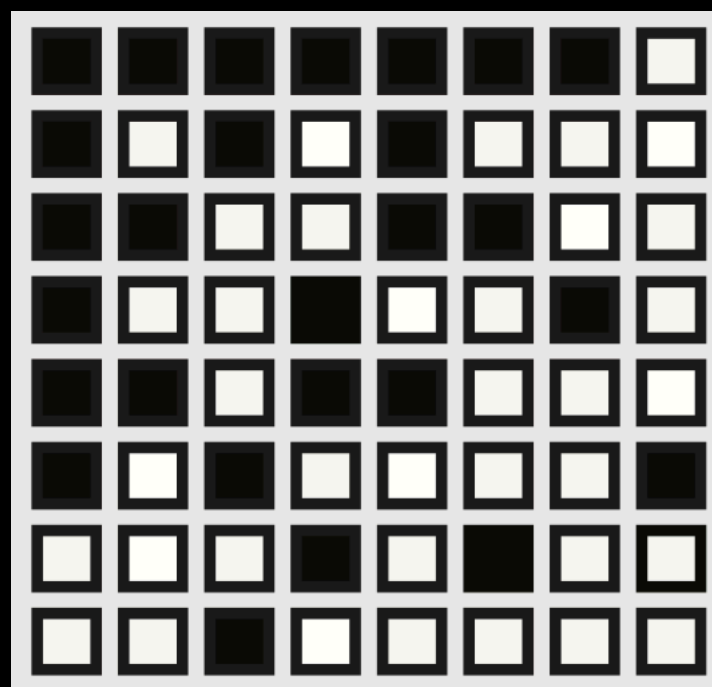
$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$

Where is the network?



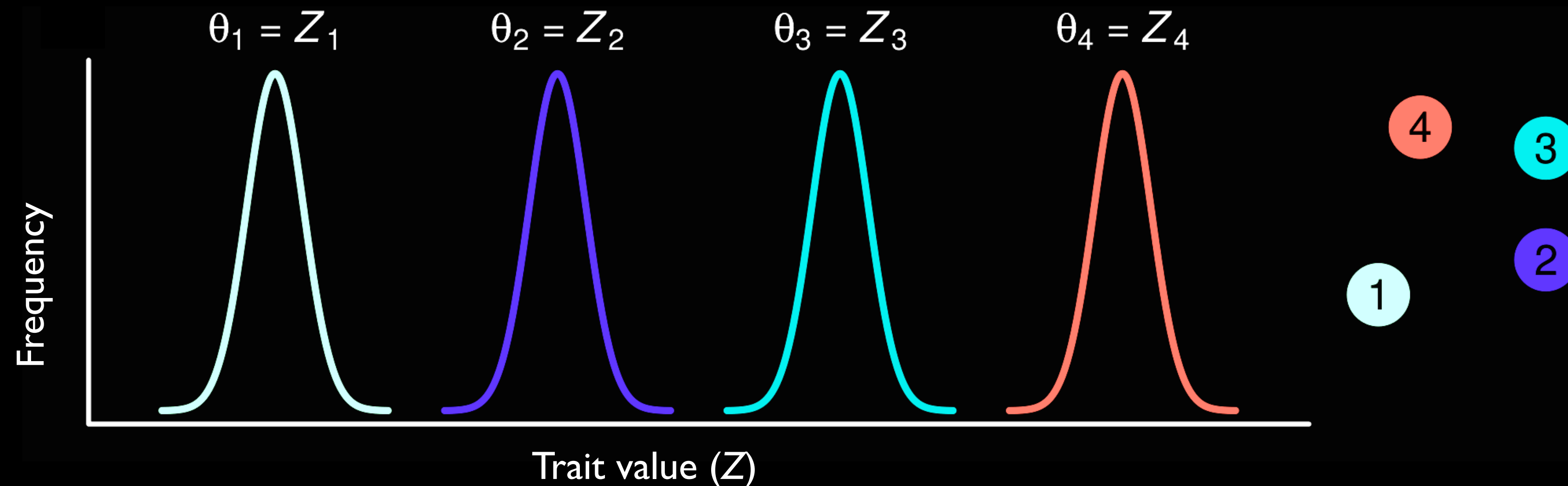
Evolution on networks: a framework to study coevolution in mutualistic networks

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\underbrace{\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right)} + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$



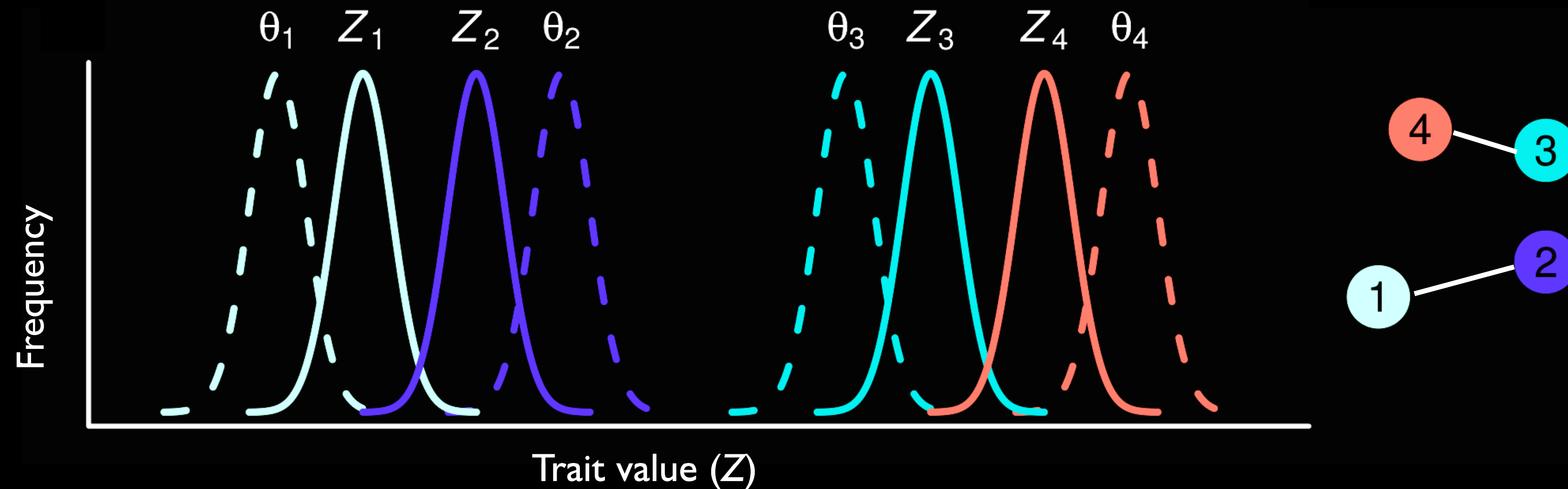
Coevolution within networks

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$



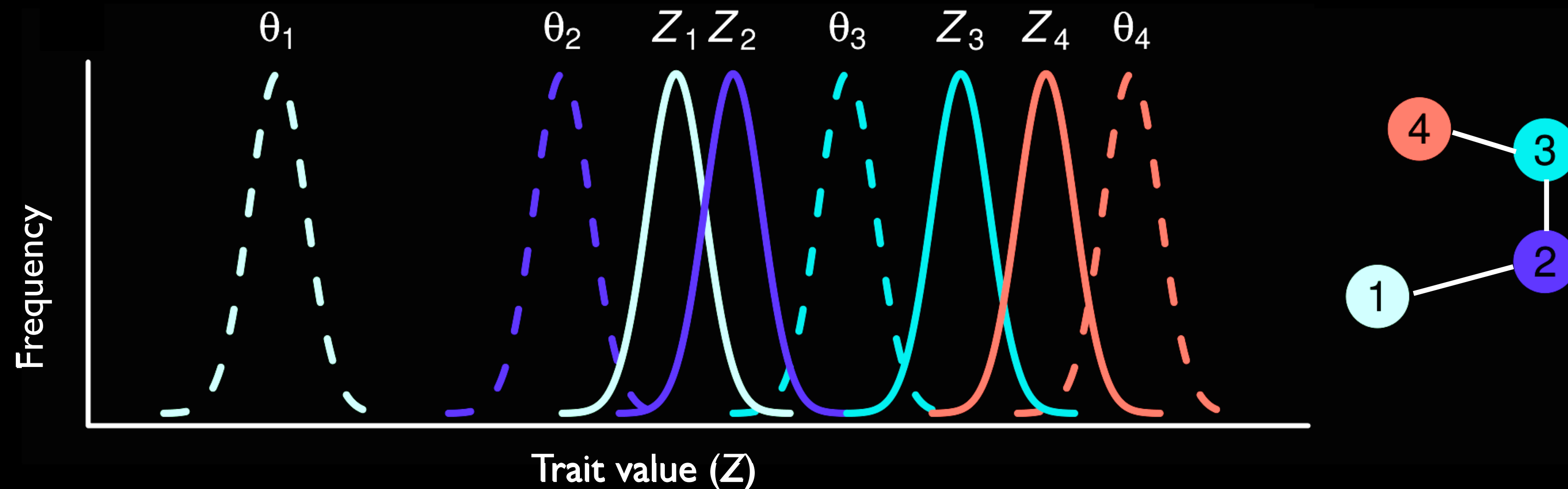
Coevolution within networks

$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$

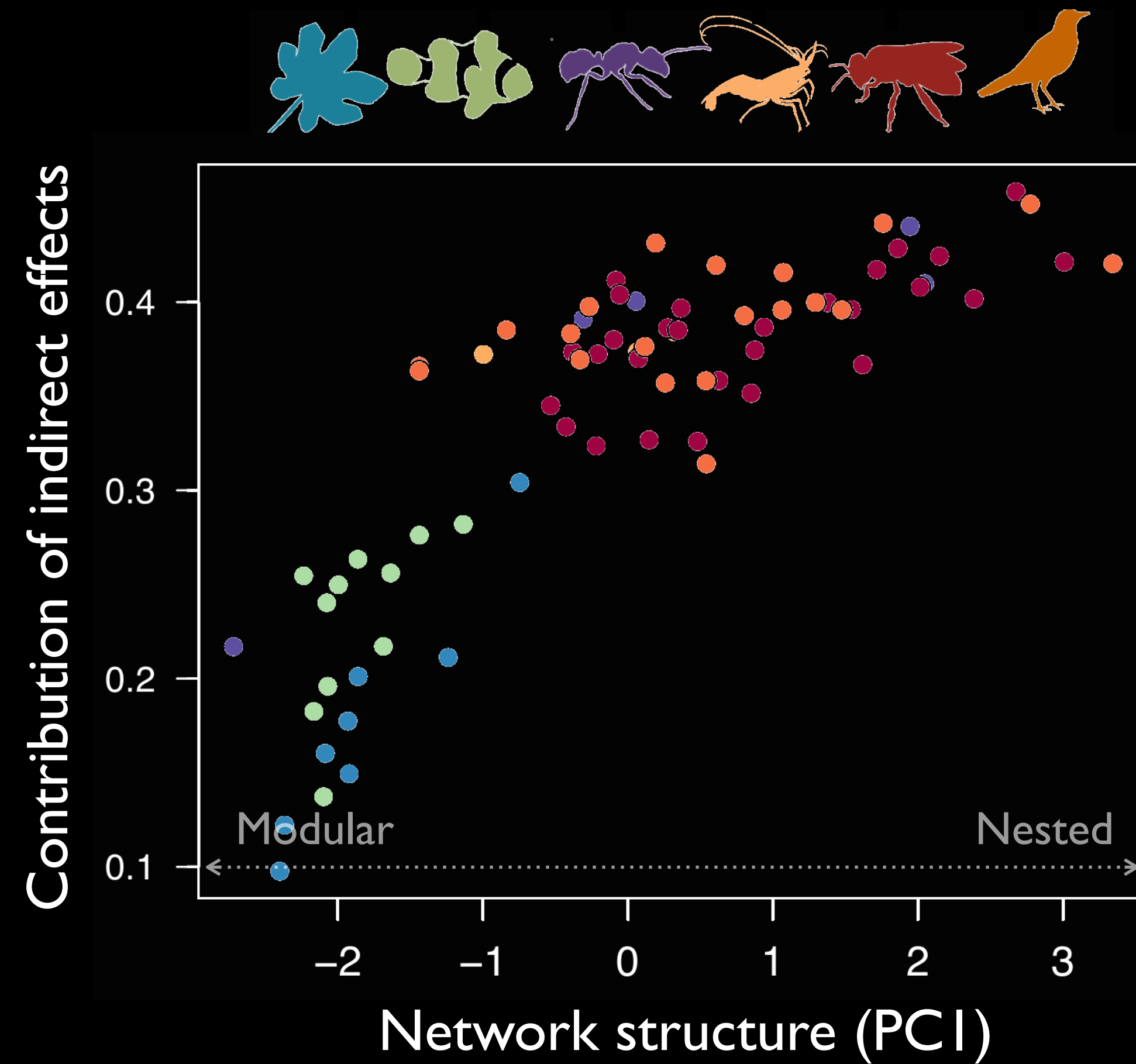


Coevolution within networks

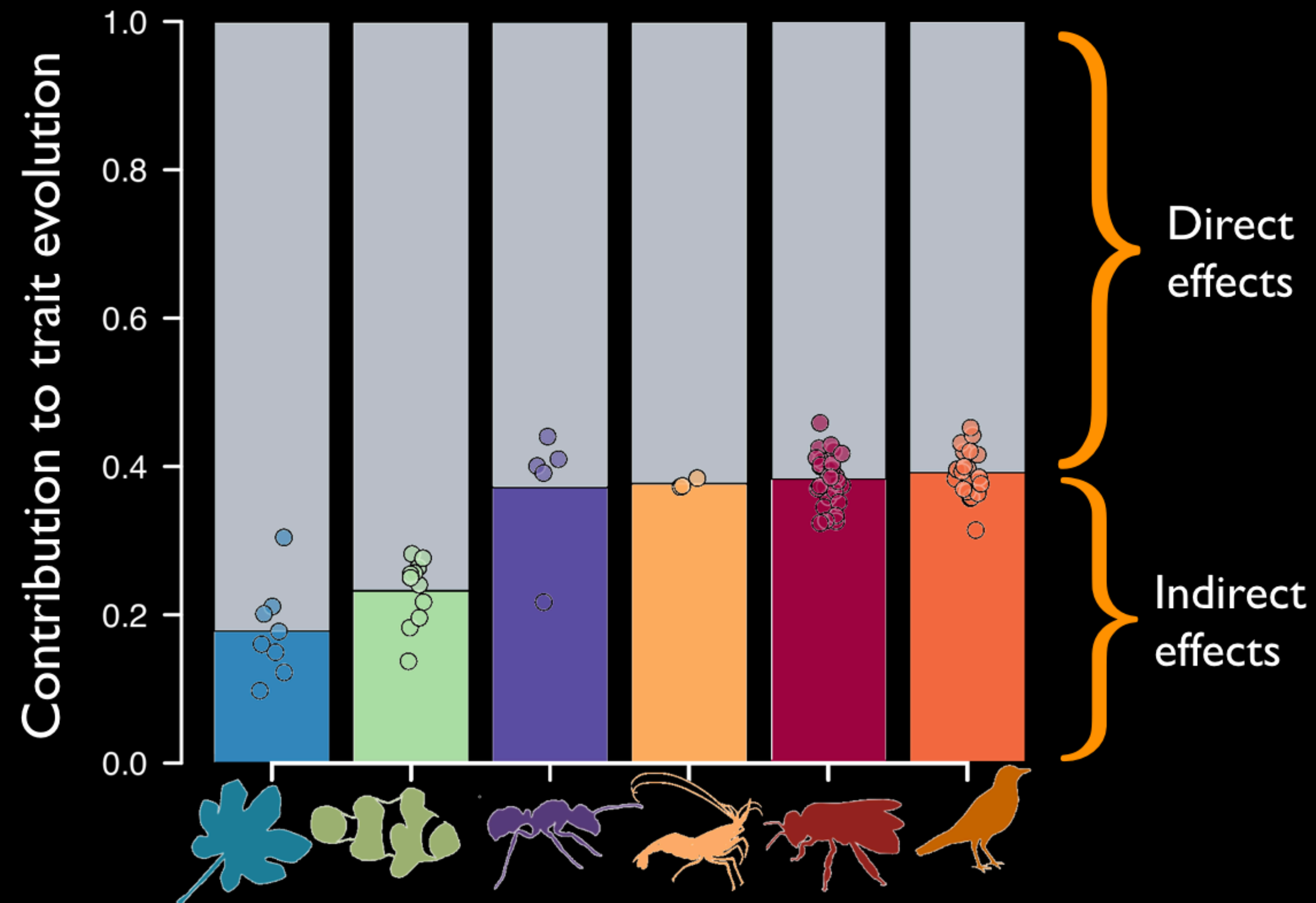
$$Z_i^{(t+1)} = Z_i^{(t)} + \varphi_i \left[\sum_{j, j \neq i}^N q_{ij}^{(t)} \left(Z_j^{(t)} - Z_i^{(t)} \right) + \left(1 - \sum_{j, j \neq i}^N q_{ij}^{(t)} \right) \left(\theta_i - Z_i^{(t)} \right) \right]$$



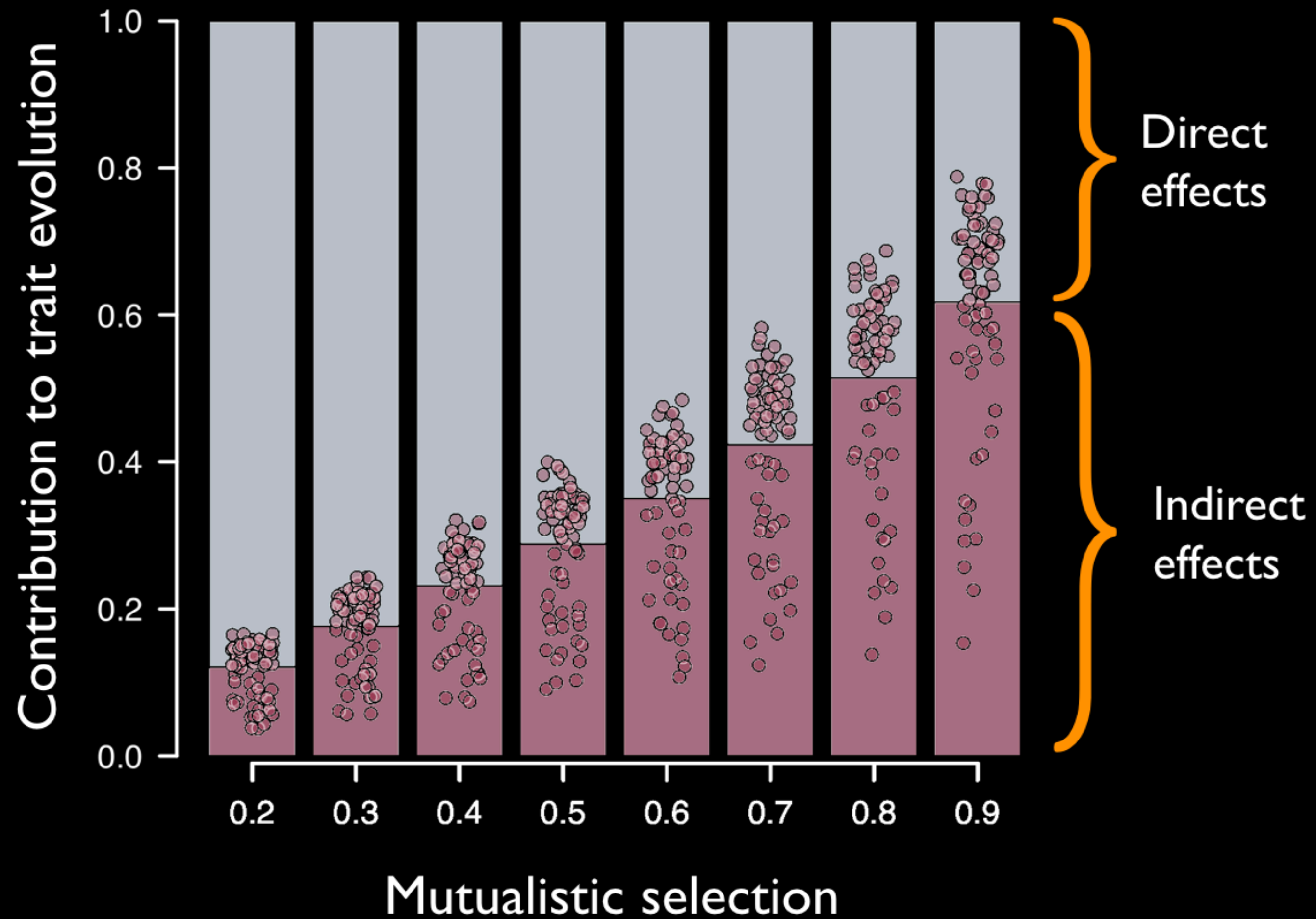
Indirect effects drive coevolution



Indirect effects drive coevolution



Indirect effects and mutualistic selection



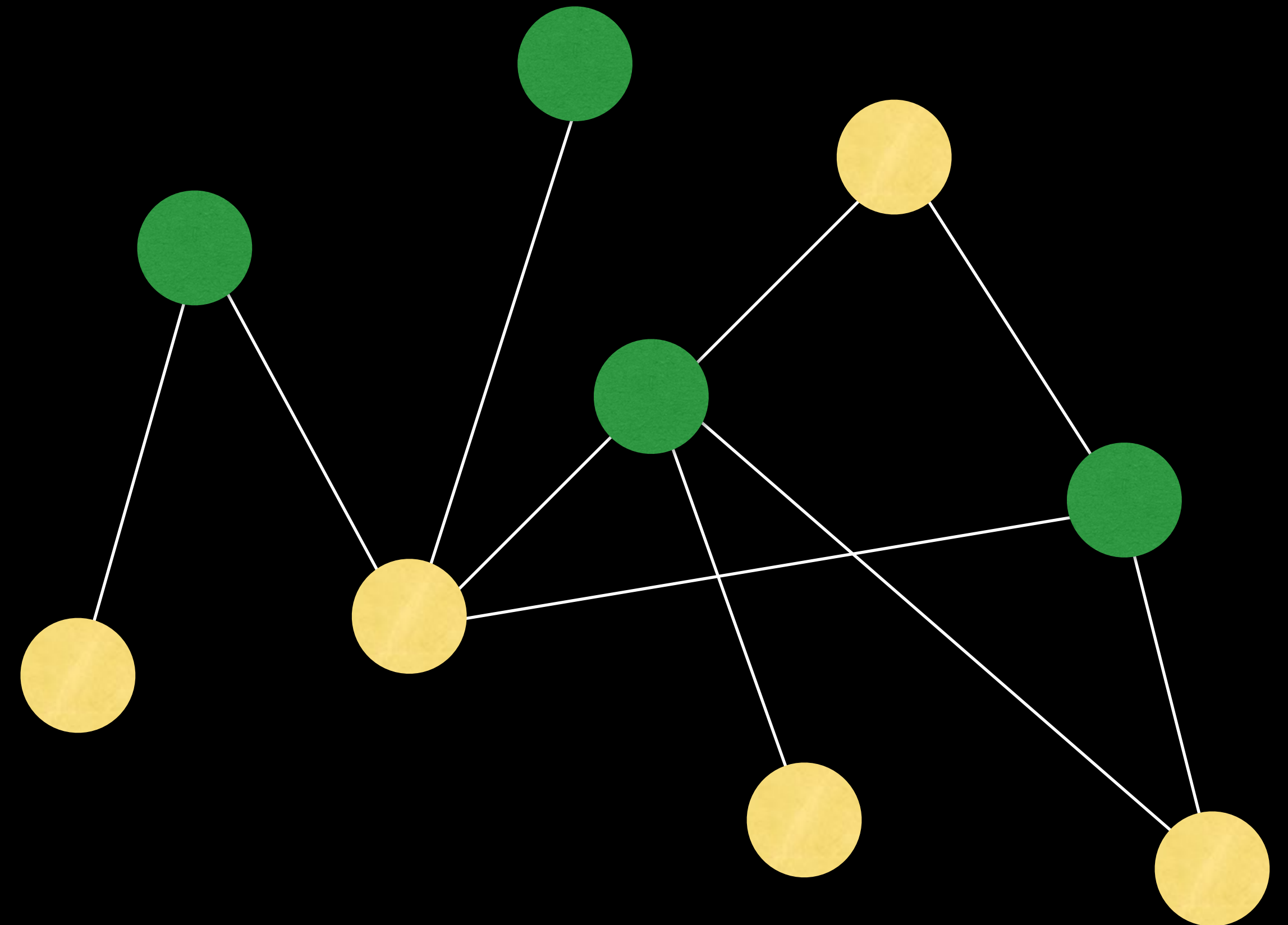
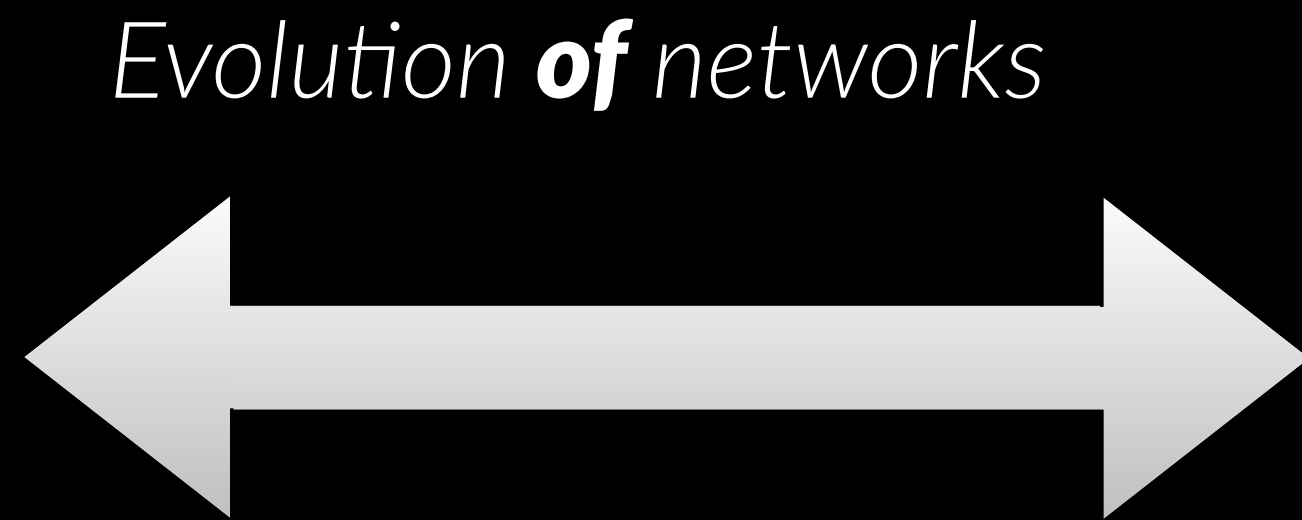
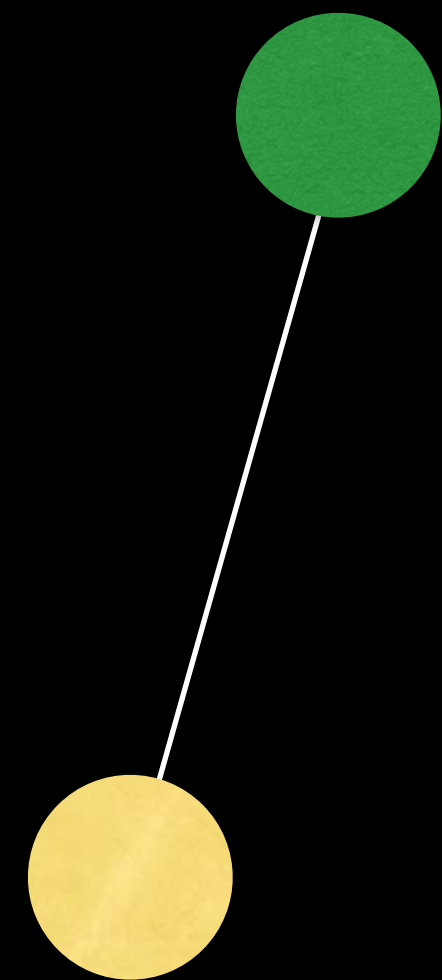
Indirect effects drive coevolution



The most specialist species are more influenced by indirect effects than by their direct partners

Evolution and networks

To what extent is network architecture associated with species phylogenetic relationship?
What is the role of coevolution in driving changes in the structure of species interaction networks?



What are the evolutionary implications of network structure?

This afternoon...

We will explore the model of mutualistic coevolution using the RStudio Server.