

*Fundamentos de uma teoria da
sistemática filogenética, Willi Hennig
e os princípios e conceitos gerais da
Sistemática Filogenética*

5920818 - Evolução e Sistemática Biológica

Dept. Biologia – FFCLRP - USP

Flávio A. Bockmann

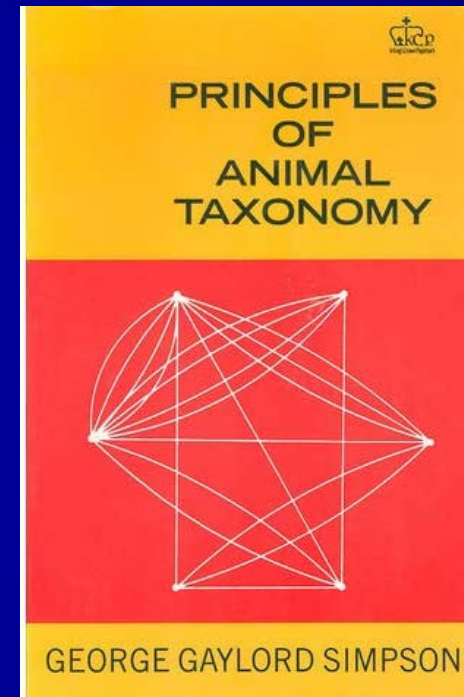
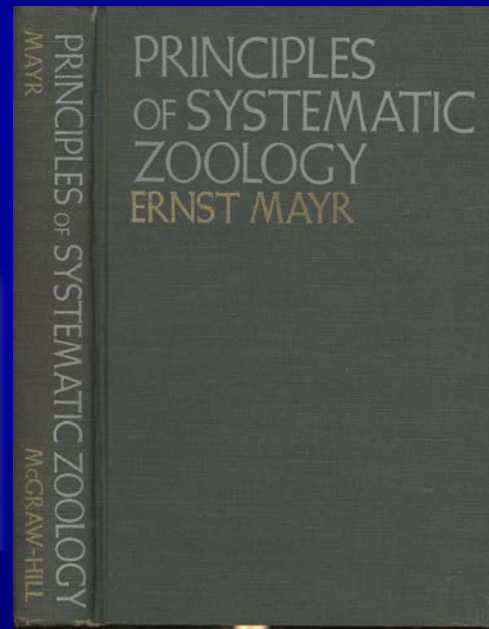
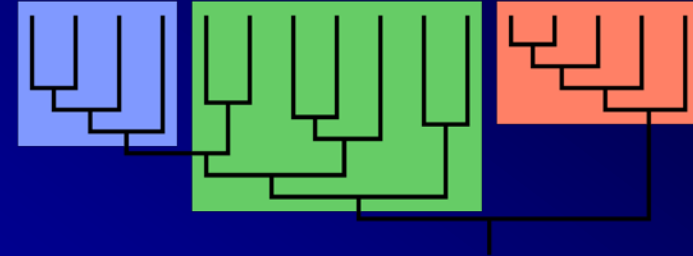
2023

Problema: como resolver (ou minimizar) a subjetividade na inferência de filogenias e mesmo das classificações?

Resposta: estabelecimento de uma base teórica e metodologias mais robustas

Taxonomia evolutiva ou gradismo

- “*Grade*” - táxon unido por um nível de complexidade morfológica ou fisiológica, em oposição ao “clade” (Julian Huxley - 1957)
- “*Grade*”- definido por uma característica geral, de “importância”, determinada pelo especialista
- Ancestral não faz parte do “grade” (e.g., Reptilia, Pisces); um grupo dá origem ao outro; o ancestral é real



Taxonomia evolutiva ou gradismo



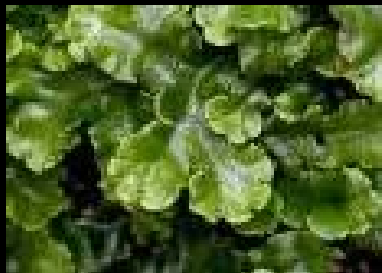
Angiospermas



Gimnospermas



Pteridófitas



Briófitas

“Graus” ou
“Grados”
evolutivos

Taxonomia evolutiva ou gradismo



Aves

Mamíferos



Répteis

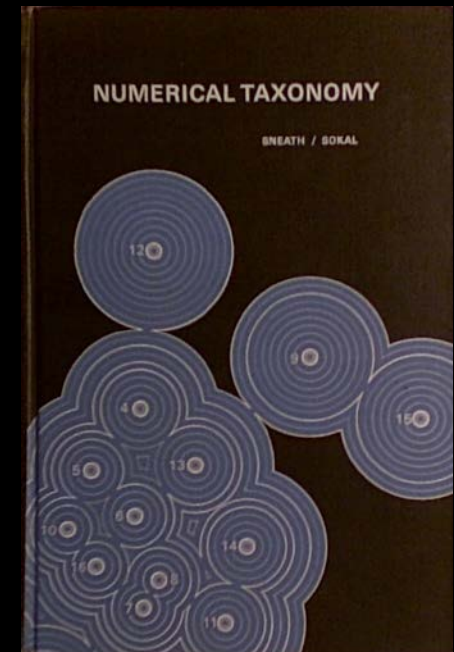
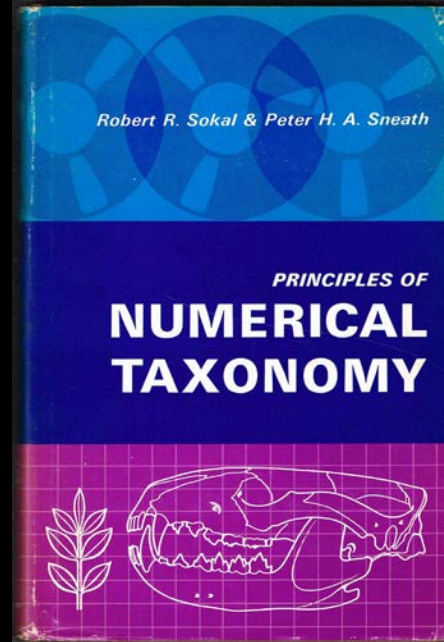


Anfíbios

“Graus” ou
“Grados”
evolutivos

Fenética ou Taximetria => taxonomia numérica

- Classificar organismos com base na **semelhança global**, independentemente de sua **filogenia** ou **relação evolutiva**;
- Aumento exponencial na complexidade de dados - acúmulo de informação anatômica e sobre a diversidade biológica;
- Insatisfação com abordagens tradicionais;
- Popularização do uso de computadores e de algoritmos computacionais: UPGMA, Neighbor-Joining (NJ), Minimal Evolution...=> Construção de tabelas (matrizes) de similaridade (proporções de presenças vs. ausências)



Fenética ou Taximetria => taxonomia numérica

Fenética: matriz de similaridades

Table 2 - Isoenzymatic profiles displayed by the *P. megistus* and *Dipetalogaster maxima* (outgroup) populations, corresponding zymodemes and electromorphs for isoenzyme G6PD.

Isoenzyme Population	GPI	PGM	NP ¹	NP ²	MPI	DIA	ICD	FH	G6PD	6PGD	ME ¹	ME ²	MDH	GOT ¹	GOT ²	Zymo-deme	Electro-morph
Pr.Ara.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Ara.2	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Ara.3	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Ara.4	1	1	1	0	1	1/1	1	1	1	1	1	0	1	1	0	Lpm2	G6PD1
Pr.Ara.5	1	1	1	0	1	1/1	1	1	3	1	1	0	1	1	0	Lpm4	G6PD3
Pr.Ara.6	1	1	1	0	1	1/1	1	1	1	1	1	0	1	1	0	Lpm2	G6PD1
Pr.Cam.1	1	1	1	0	1	1/1	1	1	2	1	1	0	1	1	0	Lpm3	G6PD2
Pr.Cam.2	1	1	1	0	1	1/1	1	1	1	1	1	0	1	1	0	Lpm2	G6PD1
Pr.Rol.1	1	1	1	0	1	1/1	1	1	3	1	1	0	1	1	0	Lpm4	G6PD3
Pr.Rol.2	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Lon.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Fax.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Aru.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Nau.1	1	1	1	0	1	1/1	1	1	3	1	1	0	1	1	0	Lpm4	G6PD3
Pr.Pal.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Rbs.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Rbs.2	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Alt.1	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
Pr.Alt.2	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
MG	1	1	1	0	1	1/1	1	1	1	1	1	0	1	1	0	Lpm2	G6PD1
RS	1	1	1	0	1	1/1	1	1	3	1	1	0	1	1	0	Lpm4	G6PD3
SE	1	1	1	0	1	1/1	1	1	3	1	1	0	1	1	0	Lpm4	G6PD3
SC	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
SP	1	1	1	0	1	1/1	1	1	4	1	1	0	1	1	0	Lpm1	G6PD4
<i>D.maxima</i>	2	2	1	0	2	1/1	2	2	3	2	1	0	1	2	0	Lpm5	G6PD3

Fenética: Fenograma (atenção: NÃO É UM CLADOGRAMA)

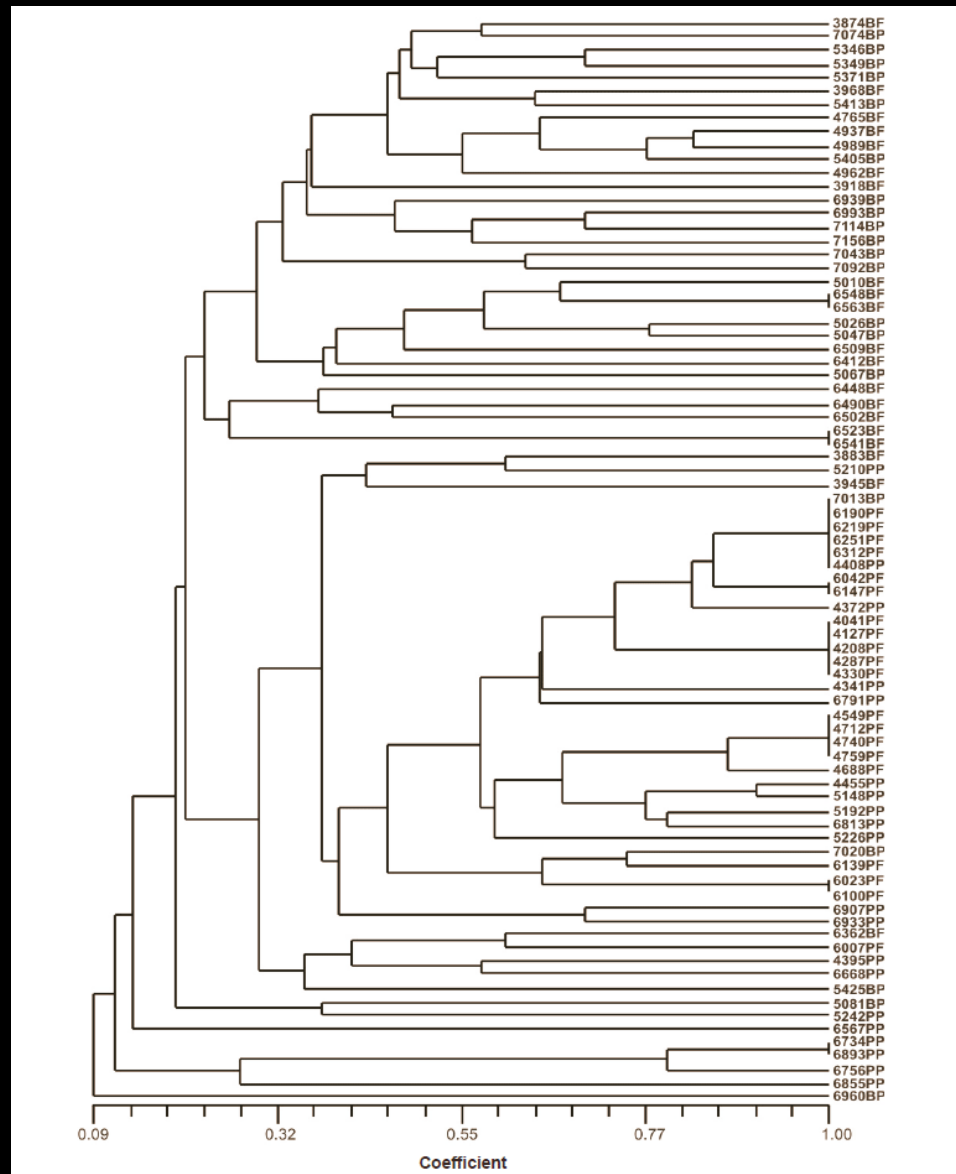


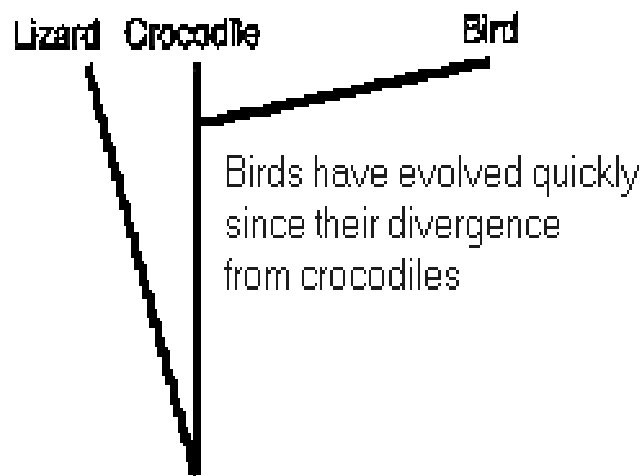
FIGURE 3 - Phenogram of 80 randomly selected isolates of *Magnaporthe oryzae* from leaves and panicles of rice cultivars BRS Bonaça and Primavera, generated by unweighted pair group method arithmetic mean (UPGMA) analysis. Co-phenetic correlation of the phenogram was 0.84. BF=BRS Bonaça leaf isolates; BP=BRS Bonaça panicle isolates; PF=Primavera leaf isolates; PP=Primavera panicle isolates.

Fenética ou Taximetria => taxonomia numérica

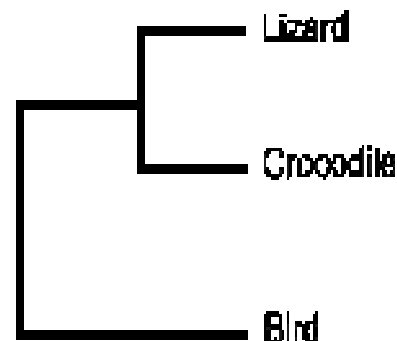
Críticas ao uso da fenética para inferir filogenias:

- não há preocupação real em inferir filogenias, mas sim semelhanças totais
- os caracteres são usados não se importando se são novidades evolutivas (apomorfias) ou características “primitivas” (plesiomorfias)

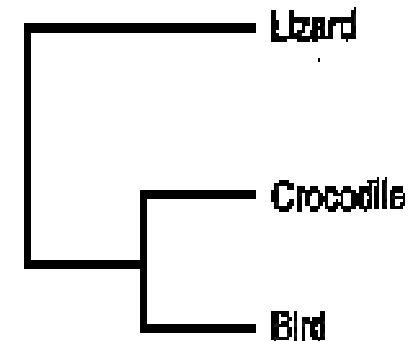
The Phenetic & Cladistic criteria of relationship differ if evolutionary rates are unequal



Phenetic



Cladistic



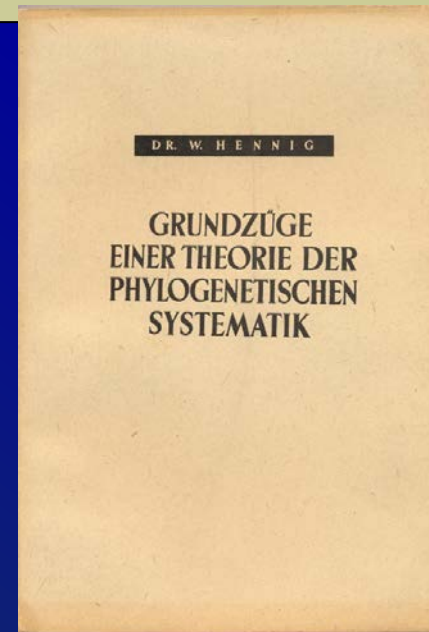
Sistemática Filogenética

Princípios gerais

- Relação hierárquica entre as **espécies** e seus **ancestrais (hipotéticos)**
- Descoberta dos diferentes níveis de universalidade dos atributos – Hennig cunhou os termos **sinapomorfia** e **simplesiomorfia**
- Diferentes escalas de relações evolutivas (**hologenéticas**): no mesmo indivíduo (**ontogenéticas - semaforontes**), entre indivíduos (**tocogenéticas**), entre espécies (**filogenéticas**)
- **Classificação** deve ser sempre baseada em **grupos monofiléticos** (compostos pelo ancestral direto e todos os seus descendentes); cunhou o termo **parafilia**
- **Princípio auxiliar de Hennig** – “parcimônia”



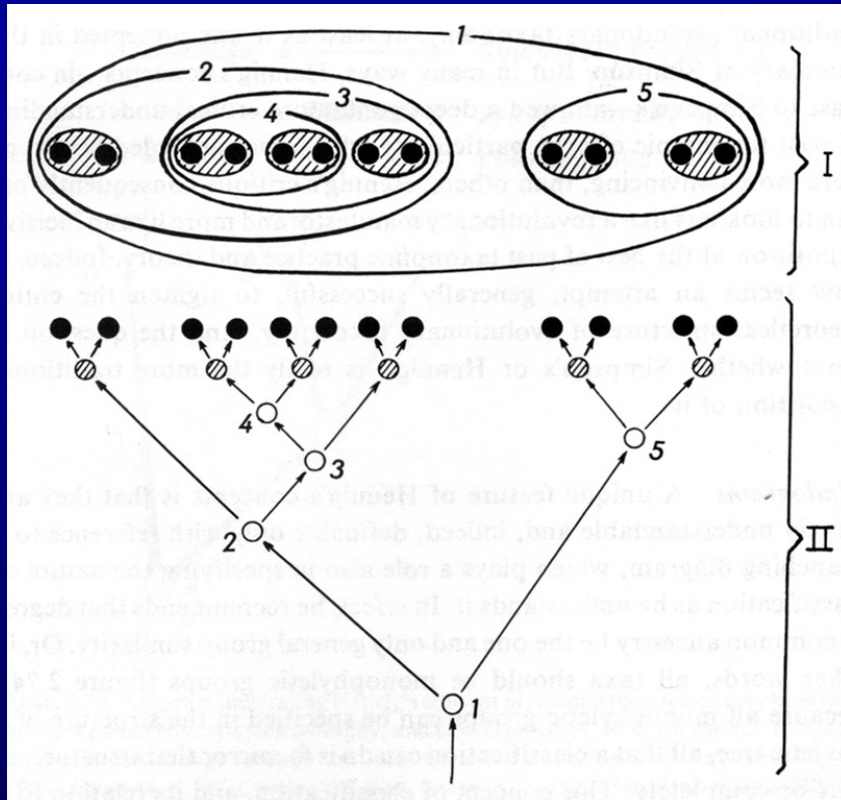
Willi Hennig (1913-1976)



*Teoria geral da
Sistemática
Filogenética (1950)*


Sistemática Filogenética

- Universalidade dos atributos (hierarquia) –sinapomorfia e simplesiomorfia



102

HENNIG

a  $a \longrightarrow a'$ Symplesiomorphy (A,B)

$a \longrightarrow a' \text{---} a'$ Synapomorphy (B,C)

$a' \longleftarrow a \longrightarrow a'$ Convergence (A,C)

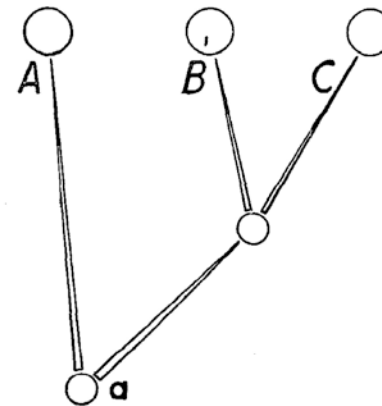
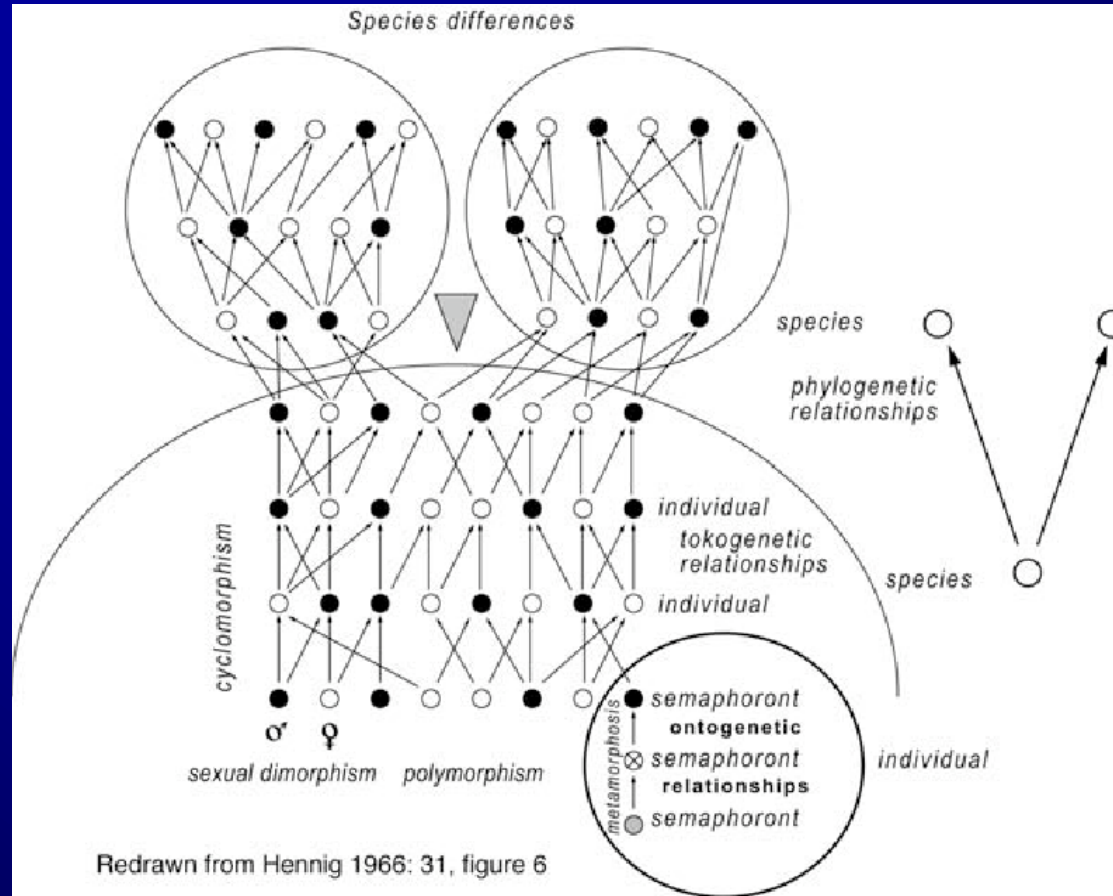


FIG. 1. The three different categories of morphological resemblance. a plesiomorph; a' apomorph expression of the morphological character a . Agreement may rest on sympleisiomorphy (a - a), synapomorphy (a' - a') or convergence (a' - a').

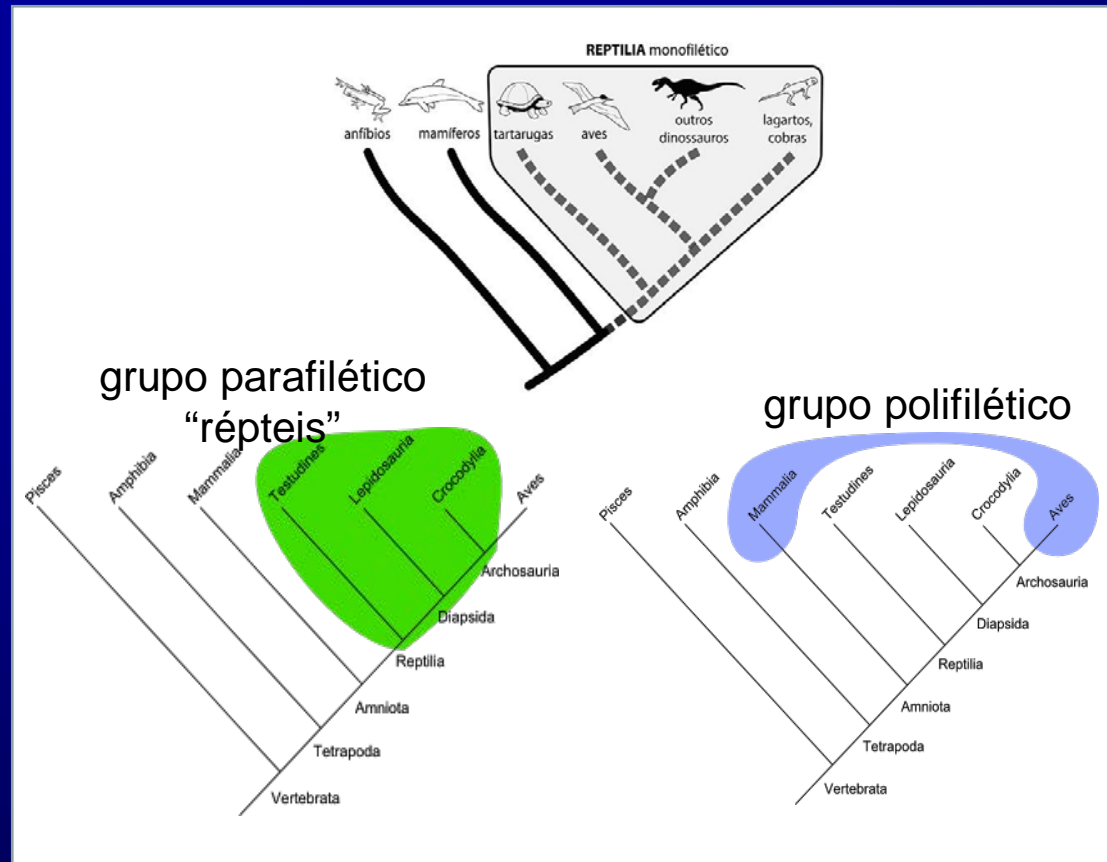
Sistemática Filogenética

– Escalas de relações (*hologenéticas*): *ontogenéticas* (semaforontes), *tocogenéticas* e *filogenéticas*



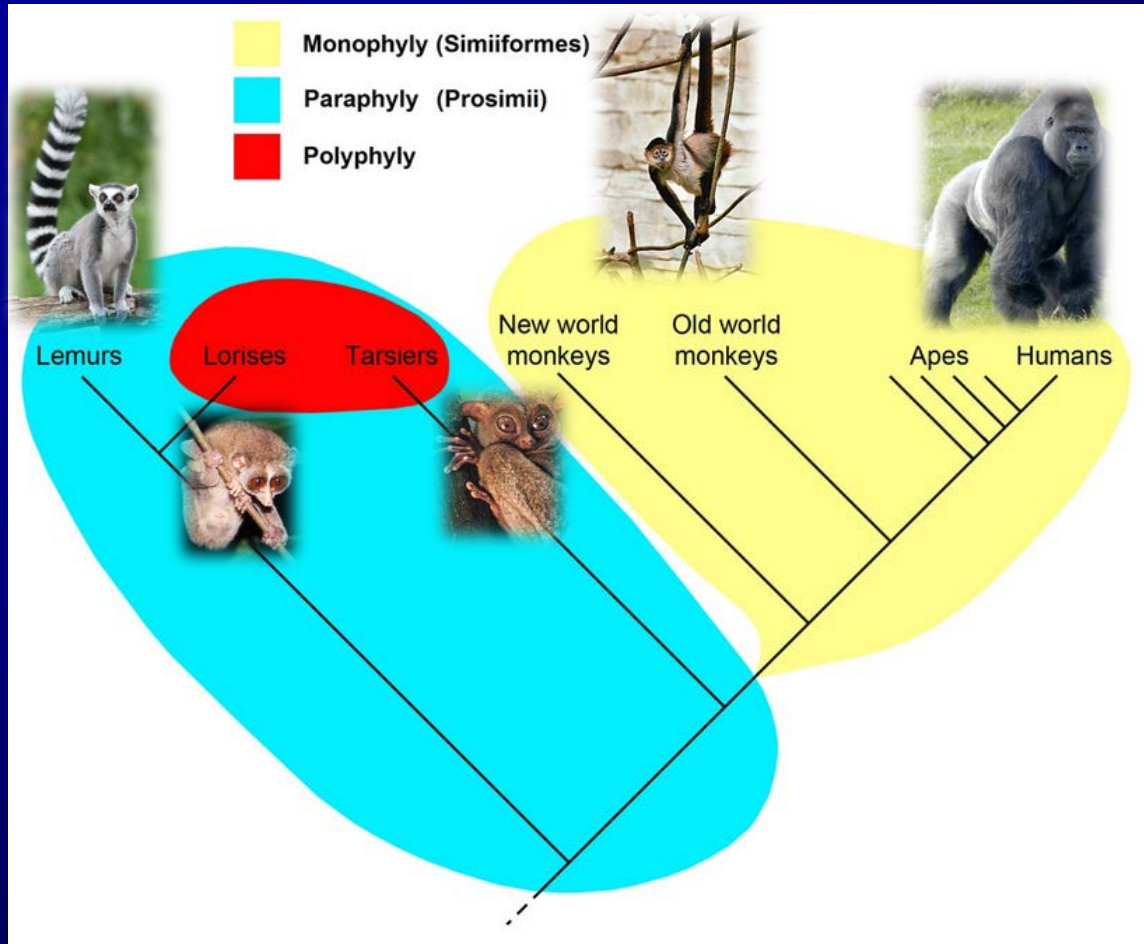
Sistemática Filogenética

- **Classificação** deve ser sempre baseada em **grupos monofiléticos** (compostos pelo ancestral direto e todos os seus descendentes); **parafilia**



Sistemática Filogenética

- *Classificação deve ser sempre baseada em grupos monofiléticos (compostos pelo ancestral direto e todos os seus descendentes); parafilia*



Sistemática Filogenética

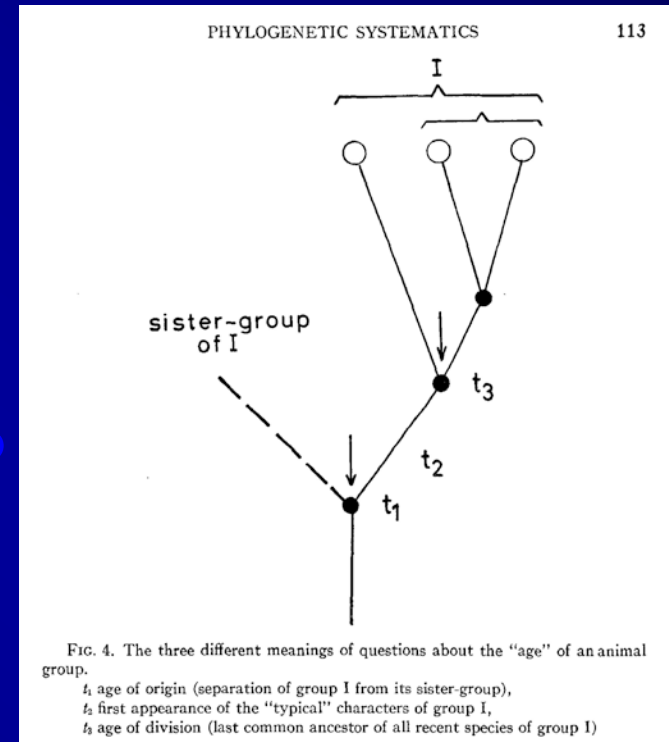
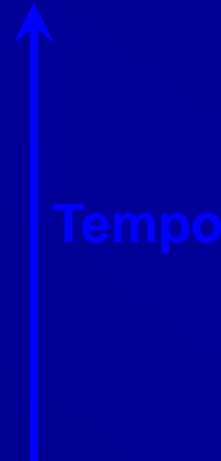
Preceitos básicos:

- Grupos devem ser reunidos levando em conta ancestralidade – descendência (como qualquer sistema filogenético) – idéia de Darwin
- Essa relação é inferida por novidades evolutivas exclusivas (baseado no conceito de homologia) - **apomorfias**
- Grupos naturais devem ser **monofiléticos**

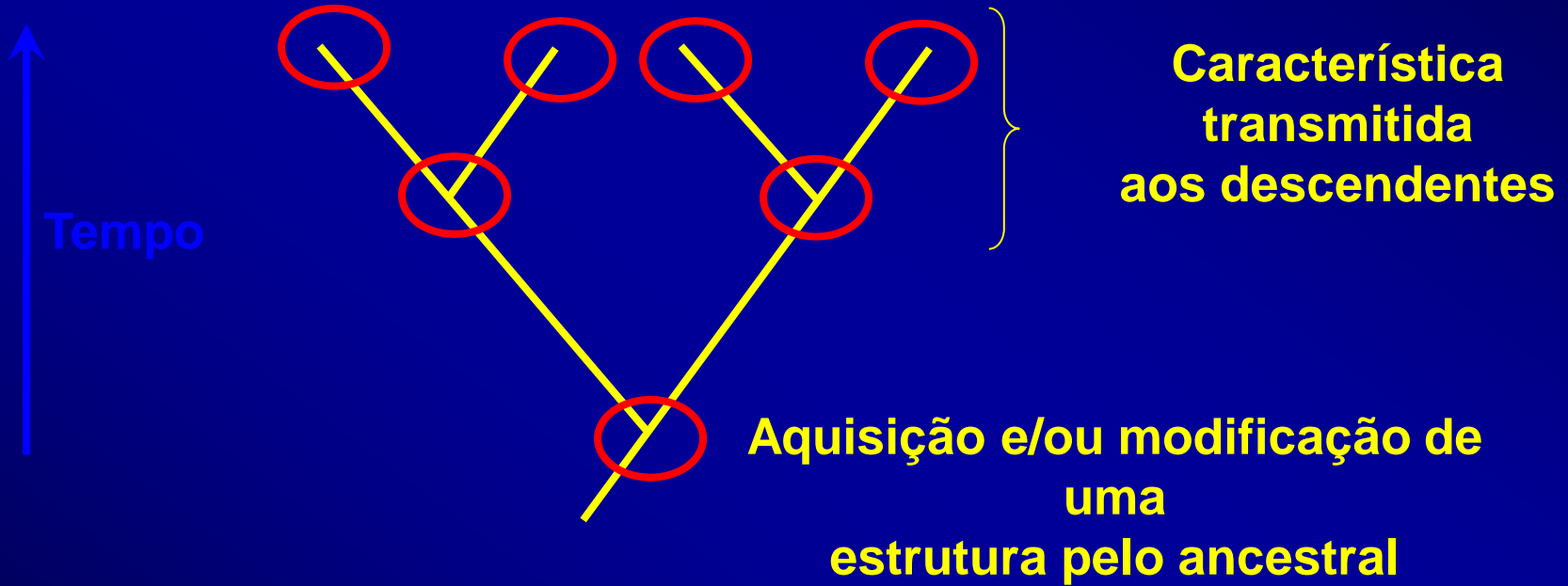
Sistemática Filogenética

Cladograma (grego klados = ramo)

Diagramada bifurcado representando uma hipótese de filogenia



Sistemática Filogenética

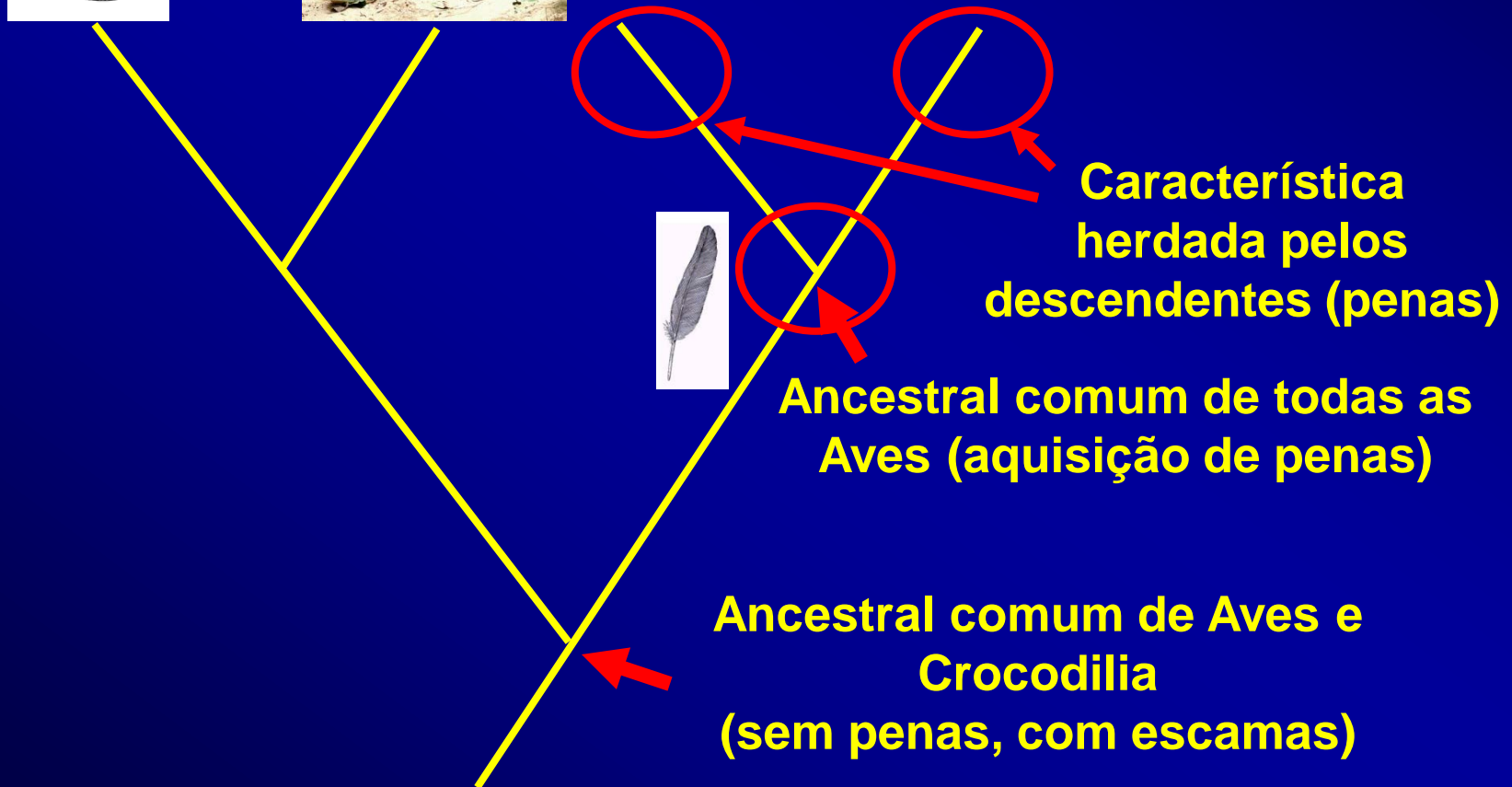


Sistemática Filogenética

Exemplo: aquisição de penas em Aves

Crocodylia

Aves



Sistemática Filogenética

Plesiomorfia X Apomorfia

Plesiomorfia: estado de caráter ancestral (ou “primitivo”)

Apomorfia: estado de caráter derivado (“novidade evolutiva”)

Somente podemos comparar apenas caracteres
supostamente HOMÓLOGOS

Sistemática Filogenética

Caráter. qualquer atributo que possamos delimitar e para o qual reconhecemos pelo menos dois estados (ex.: apêndices epidérmicos da pele)

Estados de caráter. as variações que podemos observar em um determinado caráter (ex.: apêndices em forma de escamas, penas ou pelos)

Séries de transformação

Para caráter com dois estados A, B:

A — B

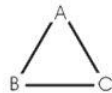
Temos as seguintes possibilidades:

A ↔ B

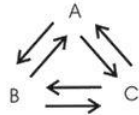
Assim,

A → B B → A

Para caráter com três estados:



Temos as seguintes possibilidades:



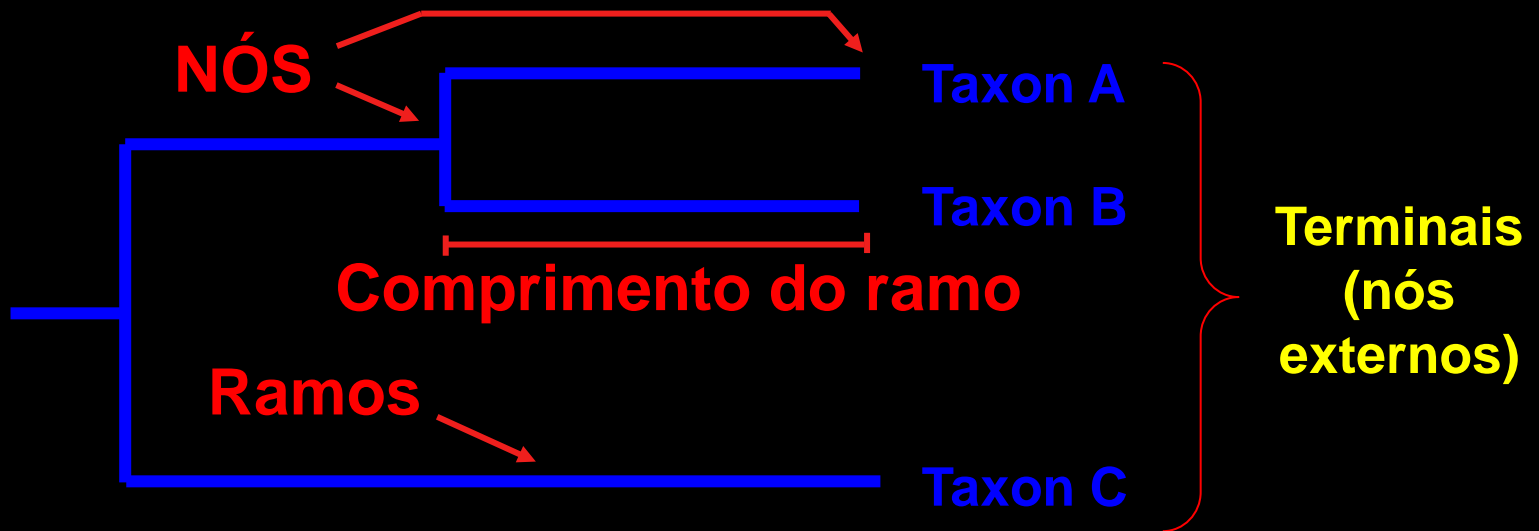
ou

A → B → C B → A → C A → C → B
A ← B ← C B ← A ← C A ← C ← B
A ← B → C B ← A → C A ← C → B

É o encadeamento do conjunto de estados de um caráter.

Sistemática Filogenética

Terminologia das árvores

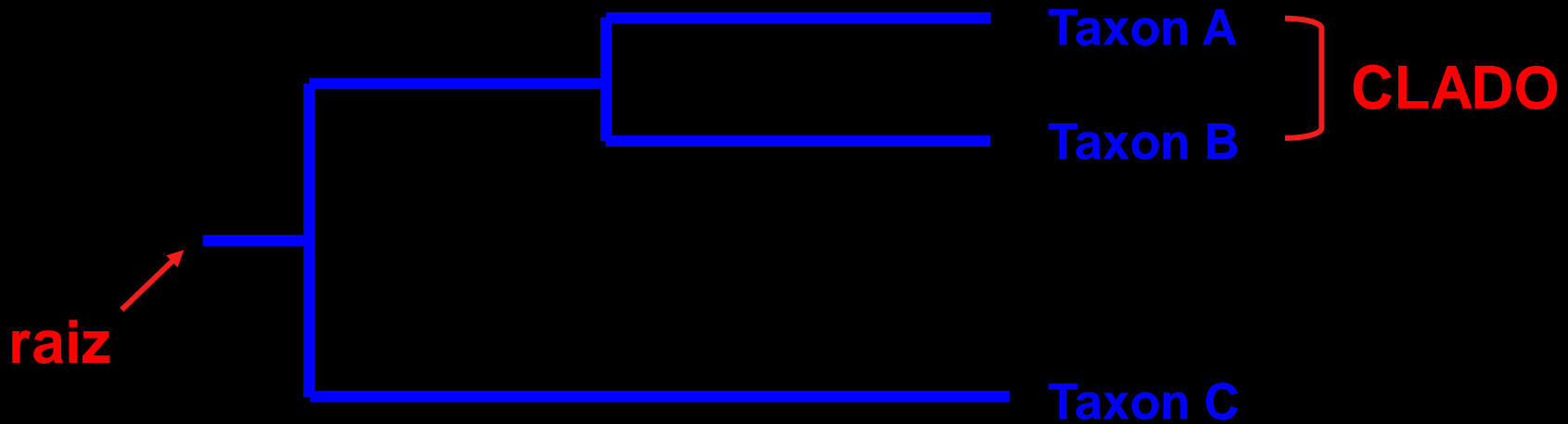


- NÓ:** Uma unidade taxonômica (“OTU: operational taxonomic unit”)
- Pode ser uma espécie, uma população, um indivíduo ou um gene
 - Nós externos representam táxons existentes
 - Nós internos representam táxons ancestrais (inferidos)

COMPRIMENTO DO RAMO: quantidade de mudanças que correram ao longo de um ramo

Sistemática Filogenética

Terminologia das árvores



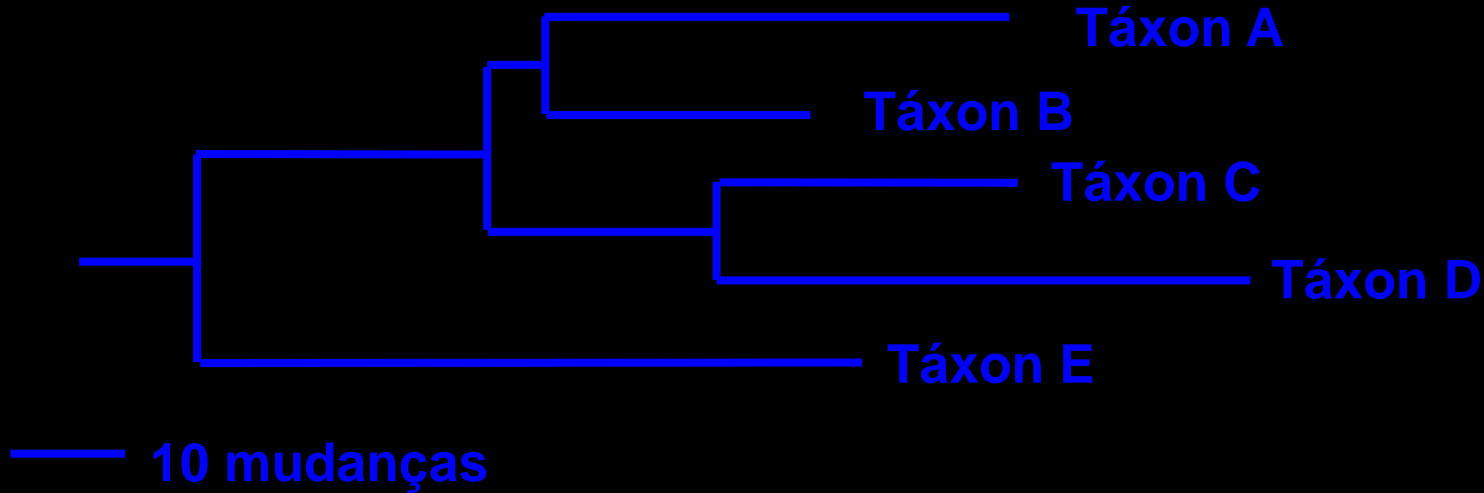
CLADO: Um grupo que contém um ancestral comum e todos os seus descendentes (grupo monofiletico)

RAIZ: O ancestral comum de todos os táxons na árvore

TOPOLOGIA: O padrão de ramificação geral da árvore

Sistemática Filogenética

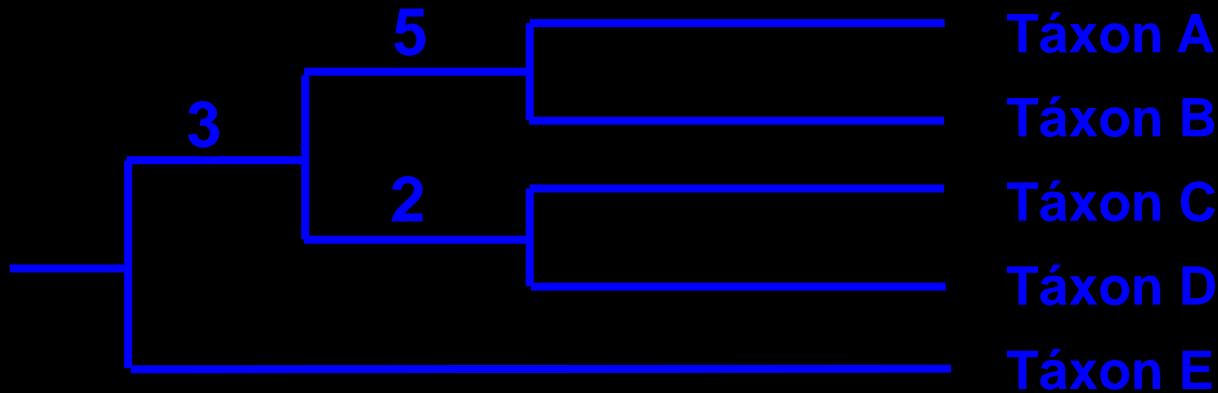
Ramos com escalas



- Um ramo em escala é desenhado proporcionalmente ao número de mudanças que ocorreram ao longo daquele ramo
- Pode expressar TEMPO de DIVERGÊNCIA das linhagens

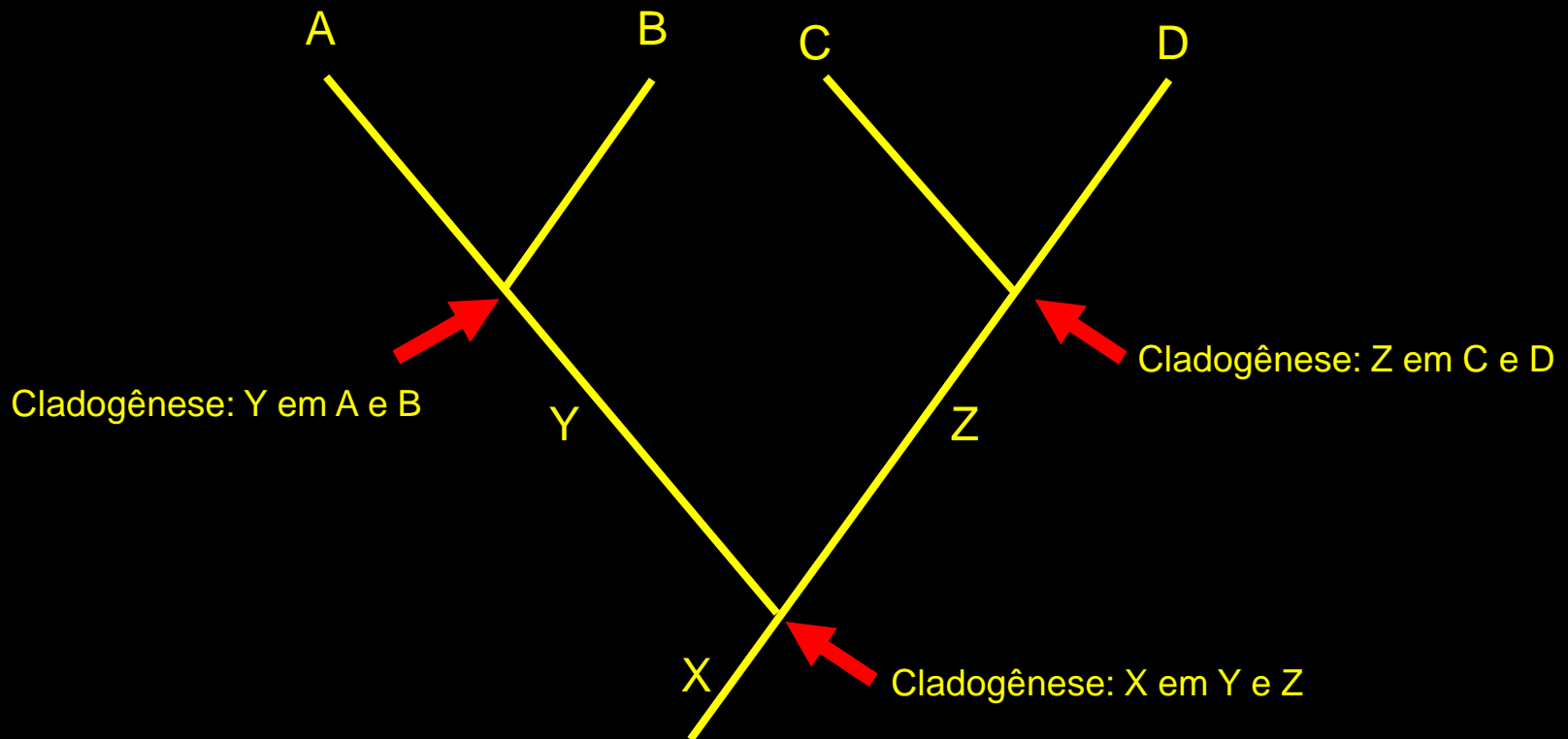
Sistemática Filogenética

Ramos sem escalas

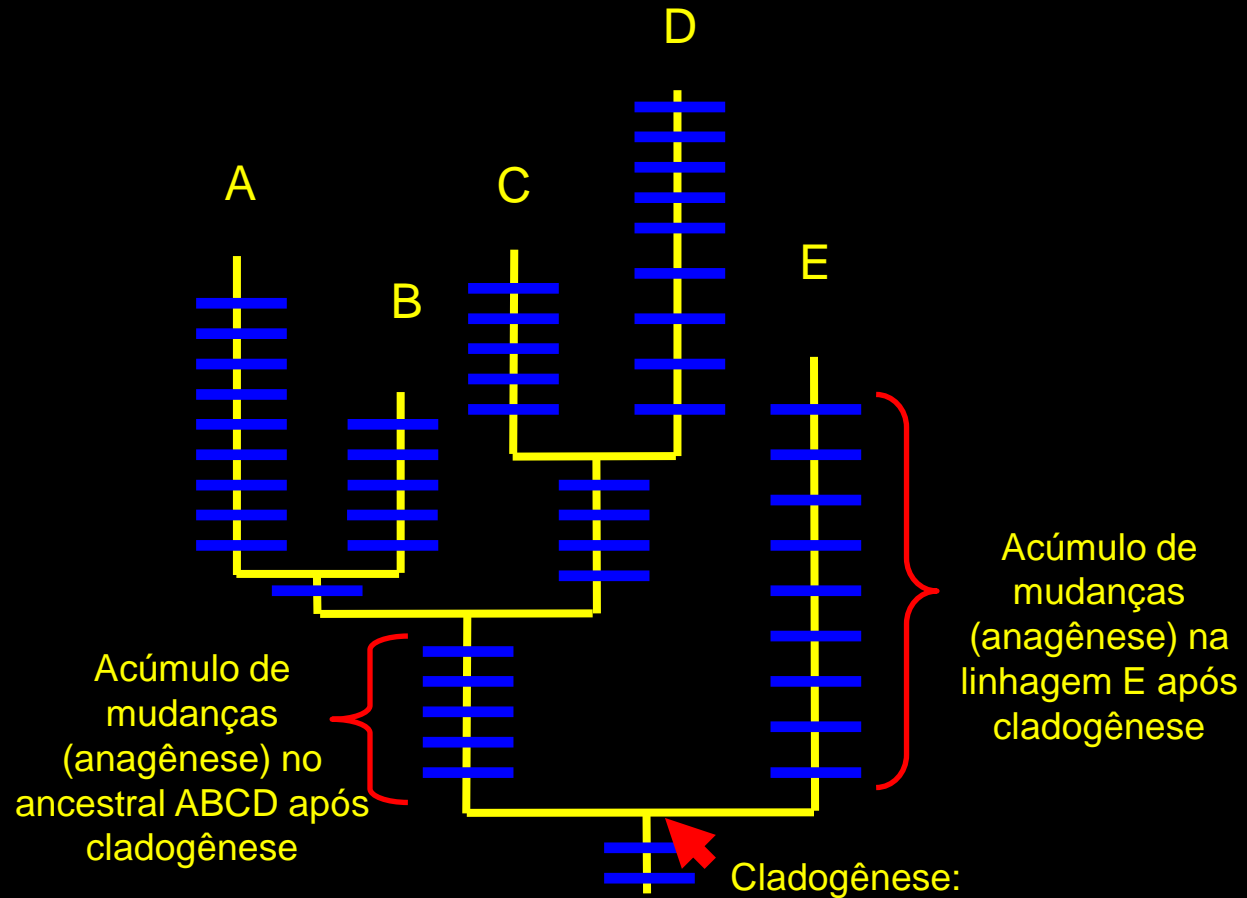


- Números que indicam o número de mudanças são freqüentemente posicionados acima dos ramos

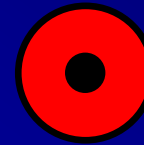
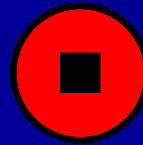
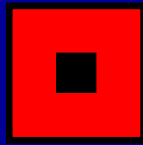
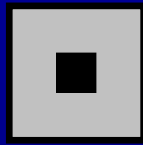
Cladogênese (ou Evento Cladogenético)–
processo de separação de linhagens com história
evolutiva comum



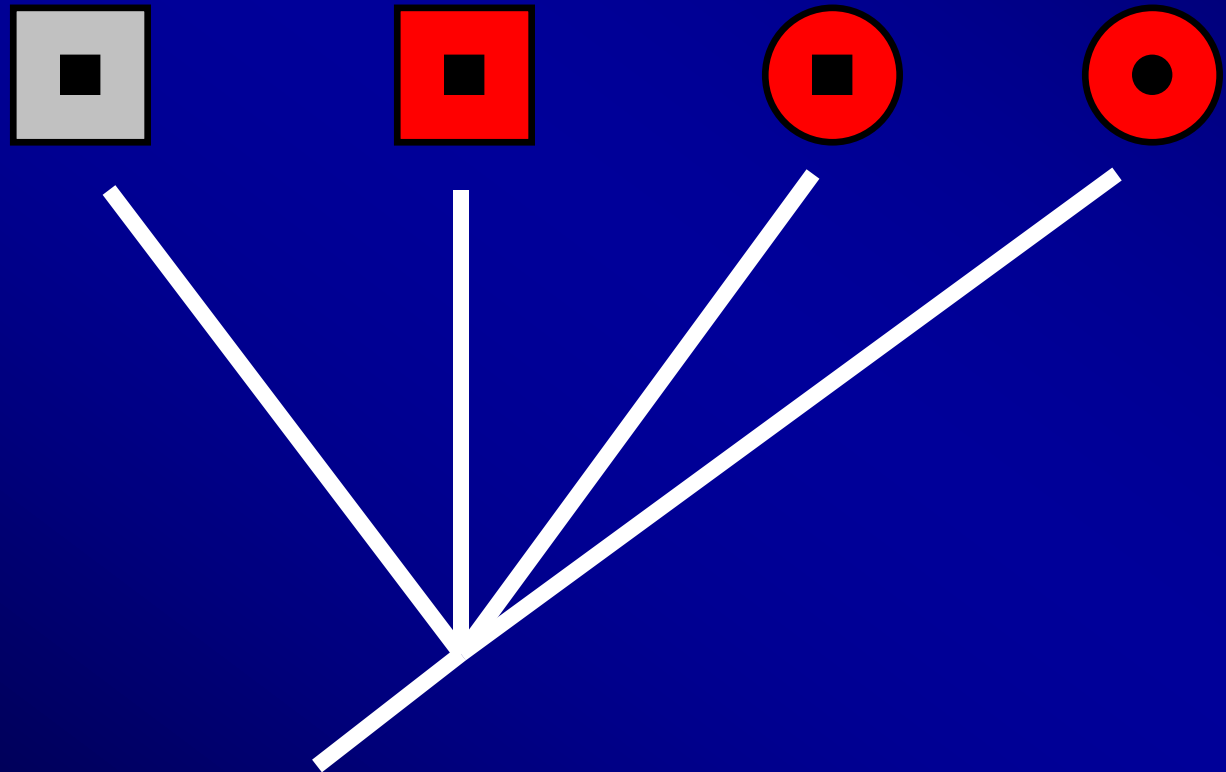
Anagênese (ou Processo Anagenético)–
processo de mudanças (genéticas, morfológicas)
nas linhagens ao longo do tempo entre os
eventos cladogenéticos



Sistemática Filogenética

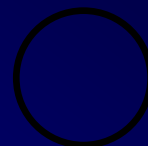
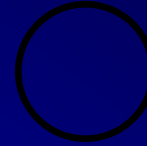
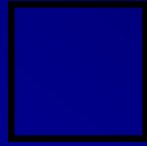
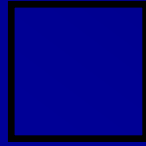


Sistemática Filogenética

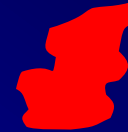
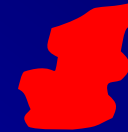
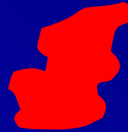


Sistemática Filogenética

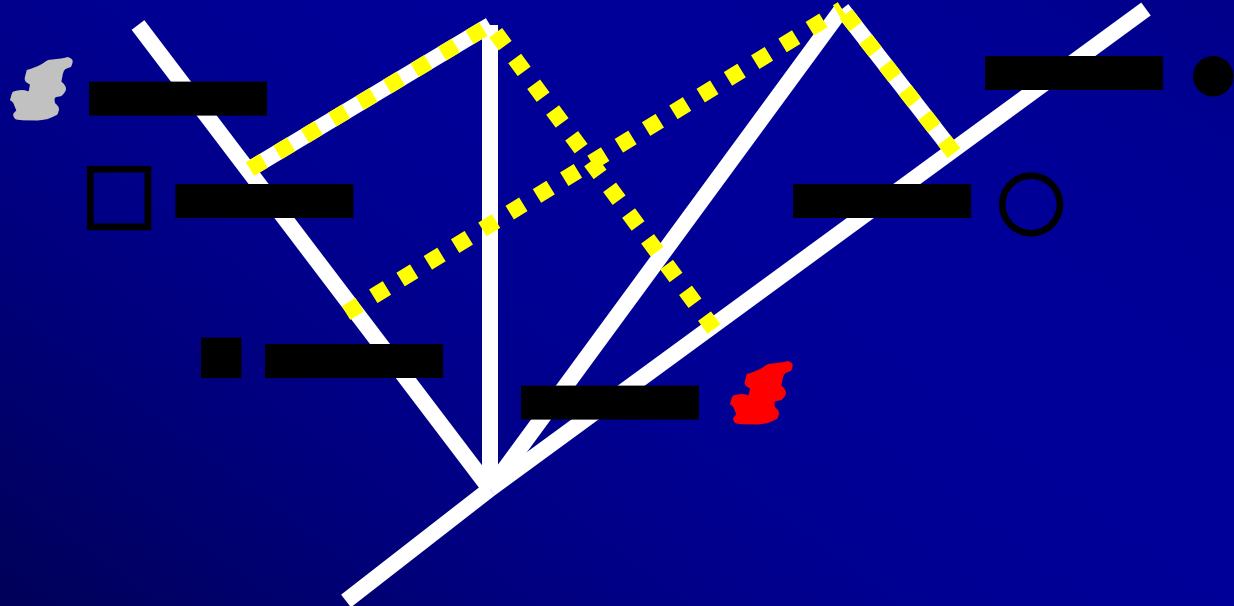
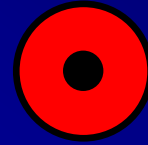
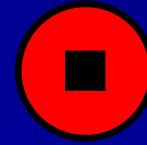
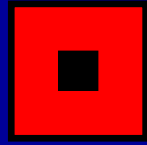
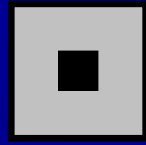
Formato do corpo



Cor



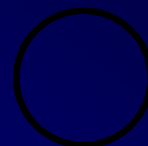
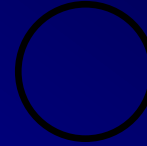
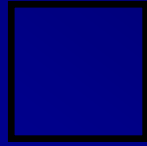
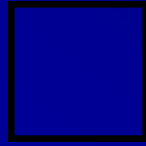
Formato do apêndice central



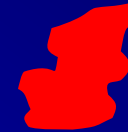
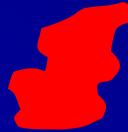
Sistemática Filogenética

Sistemática Filogenética

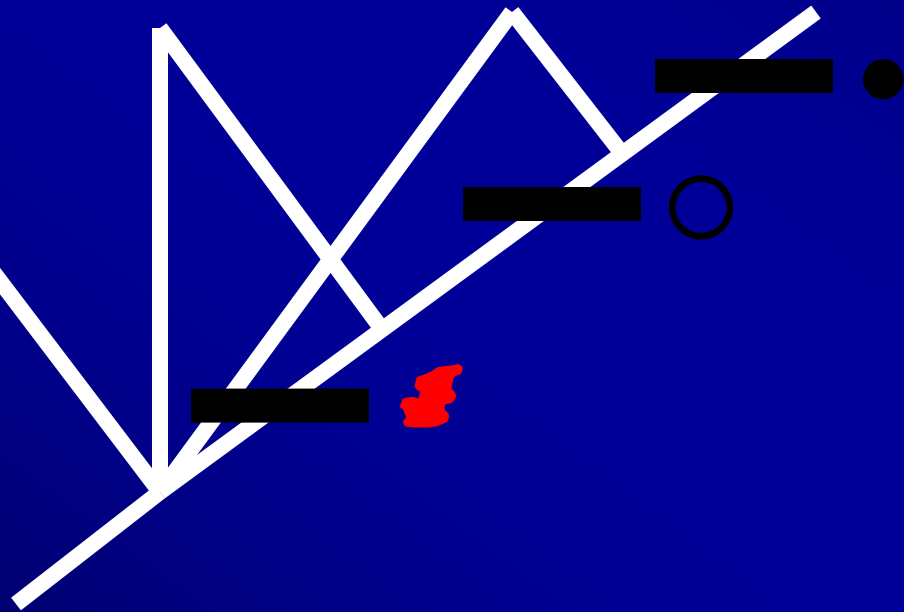
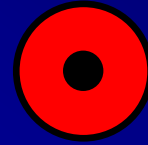
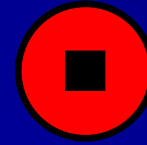
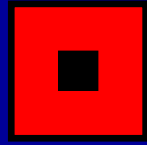
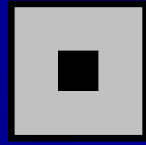
Formato do corpo



Cor

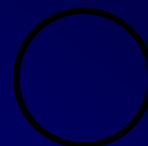
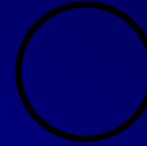
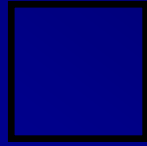
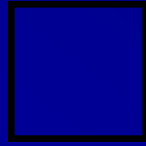


Formato do apêndice central

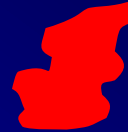
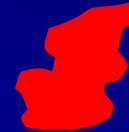
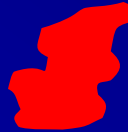


Sistemática Filogenética

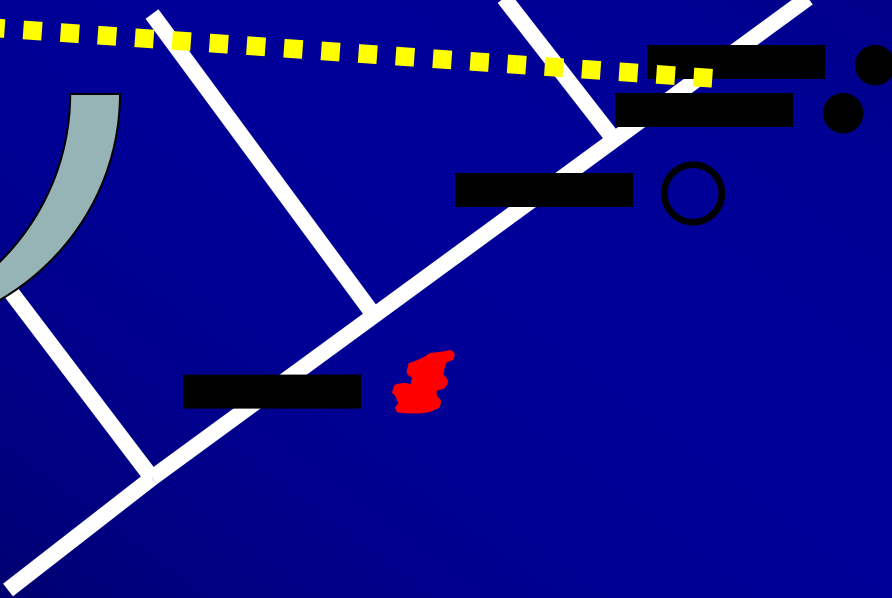
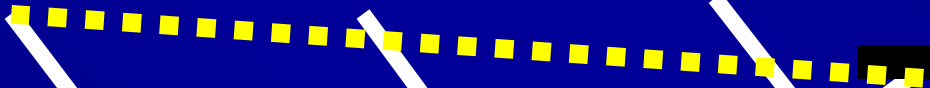
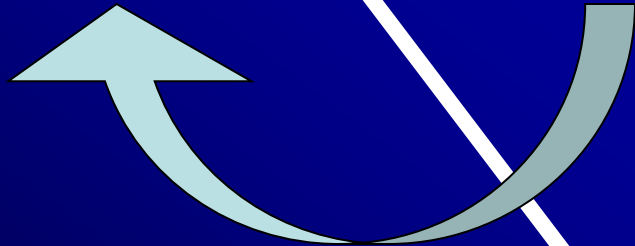
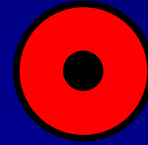
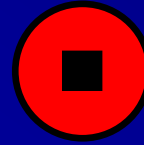
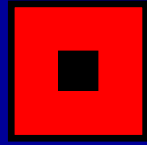
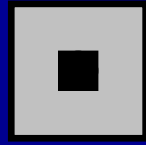
Formato do corpo



Cor

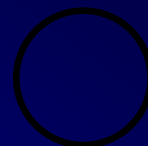
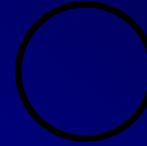
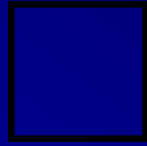
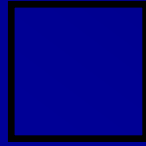


Formato do apêndice central

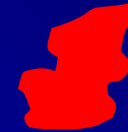
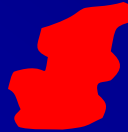


Sistemática Filogenética

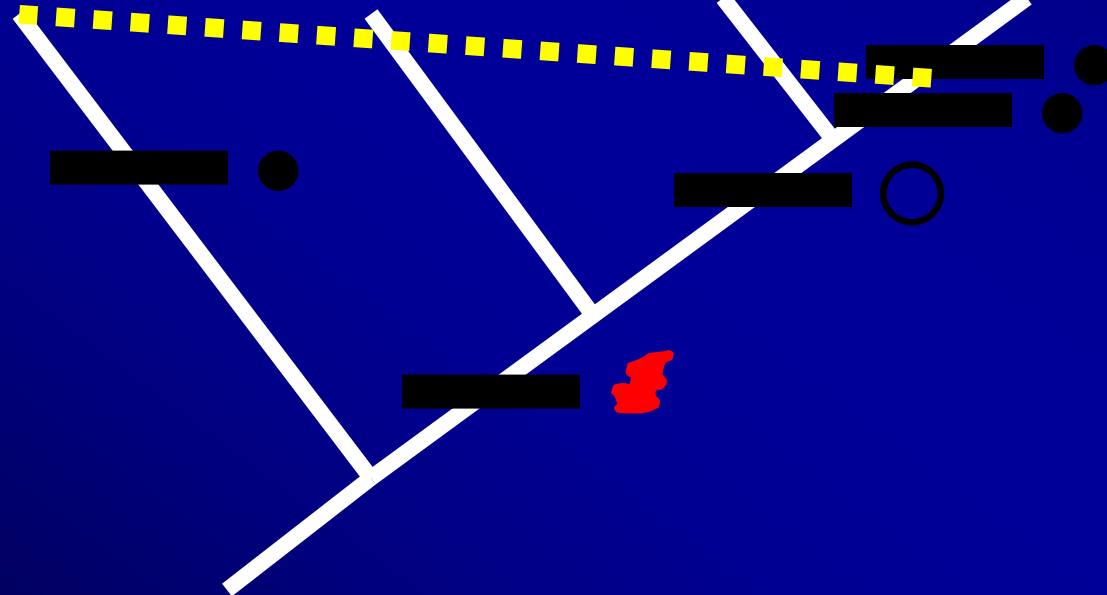
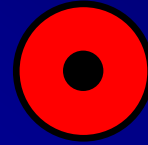
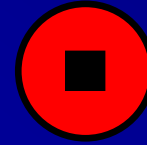
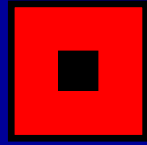
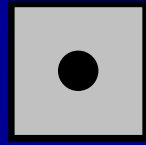
Formato do corpo



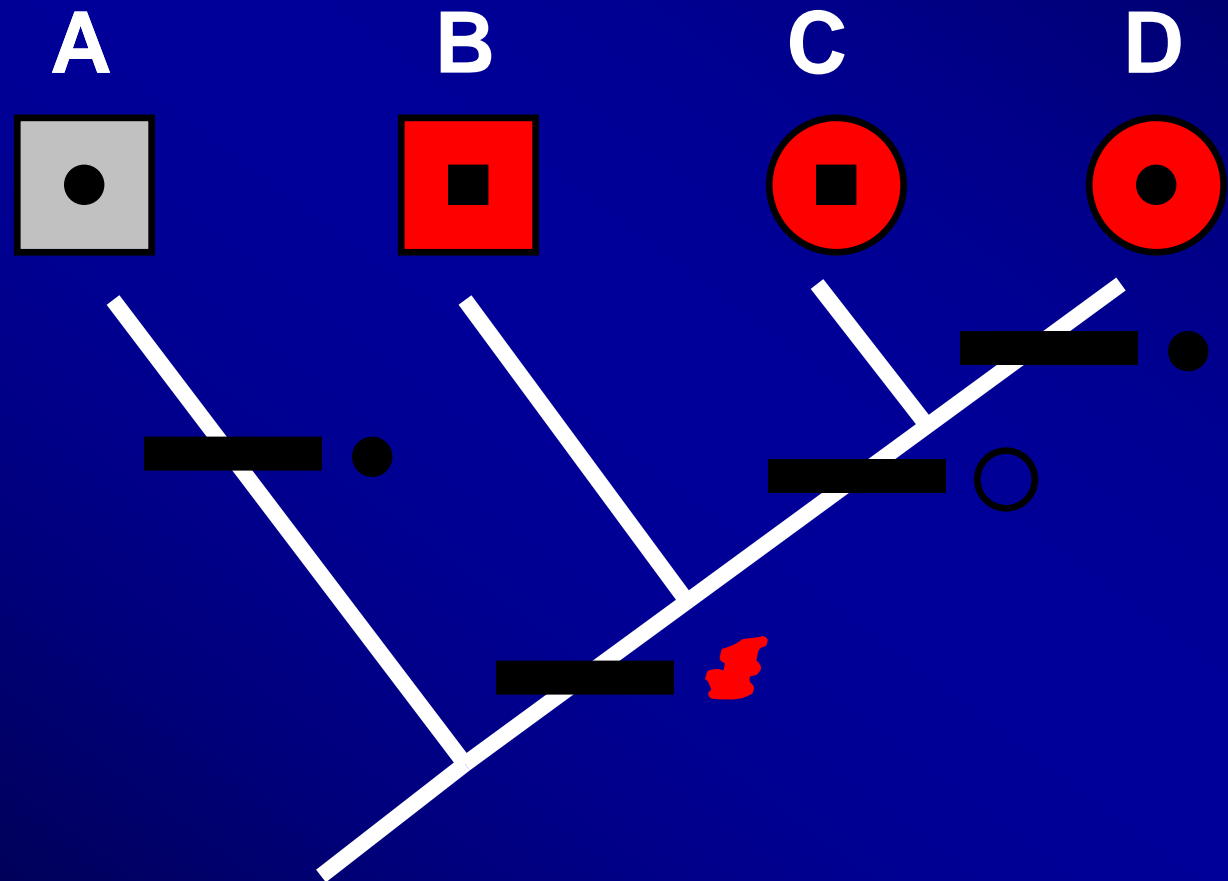
Cor



Formato do apêndice central

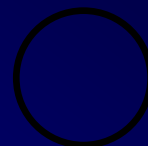
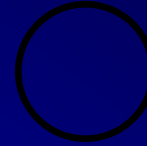
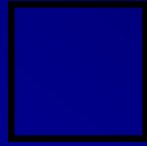
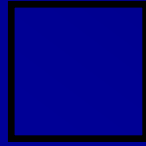


Sistemática Filogenética

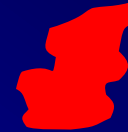
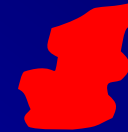
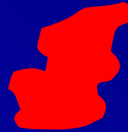


Sistemática Filogenética

Formato do corpo



Cor

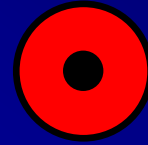
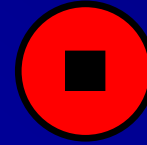
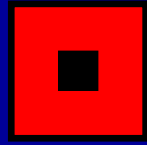
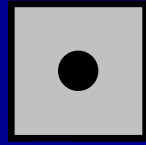


A

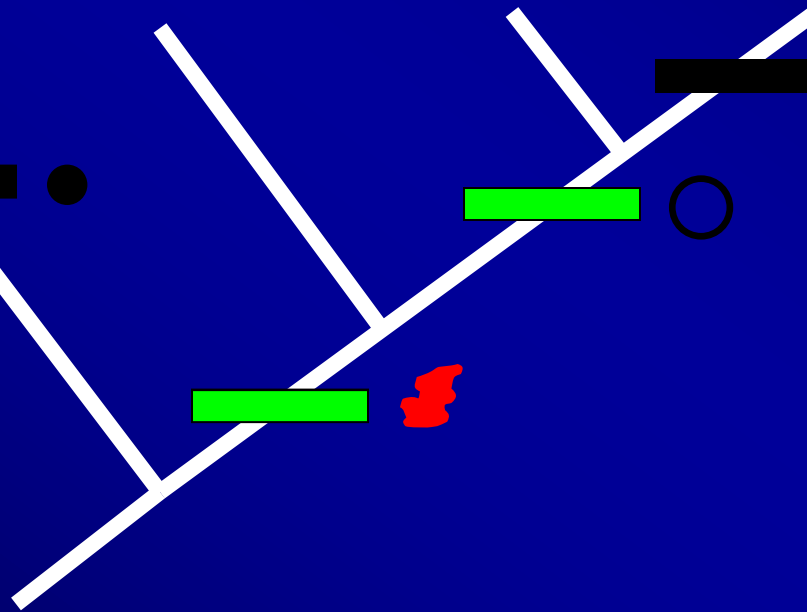
B

C

D



- Sinapomorfia

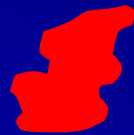
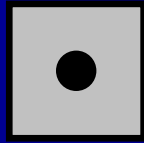


Sistemática Filogenética

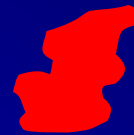
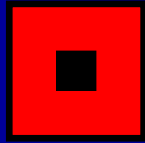
Cor



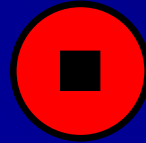
A



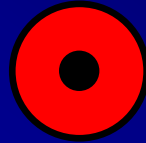
B



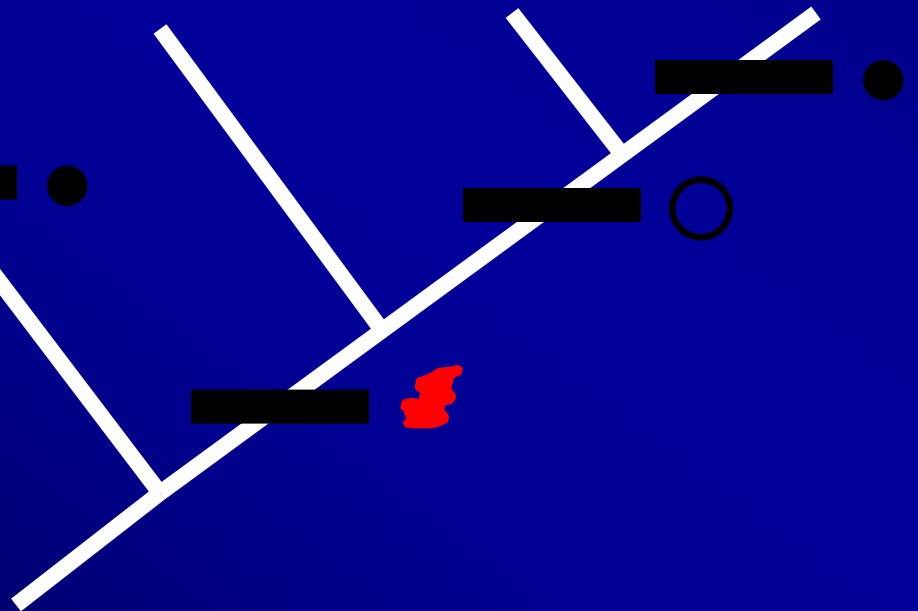
C



D

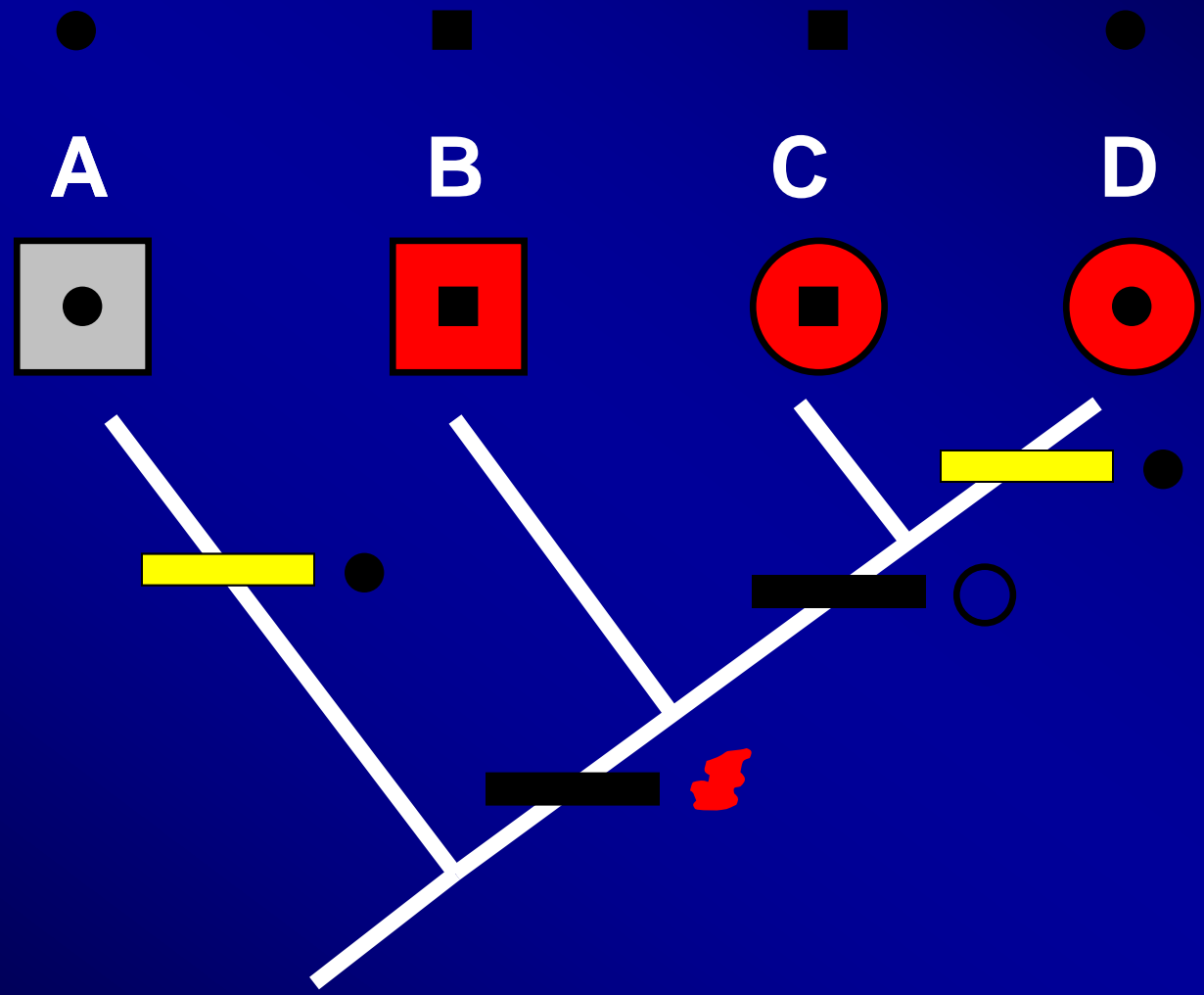


- *Simplesiomorfia*



Sistemática Filogenética

Formato do apêndice central



- Homoplasia

Sistemática Filogenética

- Grupos monofiléticos

