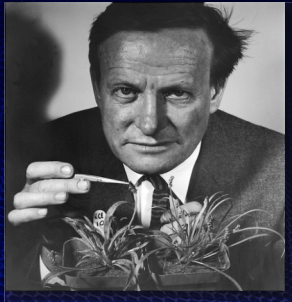




# Schemes for Increasing Complexity I

*The Basis of Progressive Evolution (1969)*



G. Ledyard Stebbins

Self-replicating molecules  
Prokaryotes  
Single-celled eukaryotes  
Multicelled eukaryotes with cellular differentiation  
Organisms with differentiated tissues and organs  
Organisms with well-developed limbs and nervous systems  
Homeotherms  
Human beings



# Schemes for Increasing Complexity II

*Major Transitions in Evolution (1995)*

Replicating molecules --> Populations of molecules in compartments  
Independent replicators --> Chromosomes  
RNA as gene and enzyme --> DNA + protein  
Prokaryotes --> Eukaryotes  
Asexual clones --> Sexual populations  
Protists --> Animals, plants, fungi (cell differentiation)  
Solitary individuals --> Colonies (non-reproductive castes)  
Primate societies --> Human societies (language)



Maynard Smith and Szathmáry

## Schemes for Increasing Complexity III

### Megatrajectory Sequence

Increase in efficiency of life processes  
Prokaryote diversification  
Unicellular eukaryote diversification  
Aquatic multicellularity  
Invasion of the land  
Intelligence

Increasing complexity



Knoll & Bambach 2000

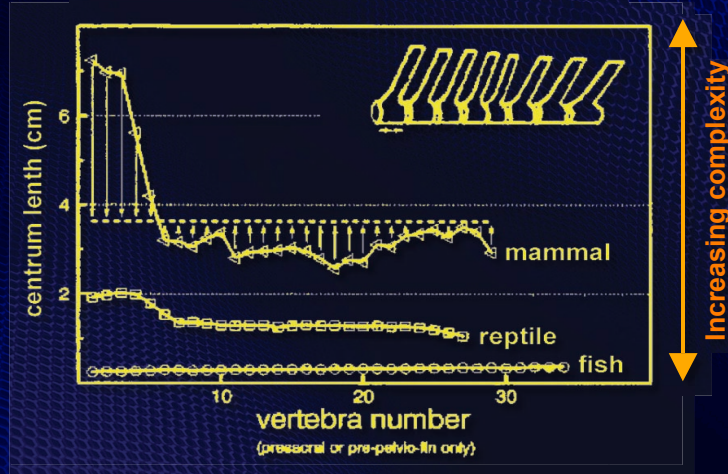
## The Problem

“Complexity is hard to define or measure...”

Maynard Smith and Szathmáry, 1995

# Segmentation and Complexity I

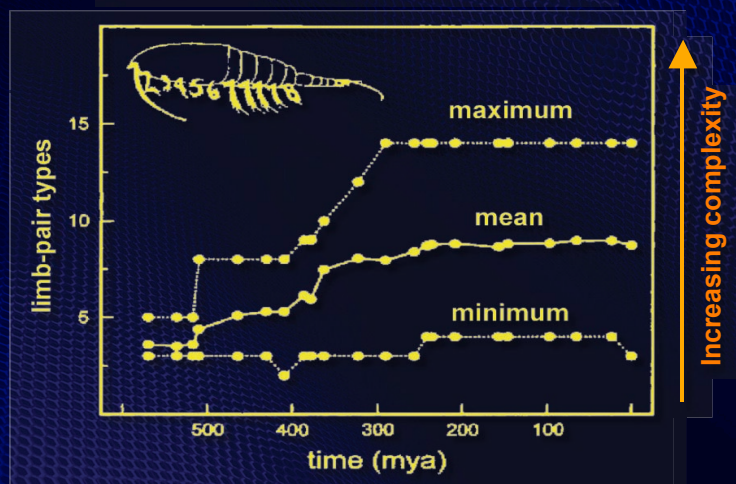
Differentiation of centrum length in vertebrates



(from McShea 1992)

# Segmentation and Complexity II

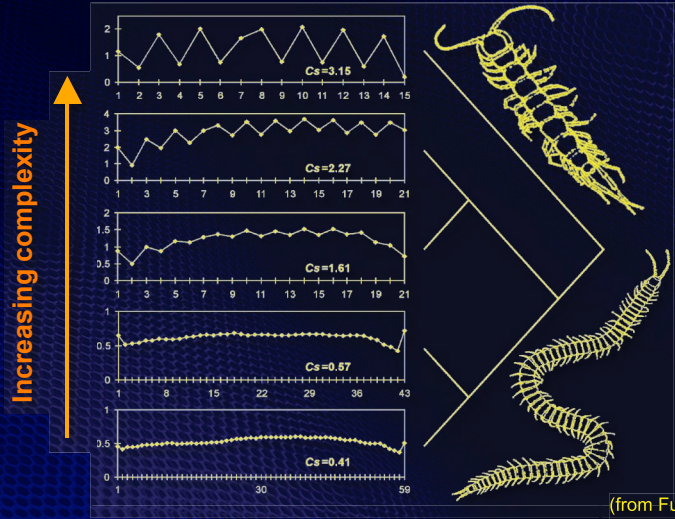
Functional differentiation in arthropod limbs



(from Cisne 1974)

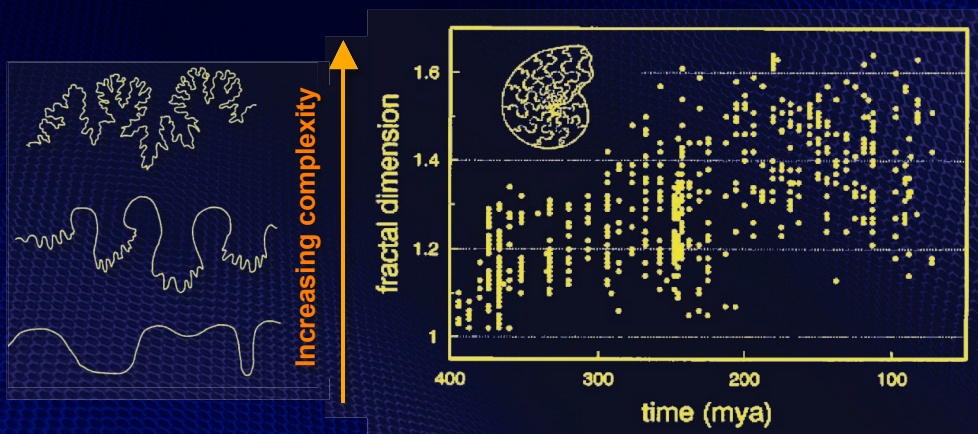
# Segmentation and Complexity III

Differentiation of segment length in centipedes



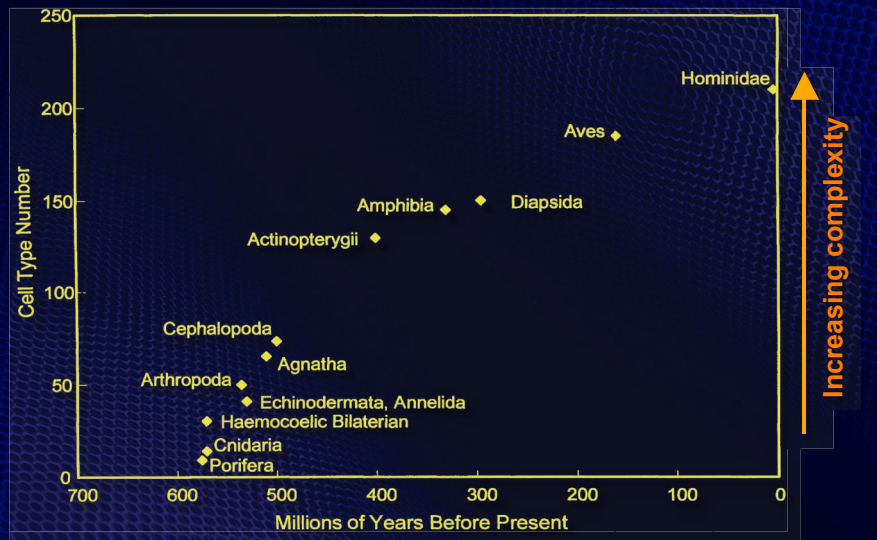
# Fractals and Complexity

Fractal dimension in ammonoids



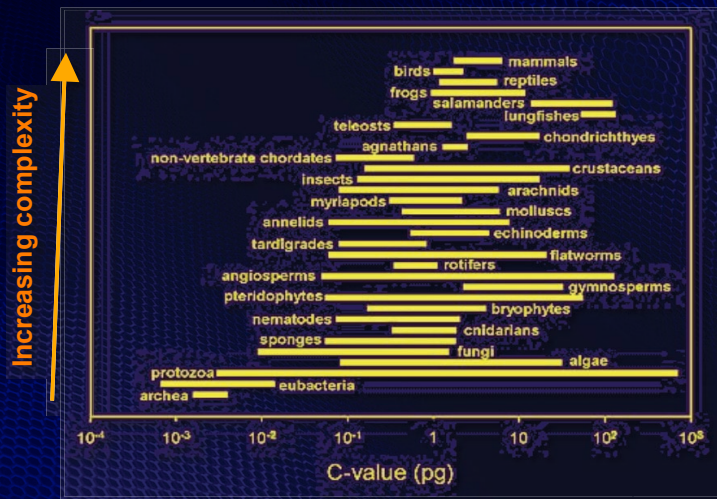
(from Boyajjian & Lutz 1992)

## Cell Number and Complexity



(from Valentine *et al.* 1994)

## Genome Size and the Scala Naturae

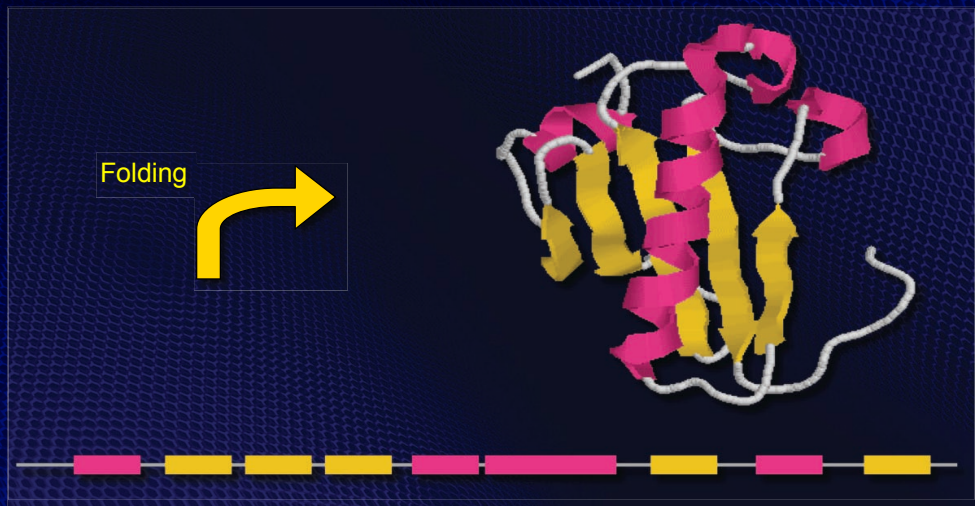


(from Gregory 2005)

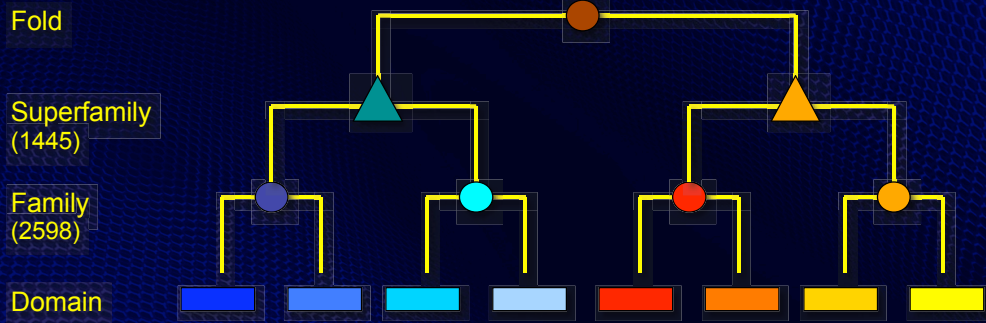
## Proteome Size and the Scala Naturae

?

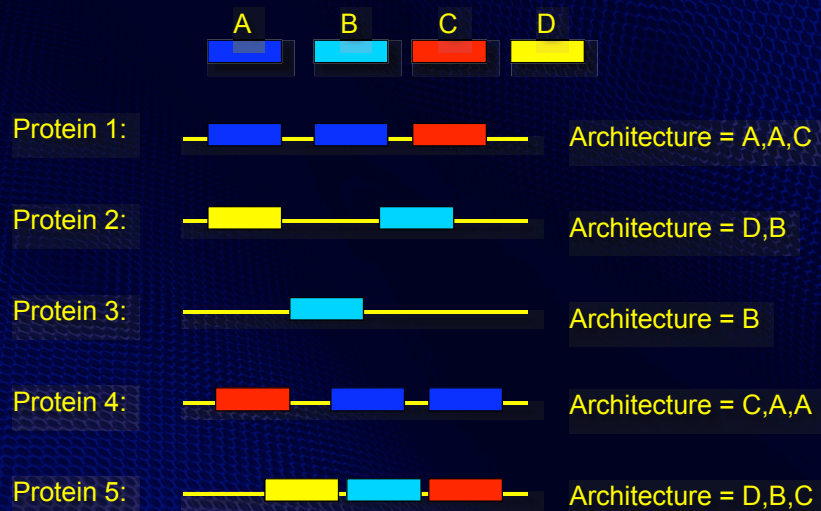
## Protein Structural Domains



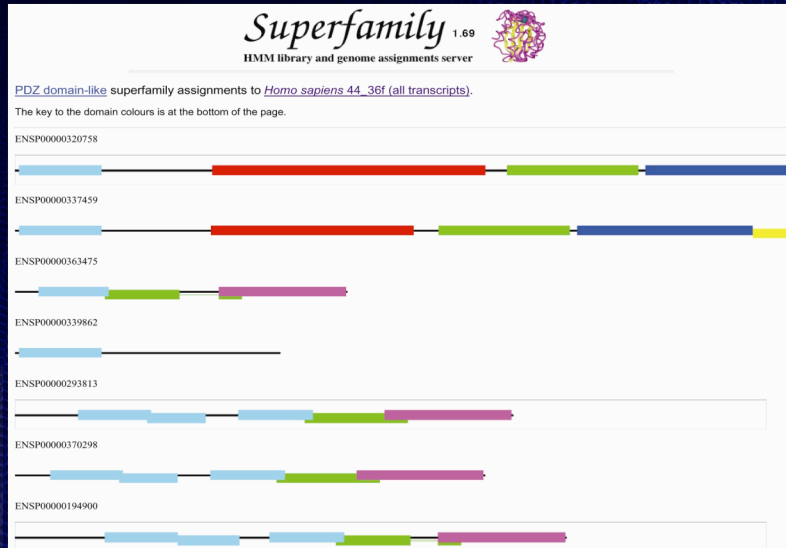
# Protein Domain Classification I



# Protein Domain Classification II



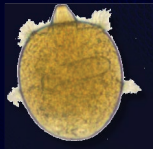
# Protein Domain Database I



# Protein Domain Database II



238 Bacteria



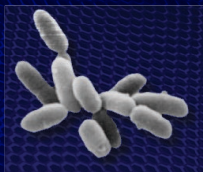
26 Basal Eukaryotes



53 Fungi



8 Arthropods



27 Archaea



9 Plants

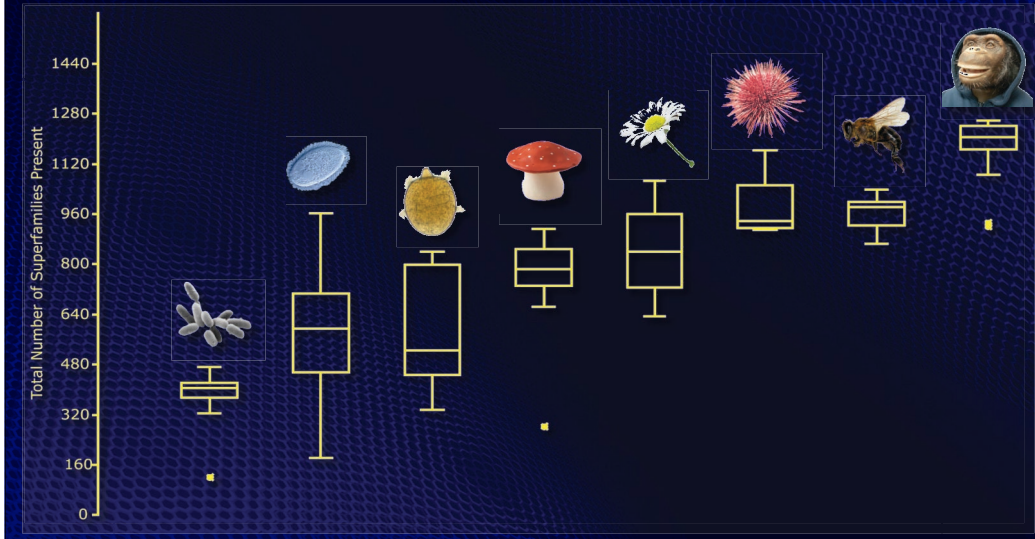


5 Invertebrates (excl. Arthropods)

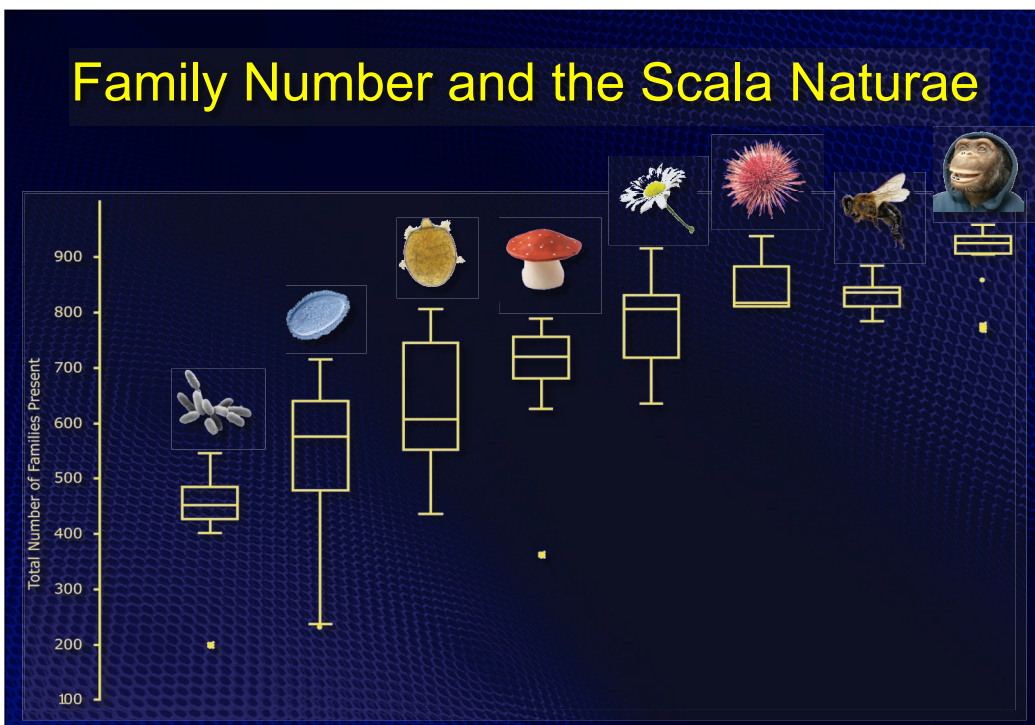


19 Chordates

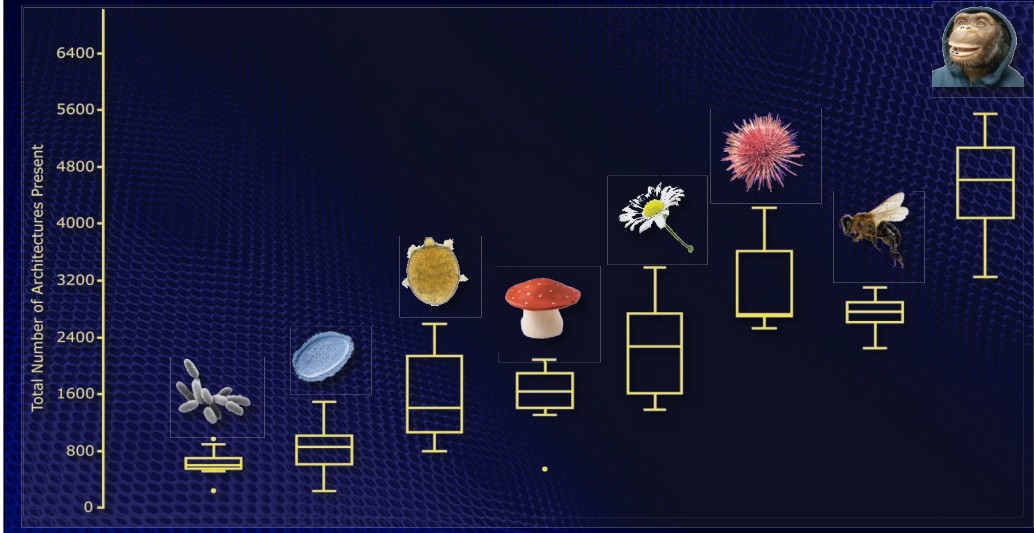
## Superfamily Number and the Scala Naturae



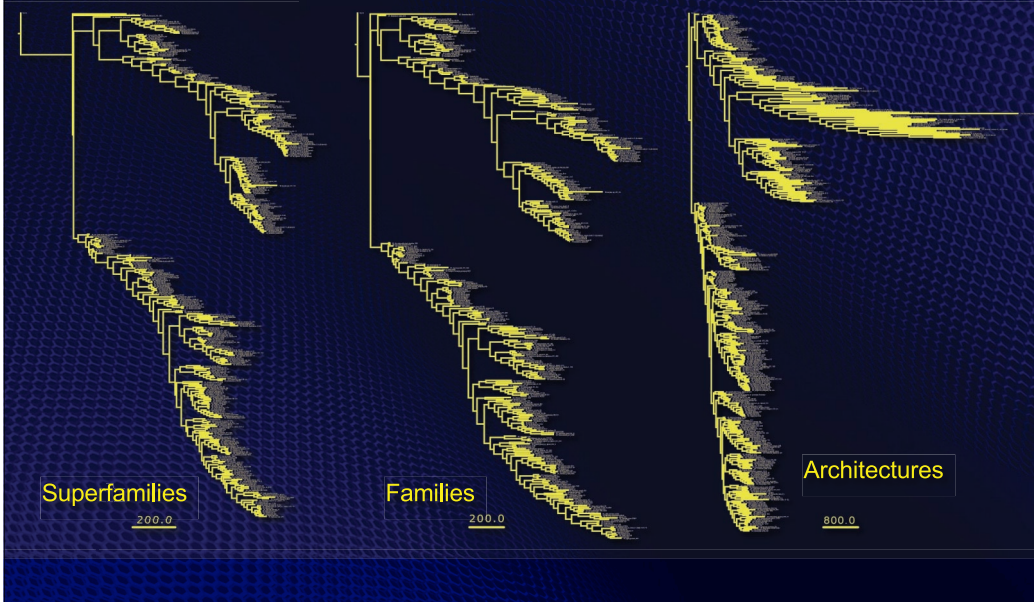
## Family Number and the Scala Naturae



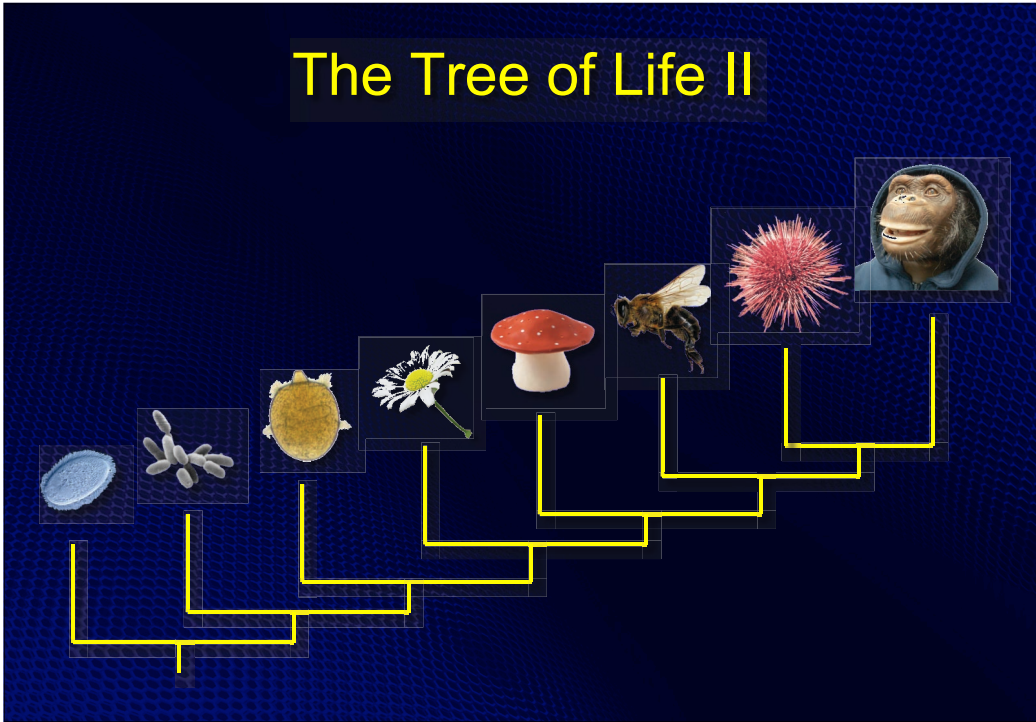
# Architecture Number and the Scala Naturae



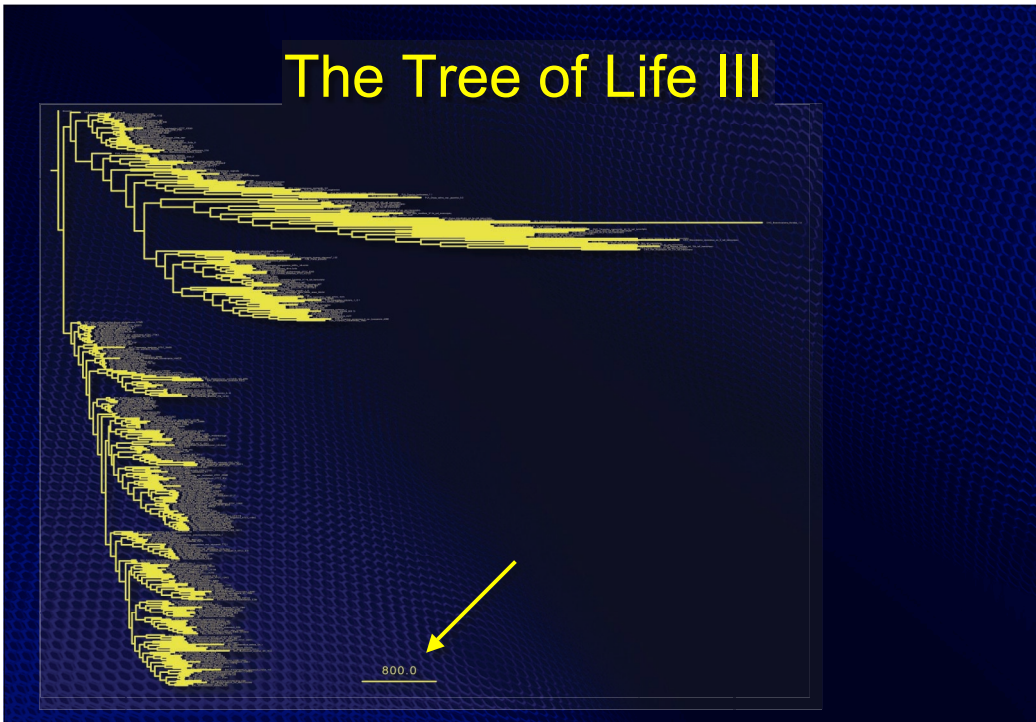
# The Tree of Life I



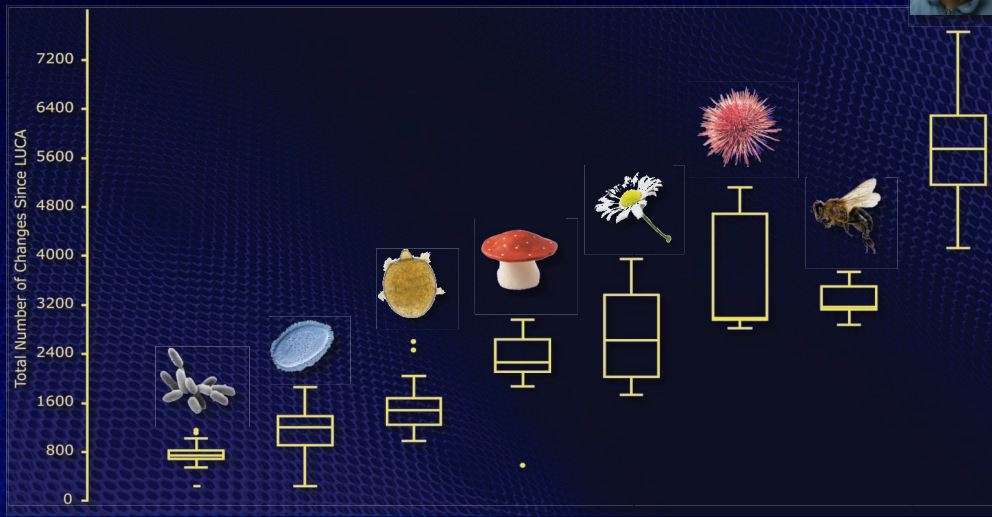
## The Tree of Life II



## The Tree of Life III



# The Tree of Life IV



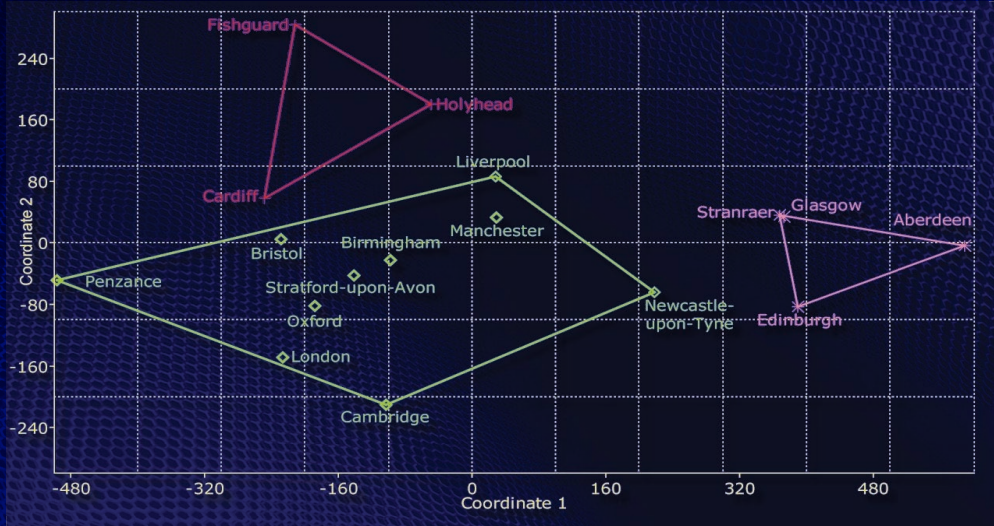
# Protein Space



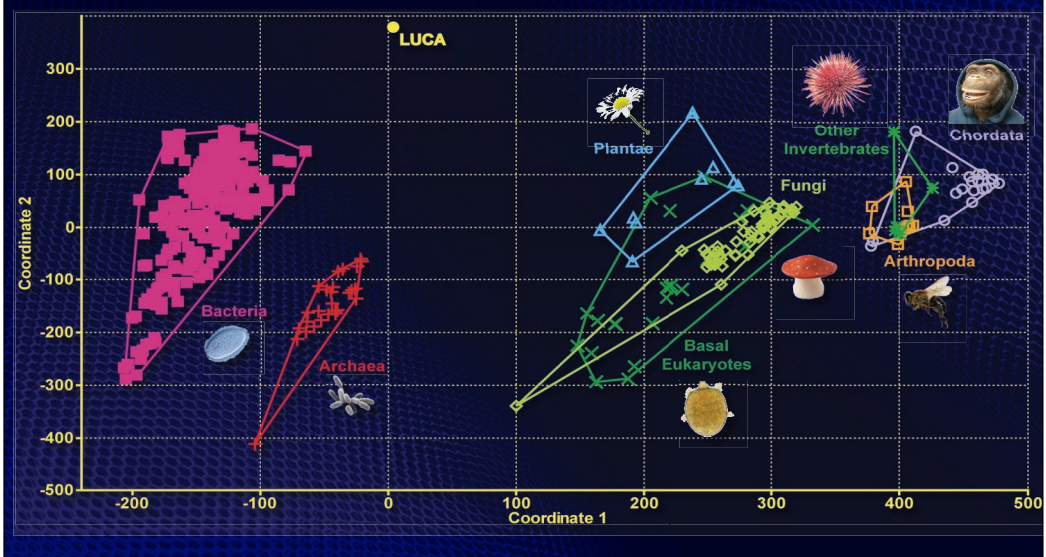


# Protein Space

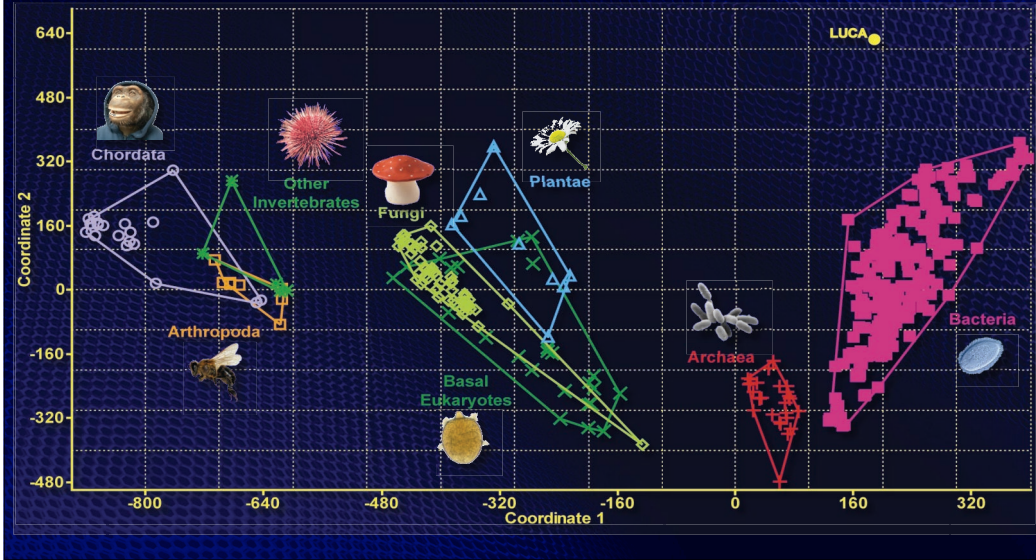
## Principal Coordinate Analysis – A Very Brief Introduction



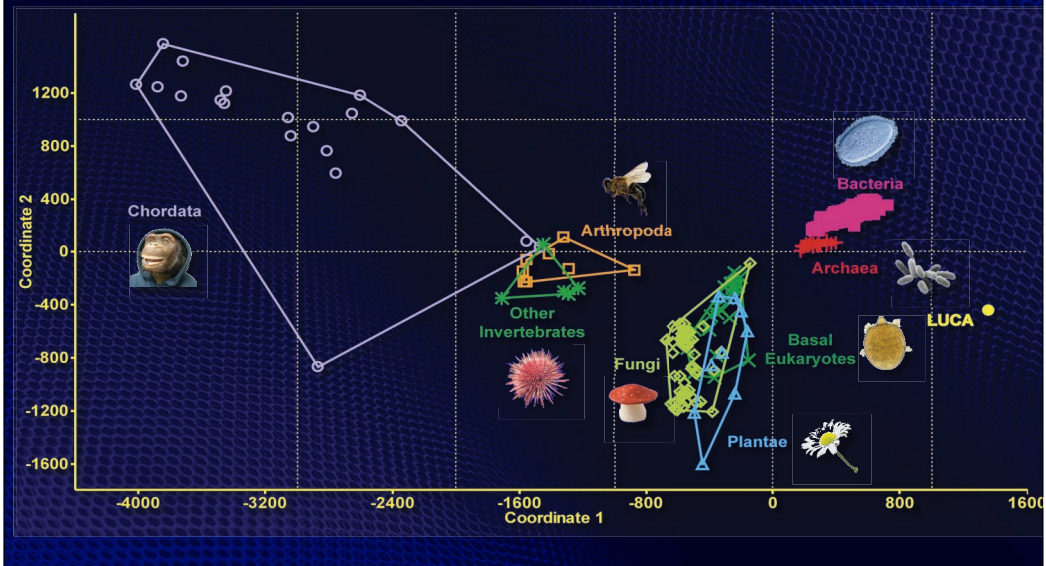
# Protein Space - Superfamilies



# Protein Space - Families



# Protein Space - Architectures

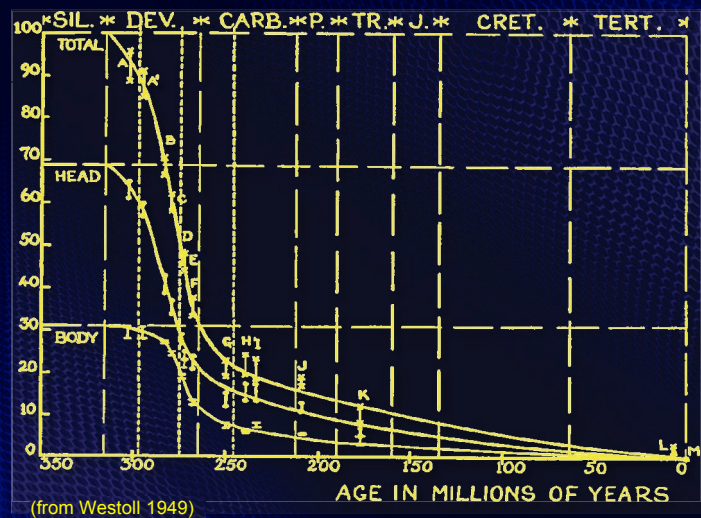


# Tempo and Protein Evolution



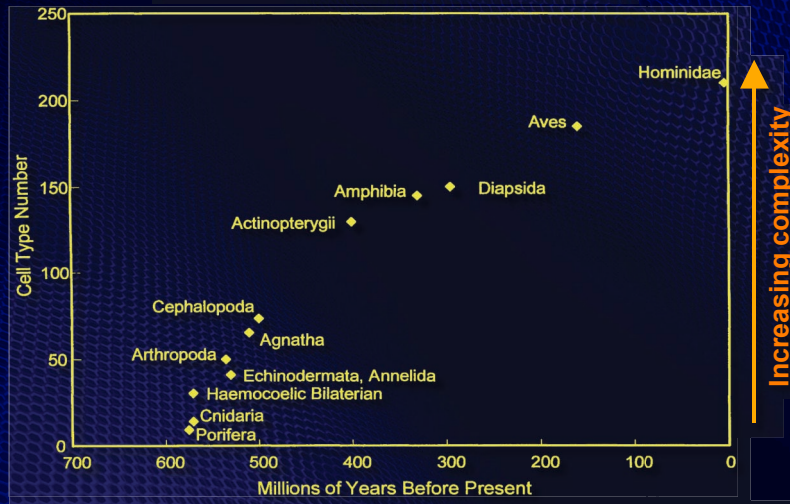
# Tempo and Protein Evolution

Tempo and mode of evolution in a character complex



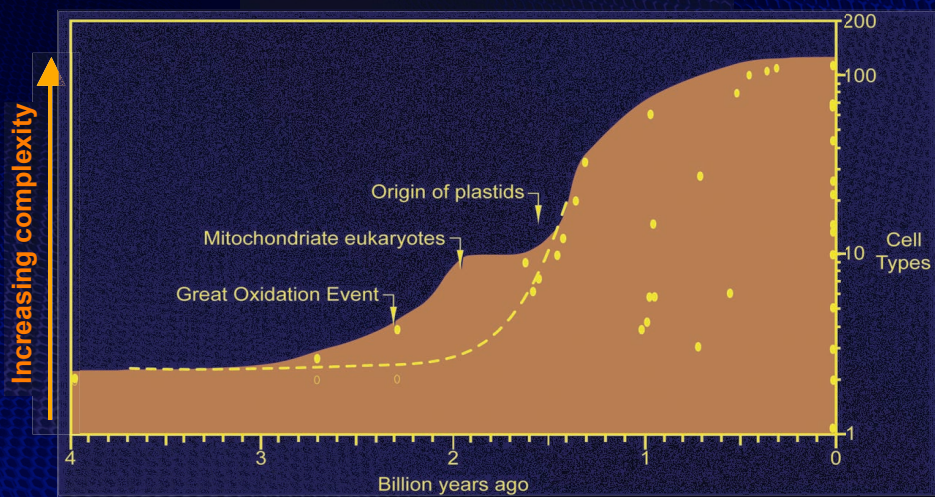
# Tempo and Protein Evolution

Tempo and mode of cell type evolution I

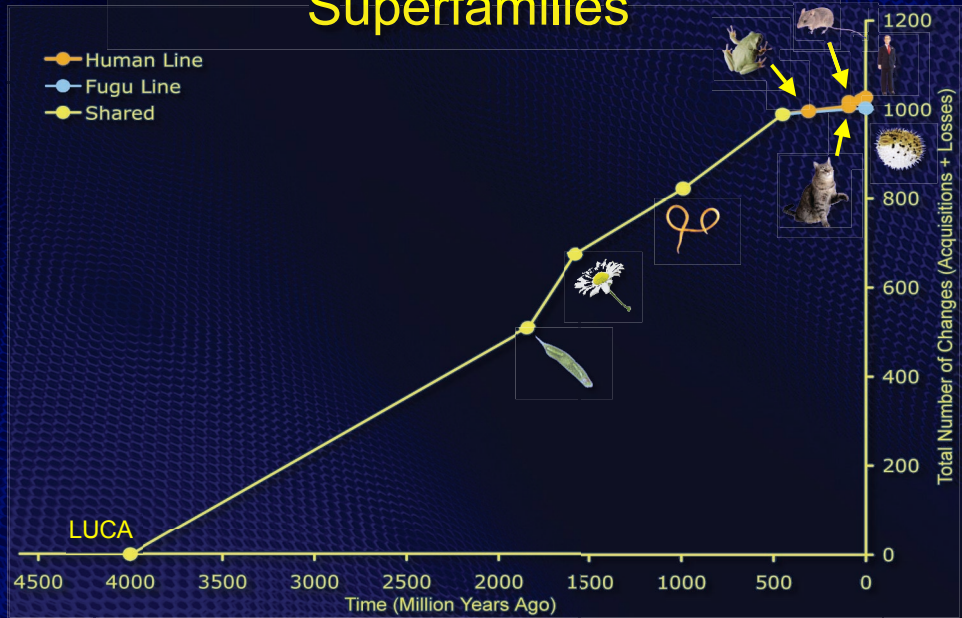


# Tempo and Protein Evolution

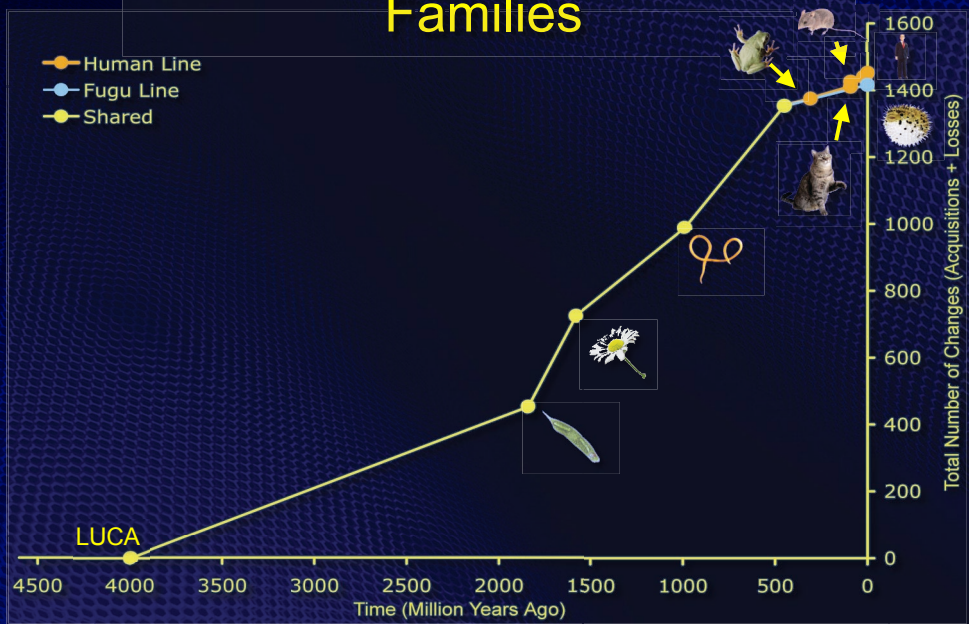
Tempo and mode of cell type evolution II



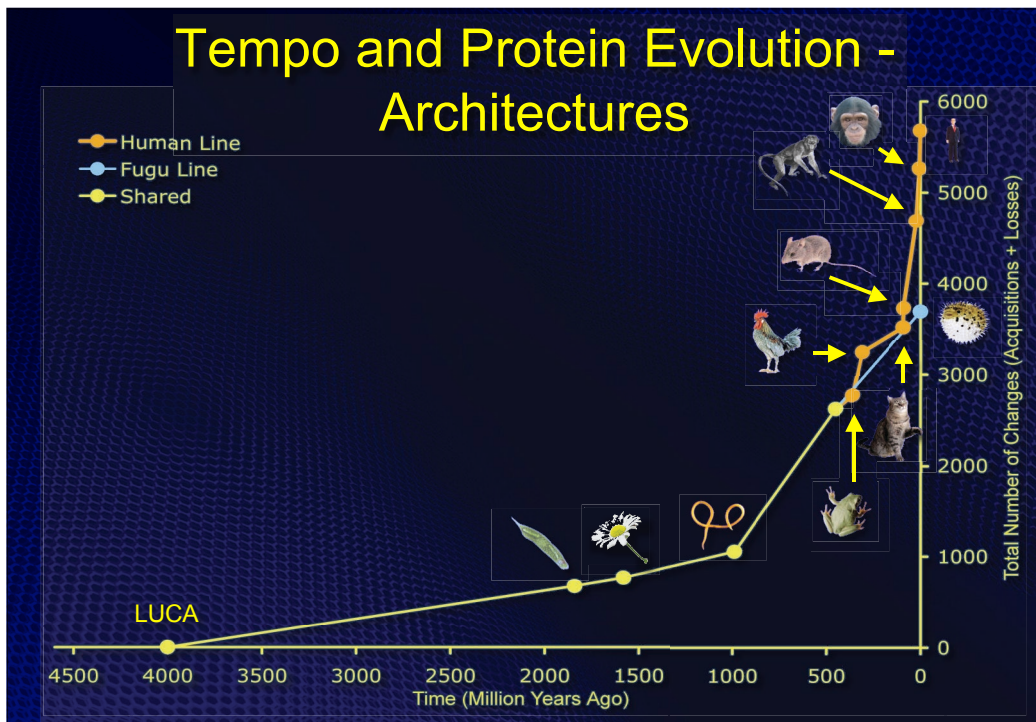
## Tempo and Protein Evolution - Superfamilies



## Tempo and Protein Evolution - Families



## Tempo and Protein Evolution - Architectures



## Conclusions

- Protein domains can help us reconstruct the tree of life and offer a promising new metric for biologic complexity
- Novel domain families and superfamilies have appeared at a roughly constant rate over the history of life and across different groups
- By contrast, novel architectures (new proteins) are acquired at a faster rate in animals, and vertebrates in particular