Lecture 25
Evolution and development

Charles Darwin

Karl Ernst von Baer
Evolution and development (Evo-devo)
Evolution and development (Evo-devo)

Some important questions:
Evolution and development (Evo-devo)

Some important questions:

1. Can developmental processes lead to discontinuous new phenotypes?
Evolution and development (Evo-devo)

Some important questions:

1. Can developmental processes lead to discontinuous new phenotypes?

• if so, have such phenotypes been major contributors to evolution?
Evolution and development (Evo-devo)

Some important questions:

1. Can developmental processes lead to discontinuous new phenotypes?

   • if so, have such phenotypes been major contributors to evolution?

2. Do developmental processes bias or constrain the direction of evolution?
Evolution and development (Evo-devo)

Some important questions:

1. Can developmental processes lead to discontinuous new phenotypes?
   • if so, have such phenotypes been major contributors to evolution?

2. Do developmental processes bias or constrain the direction of evolution?

3. How do developmental processes evolve?
Heterochrony
Heterochrony

- refers to changes in the rate or the timing of developmental processes.
Heterochrony

• refers to changes in the rate or the timing of developmental processes.

• coined by Ernst Haeckel in 1875 to deal with exceptions to his biogenetic law:

  “ontogeny recapitulates phylogeny”
Heterochrony

“ontogeny recapitulates phylogeny”
Heterochrony

• refers to changes in the rate or the timing of developmental processes.

• coined by Ernst Haeckel in 1875 to deal with exceptions to his biogenetic law:

  “ontogeny recapitulates phylogeny”
During development, organisms “climb their own evolutionary trees”
Consider a trait produced by some developmental process:
Consider a trait produced by some developmental process:

embryo  juvenile  adult
Consider a trait produced by some developmental process:
Consider a trait produced by some developmental process:

```
<table>
<thead>
<tr>
<th></th>
<th>embryo</th>
<th>juvenile</th>
<th>adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onset</td>
<td>α</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offset</td>
<td></td>
<td>β</td>
<td></td>
</tr>
</tbody>
</table>
```
Consider a trait produced by some developmental process:
Consider a trait produced by some developmental process:

Heterochrony can take two basic forms:
Consider a trait produced by some developmental process:

Heterochrony can take two basic forms:

1. Paedomorphosis refers to “underdevelopment”
Consider a trait produced by some developmental process:

Heterochrony can take two basic forms:

1. Paedomorphosis refers to “underdevelopment”
2. Peramorphosis refers to “overdevelopment”
Paedomorphosis  Peramorphosis

Rate \((k)\)

onset time \((\alpha)\)

offset time \((\beta)\)
Paedomorphosis     Peramorphosis

Rate \((k)\)     slower

onset time \((\alpha)\)     later

offset time \((\beta)\)     earlier

Rate \(k\)
Paedomorphosis  Peramorphosis

Rate \( (k) \)
- slower (neoteny)

onset time \( (\alpha) \)
- later

offset time \( (\beta) \)
- earlier (progenesis)

Onset time \( \alpha \)  
Rate \( k \)  
Offset time \( \beta \)
Example of neoteny: human skull?
Example of neoteny: the axolotl
Example of progenesis: *Thorius* spp. salamanders

Some species mature at 14 mm!
Paedomorphosis  Peramorphosis

Rate \((k)\)  slower  faster  
(neoteny)

onset time \((\alpha)\)  later  earlier

offset time \((\beta)\)  earlier  later  
(progenesis)

Onset time  Offset time
\(\alpha\)  \(\beta\)
Rate \(k\)
Paedomorphosis     Peramorphosis

Rate \( (k) \)   slower   faster
(neoteny)

onset time \( (\alpha) \)  later   earlier

offset time \( (\beta) \)  earlier  later
(progenesis)   (hypermorphosis)
Examples of hypermorphosis

Komodo dragon

Seychelles giant tortoise
What is the evolutionary significance of heterochrony?
What is the evolutionary significance of heterochrony?

1. Large changes in phenotype easily accomplished
What is the evolutionary significance of heterochrony?

1. Large changes in phenotype easily accomplished
   
   • mutations at a single locus may be involved.
What is the evolutionary significance of heterochrony?

1. Large changes in phenotype easily accomplished
   • mutations at a single locus may be involved.

2. Important in speciation
What is the evolutionary significance of heterochrony?

1. Large changes in phenotype easily accomplished
   - mutations at a single locus may be involved.

2. Important in speciation
   - postzygotic isolation easily achieved between gene pools differing in heterochronic mutations.
What is the evolutionary significance of heterochrony?

3. May release lineages from “phylogenetic constraints”
What is the evolutionary significance of heterochrony?

3. May release lineages from “phylogenetic constraints”

- in paedomorphosis, later developmental stages may be “bypassed”!
Homeotic genes and evolution
Homeotic genes and evolution

• HOM genes occur in invertebrates, Hox genes in vertebrates, MADS-box genes in plants.
The *bithorax* mutant in *Drosophila*
The *antennapedia* mutant in *Drosophila*
The *antennapedia* mutant in *Drosophila*
Homeotic genes and evolution

• HOM genes occur in invertebrates, Hox genes in vertebrates, MADS-box genes in plants.

Common characteristics:
Homeotic genes and evolution

• HOM genes occur in invertebrates, Hox genes in vertebrates, MADS-box genes in plants.

Common characteristics:

1. Organized in multigene families
Homeotic genes and evolution

- HOM genes occur in invertebrates, Hox genes in vertebrates, MADS-box genes in plants.

Common characteristics:

1. Organized in multigene families

- expanded and elaborated by unequal crossing-over events.
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain

• the homeobox is a DNA binding motif.
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain
   - the homeobox is a DNA binding motif.

3. Perfect correlation between 3’-5’ order of genes and their embryonic expression/targets
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain

  • the homeobox is a DNA binding motif.

3. Perfect correlation between 3’-5’ order of genes and their embryonic expression/targets

  • genes at 3’ end of cluster expressed in head.
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain
   • the homeobox is a DNA binding motif.

3. Perfect correlation between 3’-5’ order of genes and their embryonic expression/targets
   • genes at 3’ end of cluster expressed in head.
   • genes at 5’ end expressed in most posterior regions.
Homeotic genes and evolution

2. Each gene has distinctive 180 bp homeobox domain
   • the homeobox is a DNA binding motif.

3. Perfect correlation between 3’-5’ order of genes and their embryonic expression/targets
   • genes at 3’ end of cluster expressed in head.
   • genes at 5’ end expressed in most posterior regions.
   • genes at 3’ expressed earlier and at higher levels.
Hox genes in Drosophila

*Drosophila* adult

Anterior

*T1 T2 T3 A1 A2 A3 A4 A5 A6 A7 A8*

Posterior

*Drosophila* embryo

Anterior

*int la mx 1a T1 T2 T3 A1 A2 A3 A4 A5 A6 A7 A8*

Posterior

3' lab pb Dfd Scr Antp 5'

*Bithorax* group

5' Ubx abdA AbdB

*Antennapedia* group

Figure 19-1 Evolutionary Analysis, 4/e
© 2007 Pearson Prentice Hall, Inc.
Hox genes in Drosophila
Homeotic genes and the evolution of body plans
Homeotic genes and the evolution of body plans

• Hox genes can influence morphological evolution in 3 ways:
Homeotic genes and the evolution of body plans

• Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number
Homeotic genes and the evolution of body plans

- Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
</table>


Homeotic genes and the evolution of body plans

- Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>snails, slugs</td>
<td>3-6</td>
</tr>
</tbody>
</table>
Homeotic genes and the evolution of body plans

• Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>snails, slugs</td>
<td>3-6</td>
</tr>
<tr>
<td>arthropods</td>
<td>9</td>
</tr>
</tbody>
</table>
Homeotic genes and the evolution of body plans

• Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>snails, slugs</td>
<td>3-6</td>
</tr>
<tr>
<td>arthropods</td>
<td>9</td>
</tr>
<tr>
<td>tubeworms</td>
<td>10</td>
</tr>
</tbody>
</table>
Homeotic genes and the evolution of body plans

- Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>snails, slugs</td>
<td>3-6</td>
</tr>
<tr>
<td>arthropods</td>
<td>9</td>
</tr>
<tr>
<td>tubeworms</td>
<td>10</td>
</tr>
<tr>
<td>mice</td>
<td>39</td>
</tr>
</tbody>
</table>
Homeotic genes and the evolution of body plans

- Hox genes can influence morphological evolution in 3 ways:

1. Changes in total number

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of Hox genes</th>
</tr>
</thead>
<tbody>
<tr>
<td>snails, slugs</td>
<td>3-6</td>
</tr>
<tr>
<td>arthropods</td>
<td>9</td>
</tr>
<tr>
<td>tubeworms</td>
<td>10</td>
</tr>
<tr>
<td>mice</td>
<td>39</td>
</tr>
<tr>
<td>zebrafish</td>
<td>42</td>
</tr>
</tbody>
</table>
Diversification of Hox genes in various phyla
Homeotic genes and the evolution of body plans

2. Changes in spatial expression
Homeotic genes and the evolution of body plans

2. Changes in spatial expression

Example: diversification of arthropod body plans.
Hox gene expression in various arthropods

Figure 19-5 Evolutionary Analysis, 4/e
© 2007 Pearson Prentice Hall, Inc.
Homeotic genes and the evolution of body plans

3. Changes in gene interactions
Homeotic genes and the evolution of body plans

3. Changes in gene interactions

• “downstream” targets of Hox genes modified through evolutionary time.
Homeotic genes and the evolution of body plans

3. Changes in gene interactions

• “downstream” targets of Hox genes modified through evolutionary time.

Example: ectopic expression of eyes
Homeotic genes and the evolution of body plans

3. Changes in gene interactions

• “downstream” targets of Hox genes modified through evolutionary time.

**Example**: ectopic expression of eyes

• the term “ectopic” refers to the expression of a gene in a tissue where it is not normally expressed.
• in *Drosophila*, the *Pax6/eyeless* mutation (ey) causes near complete loss of compound eyes.
• in *Drosophila*, the *Pax6/eyeless* mutation (*ey*) causes near complete loss of compound eyes.

• in mice, the small eye mutation (*Sey*) causes failure of the development of the eye.
• in *Drosophila*, the *Pax6/eyeless* mutation (ey) causes near complete loss of compound eyes.

• in mice, the small eye mutation (Sey) causes failure of the development of the eye.

• the proteins encoded by these two loci are 94% identical.
• in *Drosophila*, the *Pax6/eyeless* mutation (*ey*) causes near complete loss of compound eyes.

• in mice, the small eye mutation (*Sey*) causes failure of the development of the eye.

• proteins encoded by these two loci are 94% identical.

• Halder et al. (1995) obtained ectopic expression of the *Sey* gene in *Drosophila*!