Discussion: Evolution of the Insect Body Plan

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Evolution of the Insect Body Plan

- Major morphological transition ~400 yrs ago: hexapod insects diverged from multi-limbed crustacean-like ancestors
- Six legs, wings, head, body segments

What caused some of these changes?

- *Hox* genes
- Natural Selection

What are *Hox* genes?

- Homeobox containing genes
- Highly conserved regions in animals
- Insects retain ancestral cluster amount
- Regulate development- pattern formation genes
- Provide the “masterplan”
- Affect downstream genes
- An additional explanation for evolution

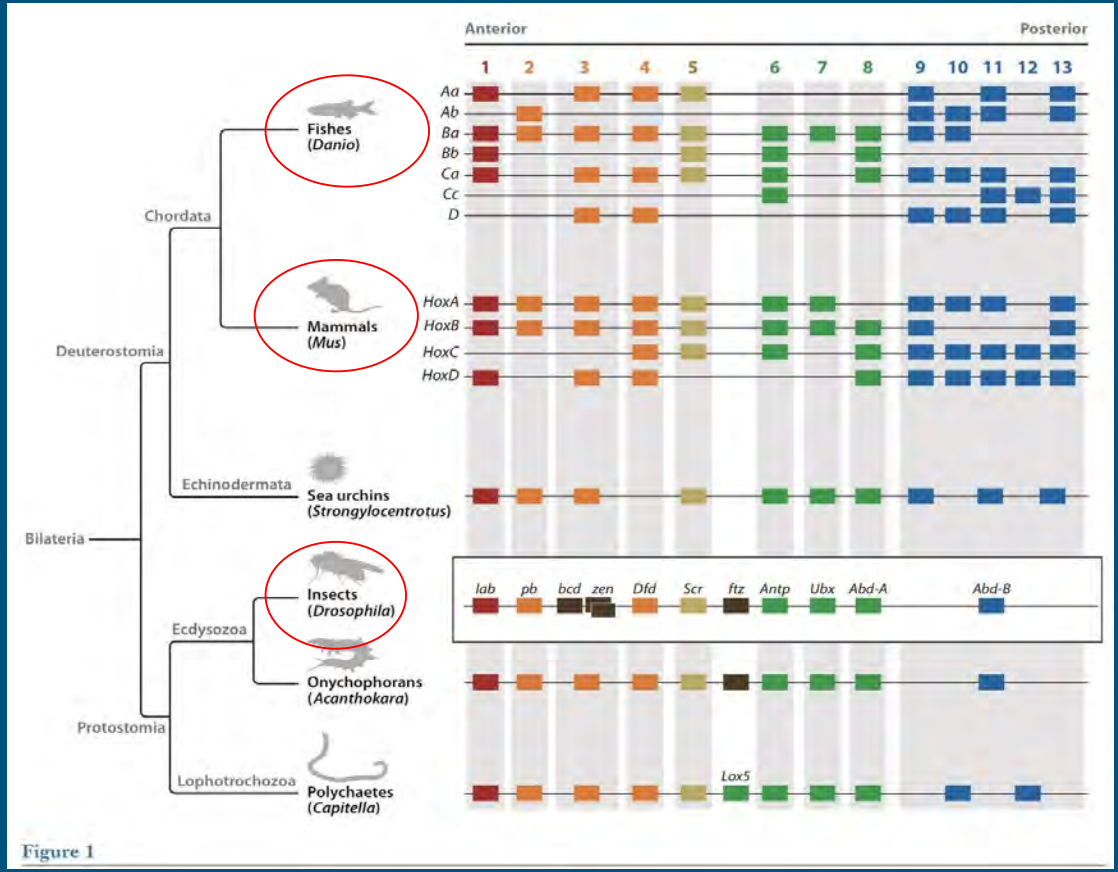


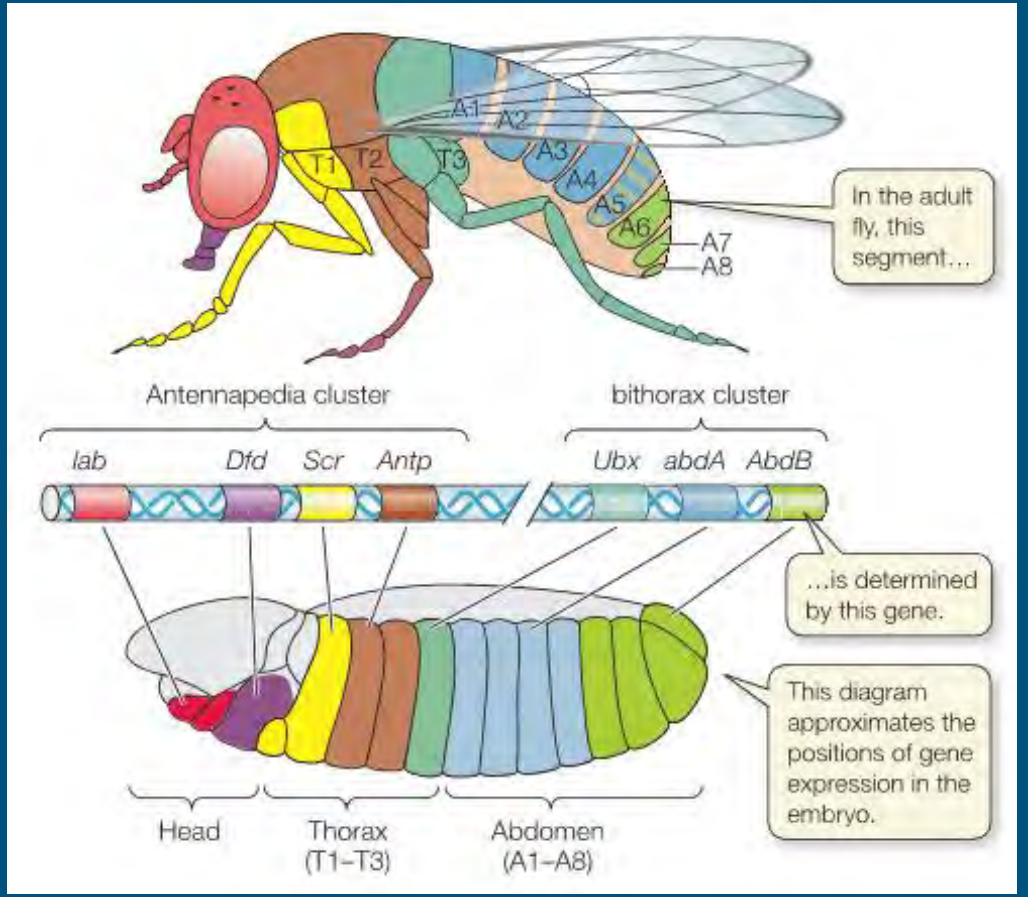
Figure 1

Hox Genes and Insect Body Development

- Collinearity= amino acid sequences in the polypeptide correspond to the codon sequences in nucleic acids, the 5′ end of the mRNA matching with the NH2 end of the polypeptide chain
- Correlation between location of cluster on chromosome to location on body
- *Drosophila* and *Artemia* contain ancestral single cluster (split in *Drosophila*)

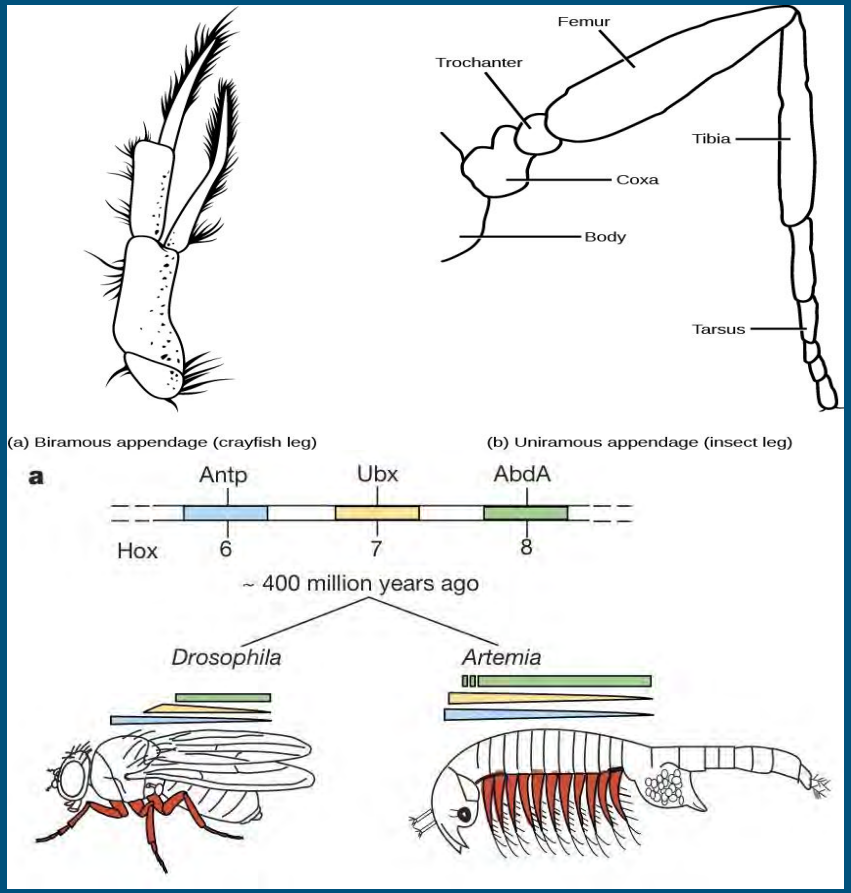
Special *Hox* genes:

- *Ubx* and *AbdA*- thorax, limb and wing development
- *Bcd*- head development
- *Scr*- head development



http://wallace.genetics.uga.edu/groups/evol3000/revisions/68043/9/

Ubx and *AbdA*



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If these changes arise from mutations, as many do, is it possible to trace the exact time or species that the change arose from?

- Proposed mechanism for loss of limbs in insects

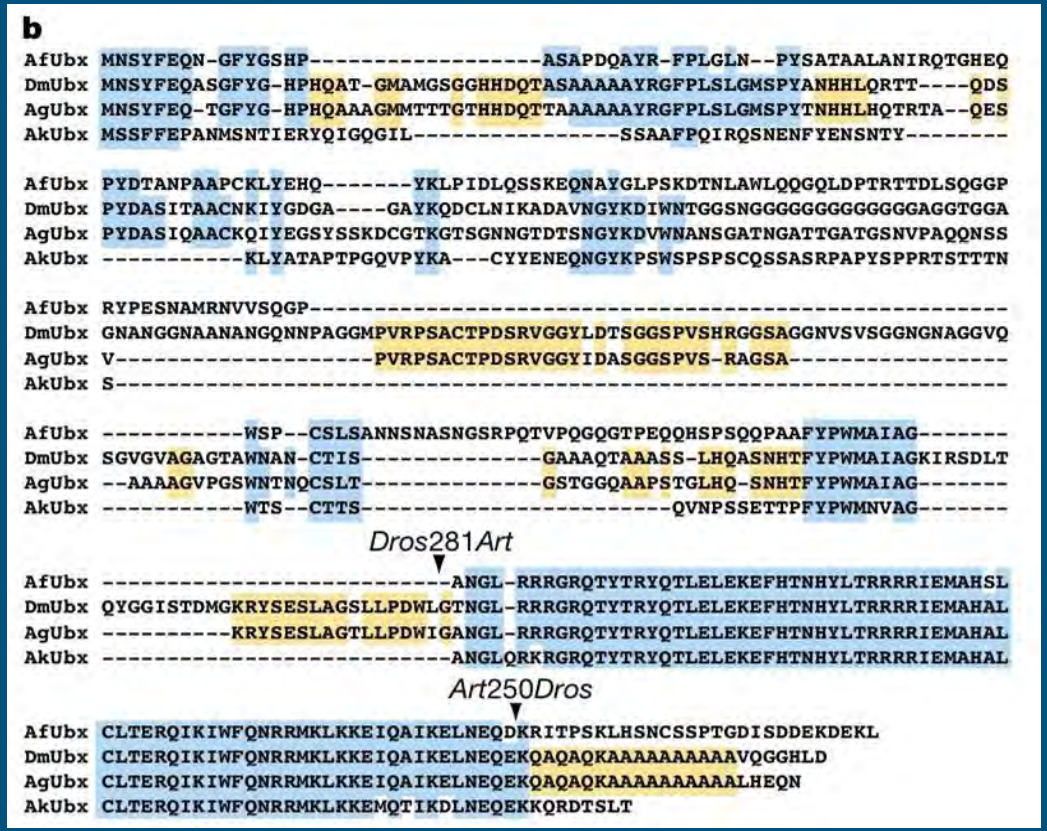
Hypothesis

Two phases:

1. Mutations restricted Ubx/AbdA expression in proto-abdomen
2. Mutations in Ubx/AbdA pathways resulted in suppression of thoracic-type limbs in proto-abdomen

Methods

- Used Polytene Chromosome Mapping
- Mapped *Ubx* limb-repression domains in *Drosophila* and *Artemia*
- In situ Hybridization
- Chimeric genes= hybrid genes from different animals

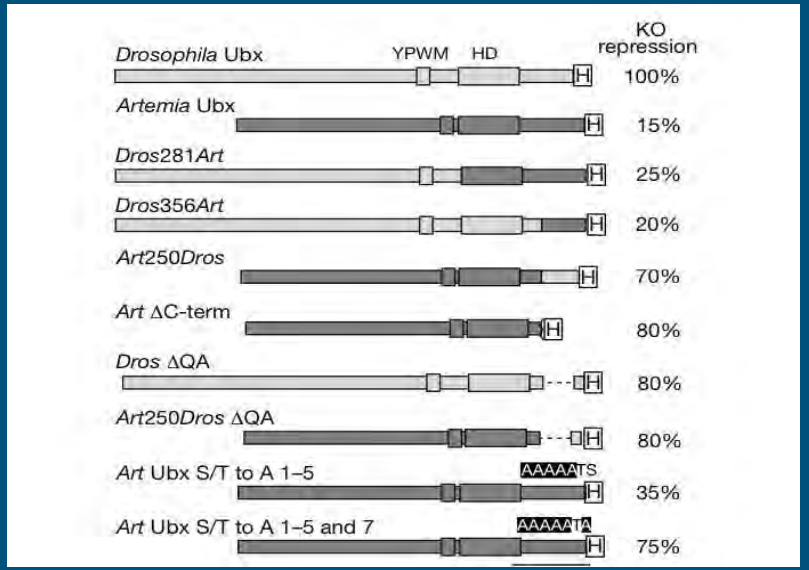


Results

What are some of the major conclusions that came from these experiments?

- C-terminal domain on the Ubx protein is significant to limb-repression in terms of amino acids
  - *Artemia* - presence Ser/Thr phosphorylation (mutation) → limb formation
  - Change all amino acids to Ala → complete limb-repression function (evolution into modern insects, seen in *Drosophila*)

Genus	C-terminus Sequence	Limb Formation	Limb Repression
Artemia	Serine/Threonine (unmutated)	yes	no
	Alanine	no	yes
	Deleted	no	yes
	Exchanged with Drosophila	no	yes
Drosophila			
	Unmutated	no	yes
	Deleted	no	yes
	Exchanged with Artemia	yes	no



What can we conclude about insect limb evolution?

- Four major results came from the experiments:

1. No difference between protein phenotypes in *Drosphila* or *Artemia*
2. The *Artemia Ubx* does not sufficiently block *Ull* trascription
3. The presence of the C-terminal in the *Drosophila Ubx* gene is sufficient to repress limbs
4. Mutations of Ser and Thr to Ala in the *Artemia* Ubx C-terminal result in limb repression

Two major reasons why mutation of multiple Ser/Thr residues that inhibit a repression function may be advantageous from evolutionary aspect:

1. Mutating residues would give dominant phenotype, eliminating need to fix two recessive mutations in a morphologically evolving lineage
2. Successive removal of Ser/Thr residues might quantitatively influence repression function and morphology, allowing viable microevolutionary steps toward macroevolutionary alterations in body shape

Ubx and Wing Development

Graellsia isabellae

What are some of the ways that *Ubx* can be expressed in wing development?

- Many insects have wings on T2 and T3 segments
- *Ubx* expressed in T3 segment
- In *Drosophila* represses wing formation in T3
- In *Lepidoptera* downstream target genes have evolved to be unresponsive
- In *Coleoptera Ubx* has shifted to repress elytra formation

Might *Ubx* or some other *Hox* gene be responsible for suppressing wing and limb development in scale insect females?

Variation in *Scr* and Novel Morphologies on the T1 Segment

- Sex-combs reduced (Scr)
- Another highly conserved
- Expressed in head and thoracic regions during embryogenesis
- Patterns T1 segments

Helmet appendages on Treehoppers (Hemipterans)

- similar genetic network to wing formation - helmet pattern

- Scr suppress wing development but not helmet formation in treehoppers - downstream genes

Pronotal horn of beetles (*Coleoptera*)

- Differences of size and location of horn

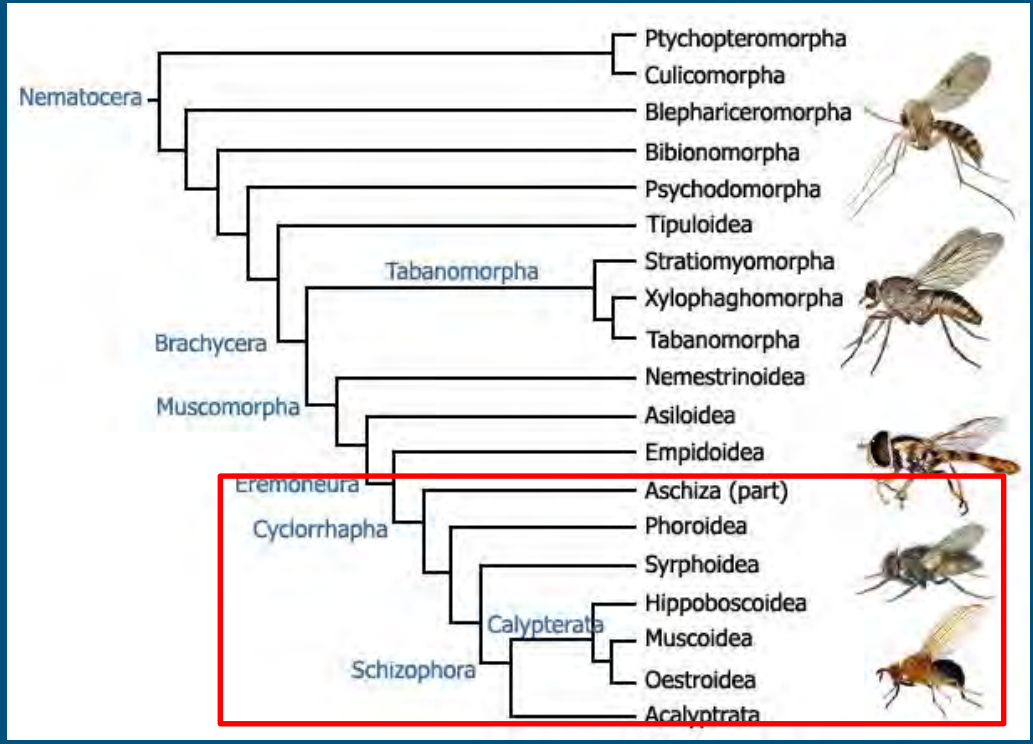
-Size and sex specific

- Mechanism unknown but programmed cell death is important in determining size and position

** Scr highly conserved role in patterning labial segment and T1 legs in most insects, but also species-specific adaptations of T1

Recent Evolution: *bicoid* (*bcd*)

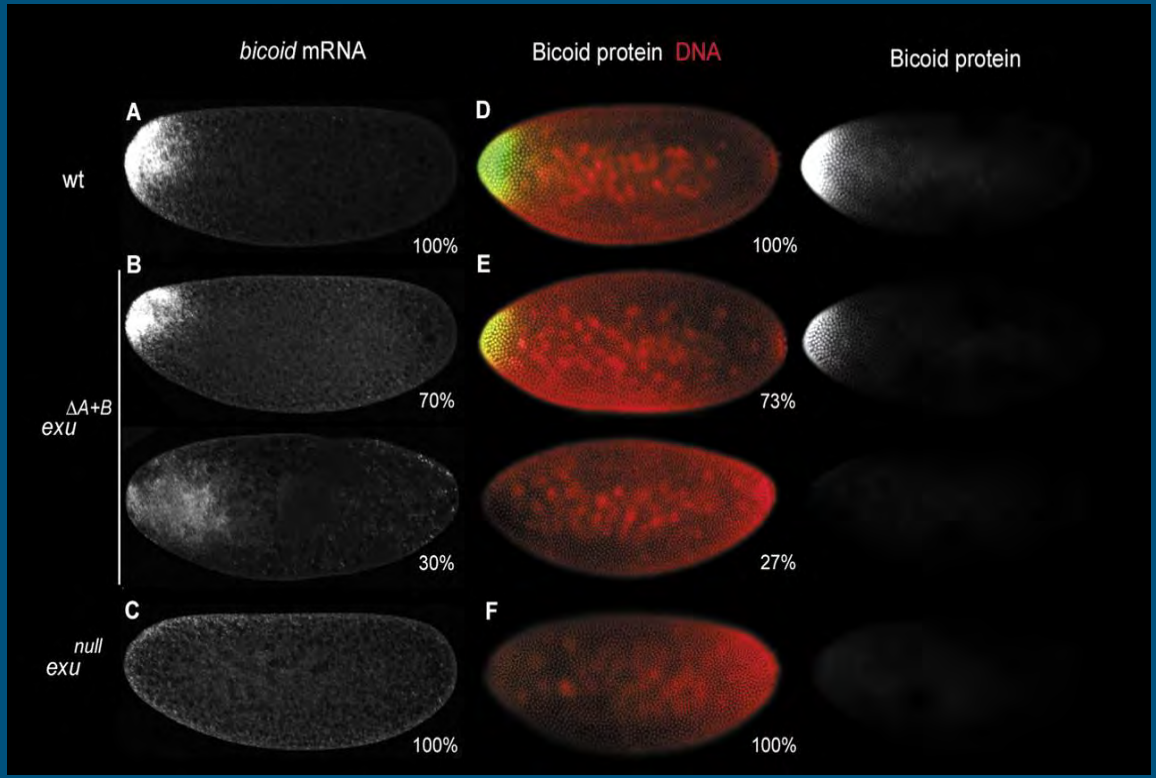
- Necessary for head development in higher *Diptera*
- Absent in most other insect orders
- Sister to *zen* gene (present in non-cyclorrhapans)
- Duplication event of *Hox*3 gene
- Evolved into *bcd* only in the cyclorrhapan lineage
- *bcd* proteins form a concentration gradient
- Expression is determined by concentration and sensitivity of enhancers



bcd continued

bcd has several tasks:

1. Localizes bcd proteins to anterior
2. Activates *tll* expression to form anterior structures
3. Blocks caudal mRNA (*cad*) to inhibit the formation of posterior structures in the anterior region



Par-1 regulates *bicoid* mRNA localisation by phosphorylating Exuperantia
Veit Riechmann, Anne Ephrussi

Advantages

Syrphidae

What evolutionary advantage would this change have?

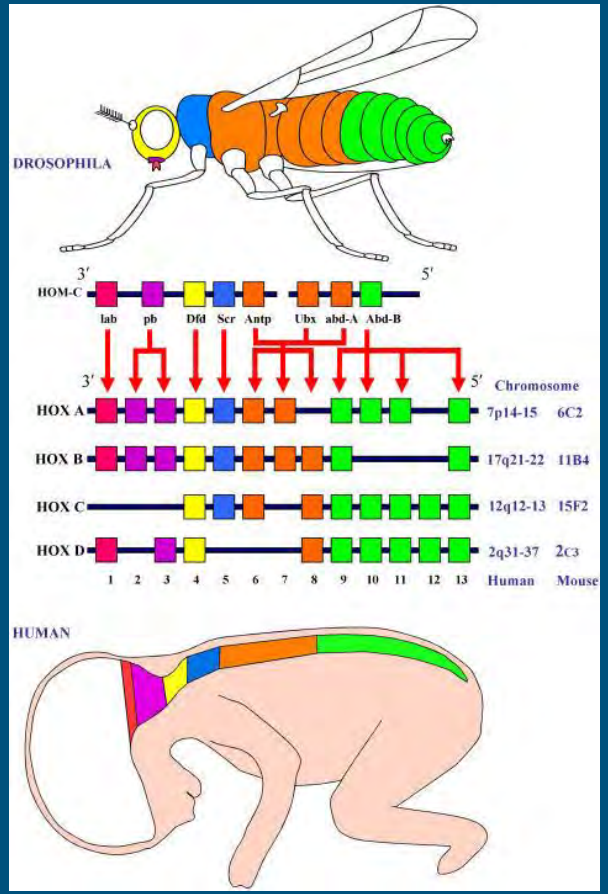
A few possibilities:

1. Gradients allow simultaneous patterning of anterior and posterior segments- leading to increased development speed

2. Simplify pathways- bcd makes Tor pathway redundant

The Big Picture: What does this mean?

- The discovery of *Hox* genes in *Drosophila* led to the study of evolutionary development
- Biologists now explore developmental genes, and how they have caused the vast morphological variation seen in nature
  - Do we see similar patterns of evolution of *Hox* genes in humans?
  - How does understanding the mechanism in which insects evolved from hexapods help us understand human development?



Lappin, R.J. (2006)Ulster Medicine Journal.

References

Heffer, A. and Pick, L. (2013). Conservation and variation in hox genes: how insect models pioneered the evo-devo field. *Annual Review of Entomology*. 58: 161-179.

McGregor, A.P. (2005). How to get ahead: the origin, evolution, and function of *bicoid. BioEssays*. 27: 904-913.

Riechmann, V. and Ephrussi, A. (2004). Par-1 regulates bicoid mRNA localisation by phosphorylating Exuperantia. *Development*.131: 5897-5907.

Ronshaugen, M., McGinnis, N., McGinnis, W. (2002). Hox protein mutation and macroevolution of the insect body plan. *Nature*. 415: 914-917.

Suryadeva, S. and Khan, M.B. (2015). Role of homeobox genes in tooth morphogenesis: a review. *Journal of Clinical and Diagnostic Research*. 9: 9-12.

Questions?