Complex systems approach in developmental biology

Cell differentiation and pattern formation

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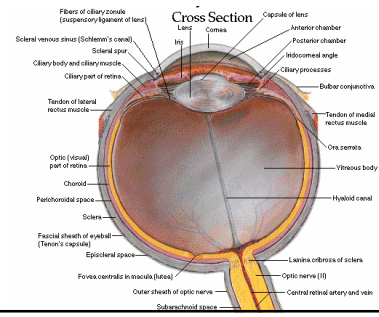
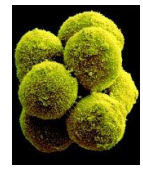
Complex systems share several agreed-upon features.

- Multiple parts interact
- Interesting collective behavior
- Collective behavior not easily predicted from knowledge of the parts

Morphogenesis can be understood as the collective behavior of cells.



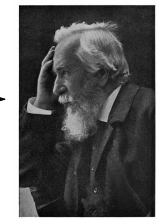
A complex systems perspective can inform several aspects of developmental biology.



DEVELOPMENT

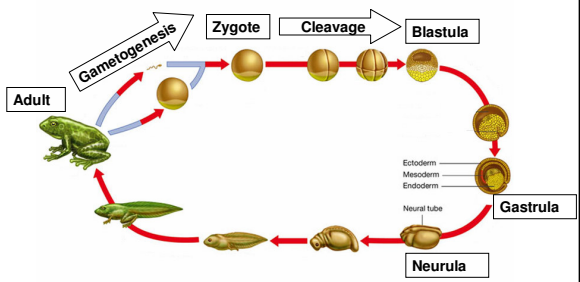
Multiple interacting parts:

- Molecular level (gene batteries, signaling molecules)
- Cellular level (autonomous cellular processes)



Collective behavior:

- Morphogenesis



Differentiated cells arise from distinct germ layers.

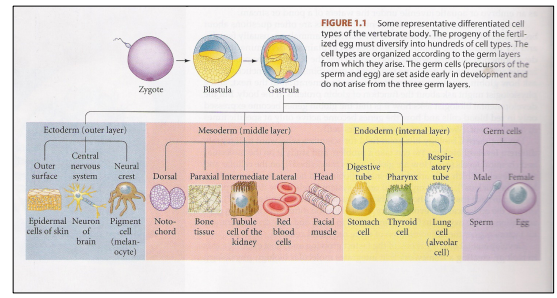
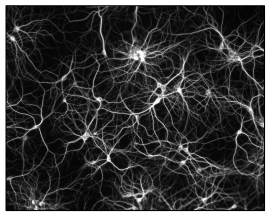
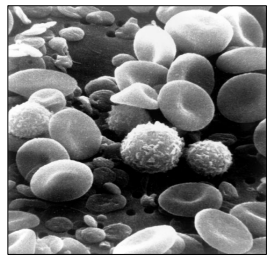


FIGURE 1.1 Some representative differentiated cell types of the vertebrate body. The progeny of the fertilized egg must diversify into hundreds of cell types. The cell types are organized according to the germ layers from which they arise. The germ cells (precursors of the sperm and egg) are set aside early in development and do not arise from the three germ layers.

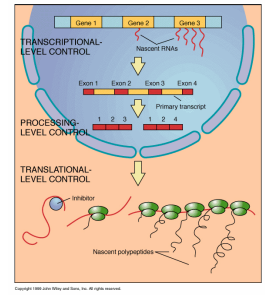
Differential gene expression from the same nuclear repertoire causes different cell phenotypes.



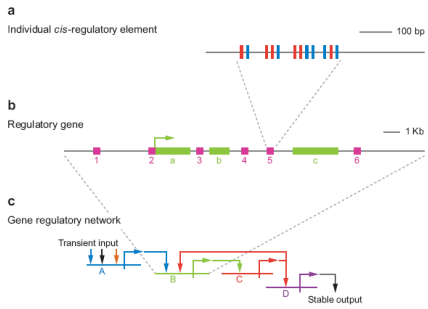


Gene expression can be regulated at several levels.

- Transcription
- Nuclear RNA processing
- mRNA translation
- Protein modification

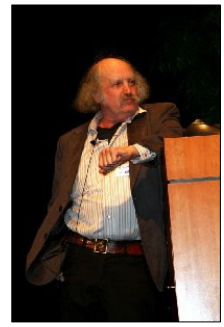


Regulation of gene expression can be understood as a network.



Eric Davidson

www.its.caltech.edu/~mirsky/labm/eric.htm



Michael Levine

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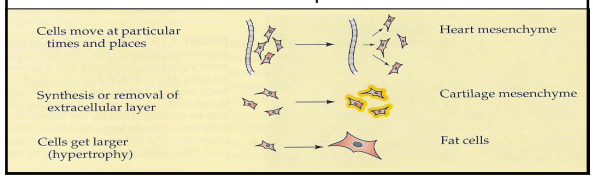
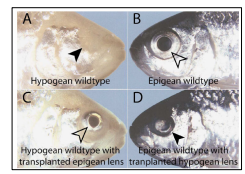
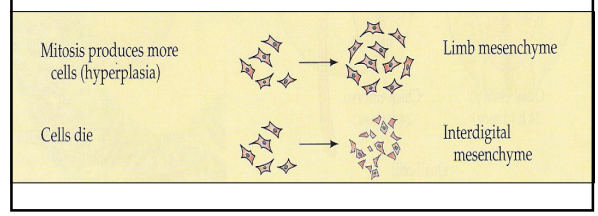
A few discrete cellular processes underlie morphogenesis.

- Direction and number of cell divisions
- Cell shape changes
- Cell migration
- Cell growth
- Programmed cell death
- Changes in the composition of the cell membrane or secreted products

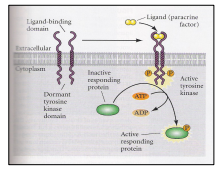


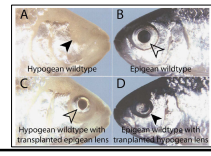




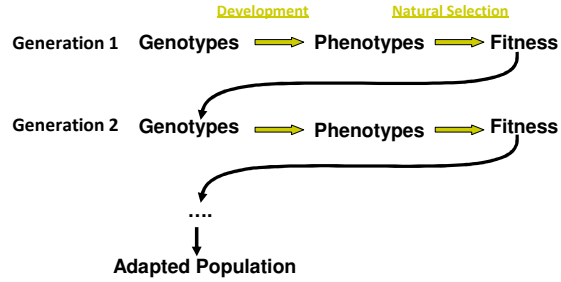
Discrete cellular processes are coordinated by signal transduction.

- Signal transduction pathways
- Cascades of inductive events
- Pattern (organ) formation





Development was largely ignored during the modern synthesis.



Complex systems approach to the evolution of development?

- Developmental constraint or bias?
- Development (and GRN) as the product of evolution?

Fig. 1. Examples of Cambrian body plans from the Early Cambrian (~530 million years ago) Chengjiang Lagerstätte, Yunnan Province, China. (**B** to **I**) and the Middle Cambrian Burgess Shale fauna of British Columbia, Canada (**A**). (**A**) Three fossils are the remains of animals all of which have body plans that can immediately be seen to be similar to ours: pikaia, as indicated, for instance, the bilateral, anterior-posterior organization and position of the gut, nerve cord, and gill slits and example recognizable those of the modern chordate-hemichordate. In addition, the chordate has a segmented dorsal muscular column and is notochord, as do the modern chordates. (**B**) *Dinomischus*: *Kuamaia yunhuiensis*; (**B**) arthropod *Mipeia*; (**C**) arthropod *Marrella*; (**D**) arthropod *Naraoia*; (**E**) *Anomalocaris*; (**F**) *Aquilorhynchus*; (**G**) *Miomelonkonia crassiata*; (**H**) pseudopod *Opabinia regalis*; (**I**) arthropod *Sidneyia inexpectans*; (**J**) chordate *Vetulicolia longiculata*; (**K**) and (**L**) are from the Burgess Shale collection; (**M**, **N**) and (**O**) to (**R**) are courtesy of J. Y. Chen, Nanjing Institute of Geology and Paleontology, China (*23*).

Images:

(1) http://www.biologyreference.com/images/biol_01_img0106.jpg
(2) http://images.apple.com/ca/science/profiles/universityofcalgary/images/image_page1-2.jpg
(3) http://www.udel.edu/chem/white/C647/Eye.GIF
(4) http://en.wikipedia.org/wiki/Ernst_Haeckel
(6) Gilbert 2006, p. 4
(7) http://www.greenspine.ca/media/neuron_culture_800px.jpg
http://commons.wikimedia.org/wiki/Image:SEM_blood_cells.jpg
(8) http://web.uconn.edu/mcb201/eukaryotictt.gif
(9) DeLeon and Davidson 2007
(10) its.caltech.edu/~mirsky/labm/eric.htmcigbrowser.berkeley.edu/levinelab/
(11) Gilbert 2006, p.14
(12) Gilbert 2006, p.14,
http://www.obgyn.net/us/gallery/OB_2_Normal_Hand_13_weeks.jpg, Rudel and Sommer 2003
(13) Rudel and Sommer 2003, Gilbert 2006, p.147
(15) Davidson and Erwin 2006
(16) http://en.wikipedia.org/wiki/Image:Haeckel_Actiniae.jpg

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