3 Developmental Biology Lectures

1. General principles of animal development
2. Hox genes in bilaterian development
3. Comparative developmental biology
   - Totipotency vs. differentiation
   - Symmetry – types and mechanisms
   - Plant development



Some themes in the comparative development of multicellular eukaryotes

1. Enormous flexibility in bilaterian design -
   - ca. 30 modern phyla with distinctive body plans
   - often utilizing homologous molecular mechanisms
2. Why study other multicellular eukaryotes?
   - Fascinating examples of biological diversity
   - Deep insights into the evolution and mechanisms of bilaterian development
   - Several issues relevant to human medicine



2) Totipotency vs. Differentiation

T- the ability of a single cell to regenerate the entire organism
D- the acquisition of specialized structures and functions

1. Prokaryotic cells are potentially immortal
2. Faustian bargain of eukaryotic reproduction

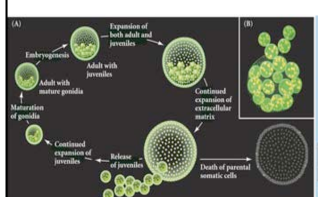
mating rituals of praying mantises

luna moths with no mouth parts

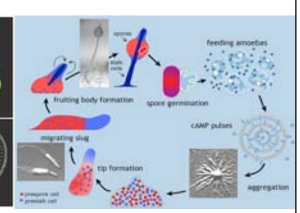
3. Which cells are potentially immortal? Which aren't?

Totipotency vs. Differentiation

Key feature – the segregation of reproductive cells from the specialized soma (body cells)

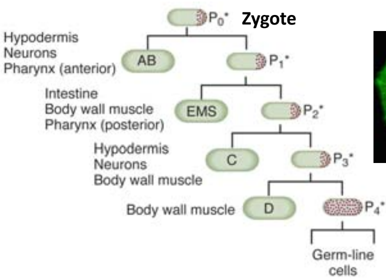


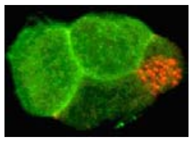
Volvox – multicellular green alga



Dictyostelium – cellular slime mold

Animals – early segregation of germ line



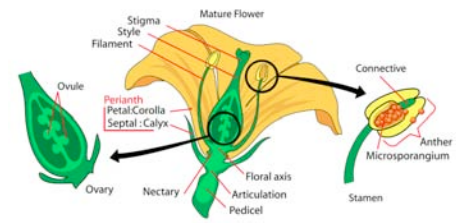


C. elegans embryo with p granules marking the germ-line cell (P_4)

Germ-line cells set aside early, but later migrate to the gonads
Many fewer mutations accumulate in animal germ lines than plants

Totipotency vs. Differentiation

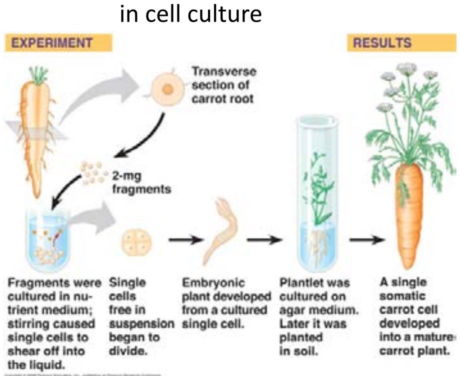
Plants – late segregation of germ line (capable of meiosis) from persistent meristematic (i.e., stem) cells – more later



Many multicellular eukaryotes express totipotency in cell culture

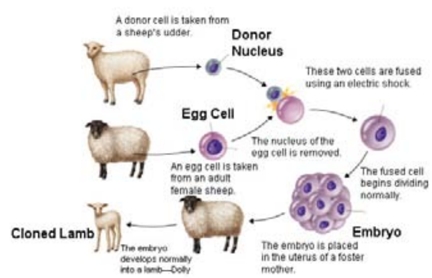
Carrot

See F. Fig. 35.13



Comparable examples of mammalian totipotency

Dolly – first example of the genes from a differentiated mammalian cell being capable of reverting to embryonic totipotent state

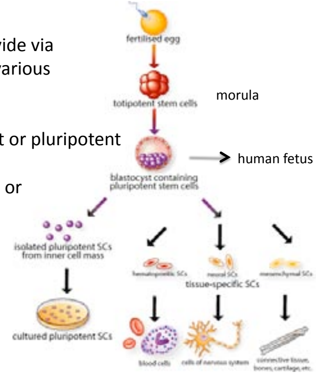


Totipotency – Human stem cells

Stem cells retain the ability to divide via mitosis and to differentiate into various specialized cell types.

Embryonic stem cells – totipotent or pluripotent

Adult stem cells – somatic (body) or germline (producing gametes)



http://en.wikipedia.org/wiki/Stem_cell

Totipotency – Trouble in Paradise

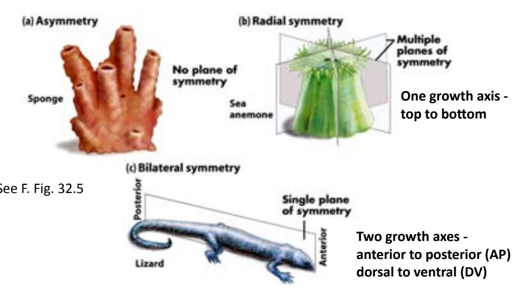
Somaclonal variation in plants – high levels of genetic, chromosomal, and epigenetic abnormalities in plants grown from cultured cells

Possible implications for stem cell regeneration?
Any difference between adult vs. embryonic stem cells?

Totipotency – Trouble in Paradise

1. Dolly's premature death – 6-year-old cells?
2. Shortened telomeres (chromosome ends) - premature ageing?
3. Embryos from nuclear transfer expts – frequent developmental abnormalities
4. Dolly – only 1 of 277 to make it to adulthood
5. Differentiation correlates – ageing, cancer, and death
6. Meiosis – repackaging chromosomes, removing epigenetic changes to genes and chromosomes, etc.
7. Next frontier in human medicine

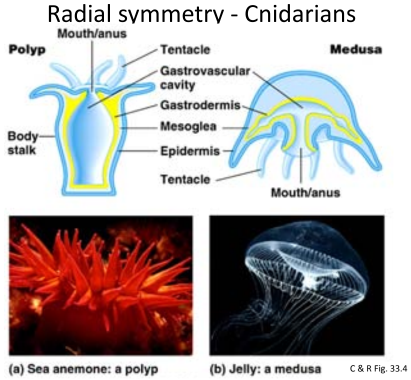
3) Design strategies of multicellular animals and plants



See F. Fig. 32.5

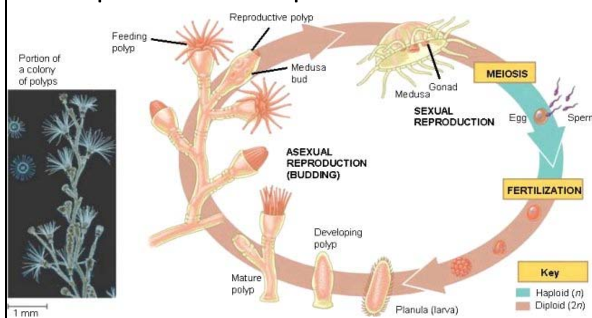
Planes of symmetry = number of so-called mirror images

Radial symmetry - Cnidarians



One central growth axis - top to bottom

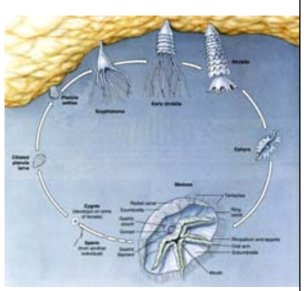
Animal version of modular development – sequential development of new axes



Single polyp develops many individual feeding and reproductive polyps

Modularity - Cnidarians

Hydra



Aurelia (Class Scyphosa)

Modularity - the formation of new axes from the surface and/or new organisms from the central axis

Bilateral symmetry

Flatworm

Nematode

Annelid

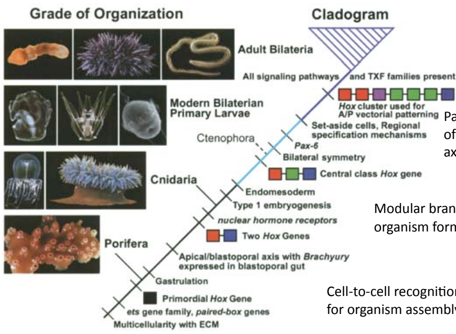
Arthropod

Mollusc

Chordate

Two growth axes - anterior - posterior (AP) axis and dorsal - ventral (DV) axis
Cephalization - the separation of the AP axis into head region for feeding, sensation, and processing and tail region for locomotion
Segmentation - the subdivision of AP axis into repeating segments in annelids, arthropods, and chordates

Evolution of developmental processes in basal metazoans



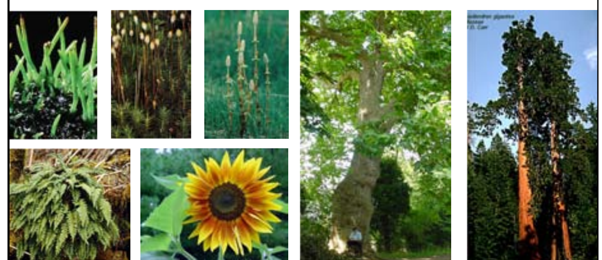
Pattern formation of developmental axes, plus induction

Modular branching for organism formation

Cell-to-cell recognition for organism assembly

Peterson and Davidson (2000) PNAS 97:4430-4433

Symmetry - plants



Animals - phylogenetic switch from radial to bilateral symmetry
Plants - persistent radial symmetry of main and lateral axes, with repeated evolution of bilateral leaves

Early land plants

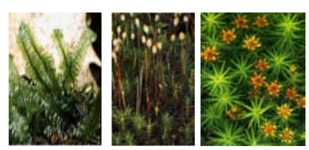
Silurian plants (400 mya)

Apical meristem – growing tip of ~100 cells

Early land plants - "naked" cylindrical axes with no leaves
Radial symmetry comes from hemispherical apical meristem that represents the growing tip of the axis

Most living plants - aboveground structures

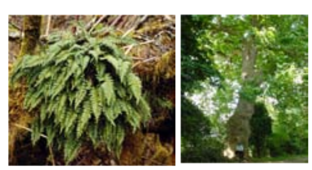
Bryophytes

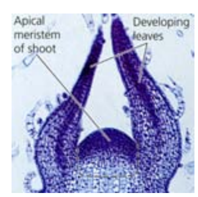


Radial axes (stems) - specialized for support and transport

Bilateral organs (leaves) - specialized for photosynthesis

Vascular plants





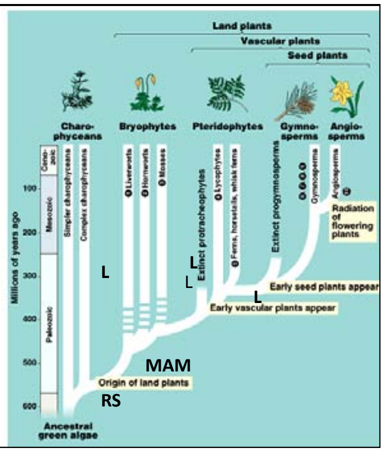
Shoot apical meristem – generates new stem-leaf modules

Evolution of land plant symmetry

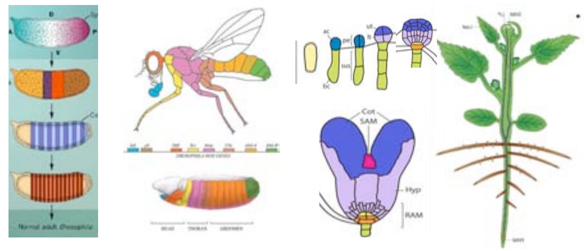
RS - radial symmetry

MAM - multicellular apical meristems

L - bilateral leaves (at least four times)



Basic principle of plant development



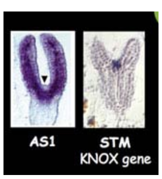
Animals – determinate organisms – cell differentiation and organ formation occurs within defined body

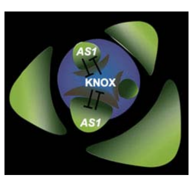
Plants – indeterminate organisms – new cells, organs, and meristems develop throughout the life span

SAM = shoot apical meristem
RAM = root apical meristem

Genetic regulation of shoot apical meristems

Background: Apical Meristems give rise to the entire plant body:
New cells for maintaining the meristem – stem cell function
New cells for differentiating organs

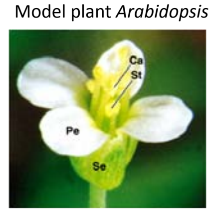




KNOTTED1-like homeobox genes (*KNOX*) control the transcription of other genes for maintaining meristematic state.
Other genes, such as *ASYMMETRIC LEAVES1 (AS1)*, suppress the expression of *KNOX* genes, resulting in the initiation of leaves.

Genetic regulation of floral organs

Model plant *Arabidopsis*



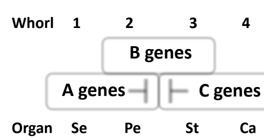
Wild-type flower

Polar view of floral meristem

Polar view of mature flower

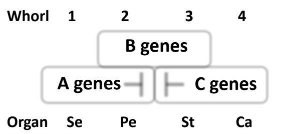
F Fig. 22.11

Zhongchi Li (CBMG)

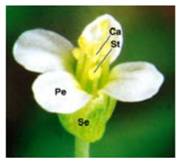


ABC model for floral induction

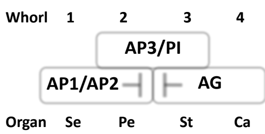
Genetic regulation of floral organs



ABC model for floral induction



Wild-type flower

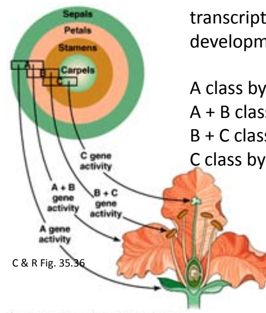


ABC model for floral induction

Can you use the ABC model to predict the phenotypes of several floral mutants?

How would you test the model?

Summary - ABC Model for Genetic Regulation of Floral Organs



C & R Fig. 35.36

Three classes of **MADS-box** genes act as transcription factors for regulating floral development

A class by itself directs sepal formation
A + B classes direct petal formation
B + C classes direct stamen formation
C class by itself direct carpel formation

A class = *APETALLA1/APETALLA2*
B class = *APETALLA3/PISTILLATA*
C class = *AGAMOUS*

Comparative development of multicellular eukaryotes

- Multiple independent origins of eukaryotic multicellularity
- Totipotency and differentiation – alternative expressions of cell specialization
- Segregation of the germ line from the soma
- The expression of totipotency in plants, Dolly, and human stem cells
- The challenge of maintaining the totipotency in cultured cells
- Molecular mechanisms for the development of unicellular protists, animals, and plants
- Symmetry - radial (1 growth axis) vs. bilateral (2 growth axes) in different organisms
- Plants - radial symmetry in axes vs. bilateral symmetry in leaves
- Apical meristems and indeterminate growth in plants
- Genetic regulation of meristem activity and flower formation
- ABC model for flower development