Overview of Development

Development is the successive process of systematic gene-directed changes throughout an organism’s life cycle.

- Can be divided into four subprocesses:
  - Growth (cell division)
  - Differentiation
  - Pattern formation
  - Morphogenesis

Cell Division

After fertilization, the diploid zygote undergoes a period of rapid mitotic divisions.

- In animals, this period is called cleavage - Increase in cell numbers, not size

- Controlled by cyclins and cyclin-dependent kinases (Cdks)

During cleavage, the zygote is divided into smaller & smaller cells called blastomeres.
- Moreover, the G1 and G2 phases are shortened or eliminated.
Cell Division

Blastomeres are nondifferentiated and can give rise to any tissue

- **Stem cells** - Cells that are capable of continued division, but can also give rise to differentiated cells

- **Degree of determination**
  - Totipotent – cell that can give rise to any tissue in an organism (embryo and extraembryonic membranes)
  - Pluripotent – give rise to all cells in the adult organism’s body
  - Multipotent – give rise to limited number of cells
  - Unipotent – give rise to only a single cell type (tissue specific)

Cell Division in plants

A plant develops by building its body outward

- Creates new parts from stem cells contained in structures called **meristems**
- Meristematic stem cells continually divide
  - Produce cells that can differentiate into the various plant tissues
  - Leaves, roots, branches, and flowers

The plant cell cycle is also regulated by cyclins and cyclin-dependent kinases
Cell Differentiation

A human body contains more than 210 major
types of differentiated cells

**Cell determination** commits a cell to a
particular developmental pathway

- Can only be “seen” by experiment
  - Cells are moved to a different location in the embryo
    - If they develop according to their new position, they are not determined

Cell Determination

Cells initiate developmental changes by using
transcriptional factors to change patterns of gene expression

Cells become committed to follow a particular
developmental pathway in one of two ways:

1) via differential inheritance of cytoplasmic determinants (molecules asymmetrically localized in the cytoplasm of the egg (or of somatic cells), which become unequally distributed among cells after cell division and then affect the activity of genes.)

2) via cell-cell interactions - cells induce new fates on their neighbors
Cell Differentiation

Induction is the change in the fate of a cell due to interaction with an adjacent cell.

If cells of a frog embryo are separated:
- One pole ("animal pole") forms ectoderm
- Other pole ("vegetal pole") forms endoderm
- No mesoderm is formed

If the two pole cells are placed side-by-side, some animal-pole cells form the mesoderm.

Pattern Formation

In the early stages of pattern formation, two perpendicular axes are established:
- Anterior/posterior (A/P, head-to-tail) axis
- Dorsal/ventral (D/V, back-to-front) axis

Polarity refers to the acquisition of axial differences in developing structures.

Position information leads to changes in gene activity, and thus cells adopt a fate appropriate for their location.
Drosophila Embryogenesis

*Drosophila* produces two body forms
- **Larva** – Tubular eating machine
- **Adult** – Flying sex machine; axes are established

**Metamorphosis** is the passage from one body form to another
**Embryogenesis** is the formation of a larva from a fertilized egg

Before fertilization, specialized nurse cells move maternal mRNAs into maturing oocyte

- These mRNA will initiate a cascade of gene activations following fertilization

Embryonic nuclei do not begin to function until approximately 10 nuclear divisions later
**Drosophila Embryogenesis**

- Syncytial blastoderm – 12 rounds of nuclear division without cytokinesis
- Nuclei space themselves out
- Membranes grow forming cellular blastoderm
- Embryonic folding and primary tissue development follow
- Within a day of fertilization, embryogenesis creates a segmented, tubular body

**Production of Body Plan**

The body plan is produced by sequential activation of three classes of **segmentation genes**

1. **Gap genes**
   - Map out the coarsest subdivision along the A/P axis
   - All 9 genes encode transcription factors that activate the next gene class

2. **Pair-rule genes**
   - Divide the embryo into seven zones
   - The 8 or more genes encode transcription factors that regulate each other, and activate the next gene class

3. **Segment polarity genes**
   - Finish defining the embryonic segments
Production of Body Plan

Segment identity arises from the action of **homeotic genes**
- Mutations in them lead to the appearance of normal body parts in unusual places
  - **Ultrabithorax** mutants produce an extra pair of wings

**Homeotic gene complexes**
- The HOM complex genes of *Drosophila* are grouped into two clusters
  - **Antennapedia complex**, which governs the anterior end of the fly
  - **Bithorax complex**, which governs the posterior end of the fly
- Interestingly, the order of genes mirrors the order of the body parts they control

**Homeotic gene complexes**
- All of these genes contain a conserved 180-base sequence, the **homeobox**
  - Encodes a 60-amino acid DNA-binding domain, the **homeodomain**
  - Homeobox-containing genes are termed **Hox genes**
  - Vertebrates have 4 Hox gene clusters
Production of Body Plan

Pattern Formation in Plants

The predominant homeotic gene family in plants is the **MADS-box genes**
- Found in most eukaryotic organisms, although in much higher numbers in plants
- MADS-box genes encode transcriptional regulators, which control various processes:
  - Transition from vegetative to reproductive growth, root development and floral organ identity
Morphogenesis

Morphogenesis is the formation of ordered form and structure.

- Animals achieve it through changes in:
  - Cell division
  - Cell shape and size
  - Cell death
  - Cell migration
- Plants use these except for cell migration.

Cell division

- The orientation of the mitotic spindle determines the plane of cell division in eukaryotic cells.
  - If spindle is centrally located, two equal-sized daughter cells will result.
  - If spindle is off to one side, two unequal daughter cells will result.

Cell shape and size

- In animals, cell differentiation is accomplished by profound changes in cell size and shape.
  - Nerve cells develop long processes called axons.
  - Skeletal muscles cells are large and multinucleated.
Morphogenesis

Cell death
- **Necrosis** is accidental cell death
- **Apoptosis** is programmed cell death
  - Is required for normal development in all animals
  - “Death program” pathway consists of:
    - Activator, inhibitor and apoptotic protease

Cell migration
- Cell movement involves both adhesion and loss of adhesion between cells and substrate
- Cell-to-cell interactions are often mediated through **cadherins**

Cell-to-substrate interactions often involve complexes between **integrins** and the **extracellular matrix (ECM)**

Development of Seed Plants

Plant development occurs in five main stages:

1. **Early embryonic cell division**
   - First division is off-center
     - Smaller cell divides to form the embryo
     - Larger cell divides to form **suspensor**
       - Cells near it ultimately form the root
       - Cells on the other end, form the shoot
Development of Seed Plants

2. Embryonic tissue formation
   - Three basic tissues differentiate:
     - Epidermal, ground and vascular

3. Seed formation
   - 1-2 cotyledons form
   - Development is arrested

4. Seed germination
   - Development resumes
   - Roots extend down, and shoots up

Development of Seed Plants

5. Meristematic development and morphogenesis
   - Apical meristems at the root and shoot tips generate a large numbers of cells
     - Form leaves, flowers and all other components of the mature plant
Environmental Effects

Both plant and animal development are affected by environmental factors:
- Germination of a dormant seed proceeds only under favorable soil and day conditions.
- Reptiles have a temperature-dependent sex determination (TSD) mechanism.
- The water flea *Daphnia* changes its shape after encountering a predatory fly larva.
In mammals, embryonic and fetal development have a longer time course - Thus they are more subject to the effects of environmental contaminants, and blood-borne agents in the mother - Thalidomide, a sedative drug - Many pregnant women who took it had children with limb defects

Endocrine disrupting chemicals (EDCs) - Interfere with synthesis, transport or receptor-binding of endogenous hormones - Derived from three main sources - Industrial wastes (polychlorinated biphenyls or PCBs) - Agricultural practices (DDT) - Effluent of sewage-treatment plants