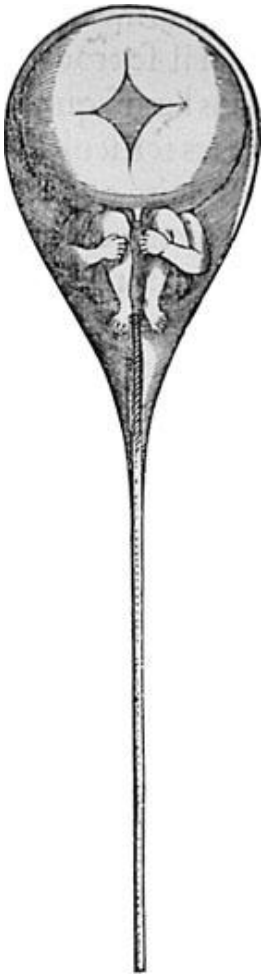
Establishment of body axes
Cell-fate by progressive and
Cytoplasmic Determinants

EARLY CONCEPTS: PREFORMATION VS EPIGENESIS

The question of how a zygote becomes an animal has been asked for centuries.

As recently as the 18th century, the prevailing theory was a notion called preformation – the idea that the egg or sperm contains an embryo.

- A preformed miniature infant, or "homunculus," that simply becomes larger during development.



EARLY CONCEPTS: PREFORMATION VS EPIGENESIS

Kaspar Friederich Wolff (1759) demonstrated there was no preformed chick in the early egg.

- Undifferentiated granular material became arranged into layers.
- The layers thickened, thinned, and folded to produce the embryo.

EARLY CONCEPTS: PREFORMATION VS EPIGENESIS

Epigenesis is the concept that the fertilized egg contains building materials only, somehow assembled by an unknown directing force.

Although current ideas of development are essentially epigenetic in concept, far more is known about what directs growth and differentiation.

KEY EVENTS IN DEVELOPMENT

Specialization of cell types occurs as a hierarchy of developmental decisions.

- Cell types arise from conditions created in preceding stages.
- Interactions become increasingly restrictive.

With each new stage:

- Each stage limits developmental fate.
- Cells lose option to become something different
  - Said to be determined.

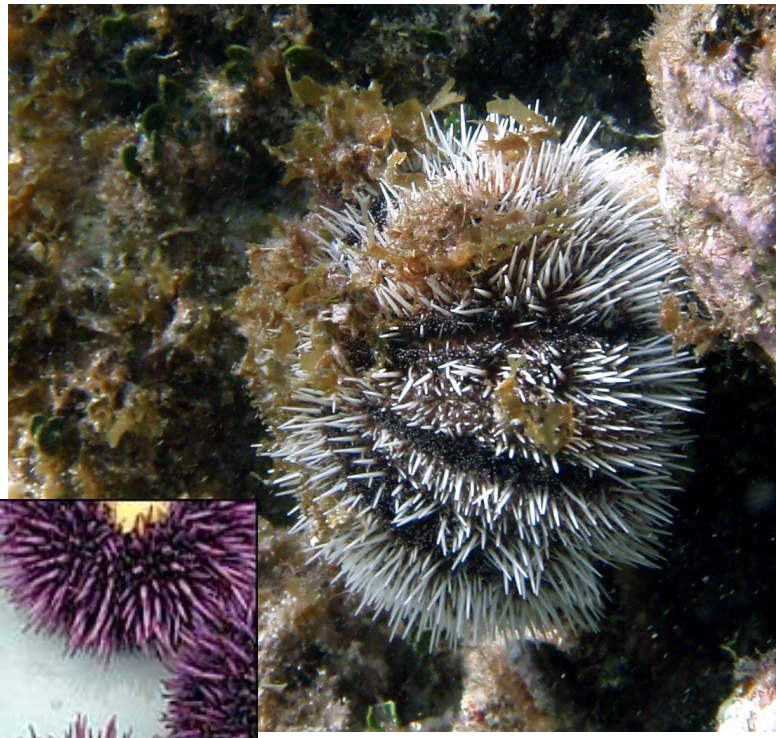
KEY EVENTS IN DEVELOPMENT

The two basic processes responsible for this progressive subdivision:

- Cytoplasmic localization
- Induction

A century of research has been conducted on marine invertebrates.

- Especially sea urchins



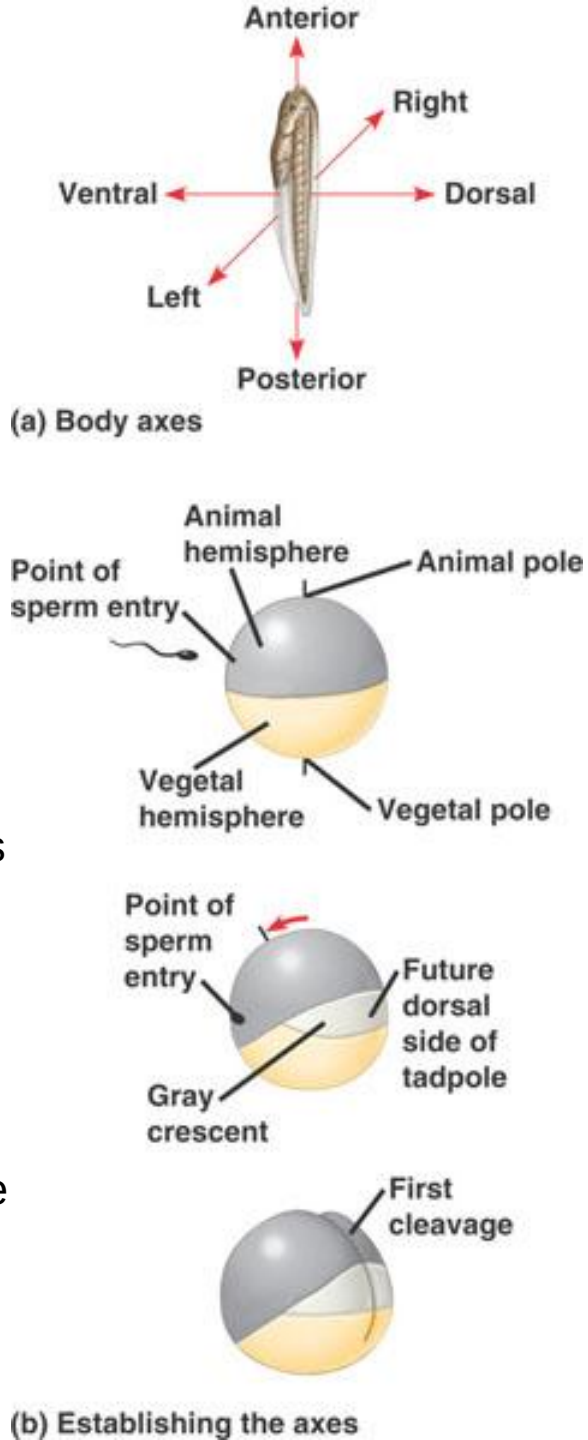
BODY AXES

The development of body axes in frogs is influenced by the polarity of the egg.

The polarity of the egg determines the anterior-posterior axis before fertilization.

At fertilization, the pigmented cortex slides over the underlying cytoplasm toward the point of sperm entry. This rotation (red arrow) exposes a region of lighter-colored cytoplasm, the gray crescent, which is a marker of the dorsal side.

The first cleavage division bisects the gray crescent. Once the anterior-posterior and dorsal-ventral axes are defined, so is the left-right axis.



DIRECT VS. INDIRECT DEVELOPMENT

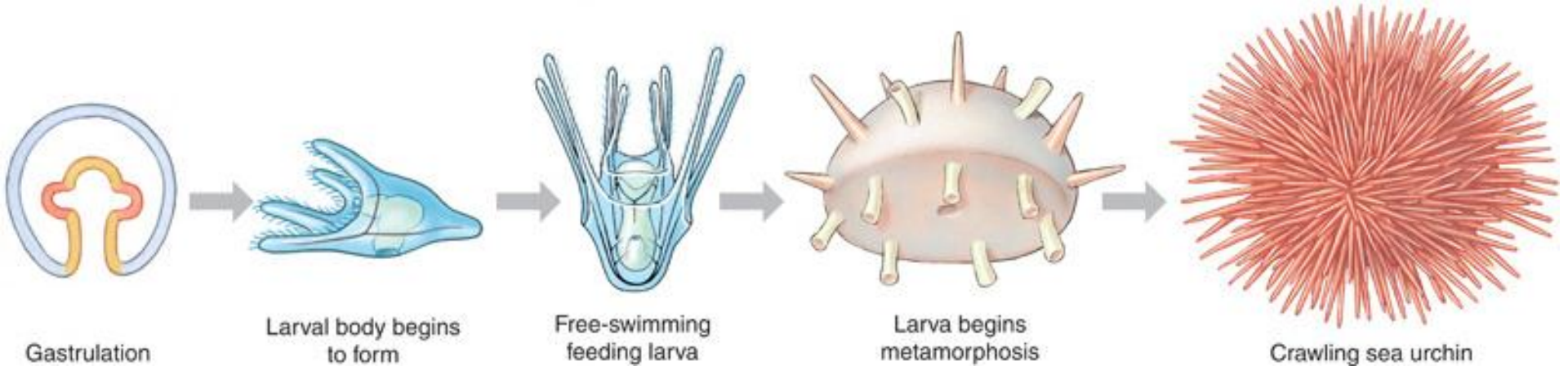
When lots of nourishing yolk is present, embryos develop into a miniature adult.

- Direct development

When little yolk is present, young develop into larval stages that can feed.

- Indirect development

Mammals have little yolk, but nourish the embryo via the placenta.



SUITES OF DEVELOPMENTAL CHARACTERS

Two major groups of triploblastic animals:

- Protostomes
- Deuterostomes

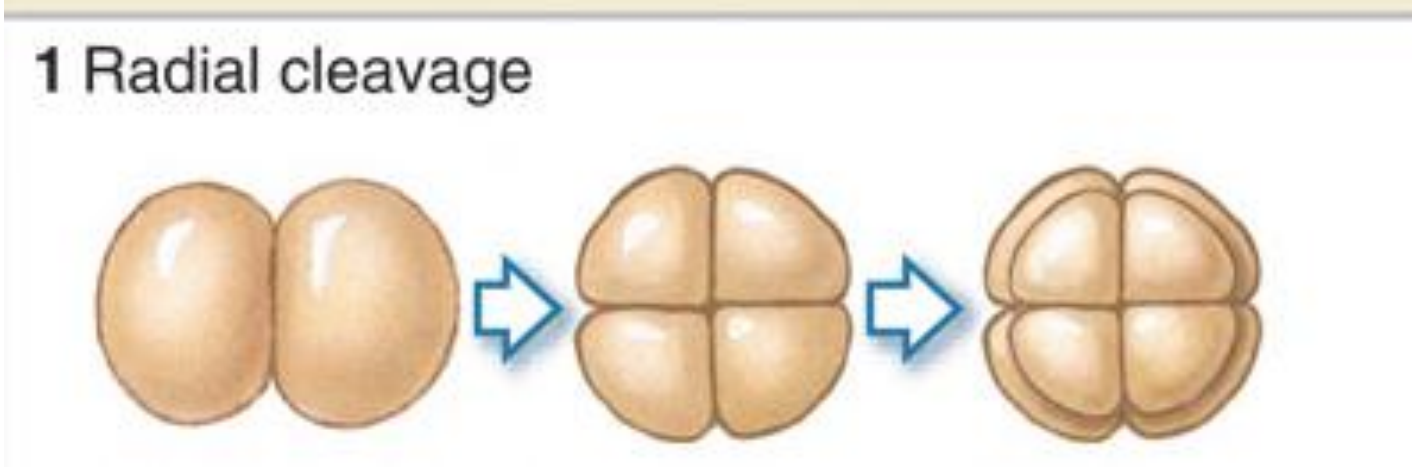
Differentiated by:

- Spiral vs. radial cleavage
- Regulative vs. mosaic cleavage
- Blastopore becomes mouth vs. anus
- Schizocoelous vs. enterocoelous coelom formation.

DEUTEROSTOME DEVELOPMENT

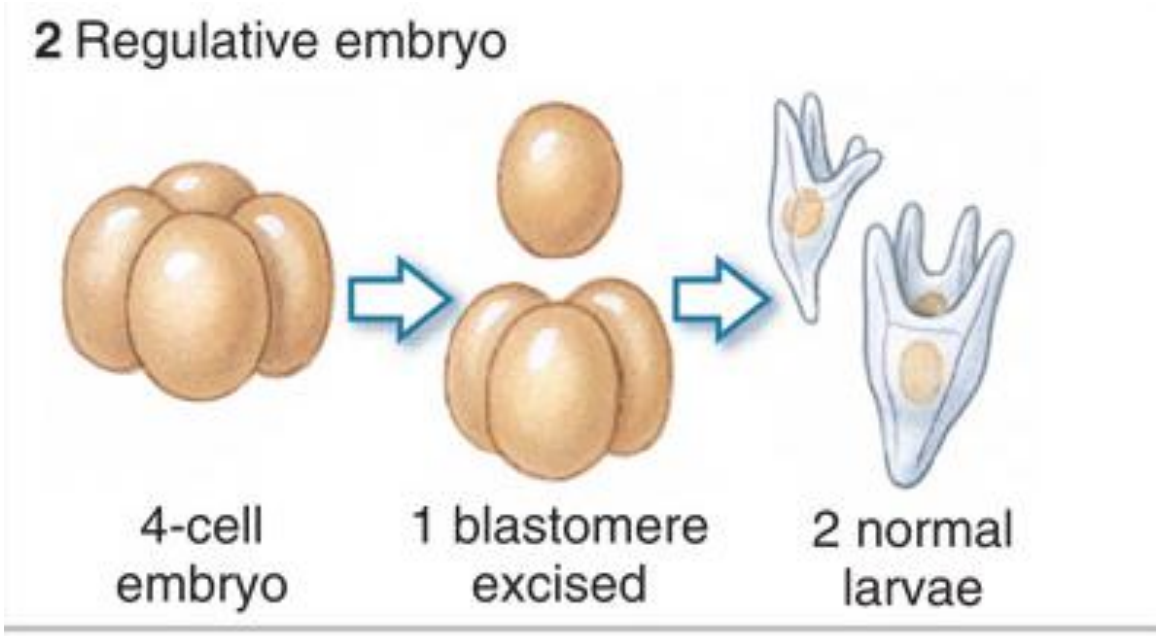
Deuterostomes include echinoderms (sea urchins, sea stars etc) and chordates.

- Radial cleavage



DEUTEROSTOME DEVELOPMENT

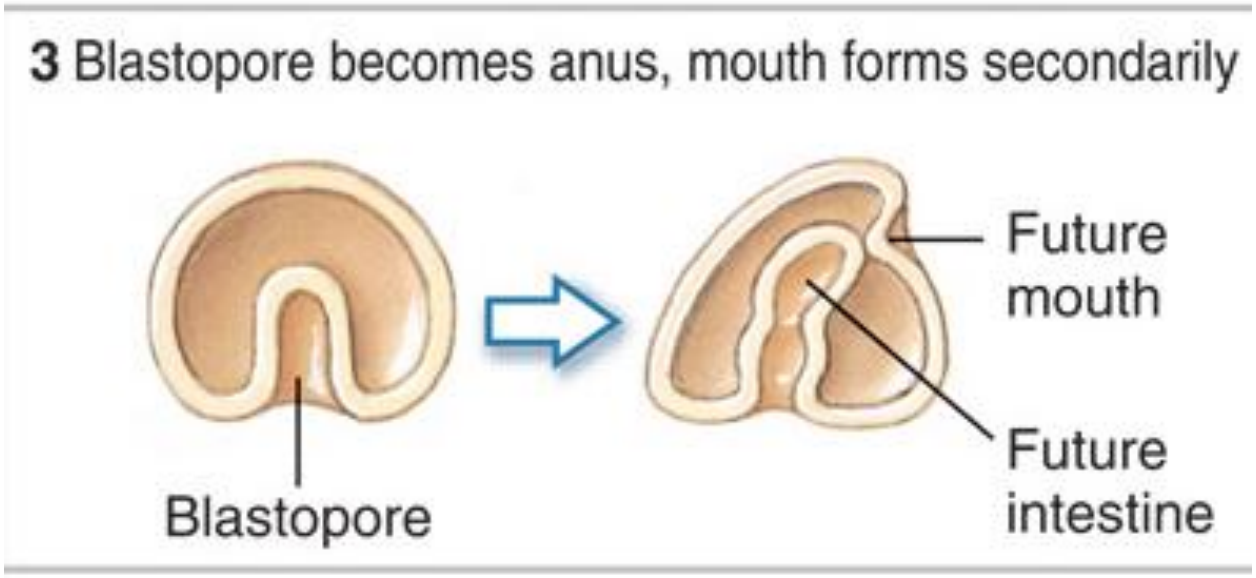
Regulative development – the fate of a cell depends on its interactions with neighbors, not what piece of cytoplasm it has. A blastomere isolated early in cleavage is able to from a whole individual.



DEUTEROSTOME DEVELOPMENT

Deuterostome means second mouth.

The blastopore becomes the anus and the mouth develops as the second opening.

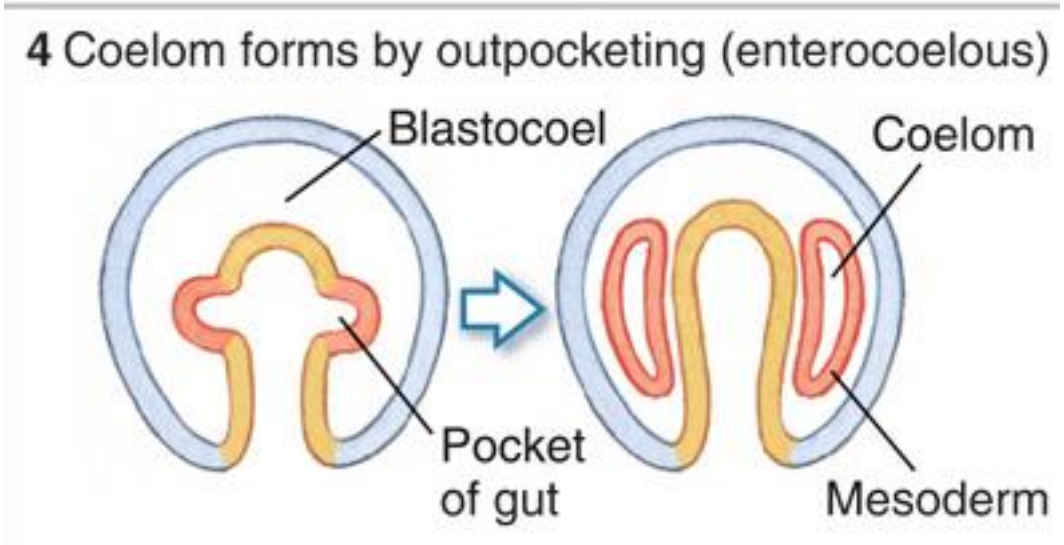


DEUTEROSTOME DEVELOPMENT

The coelom is a body cavity completely surrounded by mesoderm.

- Mesoderm & coelom form simultaneously.

In enterocoely, the coelom forms as outpocketing of the gut.



DEUTEROSTOME DEVELOPMENT

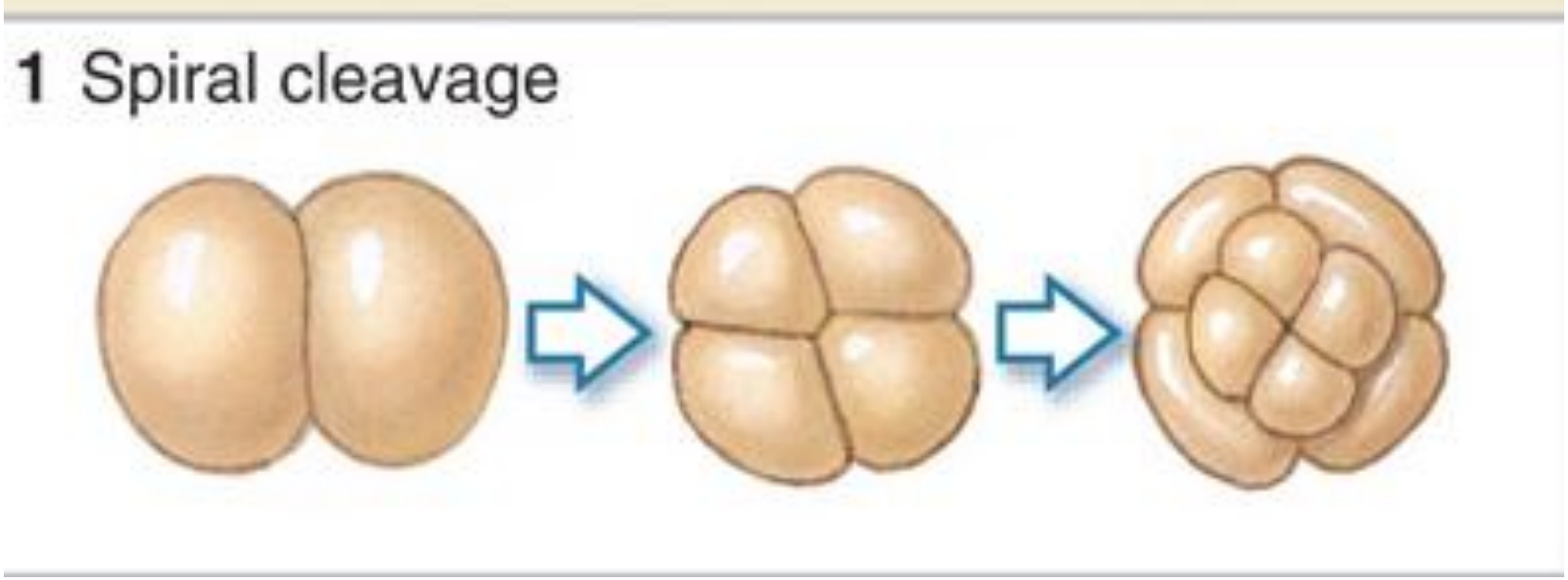
Typical deuterostomes have coeloms that develop by enterocoely.

- Vertebrates use a modified version of schizocoely.

PROTOSTOME DEVELOPMENT

Protostomes include flatworms, annelids and molluscs.

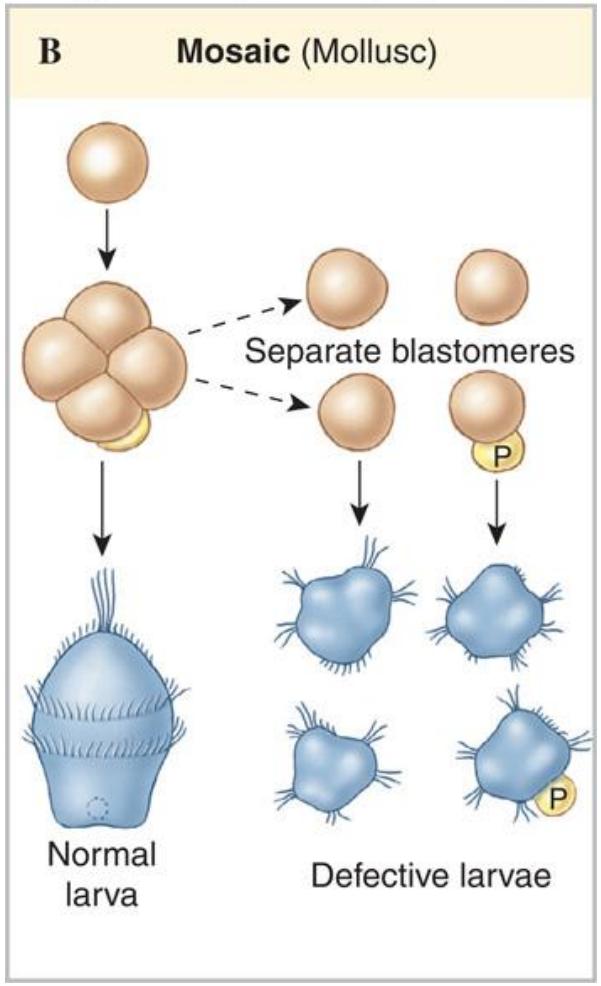
- Spiral cleavage



PROTOSTOME DEVELOPMENT

Mosaic development – cell fate is determined by the components of the cytoplasm found in each blastomere.

- Morphogenetic determinants.
- An isolated blastomere can't develop.

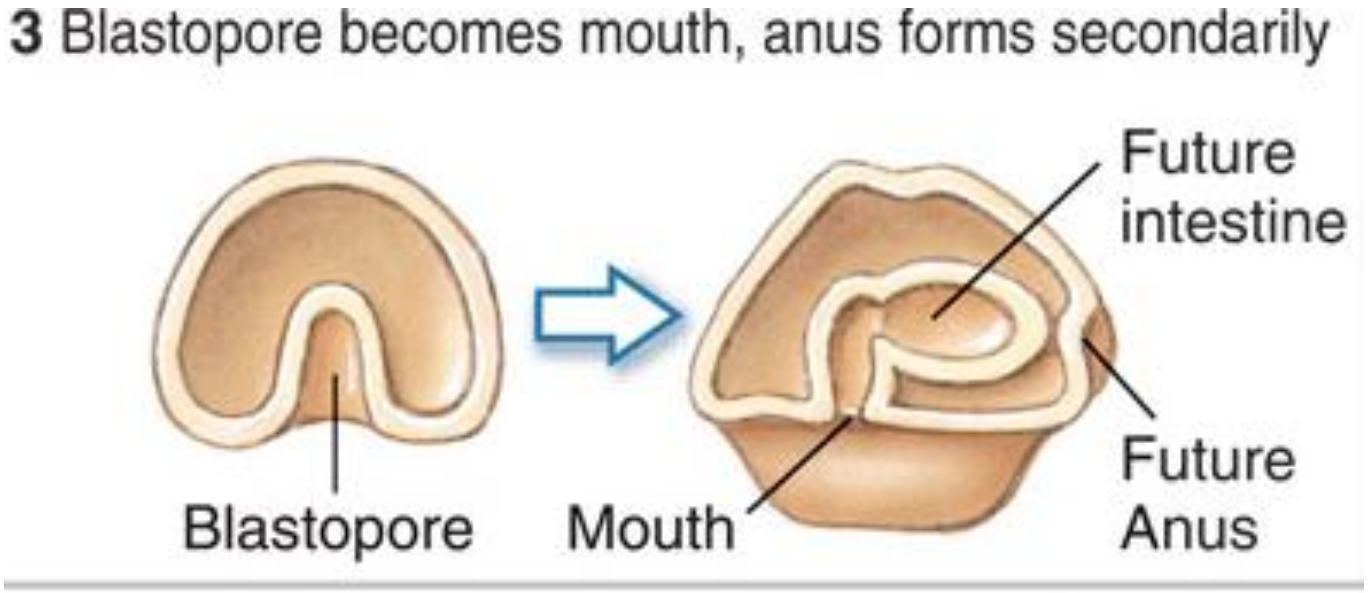


PROTOSTOME DEVELOPMENT

Protostome means first mouth.

Blastopore becomes the mouth.

The second opening will become the anus.



PROTOSTOME DEVELOPMENT

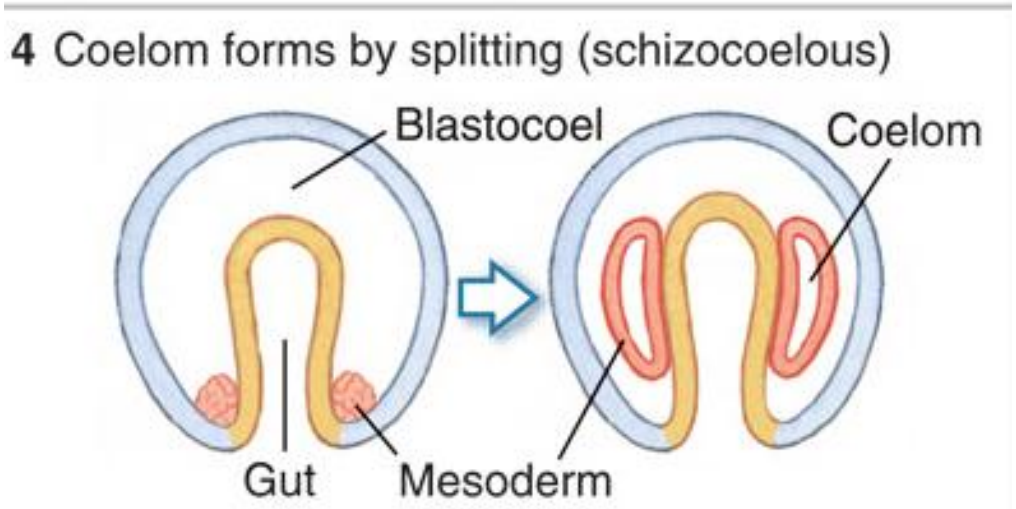
In protostomes, a mesodermal band of tissue forms *before* the coelom is formed.

The mesoderm splits to form a coelom.

- Schizocoely

Not all protostomes have a true coelom.

- Pseudocoelomates have a body cavity between mesoderm and endoderm.
- Acoelomates have no body cavity at all other than the gut.



TWO CLADES OF PROTOSTOMES

The ecdysozoan protostomes include arthropods, roundworms, and other taxa that molt their exoskeletons.

- Ecdysis – shedding of the cuticle.
- Many do not show spiral cleavage.

BUILDING A BODY PLAN

An organism's development is determined by the genome of the zygote and also by differences that arise between early embryonic cells.

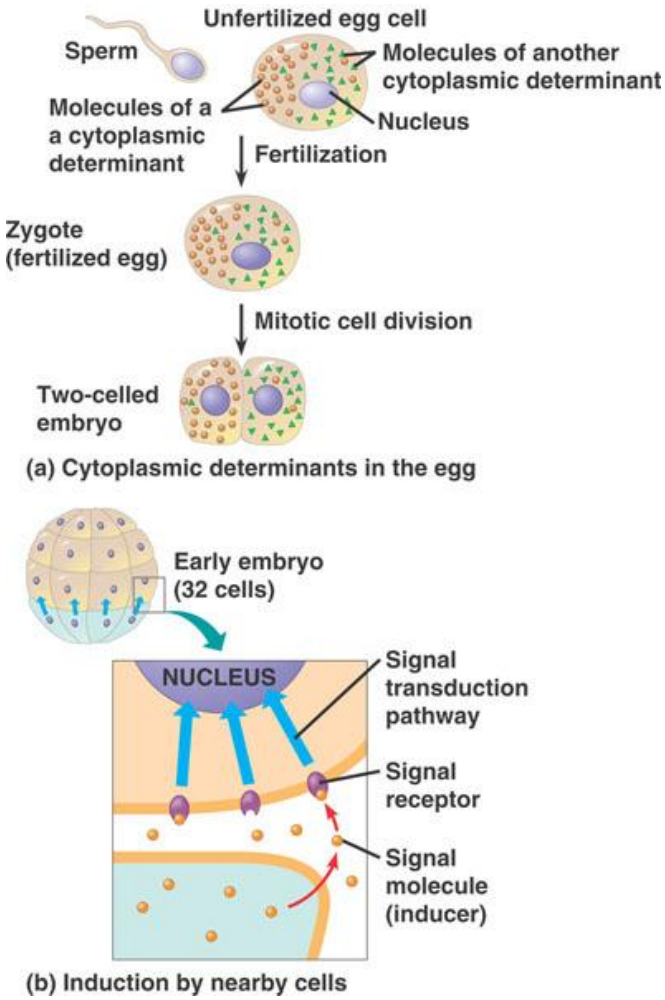
- Different genes will be expressed in different cells.

BUILDING A BODY PLAN

Uneven distribution of substances in the egg called cytoplasmic determinants results in some of these differences.

Position of cells in the early embryo result in differences as well.

- Induction



RESTRICTION OF CELLULAR POTENCY

In many species that have cytoplasmic determinants only the zygote is totipotent, capable of developing into all the cell types found in the adult.

RESTRICTION OF CELLULAR POTENCY

Unevenly distributed cytoplasmic determinants in the egg cell:

- Are important in establishing the body axes.
- Set up differences in blastomeres resulting from cleavage.

RESTRICTION OF CELLULAR POTENCY

As embryonic development proceeds, the potency of cells becomes progressively more limited in all species.

CELL FATE DETERMINATION AND PATTERN FORMATION BY INDUCTIVE SIGNALS

Once embryonic cell division creates cells that differ from each other,

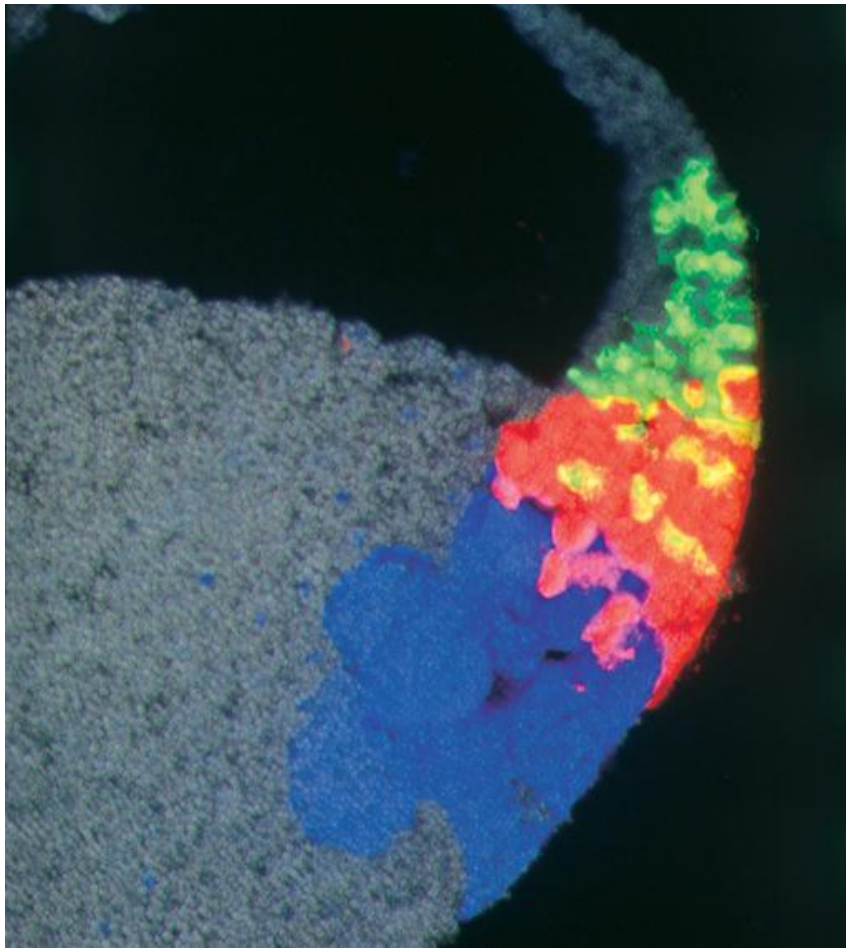
- The cells begin to influence each other's fates by induction.

INDUCTION

Induction is the capacity of some cells to cause other cells to develop in a certain way.

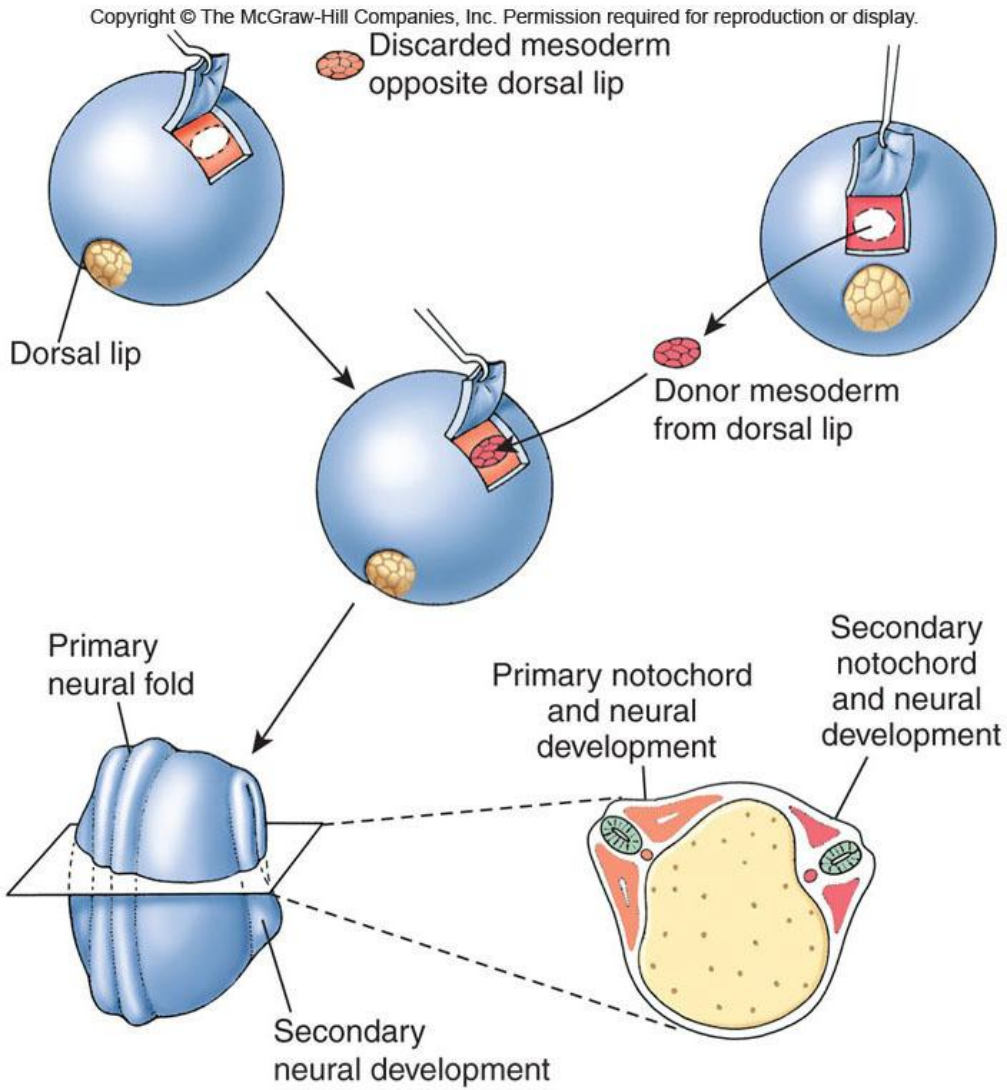
Dorsal lip of the blastopore induces neural development.

- Primary organizer



SPEMANN-MANGOLD EXPERIMENT

Transplanting a piece of dorsal blastopore lip from a salamander gastrula to a ventral or lateral position in another gastrula developed into a notochord & somites and it induced the *host* ectoderm to form a neural tube.



BUILDING A BODY PLAN

Cell differentiation – the specialization of cells in their structure and function.

Morphogenesis – the process by which an animal takes shape and differentiated cells end up in their appropriate locations.

BUILDING A BODY PLAN

The sequence includes

- Cell movement
- Changes in adhesion
- Cell proliferation

There is no “hard-wired” master control panel directing development.

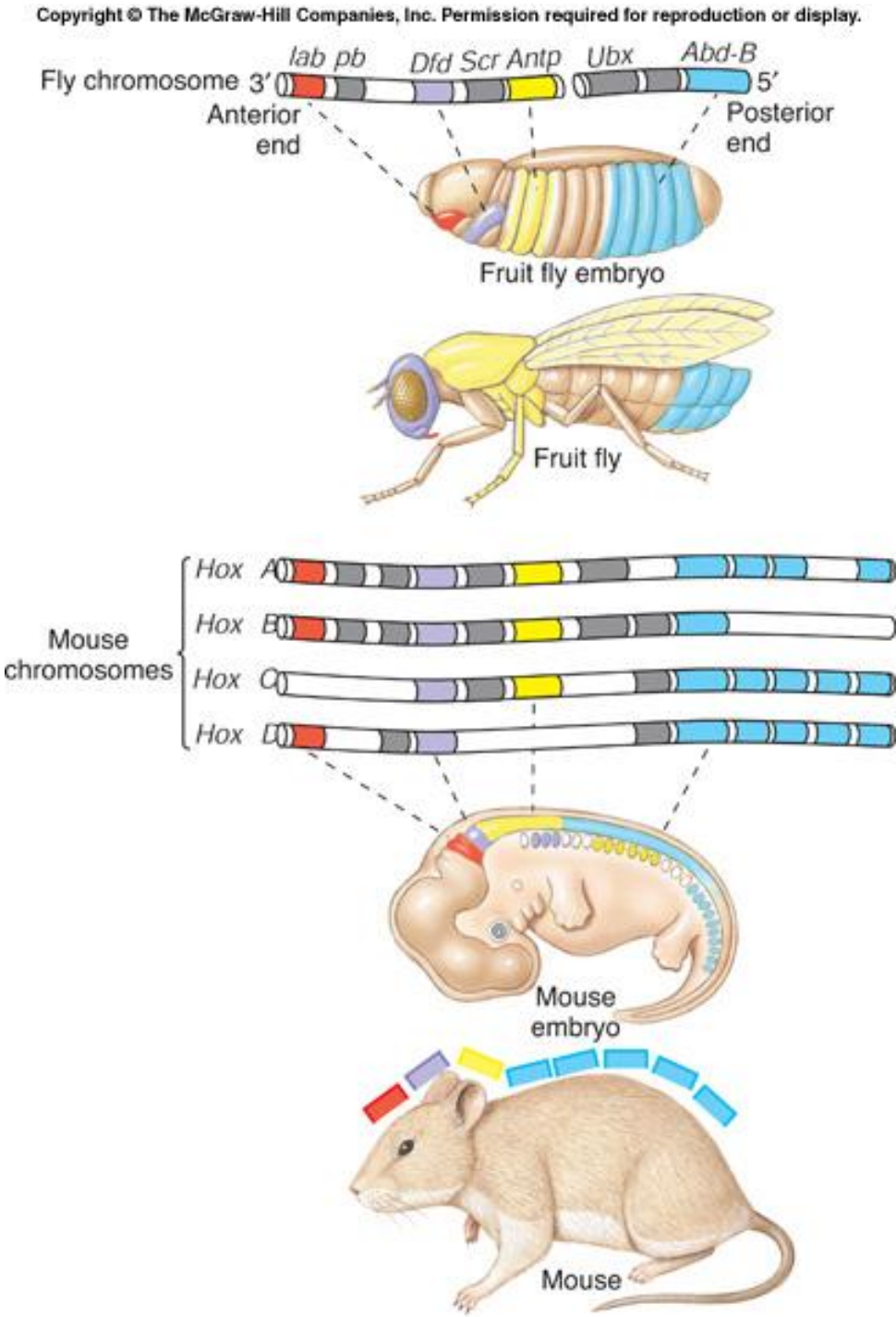
- Sequence of local patterns in which one step in development is a subunit of another.
- Each step in the developmental hierarchy is a necessary preliminary for the next.

HOX GENES

Hox genes control the subdivision of embryos into regions of different developmental fates along the anteroposterior axis.

- Homologous in diverse organisms.

These are master genes that control expression of subordinate genes.



FORMATION OF THE VERTEBRATE LIMB

Inductive signals play a major role in pattern formation – the development of an animal's spatial organization.

FORMATION OF THE VERTEBRATE LIMB

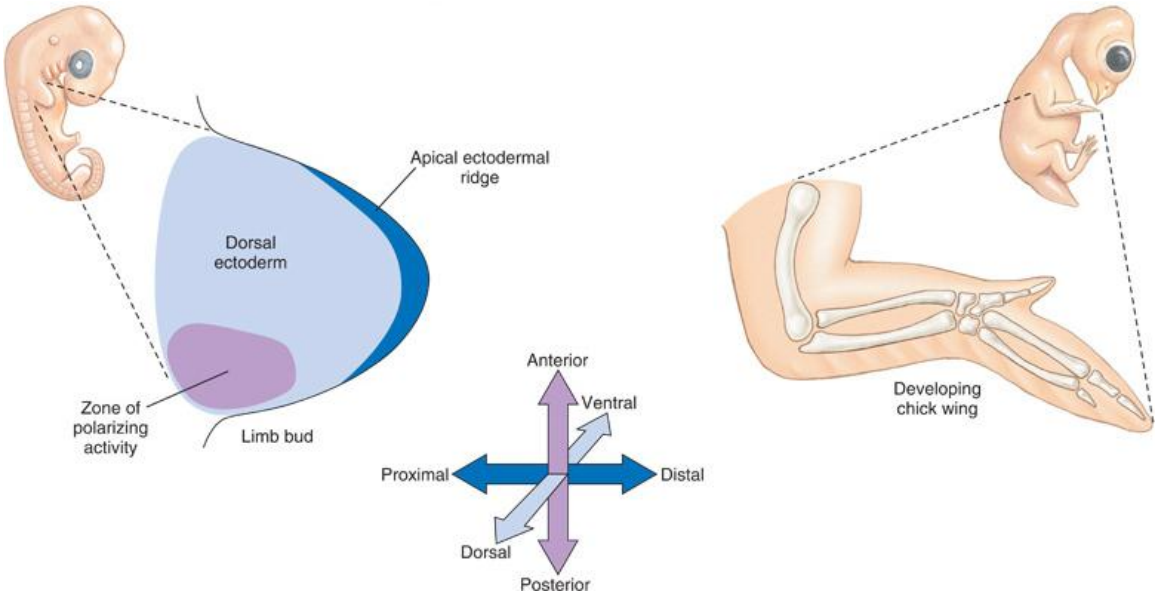
The molecular cues that control pattern formation, called positional information:

- Tell a cell where it is with respect to the animal's body axes.
- Determine how the cell and its descendents respond to future molecular signals.

FORMATION OF THE VERTEBRATE LIMB

The wings and legs of chicks, like all vertebrate limbs begin as bumps of tissue called limb buds.

The embryonic cells within a limb bud respond to positional information indicating location along three axes.



FORMATION OF THE VERTEBRATE LIMB

One limb-bud organizer region is the apical ectodermal ridge (AER).

- A thickened area of ectoderm at the tip of the bud.

The second major limb-bud organizer region is the zone of polarizing activity (ZPA).

- A block of mesodermal tissue located underneath the ectoderm where the posterior side of the bud is attached to the body.

MORPHOGENESIS

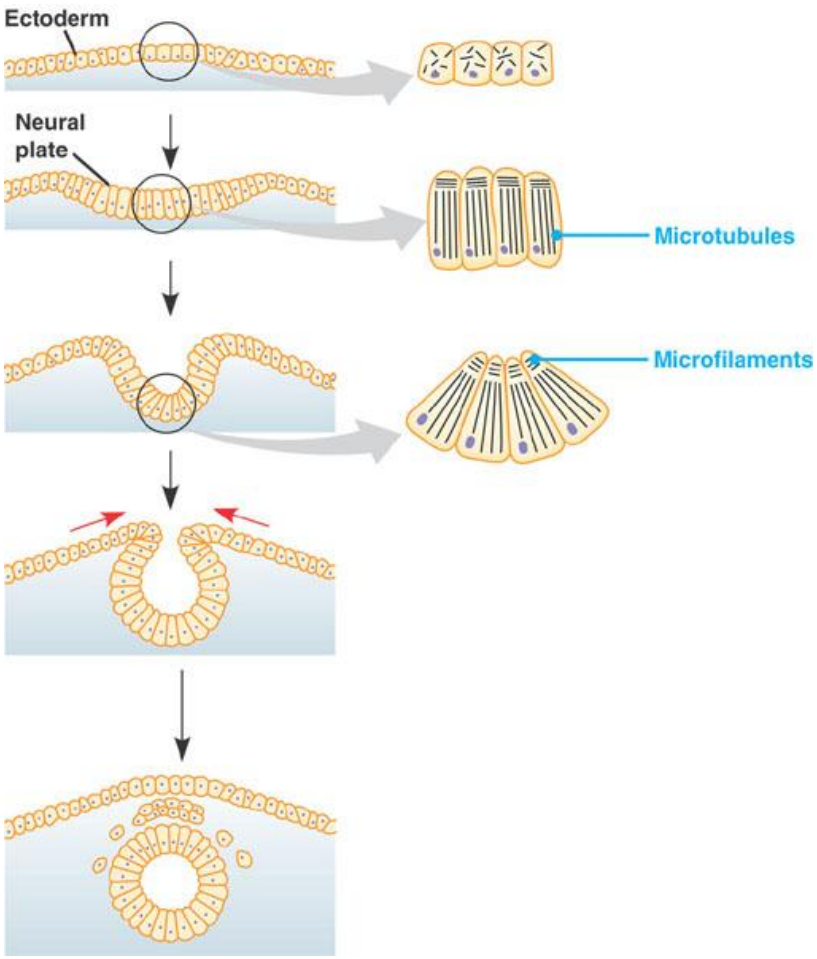
Morphogenesis is a major aspect of development in both plants and animals but only in animals does it involve the *movement* of cells.

THE CYTOSKELETON, CELL MOTILITY, AND CONVERGENT EXTENSION

Changes in the shape of a cell usually involve reorganization of the cytoskeleton.

CHANGES IN CELL SHAPE

The formation of the neural tube is affected by microtubules and microfilaments.



CELL MIGRATION

The cytoskeleton also drives cell migration, or cell crawling.

- The active movement of cells from one place to another.

In gastrulation, tissue invagination is caused by changes in both cell shape and cell migration.

EVO-DEVO

Evolutionary developmental biology - **evolution is a process in which organisms become different as a result of changes in the genetic control of development.**

- Genes that control development are similar in diverse groups of animals.
  - *Hox* genes

Hox genes, a subset of **homeobox genes**, are a group of related **genes** that specify regions of the body plan of an embryo along the head-tail axis of animals.

Hox proteins encode and specify the characteristics of 'position', ensuring that the correct structures form in the correct places of the body.

EVO-DEVO

Instead of evolution proceeding by the gradual accumulation of numerous small mutations, could it proceed by relatively few mutations in a few developmental genes?

- The induction of legs or eyes by a mutation in one gene suggests that these and other organs can develop as modules.

THE COMMON VERTEBRATE HERITAGE

Vertebrates share a common ancestry and a common pattern of early development.

- Vertebrate hallmarks all present briefly.
  - Dorsal neural tube
  - Notochord
  - Pharyngeal gill pouches
  - Postanal tail