Overview: Plastic Plants?

- The fanwort plant exhibits *developmental plasticity*, the *ability to alter itself in response to its environment*.
- Developmental plasticity is more marked in plants than in animals.
- In addition to plasticity, plant species have by natural selection accumulated characteristics of *morphology = form* that vary little within the species.
The fanwort has two types of leaves -- developmental plasticity
Concept 35.1: The plant body has a hierarchy of organs, tissues, and cells

- Like multicellular animals, plants have organs composed of different tissues, which in turn are composed of cells.

- *Three basic organs evolved: roots, stems, and leaves.*

- They are organized into a root system and a shoot system:
  - Roots rely on sugar produced by photosynthesis in the shoot system.
  - Shoots rely on water and minerals absorbed by the root system.
Flowering Plant Morphology

- Reproductive shoot (flower)
- Apical bud
- Node
- Internode
- Apical bud
- Vegetative shoot
- Leaf
- Blade
- Petiole
- Axillary bud
- Stem
- Taproot
- Lateral branch roots

Shoot system

Root system
The Three Basic Plant Organs: Roots, Stems, and Leaves

• **Roots** are multicellular organs with important functions:
  – *Anchoring* the plant
  – *Absorbing* minerals and water
  – *Storing* organic nutrients
• A taproot system consists of one main vertical root that gives rise to some large lateral roots, or branch roots.

• Adventitious roots arise from stems or leaves.

• Seedless vascular plants and monocots have a fibrous root system characterized by many thin lateral roots with no main root.

• In most plants, absorption of water and minerals occurs near the root hairs, where vast numbers of tiny root hairs increase the surface area.
Root Hairs of a radish seedling
Many plants have modified roots

- Prop roots
- “Strangling” aerial roots
- Storage roots
- Buttress roots
- Pneumatophores
Modified roots

Prop roots - support tall top heavy plants
Modified Roots

Pneumatophores - “air roots” enable root systems to capture oxygen
Modified Roots

Buttress roots - support tall trunks of some tropical trees “like butresses.”
Nodes, the points at which leaves are attached.

Internodes, the stem segments between nodes.

• An axillary bud is a structure that has the potential to form a lateral shoot, or branch.

• Apical bud, or terminal bud, is located near the shoot tip and causes elongation of a young shoot.

• Apical dominance helps to maintain dormancy in most nonapical buds.
Many Plants have Modified Stems

- Rhizomes
- Bulbs
- Storage leaves
- Stolons
- Tubers
Leaves = the main photosynthetic organs

Leaves generally consist of a flattened **blade** and a stalk called the **petiole**, which joins the leaf to a node of the stem.

- Monocots and eudicots differ in the arrangement of **veins**, the vascular tissue of leaves:
  - Most monocots have parallel veins.
  - Most eudicots have branching veins.
Simple vs. Compound Leaves

(a) Simple leaf

(b) Compound leaf

(c) Doubly compound leaf
• Some plant species have evolved modified leaves that serve various functions
Some plant species have evolved modified leaves that serve various functions.

- **Tendrils**: Cling
- **Spines**: “Prickly” Photosynthesis is carried out mainly by the fleshy stems.
- **Storage Leaves**: Succulent plant leaves store water.
- **Reproductive leaves**: Little plantlets fall off and take root in the soil.
- **Bracts**: Look like petals Attract pollinators.
Tendrils = Modified Leaves

Tendrils -- cling --> thigmotropism
Storage leaves
Tissue System:
Each plant organ has:
* dermal
* vascular and
* ground tissues
• In nonwoody plants, the dermal tissue system consists of the epidermis.

• A waxy coating called the cuticle helps prevent water loss from the epidermis.

• In woody plants, protective tissues called periderm replace the epidermis in older regions of stems and roots.

• Trichomes are outgrowths of the shoot epidermis and can help with insect defense.
• The **vascular tissue system** carries out long-distance transport of materials between roots and shoots.

• **Xylem** conveys *water and dissolved minerals* upward from roots into the shoots.

• **Phloem** transports *organic nutrients* from where they are made to where they are needed.
• Tissues that are neither dermal nor vascular are the **ground tissue system**.

• Ground tissue internal to the vascular tissue is **pith**; ground tissue external to the vascular tissue is **cortex**. Both have plastids for **storage**.

• *Ground tissue* includes cells specialized for **storage, photosynthesis, and support**.
Common Types of Plant Cells - are specialized of cells in structure and function.

• Some major types of plant cells:
  – Parenchyma - ground: thin flexible cell walls: photosynthesis, storage.
  – Collenchyma - ground: thicker cell walls for flexible support.
  – Sclerenchyma - ground: thick secondary cell walls reinforced with lignin for rigid, sturdy support.
  – Xylem - vascular: water-conducting cells.
  – Phloem - vascular: sugar-conducting cells.
Parenchyma cells in *Elodea* leaf, with chloroplasts (LM)

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Sclerenchyma Cells

- **Sclerenchyma cells** are rigid because of thick secondary walls strengthened with lignin.

- They are dead at functional maturity.

- There are two types:
  - **Sclereids** are short and irregular in shape and have thick lignified secondary walls.
  - **Fibers** are long and slender and arranged in threads.
Sclereid cells in pear (LM)

Cell wall

Fiber cells (cross section from ash tree) (LM)
Differentiated Plant Cells in the Xylem - Dead at Maturity

Vessel elements, with perforated end walls

Tracheids and vessels (colorized SEM)

Perforation plate

Vessel element

Vessel
Tracheids

100 µm

Pits

Tracheids
Water-Conducting Cells of the Xylem

The two types of water-conducting cells, **tracheids** and **vessel elements**, are dead at maturity

- **Tracheids** are found in the xylem of all vascular plants.

- **Vessel elements** are common to most angiosperms and a few gymnosperms.

- Vessel elements align end to end to form long micropipes called **vessels**.
Differentiated Plant Cells

Sieve-tube element (left) and companion cell: cross section (TEM)

Sieve-tube elements: longitudinal view (LM)

Sieve plate
Companion cells
Plasmodesma
Sieve plate elements
Nucleus of companion cells

Sieve-tube elements: longitudinal view

Sieve plate with pores (SEM)
Sugar- Conducting Cells of the Phloem

- **Sieve-tube elements** are alive at functional maturity, though they lack organelles.

- **Sieve plates** are the porous end walls that allow fluid to flow between cells along the sieve tube.

- Each sieve-tube element has a **companion cell** whose nucleus and ribosomes serve both cells.
Sieve-tube elements: longitudinal view (LM)

- Sieve plate
- Companion cells
- Sieve-tube elements

Scale: 30 µm
Sieve-tube elements: longitudinal view

Sieve-tube element

Plasmodesma

Sieve plate

Nucleus of companion cells

Sieve plate with pores (SEM)

10 µm
Concept 35.2: Meristems generate cells for new organs

- A plant can grow throughout its life; this is called **indeterminate growth**.

- Some plant organs cease to grow at a certain size; this is called **determinate growth**.

- **Annuals** complete their life cycle in a year or less.

- **Biennials** require two growing seasons.

- **Perennials** live for many years.
• **Meristems** are growth regions - have perpetual embryonic tissue that allows for indeterminate growth.

• **Apical meristems** are located at the tips of roots and shoots and at the axillary buds of shoots.

• Apical meristems *elongate* shoots and roots, a process called *primary growth*. 
• **Lateral meristems** add *thickness* to woody plants, a process called *secondary growth*.

• There are two lateral meristems: the vascular cambium and the cork cambium.

• The *vascular cambium* adds layers of vascular tissue called *secondary xylem = wood* and secondary phloem.

• The *cork cambium* replaces the epidermis with *periderm*, which is thicker and tougher.
**An overview of primary and secondary growth**

**Shoot tip (shoot apical meristem and young leaves)**

**Lateral meristems:**
- Axillary bud meristem
- Vascular cambium
- Cork cambium

**Root apical meristems**

**Primary growth in stems**
- Epidermis
- Cortex
- Primary phloem
- Primary xylem
- Pith

**Secondary growth in stems**
- Periderm
- Cork cambium
- Cortex
- Primary phloem
- Secondary phloem
- Pith
- Secondary xylem
- Vascular cambium
Primary Growth - Lengthens Roots and Shoots

- The root tip is covered by a root cap, which protects the apical meristem as the root pushes through soil.

- Growth occurs just behind the root tip, in three zones of cells:
  - Zone of cell division
  - Zone of elongation
  - Zone of maturation - differentiation.
Primary growth of a root
• The primary growth of roots produces the epidermis, ground tissue, and vascular tissue.

• In most roots, the stele is a vascular cylinder.

• The ground tissue fills the cortex, the region between the vascular cylinder and epidermis.

• The innermost layer of the cortex is called the endodermis.
Organization of primary tissues in young roots

(a) Root with xylem and phloem in the center (typical of eudicots)

(b) Root with parenchyma in the center (typical of monocots)
Lateral roots arise from within the pericycle, the outermost cell layer in the vascular cylinder.
Primary Growth of Shoots - Apical Meristems

• A shoot apical meristem is a dome-shaped mass of dividing cells at the shoot tip.

• Axillary buds develop from meristematic cells left at the bases of leaf primordia.

• Lateral shoots develop from axillary buds on the stem’s surface.

• In most eudicots, the vascular tissue consists of vascular bundles that are arranged in a ring.
Shoot tip

Shoot apical meristem

Leaf primordia

Young leaf

Developing vascular strand

Axillary bud meristems

0.25 mm
Organization of primary tissues in young stems

(a) Cross section of stem with vascular bundles forming a ring (typical of eudicots)

(b) Cross section of stem with scattered vascular bundles (typical of monocots)
In most monocot stems, the vascular bundles are scattered throughout the ground tissue, rather than forming a ring.
Tissue Organization of Leaves

- The epidermis in leaves is interrupted by **stomata**, which allow **CO₂** exchange between the air and the photosynthetic cells in a leaf.

- Each stomatal pore is flanked by two **guard cells**, which regulate its opening and closing.

- The ground tissue in a leaf, called **mesophyll**, is sandwiched between the upper and lower epidermis.
• Below the *palisade mesophyll* in the upper part of the leaf is loosely arranged *spongy mesophyll*, where gas exchange occurs.

• The vascular tissue of each leaf is continuous with the vascular tissue of the stem.

• Veins are the leaf’s vascular bundles and function as the leaf’s skeleton.

• Each vein in a leaf is enclosed by a protective bundle sheath.
Leaf anatomy

Key to labels
- Dermal
- Ground
- Vascular

(a) Cutaway drawing of leaf tissues
- Cuticle
- Sclerenchyma fibers
- Stoma
- Bundle-sheath cell
- Xylem
- Phloem
- Guard cells
- Vein

(b) Surface view of a spiderwort (Tradescantia) leaf (LM)
- Guard cells
- Stomatal pore
- Epidermal cell

(c) Cross section of a lilac (Syringa) leaf (LM)
- Upper epidermis
- Palisade mesophyll
- Spongy mesophyll
- Lower epidermis
- Vein
- Air spaces
- Guard cells
The Vascular Cambium and Secondary Vascular Tissue

• The vascular cambium is a cylinder of meristematic cells one cell layer thick.

• It develops from undifferentiated parenchyma cells.

• In cross section, the vascular cambium appears as a ring of initials.

• The initials increase the vascular cambium’s circumference and add secondary xylem to the inside and secondary phloem to the outside.
Secondary growth produced by the vascular cambium

Vascular cambium

Growth

Secondary xylem

After one year of growth

Secondary phloem

After two years of growth

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• Tree rings are visible where late and early wood meet, and can be used to estimate a tree’s age.

• *Dendrochronology* is the analysis of tree ring growth patterns, and can be used to study past climate change.

• As a tree or woody shrub ages, the older layers of secondary xylem, the *heartwood*, no longer transport water and minerals.

• The outer layers, known as *sapwood*, still transport materials through the xylem.

• Older secondary phloem sloughs off and does not accumulate.
Using dendrochronology to study climate

RESULTS

Ring-width indexes

Year

1600 1700 1800 1900 2000

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Anatomy of a tree trunk

- Growth ring
- Vascular ray
- Heartwood
- Sapwood
- Vascular cambium
- Secondary phloem
- Layers of periderm
- Bark

Secondary xylem
Is this tree living or dead?
The Cork Cambium and the Production of Periderm

• The cork cambium gives rise to the secondary plant body’s protective covering, or periderm.

• Periderm consists of the cork cambium plus the layers of cork cells it produces.

• **Bark** consists of all the tissues external to the vascular cambium, including secondary phloem and periderm.

• **Lenticels** in the periderm allow for gas exchange between living stem or root cells and the outside air.
Concept 35.5: Growth, morphogenesis, and differentiation produce the plant body

- **Morphogenesis** is the development of body form and organization.

- The three developmental processes of growth, morphogenesis, and cellular differentiation act in concert to transform the fertilized egg into a plant.
Growth: Cell Division and Cell Expansion

• By increasing cell number, cell division in meristems increases the potential for growth.

• Cell expansion accounts for the actual increase in plant size.
The plane and symmetry of cell division influence development of form.

(a) Planes of cell division

(b) Asymmetrical cell division
Orientation of Cell Expansion

• Plant cells grow rapidly and “cheaply” by intake and storage of water in vacuoles.

• Plant cells expand primarily along the plant’s main axis.

• Cellulose microfibrils in the cell wall restrict the direction of cell elongation.
The plane and symmetry of cell division influence development of form.
Morphogenesis and Pattern Formation

- **Pattern formation** is the development of specific structures in specific locations.

- It is determined by **positional information** in the form of signals indicating to each cell its location.

- Positional information may be provided by gradients of molecules.

- **Polarity**, having structural or chemical differences at opposite ends of an organism, provides one type of positional information.
Morphogenesis in plants, as in other multicellular organisms, is often controlled by homeotic genes.
Gene Expression and Control of Cellular Differentiation

- In cellular differentiation, cells of a developing organism synthesize different proteins and diverge in structure and function even though they have a common genome.

- Cellular differentiation to a large extent depends on positional information and is affected by homeotic genes.
Location and a Cell’s Developmental Fate

- Positional information underlies all the processes of development: growth, morphogenesis, and differentiation.

- Cells are not dedicated early to forming specific tissues and organs.

- The cell’s final position determines what kind of cell it will become.
Phase change in the shoot system

Leaves produced by adult phase of apical meristem

Leaves produced by juvenile phase of apical meristem
Genetic Control of Flowering

• Flower formation involves a phase change from vegetative growth to reproductive growth.

• It is triggered by a combination of environmental cues and internal signals.

• Transition from vegetative growth to flowering is associated with the switching on of floral meristem identity genes.
Plant biologists have identified several **organ identity genes** = plant homeotic genes. These genes regulate the development of floral pattern.

A mutation in a plant organ identity gene can cause abnormal floral development.
Organ identity genes and pattern formation in flower development

(a) Normal *Arabidopsis* flower
(b) Abnormal *Arabidopsis* flower
• Researchers have identified three classes of floral organ identity genes.

• The **ABC model** of flower formation identifies how floral organ identity genes direct the formation of the four types of floral organs.

• An understanding of mutants of the organ identity genes depicts how this model accounts for floral phenotypes.
The ABC hypothesis for the functioning of organ identity genes in flower development

(a) A schematic diagram of the ABC hypothesis

(b) Side view of flowers with organ identity mutations
You should now be able to:

1. Compare the following structures or cells:
   - Fibrous roots, taproots, root hairs, adventitious roots
   - Dermal, vascular, and ground tissues
   - Monocot leaves and eudicot leaves
   - Parenchyma, collenchyma, sclerenchyma, water-conducting cells of the xylem, and sugar-conducting cells of the phloem
   - Sieve-tube element and companion cell.
2. Explain the phenomenon of apical dominance.

3. Distinguish between determinate and indeterminate growth.

4. Describe in detail the primary and secondary growth of the tissues of roots and shoots.

5. Describe the composition of wood and bark.
6. Distinguish between morphogenesis, differentiation, and growth.

7. Explain how a vegetative shoot tip changes into a floral meristem.