Introduction to Botany: BIOL 154
Study guide for Exam 4

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Lectures 27–37

Contents

1 Questions and answers

1.1 Quiz

Final question (2 points)

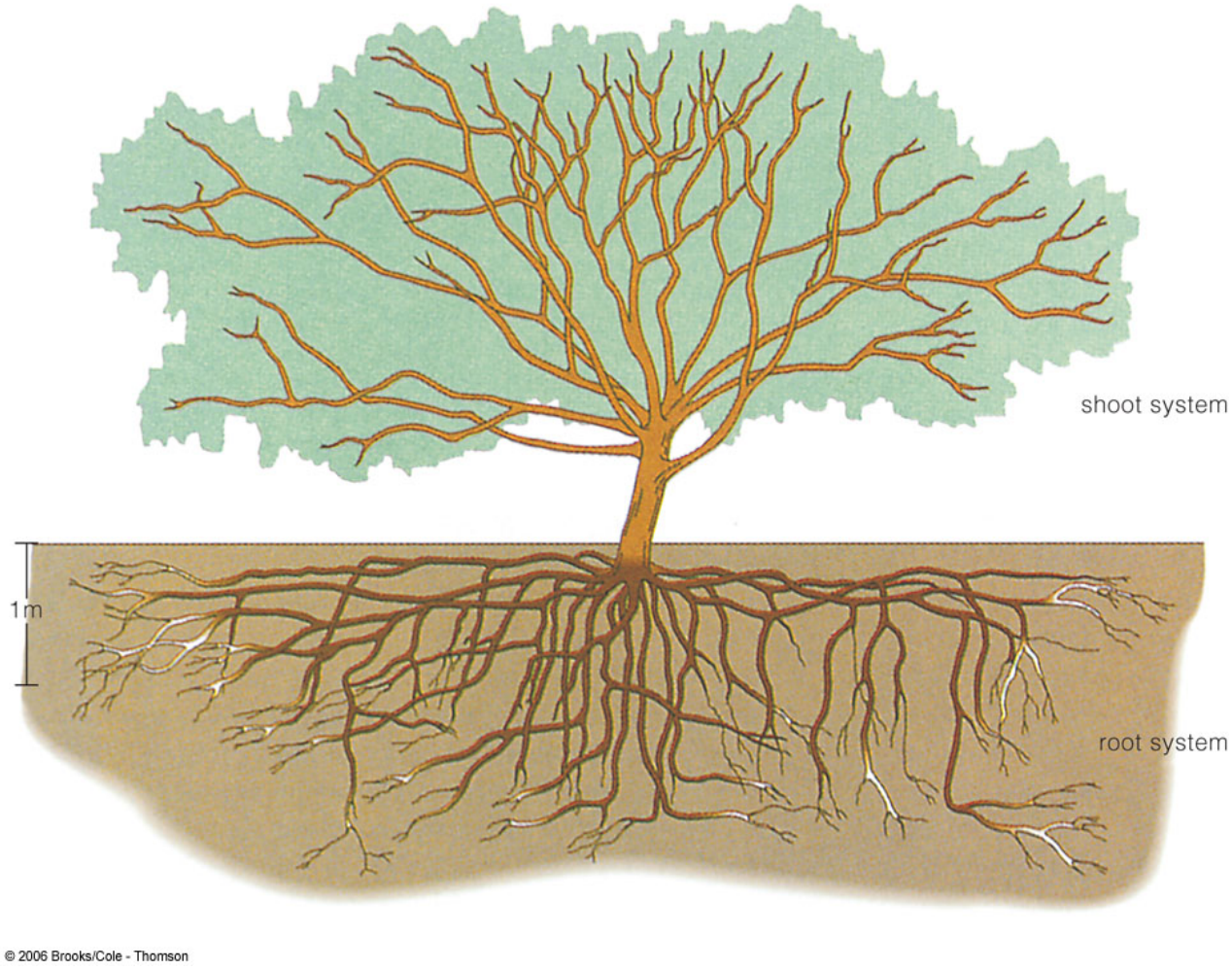
What is procambium?

- Primary meristem which makes stele.

2 Root

2.1 Root morphology

Root system and shoot system



Definition and functions

- Axial vegetative organ with a function of soil nutrition
- Other functions:
    A. Anchor
    B. Synthesis
    C. Storage
    D. Communication
- Features:
    A. No leaves
    B. Geotropic growth
    C. Locates in soil or water

Types of roots

- Primary root: originates from root of seedling
- Secondary (lateral) roots: originate from primary roots
- Adventitious roots: originate from stems

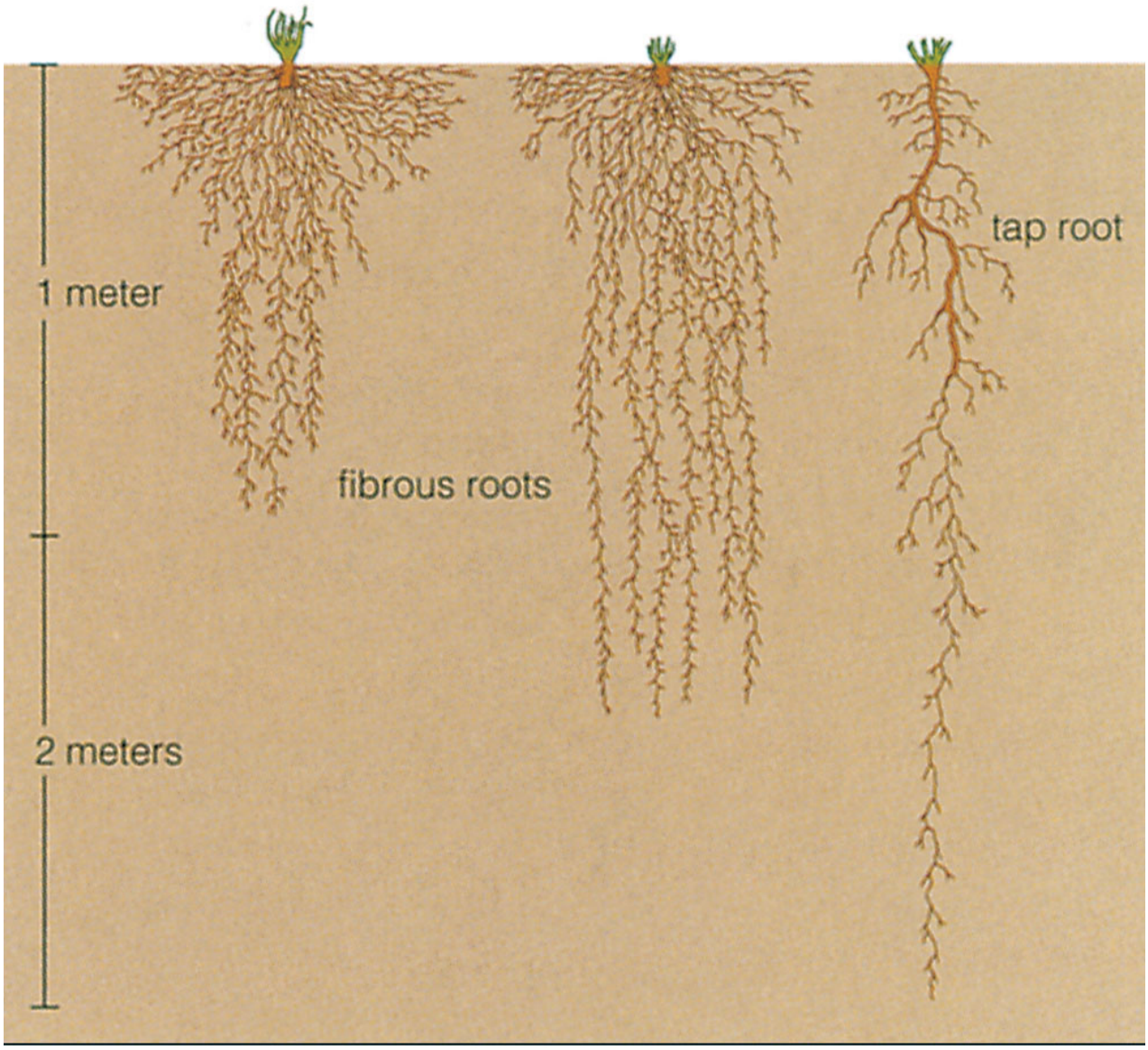
Primary root

Adventitious roots

Root systems

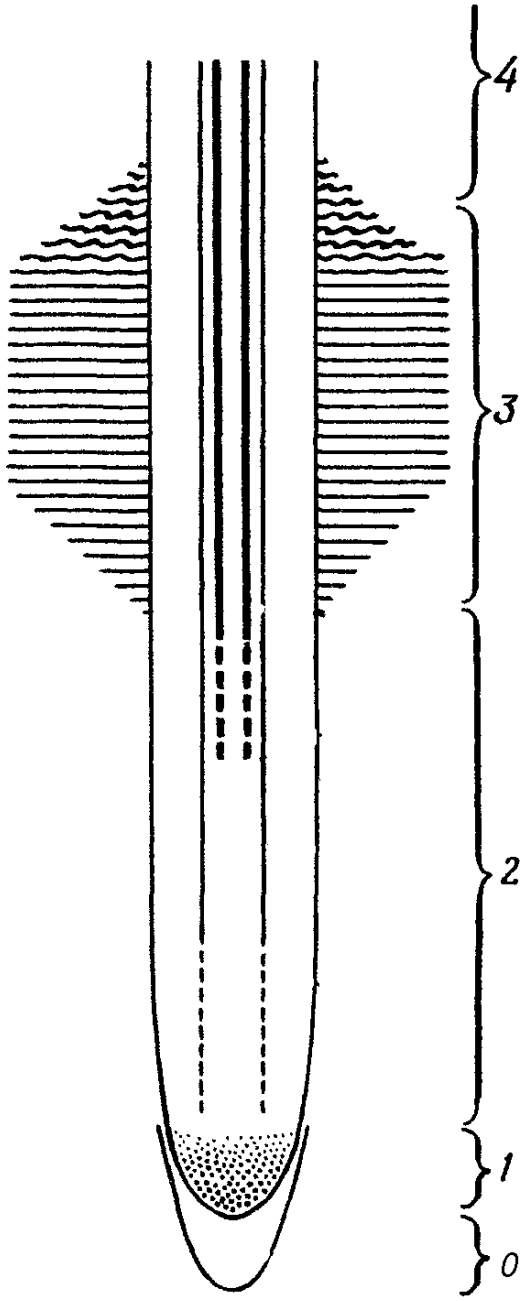
- Tap root system: with well developed primary root (most seed plants)
- Fibrous root system: without clearly visible primary root (monocots, ferns)

Fibrous and tap root systems



2.2 Anatomy and development of roots

Root zones



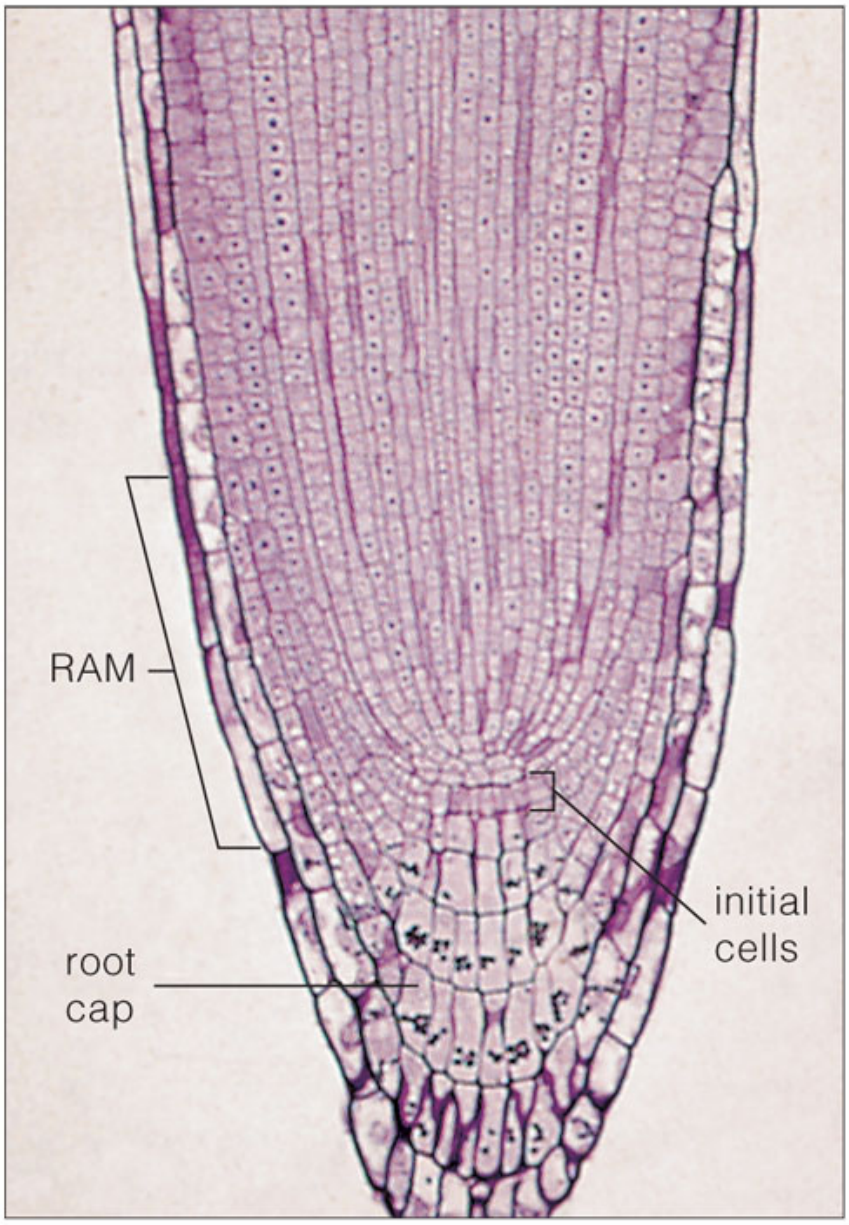
- Root cap
- Root meristem
- Elongation zone
- Absorption zone
- Maturation zone

Structure of root tip

- Initial cells (quiescent center)
- RAM

- Root tip growing both forward (root cap) and backward (other root tissues), initial cells determine the direction of growth
- If root tip touch barrier, it starts to make rotating movements

Root tip



Periphery of root

- Rhizodermis (rhizoderm, root epidermis): fast-degrading cells
- Cortex, which includes also:
  - Endodermis (endoderm): 1-cell layer with specialized cell walls, located on the border with vascular cylinder

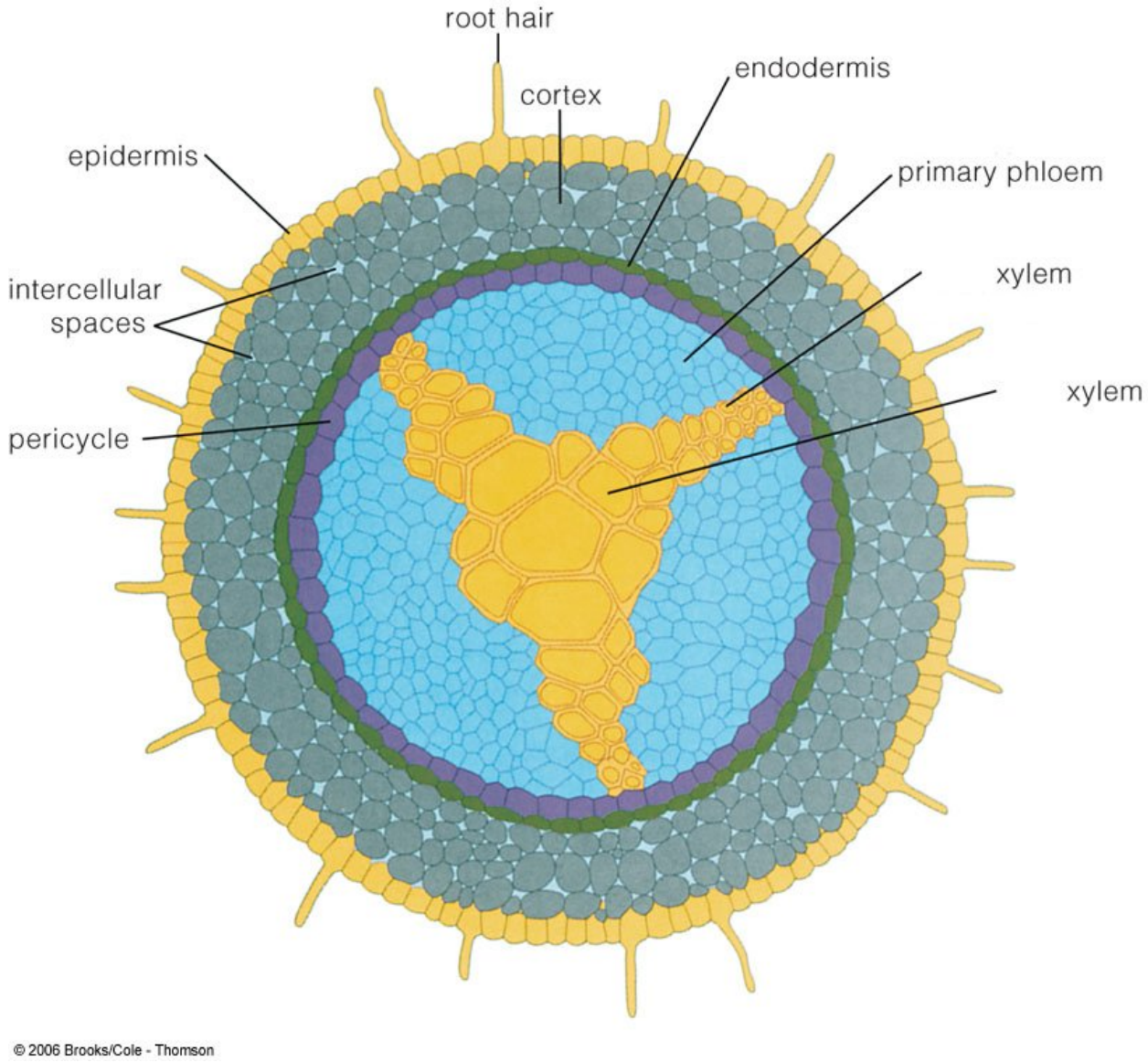
  - And (sometimes) exodermis (exoderm): similar to endoderm but located just under rhizodermis

- In some plants (i.e., orchids), cortex modified into velamen

Root center: vascular cylinder

- Pericycle
- Vascular tissues located in the center
- No central hollow, central parenchyma presents in monocot roots

Anatomy of root



Summary

- Vascular tissues of root is a modified protostele or solenostele (monocots).

Final question (2 points)

What are adventitious roots?

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

3 Questions and answers

3.1 Quiz

Final question (2 points)

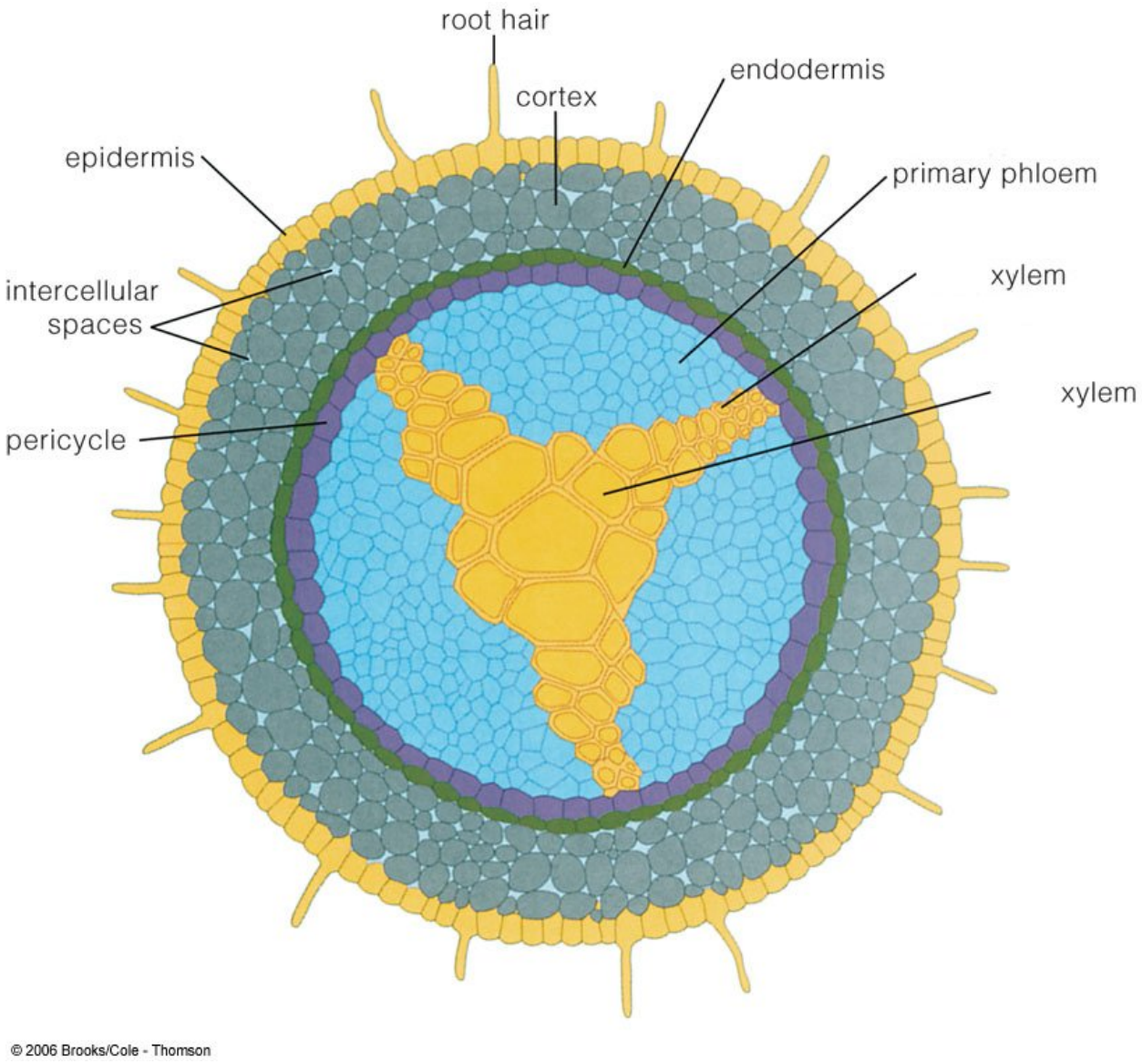
What are adventitious roots?

- Roots which grow out of stem.

4 Root

4.1 Anatomy and development of roots

Anatomy of root

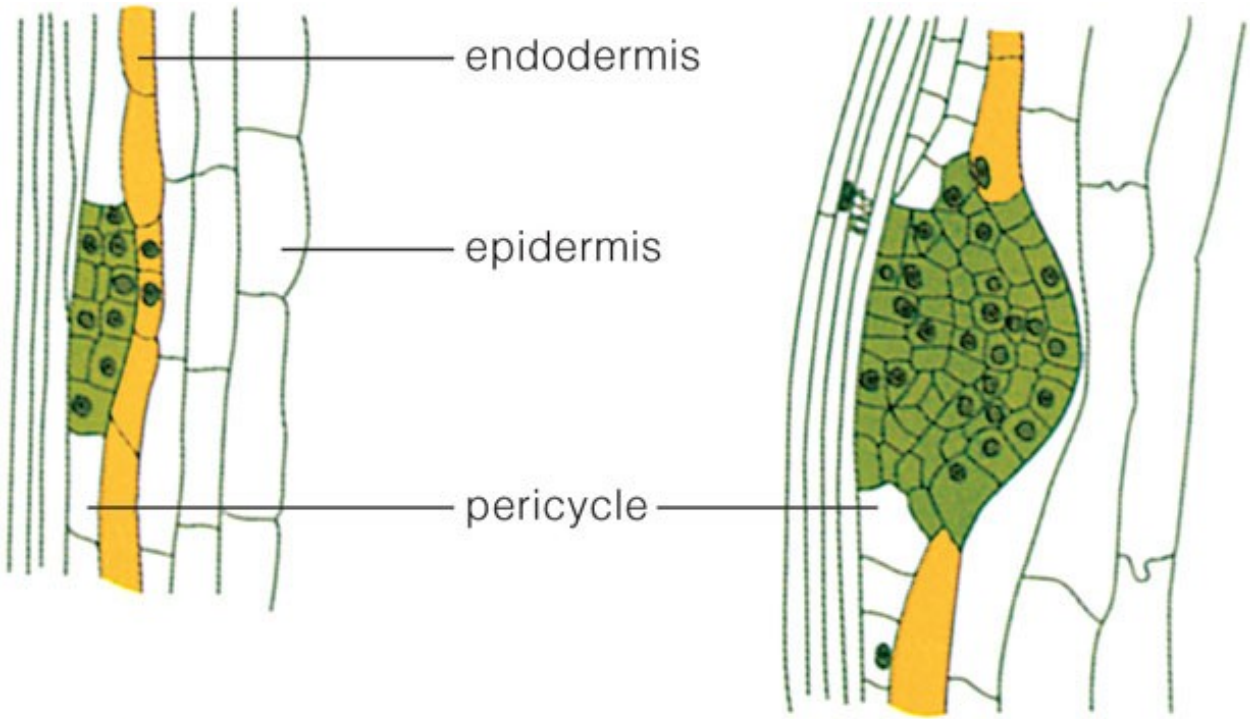


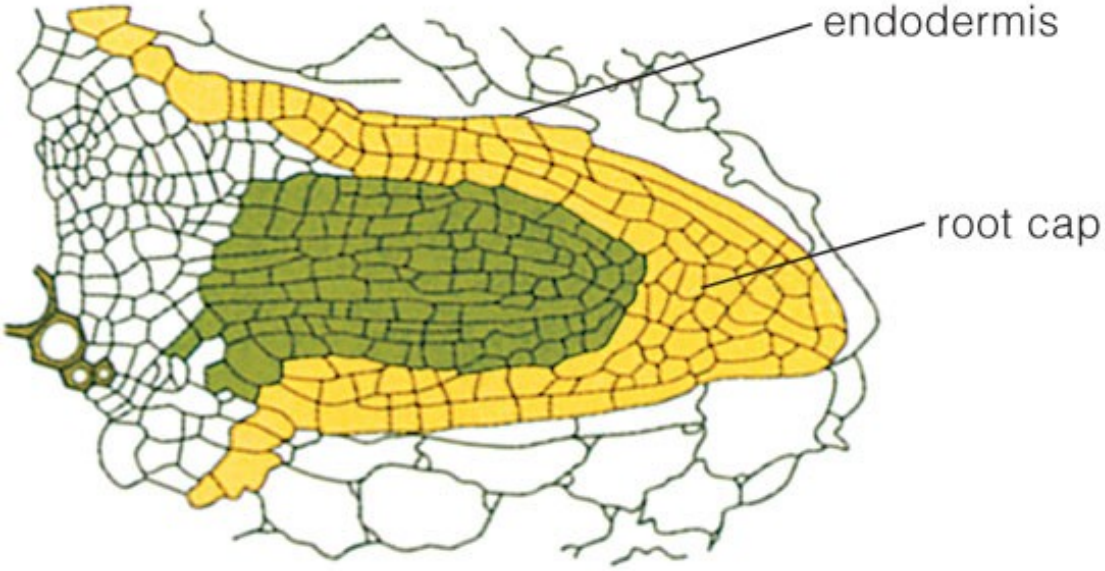
Pericycle

- Long-lived parenchyma cells served as half-meristem
- Initiates development of lateral roots
- Contributes to vascular cambium
- Contributes to cork cambium

Development of lateral roots

Development of lateral roots (step by step)

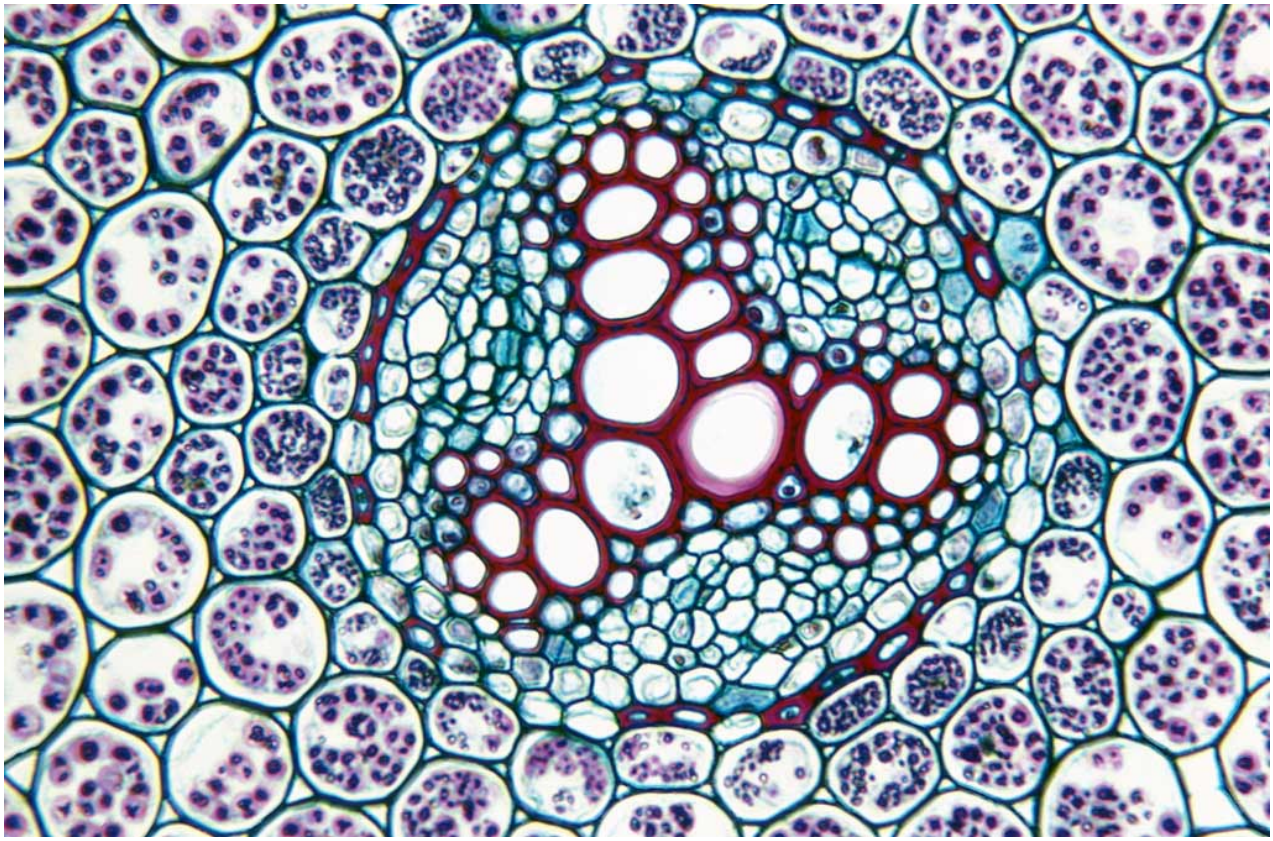




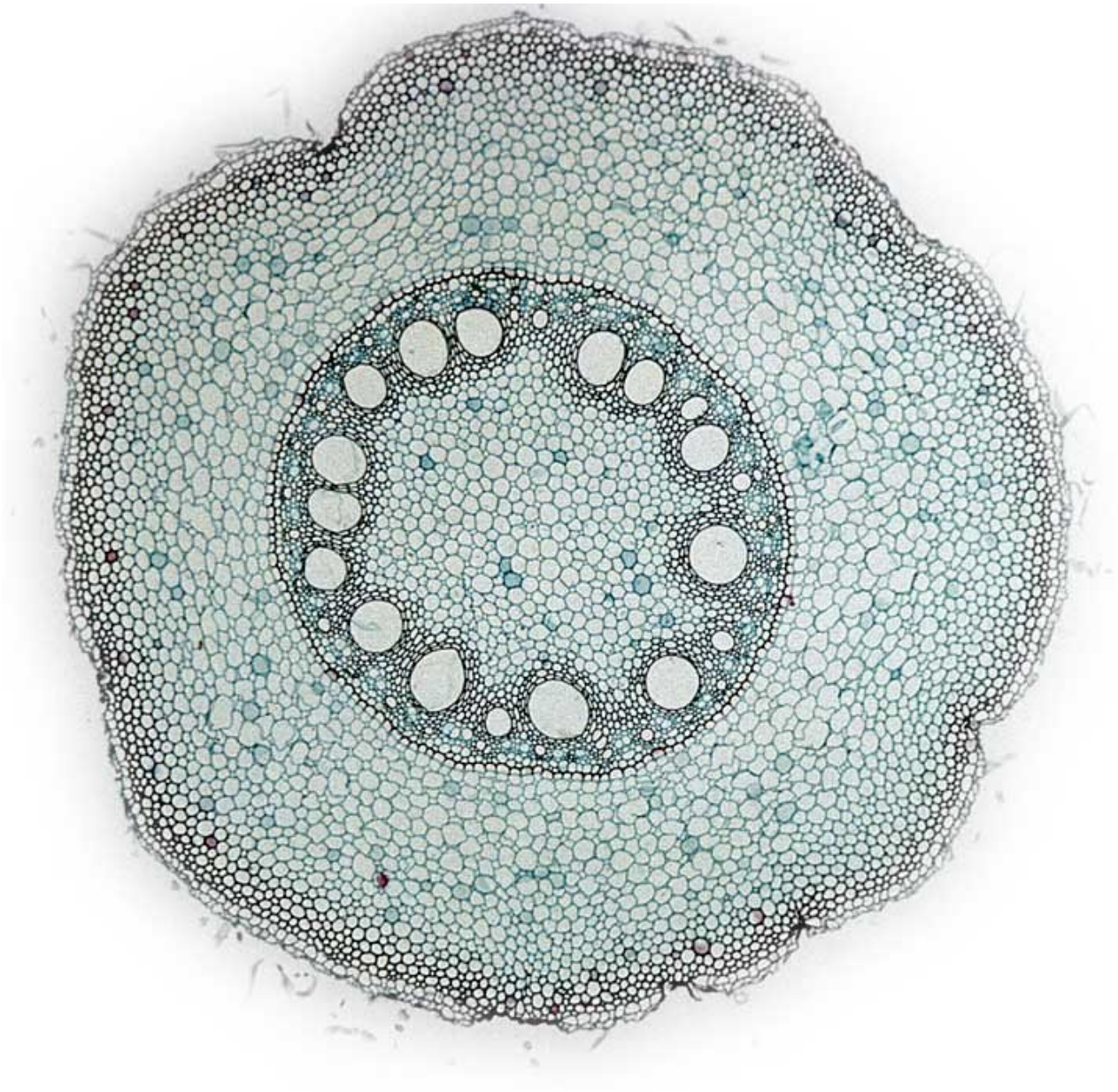
Vascular bundle

- Only one!
- Has radial (star-like) symmetry
- Xylem arranged in rays, multiple in monocots, 2-4 in other plants

Radial structure of root vascular bundle in buttercup (*Ranunculus* sp.)

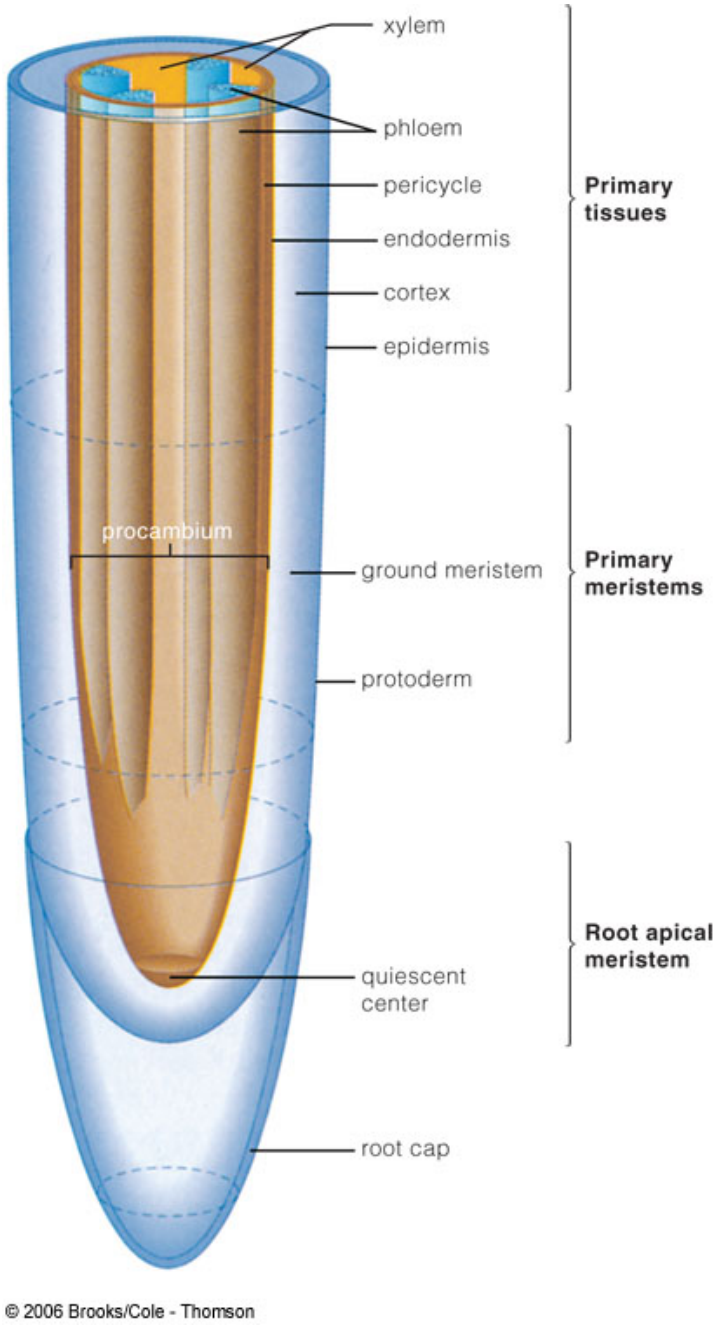


Root of monocot (*Zea mays*



4.2 Origins of root tissues

Development of tissues



In essence, development of tissues in root is analogous to stem.

4.3 Water transport in roots

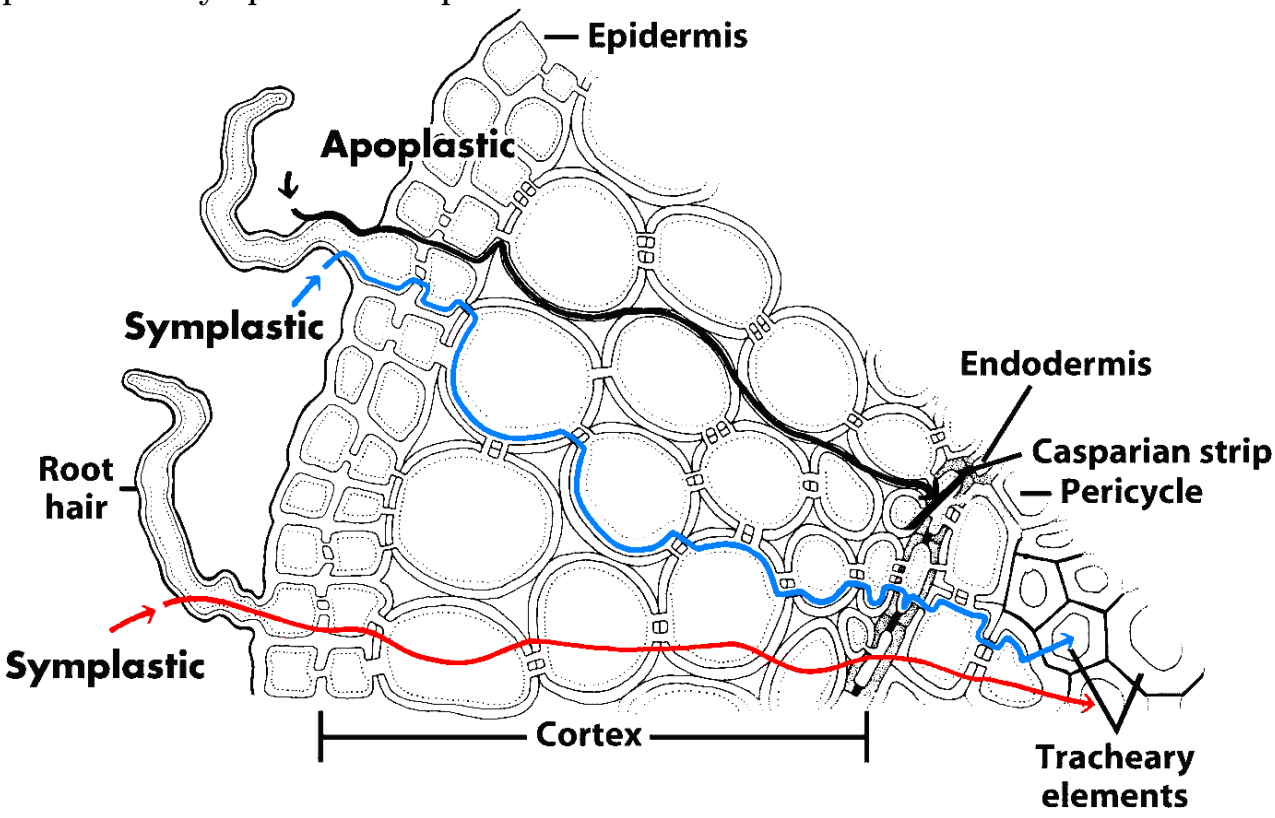
Rhizodermis and osmosis

- The existence of root hairs dramatically increases the surface of absorption
- Every root hair cell increase the internal concentration of large molecules, typically organic acids
- Process of concentration requires ATP
- As a result, osmosis water flow starts from soil to root cells

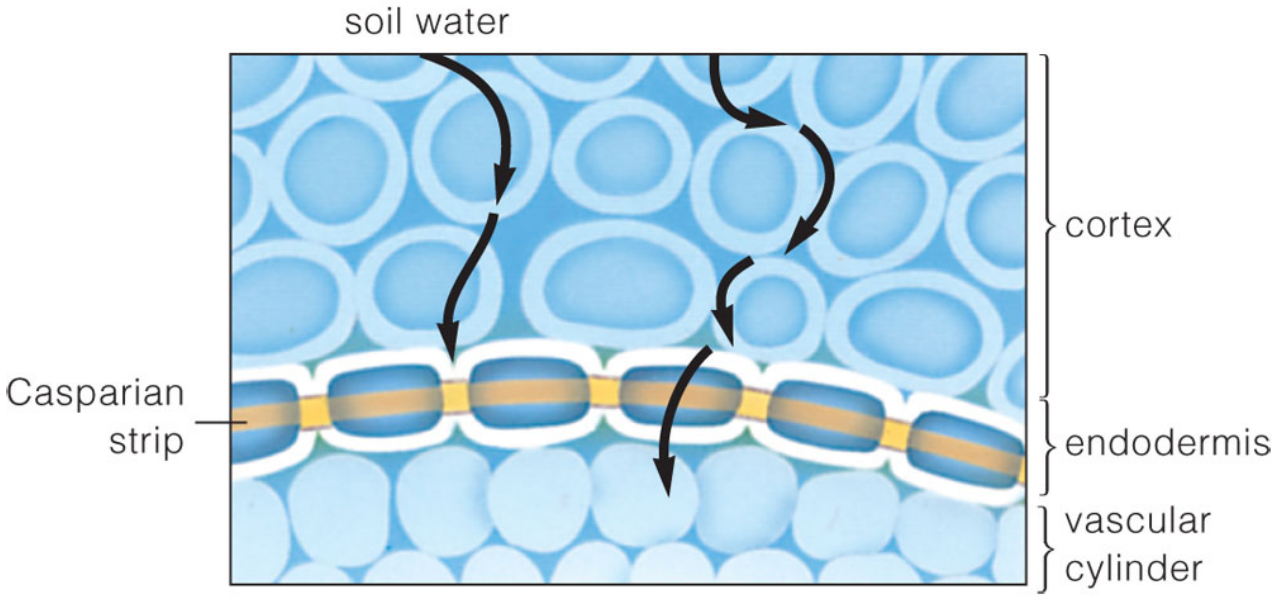
Endodermis and root pressure

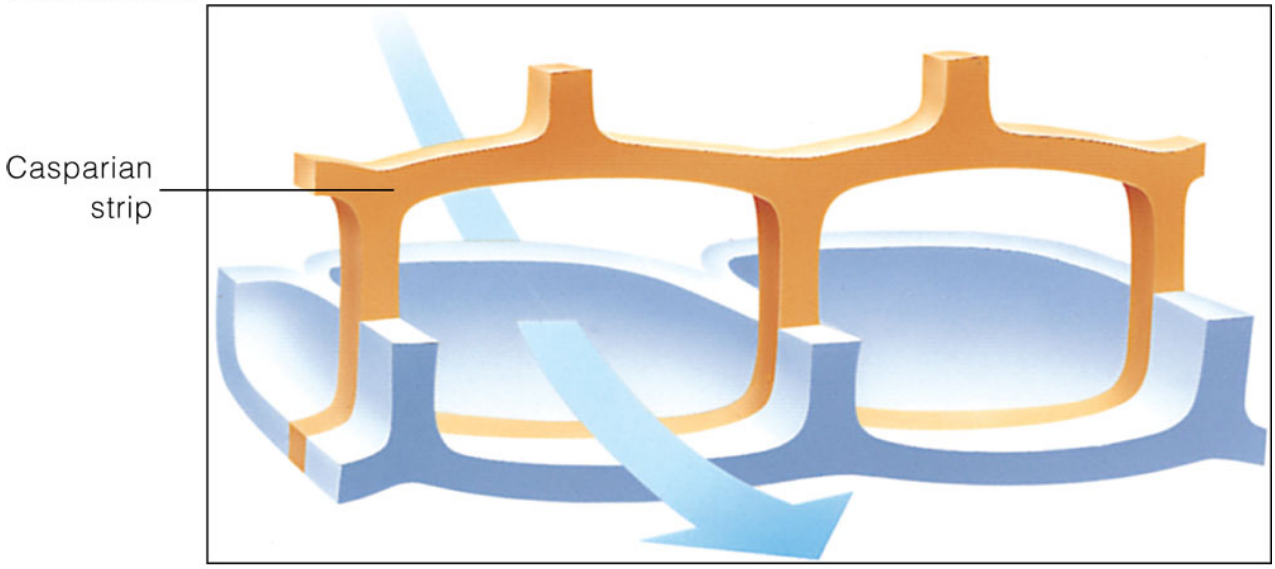
- From rhizodermis to endodermis, transport of water is both symplastic and apoplastic
- In the endodermis cells, Caspari stripes stop apoplastic transport and therefore forced symplastic transport
- This is a high-energetic process requires ATP
- As a result, water will be pushed up from root: this is the root pressure

Apoplastic and symplastic transport in the root

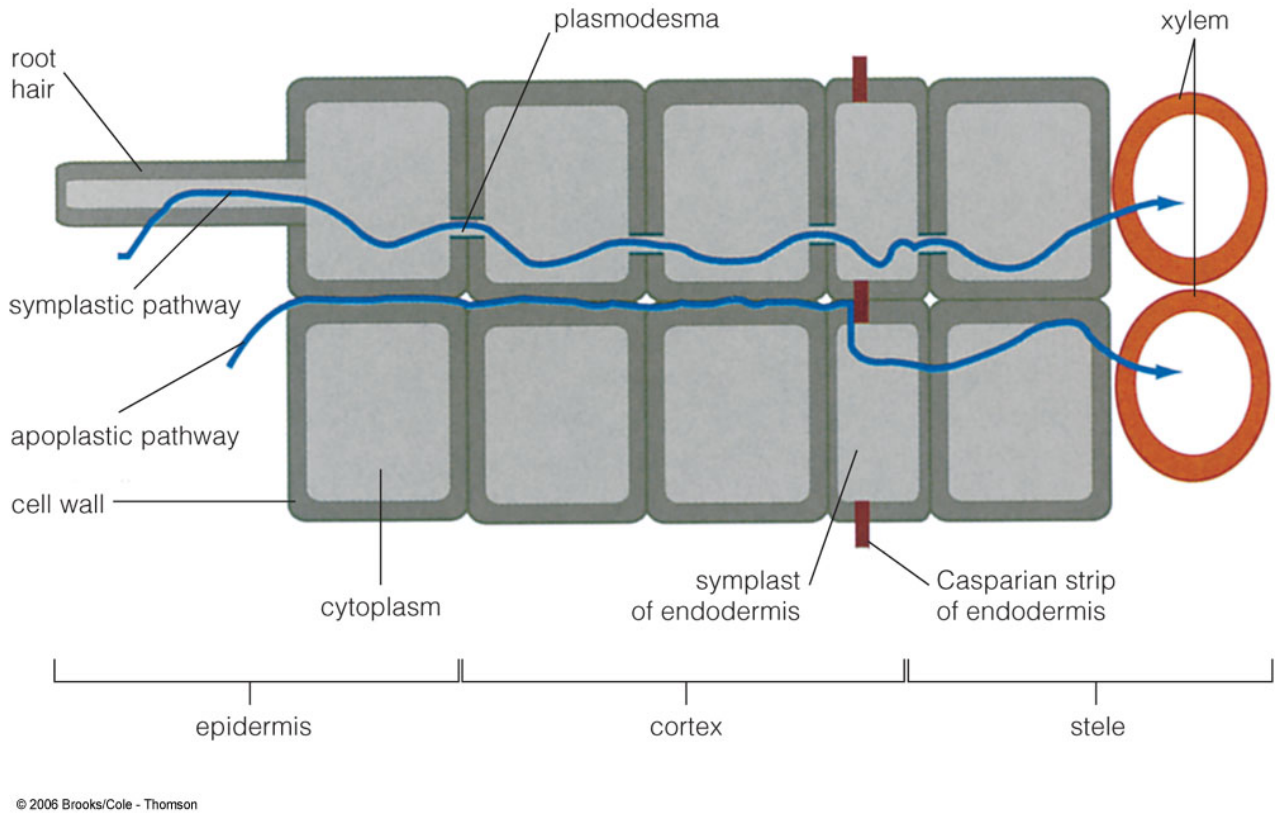


Casparian strips

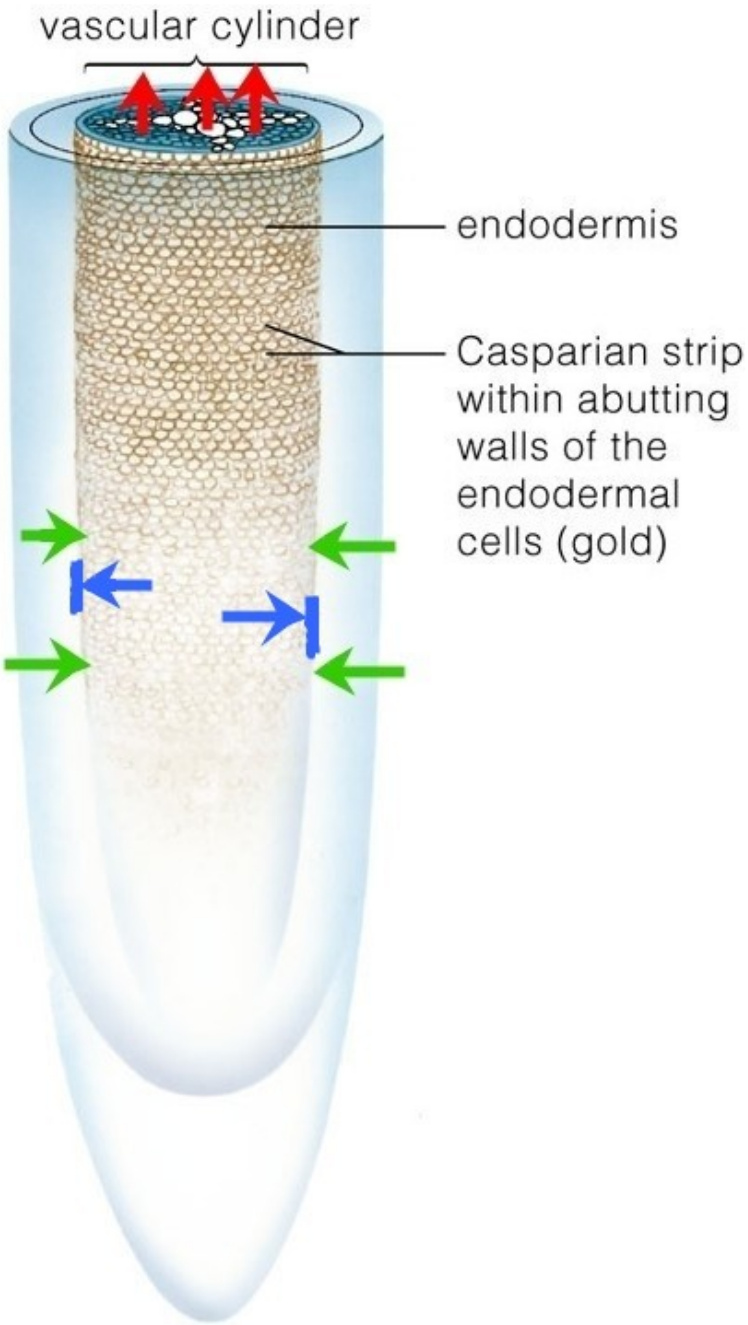




How Casparian strips are working



Origin of root pressure



Water flow in plants

- Plants need water:
  - To supply photosynthesis
  - To cool via transpiration
  - To obtain required minerals
- Water flows because of:
  - Root pressure
  - Capillarity force
  - Transpiration "suction"

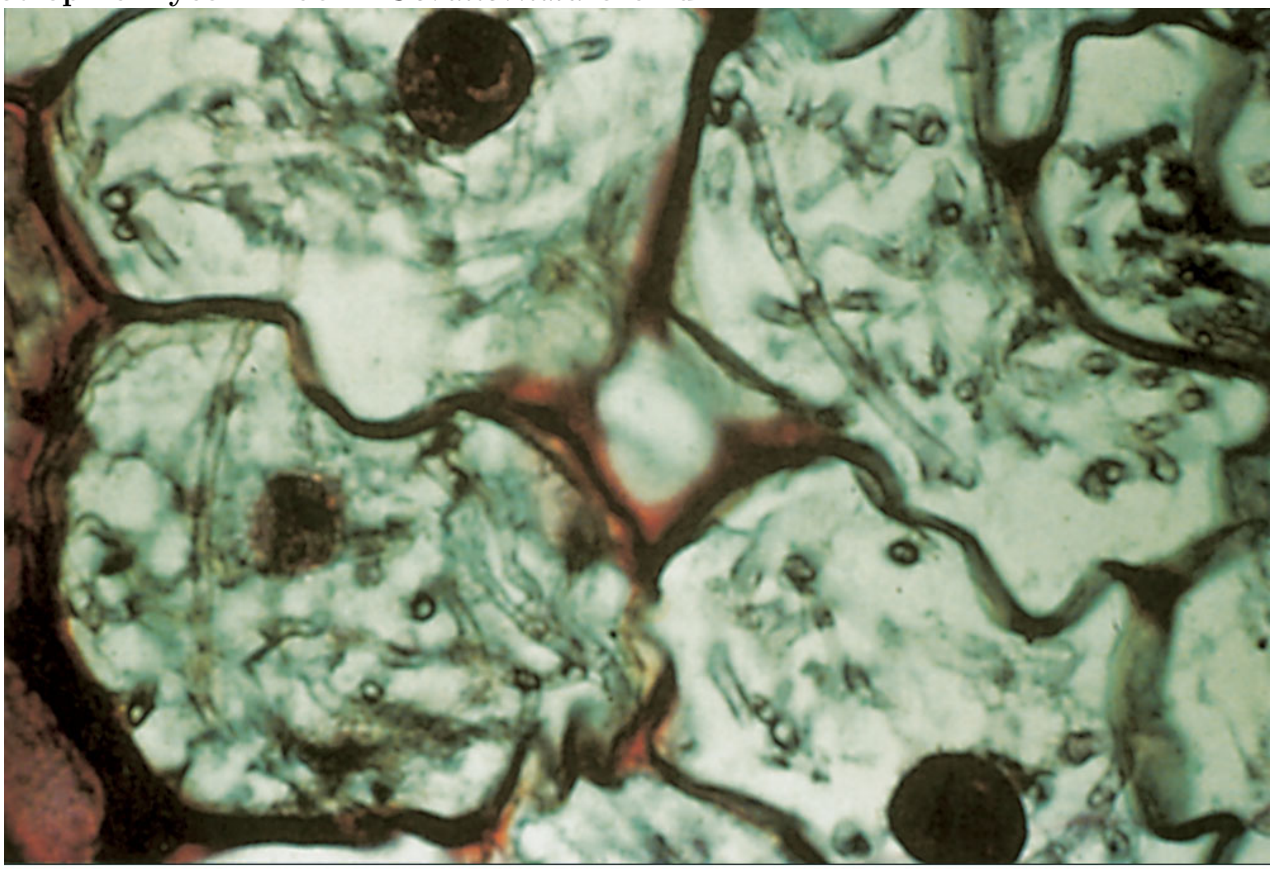
4.4 Diversity of roots

Modifications of roots

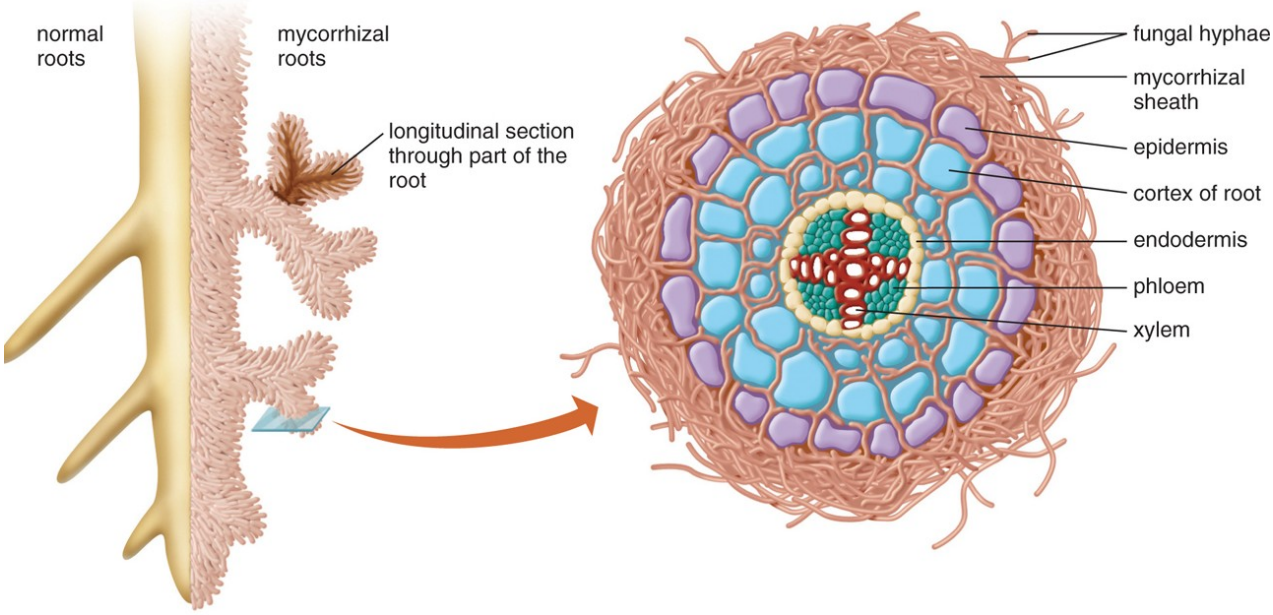
- Adventive buds with root origin (many plants)
- Mycorrhizae: endotrophic (grasses, orchids) and ectotrophic (trees)
- Haustoria (parasites like Cuscuta—dodder plant)
- Root nodules (legumes, Fabaceae family)
- Contractile roots (*Hyacinthus* spp.—hyacynth, *Taraxacum* spp.—dandelion)
- Storage roots (*Daucus carota*—carrot, *Armoracia officinalis*—horseradish)
- Supportive roots (many tropical plants)
- Defensive, spiny roots (ivy)
- Photosynthetic roots (some orchids)

4.5 Diversity of roots

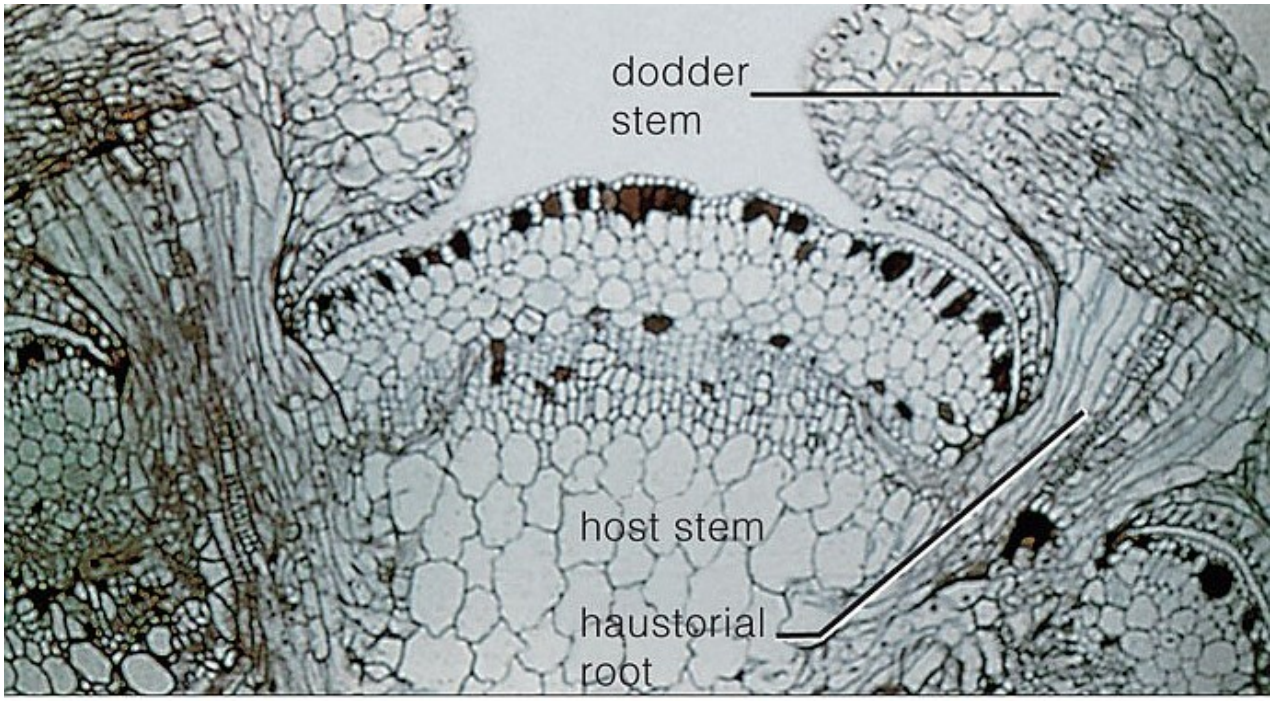
Endotrophic mycorrhizae in *Corallorhiza* orchid



Ectotrophic mycorrhizae of trees



Haustoria of *Cuscuta* (dodder)



Nodulated roots of soybean (*Glycine max*)

Contractile roots of *Hyacinthus orientalis*

Supportive roots of mangrove plants

Supportive roots of *Pandanus* sp.

Defensive spiny roots of ivy (*Hedera* sp.)

Photosynthetic aerial roots of orchids

Table of modifications

Function	Stem	Leaf	Root
Expansion	...	Plantets	Adventive buds
Storage	...	Succulent leaves	Storage roots
Photosynthesis	...	DEFAULT	Some aerial roots
Defense	...	Spines, scale	Root spines
Support	DEFAULT	Leaf tendrils	Aerial and contractile roots
Interactions	...	Traps, “sticky tapes”, urns	Mycorrhizae, haustoria, nodulated roots

Summary

- Vascular tissues of root is a modified protostele or solenostele (monocots).

- Root hairs, Casparian strips, capillarity and transpiration work together to make water flow in plant.
- Root-related part of water flow is the **root pressure**.
- Roots have not less modifications than leaves.

5 Plant diversity

5.1 Systematics

Basics of systematics

Terms covered:

- Systematics = taxonomy
- Species, taxonomic hierarchy
- Taxon, rank = category, classification
- Kingdom, phylum, class, order, family, genus, species
- Subclass, subfamily and other intermediate ranks
- Subspecies and cultivars

Biological nomenclature

Terms covered:

- Binomial name, species epithet, reference = citation
- Synonyms, priority (older names have preference), starting dates (1753 for plants)

Examples

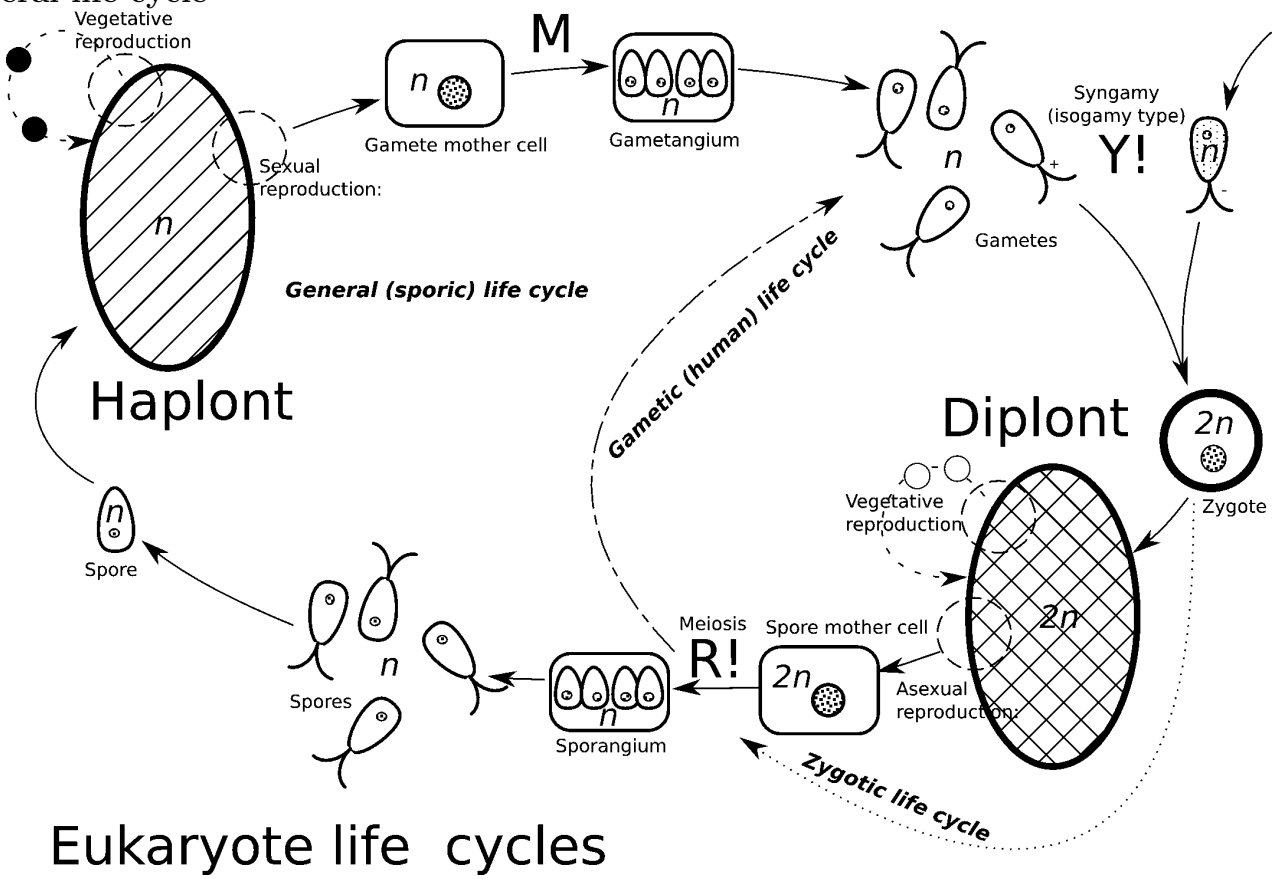
		Example 1	Example 2
Kingdom	Regnum	Vegetabilia	Animalia
Phylum	Phylum	Spermatophyta	Chordata
Class	Classis	Angiospermae (Magnoliopsida)	Mammalia
Order	Ordo	Liliales	Primates
Family	Familia	Asparagaceae	Hominidae
Genus	Genus	*Chlorophytum*	*Homo*
Species	Species	*Chlorophytum comosum* (Thunb.) Jacq. 1862	*Homo sapiens* L.

Species name

Chlorophytum	comosum	(Thunb.)	Jacq.	1862
Genus name	*Species epithet*	*First author*	*Second author*	*Year of description*

5.2 Kingdom Vegetabilia, land plants

General life cycle

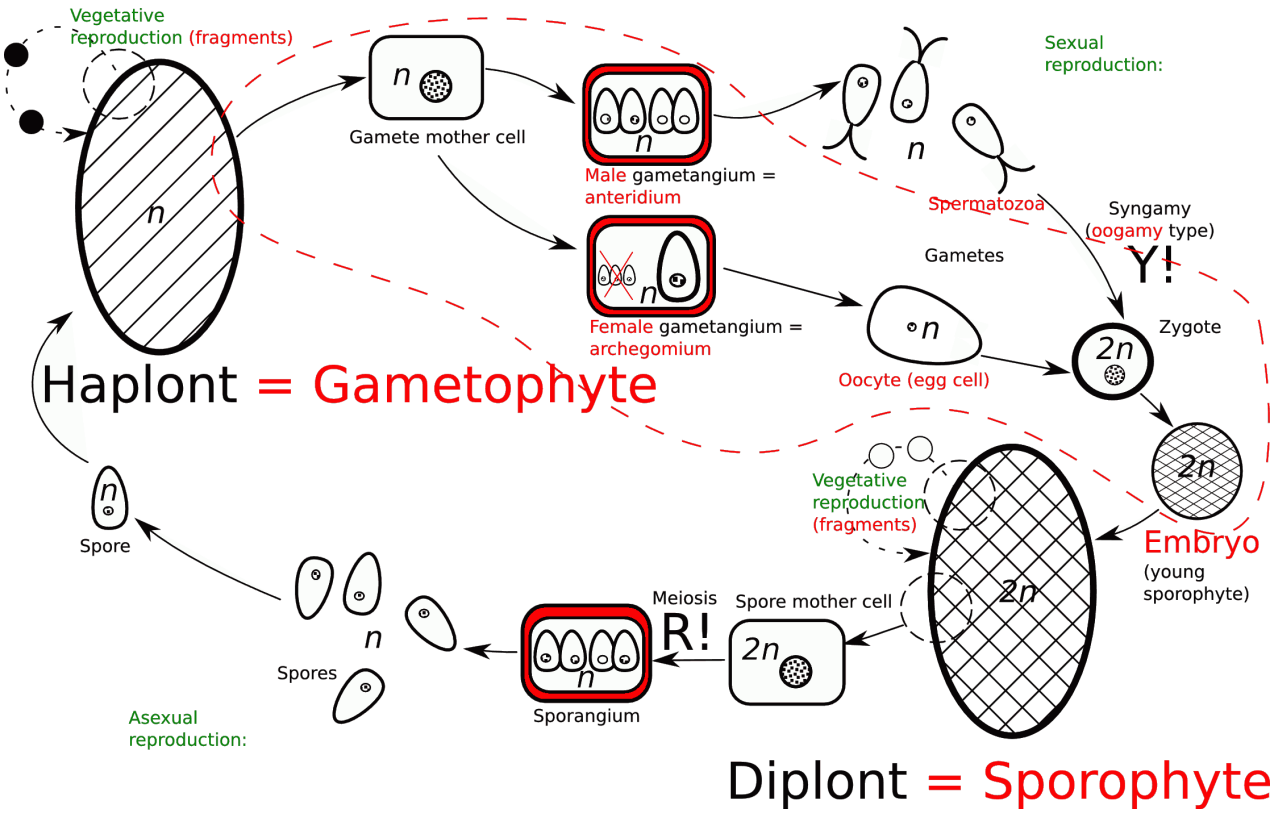


Life cycle of land plants

Terms covered:

- Sporophyte and gametophyte
- Gametangia: archegonium and antheridium
- Spermatozoa and oocyte (egg cell)
- Embryo and parasitic sporophyte
- Predominance of sporophyte or gametophyte

Life cycle of land plants: differences



Final question (2 points)

What is endoderm?

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

6 Questions and answers

6.1 Quiz

Final question (2 points)

What is endoderm?

- Tissue responsible for root pressure.

7 Kingdom Vegetabilia, land plants

7.1 Mosses

Three main phyla

- **Bryophyta**: gametophyte predominance
- **Pteridophyta**: sporophyte predominance, no seed
- **Spermatophyta**: sporophyte predominance, seed

Bryophyta

- $\approx 20,000$ species
- Sporic life cycle with gametophyte predominance
- Sporophyte reduced to sporogon (sporangium with seta), usually achlorophyllous, parasitic
- No roots, only rhizoid cells (long hairy dead cells capable for apoplastic transport)
- Poikilohydric plants
- Gametophyte starts development from protonema

Protonema

Life cycle of mosses

Covers: sporogon, biflagellate spermatozoa, the conflict between water cross-fertilization and wind distribution of spores which may be considered as "evolutionary dead end".

Three main kinds (subphyla) of mosses

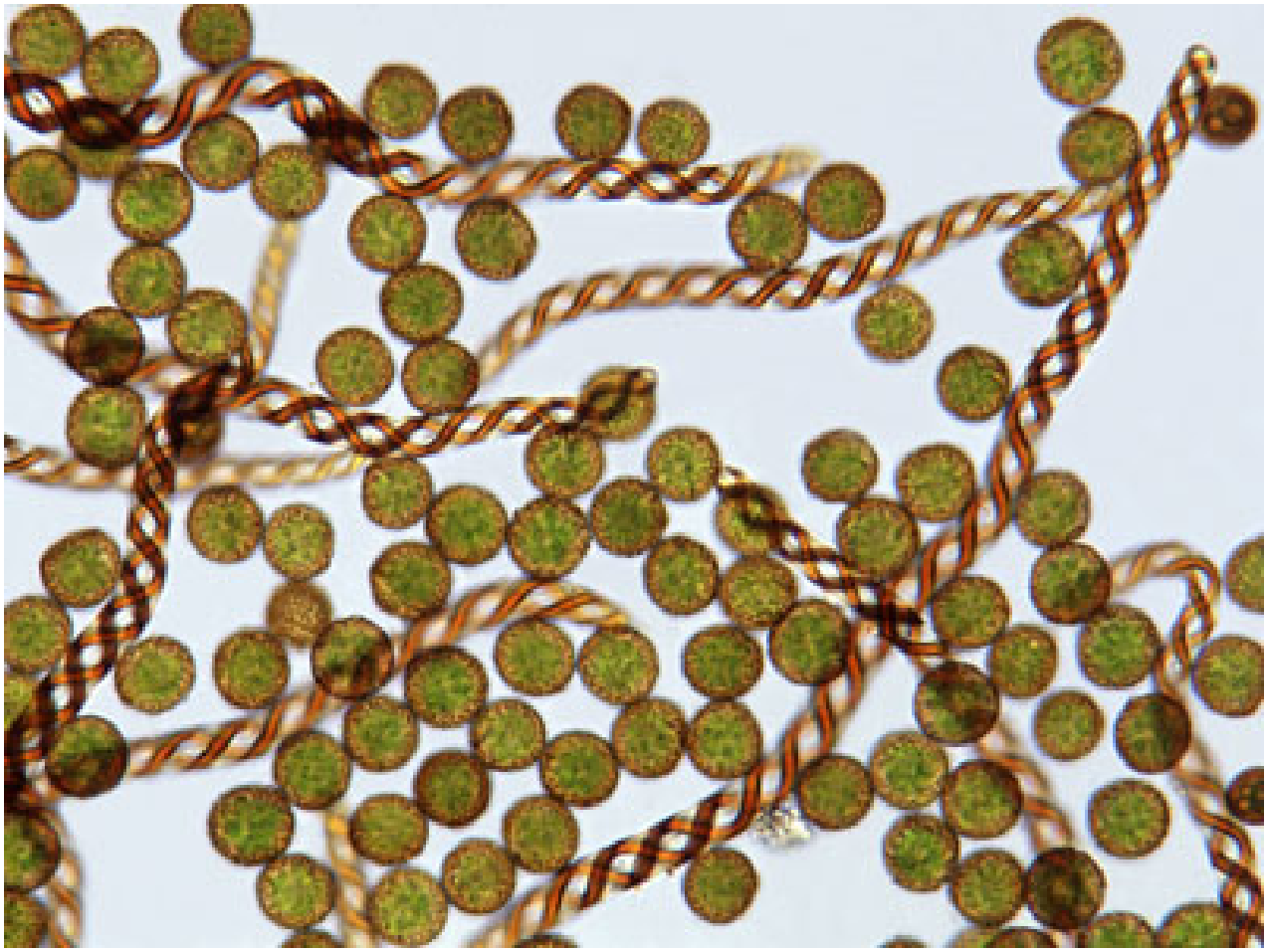
- **Hepaticae**—liverworts. Three classes, most primitive are Haplomitriopsida. Body leafy or thalloid, usually has dorsal and ventral parts, sporogon bag-like, without columella, spores with elaters.
- **Bryophytina**—true mosses. Six classes, most important are Sphagnopsida (peat mosses), Polytrichopsida (haircap mosses) and Bryopsida. Body radial, sporogon long, with columella, spores without elaters.
- **Anthocerotophytina**—hornworts. One class. Body flattened (thallus), sporogon long, green, sometimes branched, with columella and stomata, spores with elaters.

Mosses in the "evolutionary dead end"

- They resolved "skyscrapers problem" via gametophyte, not sporophyte
- Gametophyte needs water fertilization, which restricts the size and also requires the dense growing
- Also, root system is absent: this is an additional size restriction
- If sexual organs appear on the bottom of leafy shoot, sporogon (sporophyte) could not distribute spores with a wind
- The only way out is to "start over" from thallus and make sporophyte (which was highly specialized for the spore distribution) a main stage and reduce gametophyte

***Haplomitrium gibbsiae*, primitive liverwort**

Elaters of liverworts (*Lepidozia* sp.)



***Sphagnum* sp. (Bryophyta, Sphagnopsida) with sporogons**

***Dawsonia superba* (Bryophyta, Polytrichopsida)—the largest moss with vascular system**

Bryum capillare **(Bryophyta, Bryopsida)**

***Leiosporoceros dussii* (Bryophyta, Anthocerotopsida)—primitive hornwort**

7.2 Ferns

Pteridophyta: ferns and allies

- $\approx 12,000$ species and six classes
- Sporic life cycle with sporophyte predominance
- Gametophyte is often reduced to **prothallium** (small hornwort-like plant), some Pteridophyta have male and female gametophytes
- Have true roots (only whisk ferns, Psilotopsida are exception)
- Homoiohydric plants (same as seed plants)
- Sporophyte always starts development from embryo located on gametophyte
- Have true xylem and phloem, but do not have secondary thickening (exceptions: fossils and extant *Isoëtes* and *Botrychium*)

Pteridophyta classes

- Subphylum Lycopodiophytina (lycophytes)
  - Class **Lycopodiopsida**
- Subphylum Pteridophytina (monilophytes)

- Class **Equisetopsida** (horsetails)
- Class **Psilotopsida** (whisk ferns)
- Class **Ophioglossopsida** (ophioglossalean ferns)
- Class **Marattiopsida** (giant, or marattialean ferns)
- Class **Pteridopsida** ("true" ferns)

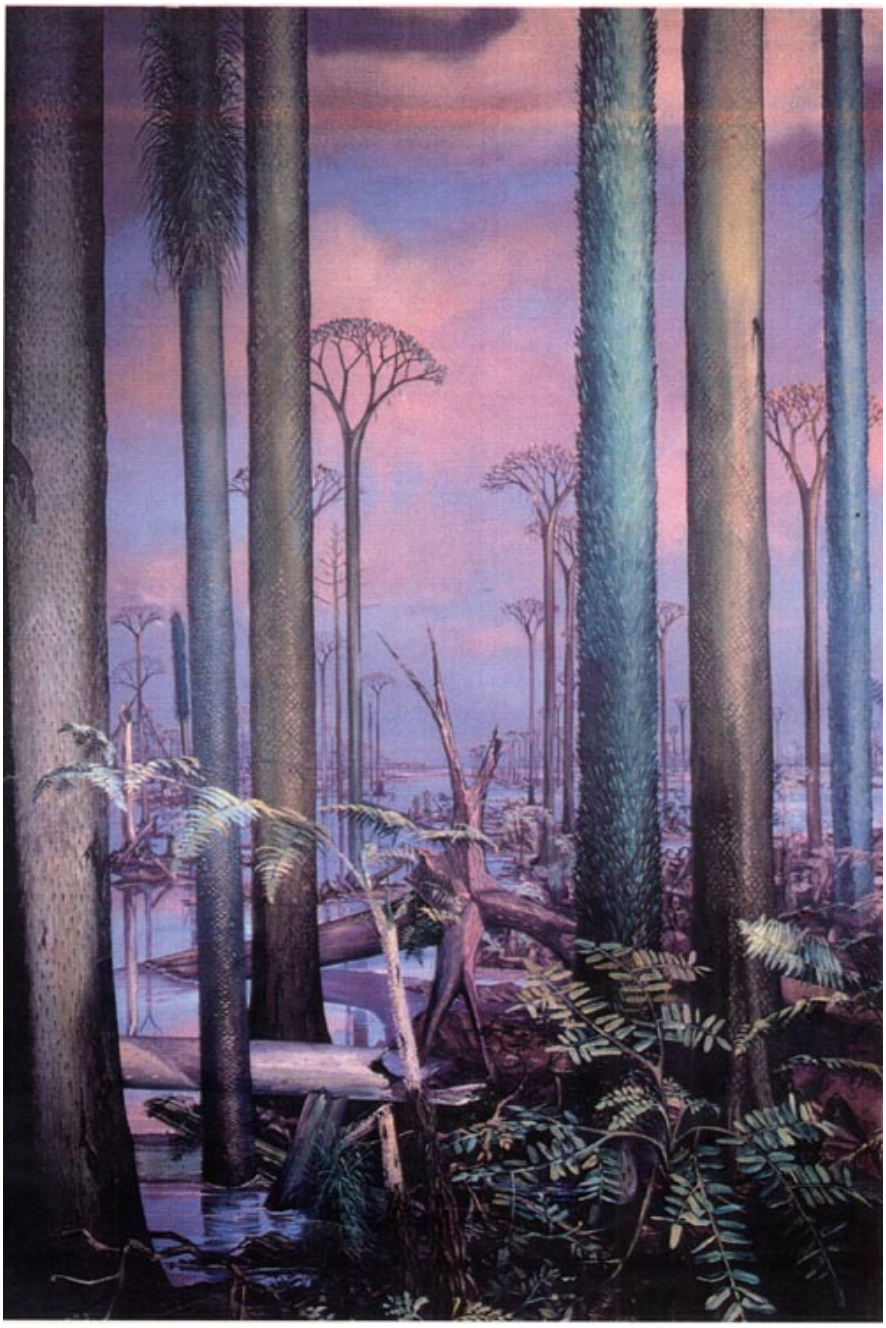
Lycopodiopsida

- Four main genera (*Huperzia*, *Lycopodium*, *Selaginella* and *Isoëtes*) and ≈ 1000 species
- Separate, **microphyllous*** lineage of Pteridophyta (all other groups are **megaphyllous**)
- Sporangia associated with leaves and often form **strobilus***. Spermatozoon typically with two flagella (like in mosses). Homosporous genera have achlorophyllous, mycoparasitic underground gametophyte.
- In the past, were dominant trees of Carboniferous tropical swamp forests (lepidodendrids) and their remains became a coal
- Two genera, *Selaginella* (spike moss) and *Isoëtes* (quillwort) are heterosporous.

Tropical lycophyte, *Huperzia linifolia*

***Phylloglossum drummondii*, one of smallest lycophytes**

Before: Chicago 300 Million Years Ago (lepidodendrids)



After: quillwort, aquatic lycophyte *Isoëtes* sp.

Final question (3 points)

Why are mosses "evolutionary dead end"?

For Further Reading

References

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Outline

8 Questions and answers

8.1 Quiz

Final question (3 points)

Why are mosses "evolutionary dead end"?

- Their (parazitic) sporophyte "interests" conflict with gametophyte "interests".

9 Phylum Pteridophyta

Pteridophyta classes

- Subphylum Lycopodiophytina (lycophytes)
  [Microphyllous]
  - Class **Lycopodiopsida**
- Subphylum Pteridophytina (monilophytes)
  [Megaphyllous]
  - Class **Equisetopsida** (horsetails)
  - Class **Psilotopsida** (whisk ferns)
  - Class **Ophioglossopsida** (ophioglossalean ferns)
  - Class **Marattiopsida** (giant, or marattialean ferns)
  - Class **Pteridopsida** ("true" ferns)

9.1 Classis Equsetopsida, horsetails

Equisetopsida

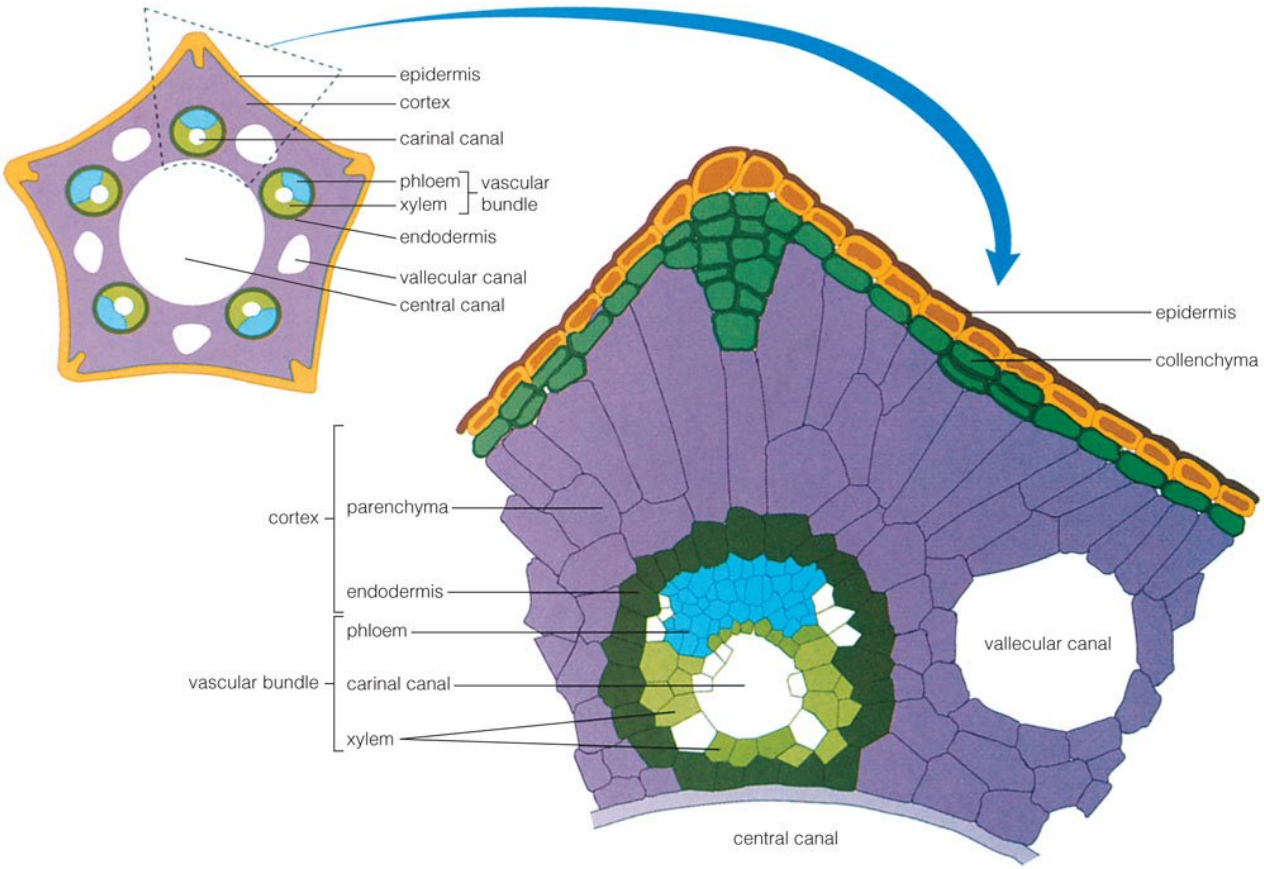
- Small group of one genus, *Equisetum* with ≈ 30 species
- Leaves are reduced into scales, stems are segmented, photosynthetic. Have specific stele—**artrostele** with specific central and peripheral canals (similar to stele of some grasses)
- Sporangia associated with specialized leaves—sporangiophores. Spores have attached **elaters**. Gametophyte minute, usually dioecious but plants are homosporous

Strobili and sporangiophores of *Equisetum arvense*

Equisetum giganteum

***Equisetum* sp. elaters**

Artrostele



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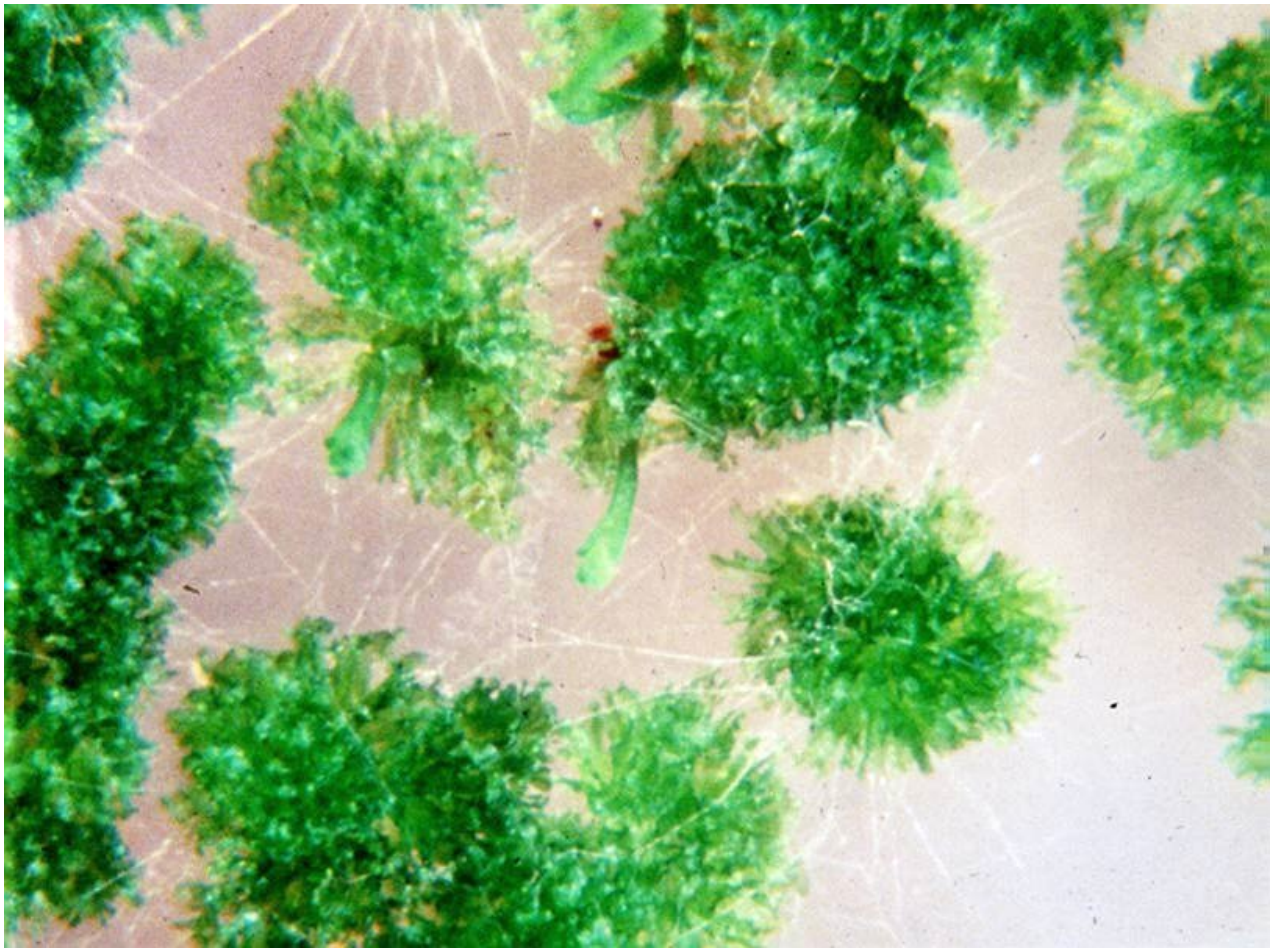
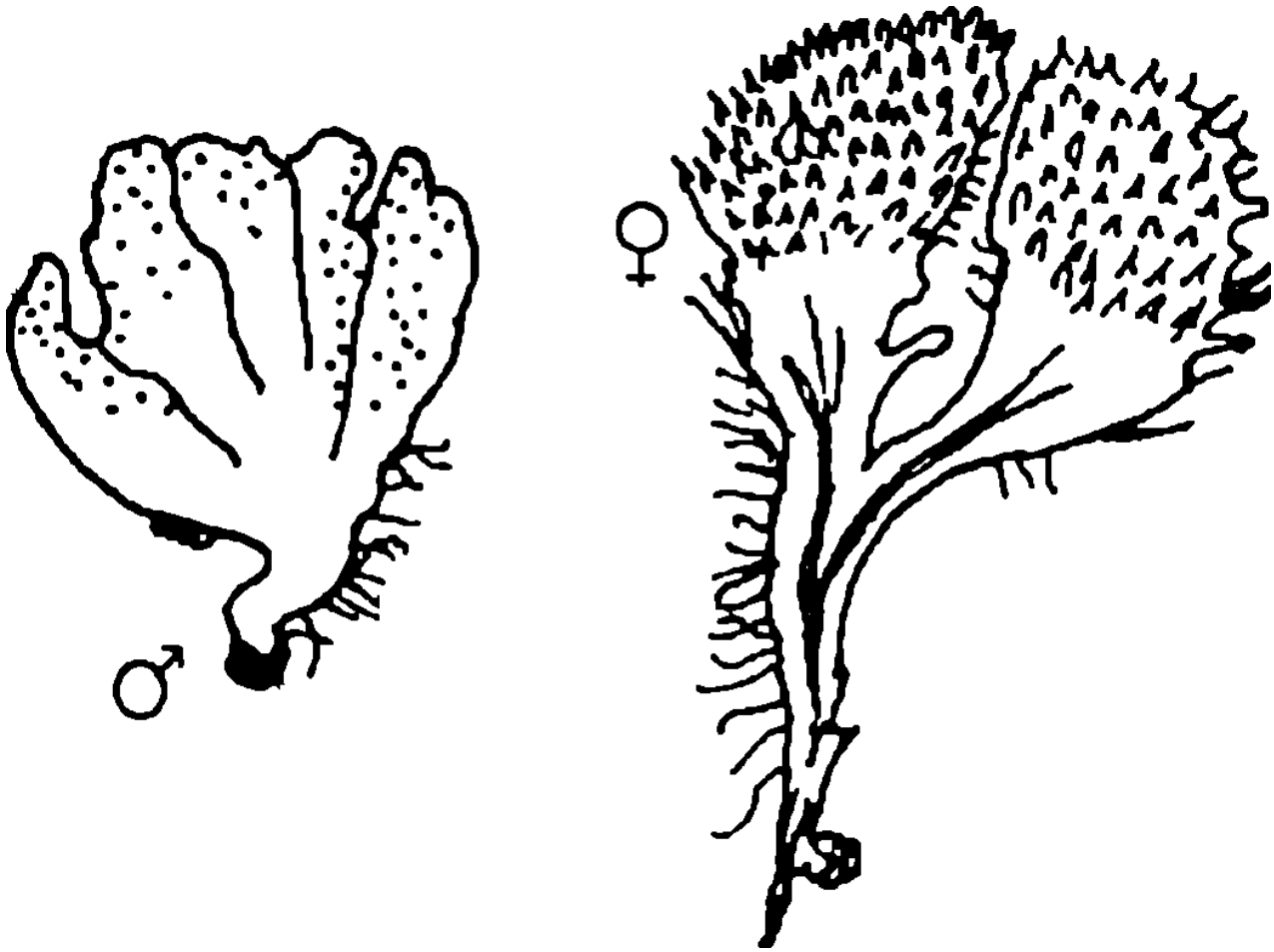
Horsetail gametophytes

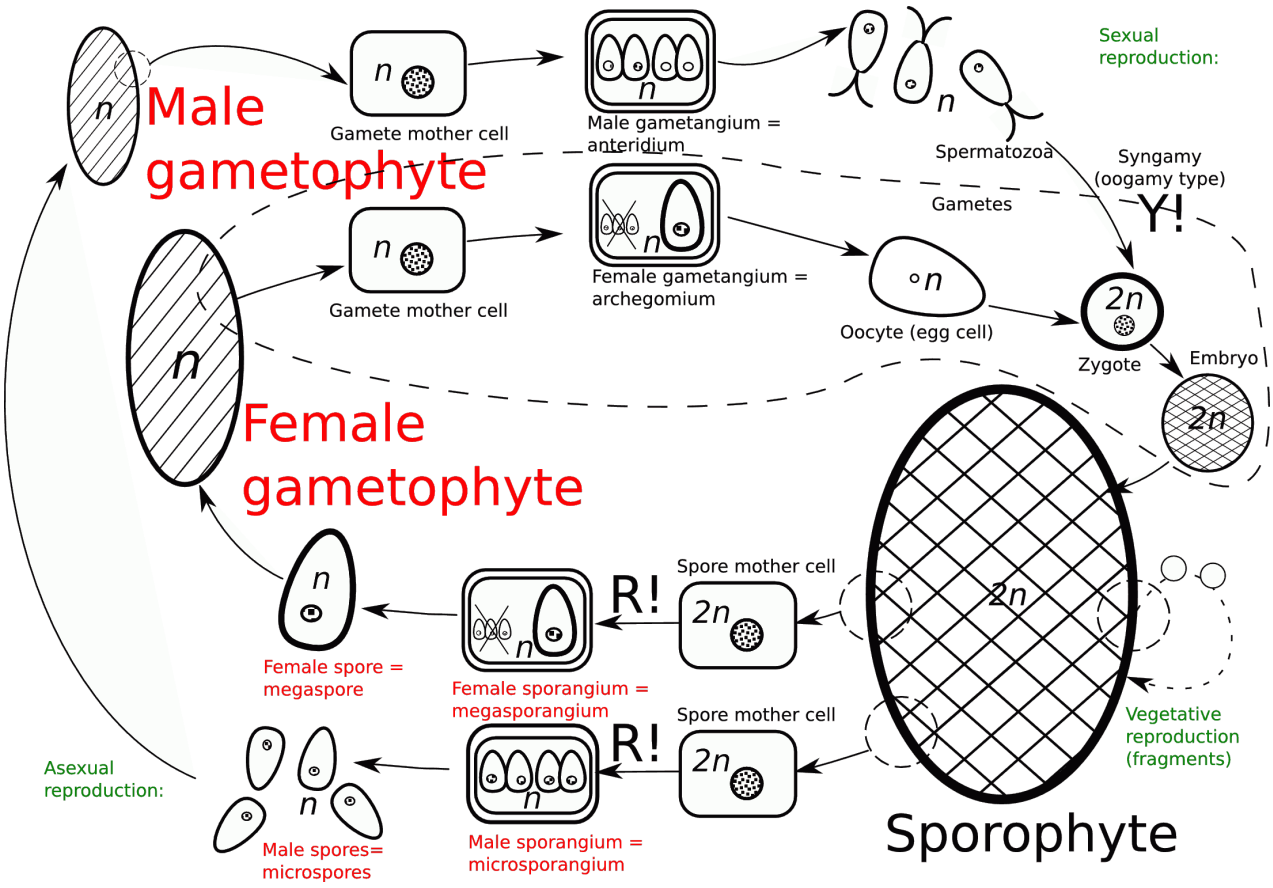


9.2 Heterospory

Horsetails start it: spores same, gametophytes different



Heterosporic cycle: differences



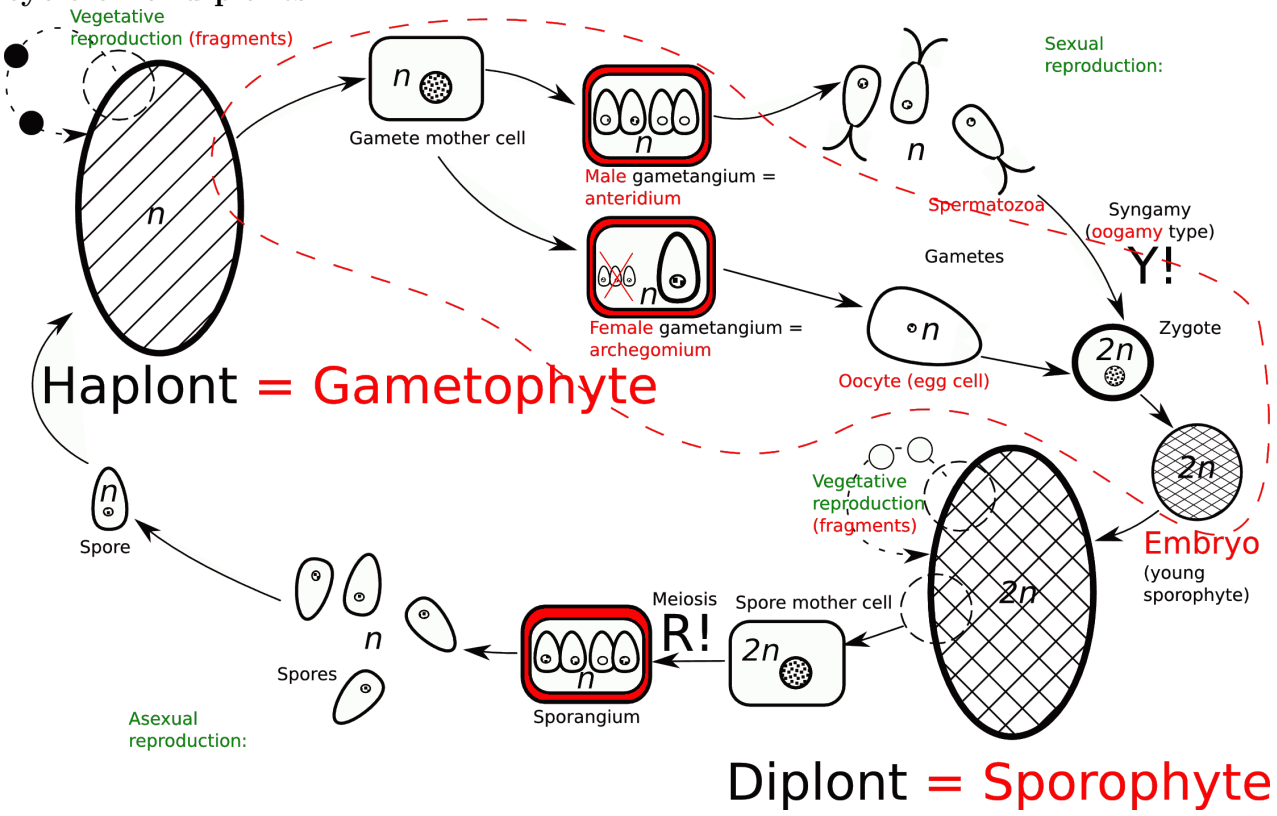
Heterospory

Heterosporous ferns (lycophytes *Selaginella* and *Isoëtes*, monilophytes *Salvinia*, *Marsilea*, *Pilularia*, *Regnellidium* and *Azolla*) went one step further and made their spores different too. It will allow the better allocation of resources and will restrict the self-fertilization.

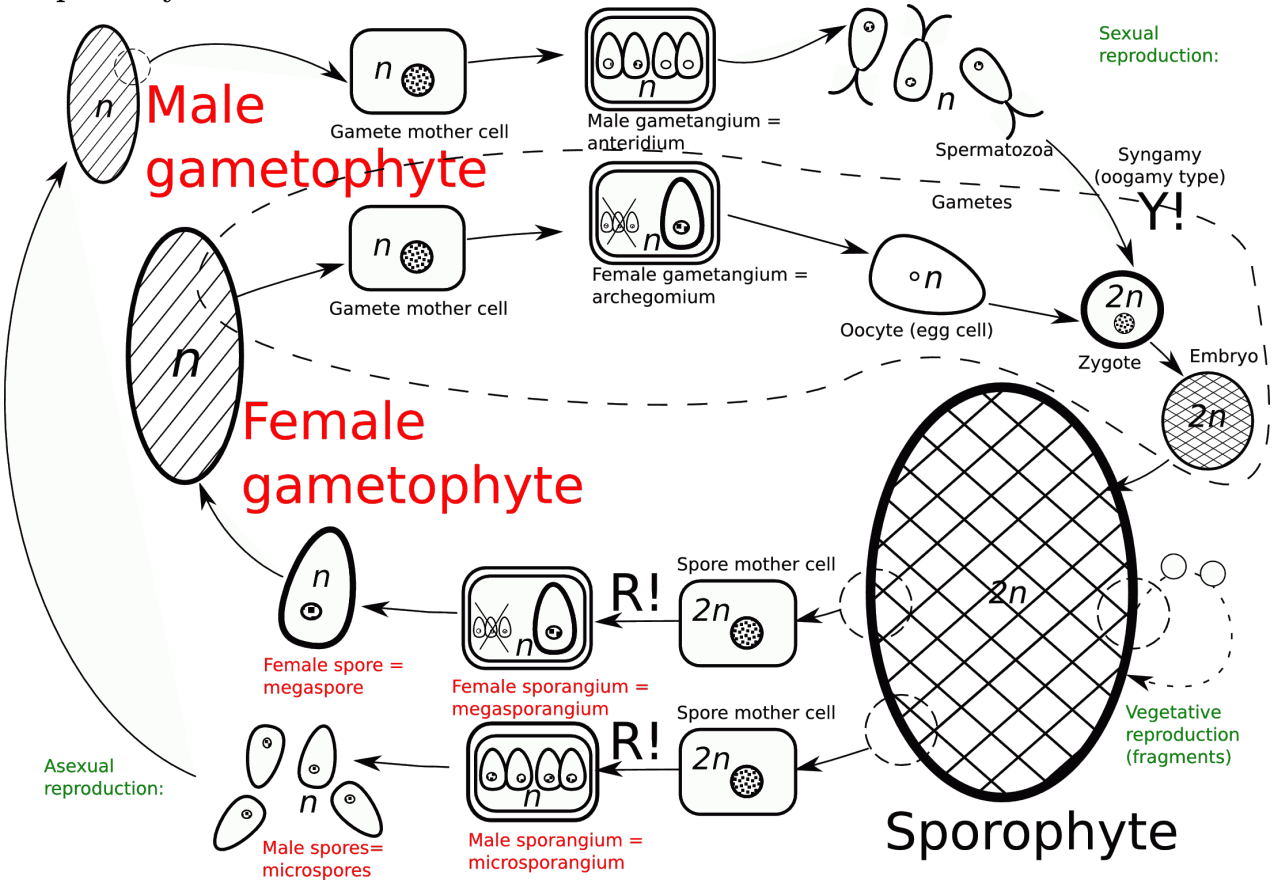
Terms covered:

- Male gametophyte, female gametophyte
- Microspores and microsporangium
- Megaspores and megasporangium

Life cycle of land plants



Heterosporic cycle: differences



9.3 More "ferny" ferns

Psilotopsida

- Small tropical group of two genera, *Psilotum* and *Tmesipteris* and 7 species
- Have protostele (like lycophytes), underground long-lived gametophytes but multiflagellate spermatozoa (like horsetails and all "higher" ferns). Sporangia unite into **synangia**. Leaves may absent (*Psilotum*) and replaced with **enatia**.
- Externally remain fossil **rhyniophytes**, the oldest extinct Pteridophyta

Hawaiian *Psilotum complanatum*

New Zealand *Tmesipteris tannensis* with double synangium

Ophioglossopsida

- Small group (*Ophioglossum*, *Botrychium*, *Mankyua* and *Helminthostachys*) and ≈ 75 species
- Always have underground rhizome and aboveground bisected leaves: one half is the leaf blade and other half is **sporangiophore**. Gametophytes grow underground.
- Some (namely, *Botrychium*, grape fern) have **secondary thickening** of underground rhizome.
- *Ophioglossum vulgatum*, adder's tongue fern, has $2n = 1360$, the largest chromosome number ever.

***Ophiloglossum vulgatum*, $2n = 1360$ hero**

Helminthostachys zeylanicum **(Ophioglossopsida)**

***Mankyua chejuense* (Ophioglossopsida)**

Marattiopsida

- Tropical ferns, several genera with ≈ 100 species
- Biggest ferns, one leaf (frond) could be 6 m length, but stems are smaller. Leaves with stipules.
- Sporangia (**eusporangia** like in all other Pteridophyta except "true" ferns) usually unite in **synangia**, gametophytes 1-2 cm in diameter, photosynthetic, terrestrial, usually long-lived.
- In a past, also were dominants of Carboniferous swamp forests.

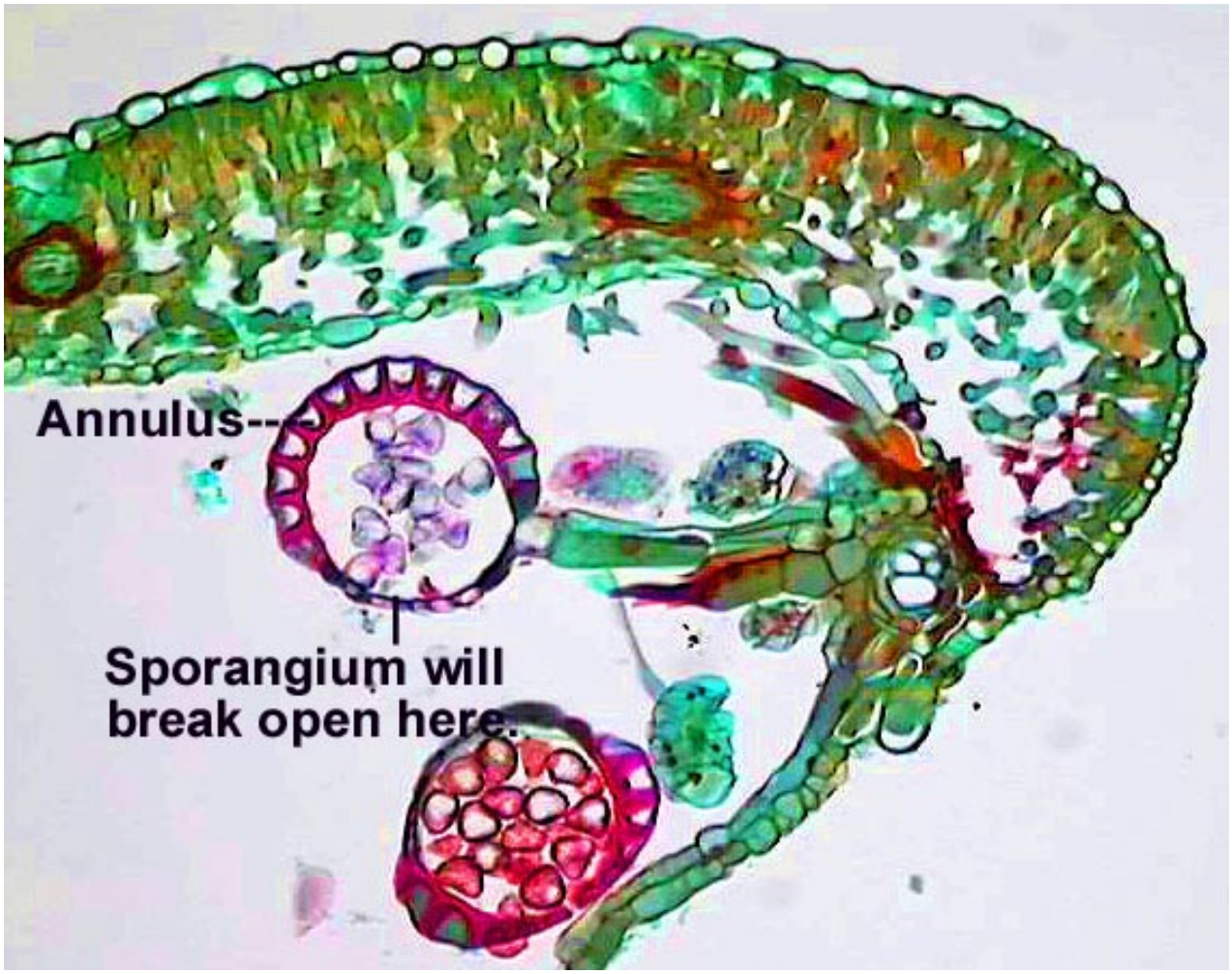
***Angiopteris* sp. (Marattiopsida)**

Synangia of *Danaea nodosa* (Marattiopsida)

Pteridopsida

- "True" ferns, about 10,000 species.
- Leaves are fronds, with apical growth. Young leaves are coiled in **fiddleheads**.
- Sporangia have one-celled wall (**leptosporangia**) and grouped in **sori** (often covered with indusium)
- Gametophyte minute, grow aboveground. Some genera of ferns are heterosporous.
- Bracken fern, *Pteridium acquilinum*, is the most widespread plant of the world.
- Many ferns have various vegetative reproduction.

Sorus, indusium, leptosporangium and annulus



Heterosporous fern *Marsilea quadrifolia*, the Shamrock. Well, almost...

Young leaves of bracken fern: Korean "gosari"

Final question (3 points)

Why heterospory "is better"?

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

10 Questions and answers

10.1 Quiz

Final question (3 points)

Why heterospory "is better"?

- It allows for numerous optimizations of life cycle.

11 Branching, thickening and the origin of seed

11.1 Branching

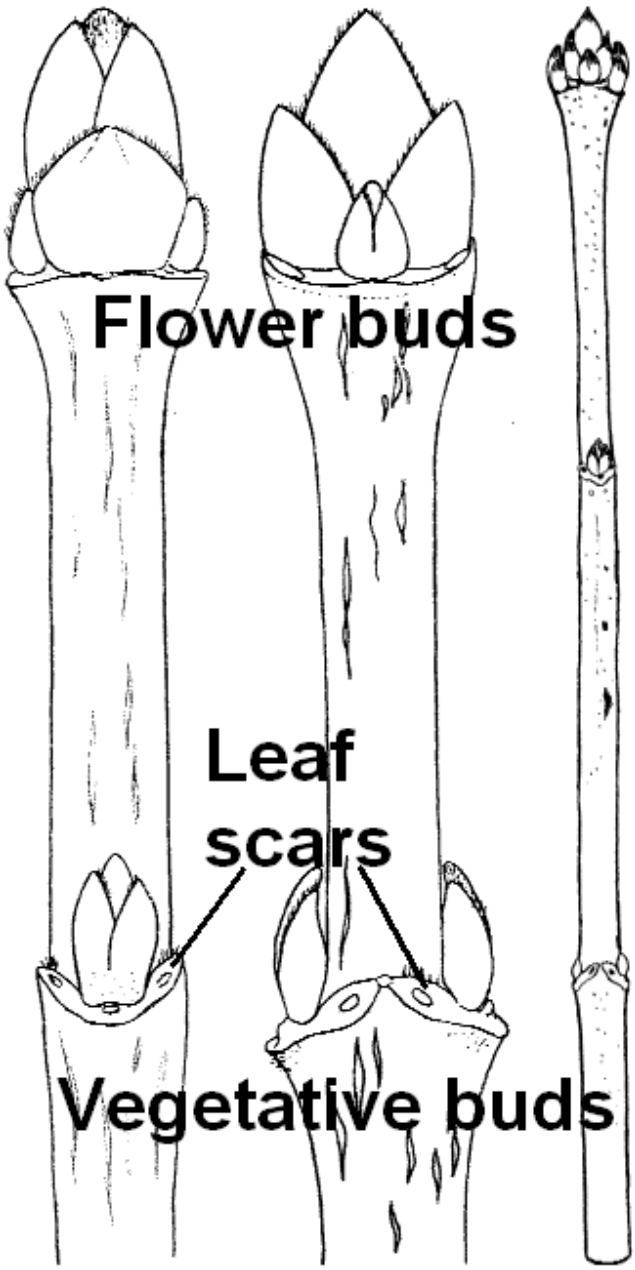
Where to see branching: winter shoot

A. Vegetative, flower, and mixed buds

B. Leaf and bud scars

C. Leaf traces

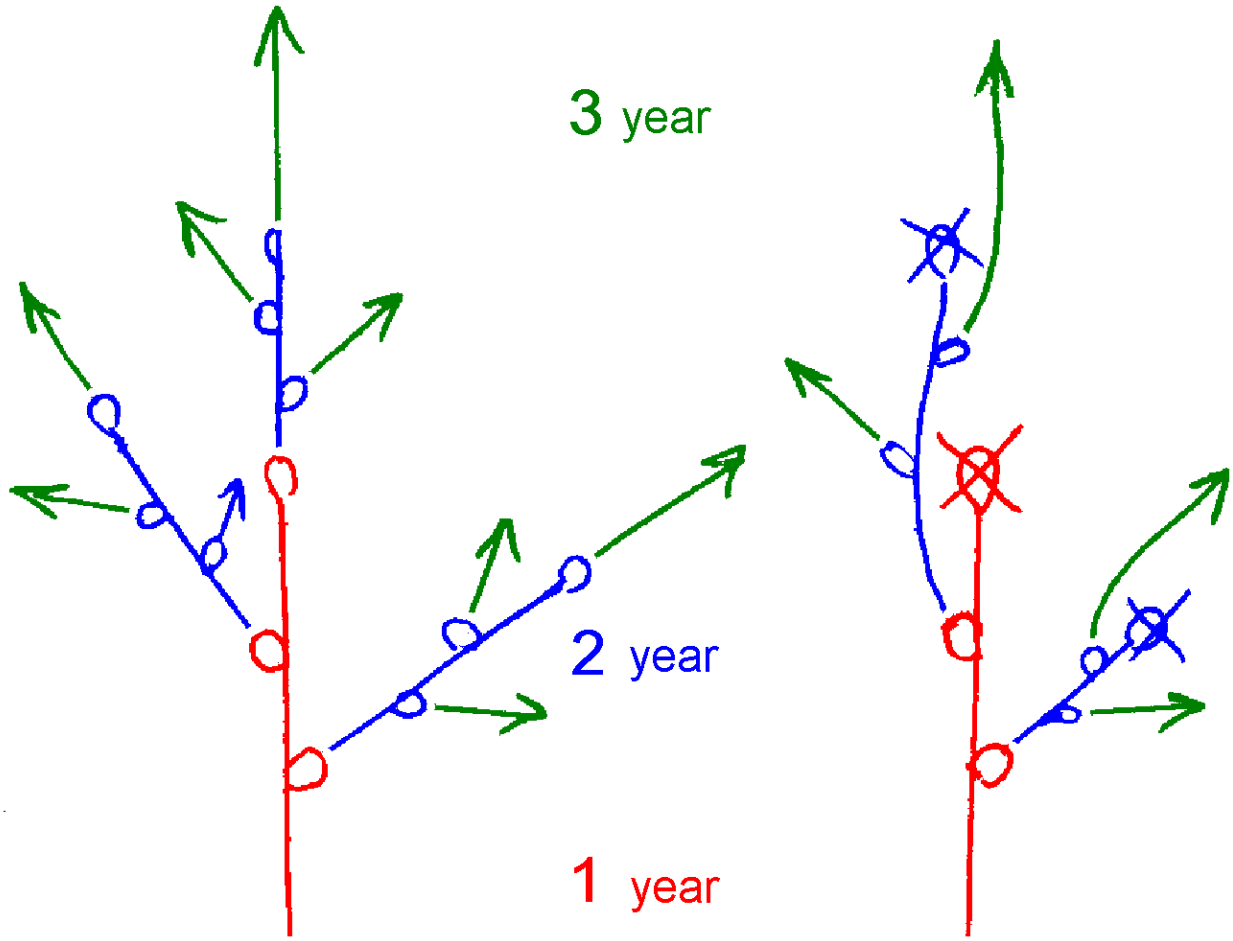
Winter shoot of maple (*Acer platanoides*)



Types of branching

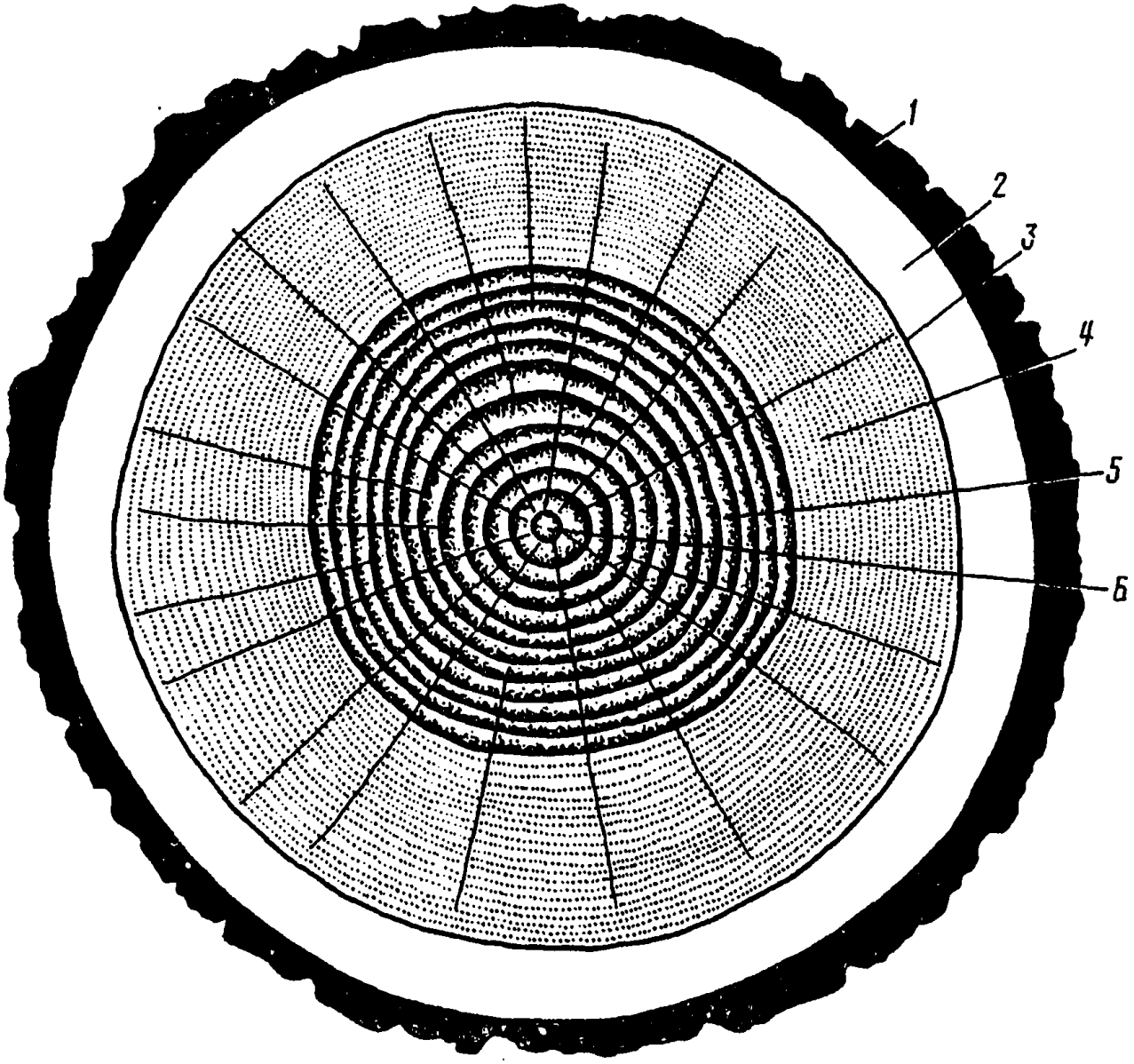
- **Monopodial**: buds do not degrade, all shoots continue to grow
- **Sympodial**: terminal buds degrade, the lateral shoot closest to terminal bud becomes terminal shoot

Monopodial (left) and sympodial branching



11.2 Secondary stem

Secondary stem = bark + wood



1 cork, 2 bast, 1 + 2 = bark, 3 cambium, 4 + 5 wood, 4 **sapwood**, 5 **heartwood**, 6 pith (if any)

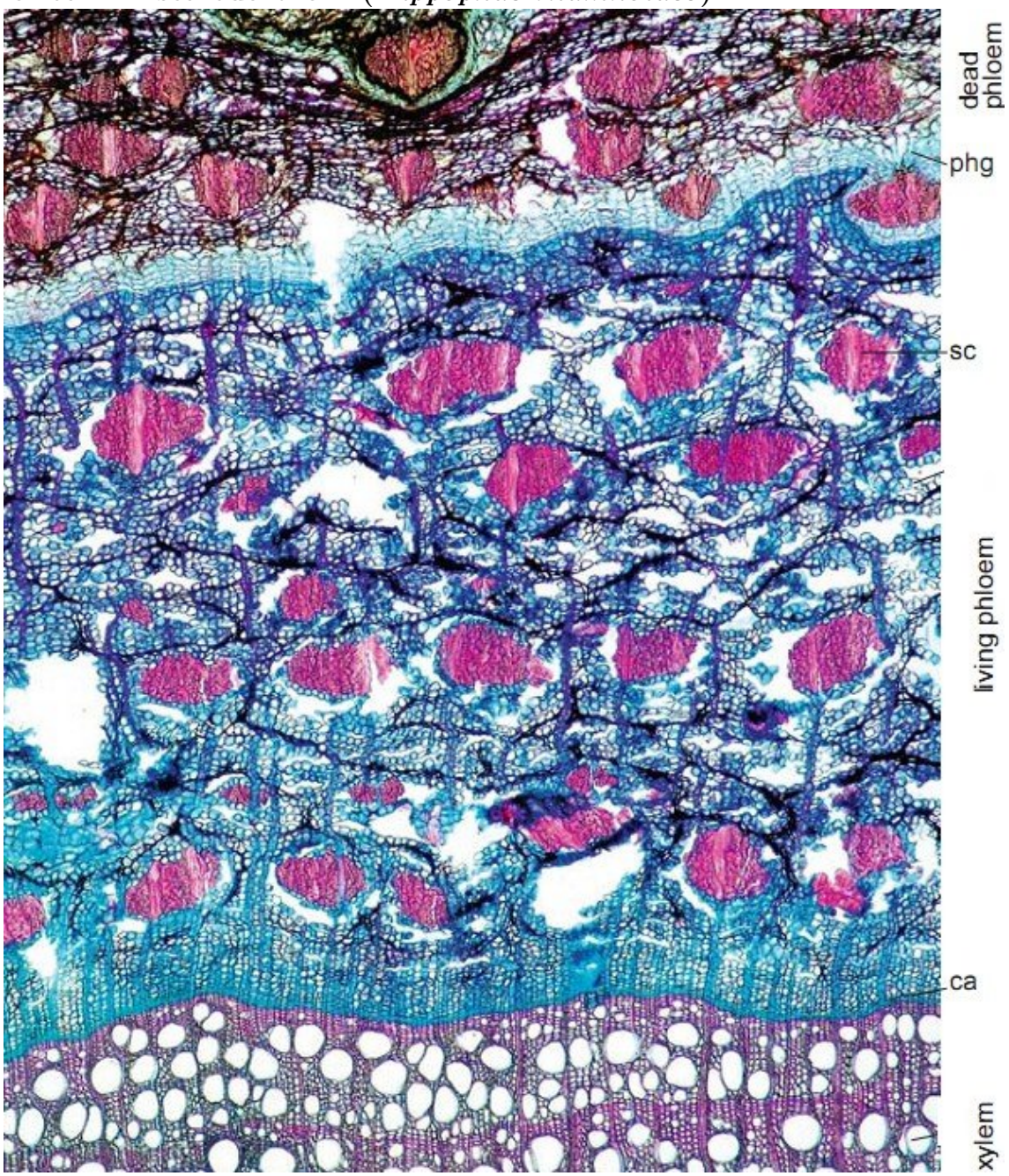
Bark, cork, periderm and wood

- **Bark** is everything outside vascular cambium, i.e. **bark** = secondary phloem + periderm [optionally, also primary phloem, cortex and epidermis]
- **Periderm** = [phelloderm] + cork cambium (phellogen) + phellem (cork)
- **Wood** = trunk − bark, or secondary xylem + [all remnants of central primary tissues]

Cork cambium and origin of bark

- Initially, cork cambium appears in cortex, works some time and then dies out
- Each year new layer of cork cambium appears from parenchyma cells of secondary phloem
- Consequently, bark consists of multiple and mostly uneven layers

Renewal of bark in sea buckthorn (*Hippophaë rhamnoides*)

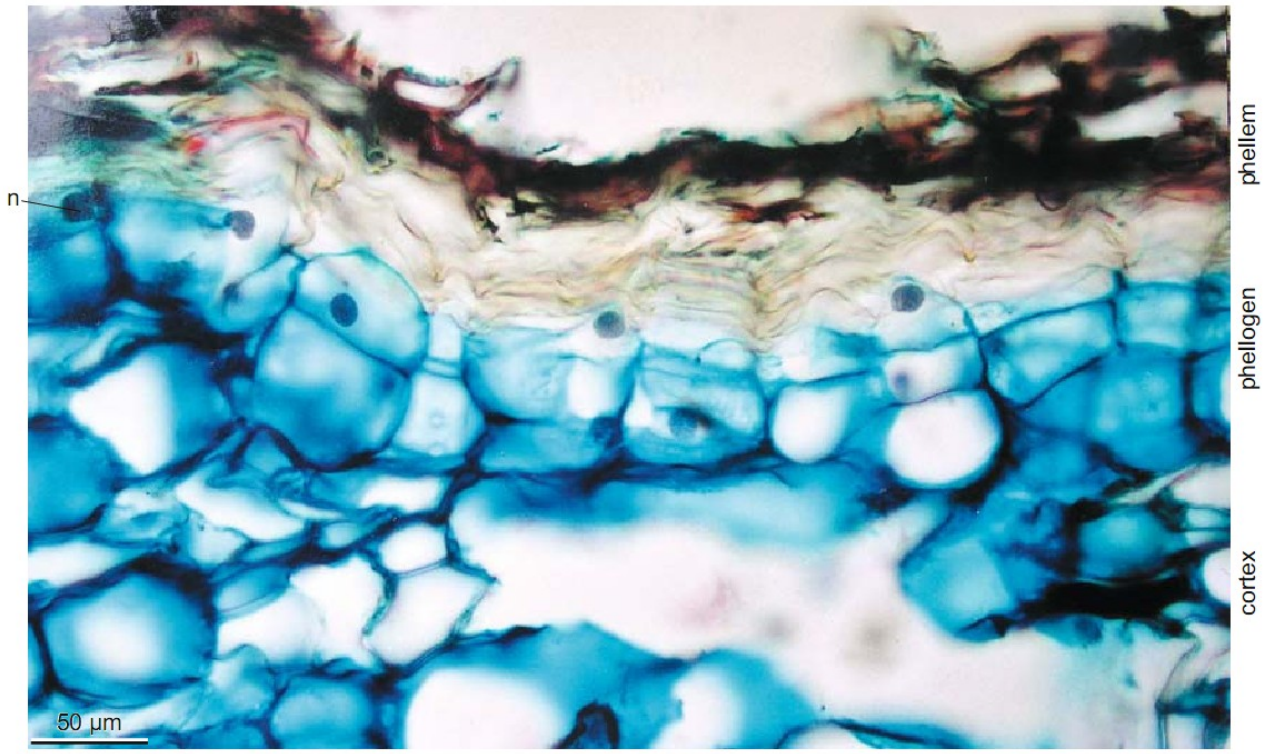


phg phellogen, ca cambium, sc sclerenchyma

Periderm

- Periderm is the product of cork cambium
- 99% of periderm is a **phellem** (cork), thick outside layer
- **Phelloderm** is a tiny layer of living cells inside of cork cambium (phellogen). Phelloderm is sometimes absent.

Formation of periderm zone in medlar (*Mespilus germanica*)



No phelloderm

Lenticels

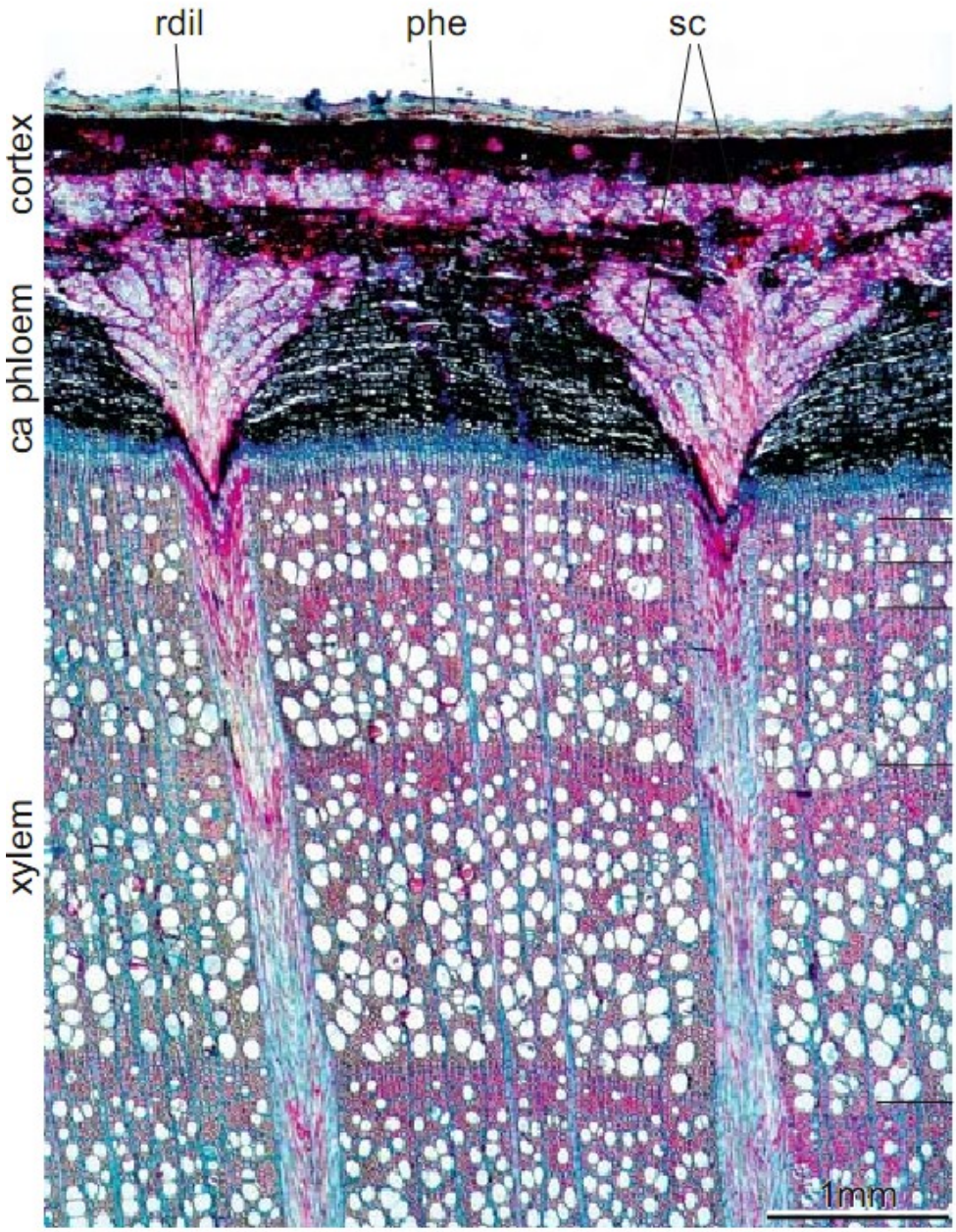
- **Lenticels** are specialized regions of periderm; they supply stem cells with oxygen
- In order to produce lenticel, some cells of cork cambium divide and grow much faster than others

Lenticel of elderberry (*Sambucus* sp.)

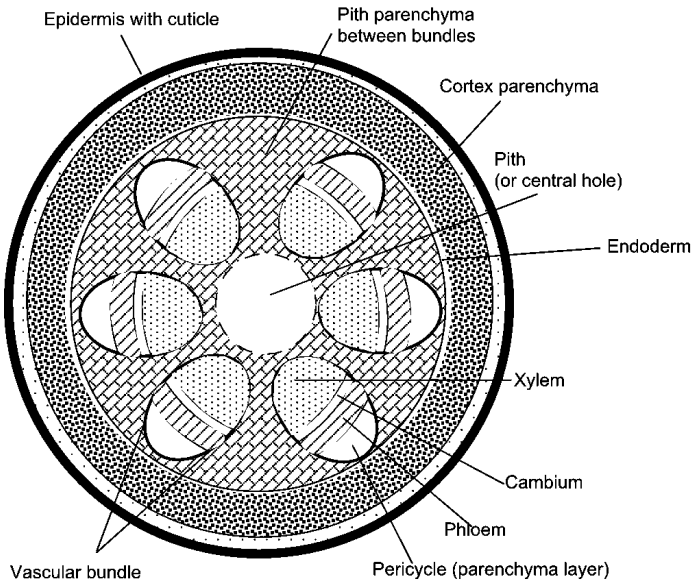
Secondary phloem (bast)

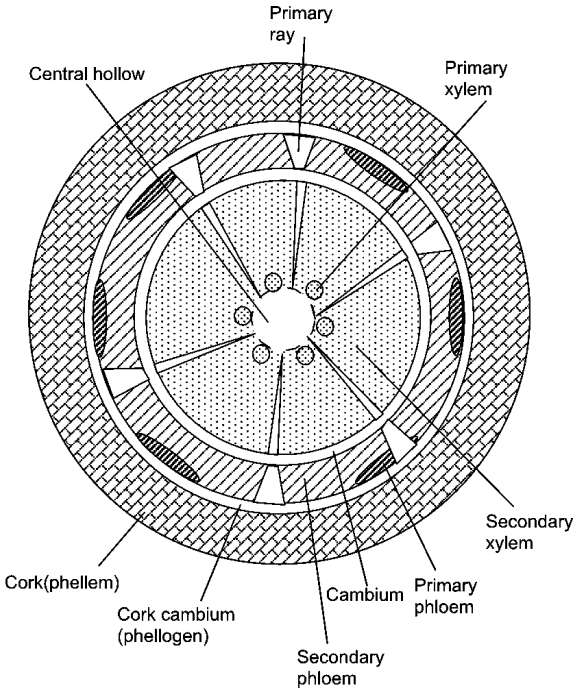
- Forms outside vascular cambium
- Rich of fibers
- Does not form annual rings
- Has rays of parenchyma cells, sometimes wedge-shaped (**dilated**)

Dilated rays in beech (*Fagus* sp.) stem

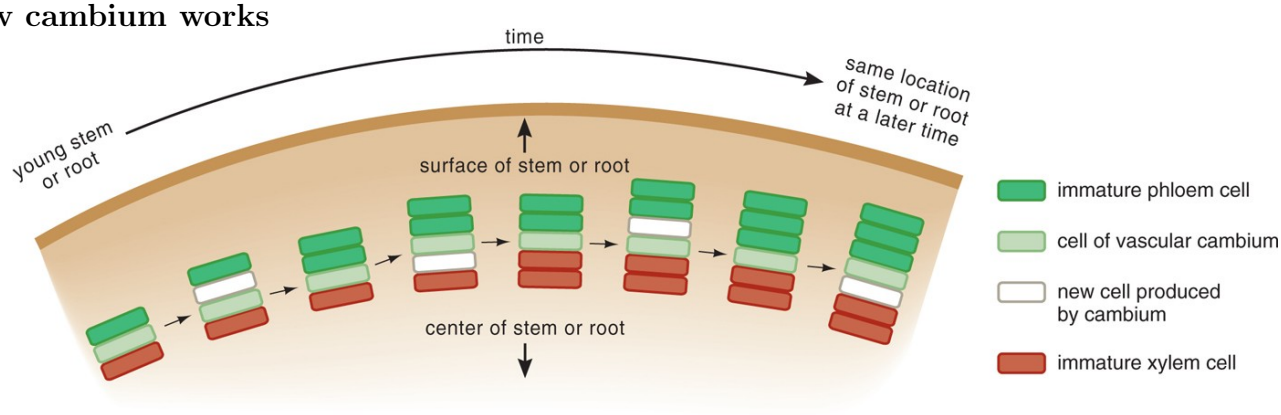


Primary and secondary stems (scheme)

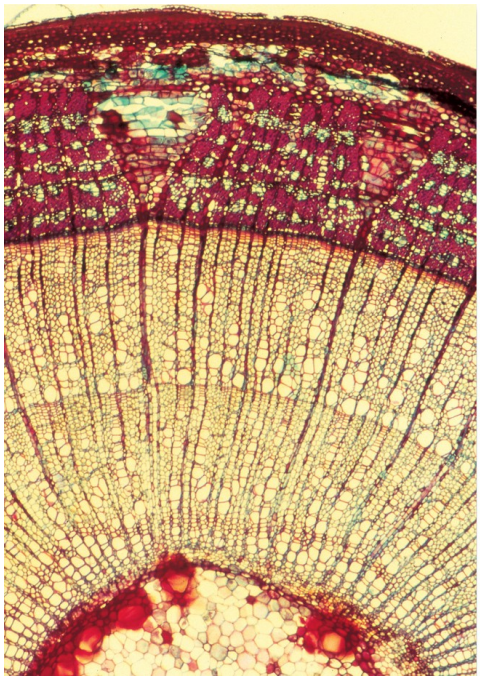


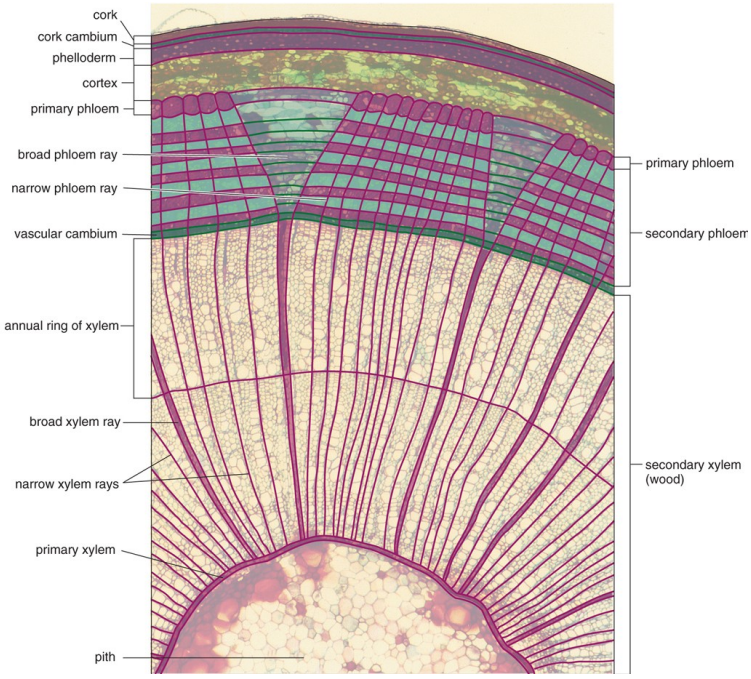


How cambium works



Secondary structure of stem (photo and explanations)

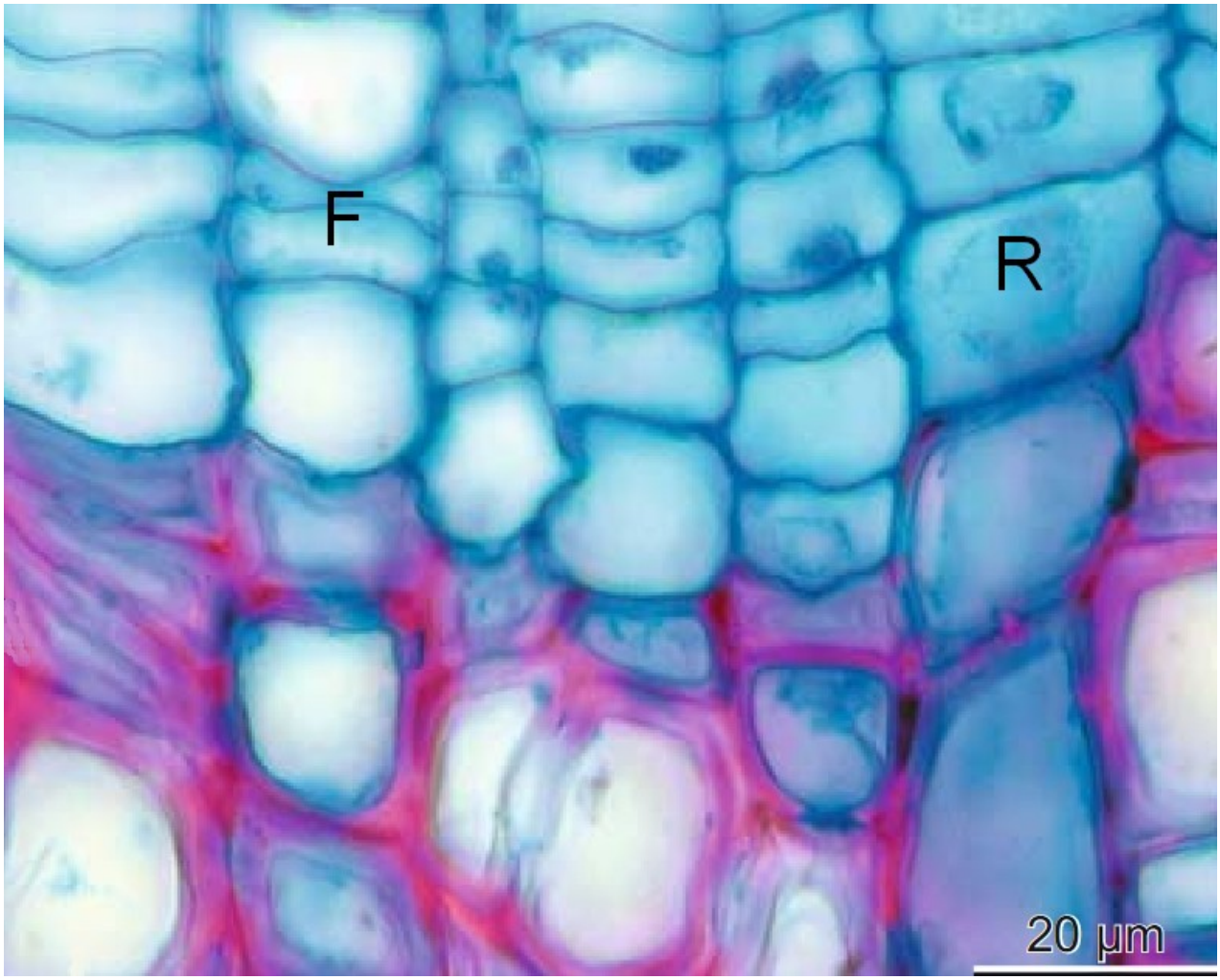




Secondary xylem and rays

- Secondary xylem, or wood, is the product of vascular cambium
- Some cambium cells are **fusiform initials**; they form axial vessel elements
- Other cambium cells are **ray initials**; they form rays (parenchyma + tracheids)
- **Rays** provide horizontal transport of water; **axial system** provide vertical transport

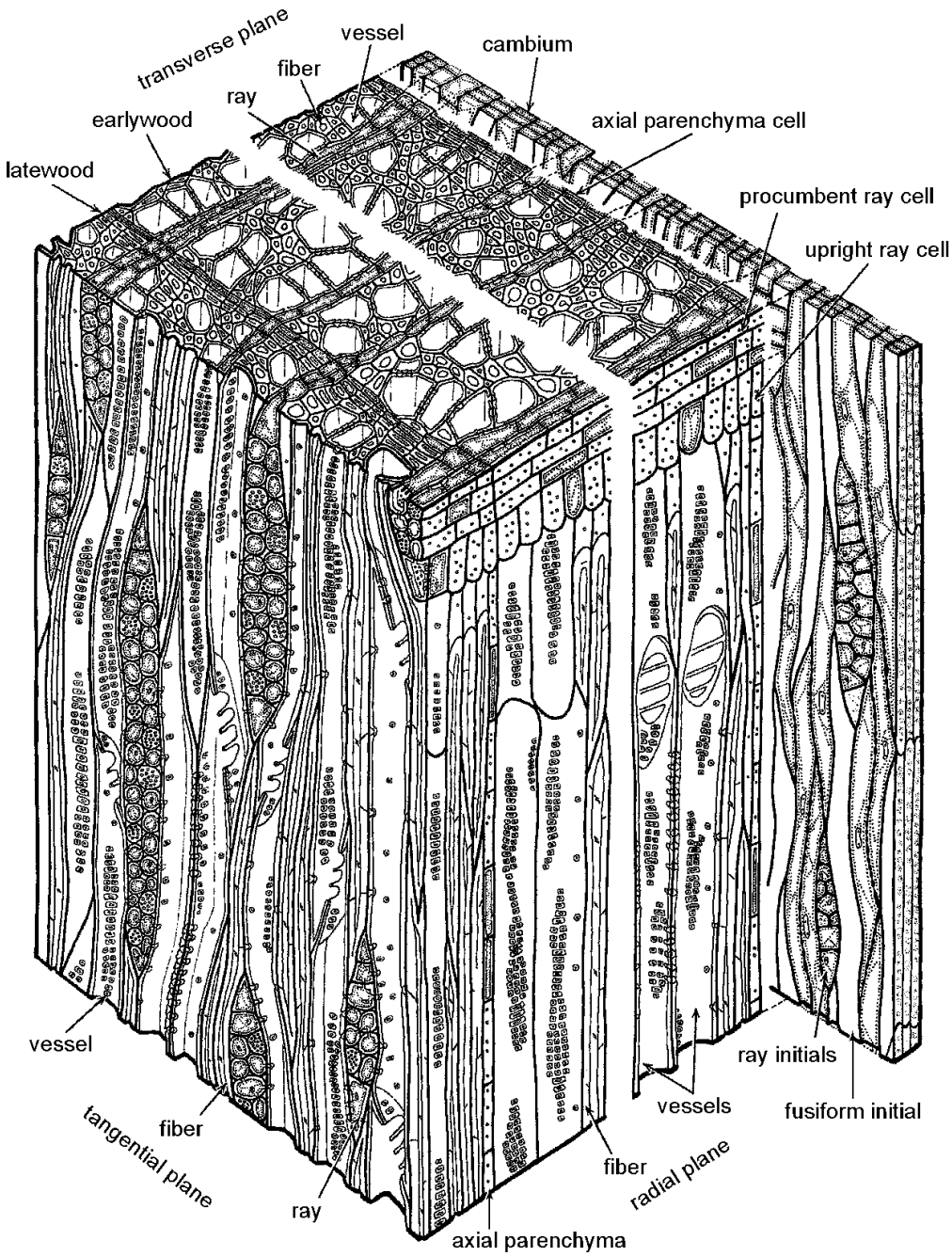
Fusiform and ray initials



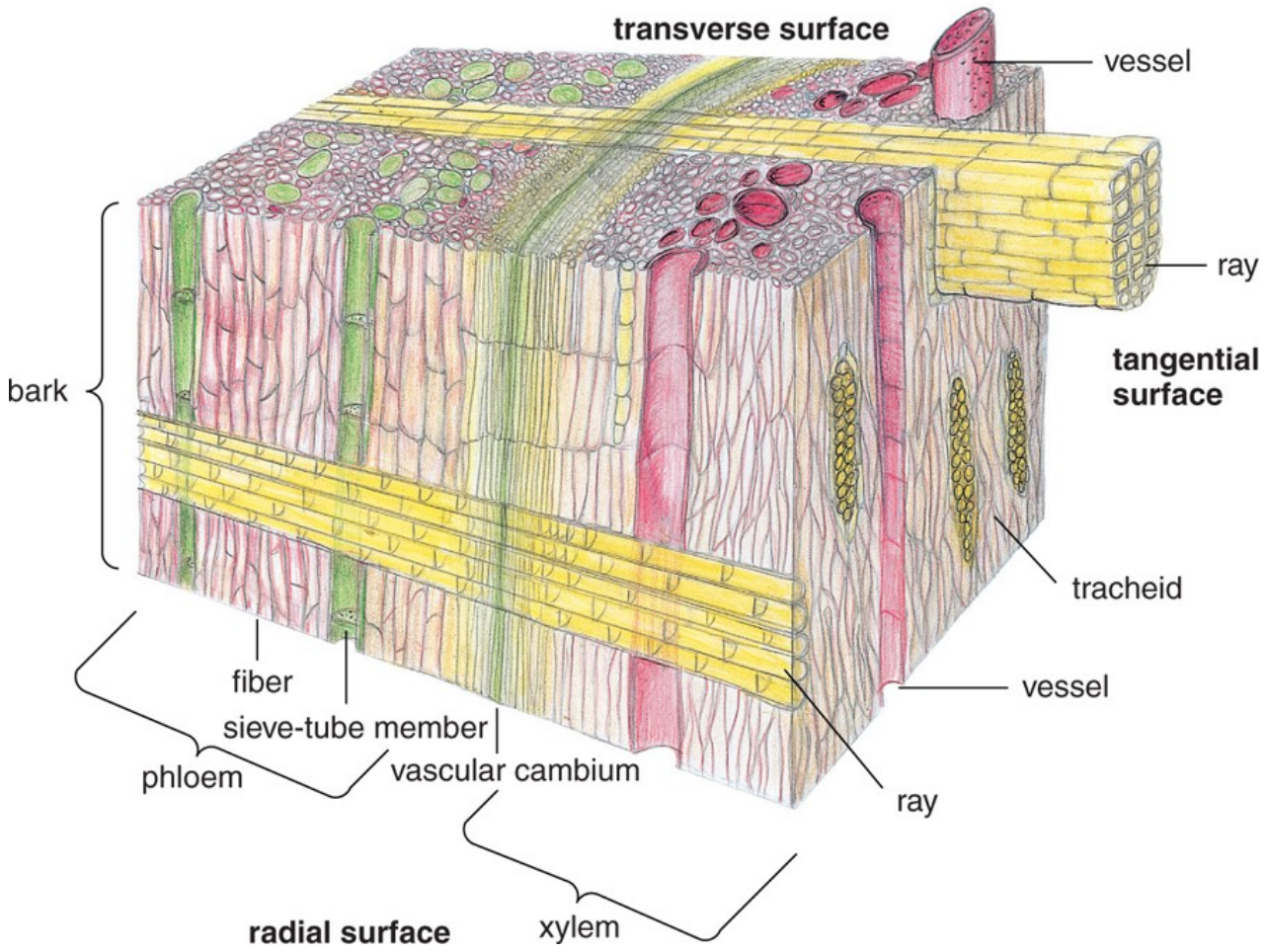
Three planes of view

- **Transverse** (cross-section)
- **Radial** (longitudinal section from center to periphery and perpendicular to stem surface)
- **Tangential** (longitudinal section parallel to stem surface)

Three plains of maple (*Acer* sp.) wood



Three plains again (the scheme)



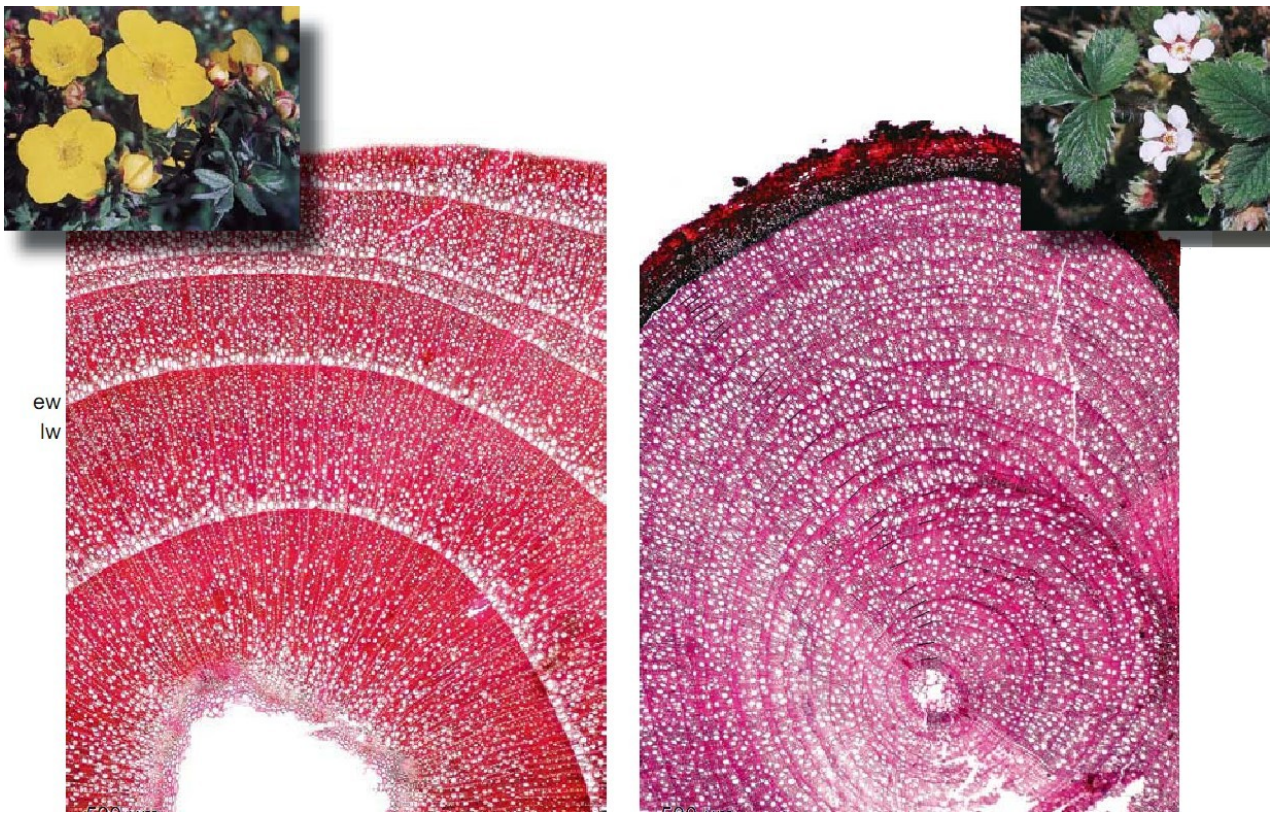
Earlywood and latewood

- **Earlywood** (springwood) contains more parenchyma and often have larger vessel elements
- **Latewood** (summerwood) often have small vessel elements and looks darker

Diffuse and ring porous wood

- In **ring porous** wood (like in red oak) bigger vessel elements concentrate in earlywood
- In **diffuse porous** wood larger vessel elements spread across early- and latewood (American elm)

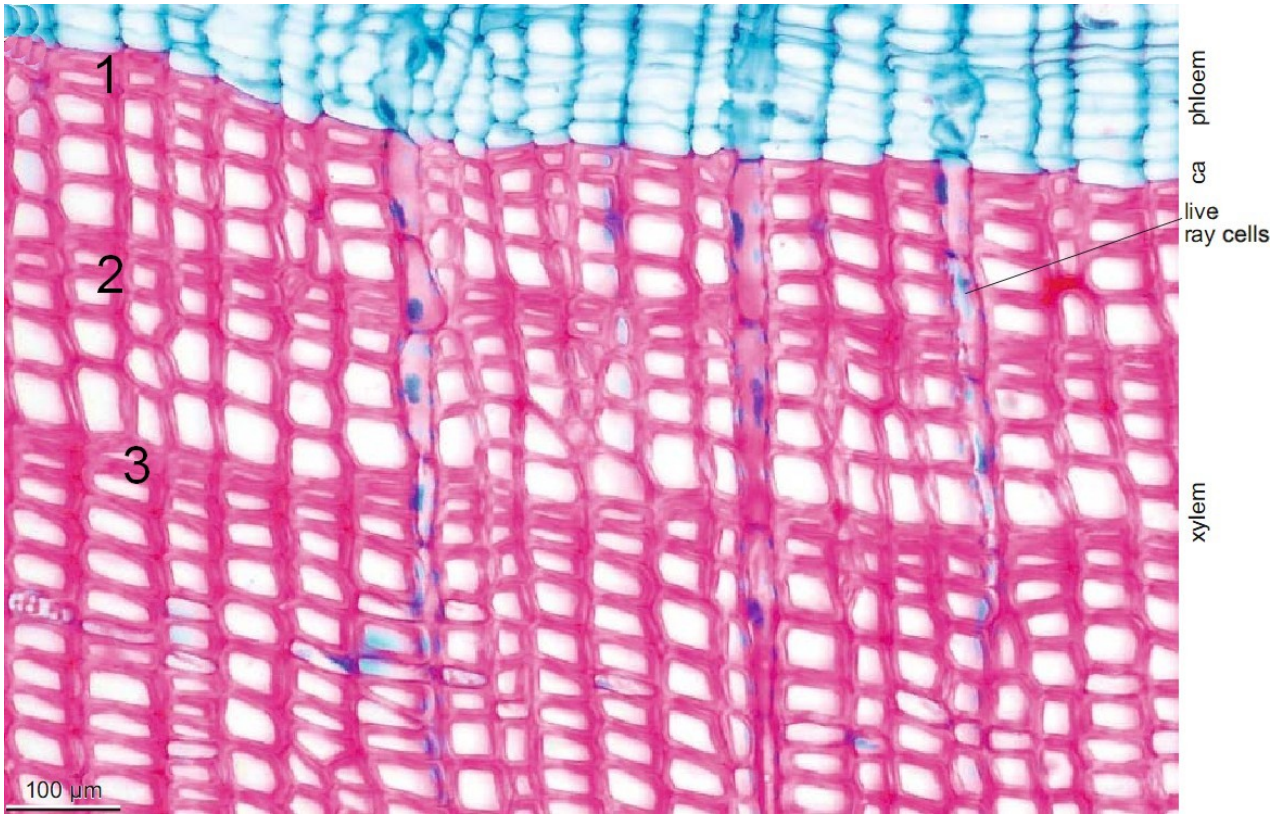
Diffuse and ring porous wood in two species of cinquefoil (*Potentilla* spp.)



Annual rings

- Interleaving early- and latewood from to sequential years form an impression of annual ring
- "Ring" is just a layer of darker (i.e., smaller) cells
- Tropical trees do not form annual rings

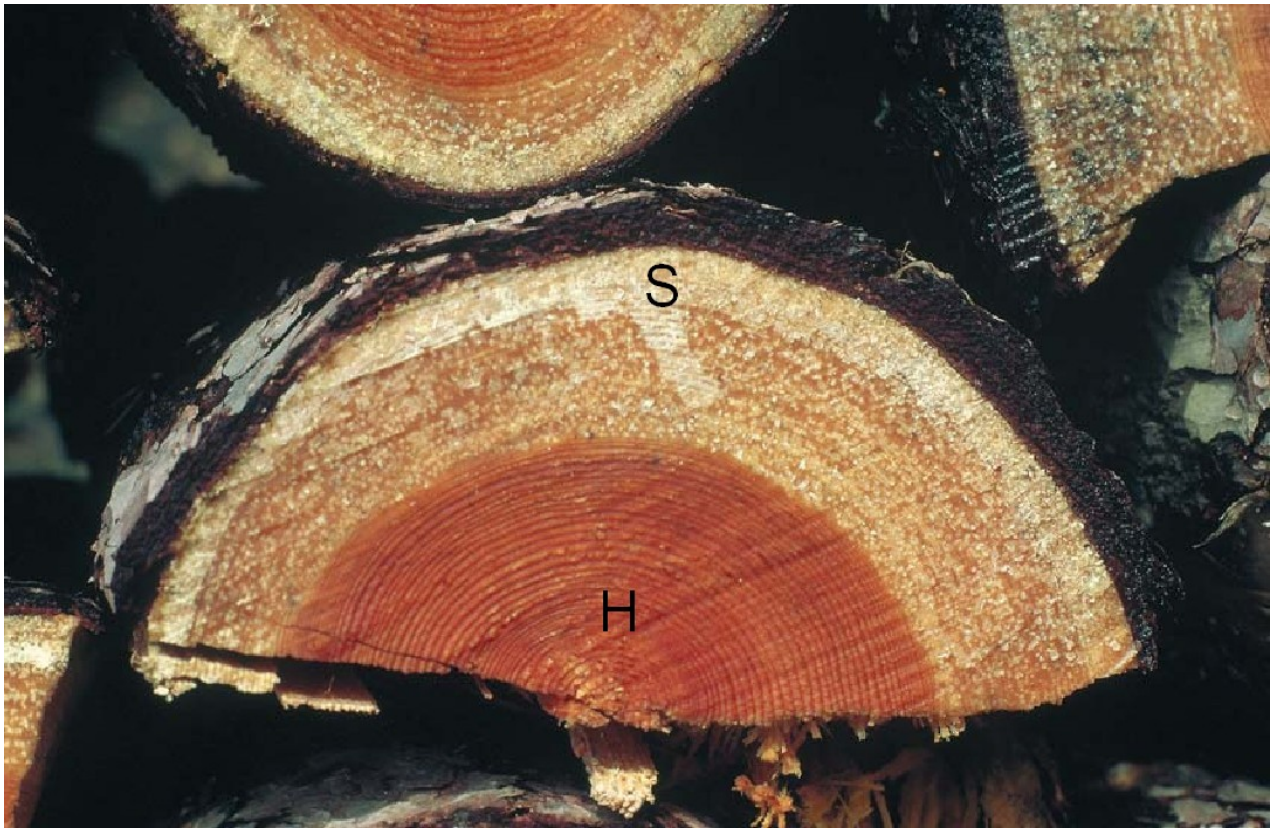
Annual rings in juniper (*Juniperus* sp.)



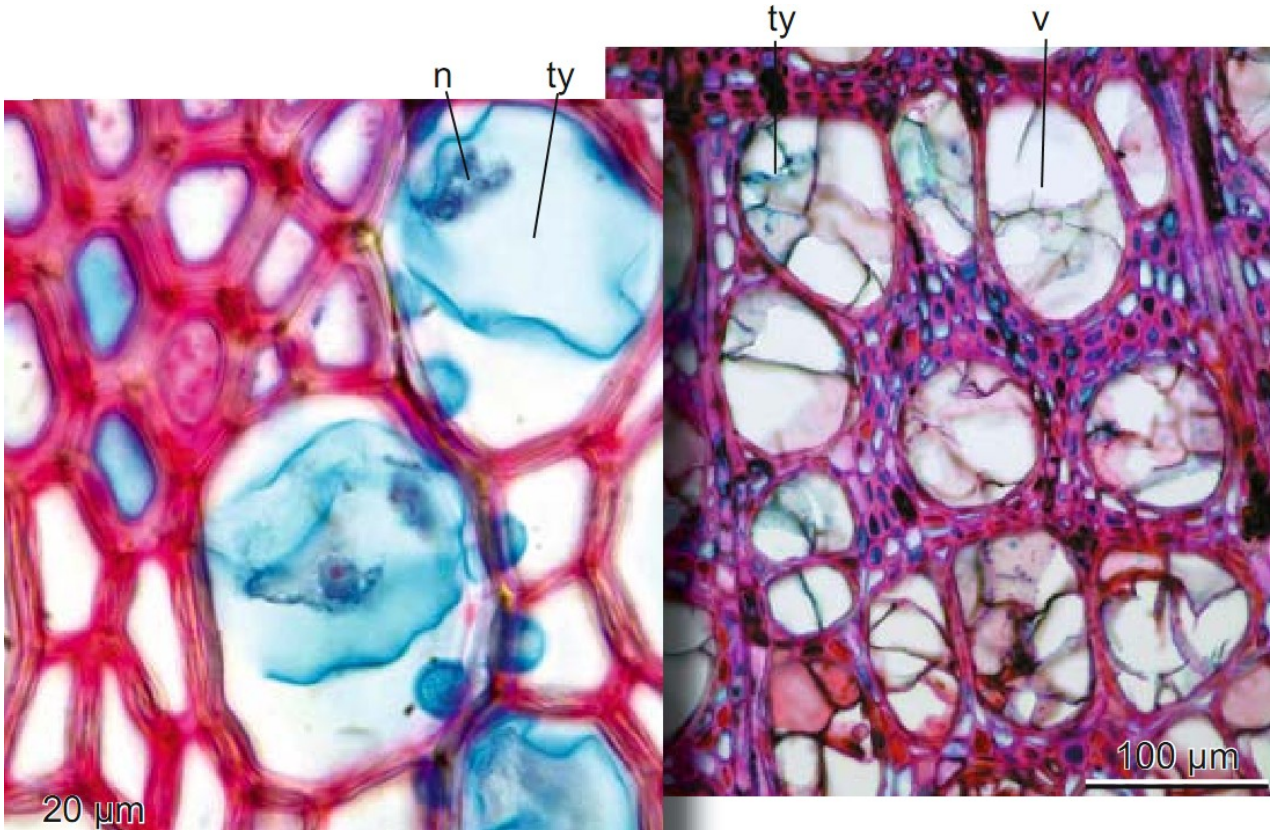
Sapwood and heartwood

- **Sapwood** is a peripheral layer of working xylem, it usually has relatively light color
- **Heartwood** is a central, non-functional, old, dark-colored xylem

Sapwood and heartwood of European pine (*Pinus sylvestris*)



Tyloses



Tyloses control the winter functioning of vessels

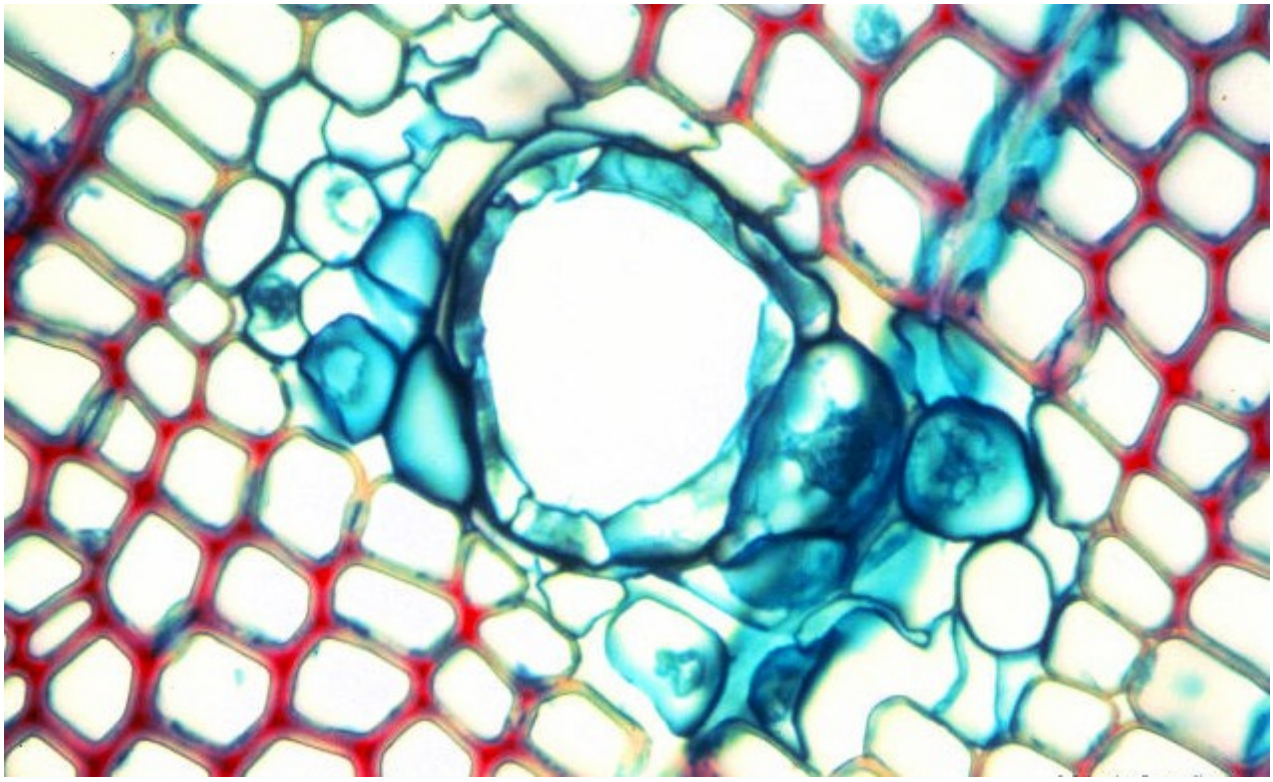
11.3 Diversity of wood

Conifer wood

- Simpler structure, few cell types
- Simple rays
- Sometimes have **resin ducts**; resin secreted by epithelial cells

Ginkgo (*Ginkgo biloba*) wood (not a conifer, but gymnosperm)

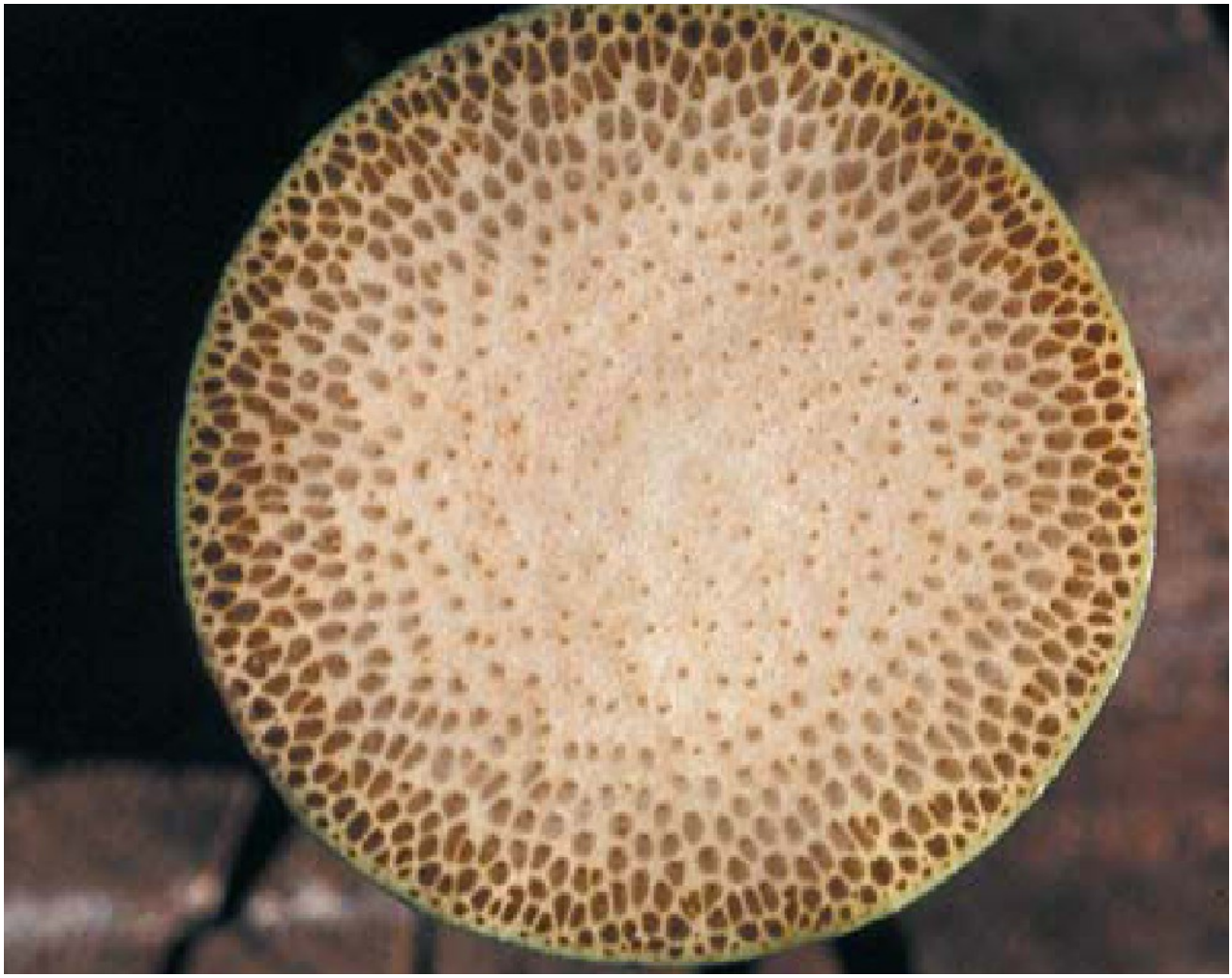
Resin duct in pine wood (©BSA)



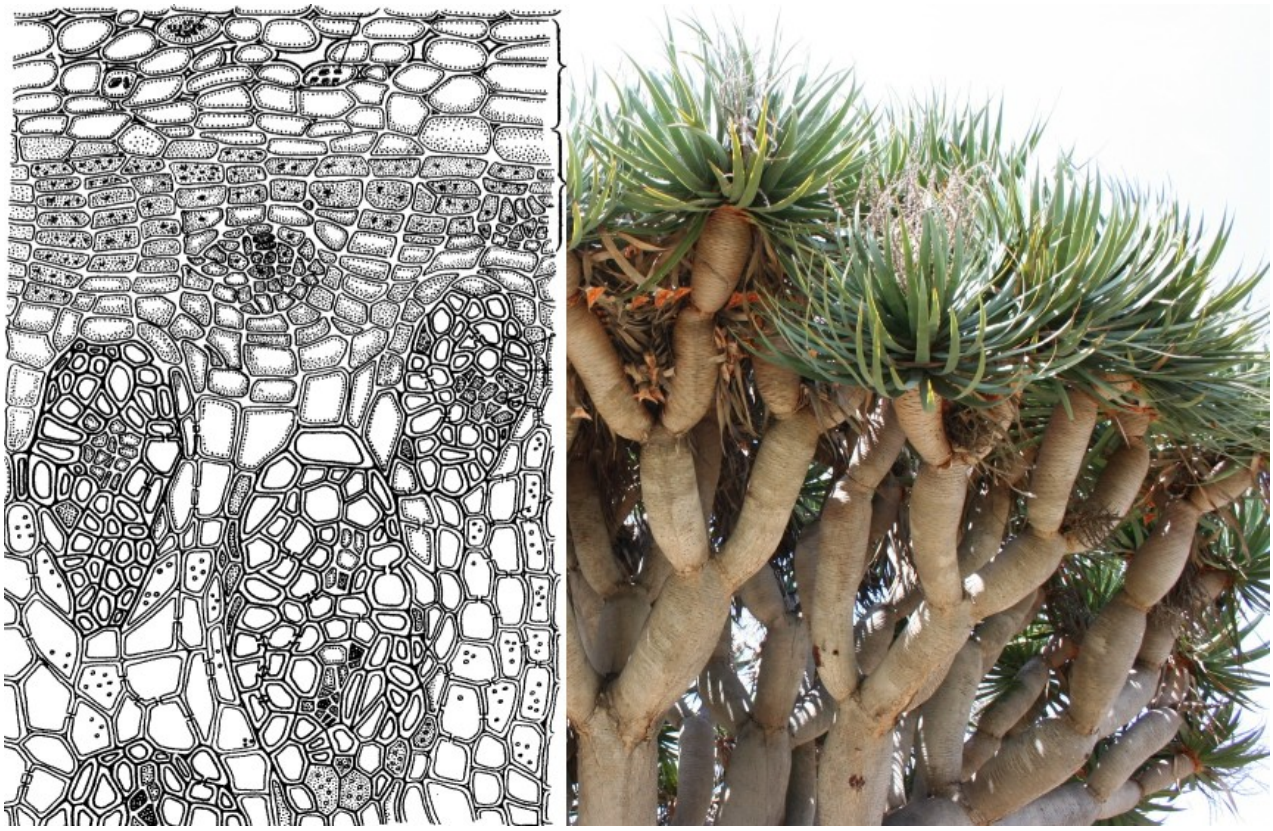
Monocot "wood"

- Most of monocots do not have lateral meristems and therefore have no true wood
- Palms have only primary tissues; their trunk widens from bottom to top
- Some monocots (dragon trees) have **anomalous secondary growth**

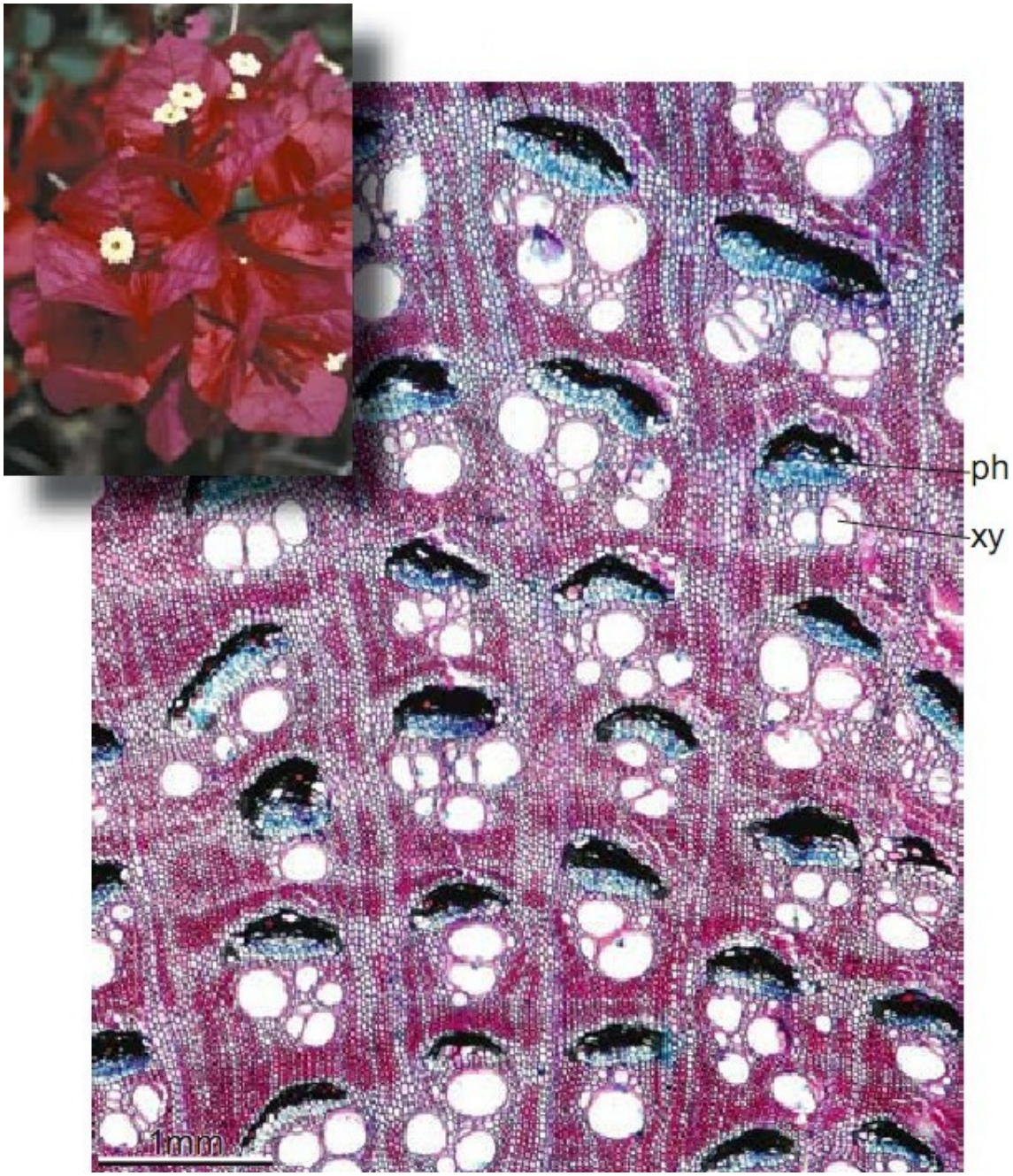
Cross section of palm (*Phoenix canariensis*) trunk



Dragon tree (*Dracaena draco*) and its anomalous cambium



Anomalous secondary growth in Bougainvillea (*Bougainvillea spectabilis*)



11.4 Life forms

Life forms

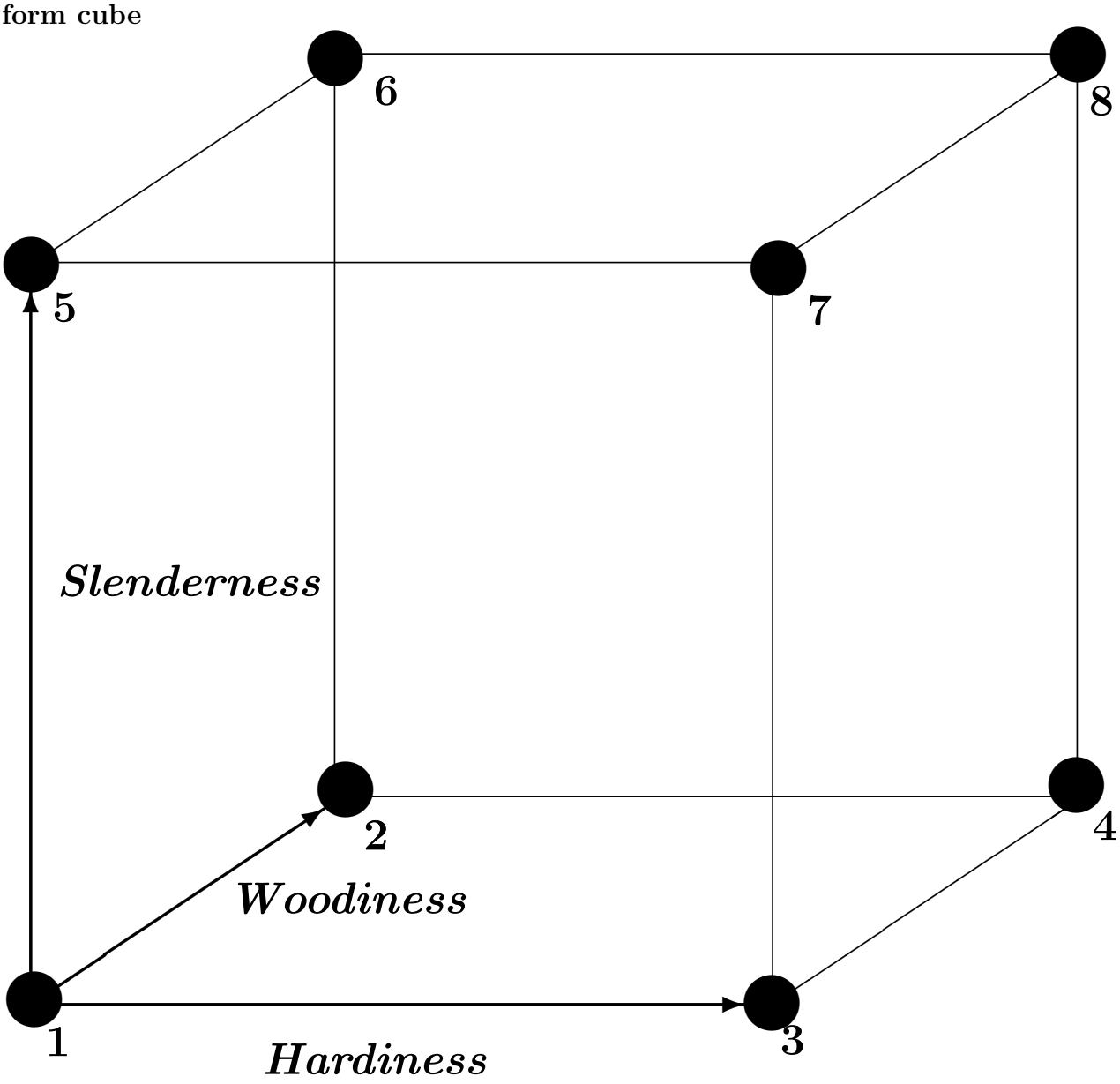
- It is a different view on the plant diversity
- Life forms represent different lifestyles
- For example, trees, shrubs, vines, annual and perennial herbs are life forms

Life forms: dynamic approach

- **Hardiness**: sensitivity to all negative influence
- **Woodiness**: % of cells with secondary walls

- **Slenderness**: proportion of linearly ordered stems

Life form cube



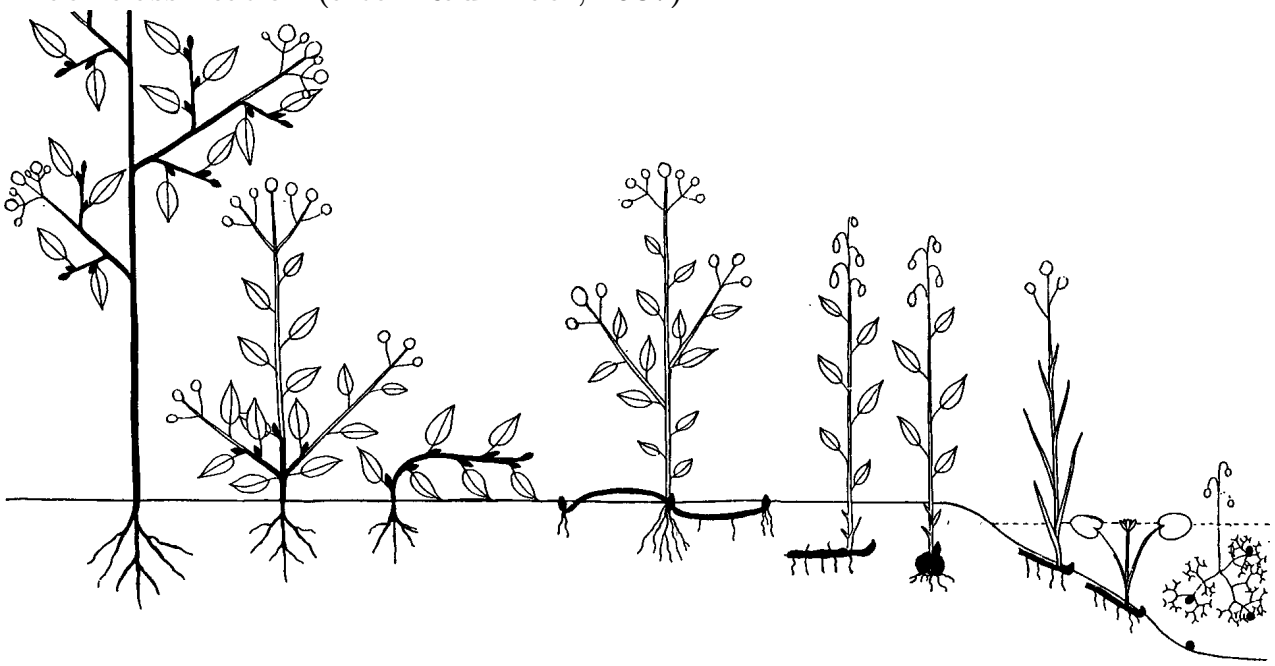
#1 could be similar to duckweed, #8—to sequoia

Life forms: Raunkiaer's approach

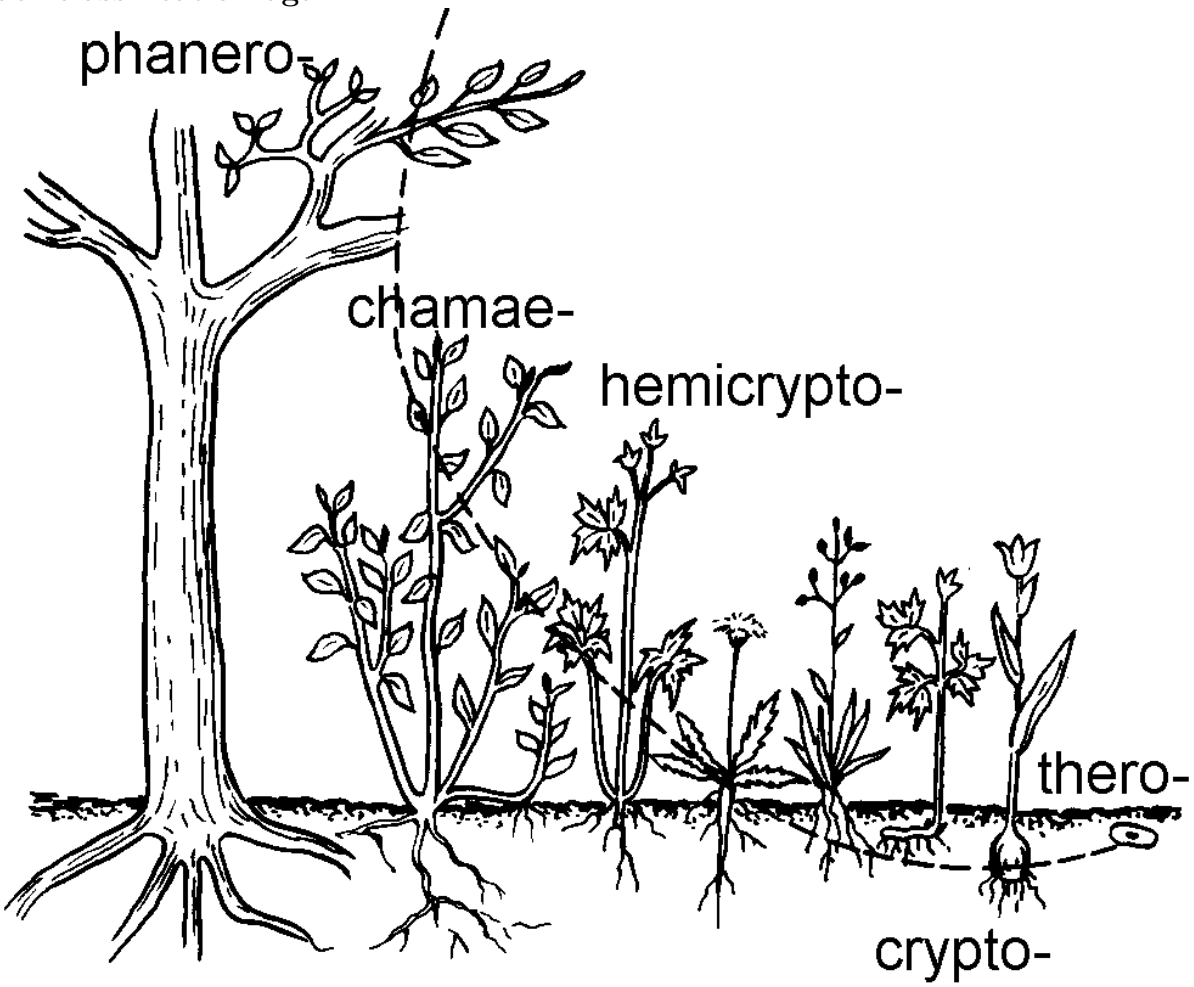
- **Epiphytes**: aboveground plants
- **Phanerophytes**: winter buds openly exposed
- **Chamaephytes**: winter buds under snow
- **Hemicryptophytes**: winter buds on soil surface
- **Cryptophytes**: winter buds in the soil
- **Therophytes**: no winter buds, only seeds

The Raunkiaer system is very useful to characterize the whole *floras*, especially temperate floras

Raunkiaer classification (after Raunkiaer, 1937)



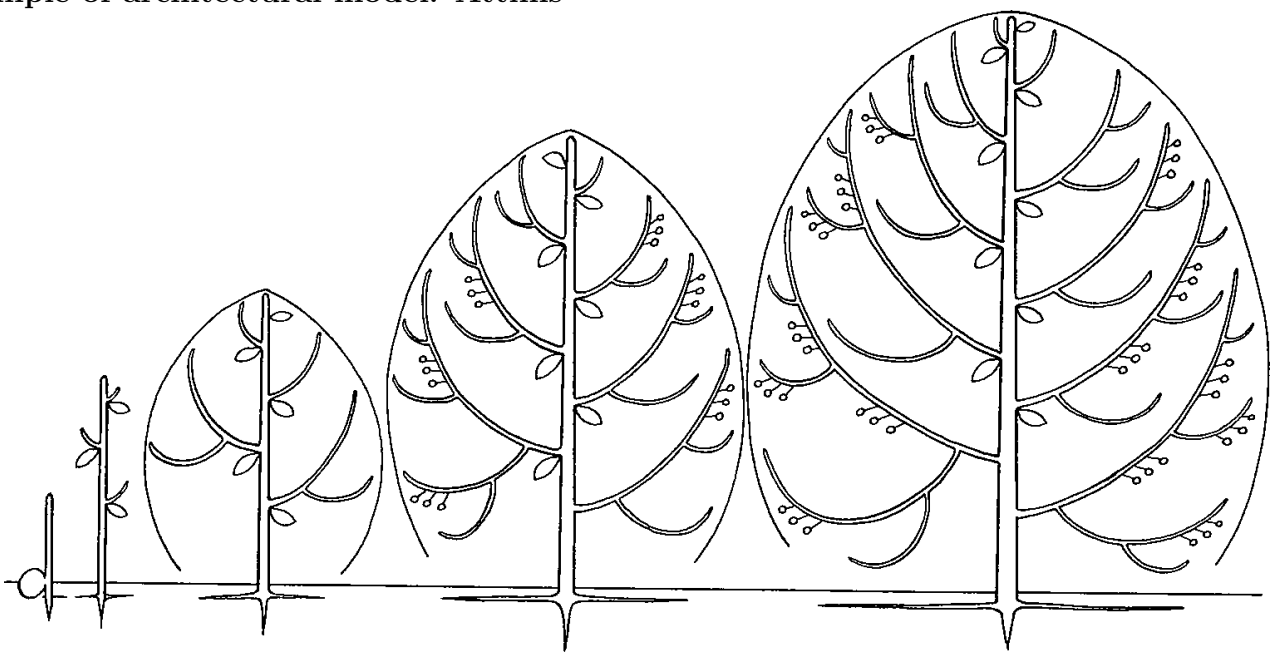
Raunkiaer classification again



Life forms: architectural models

- Developed for tropical trees, but also cover temperate forms which are less diverse
- Each model has a name of famous botanist, e.g. Thomlinson, Cook, Attims
- Based on the character of branching, development of generative shoots, directions of growing

Example of architectural model: Attims



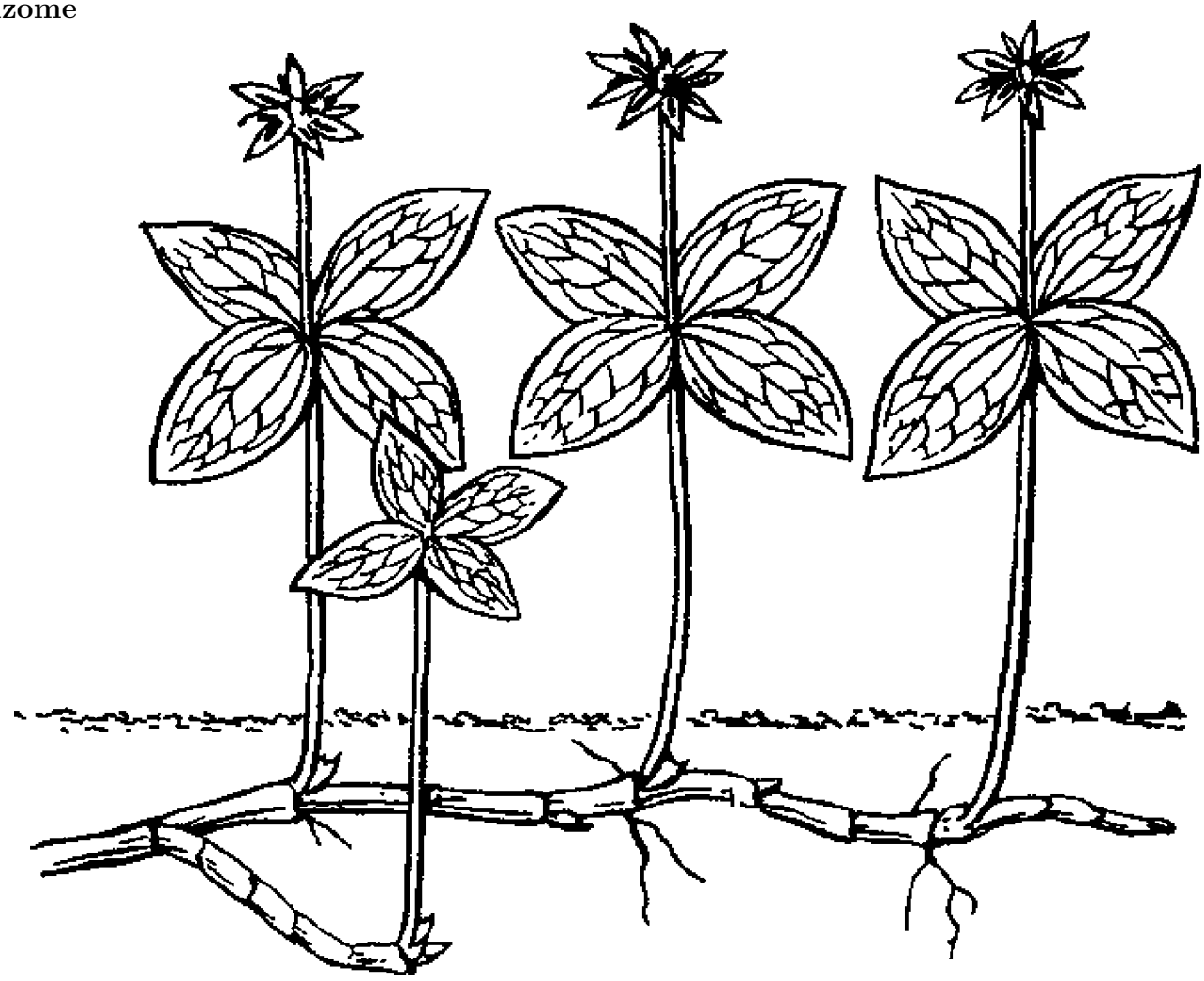
Many temperate trees are growing according to this model

11.5 Modifications of stem / shoot

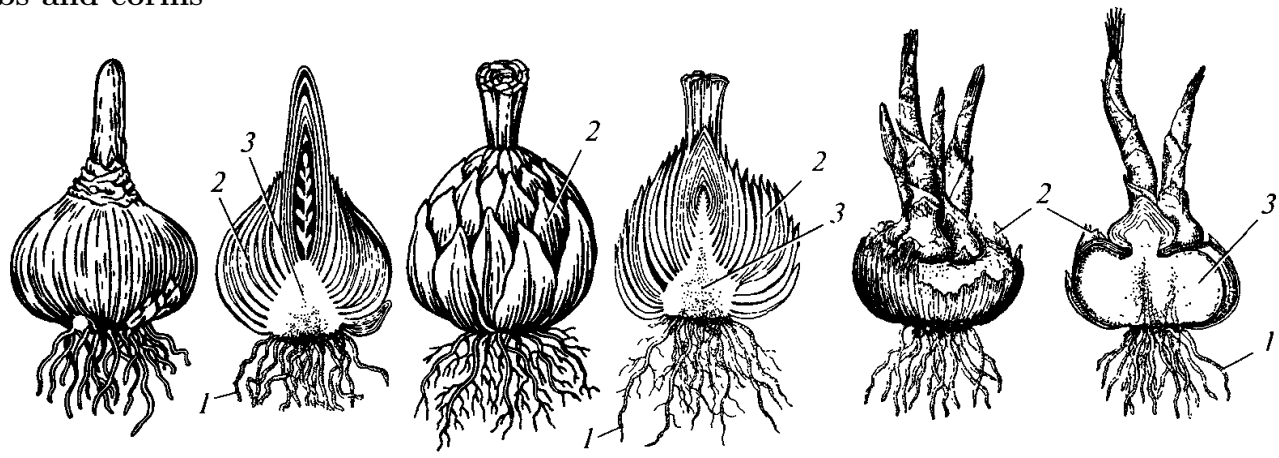
Modifications of shoots and stems

- **Rhizomes**: underground stems
- **Stolons** (runners): aboveground horizontal shoots
- **Tubers**: enlarged portions of rhizomes
- **Bulbs**: storage shoots, leaves $> 50\%$ of volume
- **Corms**: storage shoots, leaves $< 50\%$ of volume
- **Thorns**: defense shoots
- **Spines**: defensive emergencies of stem surface
- **Cladophylls**: leaf-like shoots
- **Stem traps**: catch animals for some carnivorous plants

Rhizome

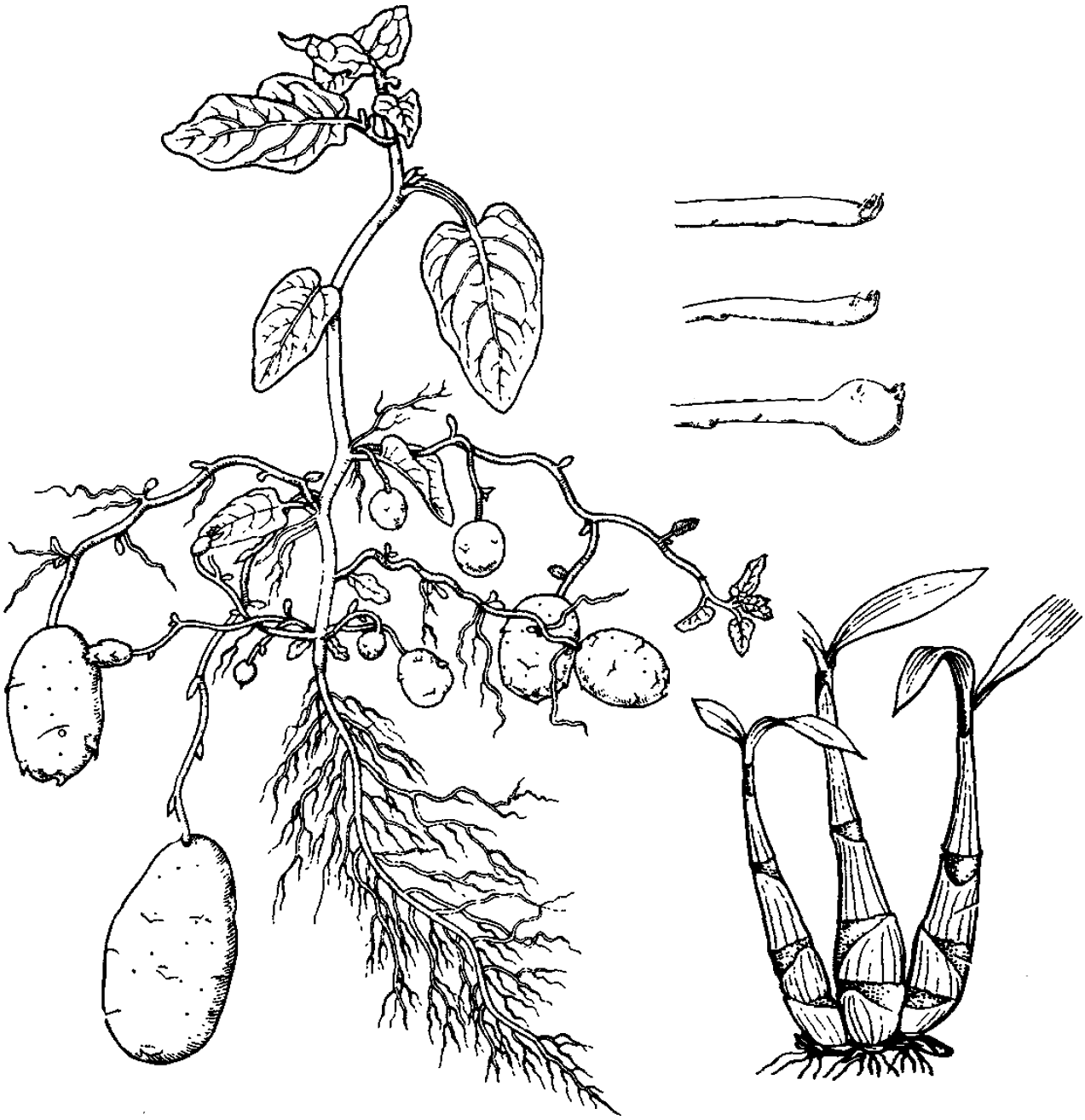


Bulbs and corms



(1) roots, (2) leaves, (3) stems

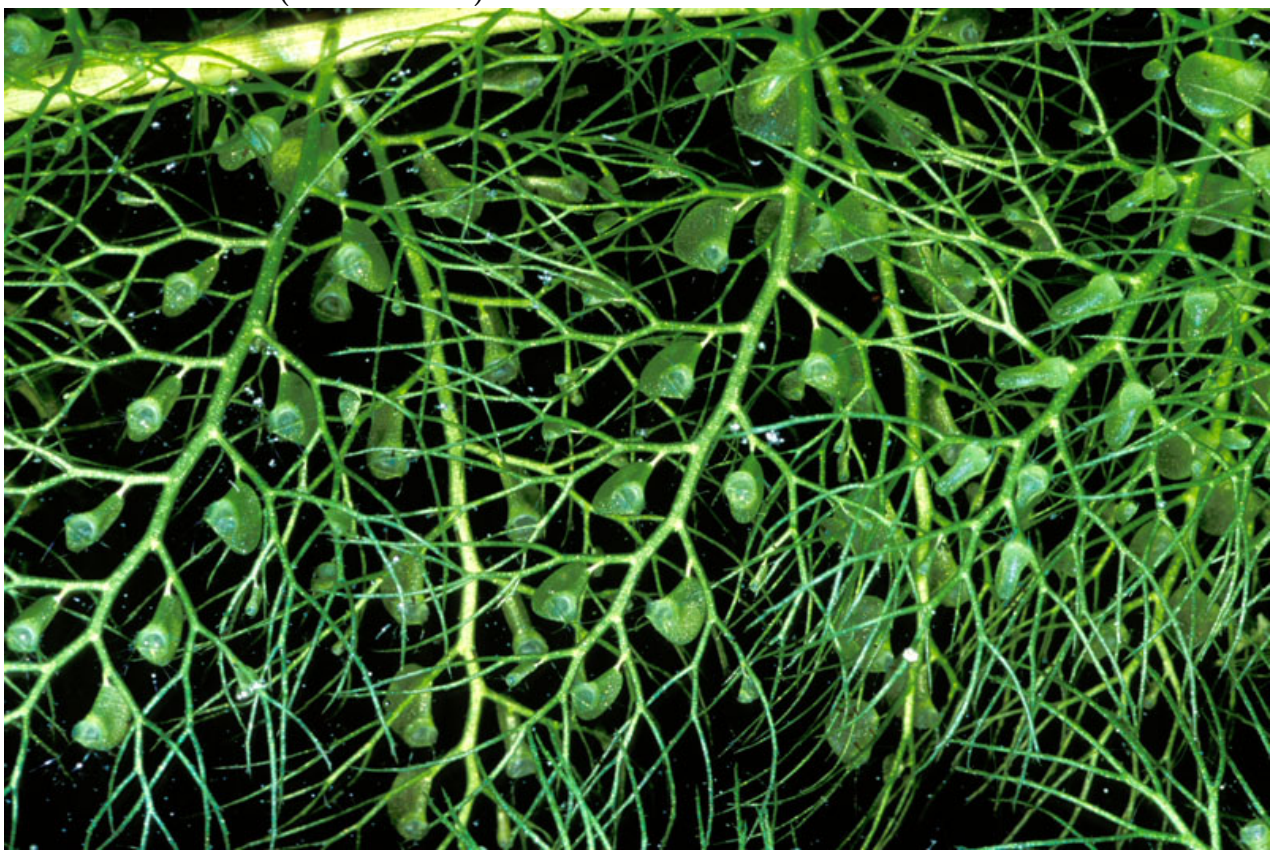
Tubers: potato and orchids



Thorns

Cladophylls: leafy stems

Traps of bladderwort (*Utricularia*)



Final question (2 points)

What is a heartwood?

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

12 Questions and answers

12.1 Quiz

Final question (2 points)

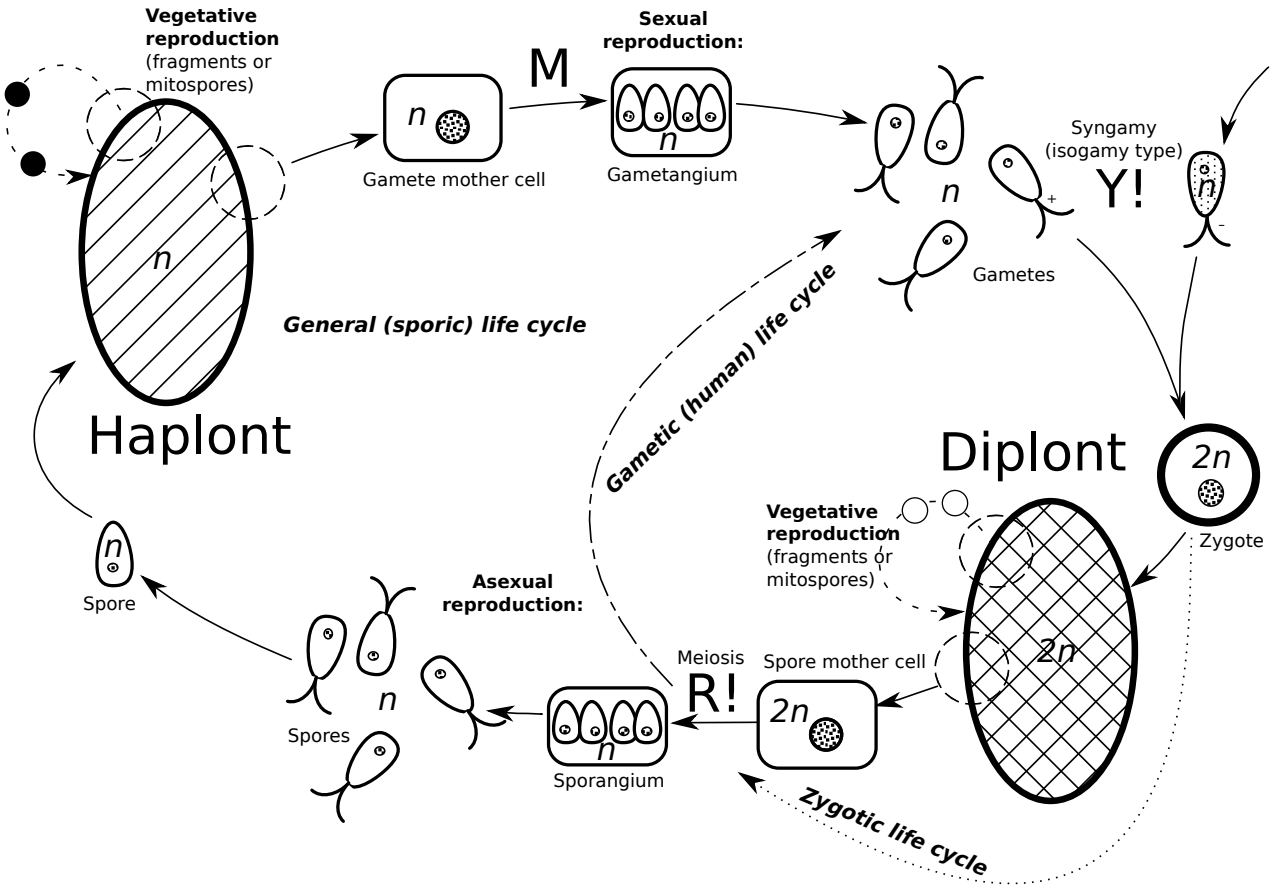
What is a heartwood?

- Non-functional xylem in the center of stem.

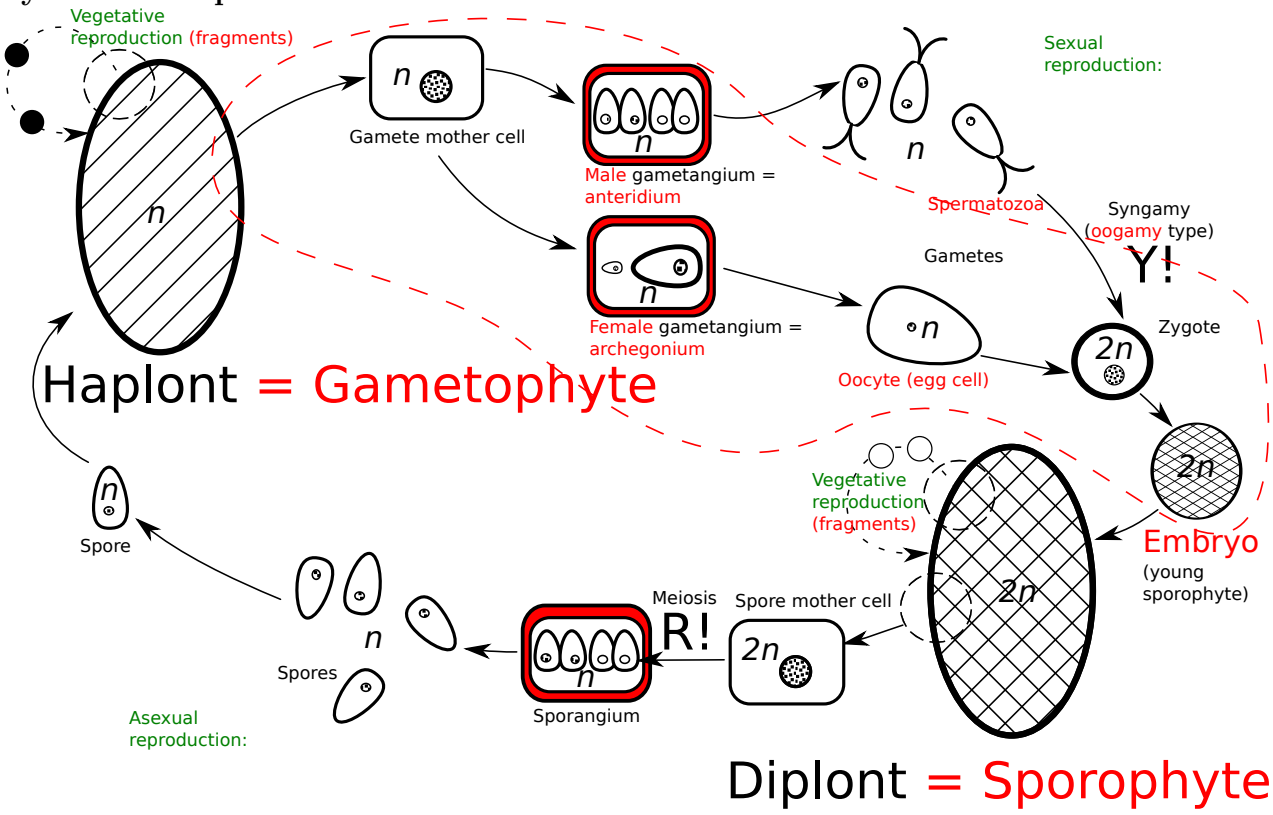
13 Branching, thickening and seed

13.1 Origin of seed

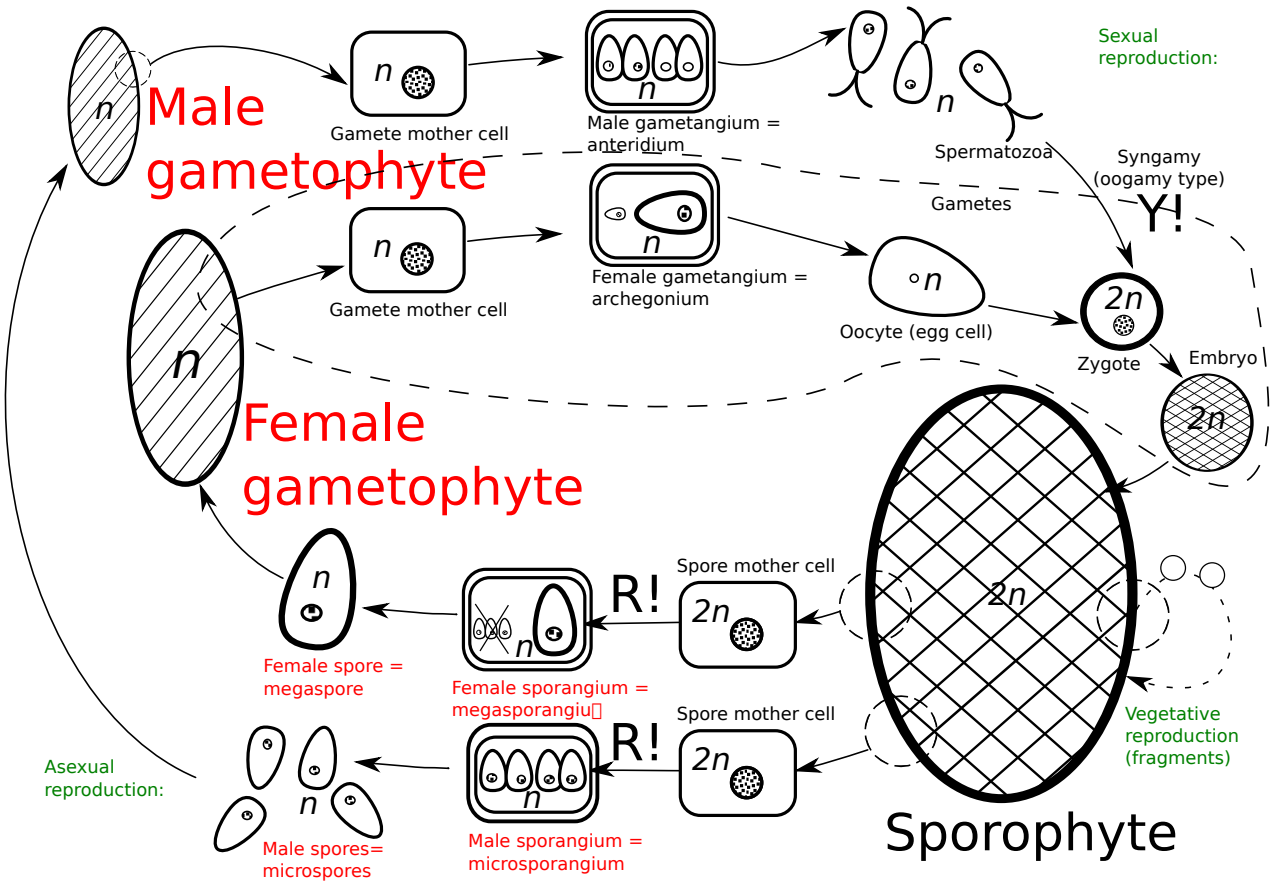
General life cycle



Life cycle of land plants: differences



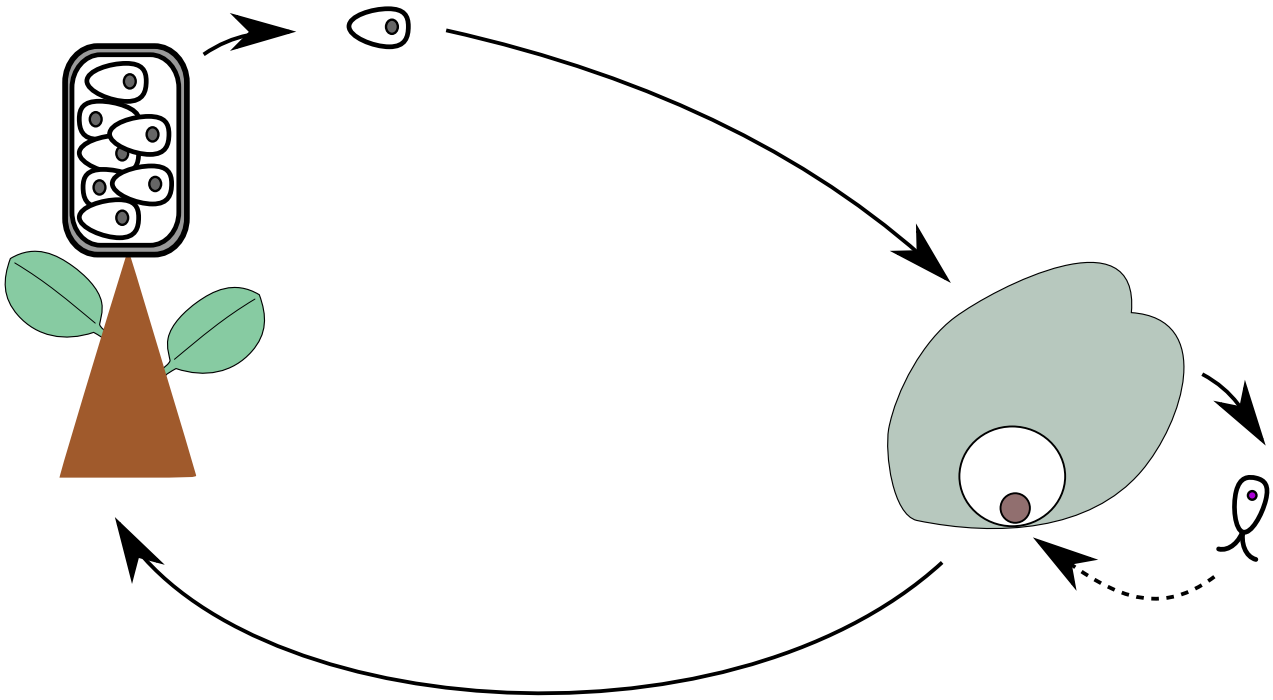
Heterosporic cycle: differences



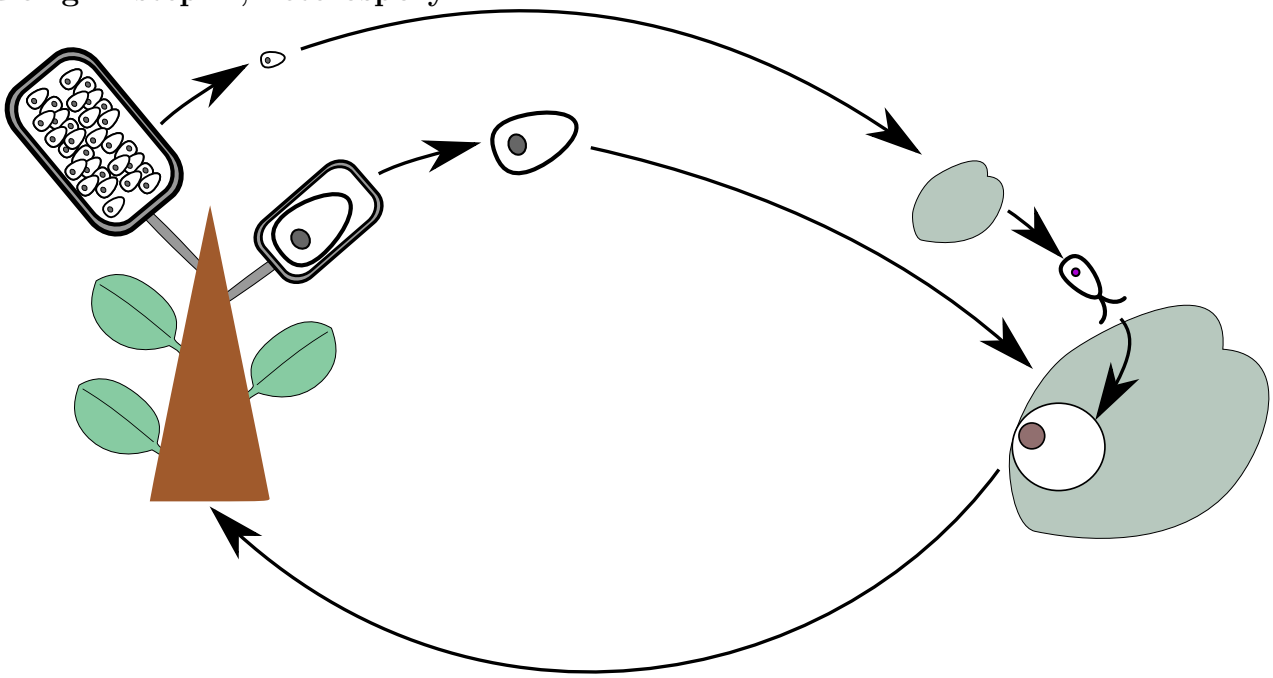
Origin of seed

- **"Dinosaur problem":** without control on the r-strategic gametophyte, K-strategic tree sporophyte cannot guarantee its reproduction
- **Seed is the result of enforced control of sporophyte over gametophyte**
- Growing of gametophytes, syngamy (fertilization) and growing of daughter sporophyte—everything happens **directly on mother sporophyte**

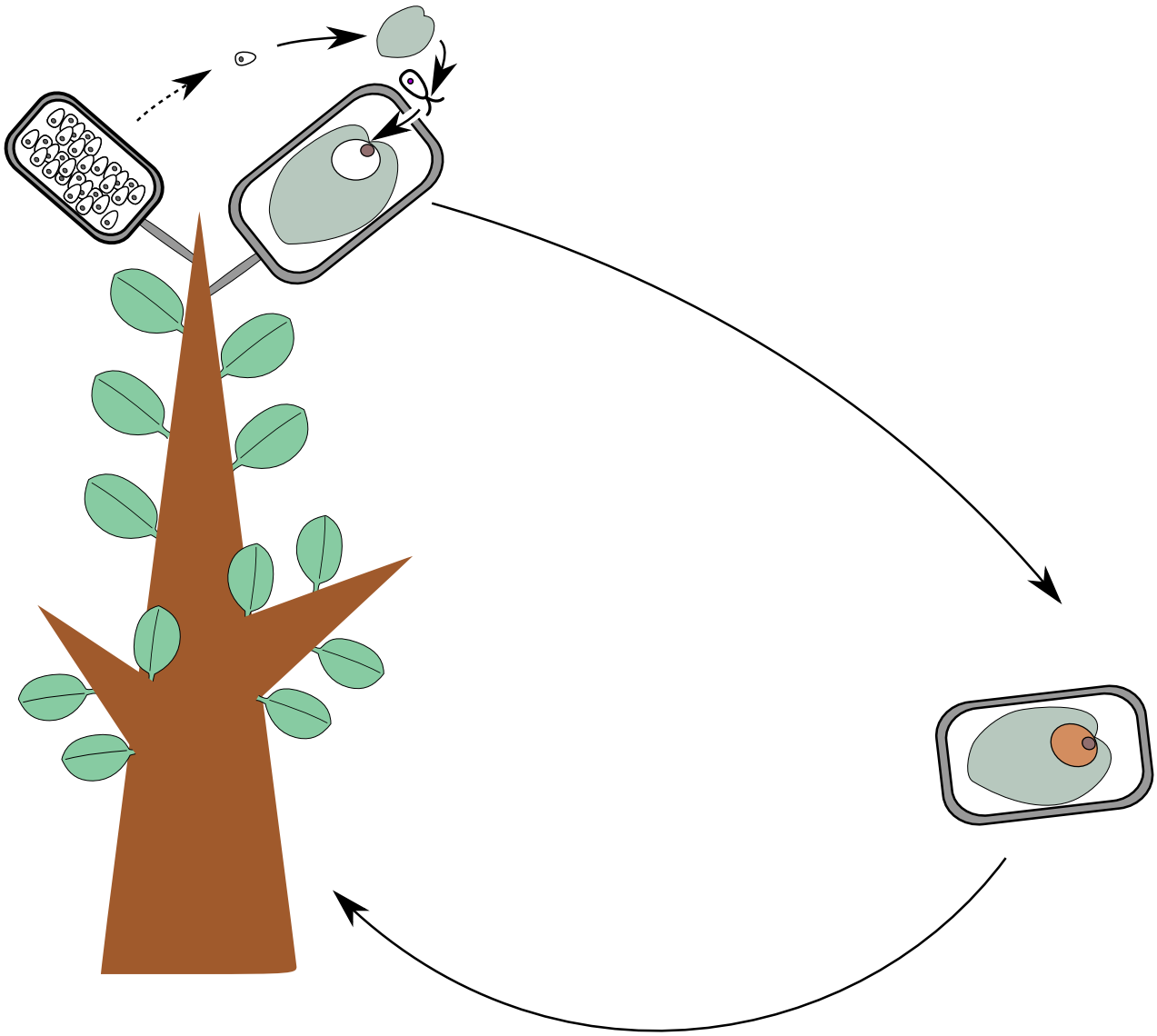
Seed origin: step I, homospory



Seed origin: step II, heterospory



Seed origin: step III, seed

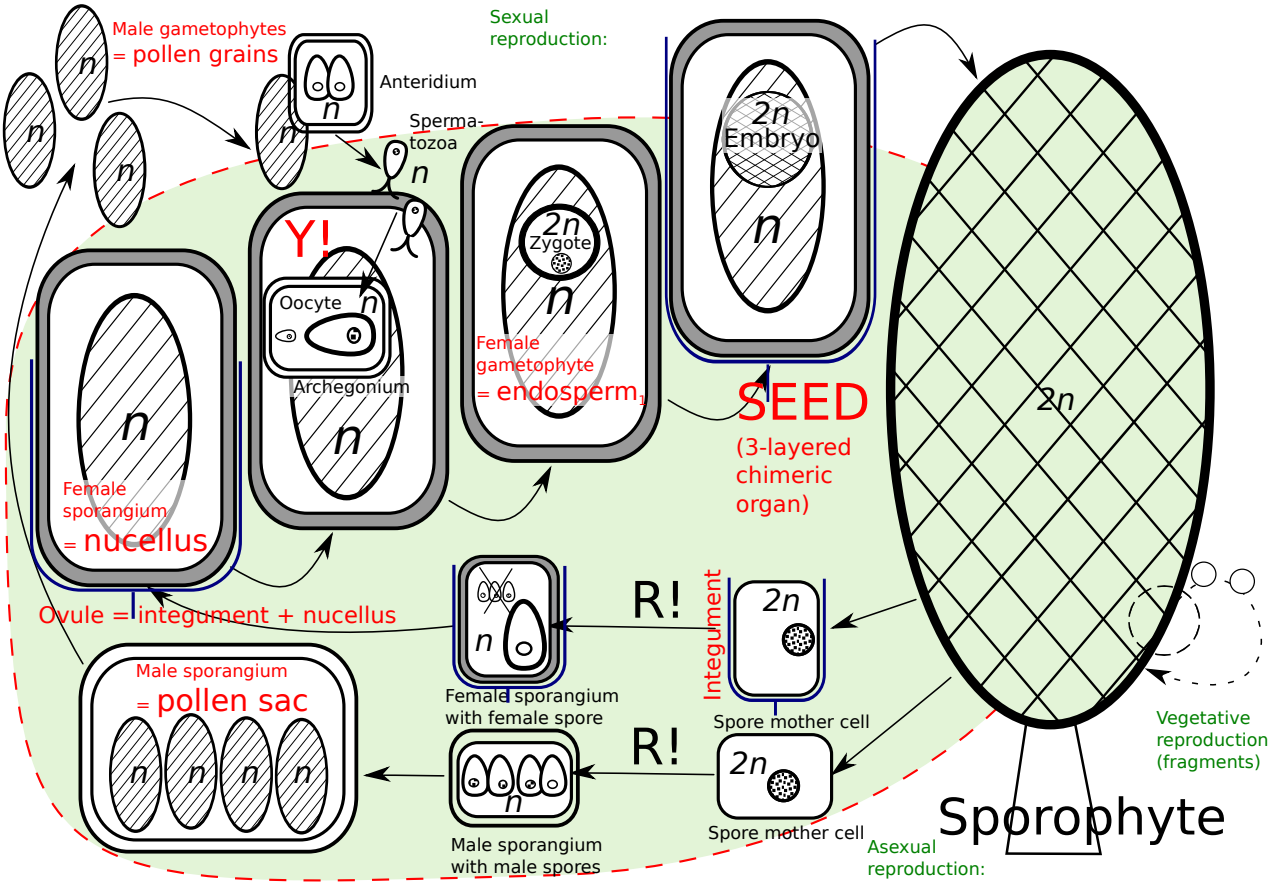


Seed plants have life cycle where almost all stages happen on mother sporophyte

Terms covered:

- Ovule and integument
- Nucellus and pollen sac
- Pollen grains and endosperm
- Seed

Seed plant cycle: differences



Summary: the seed

- Seed is a **chimeric organ** with three layers: (1) mother sporophyte tissue (integument + nucellus), (2) female gametophyte tissue (endosperm) and (3) daughter sporophyte (embryo)
- Biggest disadvantages of having seed are: (a) low probability of fertilization (pollination needed) and (b) overall slowness of cycle
- "Hot spots" of seed life cycle: (1) pollination with wind, insects or anything, (2) fertilization with **pollen tube** and (3) reduction of gametophytes

Final question (2 points)

TBA

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

14 Questions and answers

14.1 Quiz

15 Seed plants

15.1 Diversity of seed plants

Spermatophyta: seed plants

- ≈ 1000 species of non-angiosperms and $\approx 250,000$ species of angiosperms (99.6% of seed plants)
- Sporic life cycle with sporophyte predominance and **seed**
- Gametophyte is reduced to cells inside ovule or inside pollen grain. Minimum number of cells is 3 for male gametophyte (pollen grain) and 4 for female gametophyte (embryo sac of angiosperms). Anteridia are reduced. In angiosperms and Gnetopsida, archegonia are also reduced.
- Sporophyte always starts development from embryo located inside nutrition tissue, endosperm_1 (female gametophyte) or endosperm_2 (second embryo)
- Have axillary buds
- Homoiohydric plants (same as ferns)
- Have secondary thickening

Spermatophyta classes

- **Ginkgoopsida**, ginkgo class
- **Cycadopsida**, cycads
- **Pinopsida**, conifers
- **Gnetopsida**, gnetophytes or chlamydosperms
- **Angiospermae**, or Magnoliopsida, flowering plants

Ginkgoopsida

- Smallest class, only one species (!), Chinese tree *Gigkgo biloba* which became extinct several thousand years ago but saved as a "church tree".
- Distinctive triangle-shaped leaves with dichotomous venation
- Ovules are solitary or paired; microsporangia are in catkin-like structures; has sexual chromosomes (!)
- Pollen grains produce two mutli-flagellate spermatozoa which swim to large oocyte
- Seeds are fruit-like (generally edible), become ripe laying on a ground for a long time
- Almost no phytophagous insects damage *Ginkgo* leaves; the fungal symbiont of *Ginkgo* also belongs to separate class inside basidiomycetes, Bartheletiomycetes.

***Ginkgo biloba* ovules**

***Ginkgo biloba* male organs**

***Ginkgo biloba* seeds**

Cycadopsida

- Two families, dozen genera and ≈ 300 species distributed mostly in tropics
- Palm-like plants, with large (and usually very rigid) pinnate leaves
- Stem structure is not similar to conifers and *Ginkgo*; cycads have large pith and anomalous secondary thickening via multiple cambium rings
- Ovules are attached to modified leaves (sporophylls) and usually gathered in large upright cones; microsporangia are always in cones
- Also have multi-flagellate spermatozoa, archegonia and large oocyte
- Large seeds are animal-distributed; life cycle is extremely slow (several years from initiation of cone to germination of seed).

Cycadopsida families

- Two families, sometimes even placed in different orders:
  - Cycadaceae, whith only genus *Cycas*. They do not have female cones, ovules are attached to leaves which are not radically modified. Leaves have fiddleheads (same in ferns!).
  - Zamiaceae, with all other genera (*Zamia integrifolia* is native to USA). Have female cones.

***Cycas* sp.: young leaflets form fiddleheads**

Male *Cycas* sp. in dry season

***Cycas* sp. seeds**

***Encephalartos gratus* (Zamiaceae)**

***Zamia integrifolia* (Zamiaceae)**

15.2 "Higher" seed plants

Spermatophyta classes

"Lower":

- **Ginkgoopsida**, ginkgo class
- **Cycadopsida**, cycads

"Higher":

- **Pinopsida**, conifers
- **Gnetopsida**, gnetophytes or chlamydosperms
- **Angiospermae**, or Magnoliopsida, flowering plants

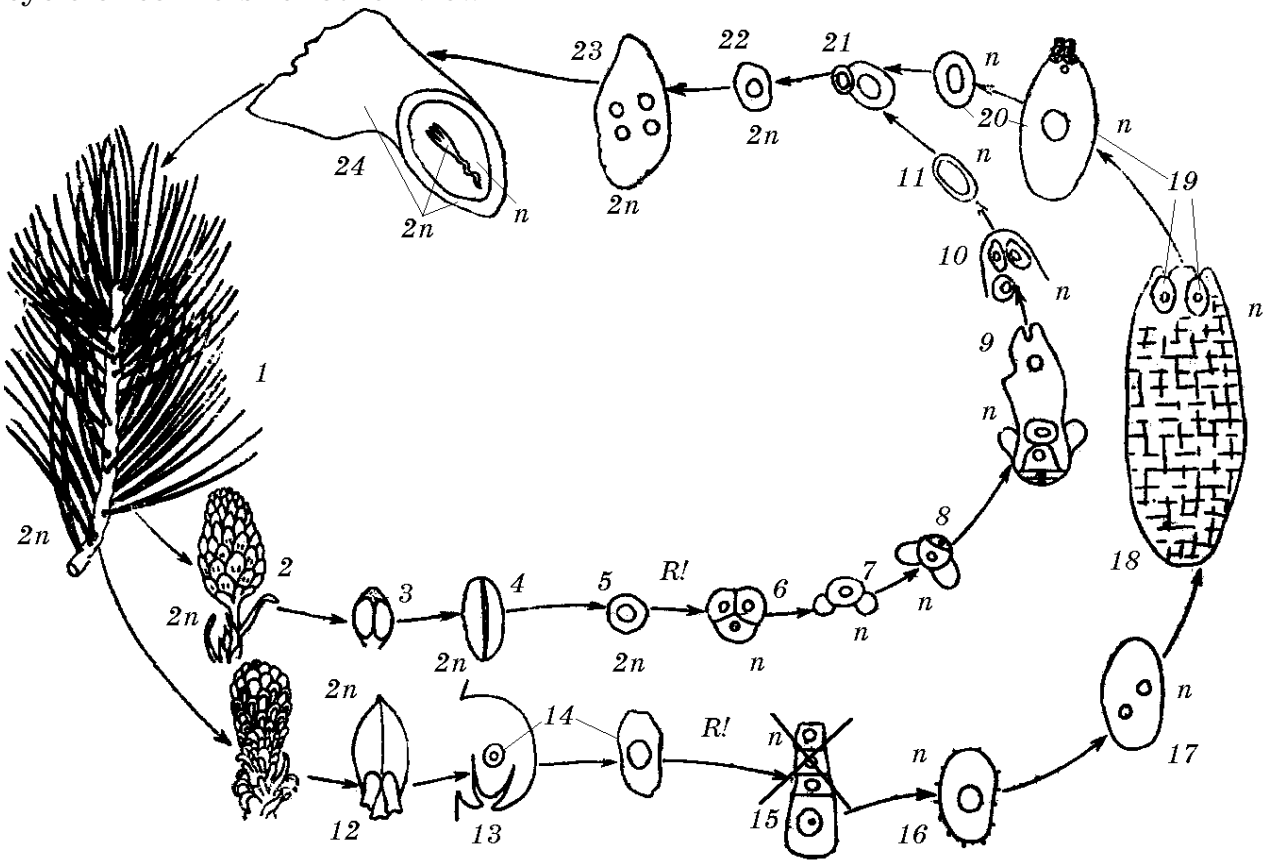
15.3 Conifers

Pinopsida

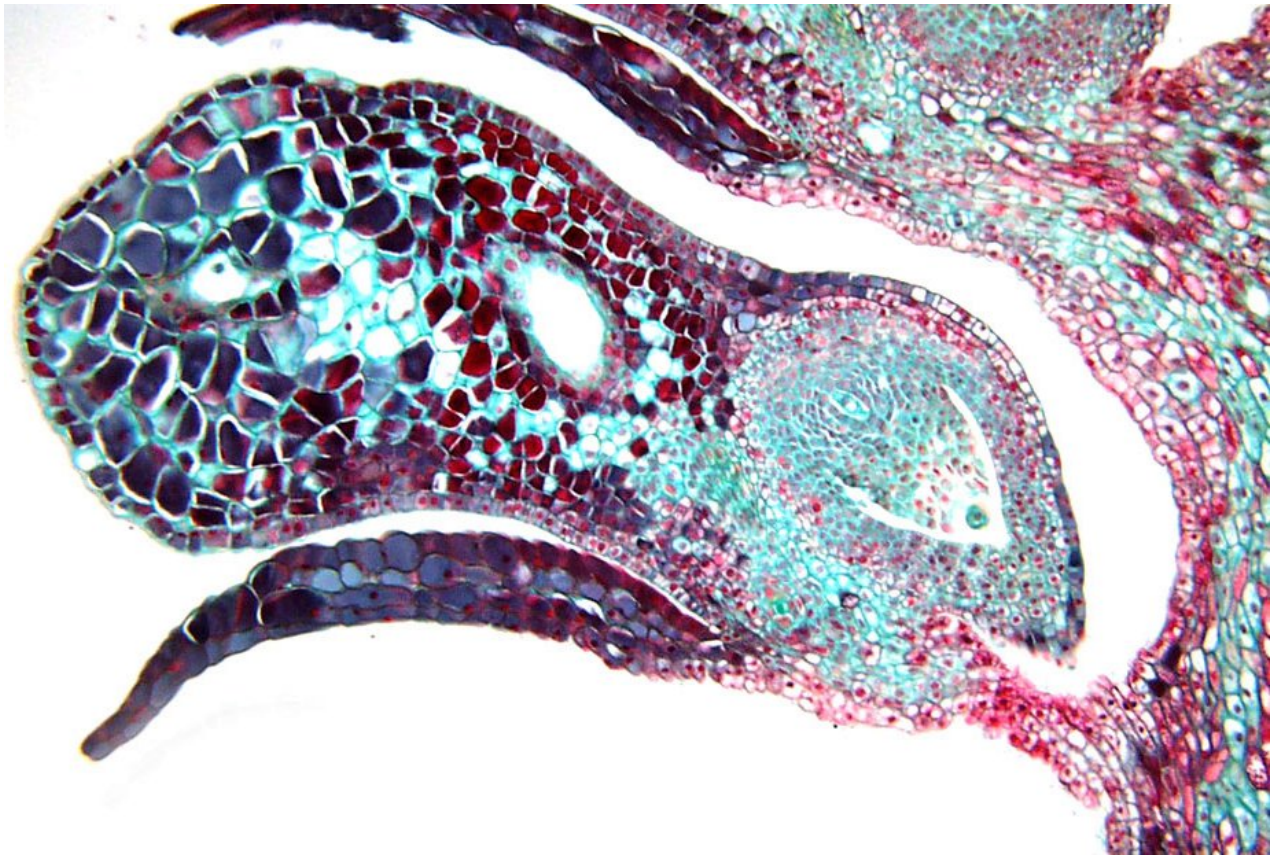
- Three orders, several families and ≈ 300 species
- Mostly temperate evergreen trees, but some are deciduous (like *Larix*, *Pseudolarix*, and part of Cupressaceae)

- Stem with large amount of xylem, relatively small cork and minute pith
- Ovules are always attached to specialized leaves (seed scales) and together with bract scales they are compacted in cones; microsporangia are attached to microsporophylls and also occur in cones of simpler structure
- Male gametes without flagella (spermatia), consequently, pollen grains grow into **pollen tubes**
- Female gametophyte is more reduced than in cycads and *Ginkgo*
- Seeds are wind- and animal-distributed, life cycle shorter but still up to two years

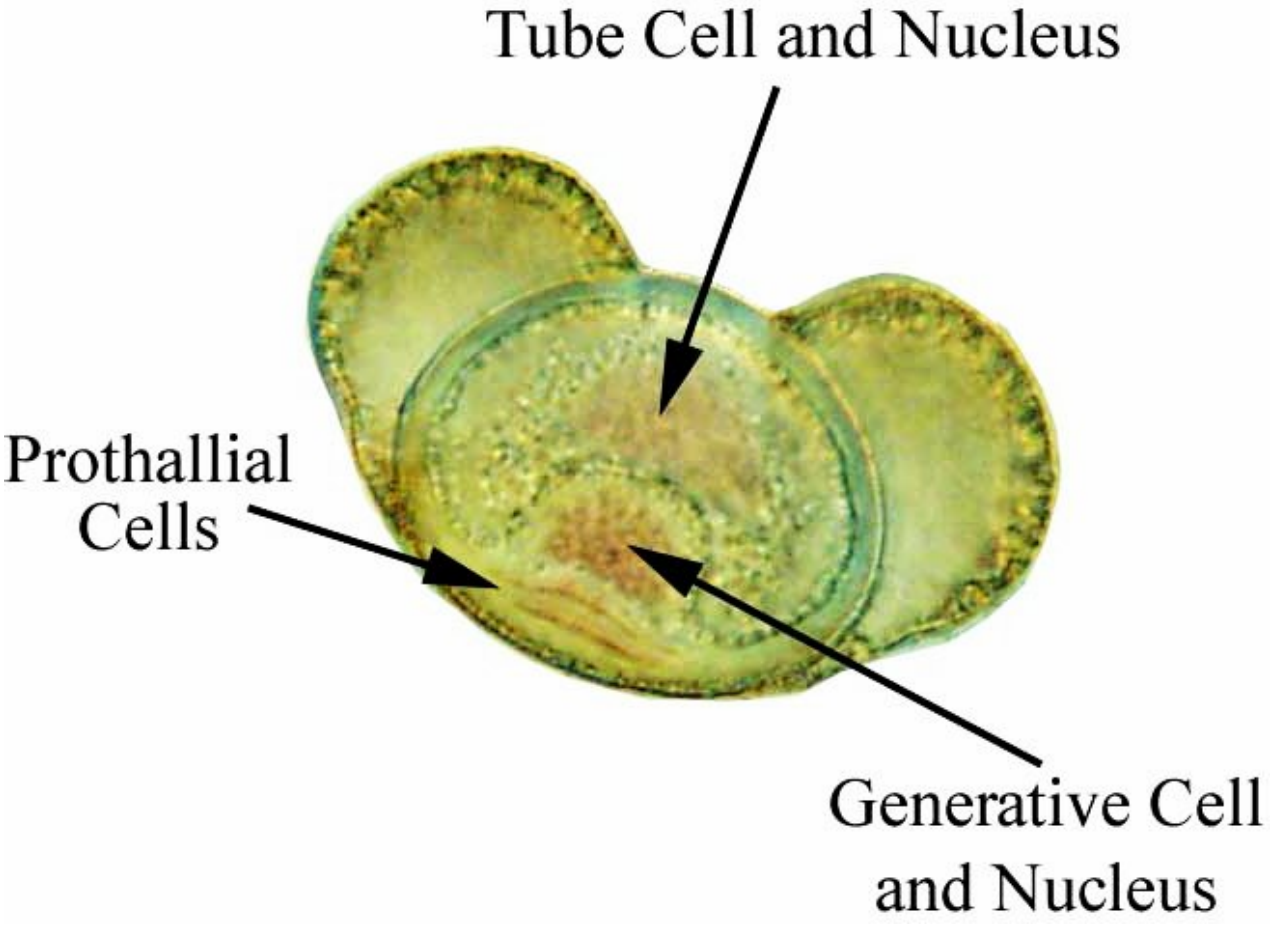
Life cycle of conifers: another view



Bract scale, seed scale and ovule



Pollen grain



Pinopsida orders and families

- Pinales
  - **Pinaceae**.
- Araucariales—grow mostly in tropics or in South Hemisphere.
  - Araucariaceae
  - Podocarpaceae
- Cupressales
  - Sciadopityaceae
  - Cupressaceae (incl. Taxodiaceae)
  - Cephalotaxaceae
  - Taxaceae

Pinaceae

- Have resin and needle-like leaves, often in shortened shoots, **brachyblasts**. Large cones with paired (seed and bract) scales.
- Biggest conifer family, include large genus *Pinus* (pine) and other genera like *Larix* (larch), *Cedrus* (cedar), *Picea* (spruce), *Abies* (fir) etc.

Cupressaceae and Taxaceae

- **Cupressaceae**—cypress family. No resin. Cones are small, with fused bract and seed scales. Leaves are dimorphic, needle-like and scale-like. Part of genera (formerly belong to Taxaceae family) are deciduous but with branches instead of leaves. Genera: *Cupressus* (cypress), *Juniperus* (juniper), *Taxodium* (bald cypress), *Sequoia* (coastal red cedar), *Sequoiadendron* (mountain red cedar), *Metasequoia* etc.
- **Taxaceae**—yew family. Female cones are modified in berry-like structures with one enlarged red scale. Leaves are needle-like. No resin. *Taxus* (yew) provides famous reddish-brown, springy wood.

***Pseudolarix amabilis* (Pinaceae), spring**

Sequoia sempervirens **(Cupressaceae)**

***Taxus baccata*, Taxaceae**

15.4 Gnetophytes

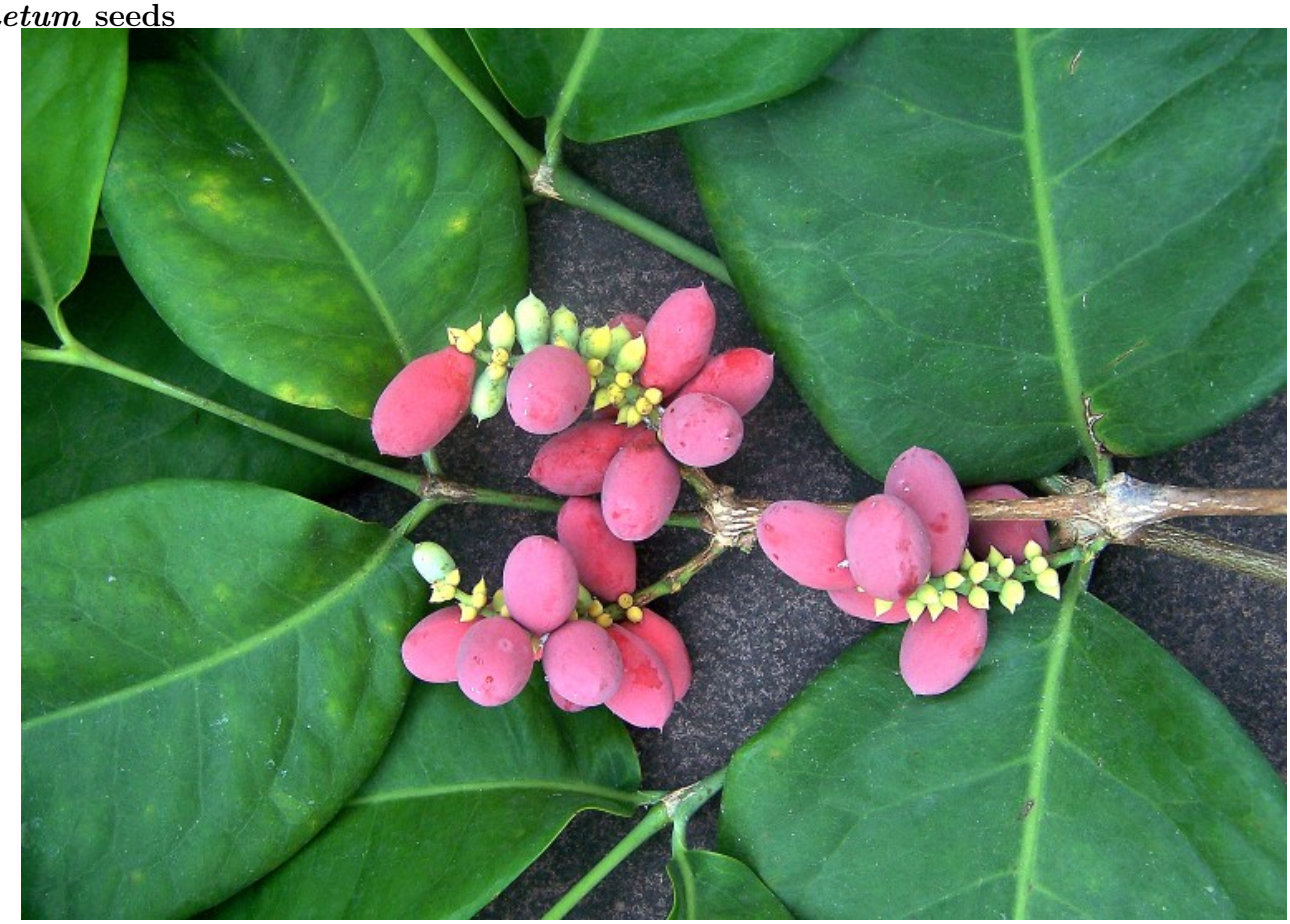
Gnetopsida

- Small class of only three genera (*Ephedra*, *Welwitschia*, *Gnetum*), which are so different that botanists place them in different orders (and sometimes even subclasses).
- Tropical trees (*Gnetum*) or desert shrubs (*Ephedra*) or nobody-knows-what (*Welwitschia*)
- Stem structure is similar to conifers but *Gnetum* and *Welwitschia* have vessels (like angiosperms)
- Ovules are solitary, **covered with additional outer integument** (however, **this is not a pistil** because micropyle come out of this cover)
- Male gametes are spermatia, have pollen tube and **no archegonia** in *Gnetum* and *Welwitschia* (like in angiosperms). Multiple fertilization an polyembryony is widespread, *Ephedra* and *Gnetum* even has a double fertilizarion (like angiosperms). Only one embryo survives, other are eaten (endosperm$_2$). Also have endosperm$_1$ (female gametophyte).
- *Welwitschia* is insect-pollinated, other are wind-pollinated like most non-angiosperms.
- Seeds are animal-dispersed (except *Welwitschia*).
- Amazingly, molecular data show relations with conifers, not with angiosperms!

Gnetum

- Tropical shrubs, vines or small trees (30–35 species) with opposite leaves with pterodromous venation (like angiosperms again!). However, investigation of leaf development showed that initially leaf had dichotomous venation (like *Ginkgo* and some conifers).
- Dioecious plants, male and female structures (fructifications) are catkin-like
- Seeds big, colored

***Gnetum* seeds**



***Gnetum* female fructifications**

***Gnetum* male fructifications**

Welwitschia

- One species occurring in Namibian desert (South Africa)
- Life form is completely unusual, the best description is "overgrown seedling": small trunk with only two (constantly growing on the basement and degrading on top) wide leaves with parallelodromous venation. Secondary thickening anomalous (like in cycads). Wood with vessels.
- Insect-pollinated (!) dioecius plants
- Fructifications are cone-like; male one is similar to flower and contain sterile ovule (!)
- Seeds are wind-dispersed

Welwitschia

Welwitschia

***Welwitschia* female cones**

Welwitchia male cones

***Welwitchia* pollinators: *Odontopus sexpunctulatus* bug**

Ephedra

- $\approx$ 35 species growing in dry places across all North Hemisphere and also in South America
- Shrubs or small trees, leaves are usually reduced to scales, stems are articulate (like horsetails). Wood is similar to conifers.
- Plants are monoecoius or dioecious, male and female (bisexual also occur) fructifications are short, covered with thick scales
- Wind-pollinated, animal dispersed
- *Ephedra sinensis* is a source of pharmaceutically important **ephedrine**
- In all, *Ephedra* is more primitive than two other genera of Gnetopsida: wood does not contain vessels, ovule has large archegonia

Ephedra

***Ephedra nevadensis*, female fructification**

***Ephedra nevadensis*, male fructification**

***Ephedra* seeds**

15.5 Flowering plants

Flowering plants are "Spermatophyta 2.0"

- Reduction of gametophyte: 3-celled pollen and 7-celled embryo sac
- No archegonia and anteridia
- Spermatia, pollen tube
- Double fertilization
- New endosperm (second embryo)
- Cupule (pistil) and fruit
- In general, **angiosperms have accelerated life cycle** needed for fast-growing herbs

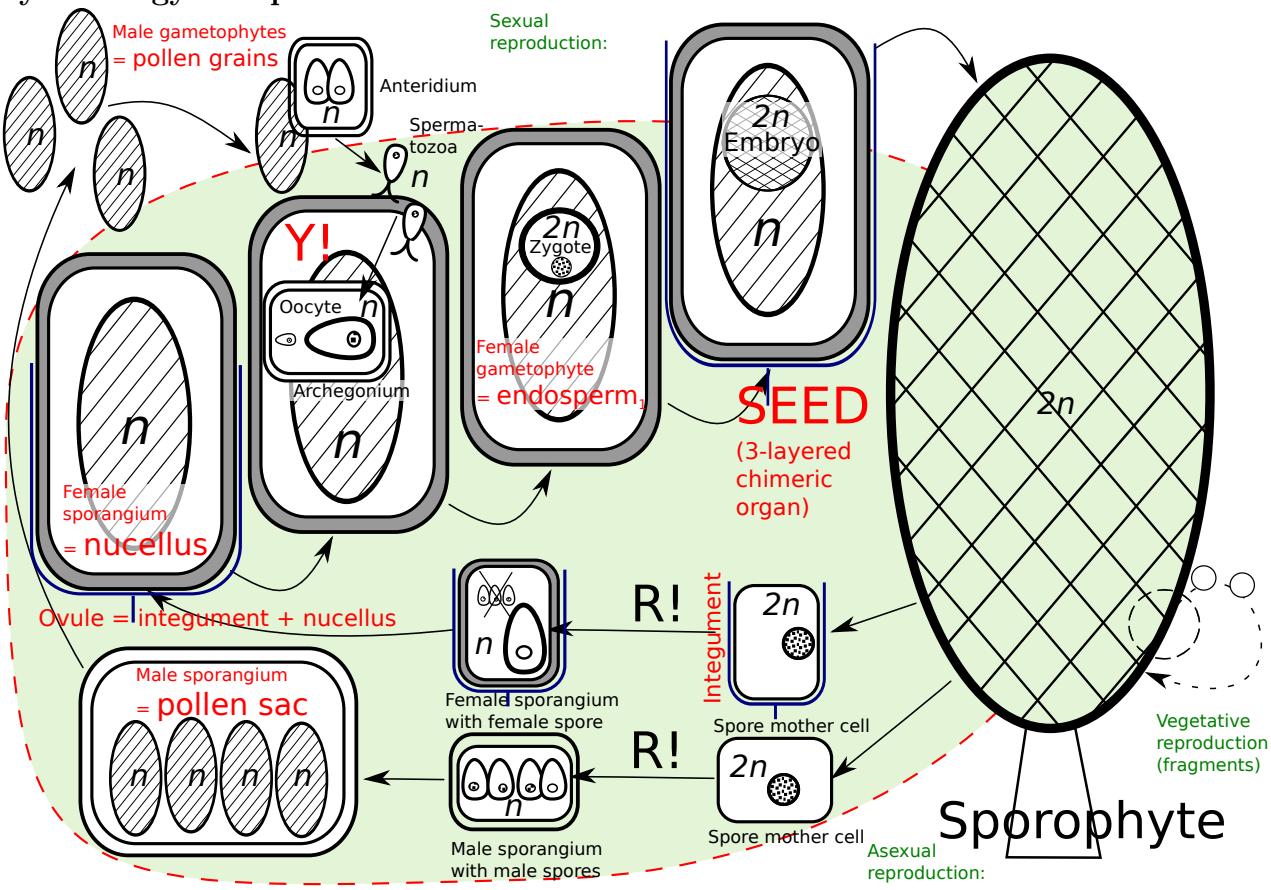
Note: angiosperms = flowering plants = class Magnoliopsida

Life cycle of angiosperms

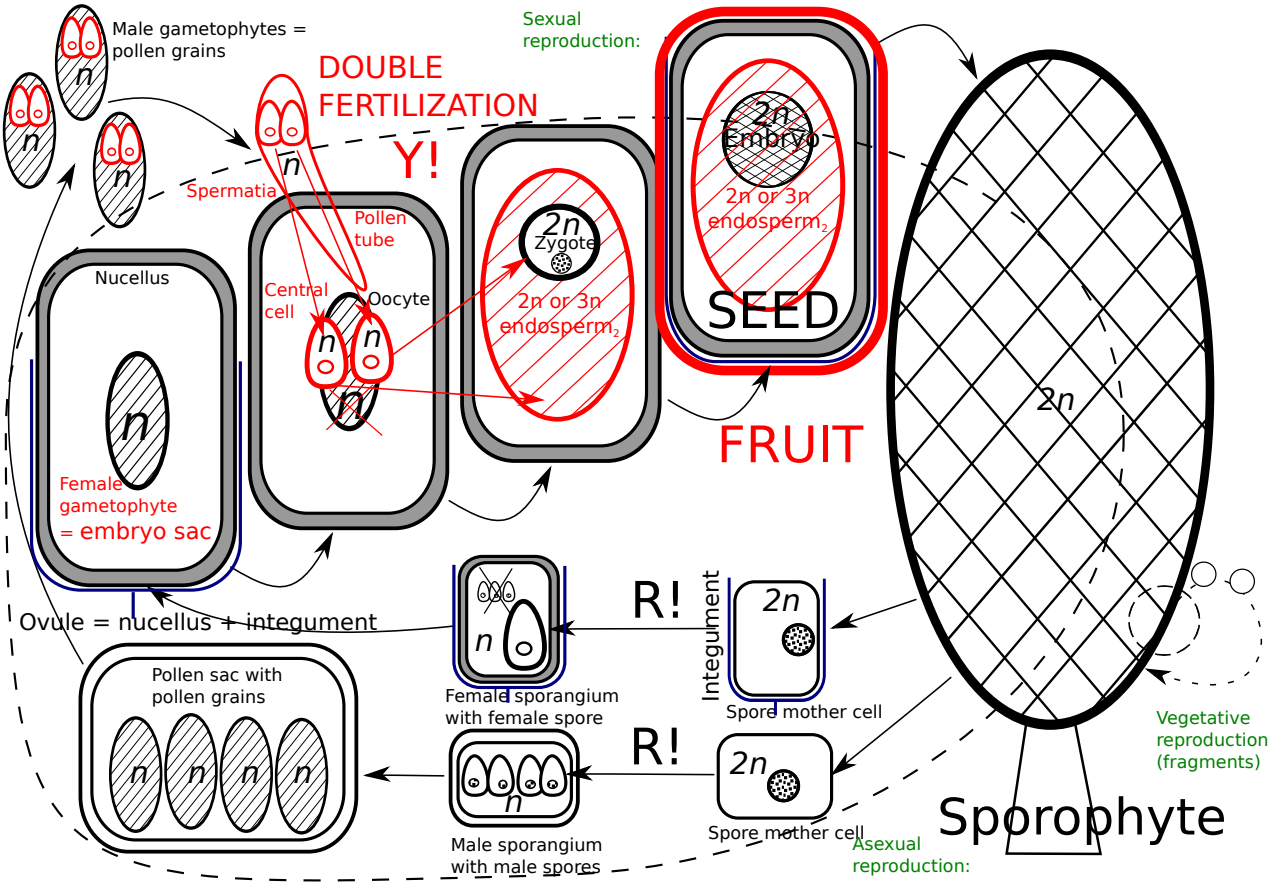
Terms covered:

- Embryo sac, central cell
- Spermatia (sperms without flagella), pollen tube
- Double fertilization
- Pistil and ovule → fruit and seed

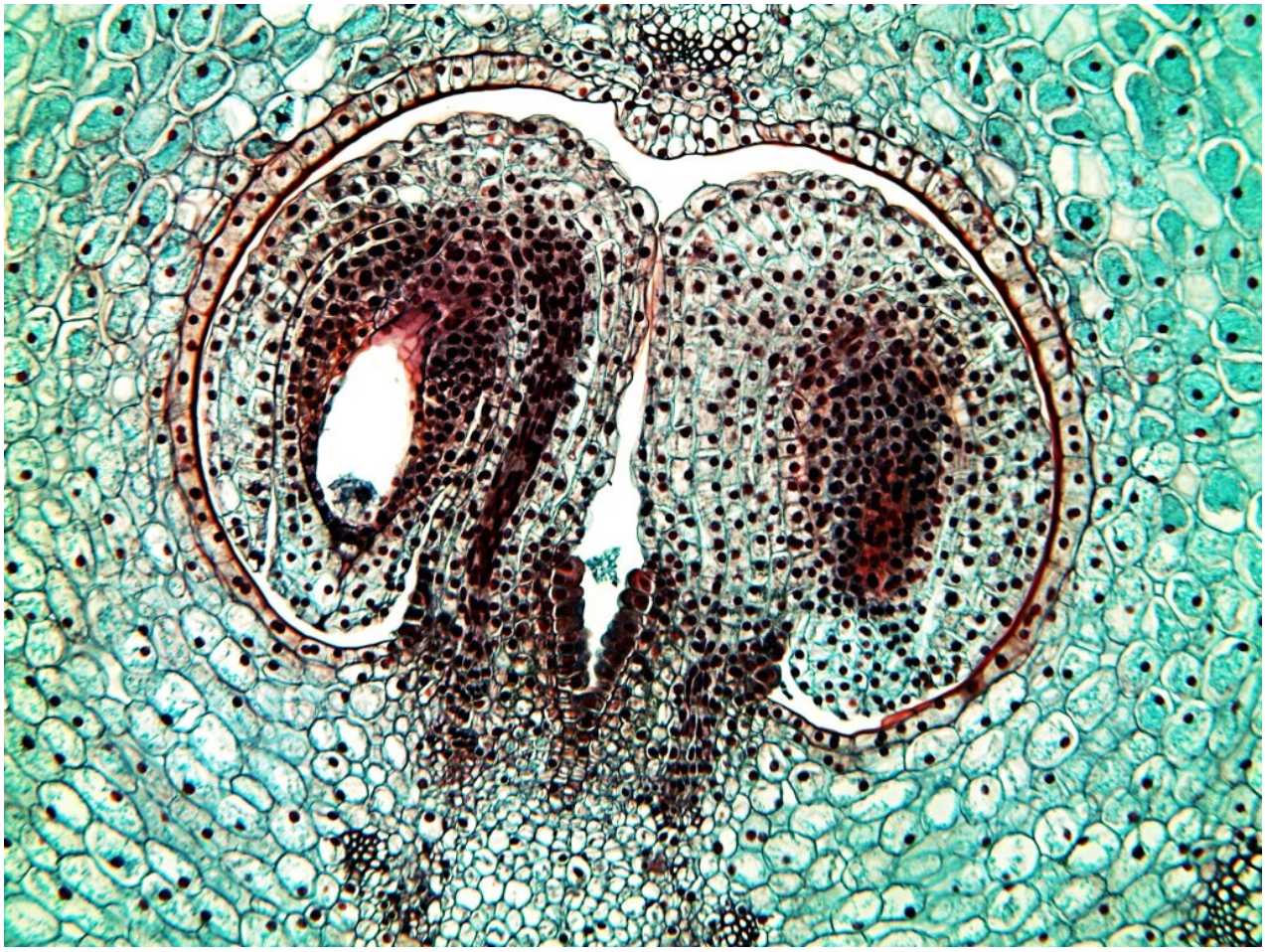
Life cycle of "gymnosperms"



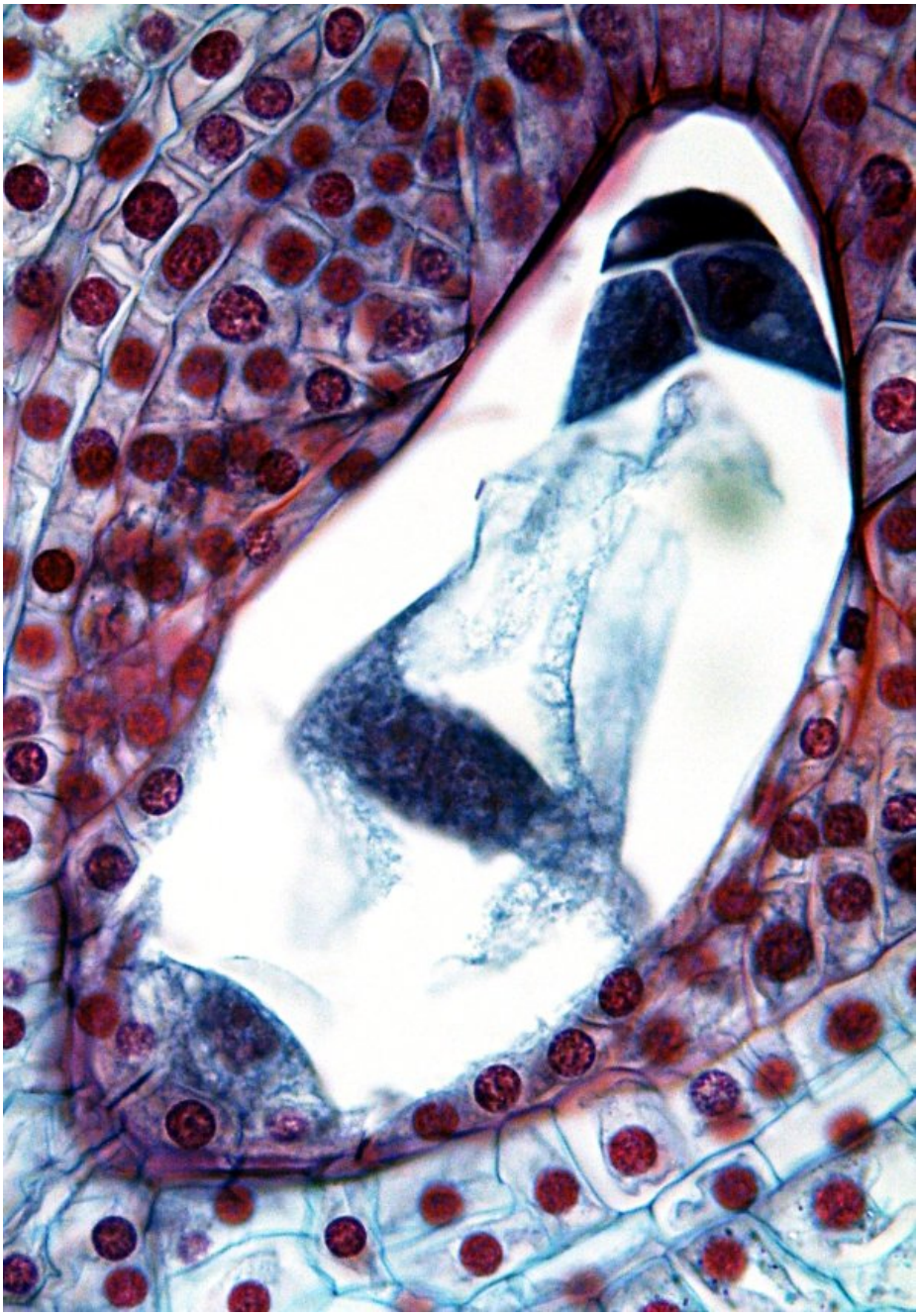
Life cycle of angiosperms: differences



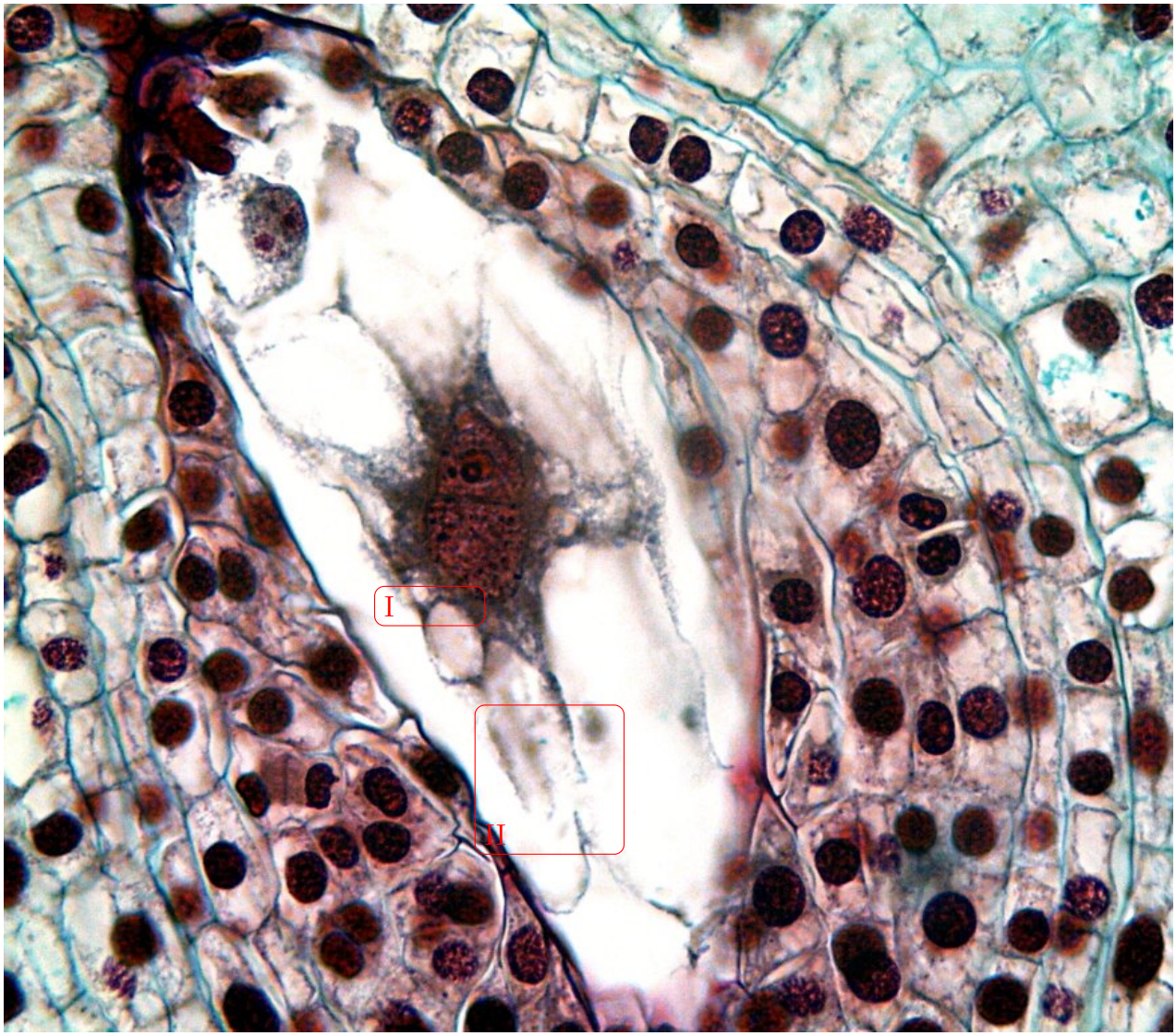
Ovules (*Lilium* sp., lily)



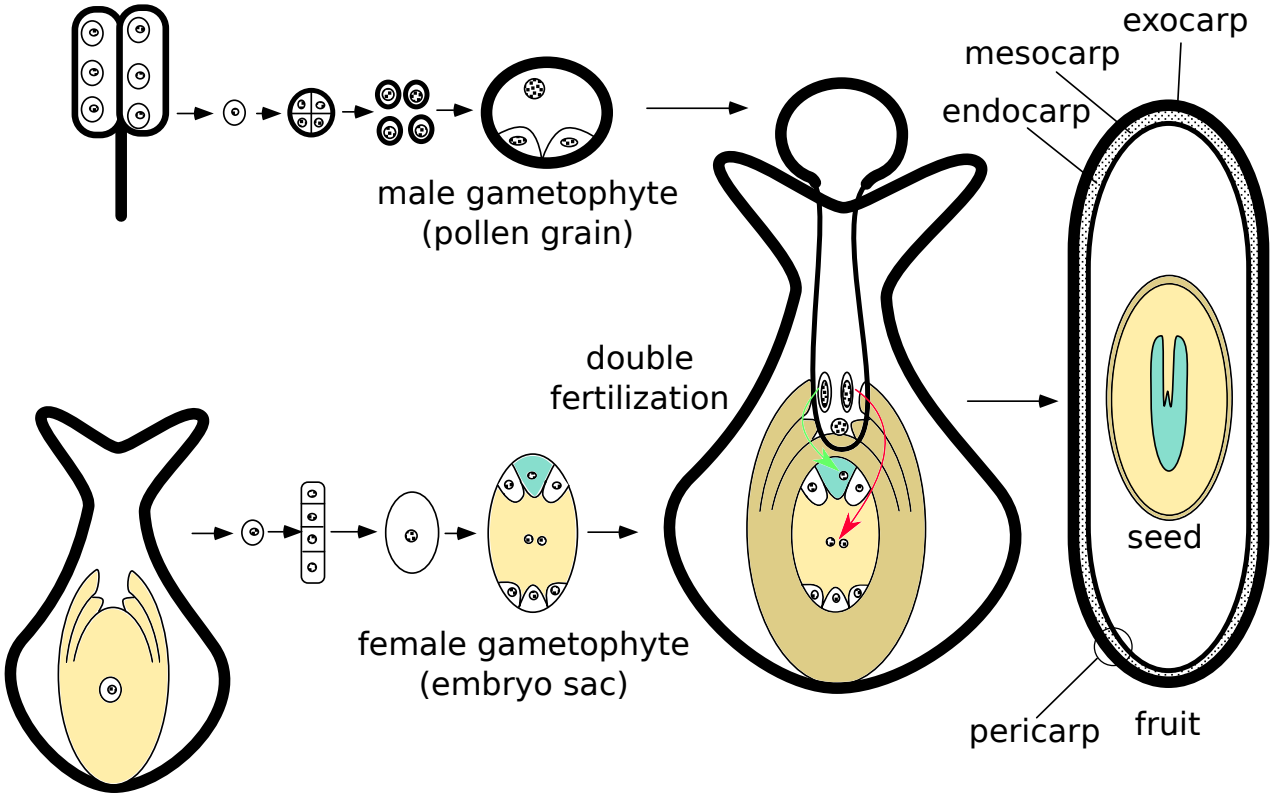
Embryo sac (*Lilium* sp., lily)



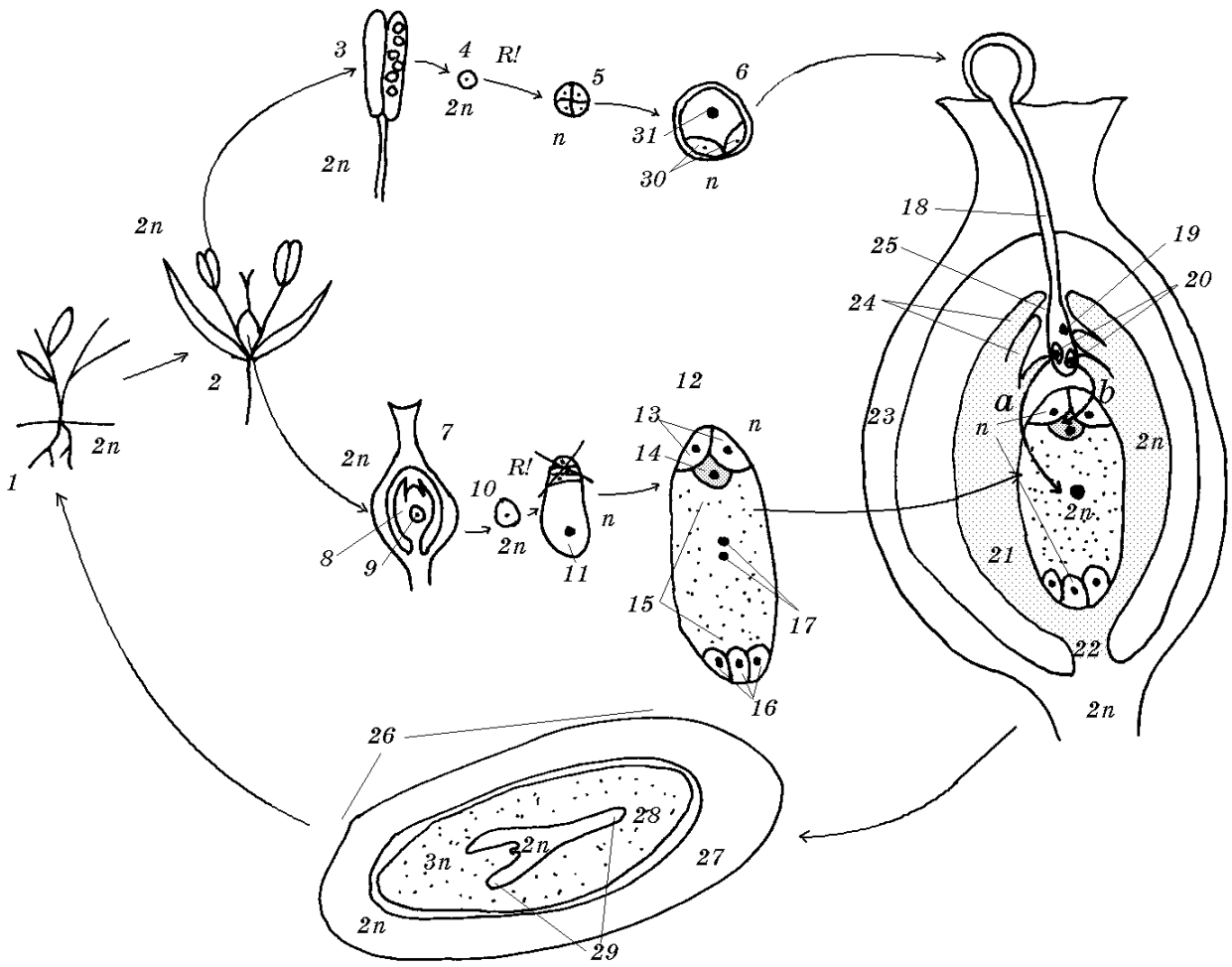
Double fertilization (*Lilium* sp., lily)



Angiosperms: relations between structures



Life cycle of angiosperms: another view



15.6 Class Magnoliopsida, or Angiospermae

Angiosperms in general

- Names: Magnoliopsida, Angiospermae ("angion" is a "bottle"), angiosperms, flowering plants
- 250,000 species, more than 90% of all plants diversity, the diversity is comparable with mollusks (200,000) and arthropods ($\approx 1,000,000$) and much more than fungi (75,000) and vertebrates (30,000)
- $\approx$ 300 families and $\approx$ 40 orders
- Grow everywhere except open ocean and central Antarctic

Diagnostic characters of angiosperms

- Flower
- Angiospermy
- Stigma
- Double fertilization:

  - 1st sperm cell (1st spermatium, n) + egg cell (n) = zygote ($2n$)
  - 2nd sperm cell (2nd spermatium, n) + central cell ($2n$ or sometimes n) = mother cell of endosperm$_2$ ($3n$ or sometimes $2n$)

  Second fertilization is a **signal** that first fertilization has been occurred. Endosperm$_2$ develops from the "signalized" female gametophyte.

- Fruit
- Parcellation

In all, any of these characters taken alone is not unique, but together they delimit the group

15.7 Flower

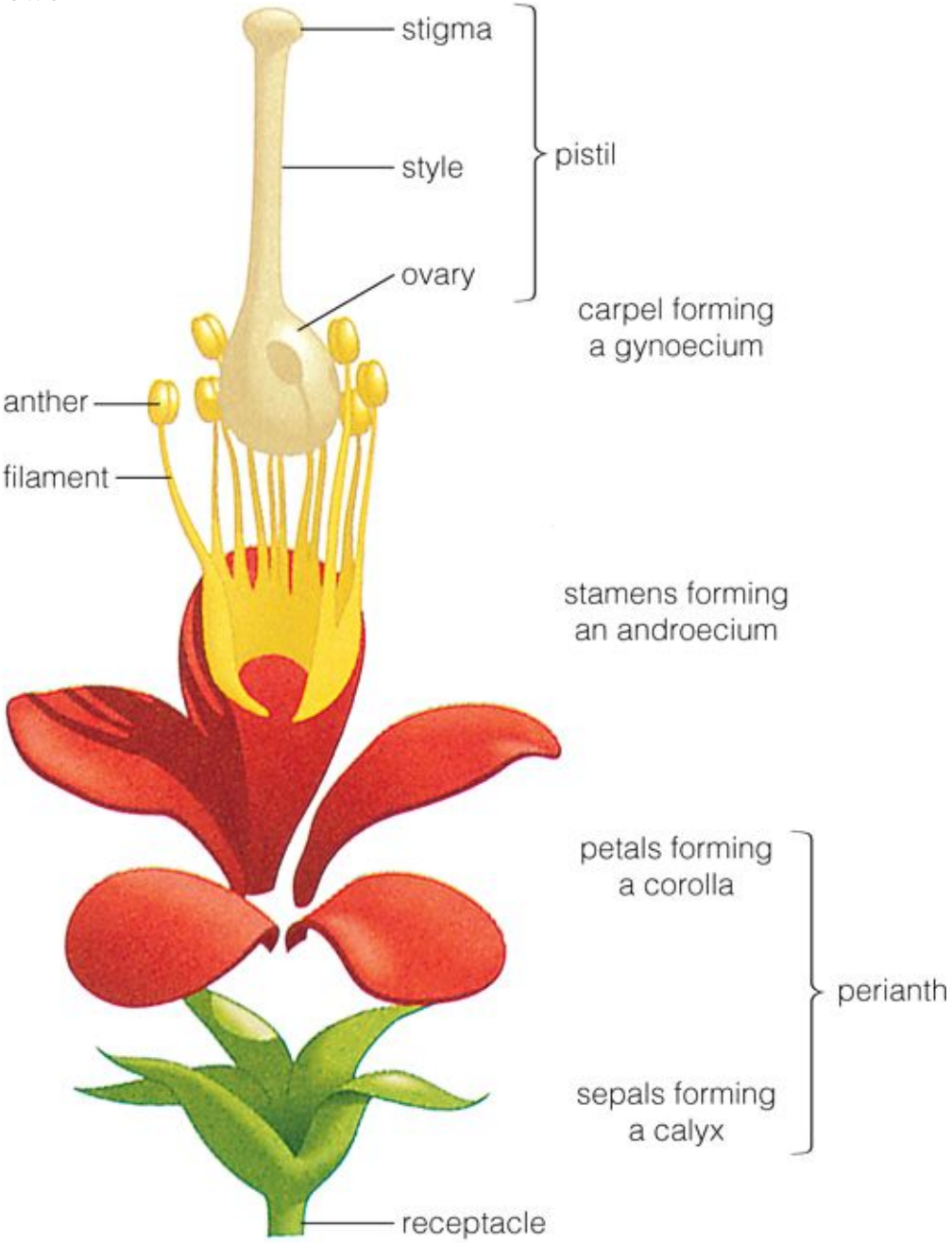
Definition of flower

- Compact generative shoot (= floral unit, FU) with three zones
- Three main zones: sterile (perianth), male (androecium) and female (gynoecium)
- General characters: sex, merosity, symmetry, position of gynoecium

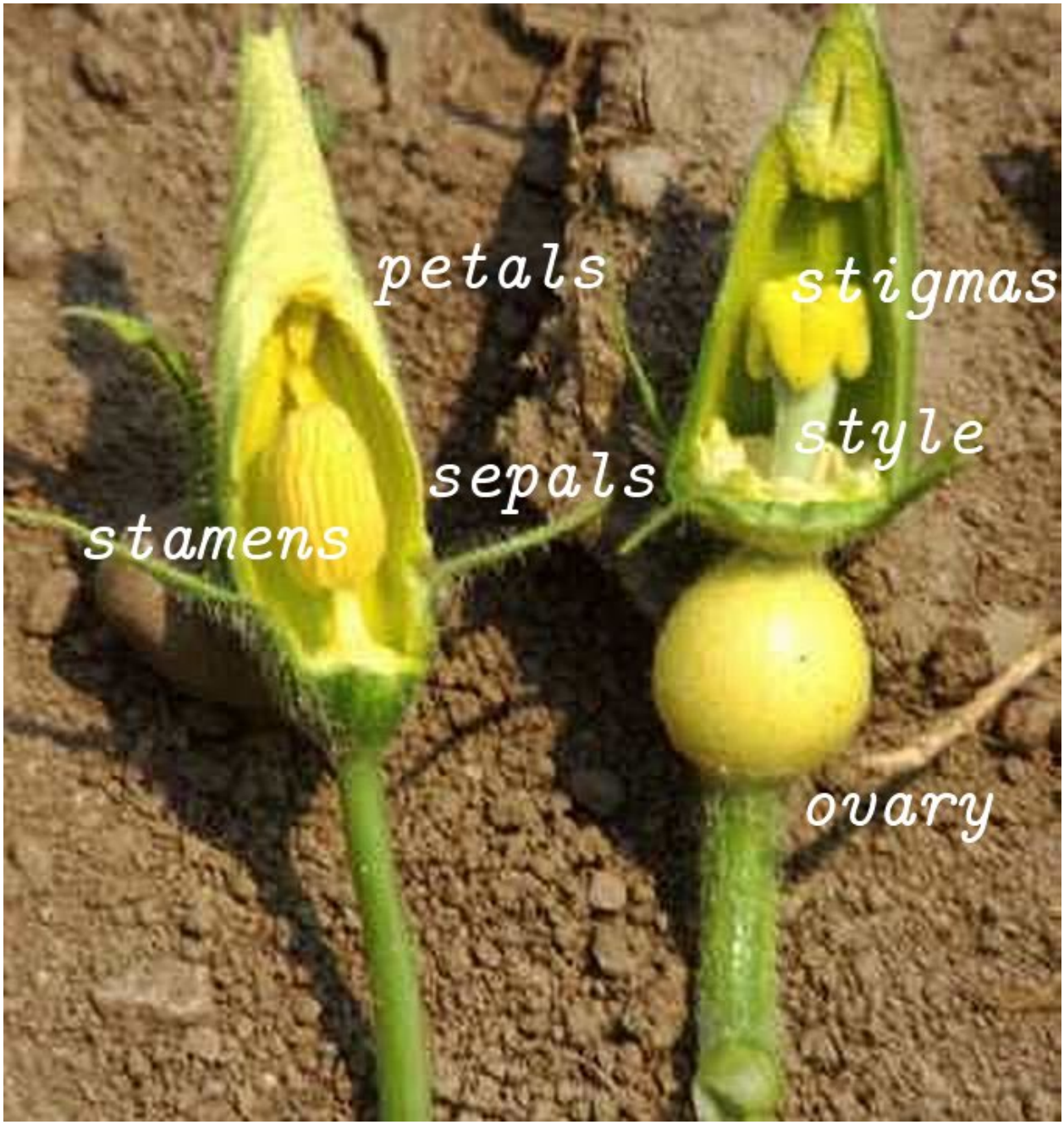
Structure of flower

- Perianth (consists of tepals)
  - Frequent case: double perianth
    - Calyx (consists of sepals)
    - Corolla (consists of petals)
- Androecium (consists of stamens)
  - Filament
  - Anther (consists of pollen sacs)
- Gynoecium (consists of pistils)
  - Ovary (consists of carpels)
  - Style
  - Stigma

Structure of flower



Pumpkin (*Cucurbita pepo*) flower

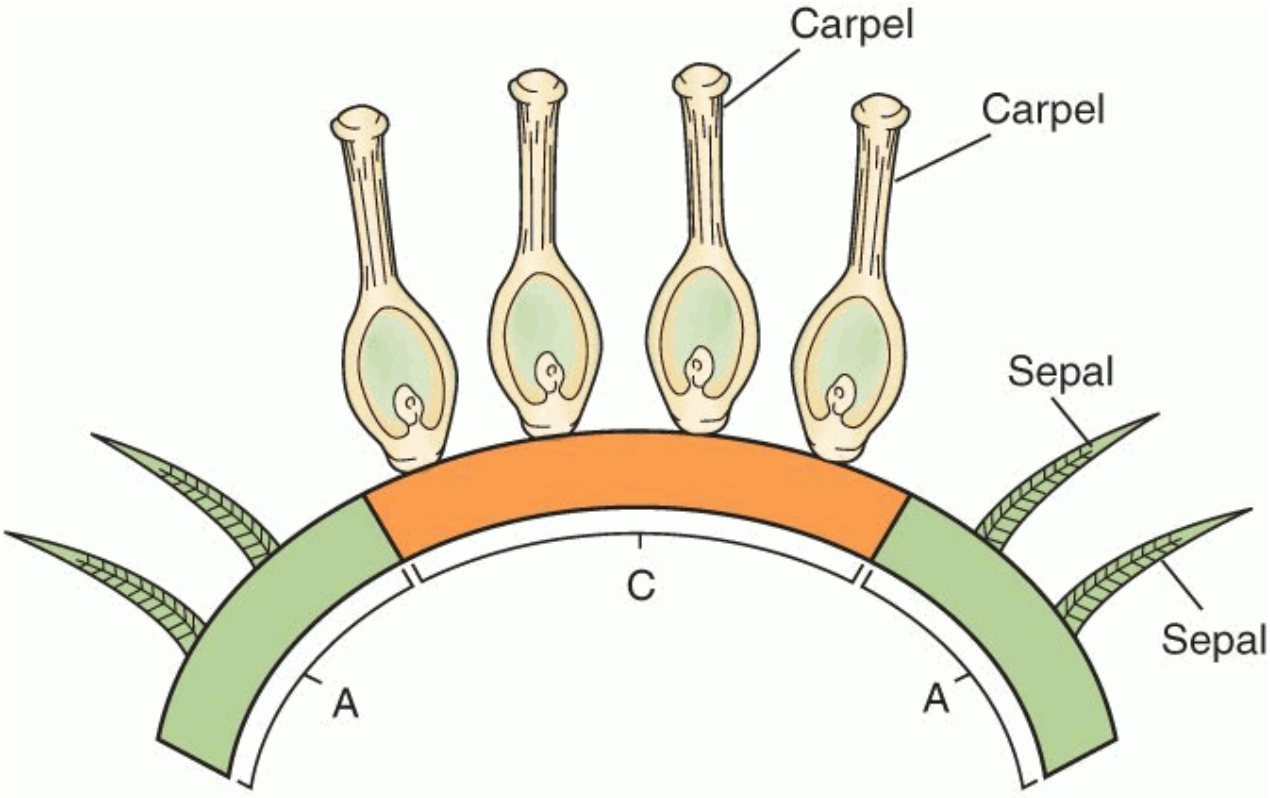


15.8 Flower development: ABC model

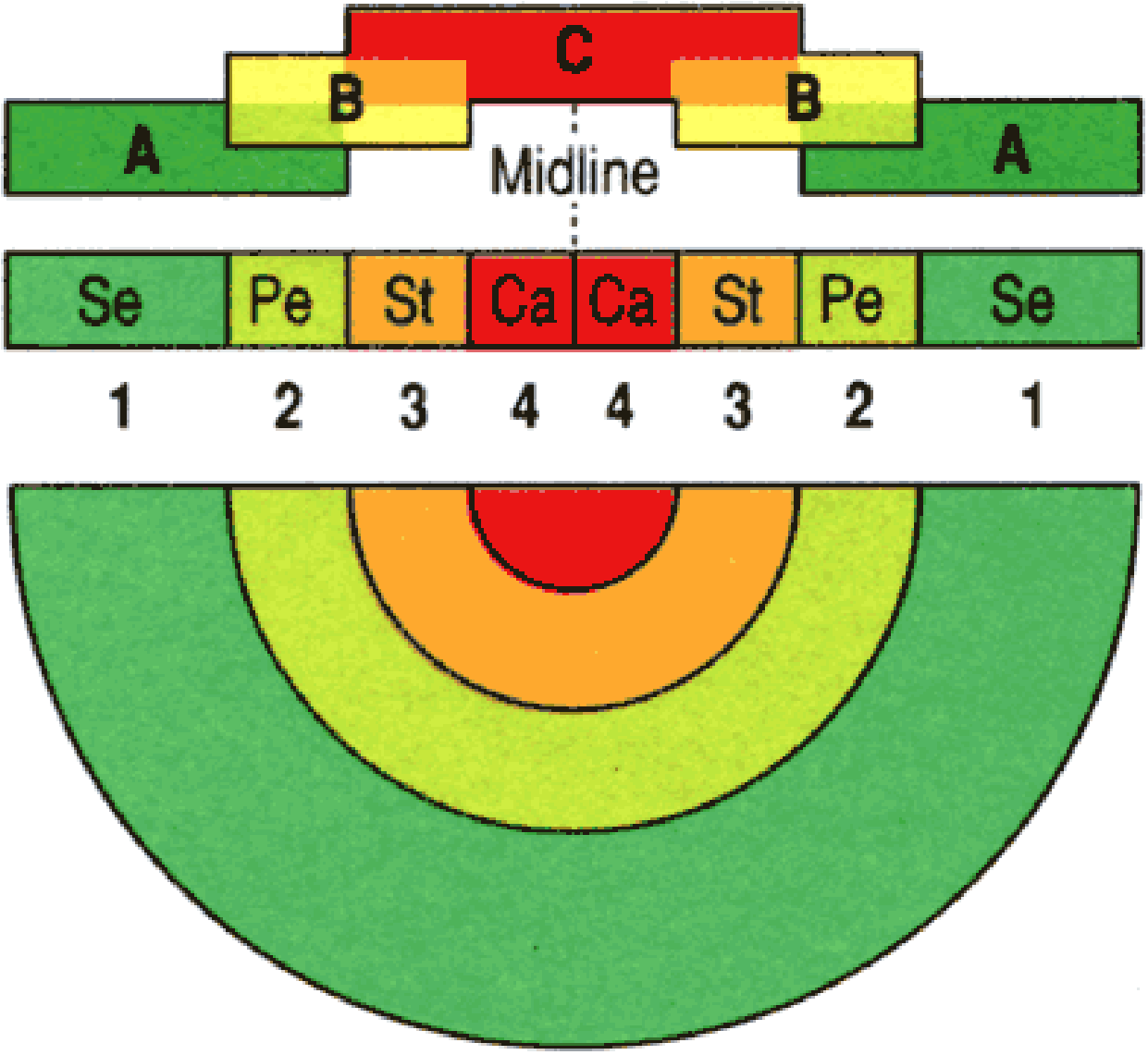
ABC-genes

- There are 3 classes of genes expressed in overlapping, concentric rings.
- The A class (like *apetala2* gene) is expressed in the outermost ring and C (like *agamous*) is expressed in the center; B (e.g., *apetala3*) is expressed at the boundary of A and C:
  - A alone → calyx
  - A + B → corolla
  - C + B → androecium
  - C alone → gynoecium

A and C genes "make" sepals and pistils



B genes "transform" them into petals and stamens



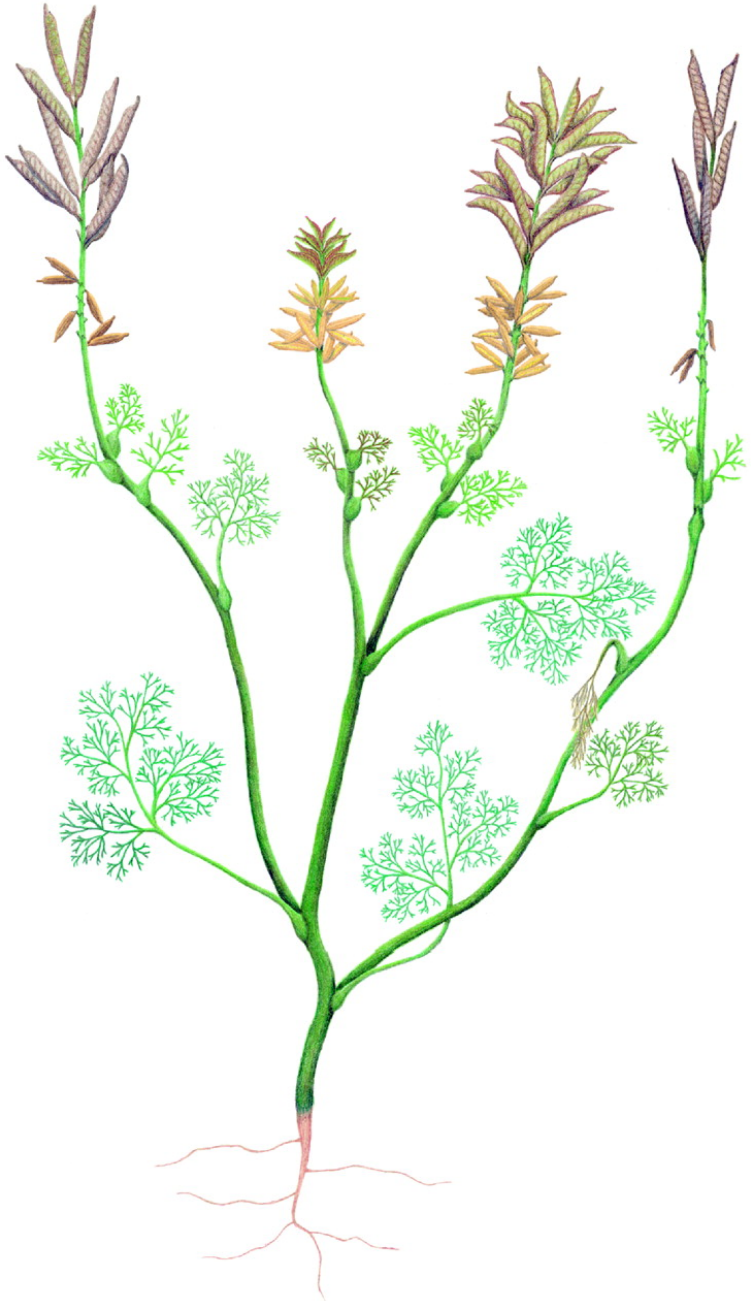
Corresponding *Arabidopsis* mutants:

15.9 Primitive flowers

Archaefructus

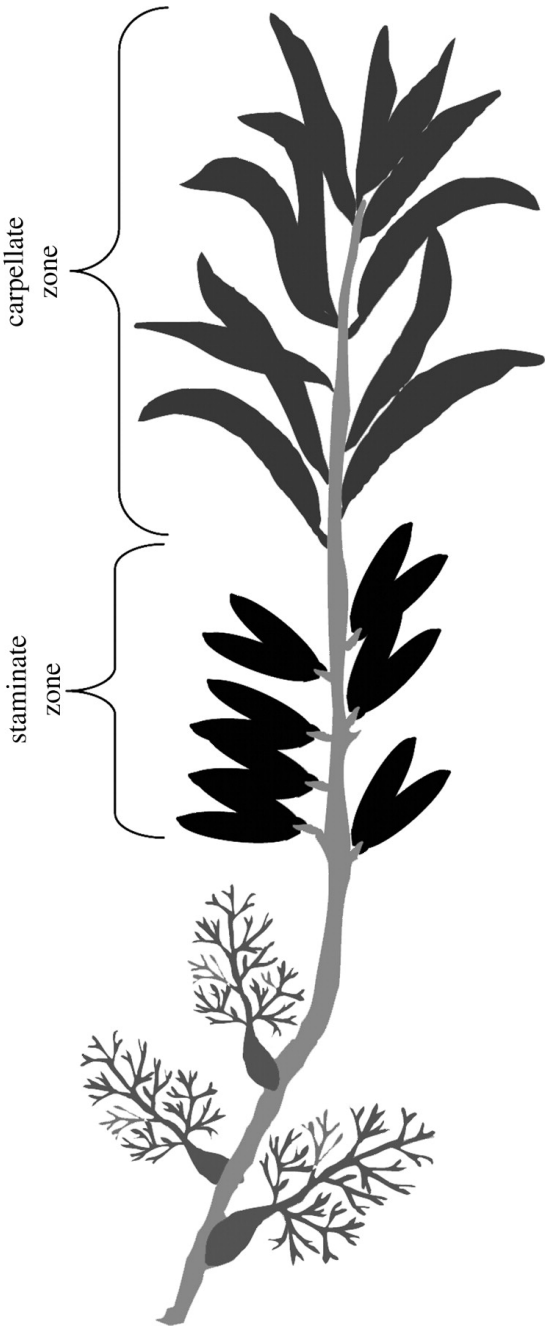
- Fossil water plant from lower Cretaceous of China
- Very primitive fructifications which are not yet compacted in flower
- Multiple free carpels, paired stamens

***Archaefructus* reconstruction**



***Archaefructus* reconstruction, 3D**

***Archaefructus*, scheme of "flower"**



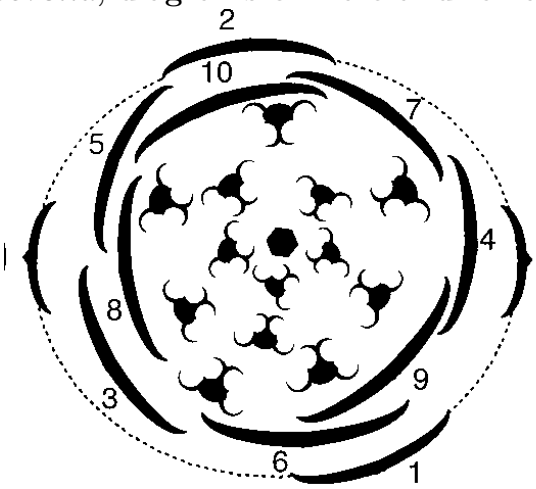
Amborella

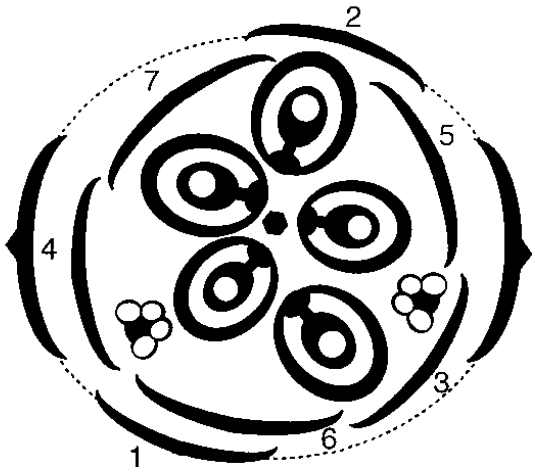
- Small forest shrub of New Caledonia (big island in Pacific ocean)
- Have irregular flowers, stylar canal, unusual embryo sac (5 cells)

***Amborella*, branch with male flowers**

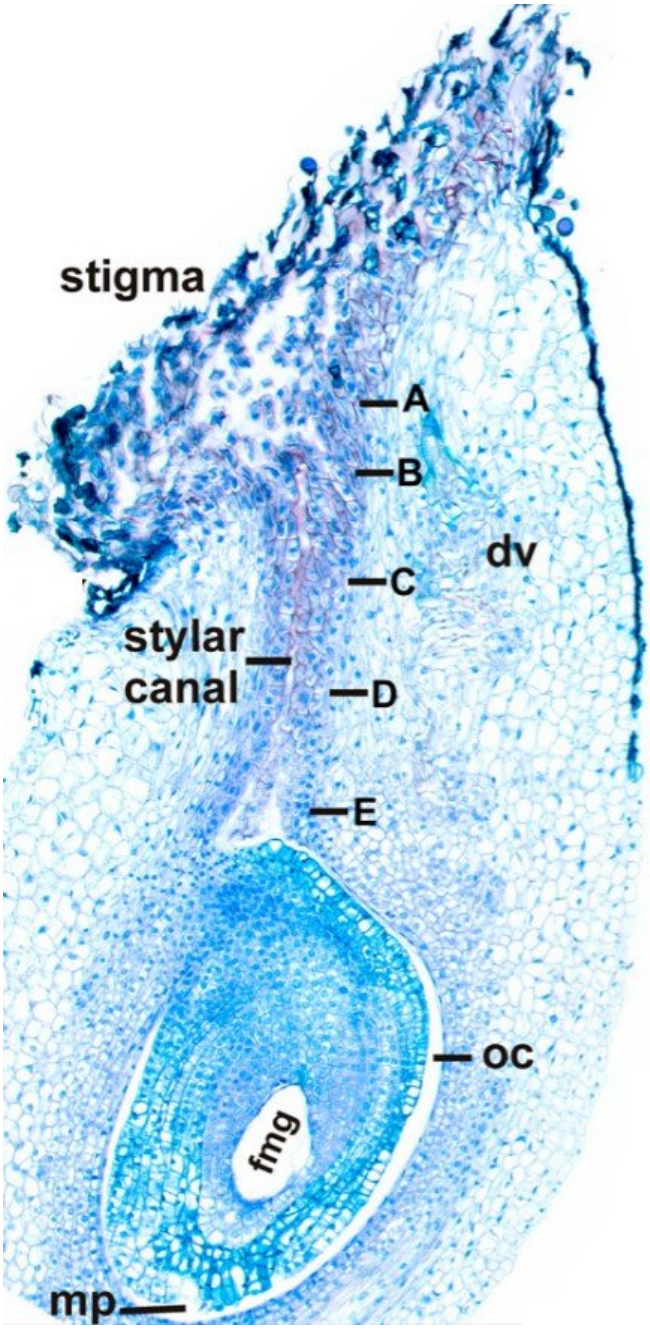
***Amborella*, male and female flowers**

***Amborella*, diagrams of male and female flowers**



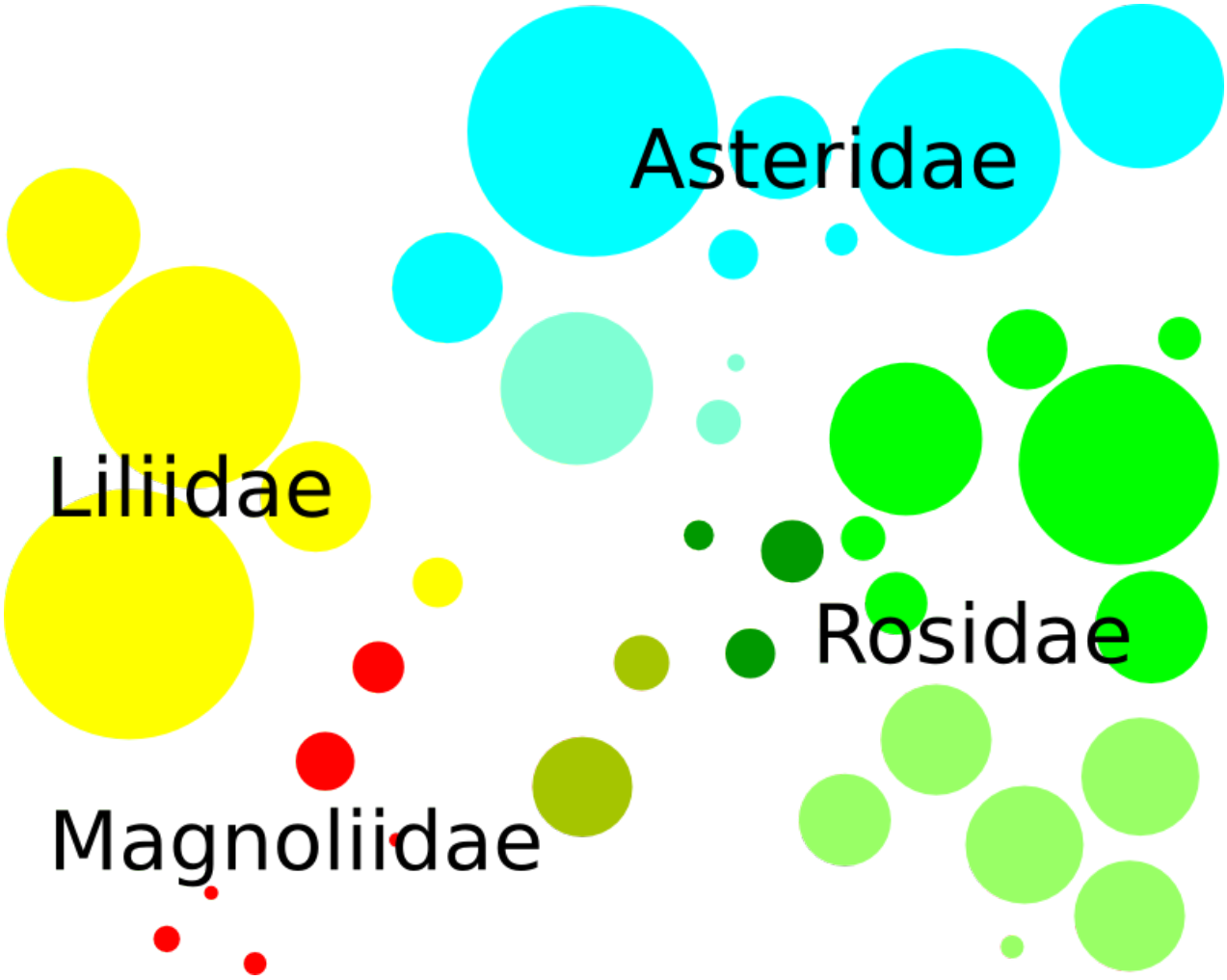


***Amborella* stylar canal**

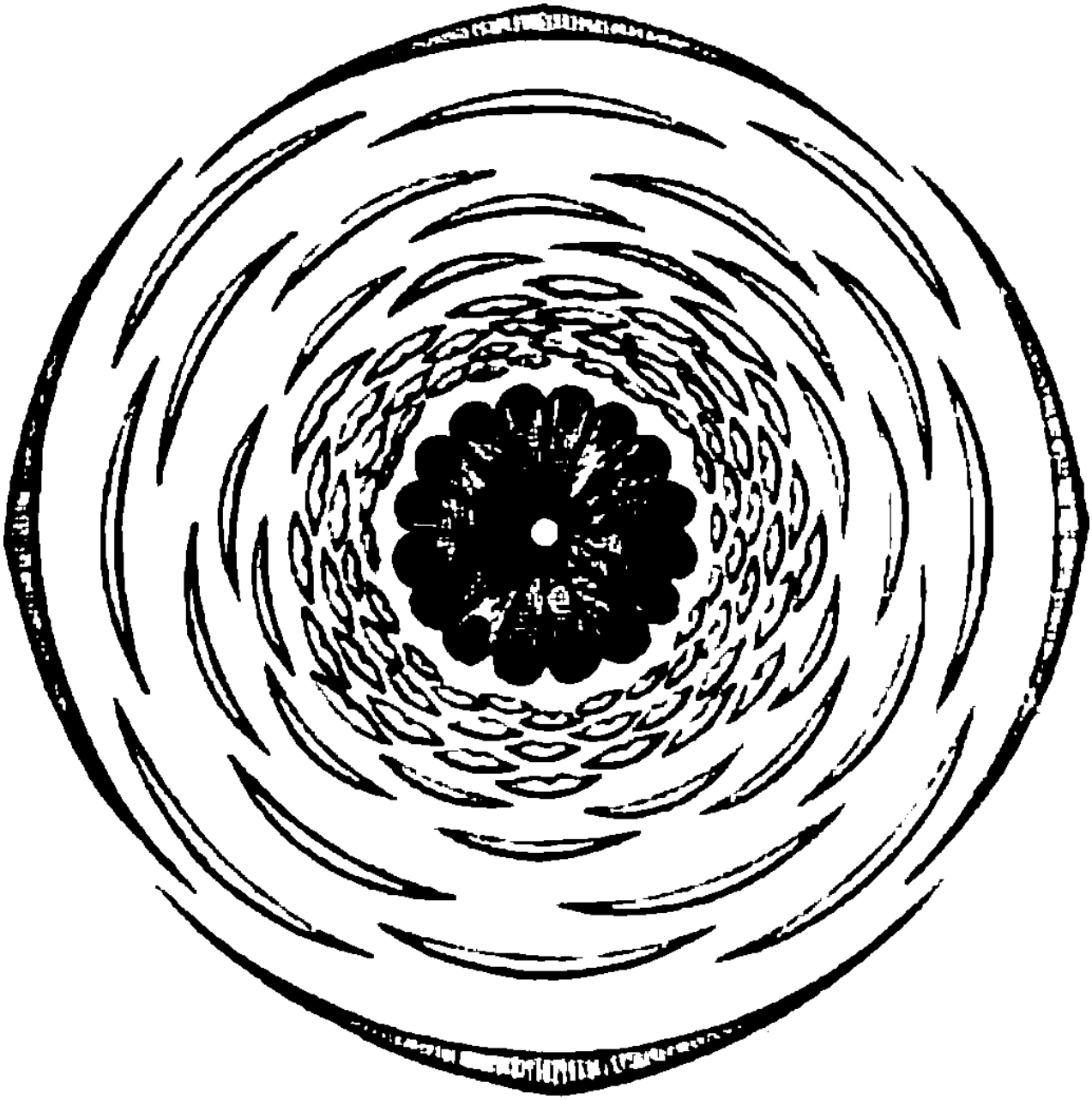


15.10 Four subclasses of angiosperms

Angiosperms: subclasses and orders

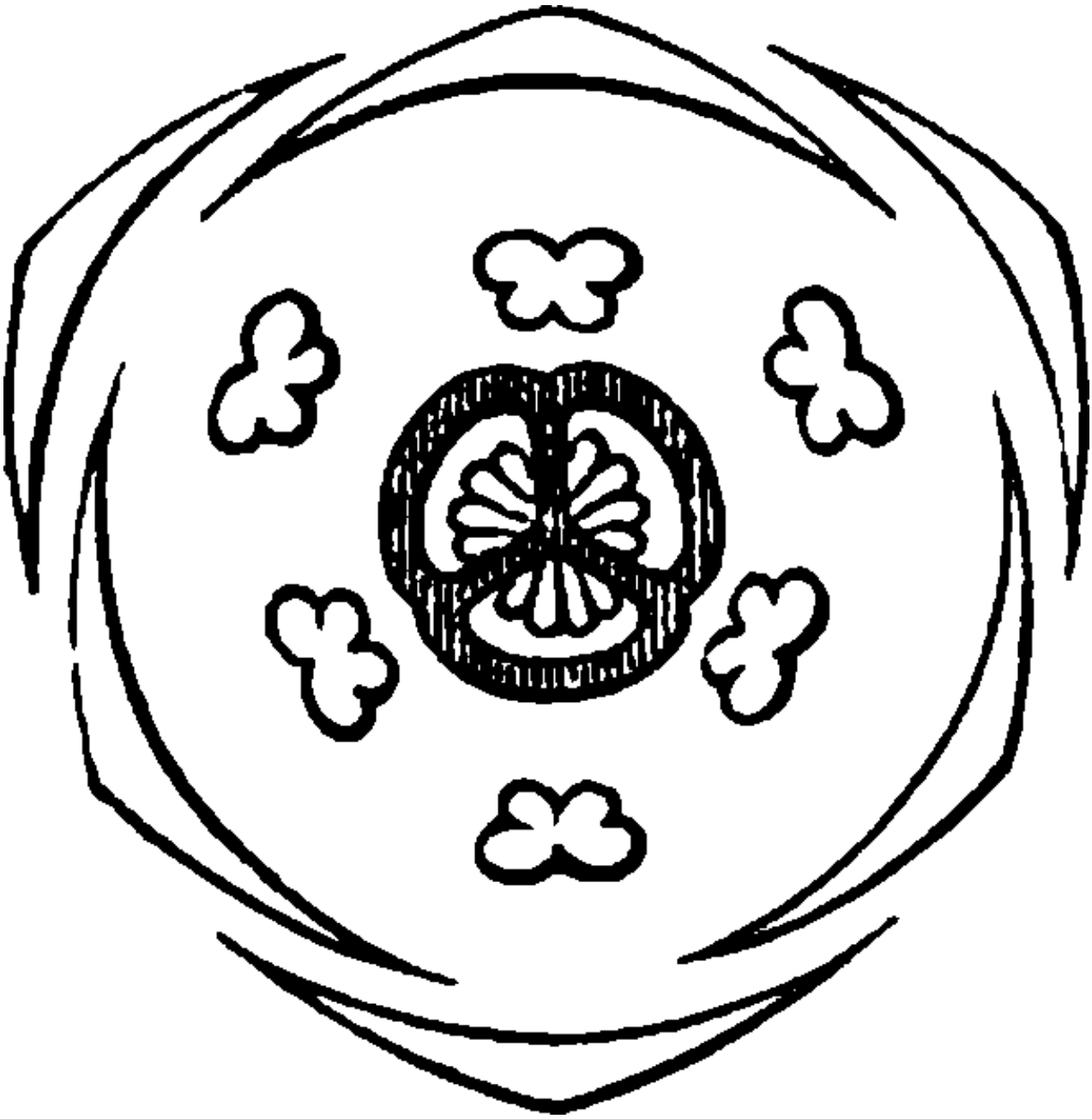


Magnoliidae portrait



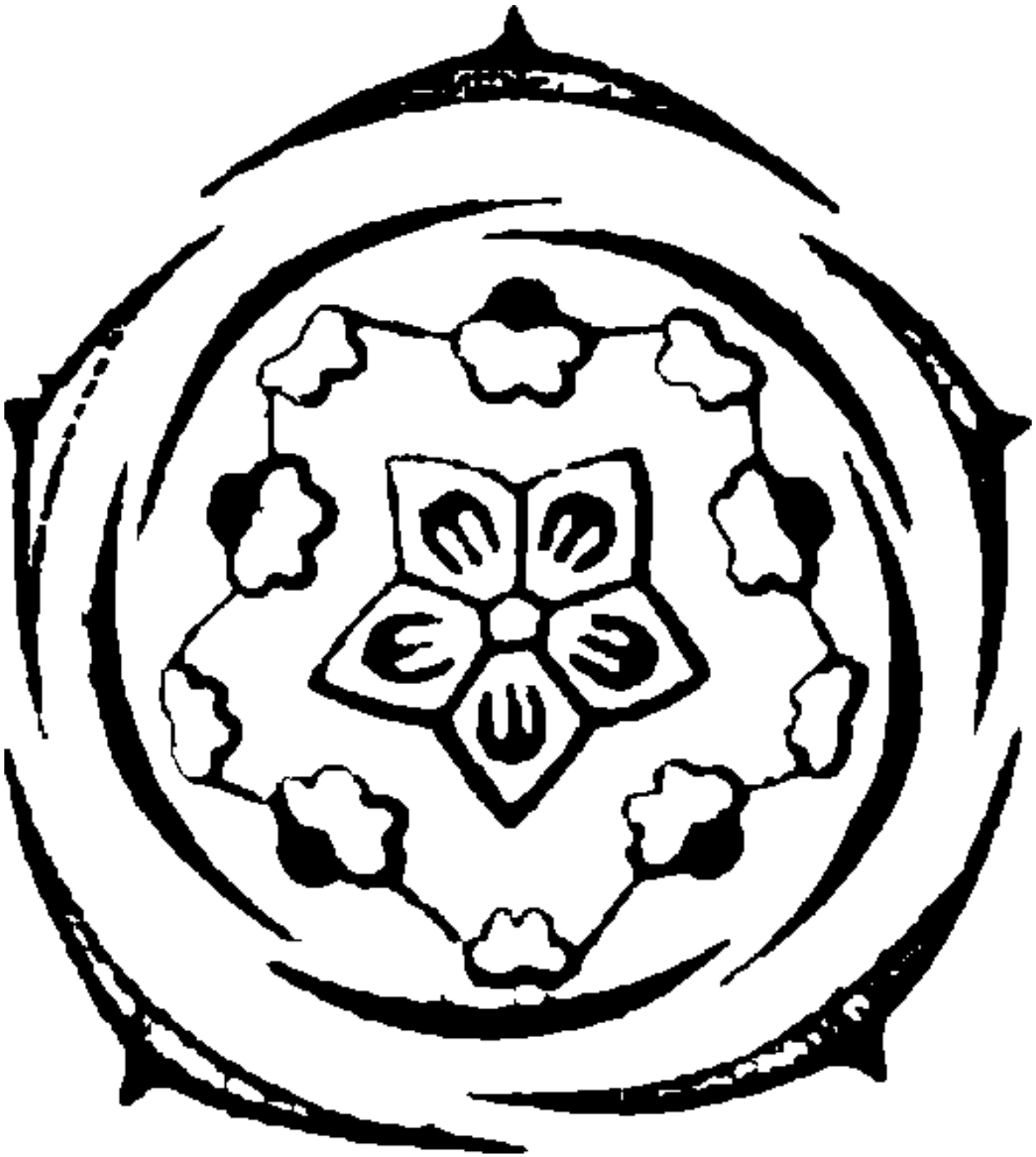
Nymphaea sp. (water-lily): multiple, disorganised

Liliidae portrait



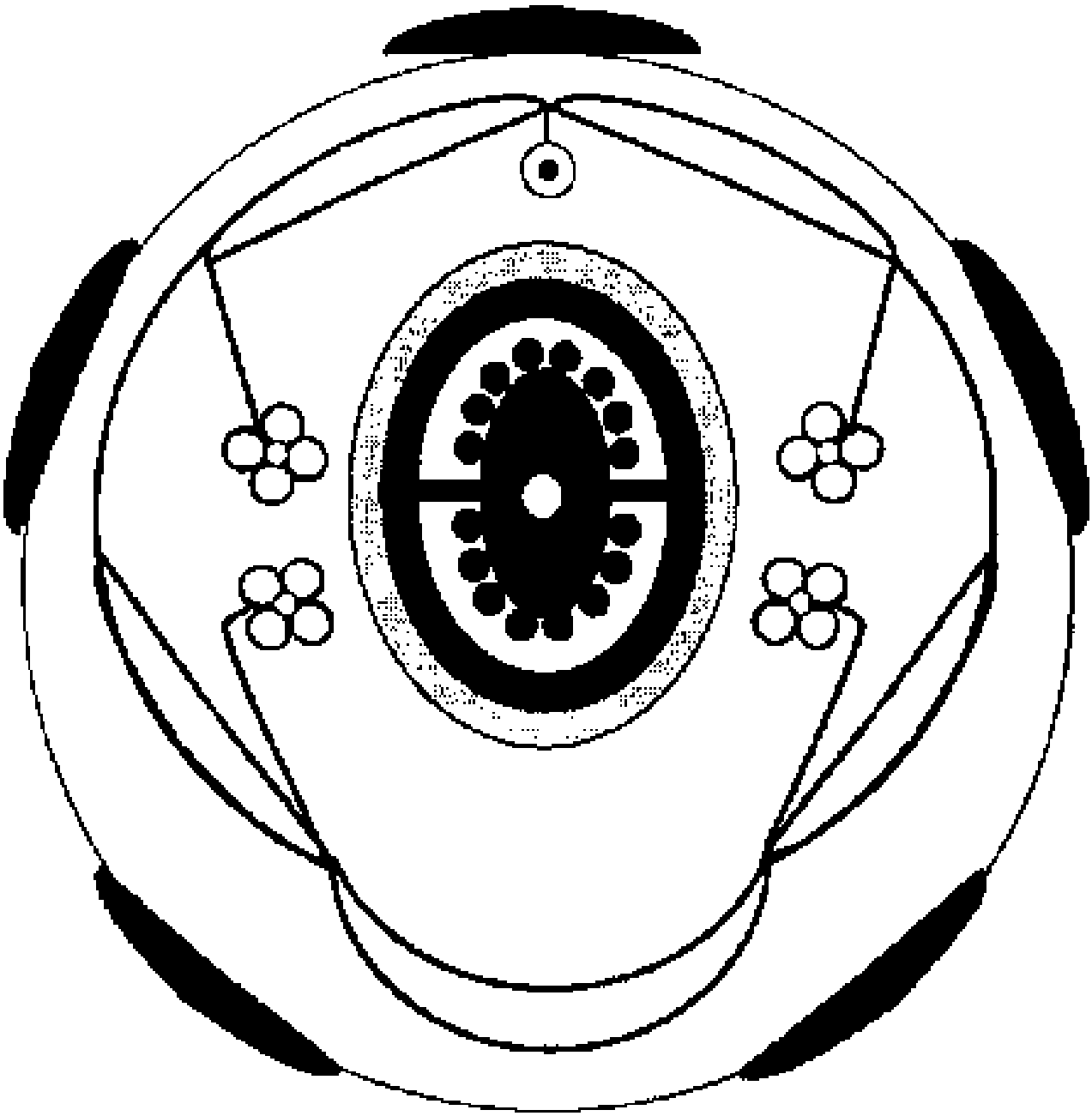
Acorus calamus (calamus, or sweet flag): trimerous

Rosidae portrait



Geranium sp.: pentamerous or tetramerous, petals free

Asteridae portrait



Penstemon sp. (beard-tongue): petals fused, more petals than carpels

15.11 Pollination

How to avoid pollination: apomixis

- Apomixis is a reproduction with reproductive organs but without fertilization
- **Apospory**: embryo develops from maternal diploid tissue, without meiosis; here asexual reproduction becomes vegetative
- **Apogamy** (i.e., parthenogenesis): embryo develops from unfertilized gamete after diploidization; sexual reproduction becomes vegetative

Pollination

- Self-pollination (only slightly better that apogamy)
- Cross-pollination: abiotic (gravity, wind, water) and biotic (insects, birds, bats, sometimes even possums)
- Every pollination type has associated **pollination syndrome**

Wind pollination: hazelnut

Water pollination: vallisneria

Bat pollination: cacti

Possum pollinaiton: Australian Myrtaceae

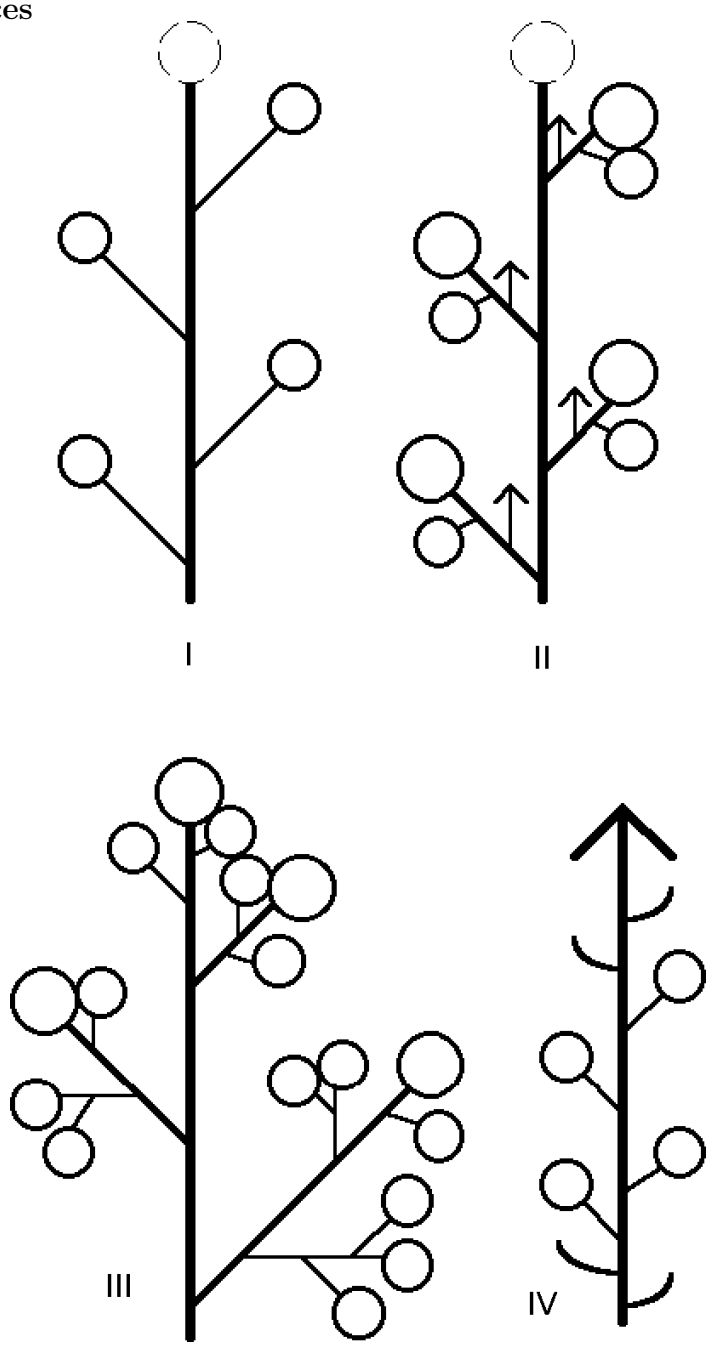
15.12 Inflorescences

Types of inflorescences

Inflorescence is an isolated generative shoot bearing flowers

- Model I. Raceme and its derivates
  - Simple: raceme (developed man axis, developed lateral axes: 11), spike/catkin (developed main axes, reduced lateral axes: 10), umbel (01), head (00)
  - Compound: compound raceme (11/11), compound umbel (01/01) etc.
- Model II. Thyrsus and its derivates
  - Reduced (cymes): dichasium, cincinnus (scorpioid inflorescence) etc.
  - Thyrses in a strict sense
- Model III. Closed panicle (also umbel-like panicles)
- Model IV. Intercalary inflorescences

Models of inflorescences



15.13 Seeds

Definition

- "Mature ovule"
- Chimeric organ consists of seed coat, endosperm and embryo

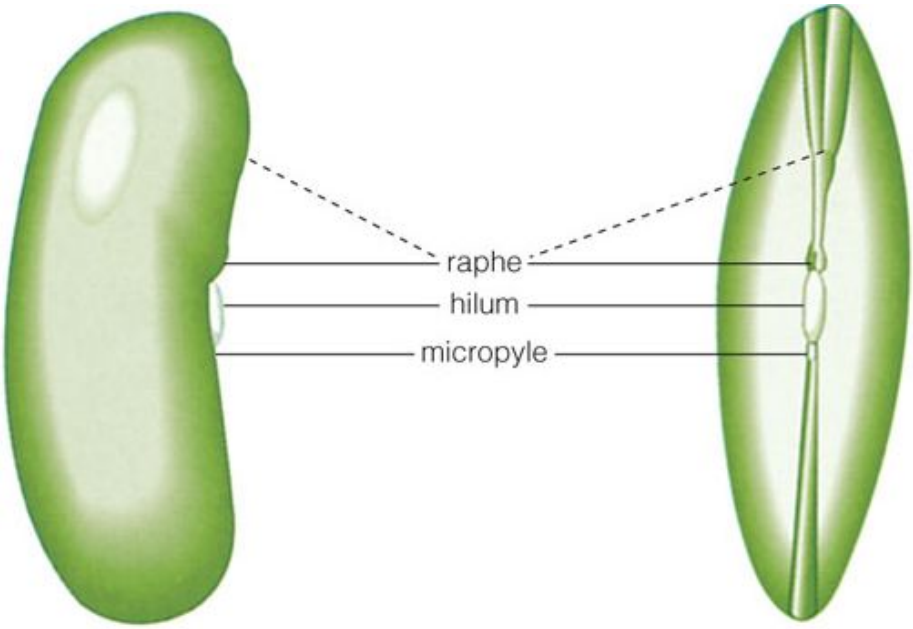
Origin of seed layers

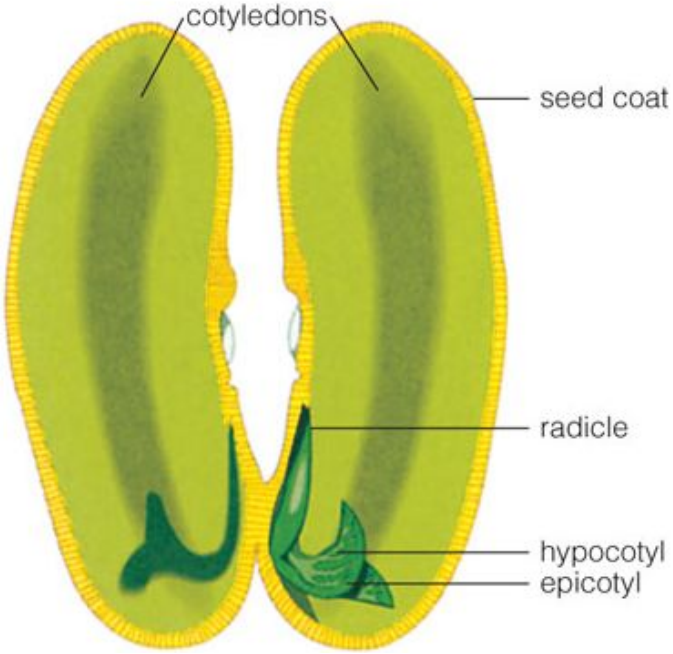
Layer	Ploidy	Origin
Seed coat	$2n$	Integument of ovule
Endosperm_2	$3n$, sometimes $2n$	Fertilized central cell of embryo sac
Embryo	$2n$	Fertilized egg
Endosperm_1	n	Female gametophyte (gymnosperms!)
Perisperm	$2n$	Nucellus of ovule

Seed structure variations

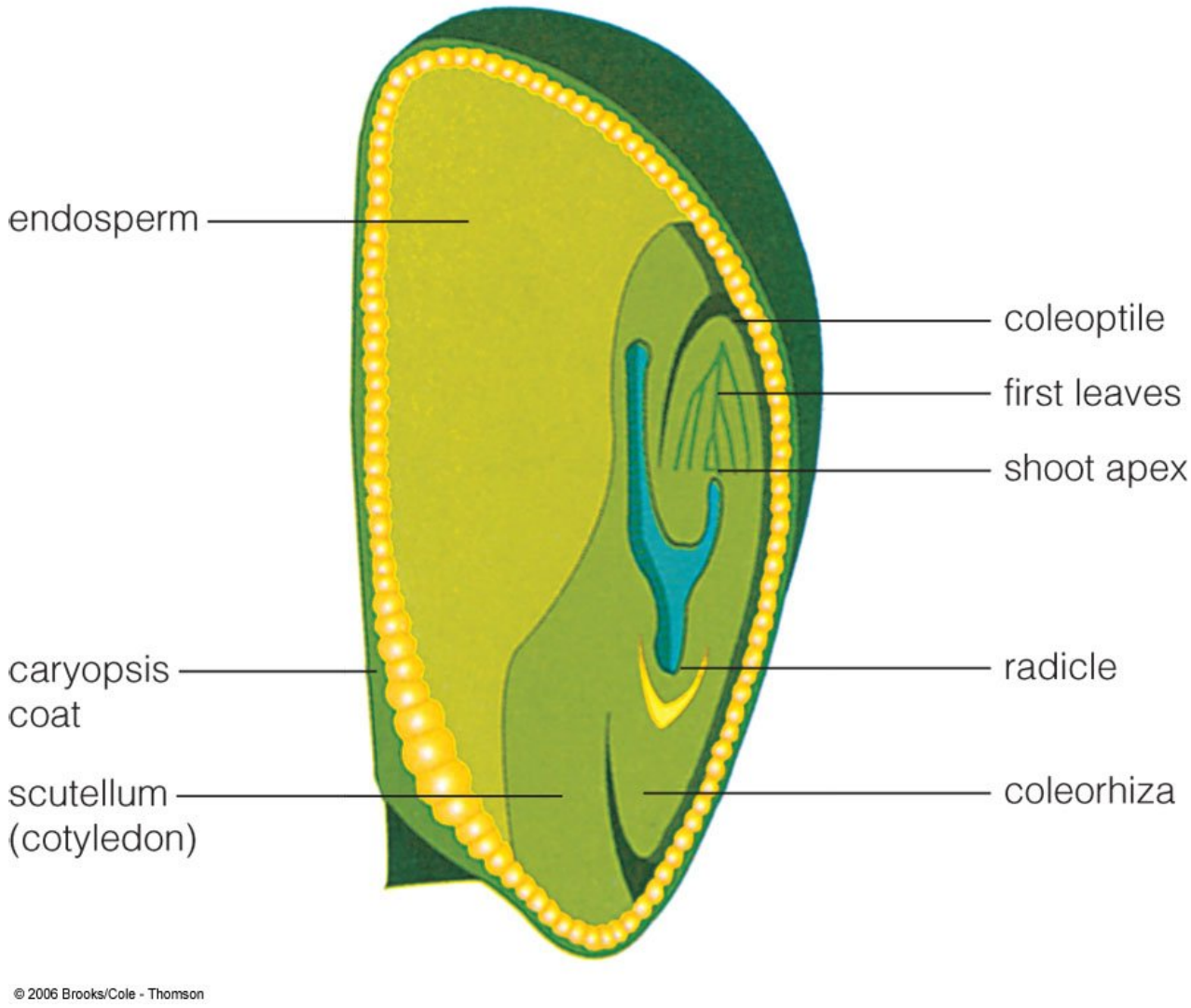
- Seed with endosperm (onion): cotyledon(s): embryonic leaves, radicle: embryonic root, apex: embryonic bud
- Seed without endosperm (beans and other Leguminosae): cotyledons, radicle, hilum, raphe
- Grass (Gramineae) seeds: coleoptile, coleorhiza, scutellum

Bean seed


raphe
hilum
micropyle


cotyledons
seed coat
radicle
hypocotyl
epicotyl

Grass seeds



Cotyledons

- Monocots have lateral bud and terminal primary leaf (cotyledon)
- Other seed plants have terminal bud and multiple (2 to many) primary leaves (cotyledons)

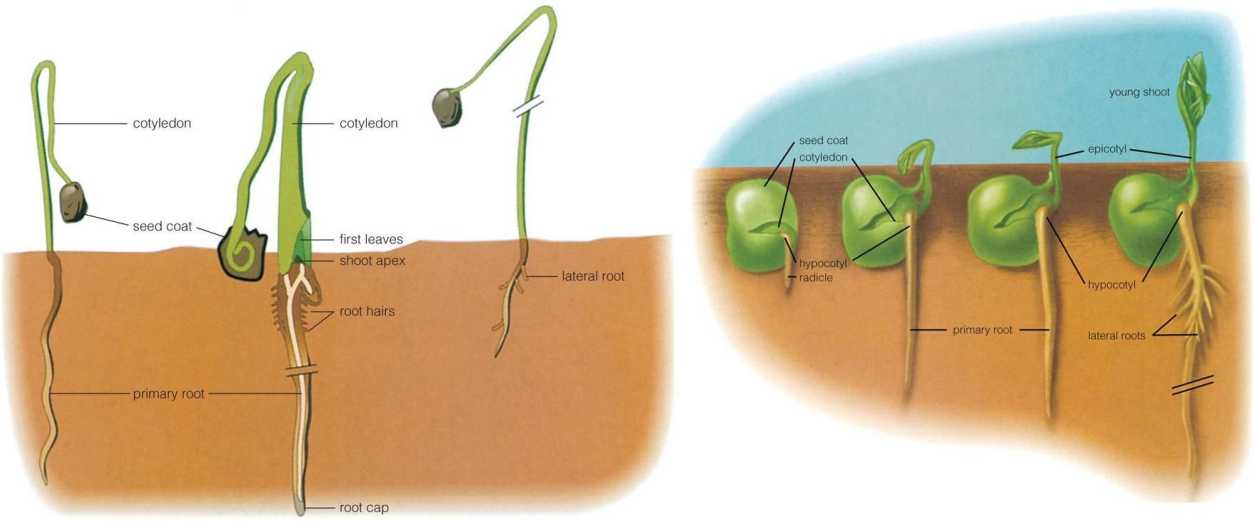
***Pinus* sp.: multiple cotyledons**

Germination

- Epigeal (e.g., onion, pea). They expose cotyledons and both hypo- and epicotyl.
- Hypogeal (e.g., bean, grasses, palms). They expose only epicotyl (first internode), cotyledons and hypocotyl (root/stem transition) is underground.

Both variants have advantages and disadvantages.

Epigeal *versus* hypogeal germination



15.14 Fruits

Definition and origin

- **Fruit** is a ripened ovary, flower or inflorescence
- Fruit coat and pericarp (exocarp + mesocarp + endocarp) origin mostly from pistil wall

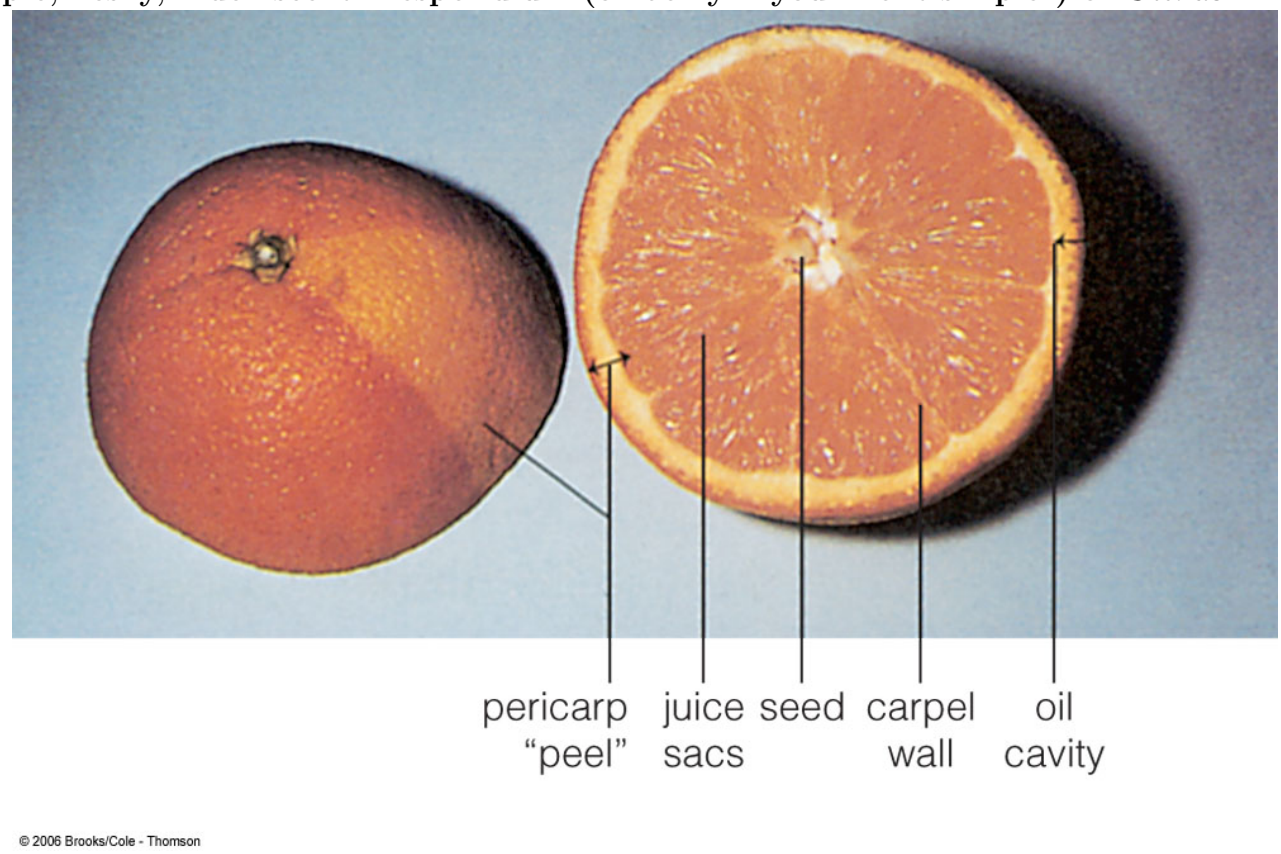
Trivial classification: criteria

- **Simple**, **multiple** (aggregate) or **compound**. Simple fruits are from one pistil (cherry), multiple from many pistils of one flower (raspberry), compound—from multiple flowers (pineapple).
- **Dry** or **fleshy**. Fleshy fruits are adapted to animal dispersion through their digestive tract.
- **Dehiscent**, **indehiscent** or **schizocarpic**. Dehiscent (opening) fruit will delegate dispersal function to individual seeds; indehiscent (closed) fruit will take these functions but will require less seeds per fruit to avoid competition between seedlings. Schizocarp has multiple seeds but will be fragmented to many one-seeded parts.

Trivial classification: examples

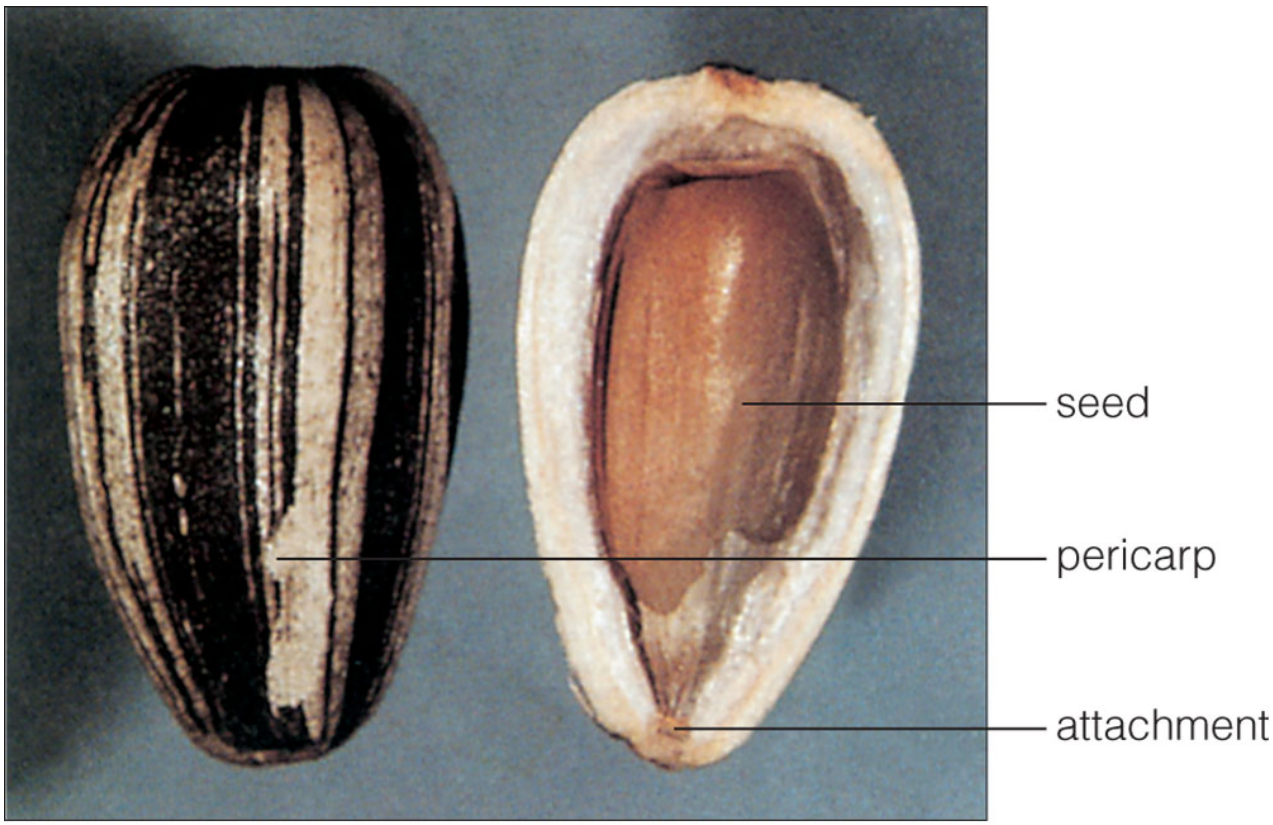
Type	Consistency	Opening	Example
Simple	Fleshy	Indehiscent	Drupe (one seed), Berry (multiple seeds), Hesperidium (citruses), Pome (apple, pear: from inferior ovary)
Simple	Dry	Dehiscent	Legume (pod), Capsule, Silique (fruit of cabbage family)
Simple	Dry	Schizocarpic	Regma (spurge), Samara (maple), Shizocarp (umbel family)
Simple	Dry	Indehiscent	Caryopsis (grain, fruit of grasses), Nut (incl. acorn), Achene (fruit of aster family)
Multiple	Fleshy	Indehiscent	Multiple drupe (raspberry)
Multiple	Dry	Dehiscent	Follicle (many pods together)
Multiple	[Dry]	Indehiscent	Multiple nut (strawberry)
Compound	Fleshy	Indehiscent	Compound berry (pineapple)
Compound	[Dry]	Indehiscent	Compound nut (fig)

Simple, fleshy, indehiscent: hesperidium (or berry if you like it simpler) of *Citrus*

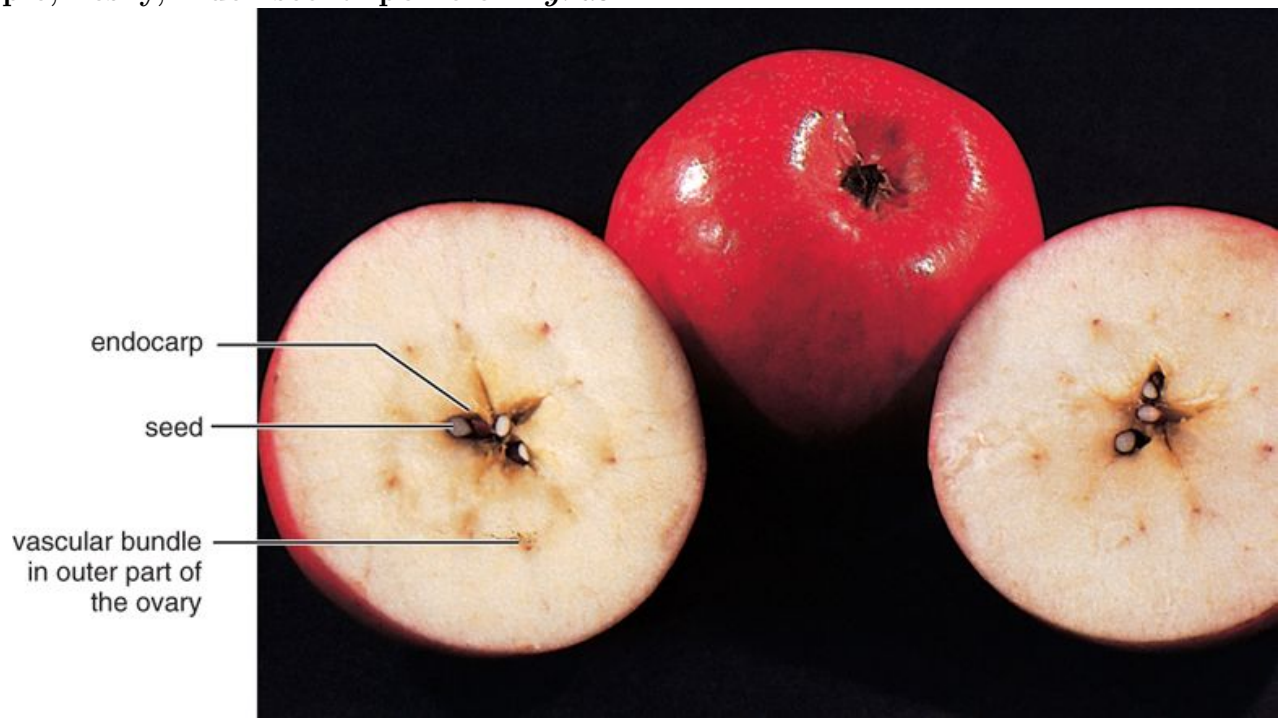


Simple, dry, dehiscent: pod of *Erythrina* legume

Simple, dry, indehiscent: achene (not "seed"!!!) of *Helianthus*



Simple, fleshy, indehiscent: pome of *Pyrus*



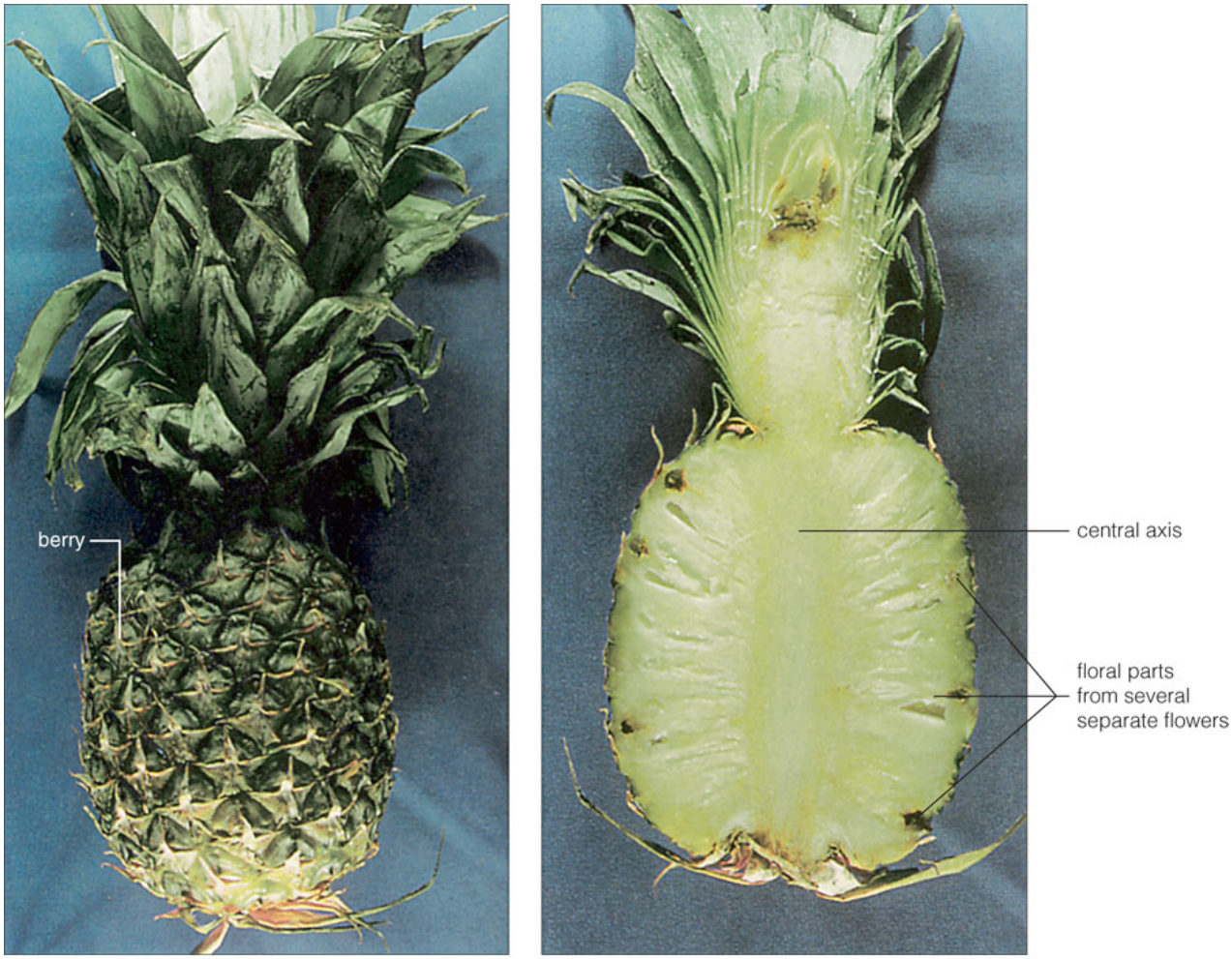
Samara of *Acer*

Schizocarp of *Zizia*

Multiple nut of *Fragaria* sp. (strawberry)

Multiple drupe of *Rubus* sp. (raspberry)

Compound berry of *Ananas comosus* (pineapple)



Compound fruit of *Ficus carica* (fig tree)

Short anonymous absolutely voluntary survey

A. What do you **like** most in Biology 154?

B. What do you **dislike** most in Biology 154?

C. **Which lab** do you remember most of all?

D. Please grade (1—bad, 5—excellent):

   (a) Lectures
   (b) Labs
   (c) Final questions
   (d) Exams

E. How to improve the textbook?

Summary

- **Flower** is a compact three-zoned generative shoot
- Three main zones of flower: sterile (**perianth**), male (**androecium**) and female (**gynoecium**)

- **ABC-genes** determine the fate of cells which are forming flower
- **Inflorescence** is an isolated generative shoot bearing flowers
- **Seed** is a chimeric organ consists of seed coat, endosperm and embryo
- **Fruit** is a ripened ovary, flower or inflorescence
- BOTANY IS COOL!

Final question (2 points)

TBA

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

16 Movie

David Attenborough. Private Life of Plants. Episode 3: Flowering. `https://en.wikipedia.org/wiki/The_Private_Life_of_Plants`

David Attenborough. Private Life of Plants. Episode 6: Surviving. `https://en.wikipedia.org/wiki/The_Private_Life_of_Plants`