

# Introduction to Botany: BIOL 154

## Study guide for Exam 4

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Lectures 27–39

## Contents

<b>1</b>	<b>Questions and answers</b>	<b>1</b>
<b>2</b>	<b>Root</b>	<b>1</b>
2.1	Root morphology . . . . .	1
2.2	Anatomy and development of roots . . . . .	5
2.3	Origins of root tissues . . . . .	12
2.4	Water transport in roots . . . . .	13
2.5	Diversity of roots . . . . .	16
<b>3</b>	<b>Questions and answers</b>	<b>25</b>
<b>4</b>	<b>Plant diversity</b>	<b>25</b>
4.1	Systematics . . . . .	25
4.2	Kingdom Vegetabilia, land plants . . . . .	26
4.3	Phylum Bryophyta: mosses . . . . .	28
<b>5</b>	<b>Questions and answers</b>	<b>29</b>
<b>6</b>	<b>Plant diversity</b>	<b>31</b>
6.1	Phylum Bryophyta: mosses . . . . .	31
<b>7</b>	<b>Questions and answers</b>	<b>33</b>
<b>8</b>	<b>Plant diversity</b>	<b>33</b>
8.1	Phylum Bryophyta: mosses . . . . .	33
8.2	Pteridophyta . . . . .	39
<b>9</b>	<b>Questions and answers</b>	<b>49</b>
<b>10</b>	<b>Plant diversity</b>	<b>49</b>
10.1	Heterospory . . . . .	49
10.2	“Ferny” ferns . . . . .	50
<b>11</b>	<b>Questions and answers</b>	<b>60</b>

<b>12 Thickening and branching</b>	<b>60</b>
12.1 Branching . . . . .	60
12.2 Secondary stem . . . . .	62
<b>13 Questions and answers</b>	<b>70</b>
<b>14 Secondary stem</b>	<b>71</b>
14.1 Wood . . . . .	71
14.2 Life forms . . . . .	84
<b>15 Questions and answers</b>	<b>88</b>
<b>16 Stem and shoot</b>	<b>88</b>
16.1 Modifications of stem / shoot . . . . .	88
<b>17 Seed plants</b>	<b>93</b>
17.1 Seed . . . . .	93
<b>18 Questions and answers</b>	<b>95</b>
<b>19 Seed plants</b>	<b>95</b>
19.1 Seed . . . . .	95
19.2 Diversity of seed plants . . . . .	98
<b>20 Questions and answers</b>	<b>99</b>
<b>21 Seed plants</b>	<b>99</b>
21.1 Diversity of seed plants . . . . .	99
21.2 Conifers . . . . .	106
21.3 Gnetophytes . . . . .	110
21.4 Flowering plants . . . . .	121
<b>22 Questions and answers</b>	<b>122</b>
<b>23 Seed plants</b>	<b>123</b>
23.1 Life cycle of flowering plants . . . . .	123
23.2 Magnoliopsida, or Angiospermae . . . . .	129
<b>24 Questions and answers</b>	<b>130</b>
<b>25 Seed plants</b>	<b>130</b>
25.1 Flower . . . . .	130
25.2 Flower development: ABC model . . . . .	133
25.3 Primitive flowers . . . . .	136
25.4 Four subclasses of angiosperms . . . . .	141
25.5 Pollination . . . . .	146
25.6 Inflorescences . . . . .	149
<b>26 Questions and answers</b>	<b>151</b>

<b>27 Seed plants</b>	<b>151</b>
27.1 Seeds . . . . .	151
27.2 Fruits . . . . .	155
<b>28 Short answers</b>	<b>166</b>
<b>29 Multiple choice</b>	<b>167</b>

## Outline

# 1 Questions and answers

Previous final question: the answer

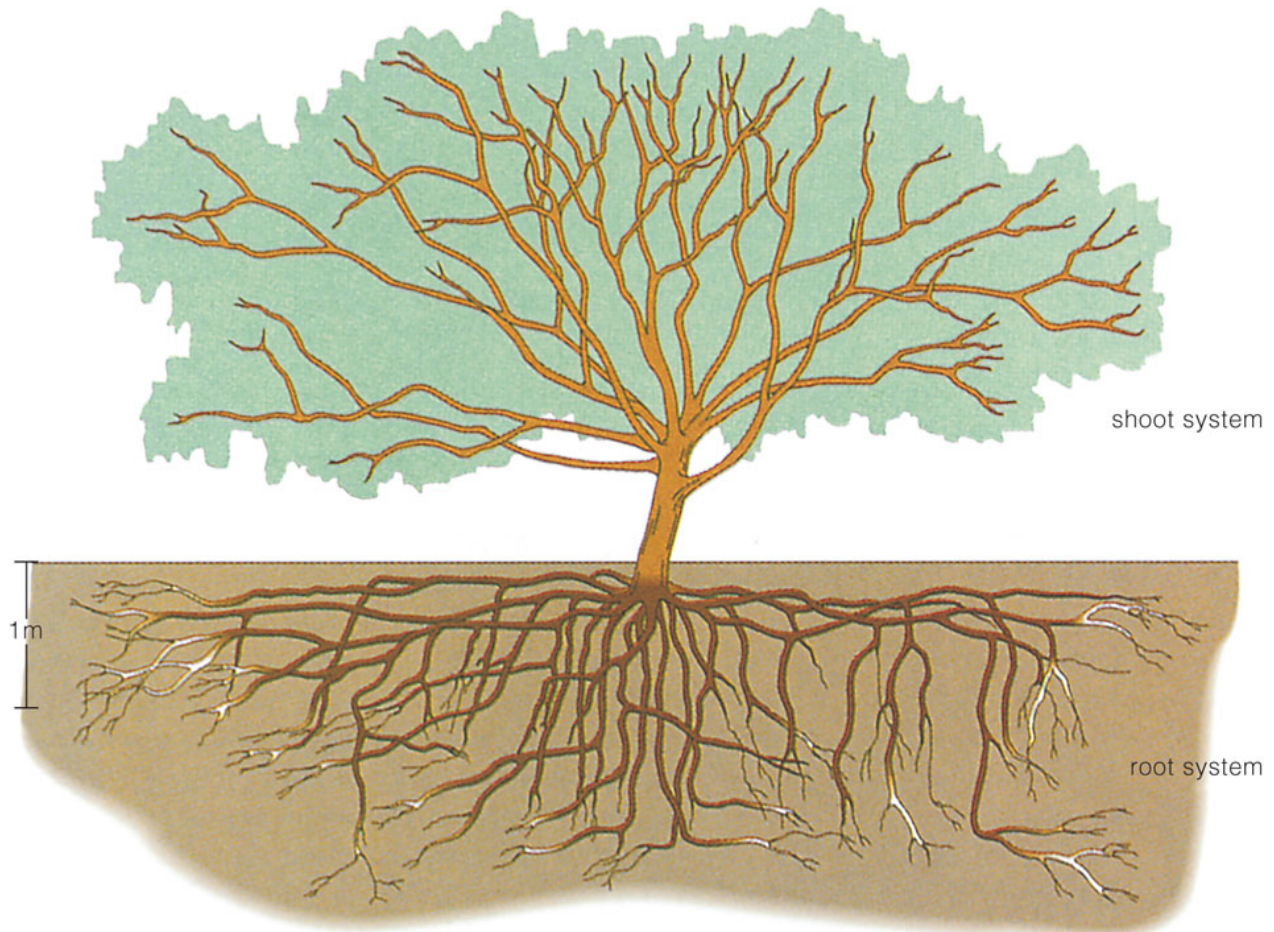
What is ataktostele?

- Dispersed vascular bundles (monocots)

## 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:
  1. Anchor
  2. Synthesis
  3. Storage
  4. Communication
- Features:
  1. No leaves
  2. Geotropic growth
  3. 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**





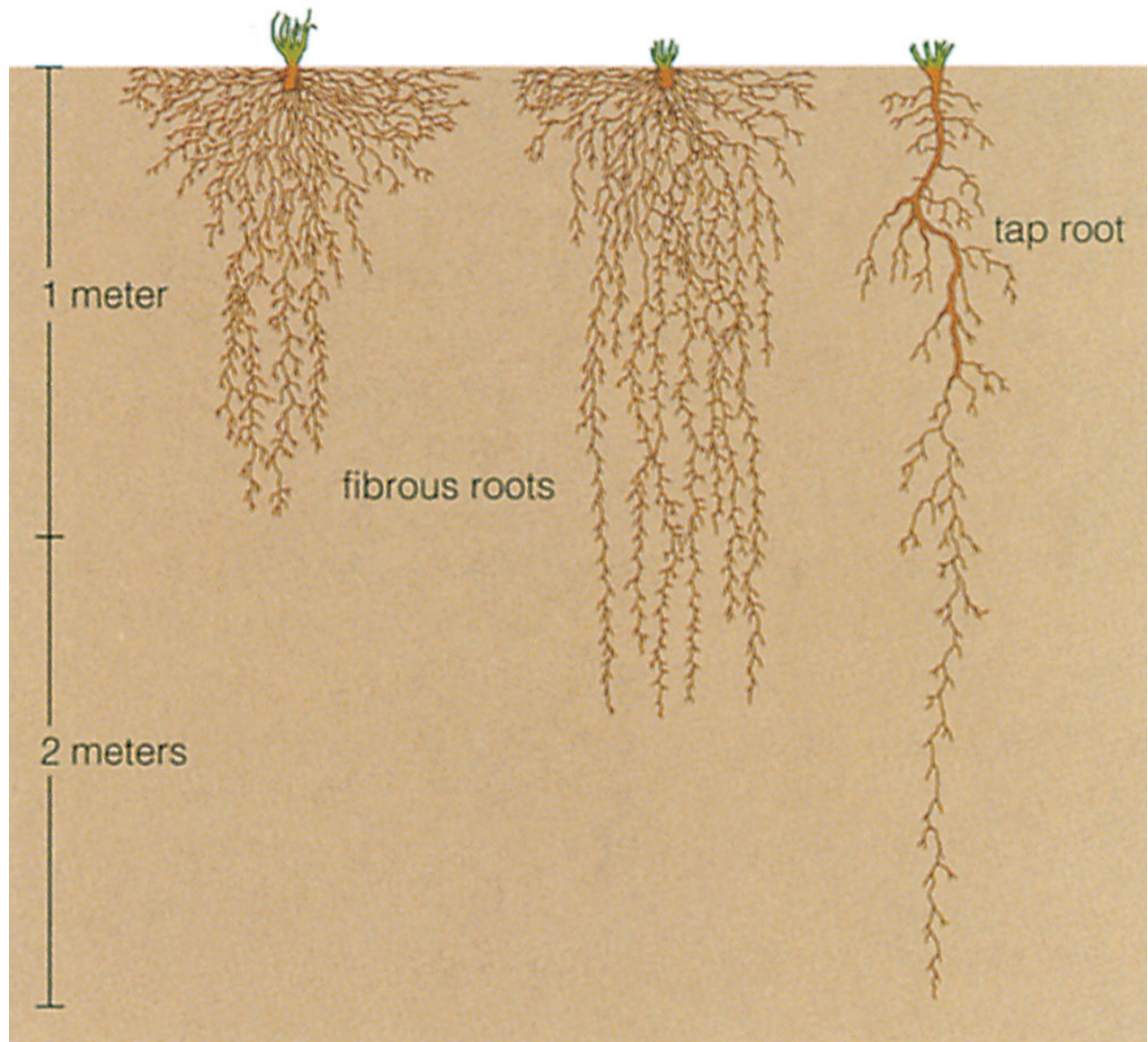
Adventitious roots



## Root systems

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

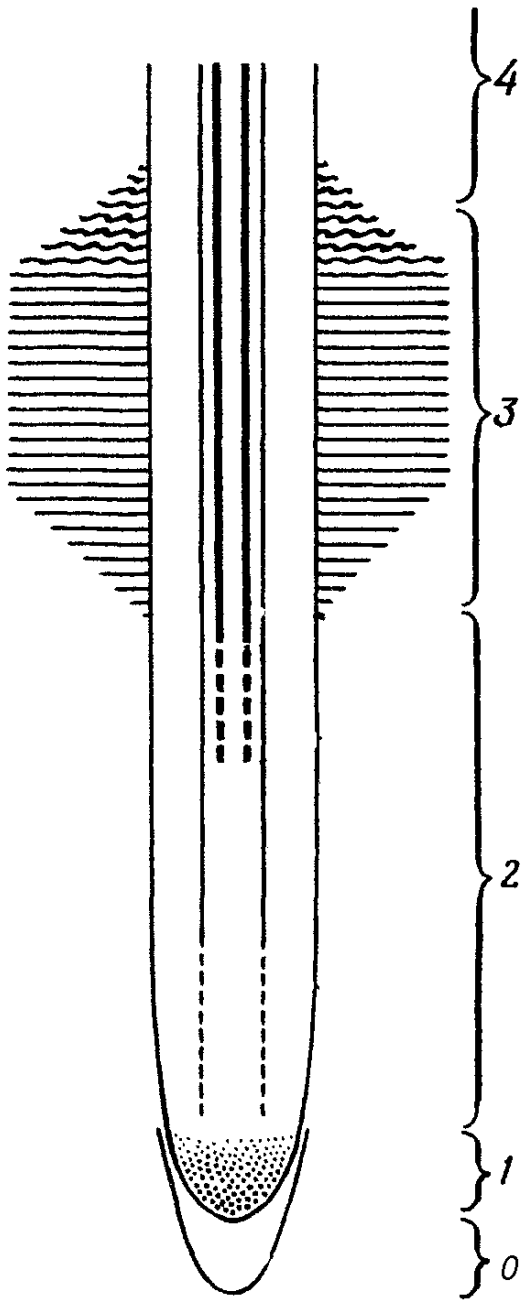
## Fibrous and tap root systems



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## 2.2 Anatomy and development of roots

### Root zones



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

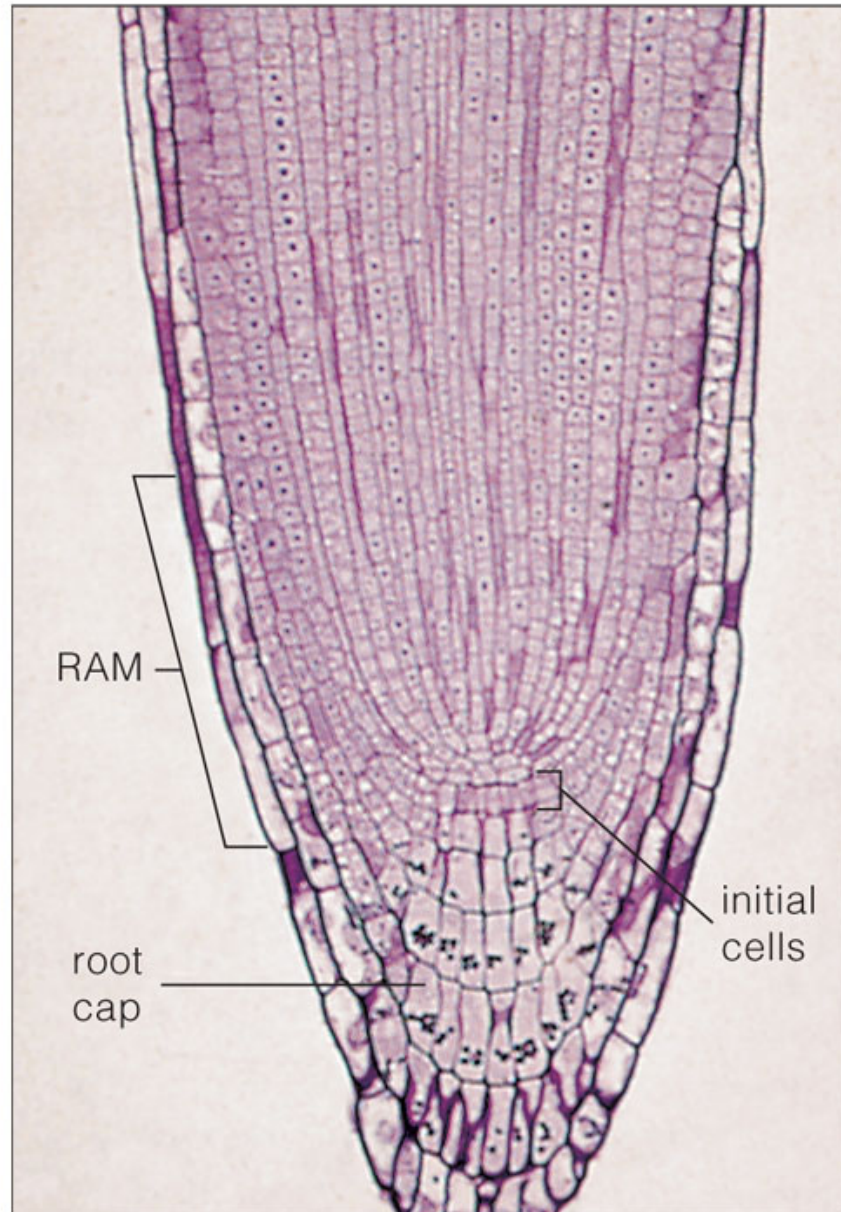
### Structure of root tip

- 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



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## Periphery of root

- Rhizoderm (root epidermis): fast-degrading cells
- Cortex, which includes also:
  - Endoderm: 1-cell layer with specialized cell walls, located on the border with vascular cylinder
  - And (sometimes) exoderm: similar to endoderm but located just under rhizoderm

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

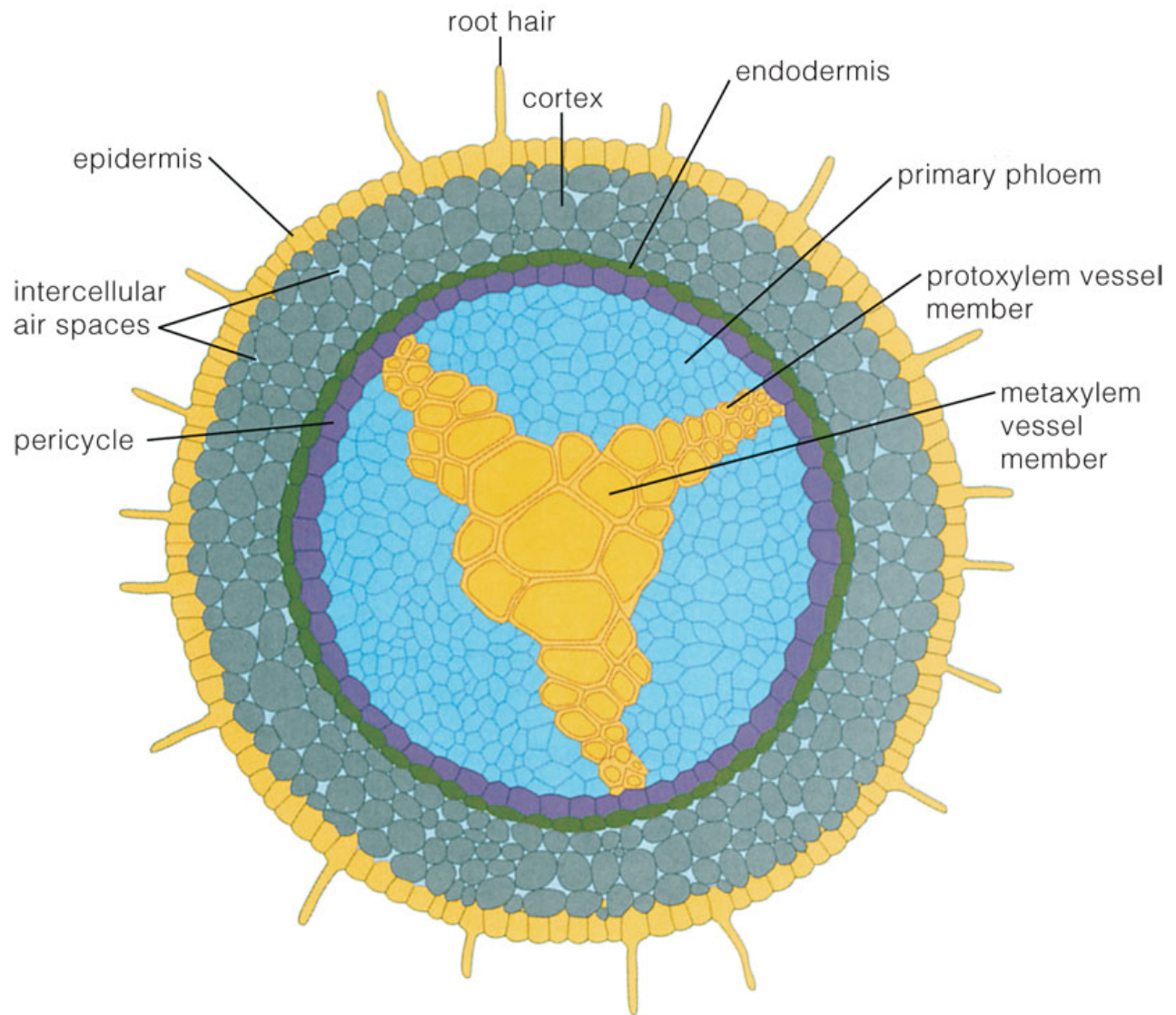
### Periphery of root

- **Rhizoderm** (root epidermis): fast-degrading cells
- **Cortex**, which includes also:
  - **Endoderm**: 1-cell layer with specialized cell walls, located on the border with vascular cylinder
  - And (sometimes) **exoderm**: similar to endoderm but located just under rhizoderm
- In some plants (i.e., orchids), part of 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



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## 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



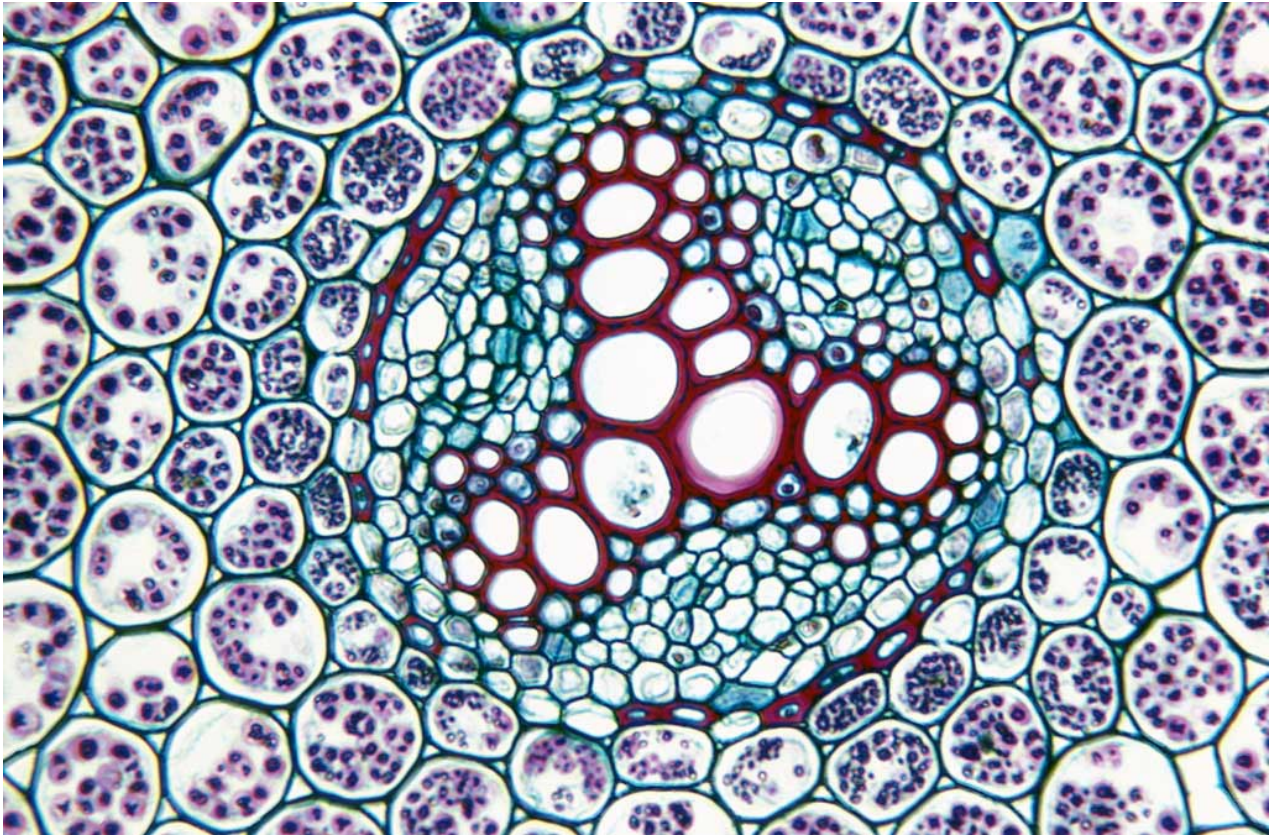


### Vascular bundle

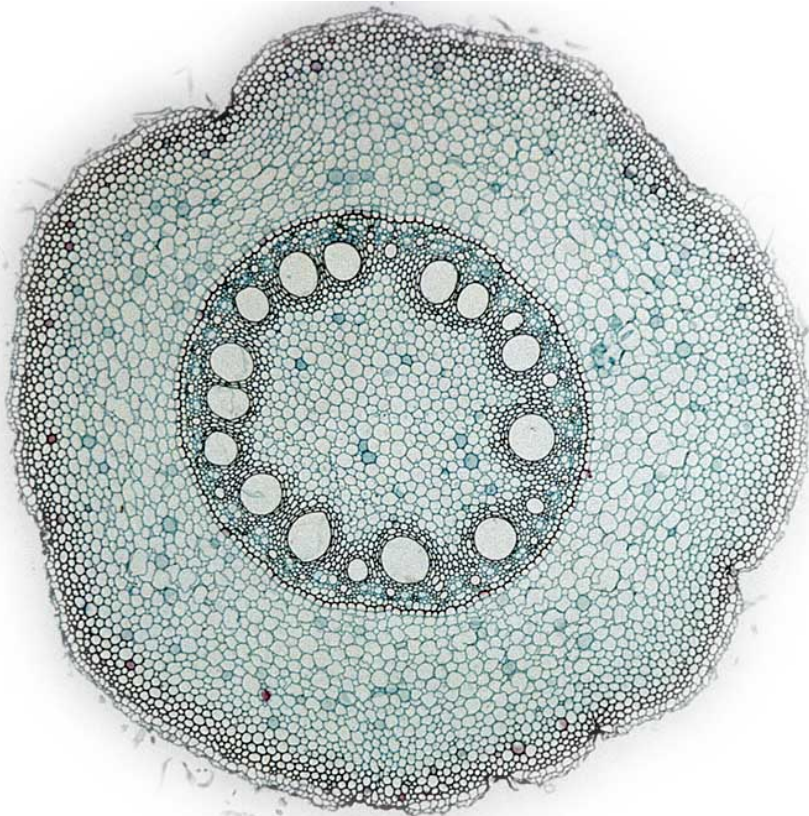
- Only one!
- Has radial (star-like) symmetry
- Xylem arranged in rays, multiple in monocots, 2-4 in other plants

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



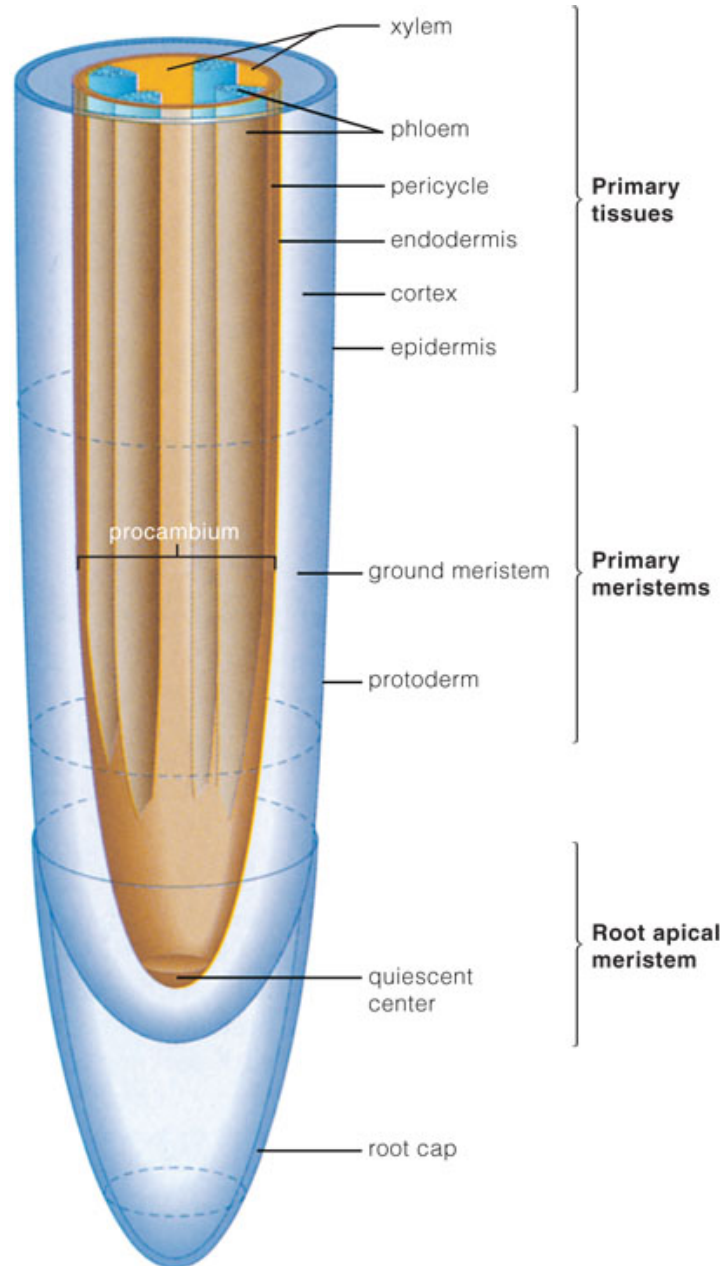


Root of monocot (*Zea mays*)



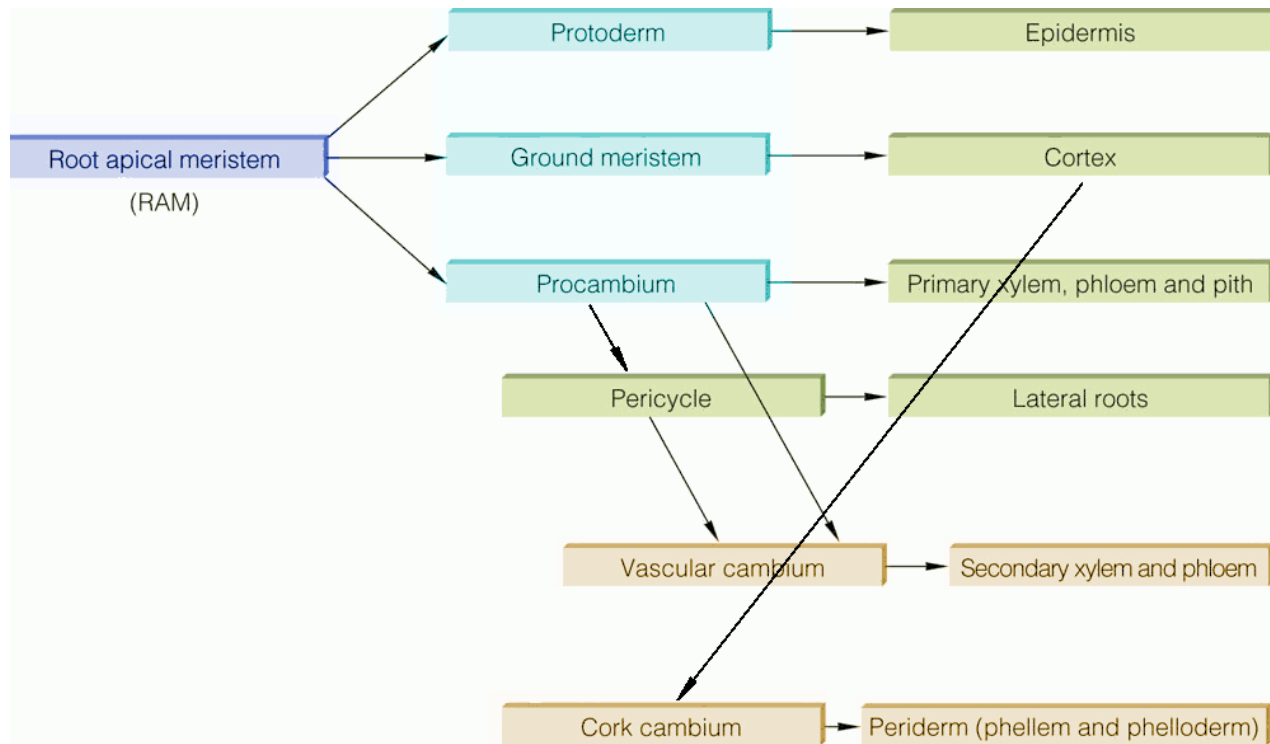
## 2.3 Origins of root tissues

### Development of tissues



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### Origins of tissues



## 2.4 Water transport in roots

### Rhizoderm and osmosis

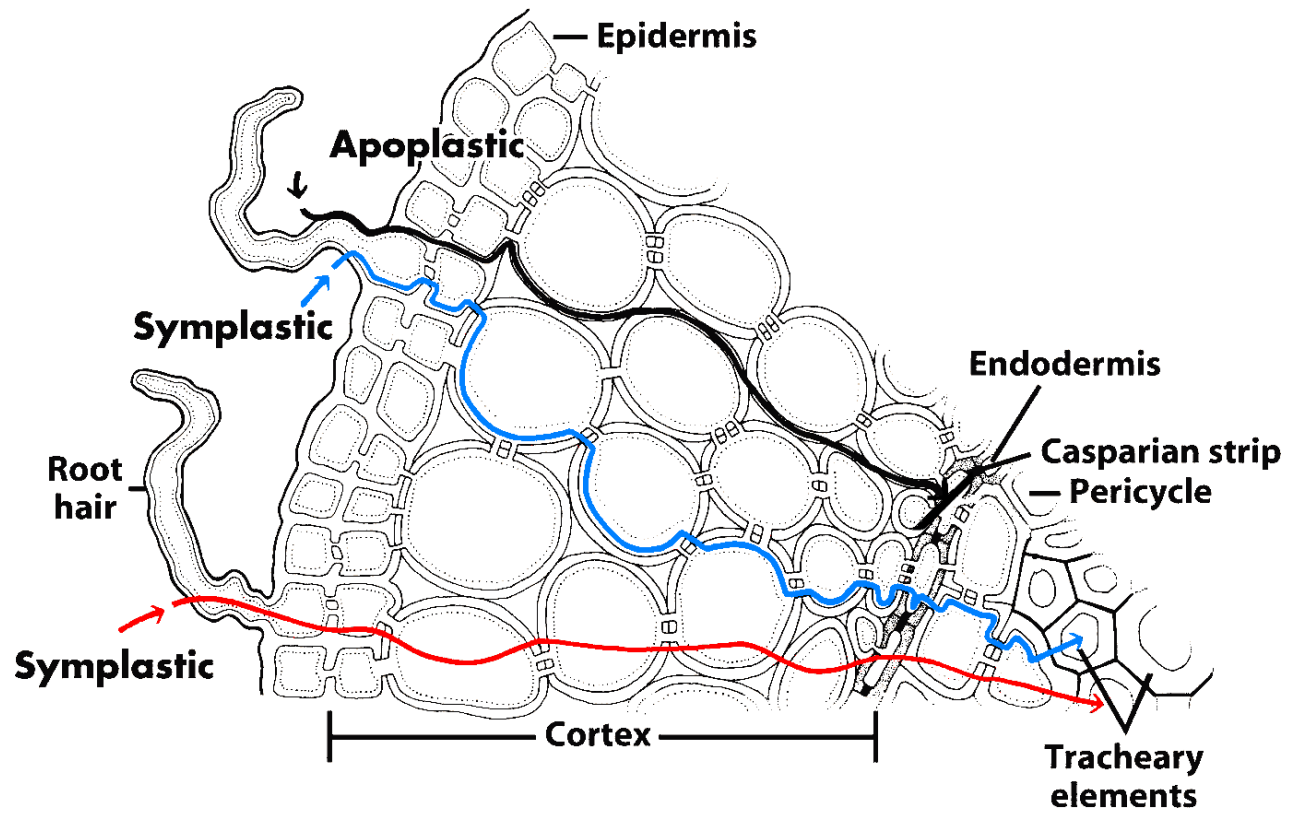
- The existence of root hairs dramatically increases the surface of absorption
- Every root hair cell increase the internal concentration of large molecules, typically organic acids
- Process of concentration requires ATP
- As a result, osmosis water flow starts from soil to root cells

### Endoderm and root pressure

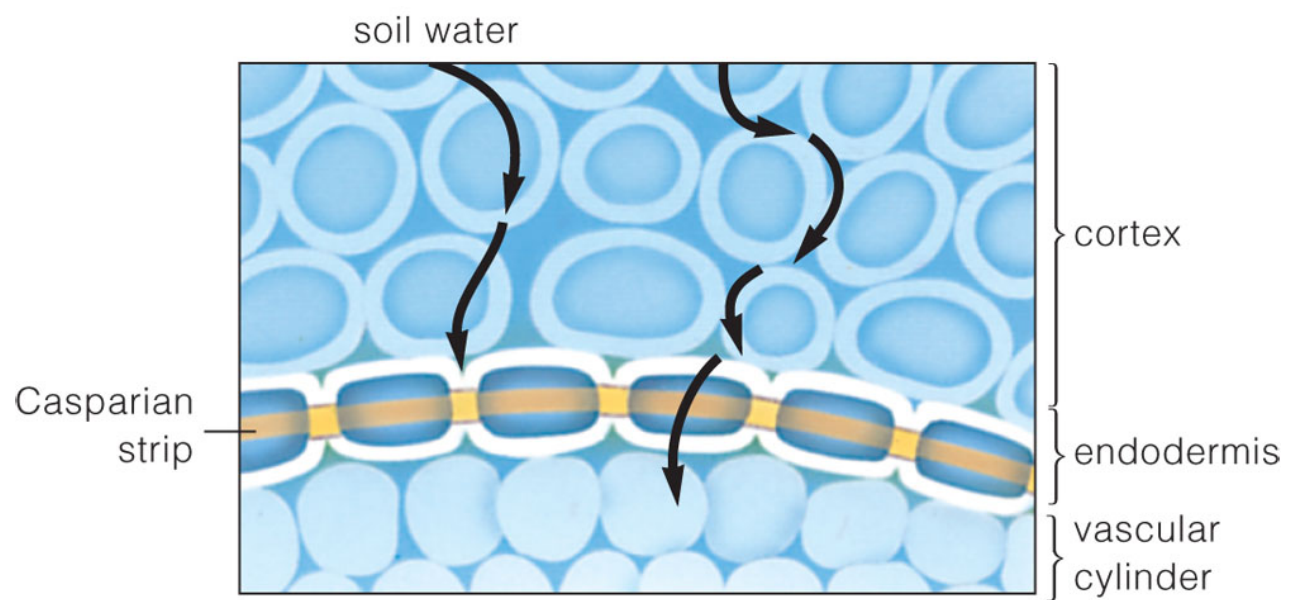
- From rhizoderm to endoderm, transport of water is both symplastic and apoplastic
- In the endoderm cells, Caspari stripes stop apoplastic transport and therefore forced symplastic transport
- This is a high-energetic process requires ATP
- As a result, water will be pushed up from root: this is the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

### Apoplastic and symplastic transport in the root

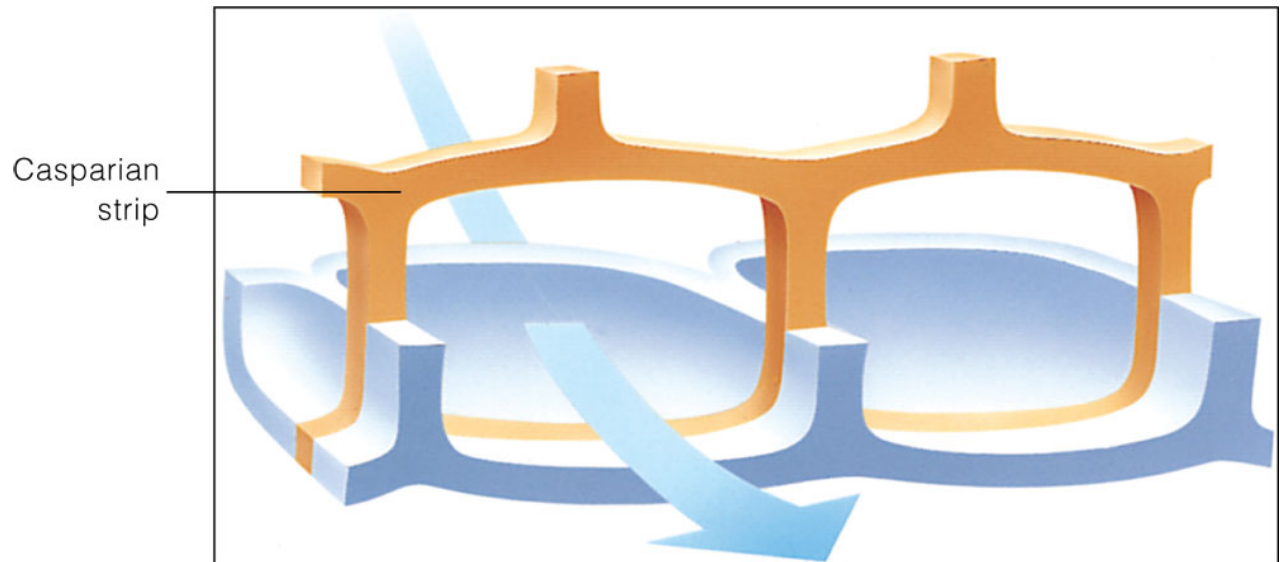




Casparian strips

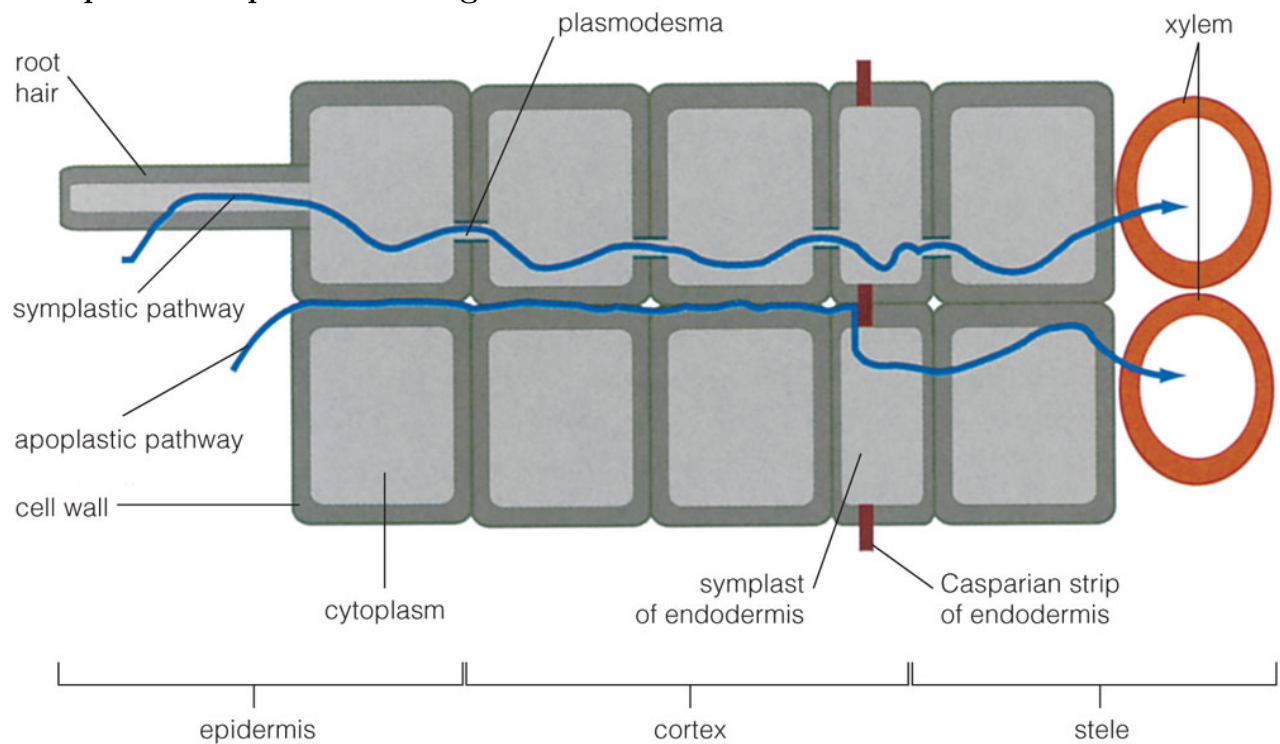


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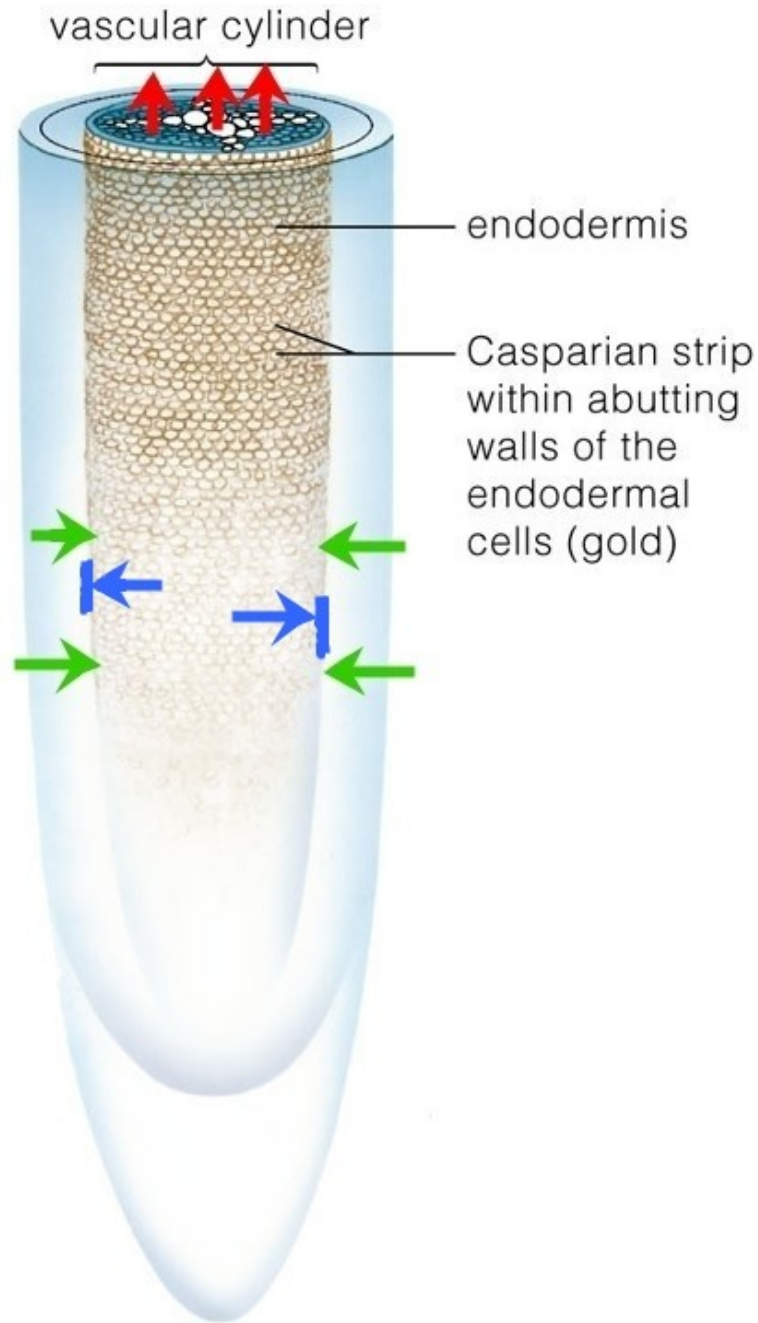
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## How Casparian strips are working



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## Origin of root pressure



## 2.5 Diversity of roots

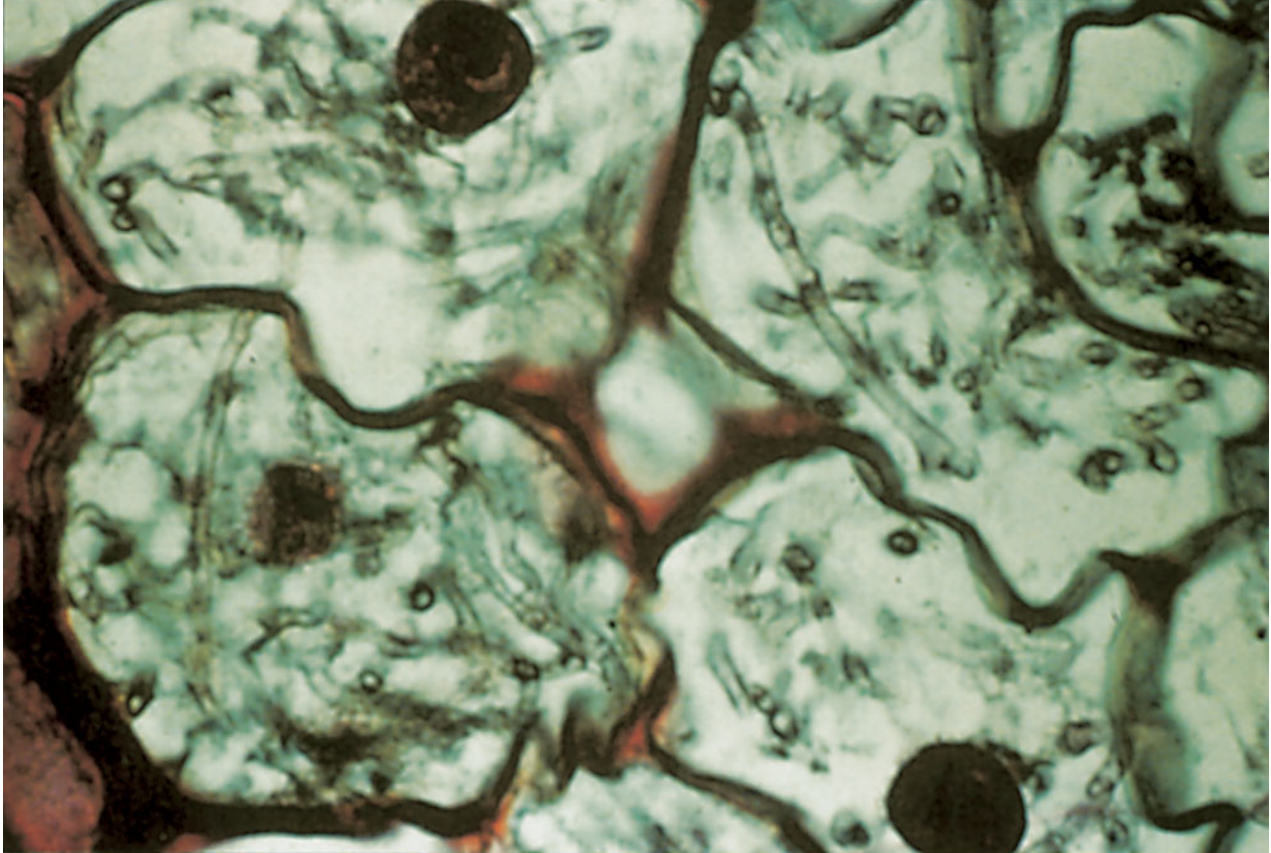
### Modifications of roots

- 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.—hyacinth, *Taraxacum* spp.—dandelion)
- Storage roots (*Daucus carota*—carrot, *Armoracia officinalis*—horseradish)



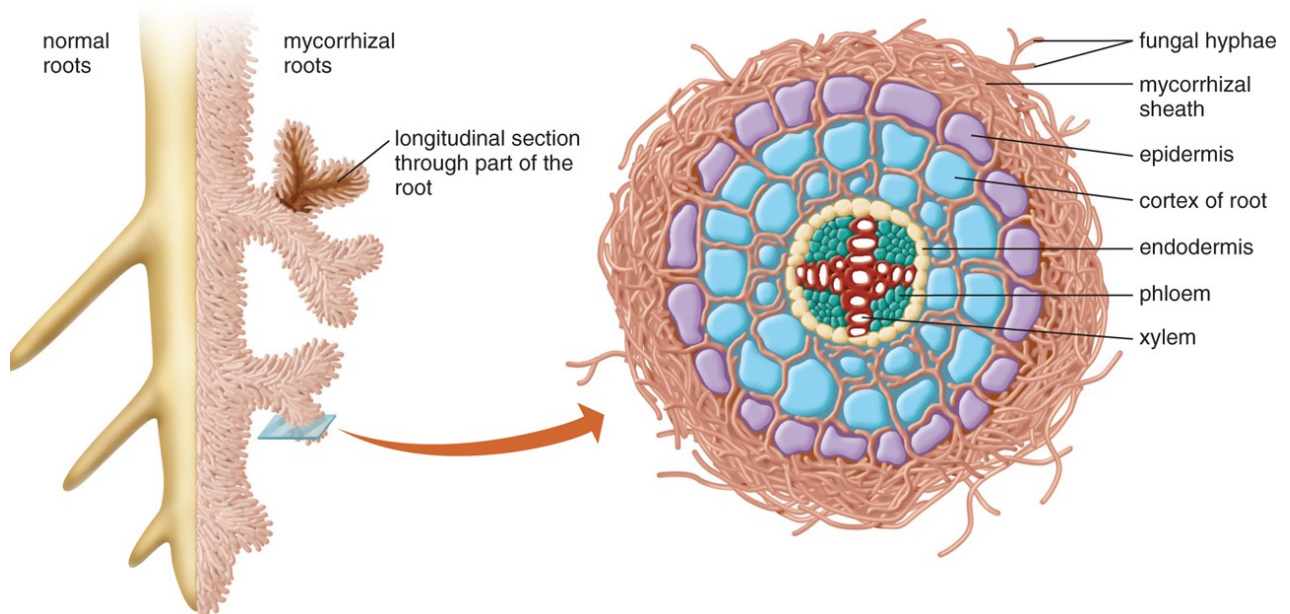
- Supportive roots (many tropical plants)
- Defensive, spiny roots (ivy)
- Photosynthetic roots (some orchids)

### Endotrophic mycorrhizae in *Corallorhiza* orchid



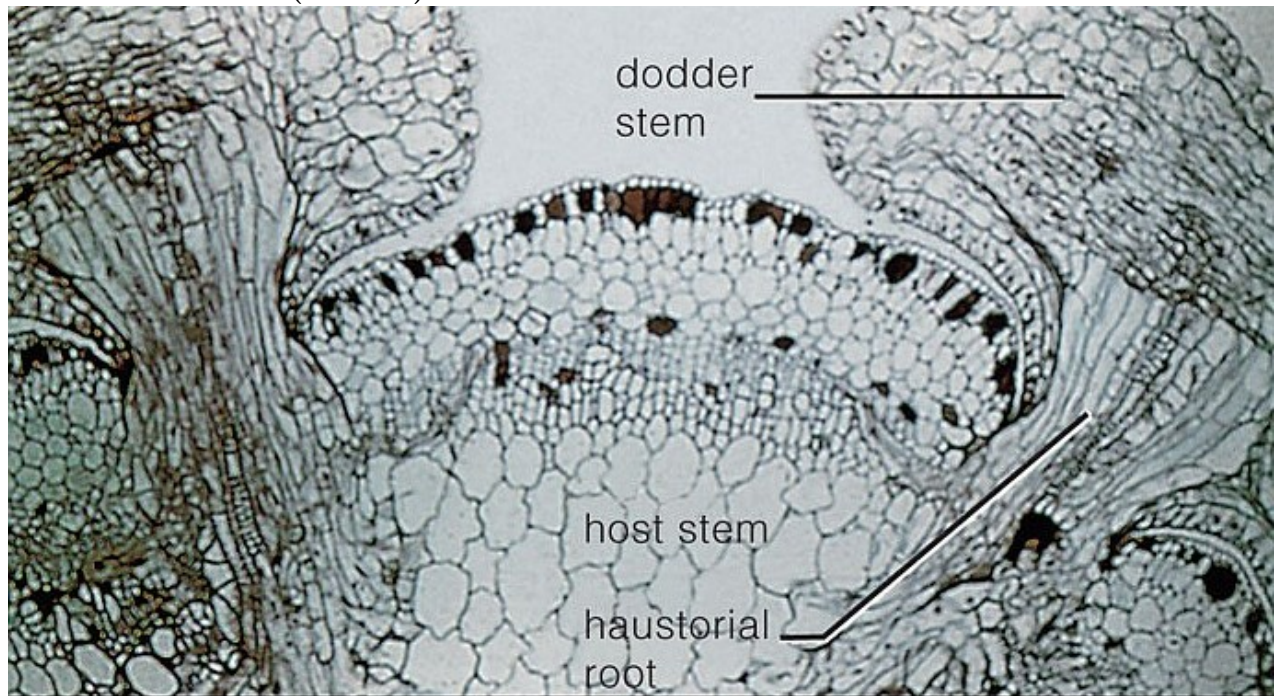
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### Ectotrophic mycorrhizae of trees





Hauatoria of *Cuscuta* (dodder)



Nodulated roots of soybean (*Glycine max*)





Contractile roots of *Hyacinthus orientalis*



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Supportive roots of mangrove plants





Supportive roots of *Pandanus* sp.



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





Photosynthetic aerial roots of orchids



David Webb

### Table of modifications

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

### Final question (2 points)

What are adventitious roots?

## Summary

- **Root** is an axial vegetative organ with a function of soil nutrition
- **Rhizoderm** and **absorption zone** are the most physiologically important parts of root
- Root differs from stem having rhizoderm, thick cortex, endoderm, long-lived pericycle and radially arranged primary vascular tissues
- Secondary thickening make root more similar to stem
- Root modifications often provide ways of interaction with other organisms: bacteria, fungi and other plants

## For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 7*.

## Outline

## 3 Questions and answers

### Previous final question: the answer

What are adventitious roots?

- Roots growing from the stem

## 4 Plant diversity

### 4.1 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
- Priority, starting dates, synonyms
- Shortcuts: “sp.”, “spp.”, “s.l.” (wide sense), “s.str.” (strict sense), “i.s.” (position unknown)

### 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	<i>Chlorophytum</i>	<i>Homo</i>
Species	Species	<i>Chlorophytum comosum</i> (Thunb.) Jacq. 1862	<i>Homo sapiens</i> L.

Species name				
<u>Chlorophytum</u>	<u>comosum</u>	<u>(Thunb.)</u>	<u>Jacq.</u>	<u>1862</u>
Genus name	Species epithet	First author	Second author	Year of description

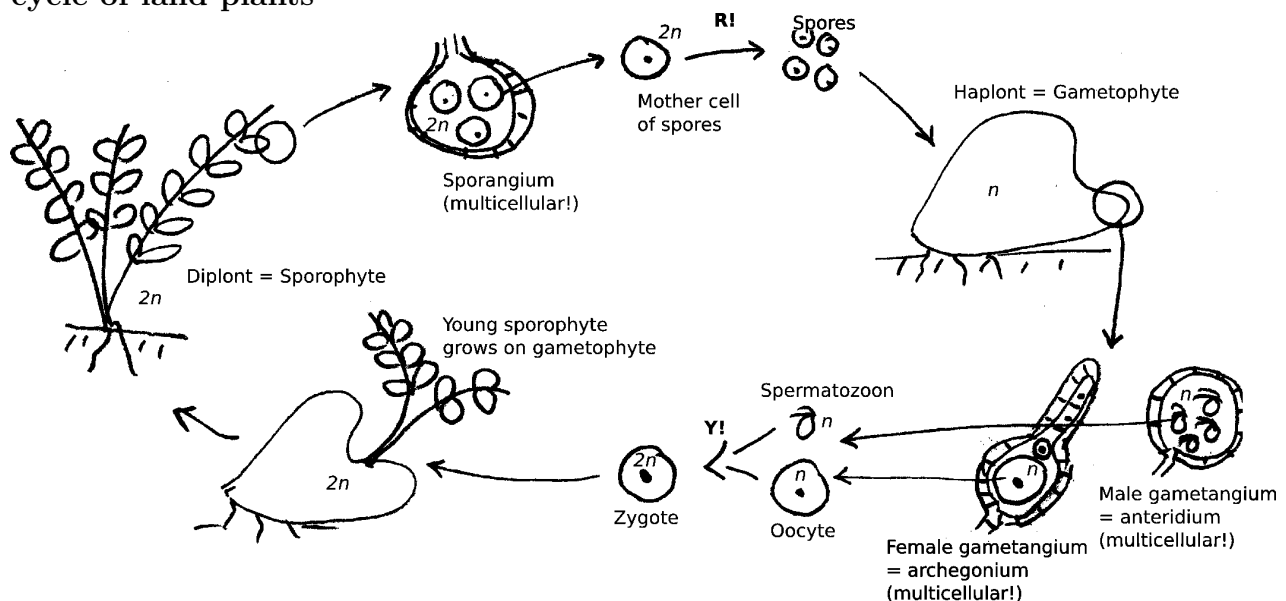
## 4.2 Kingdom Vegetabilia, land plants

### Life cycle of land plants

#### Terms covered:

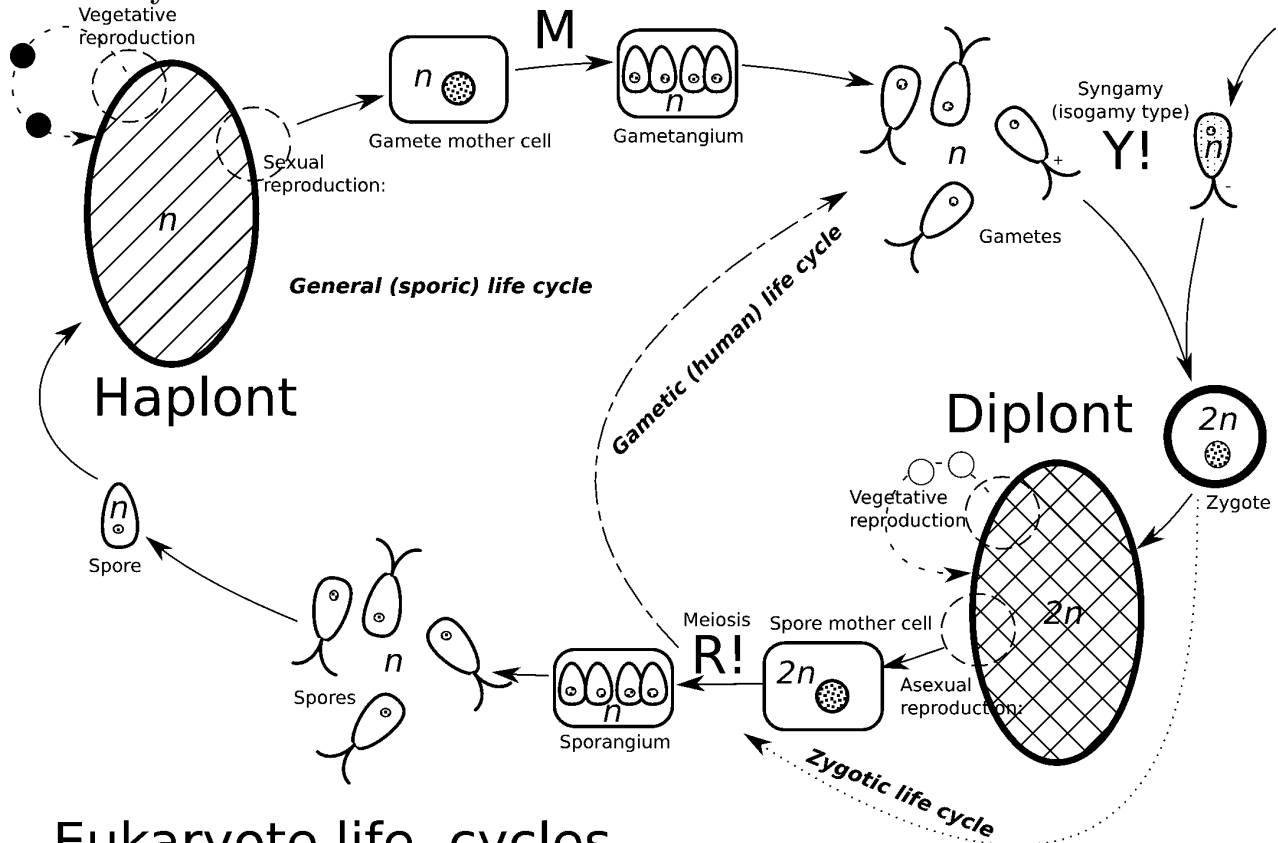
- Sporophyte and gametophyte
- Archegonium and antheridium
- Spermatozoa and oocyte (egg cell)
- Embryo and parasitic sporophyte
- Predominance of sporophyte and/or gametophyte

### Life cycle of land plants



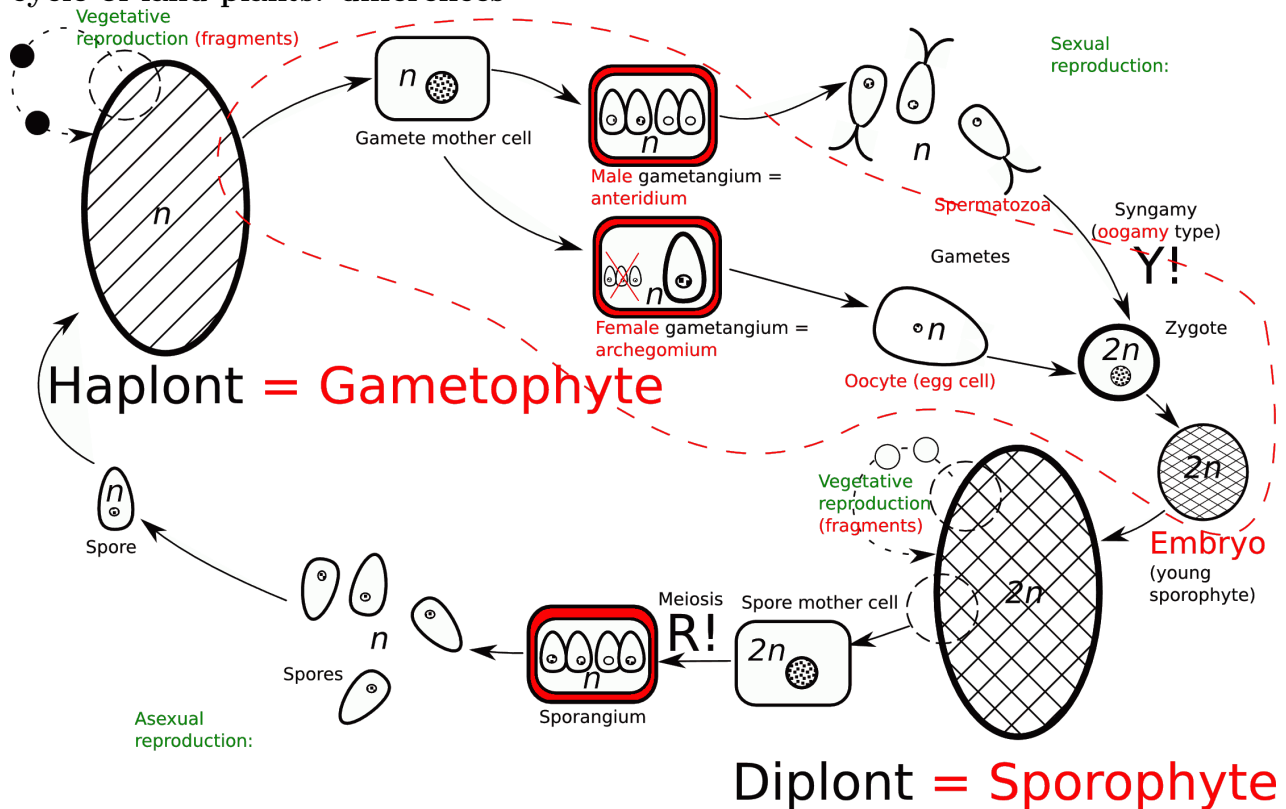


## General life cycle



## Eukaryote life cycles

### Life cycle of land plants: differences



### Three main phyla

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

### 4.3 Phylum Bryophyta: mosses

#### 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



Final question (2 points)

Phylum, ..., order?

## Summary

- Taxonomy studies the diversity of living things
- Seven main categories (ranks) are used to make the hierarchy in the classification
- Land plants have a sporic life cycle with multicellular gametangia and sporangia, oogamy and embryo.
- **Bryophyta**, **Pteridophyta** and **Spermatophyta** are three main phyla of plants<sub>2</sub>.
- **Bryophyta** are only plants<sub>2</sub> with gametophyte predominance.

## For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 18, 22*.

## Outline

## 5 Questions and answers

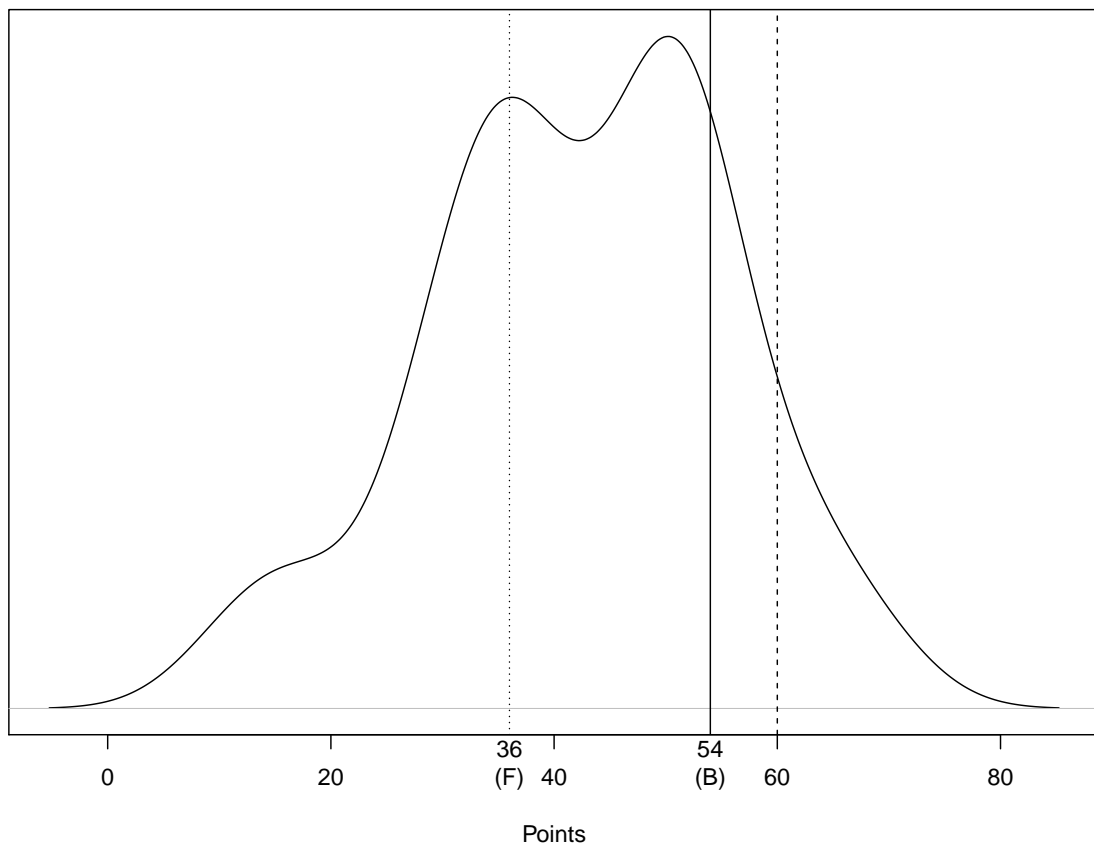
### Results of Exam 3: statistic summary

Summary:

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	NA's
11.00	35.00	43.00	42.33	51.50	69.00	1
Grades:						
F	D	C	B	max		
36	42	48	54	60		

### Results of Exam 3: the curve

### Density estimation for Exam 3 (Biol 154)



4. Which is the correct sequence of tissues from the center to the periphery?
- (a) Cork cambium, phelloderm, epidermis
  - (b) Phelloderm, cork cambium, epidermis
  - (c) **Phelloderm, cork cambium, phellem**
  - (d) Phellem, epidermis, phelloderm
7. Which of the following is a lateral meristem?
- (a) **Cork cambium**
  - (b) Secondary xylem
  - (c) Cortex
  - (d) Rhizoderm
20. Plant growing in California deserts should have well-developed:
- (a) Guard cells
  - (b) **Palisade cells**
  - (c) Spongy cells

27. Cells from which type of leaf mesophyll absorb a direct sunlight?

- (a) Palisade
- (b) **Spongy**
- (c) Vascular

*Short answers: dead cells, xylem and phloem, leaf description*

**Previous final question: the answer**

Phylum, ..., order?

- Class (Lat. classis)

## 6 Plant diversity

### 6.1 Phylum Bryophyta: mosses

#### **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 groups (subphyla)

- **Hepaticae**—liverworts. Three classes, most primitive are Haplomitriopsida. Body 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, sporogon long, green, with columella and stomata, spores with elaters.

### Final question (2 points)

What is a sporogon?

### Summary

- **Bryophyta** are only plants<sub>2</sub> with gametophyte predominance.
- Among **Bryophyta**, Hepaticae is a most primitive group closest to green algae.

### For Further Reading

# References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 22*.

## Outline

## 7 Questions and answers

Previous final question: the answer

What is a sporogon?

- Moss sporophyte

## 8 Plant diversity

### 8.1 Phylum Bryophyta: mosses

Three main groups (subphyla)

- **Hepaticae**—liverworts. Three classes, most primitive are Haplomitriopsida. Body leafy or thal-  
loid, 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), Poly-  
trichopsida (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 (Bryophytina) in the “evolutionary dead end”

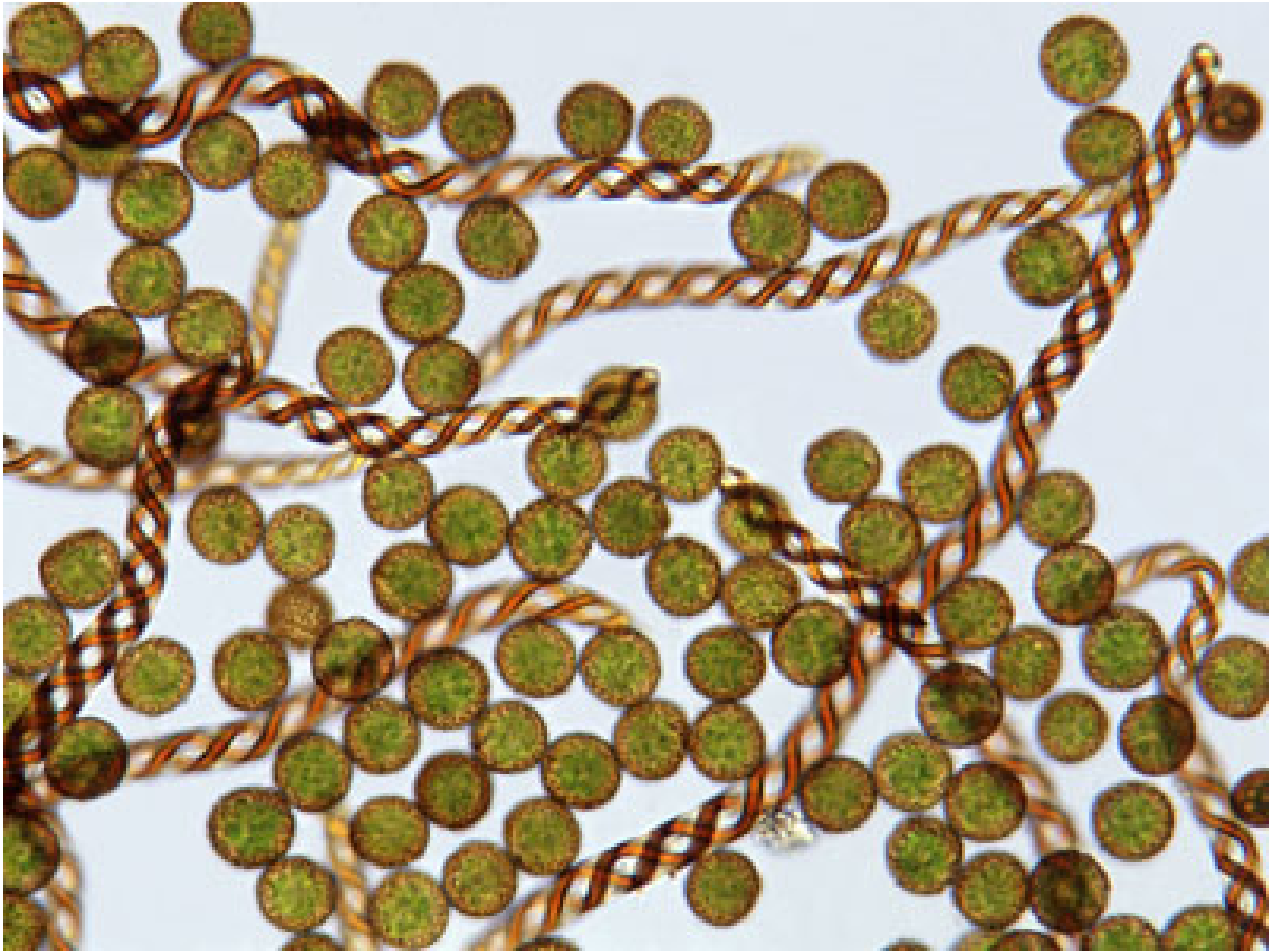
- They resolved “skyscrapers problem” via gametophyte, not sporophyte
- Gametophyte needs water fertilization, which restricts the size and also requires the dense growing
- Also, root system is absent: this is an additional size restriction
- If sexual organs appear on the bottom of leafy shoot, sporogon (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





## 8.2 Pteridophyta

### 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 *Isoetes* 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 *Isoetes*) and  $\approx 1000$  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 *Isoetes* (quillwort) are heterosporous.

### Tropical lycophyte, *Huperzia linifolia*





*Phylloglossum drummondii*, one of smallest lycophytes



Before: Chicago 300 Million Years Ago (lepidodendrids)



After: aquatic lycophyte *Isoëtes* sp.





## Equisetopsida

- Small group of one genus, *Equisetum* with  $\approx 30$  species
- Leaves are reduced into scales, stems are segmented, photosynthetic. Have specific stele—**artrostele** with specific central, **valecular** and **carinal** 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*

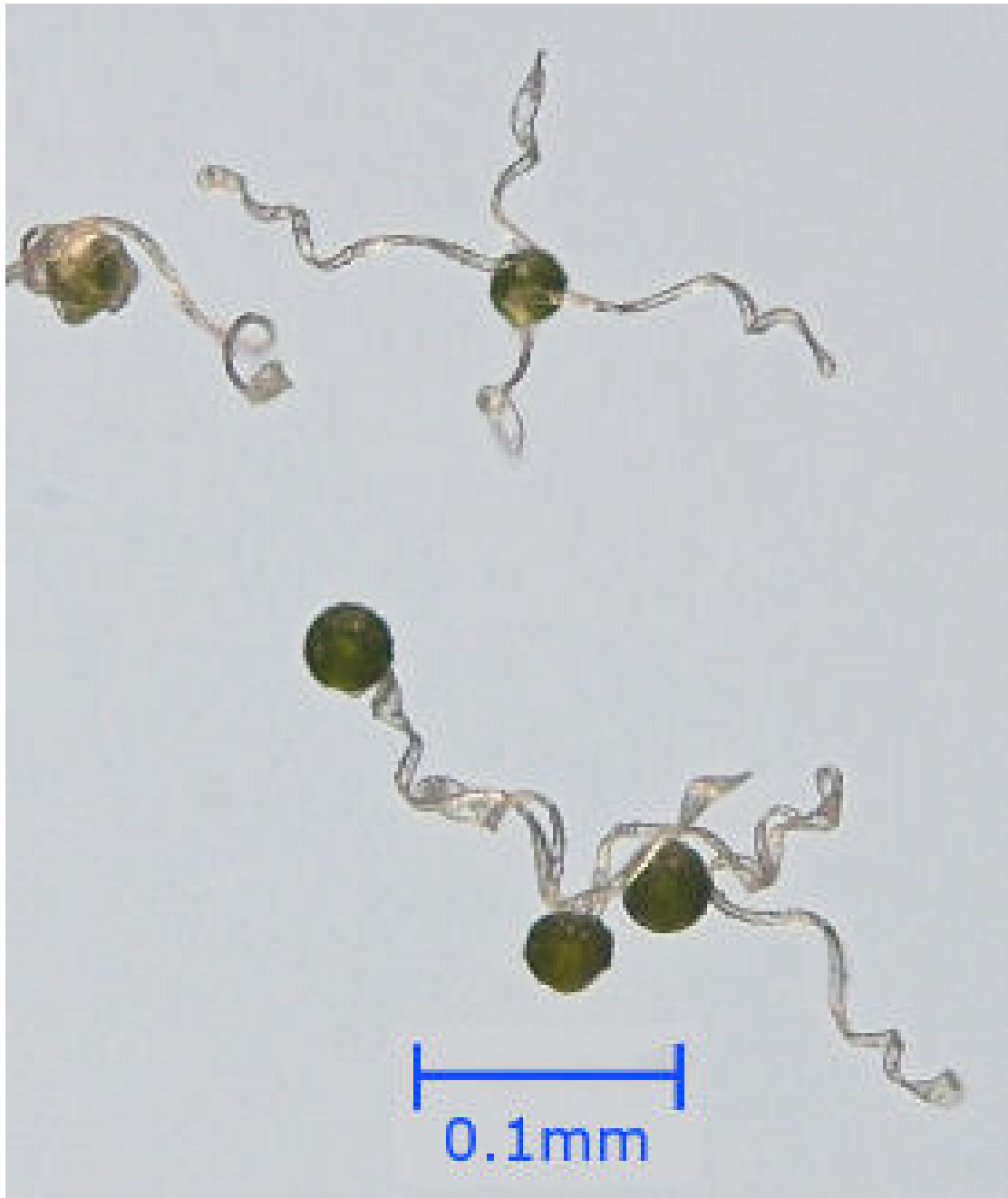


*Equisetum giganteum*



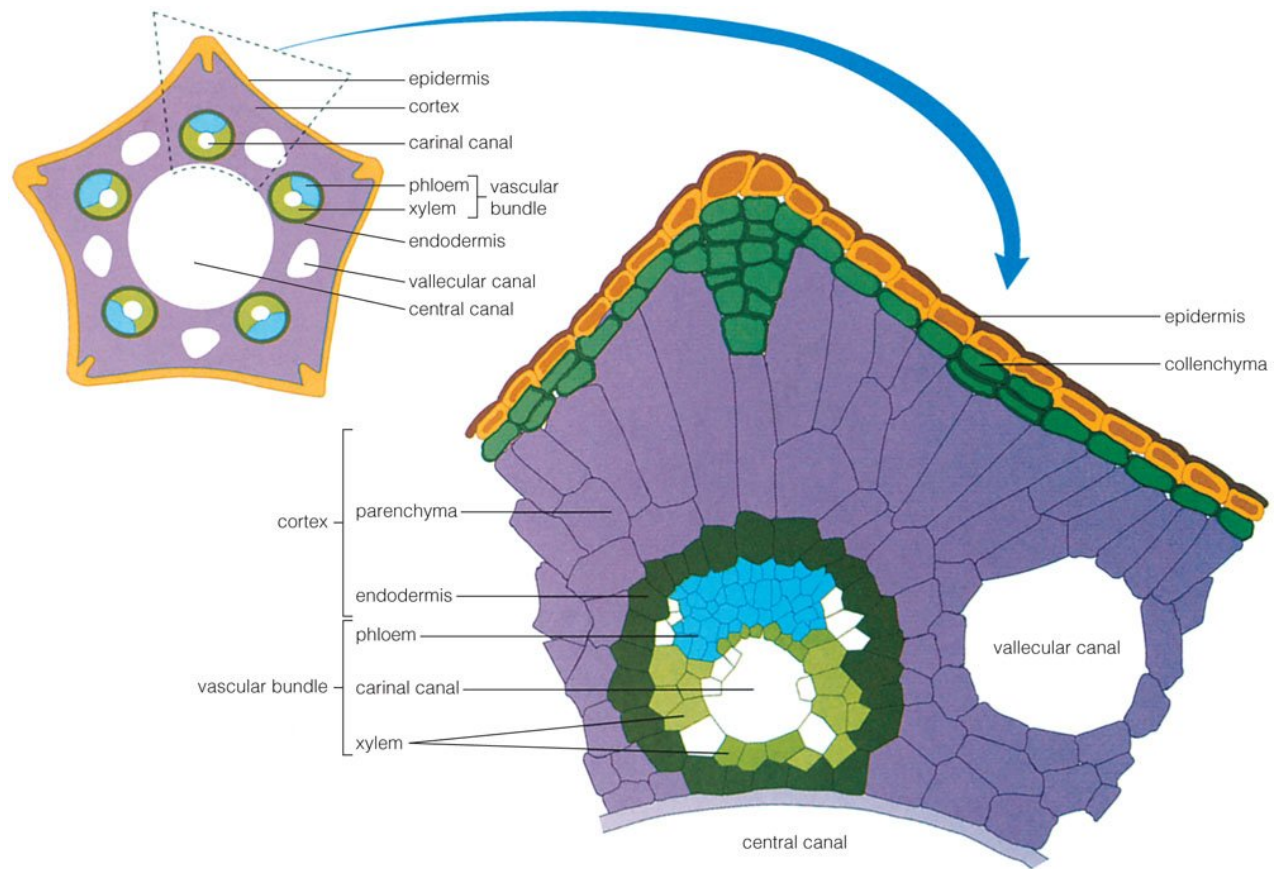


*Equisetum* sp. elaters



Artrostele





Horsetail gametophytes



Frequently, smaller ones are male whereas bigger are female

### Final question (3 points)

Why are ferns more advanced than mosses?

### Summary

- **Bryophyta** are only plants<sub>2</sub> with gametophyte predominance.
- Among **Bryophyta**, Hepaticae is a most primitive group closest to green algae.

### For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 22, 23*.

### Outline

## 9 Questions and answers

Previous final question: the answer

Why are ferns more advanced than mosses?

- Xylem and phloem (mosses: only some Polytrichopsida)
- Roots (exception: Psilotopsida)
- Better system of fertilization (small flat gametophyte and big branched photosynthetic sporophyte)

## 10 Plant diversity

### 10.1 Heterospory

Horsetails start it: spores same, gametophytes different



#### Heterospory

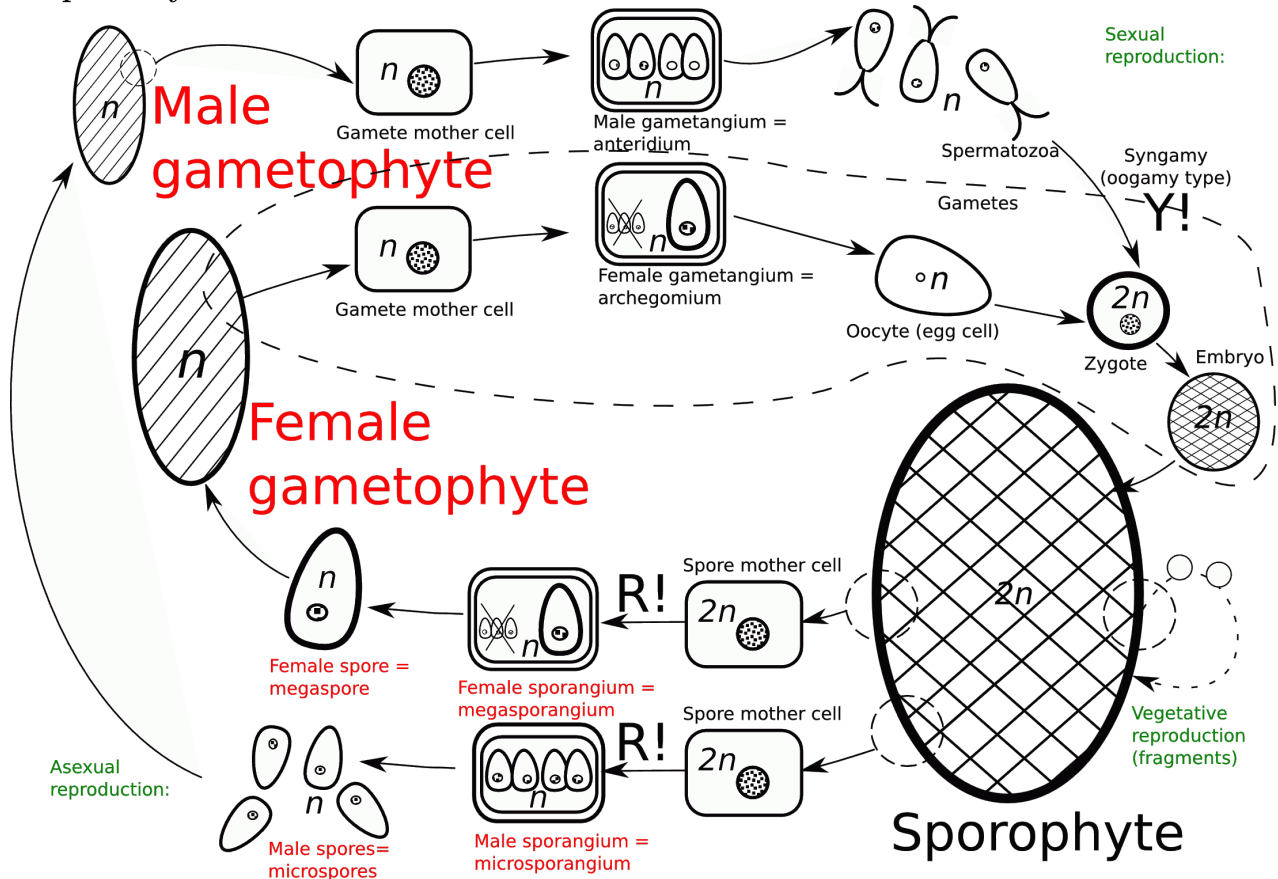
Heterosporous ferns (lycophytes *Selaginella* and *Isoetes*, monilophytes *Salvinia*, *Marsilea*, *Pilularia*, *Regnellidium* and *Azolla*) went one step further and made their spores different too. It will allow the better allocation of resources and will restrict the self-fertilization.

Terms covered:

- Male gametophyte, female gametophyte

- Microspores and microsporangium
- Megaspores and megasporangium

### Heterosporic cycle: differences



## 10.2 “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 ferns). Sporangia unite into **synangia**. Leaves may be 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  $\approx 75$  species
- Always have underground rhizome and aboveground bisected leaves: one half is the leaf blade and other half is **sporangioophore**. Gametophytes grow underground
- Some (*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  $\approx 100$  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)

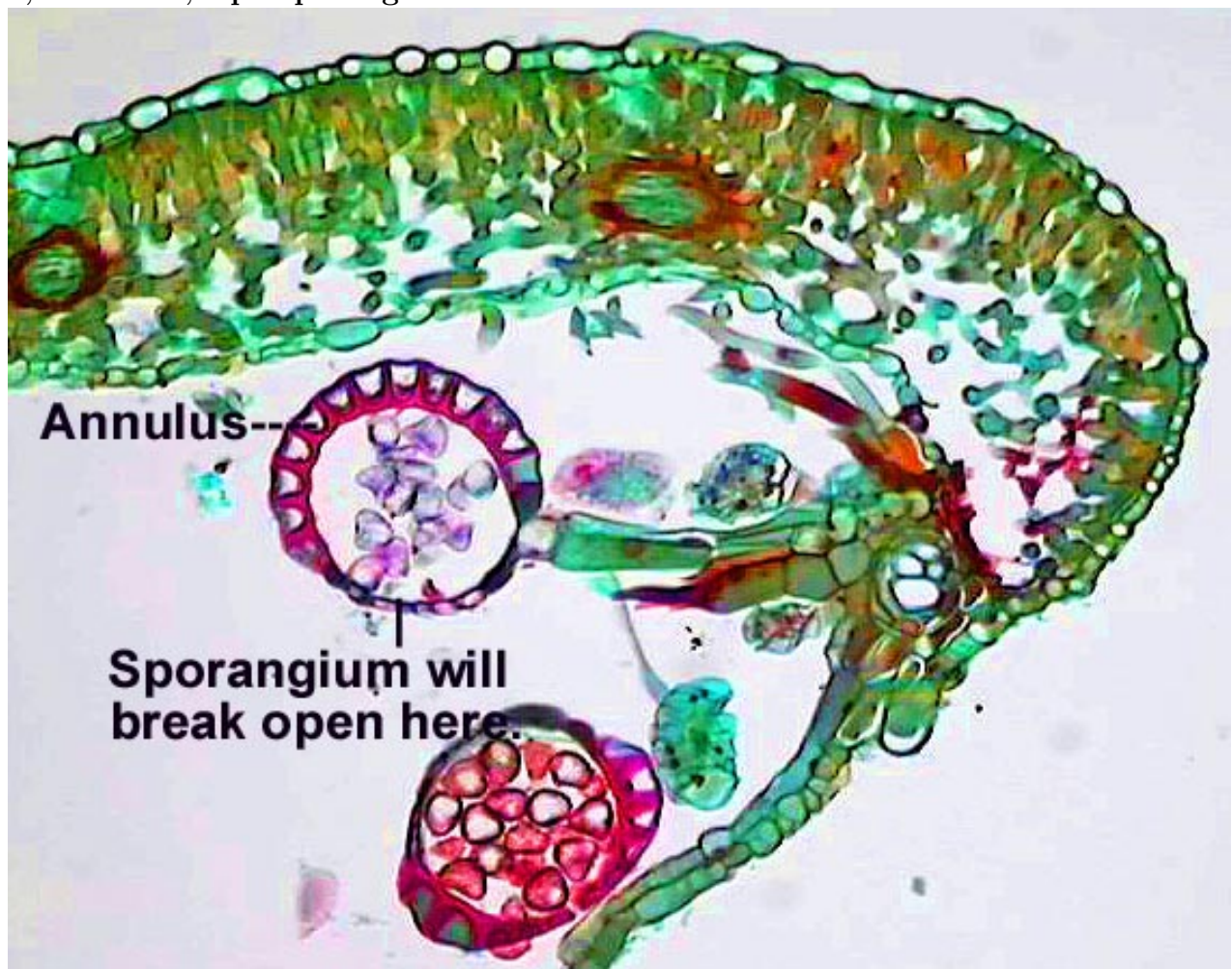




## Pteridopsida

- “True” ferns, more than 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 aquilinum*, is the most widespread plant
- Many ferns have vegetative reproduction originated from asexual (**apospory**) or sexual (**apogamy**)

### Sorus, indusium, leptosporangium and annulus



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



Young leaves of bracken fern become famous Korean food “gosari”



### Final question (2 points)

What is a heterospory?

### Summary

- Heterosporous plants have two kinds of spores: female (megaspores) and male (microspores)
- Pteridophyta consist of two lineages (subphyla): microphyllous **lycophytes** and megaphyllous **moninophytes**
- Leptosporangiate ferns (“true” ferns) have thin sporangia with annulus

### For Further Reading



## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 23*.

## Outline

## 11 Questions and answers

### Previous final question: the answer

What is a heterospory?

- Male spores (microspores) and female spores (megaspores) to produce male and female gametophytes, respectively.

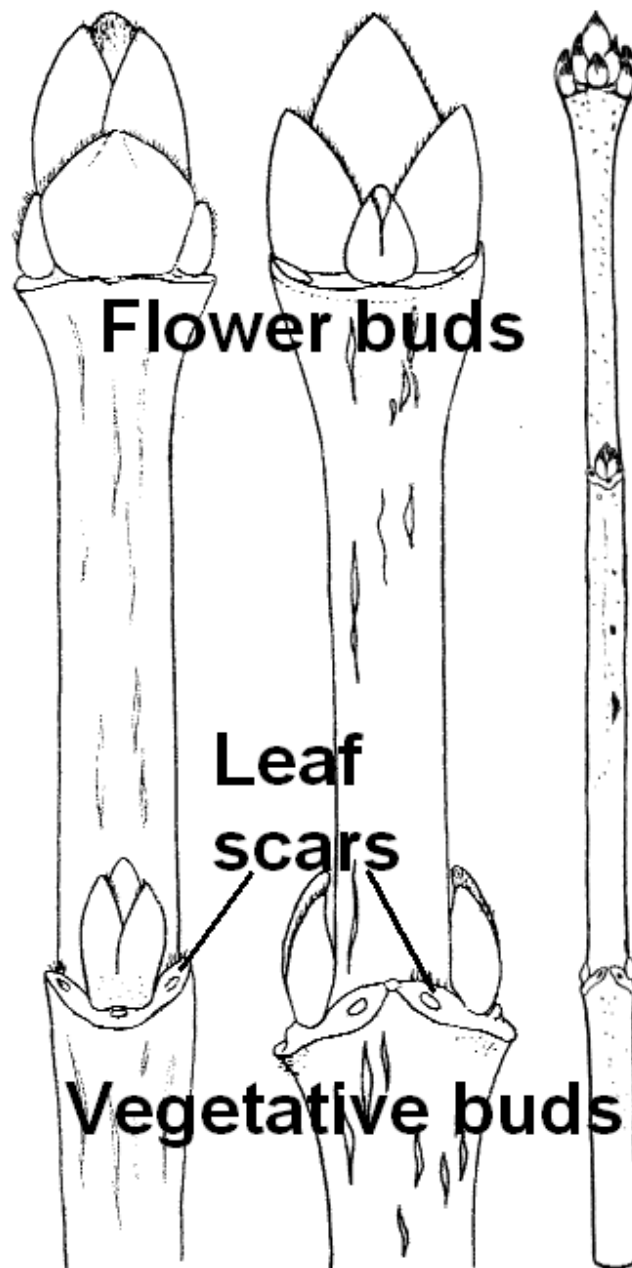
## 12 Thickening and branching

### 12.1 Branching

#### Winter shoot

1. Vegetative, flower, and mixed buds
2. Leaf and bud scars
3. Leaf traces

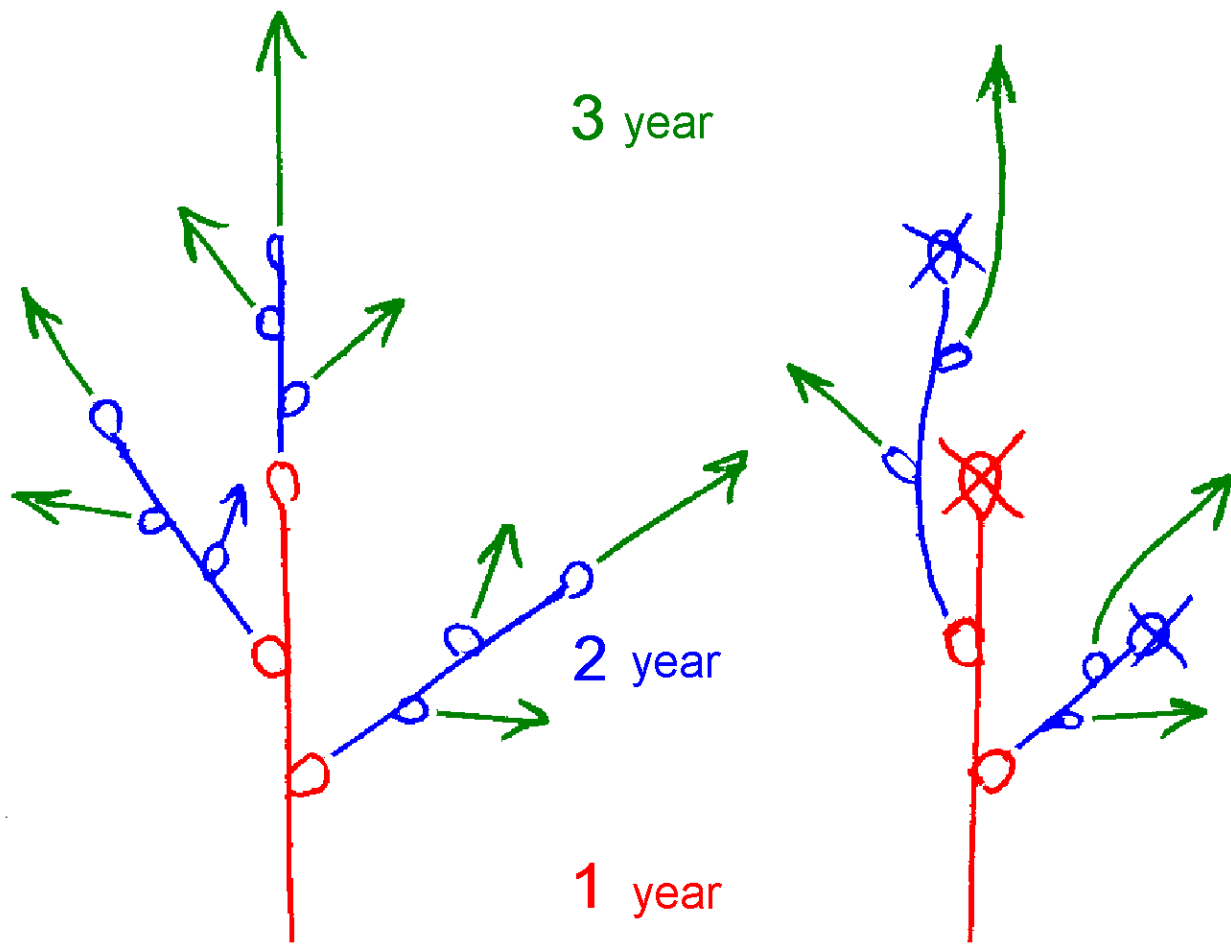
#### Winter shoot of maple (*Acer platanoides*)



### 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

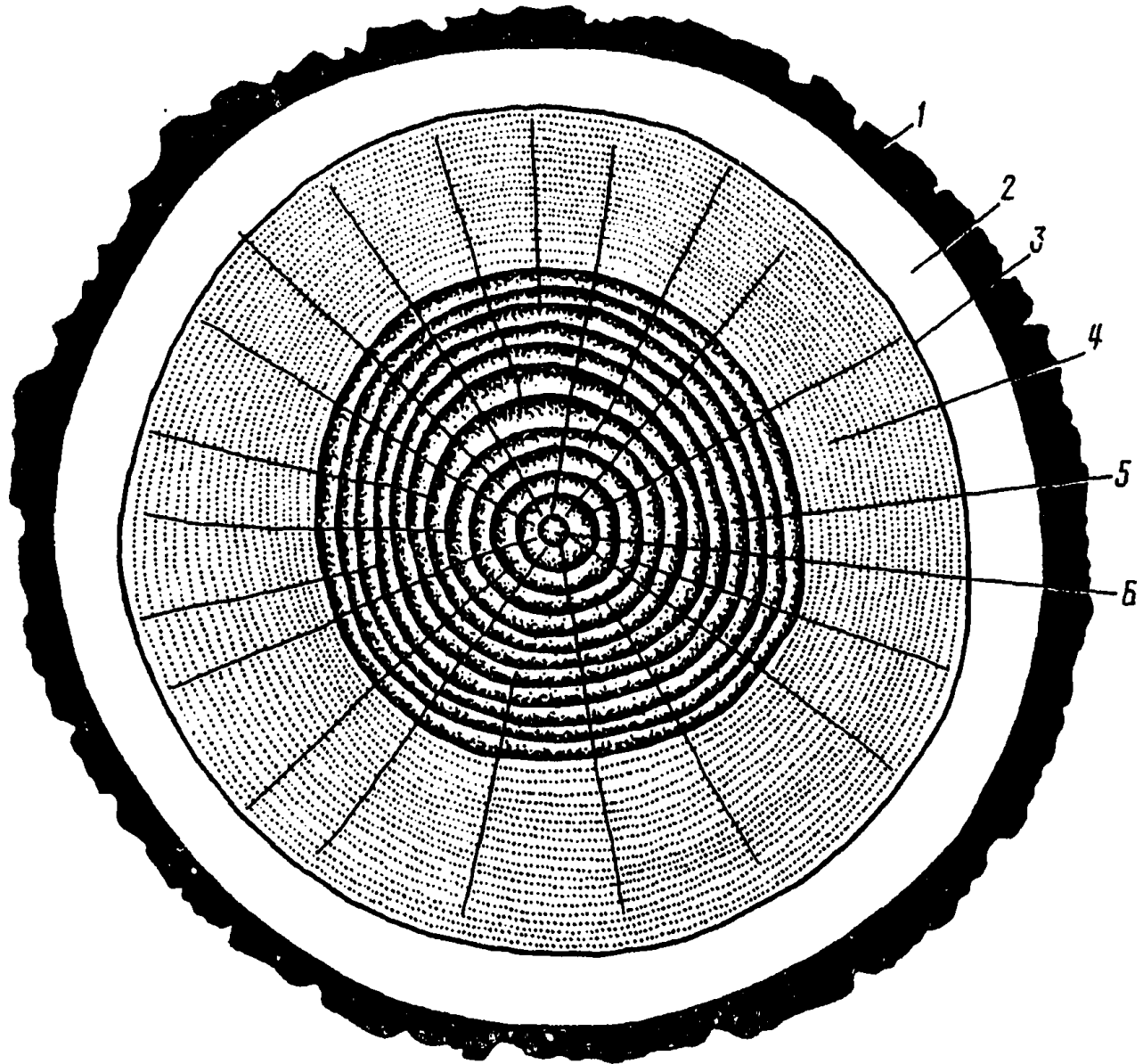
### Monopodial (left) and sympodial branching



## 12.2 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** = secondary phloem (bast) + periderm + (optionally) epidermis
- **Periderm** = phellem (cork) + cork cambium (phellogen) + phelloderm
- **Wood** = trunk – bark, or simply secondary xylem + all remnants of central primary tissues

### Cork cambium and origin of bark

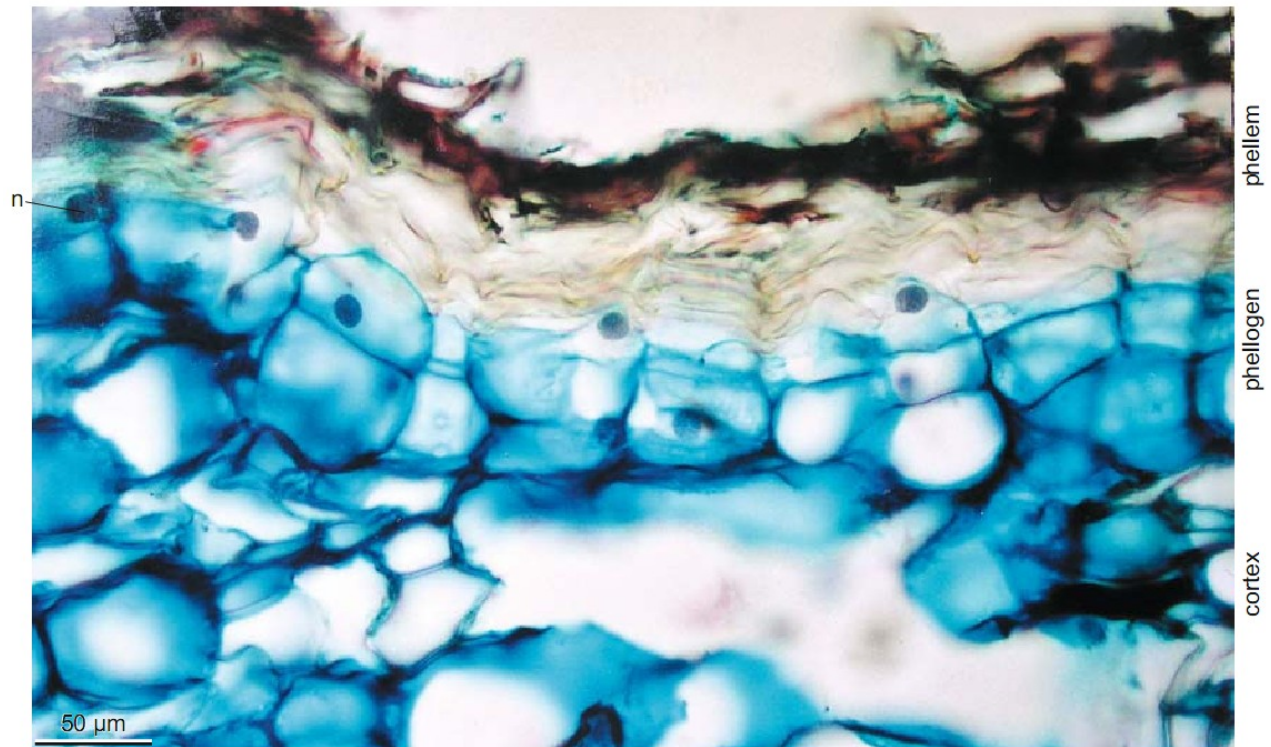
- **Bark** is everything outside vascular cambium, therefore, bark = secondary phloem + periderm
- Each year new layer of cork cambium appear from parenchyma cells of secondary phloem
- Consequently, bark consists of multiple and mostly uneven layers

Micrograph of a plant stem cross-section showing various tissues. Labels on the right side include: dead phloem, phg, sc, si, pa, living phloem, ca, v, and xylem.

- 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.

## 66





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.)



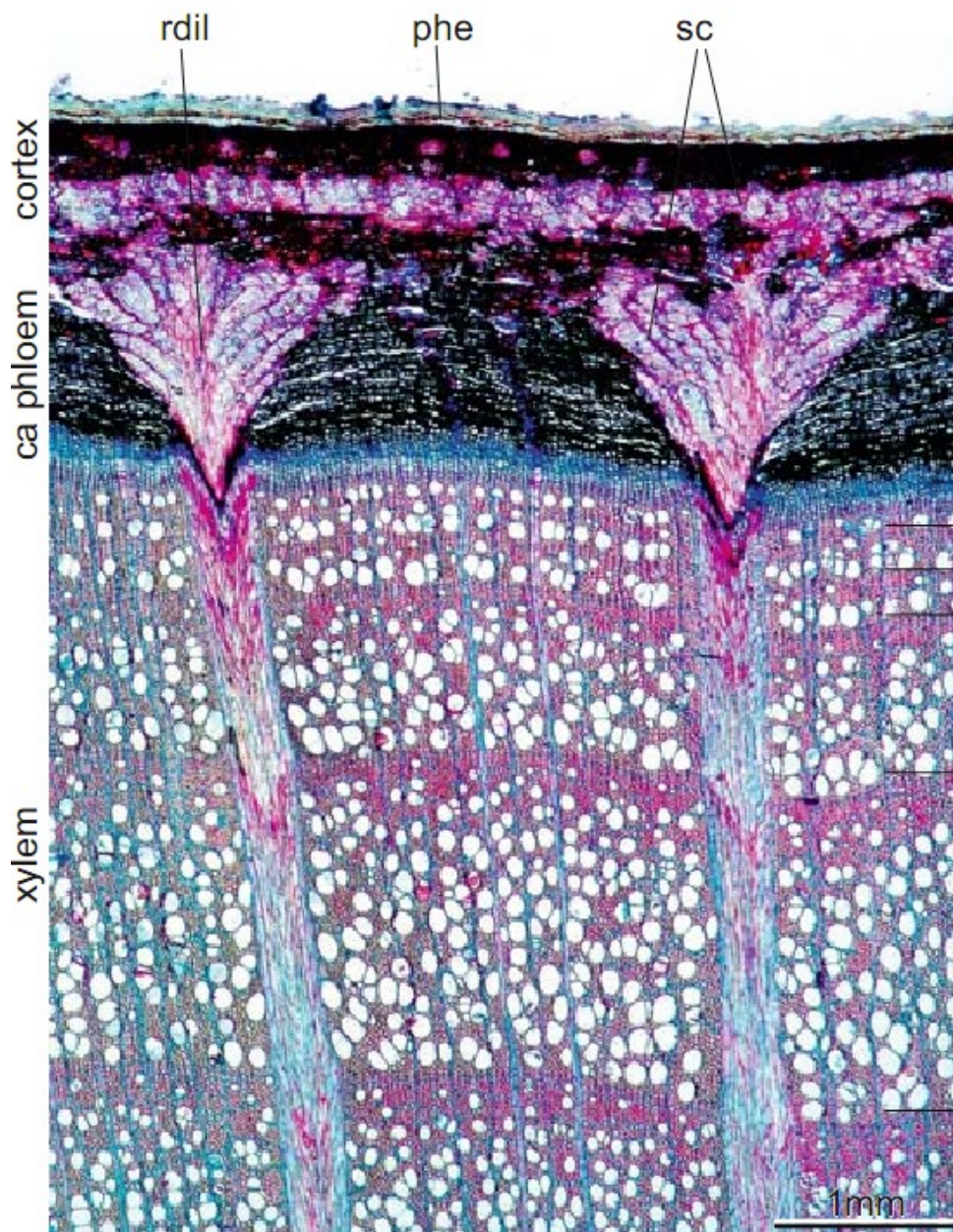


### Secondary phloem (bast)

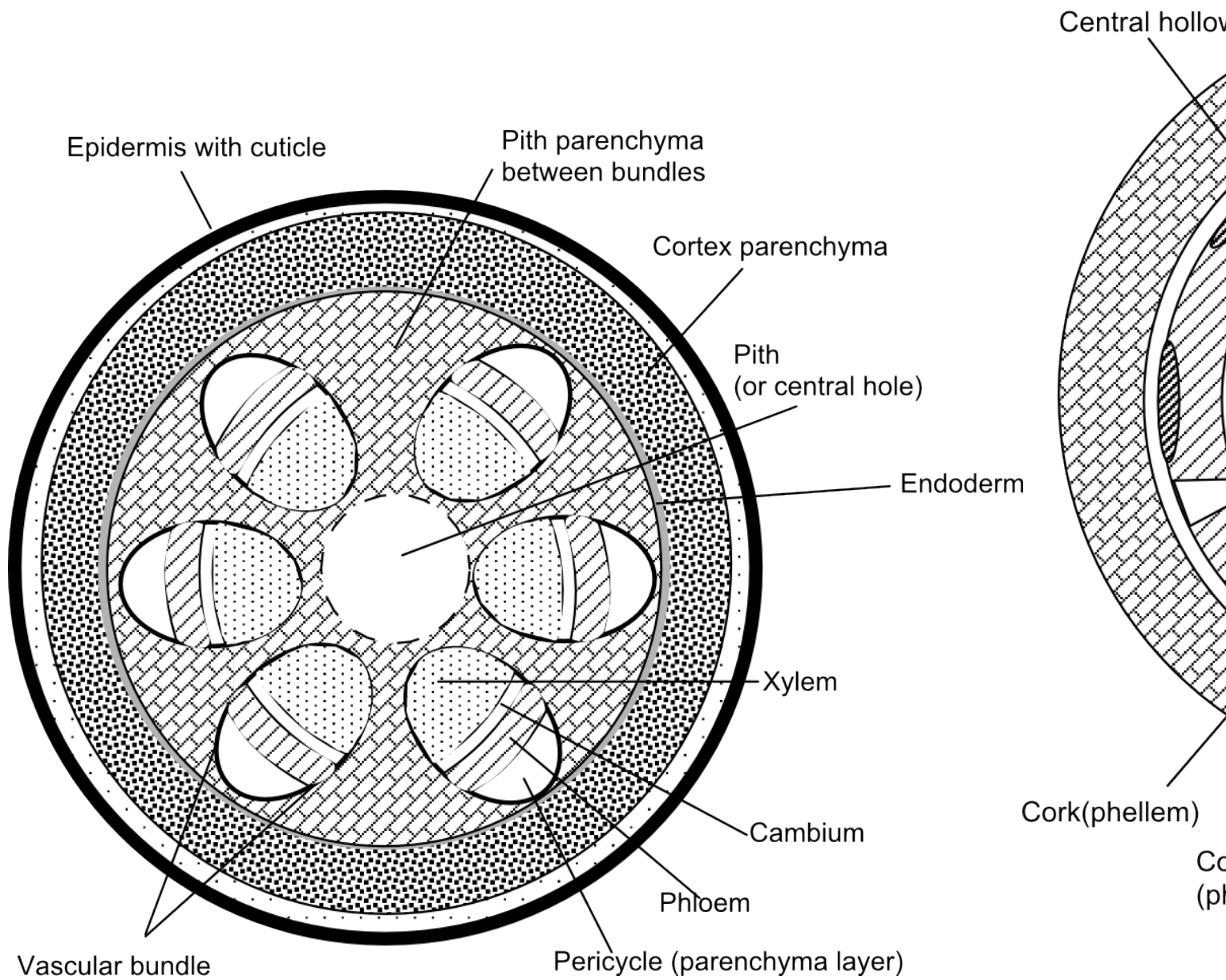
- Forms outside vascular cambium
- Rich of fibers
- Does not form annual rings
- Has rays of parenchyma cells, sometimes wedge-shaped (**dilated**)

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

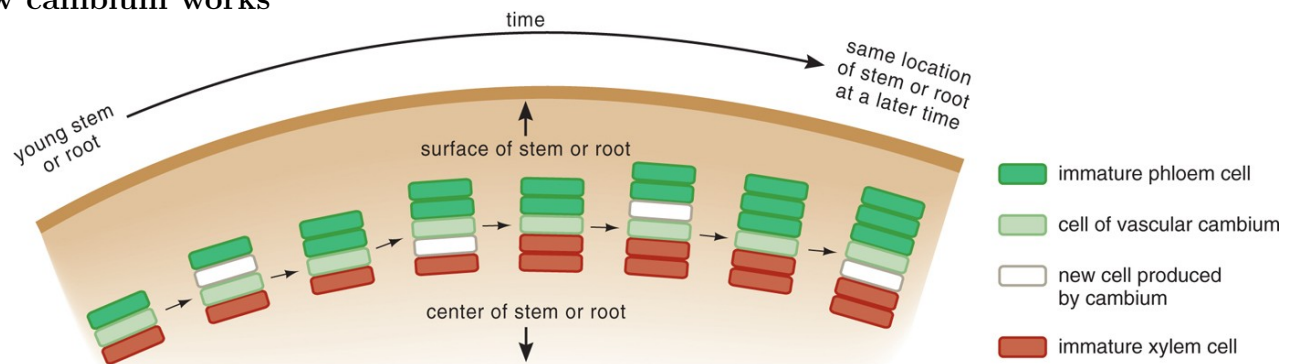




Primary and secondary stems (scheme)

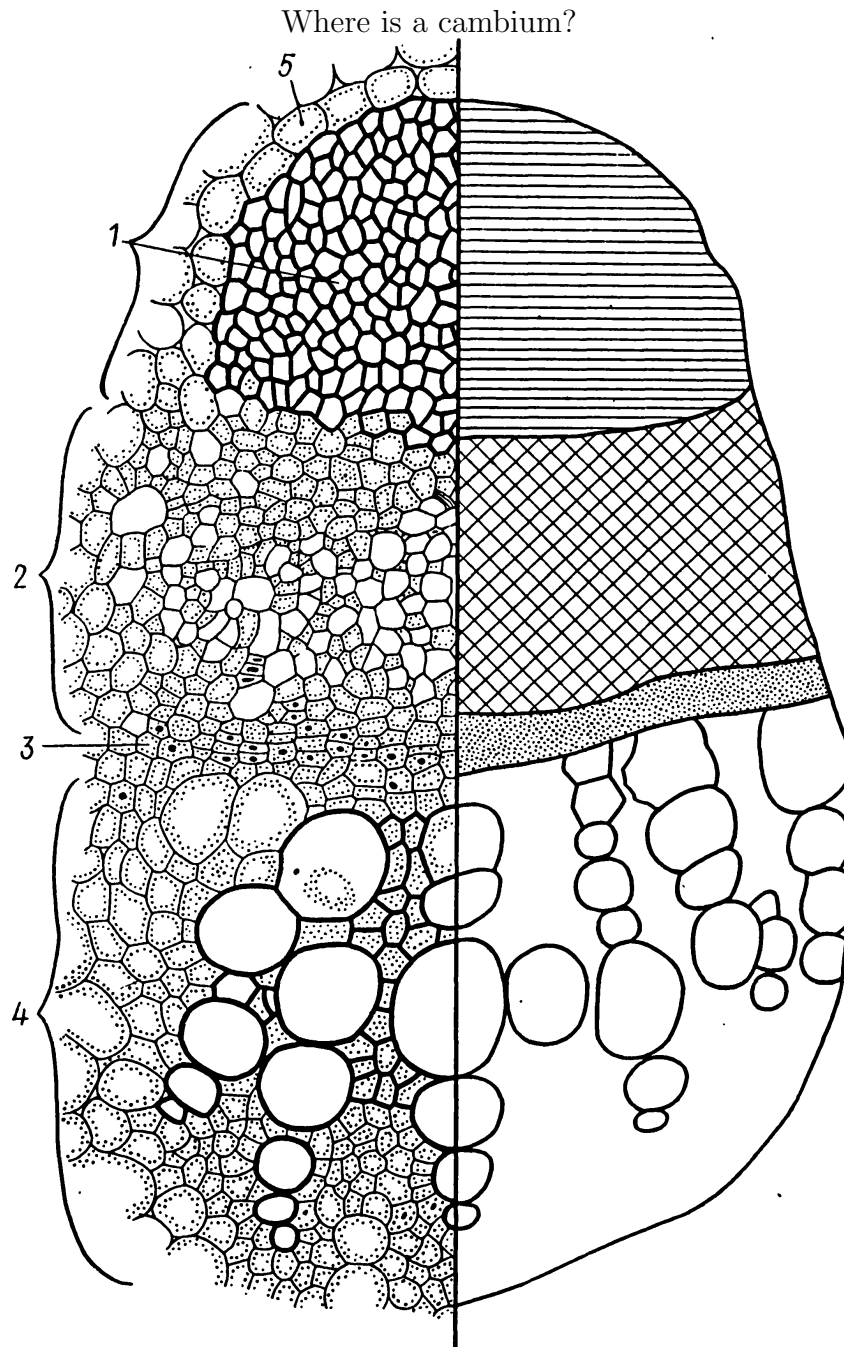


### How cambium works



Final question (2 points)





## Summary

- **Sympodial** branching is evolutionary more advanced than **monopodial**
- **Bark** consists of secondary phloem and cork
- **Wood** is a secondary xylem

## For Further Reading

## References

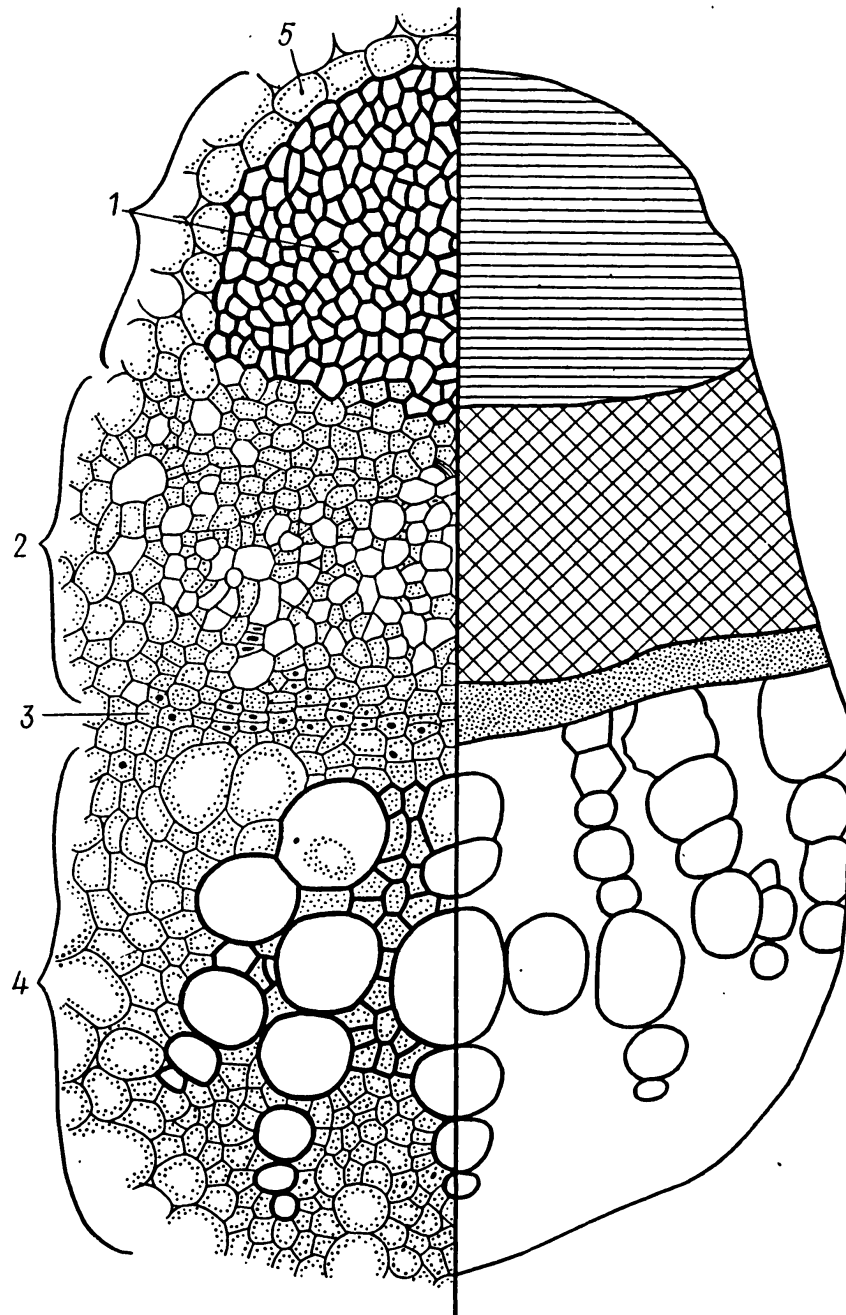
- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 5*.

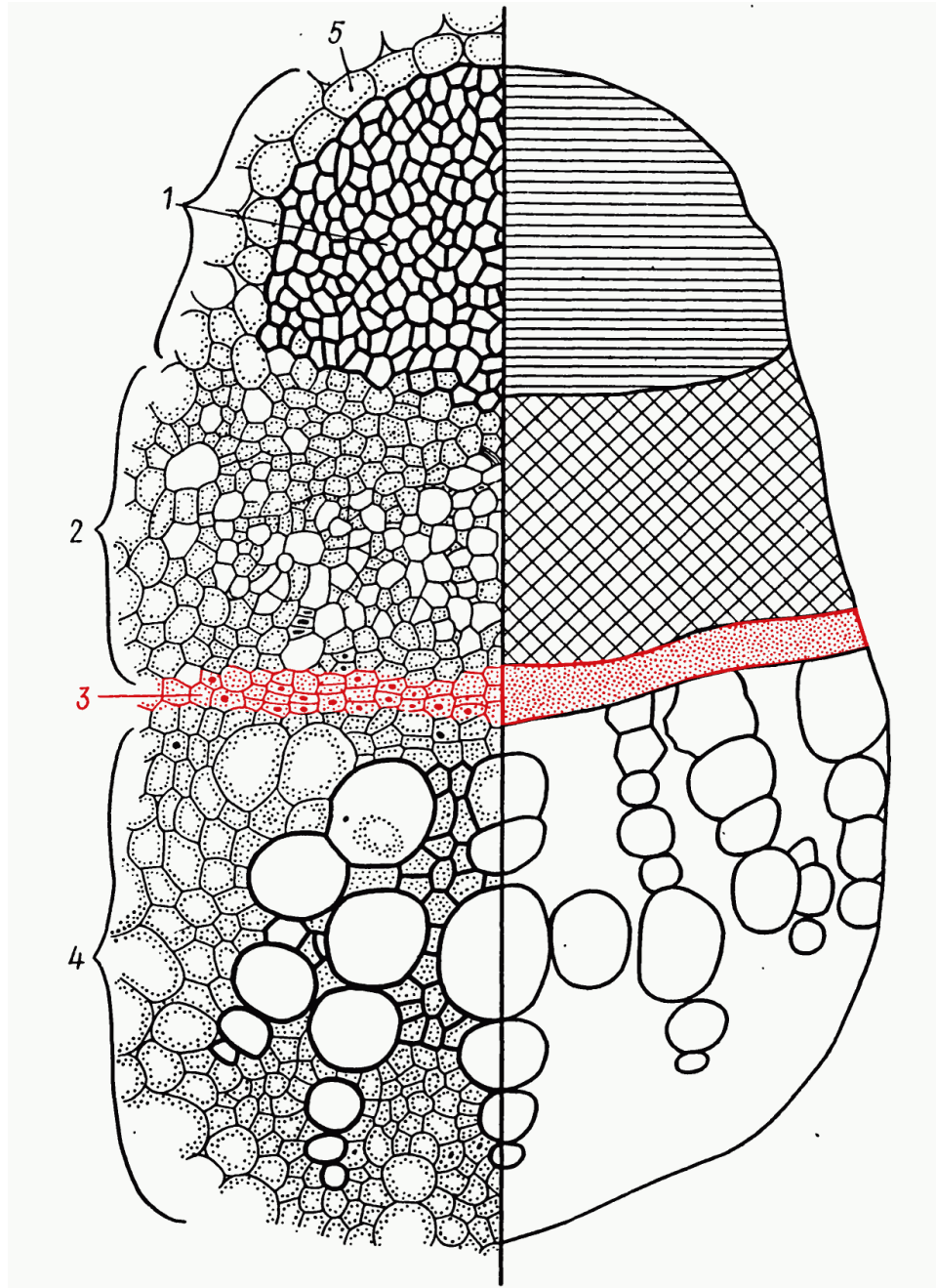
## Outline

## 13 Questions and answers

Previous final question: the answer

Where is a cambium?



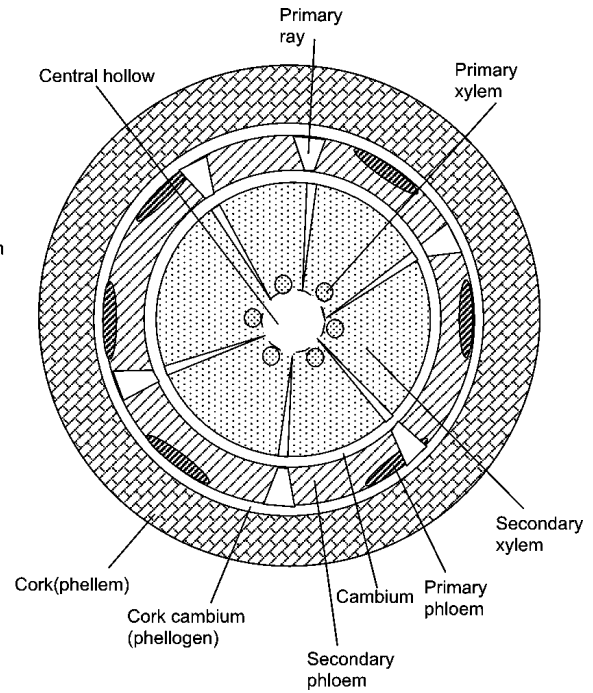
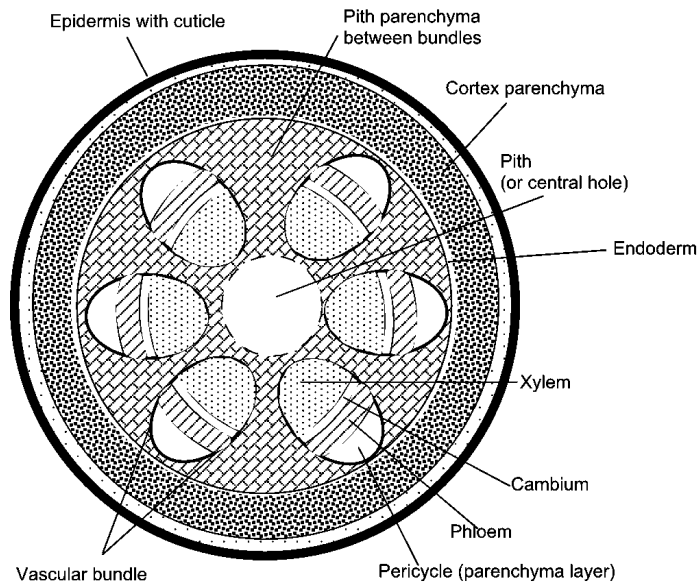


## 14 Secondary stem

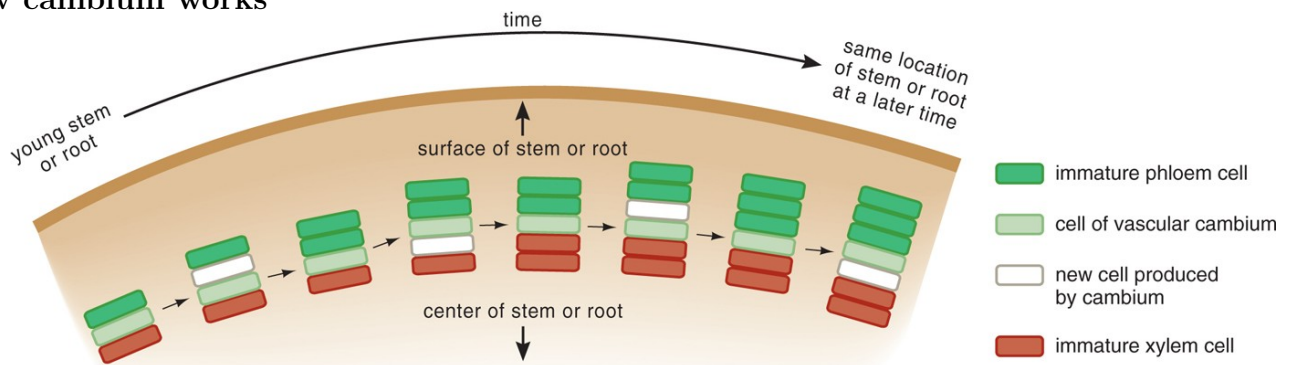
### 14.1 Wood

Primary and secondary stems (scheme)

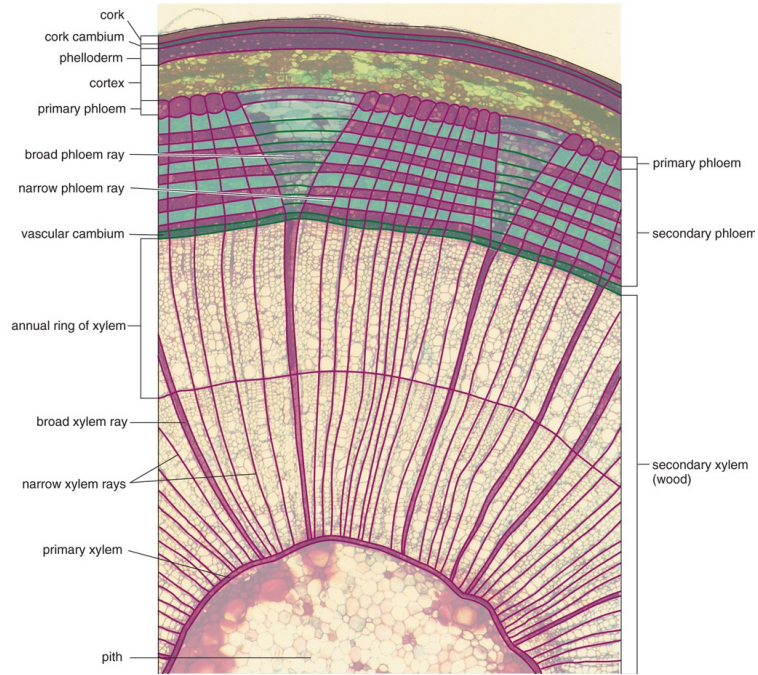
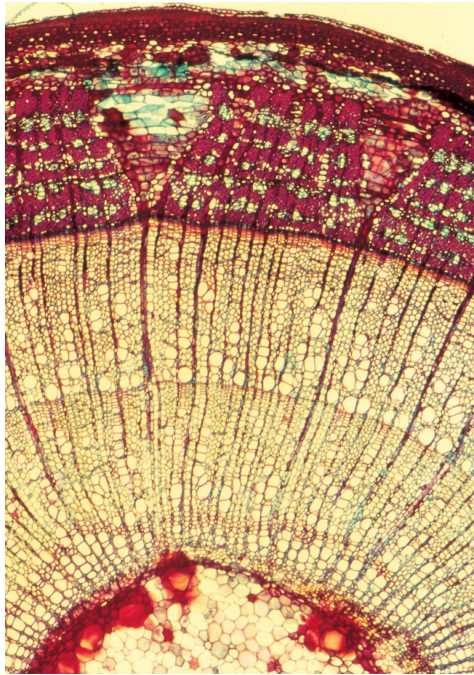




## How cambium works



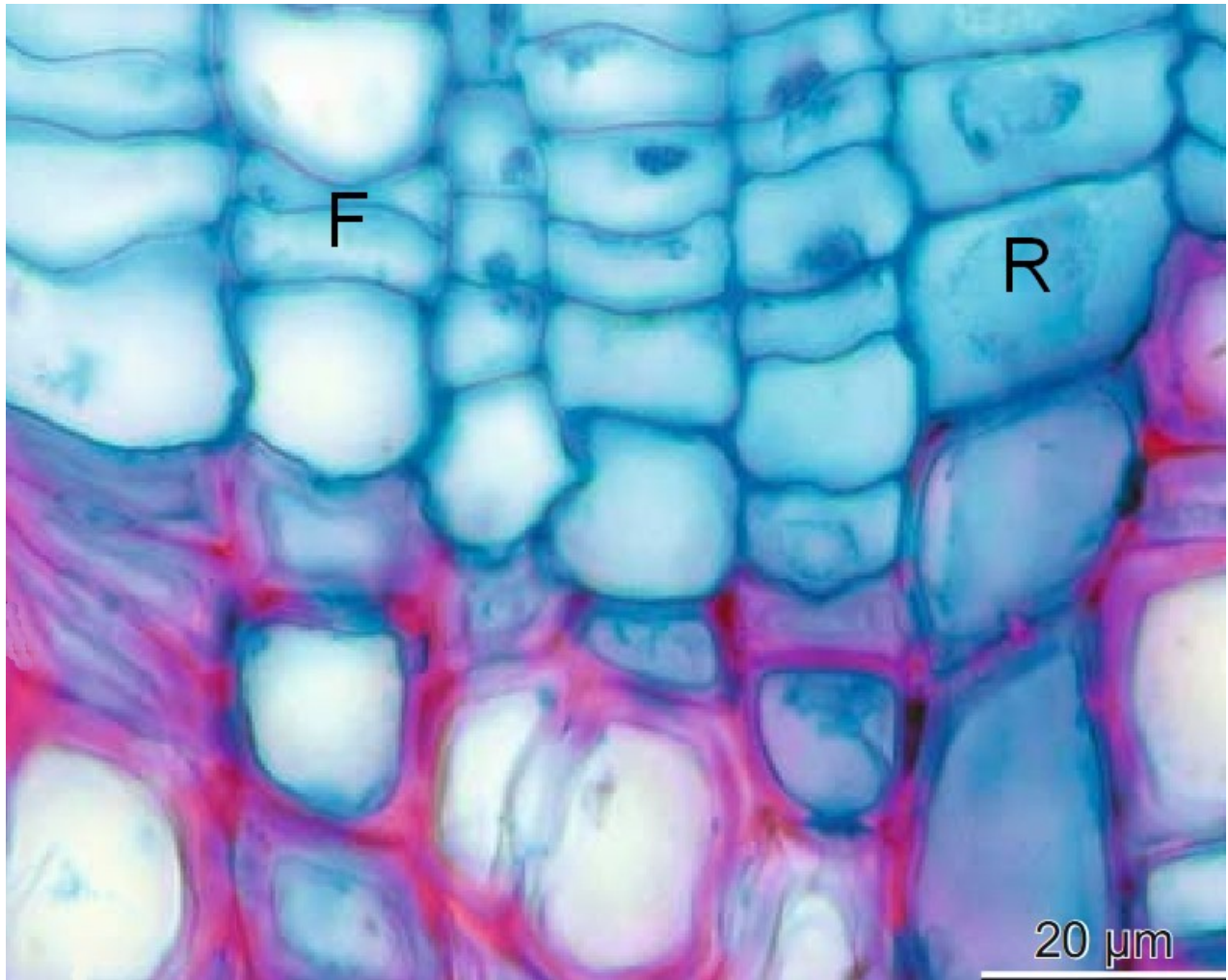
## Secondary structure of stem (photo and explanations)



## 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

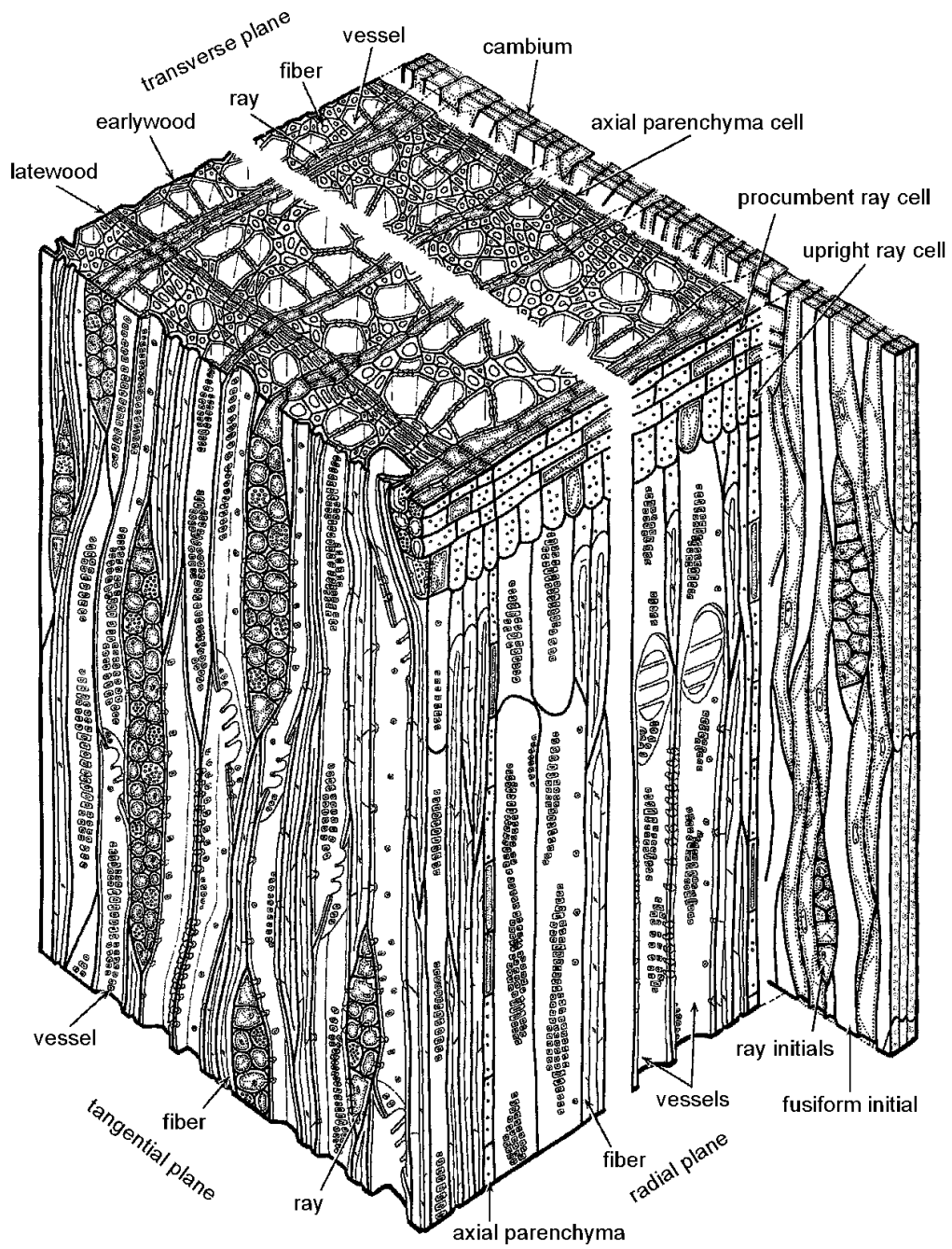


### Three planes of view

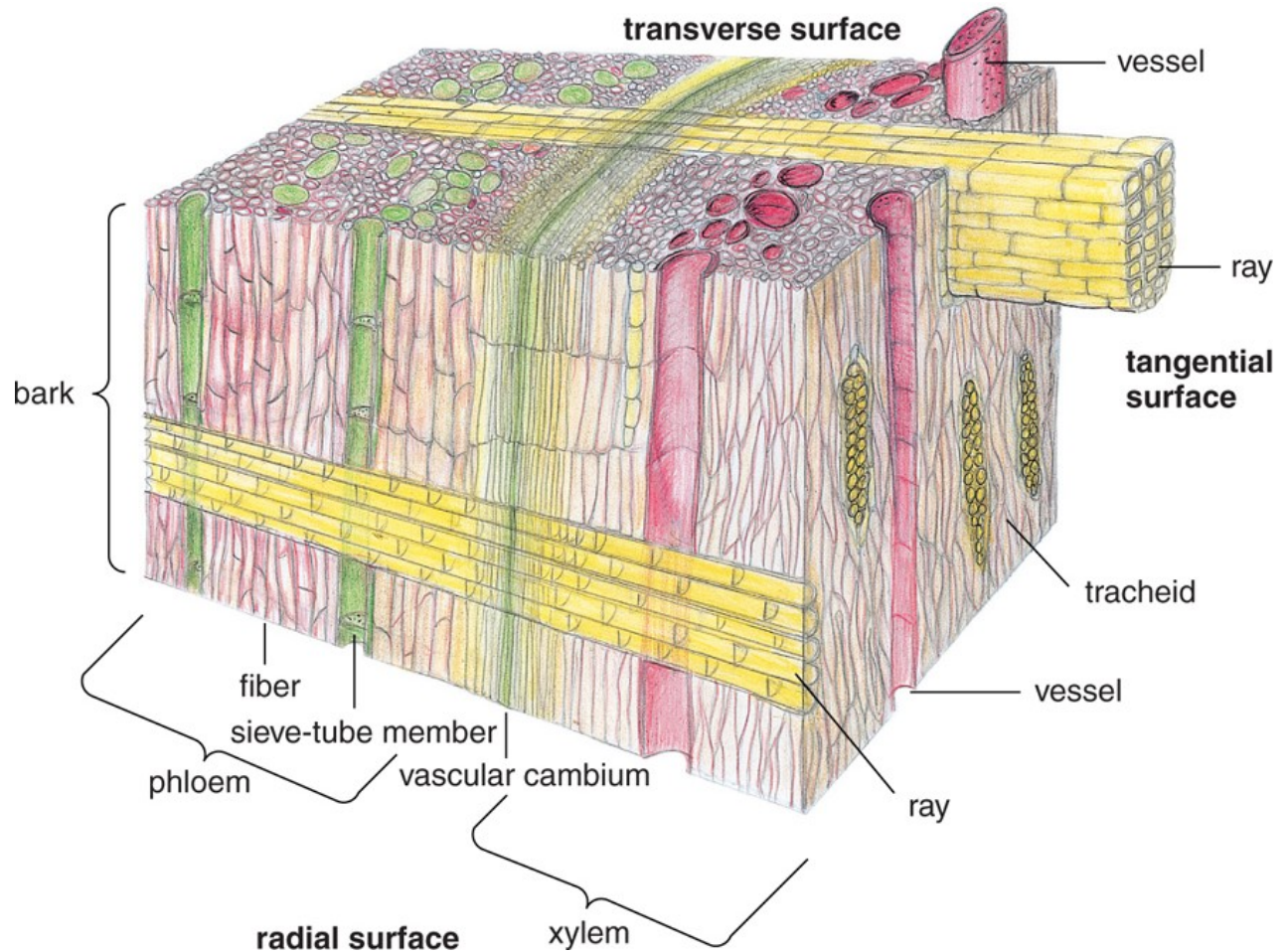
- **Transverse** (cross-section)
- **Radial** (longitudinal section from center to periphery and perpendicular to stem surface)
- **Tangential** (longitudinal section parallel to stem surface)

### Three planes 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.)



ew  
lw

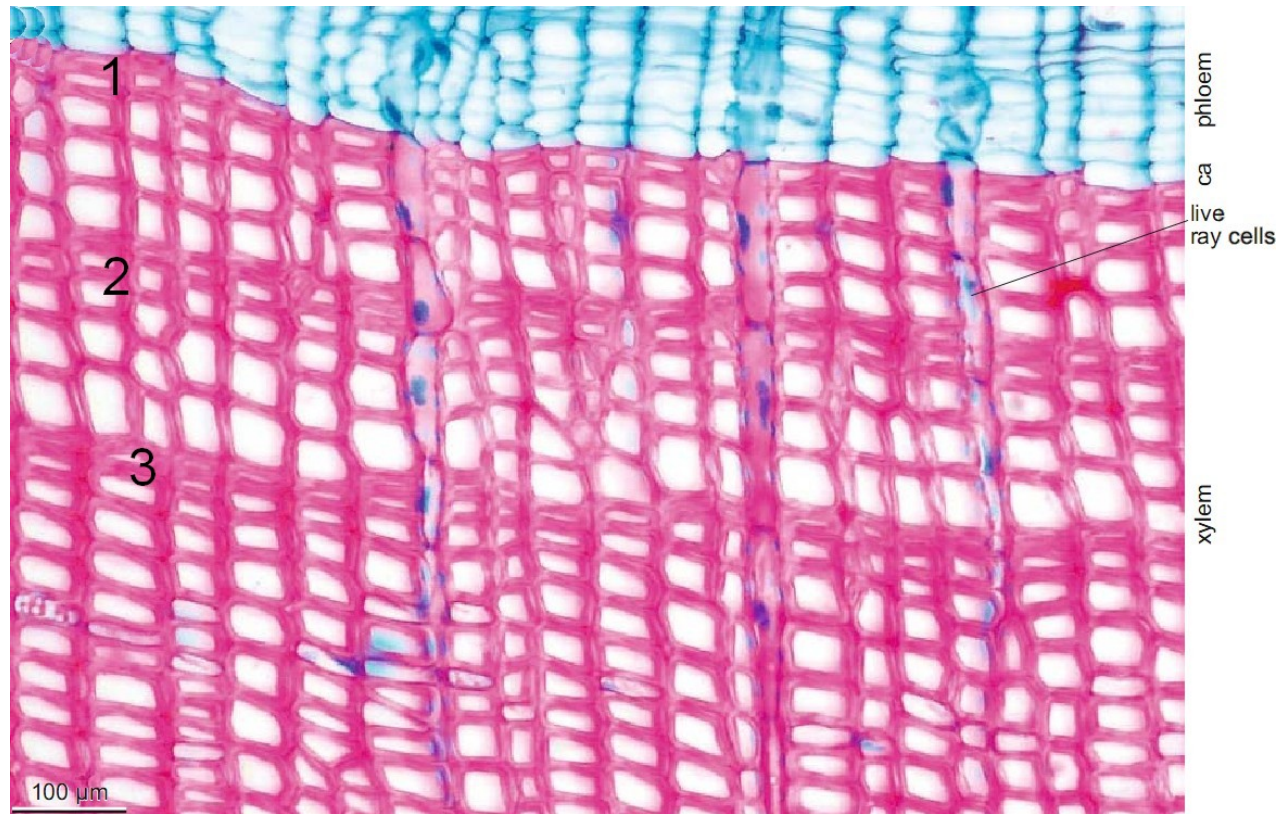


## Annual rings

- 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.)



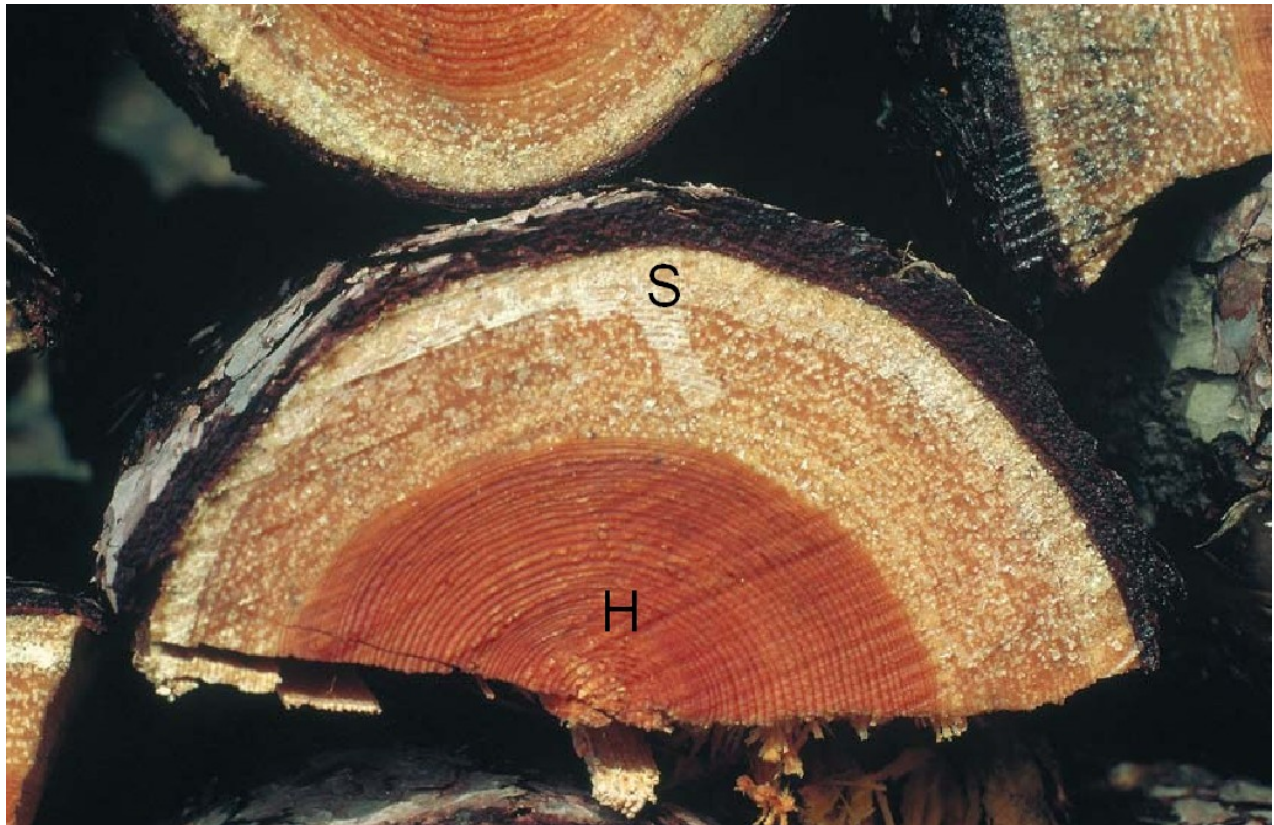


### Sapwood and heartwood

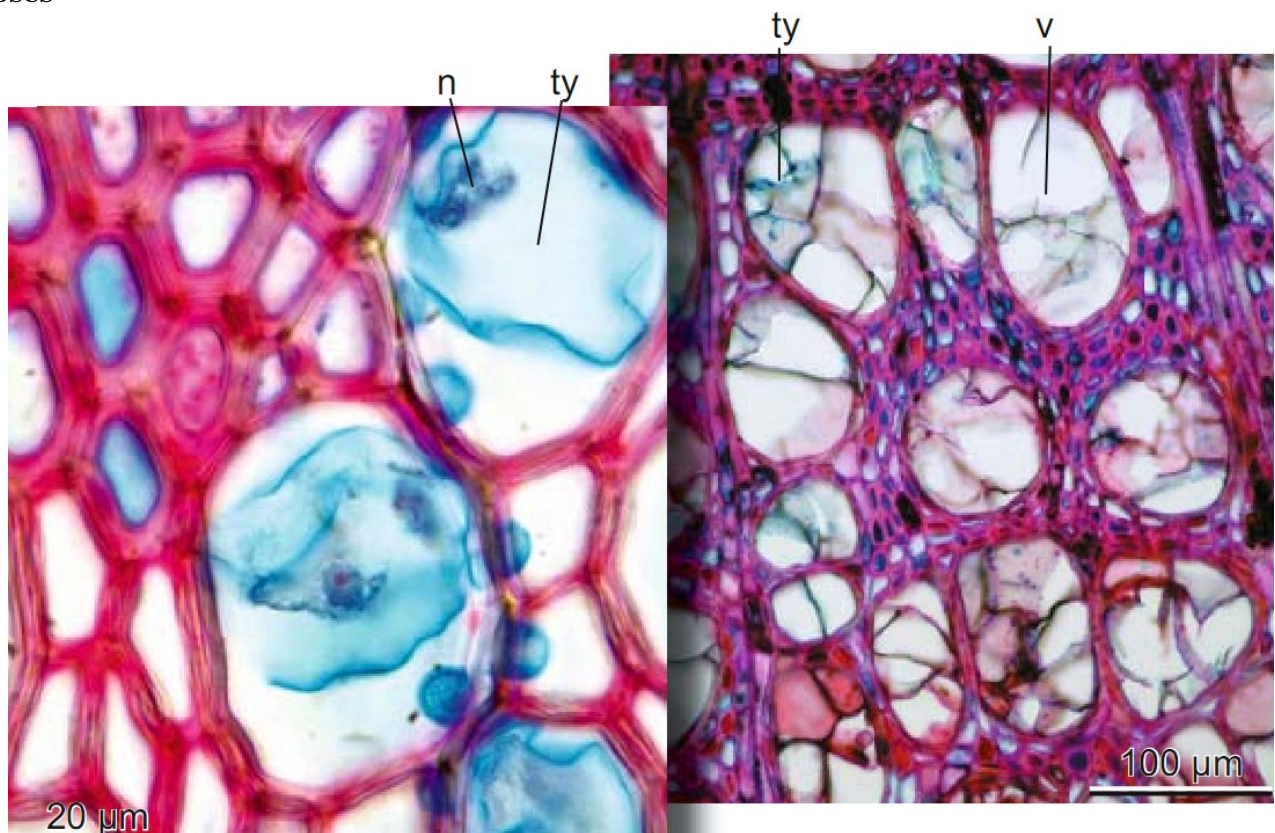
- **Sapwood** is a peripheral layer of working xylem, it usually has relatively light color
- **Heartwood** is a central, non-functional, old, dark-colored xylem

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





## Tyloses



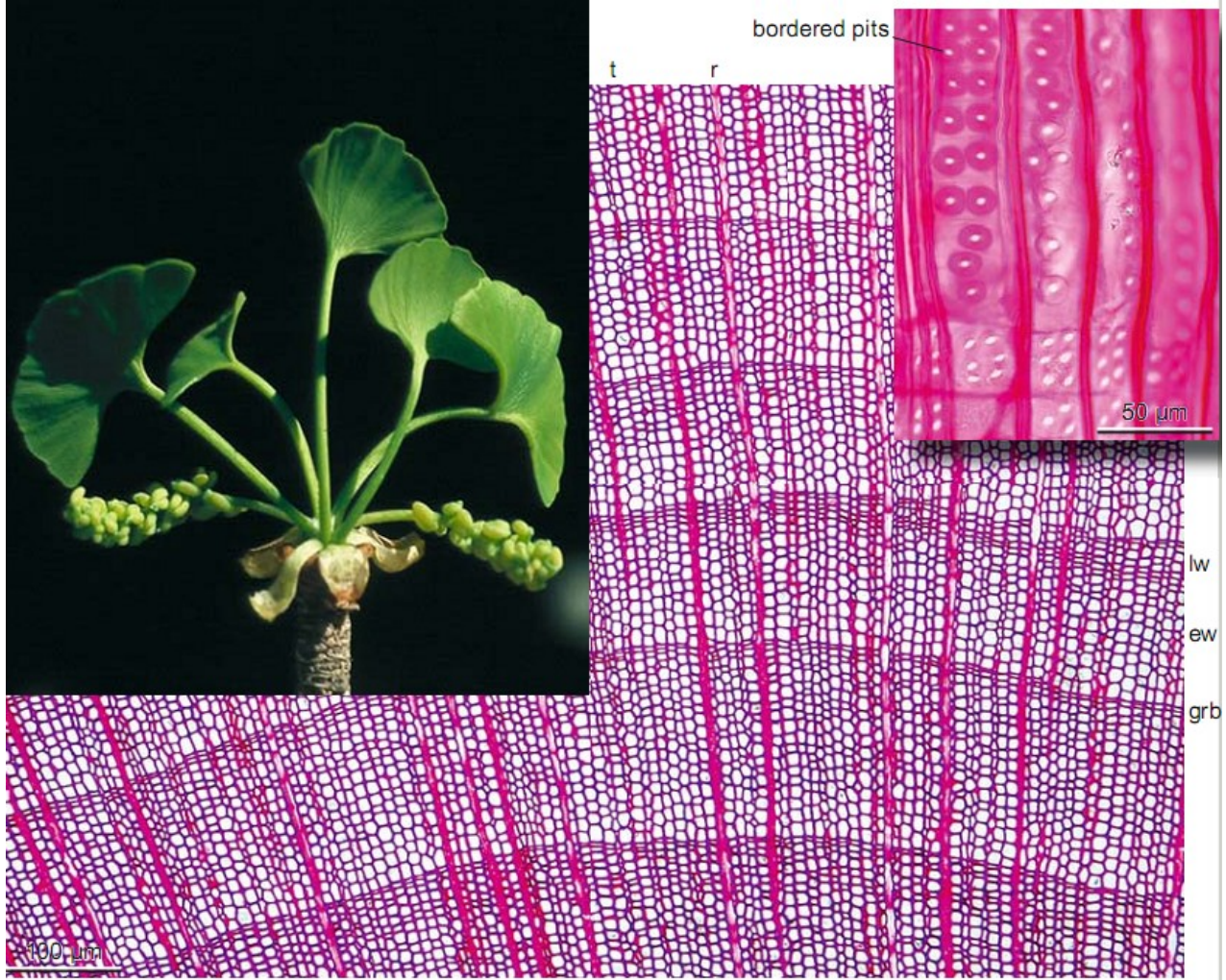
Tyloses control the winter functioning of vessels

## Conifer wood



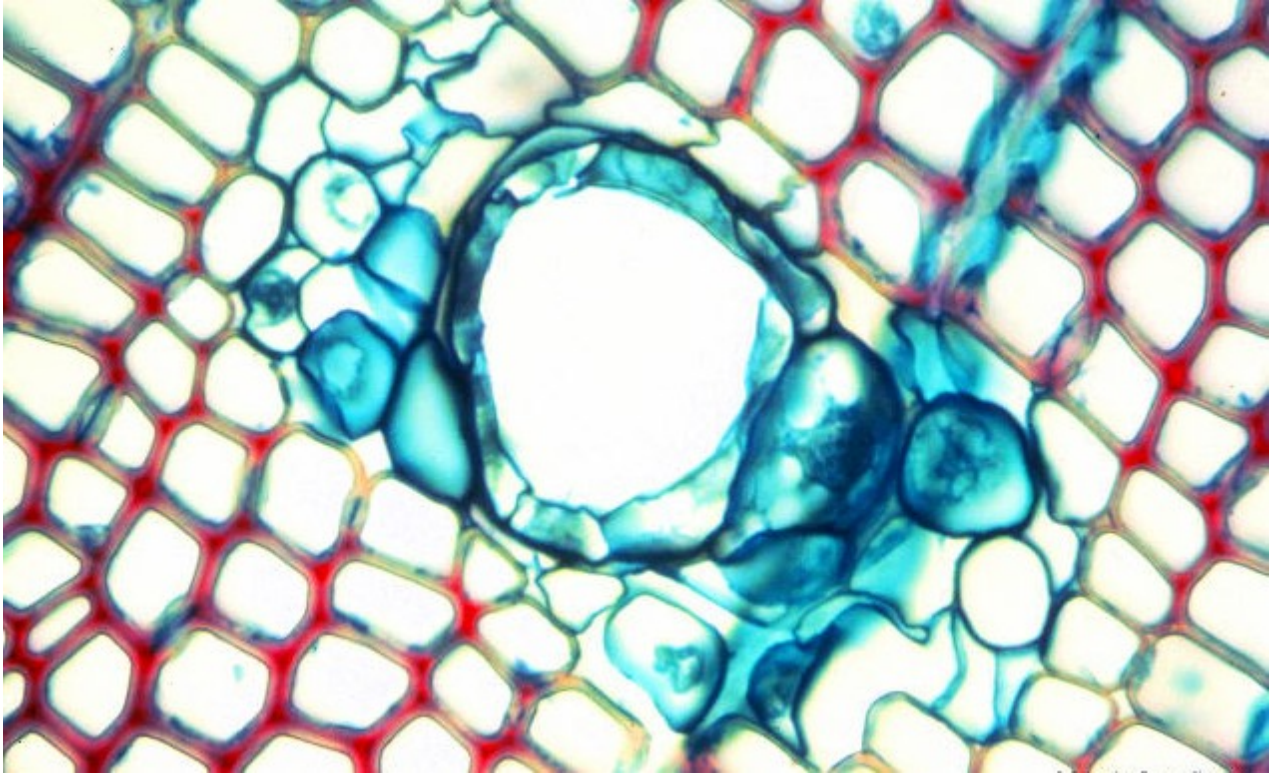
- Simpler structure, few cell types
- Simple rays
- Sometimes have **resin ducts**; resin secreted by epithelial cells

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



Resin duct in pine wood (©BSA)

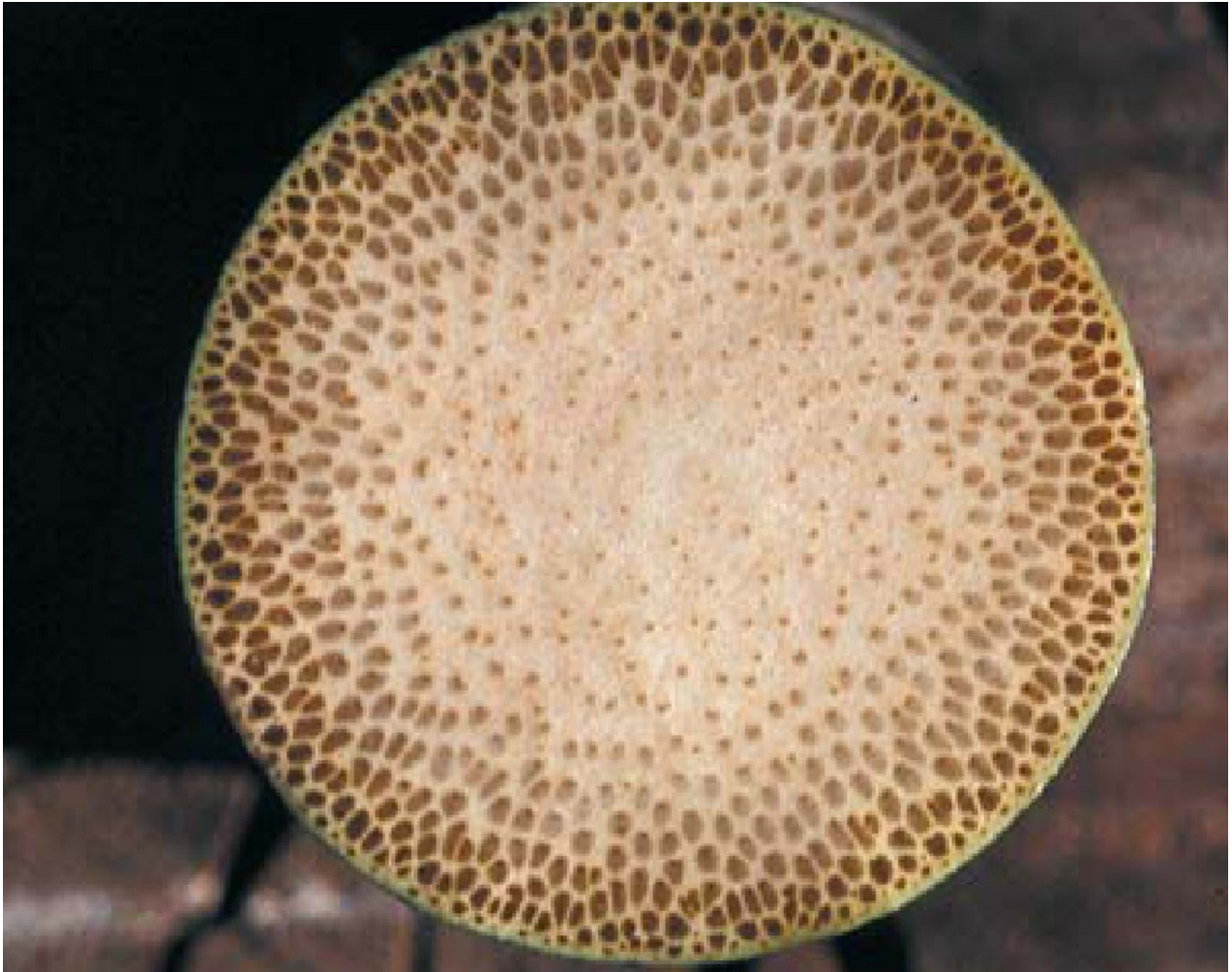




### Monocot “wood”

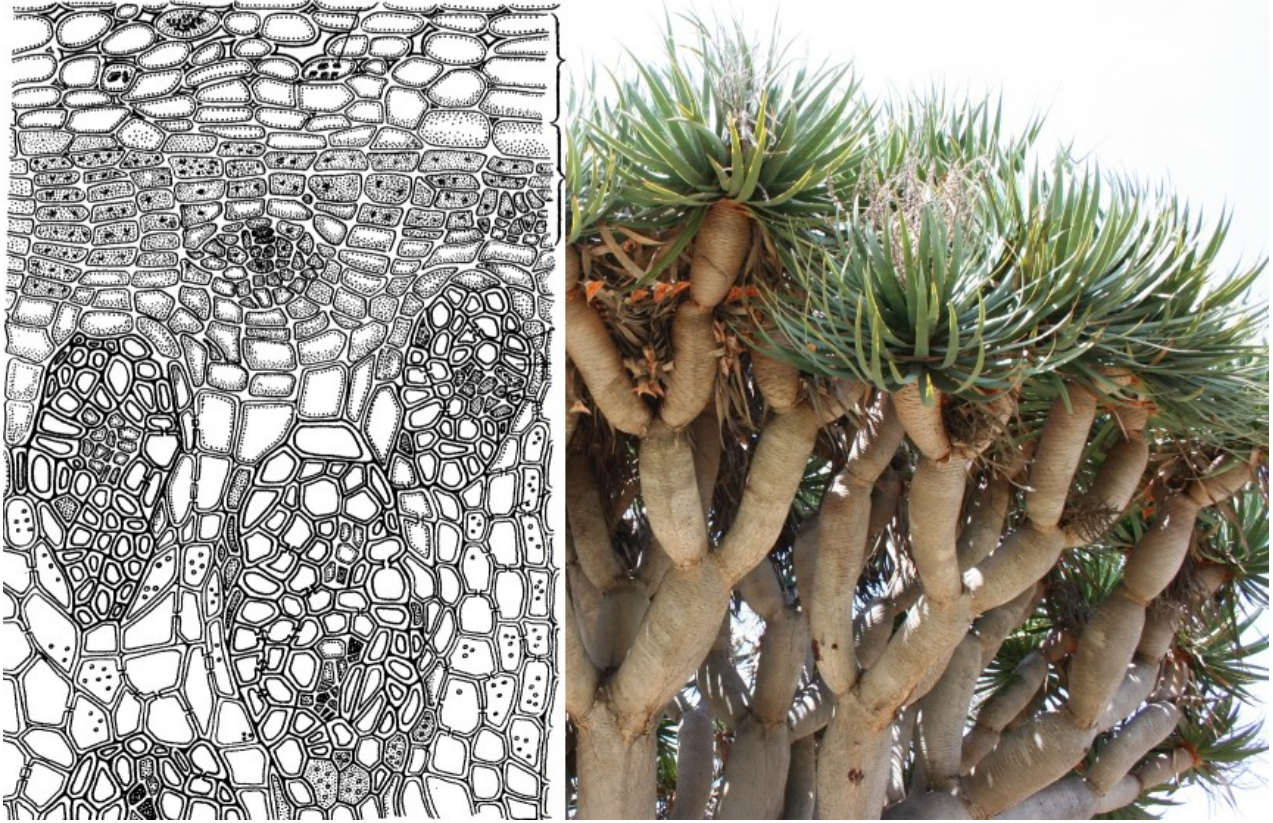
- Most of monocots do not have lateral meristems and therefore have no true wood
- Palms have only primary tissues; their trunk widens from bottom to top
- Some monocots (dragon trees) have **anomalous secondary growth**

Cross section of palm (*Phoenix canariensis*) trunk



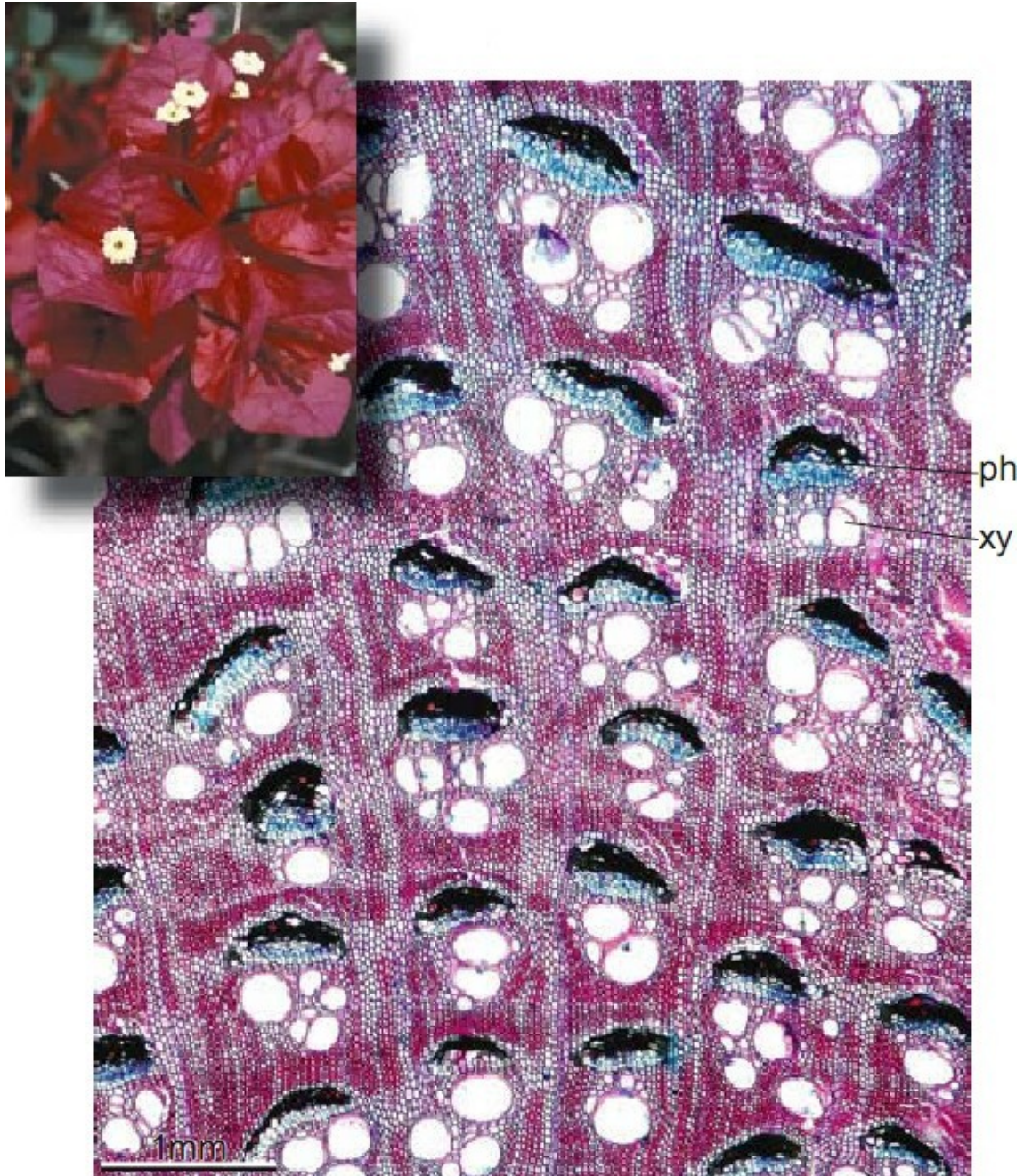
Dragon tree (*Dracaena draco*) and its anomalous cambium





Anomalous secondary growth in Bougainvillea (*Bougainvillea spectabilis*)





## 14.2 Life forms

### Life forms

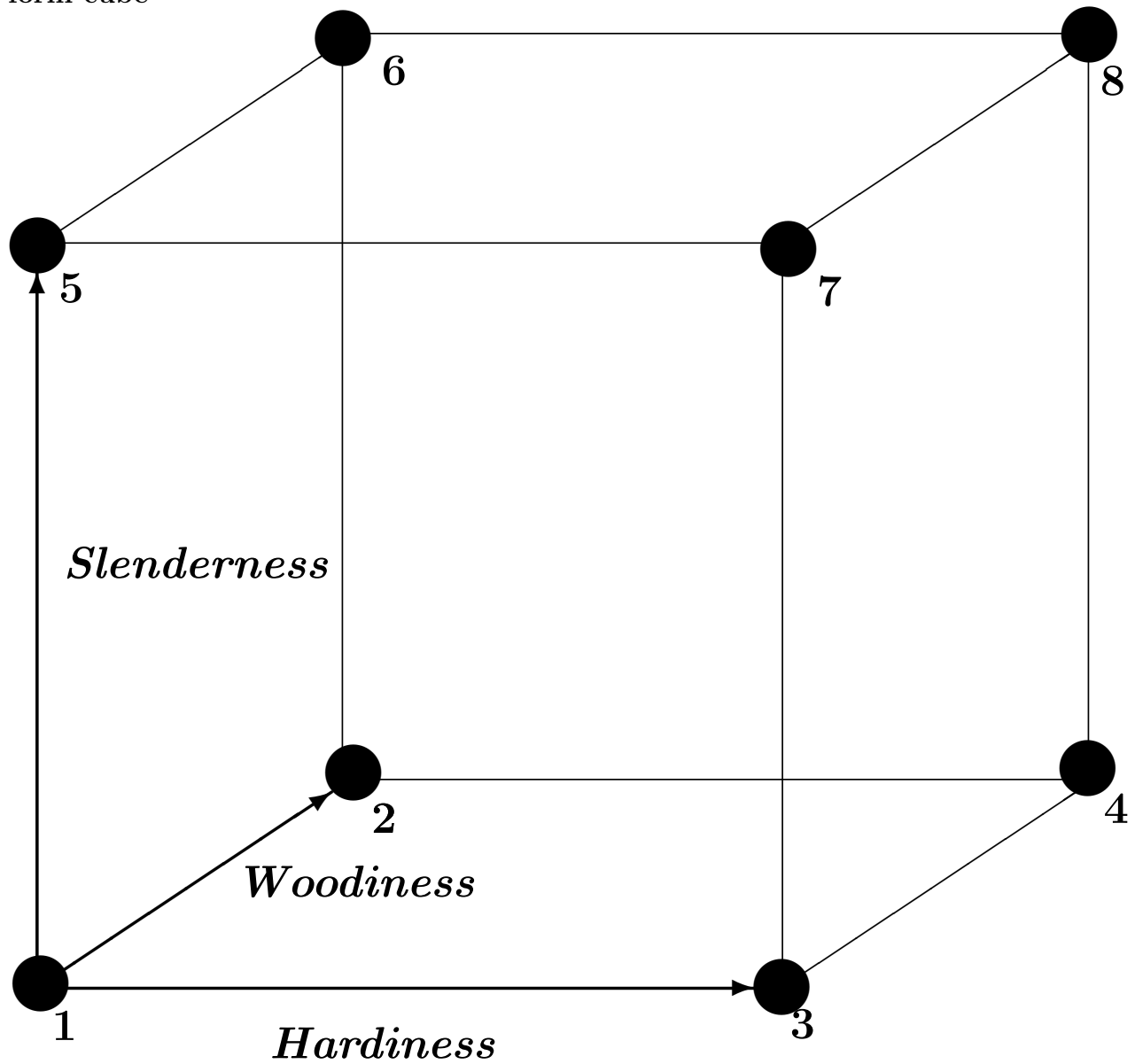
- It is a different view on the plant diversity
- Life forms represent different lifestyles
- For example, trees, shrubs and herbs are life forms

### Life forms: dynamic approach

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

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

Life form cube



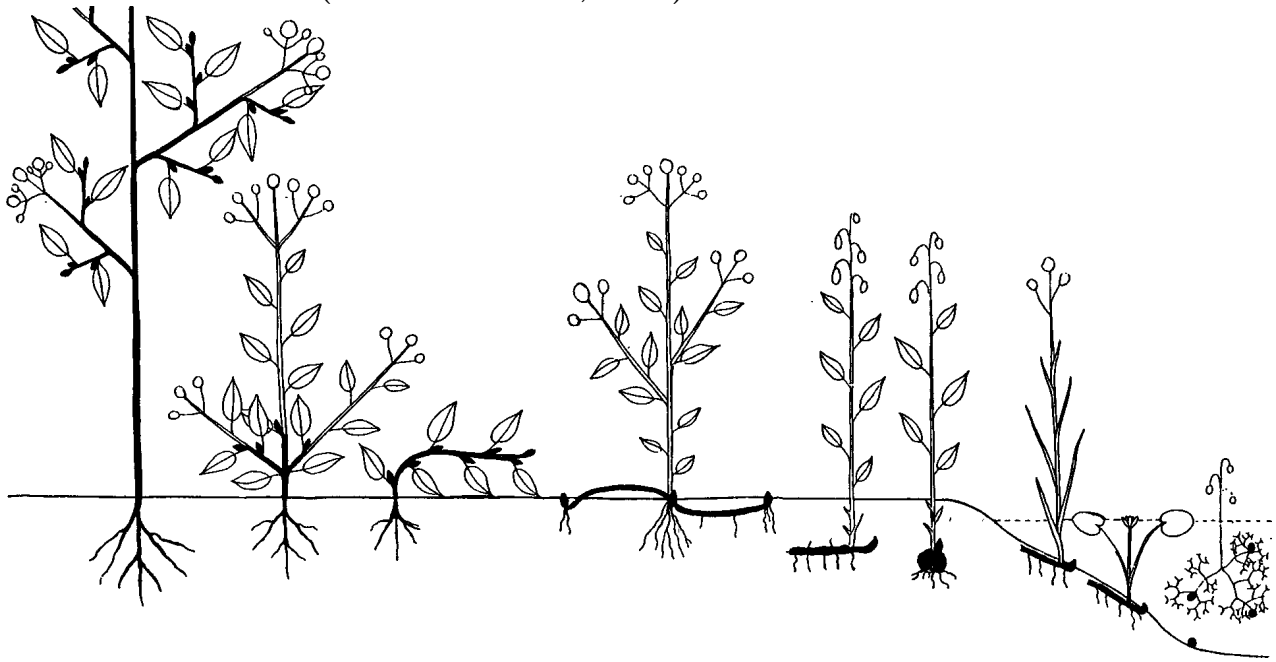
#1 could be similar to duckweed, #8—to sequoia

Life forms: Raunkiaer's approach

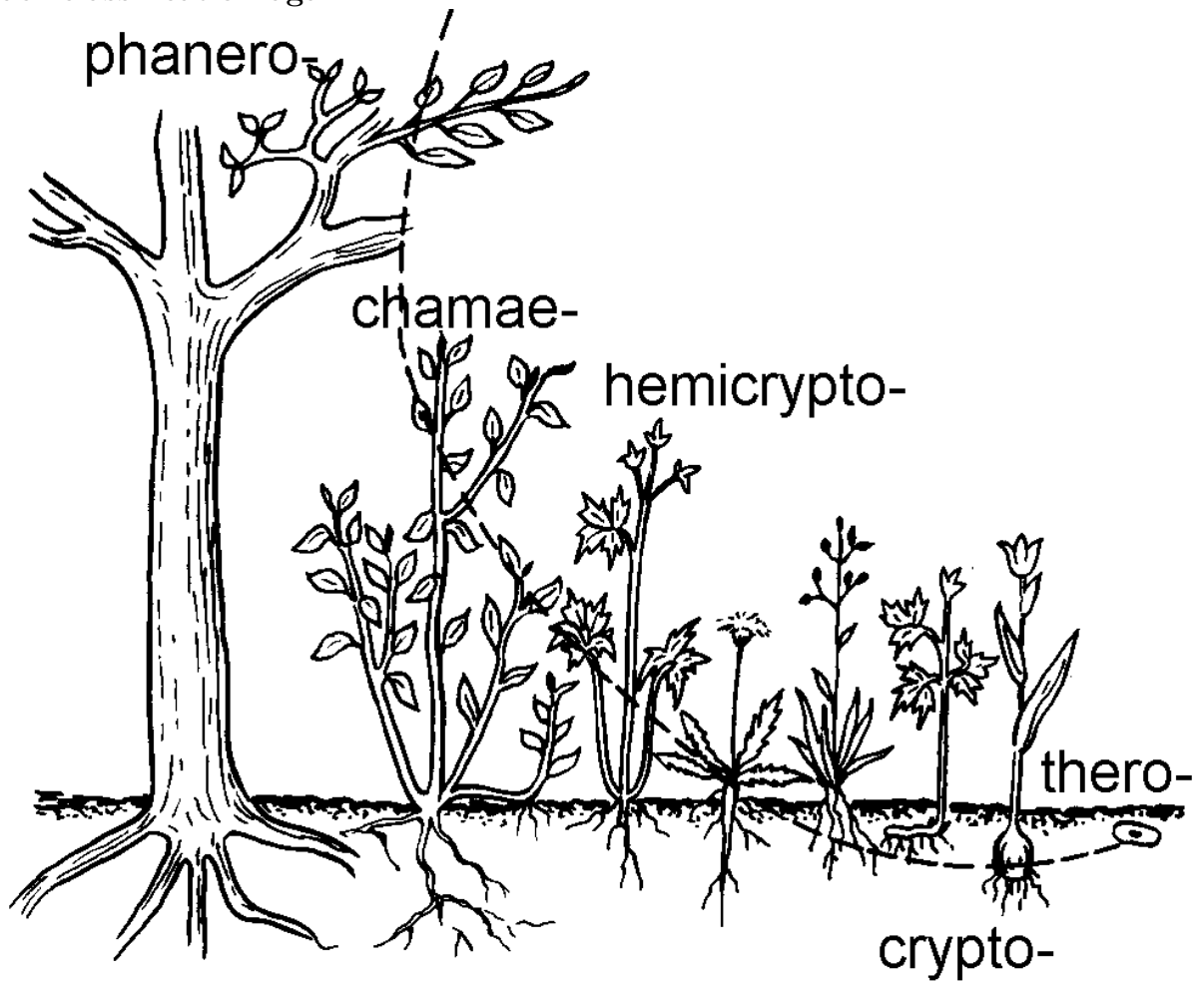
- **Phanerophytes:** winter buds openly exposed
- **Chamaephytes:** winter buds under snow
- **Hemicryptophytes:** winter buds on soil surface
- **Cryptophytes:** winter buds in the soil
- **Therophytes:** no winter buds, only seeds

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

Raunkiaer classification (after Raunkiaer, 1937)



Raunkiaer classification again

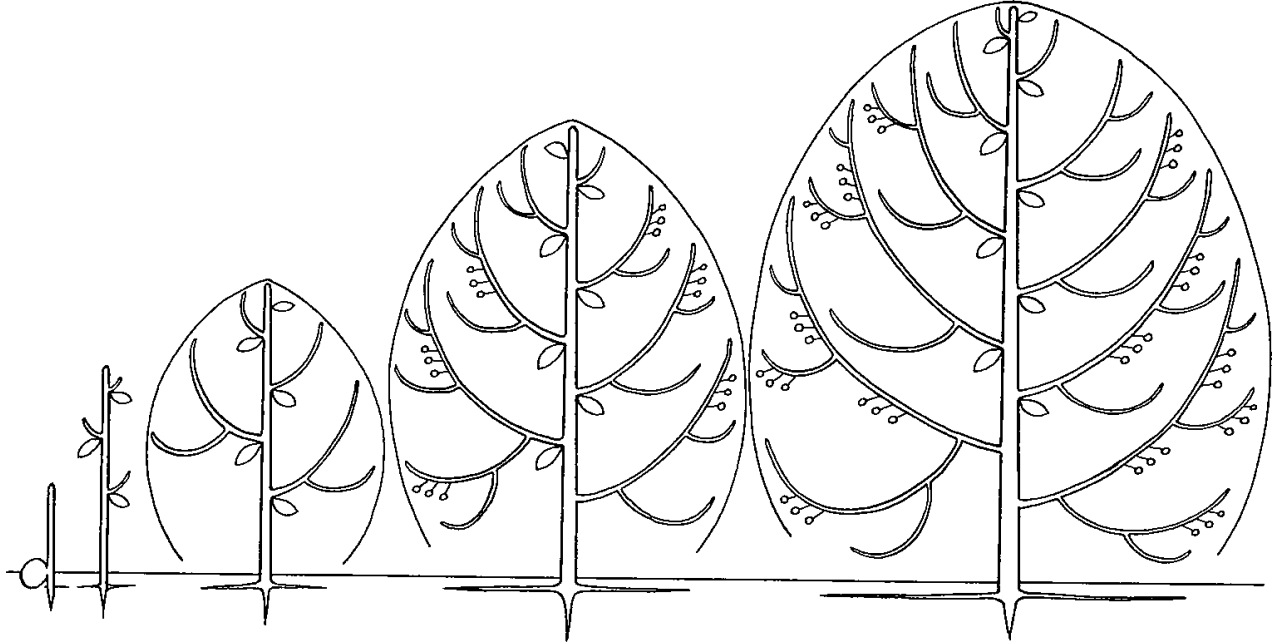


Life forms: architectural models



- 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

#### Final question (2 points)

Please describe the difference(s) between heartwood and sapwood

#### Summary

- **Wood** is a secondary xylem
- Life forms represent different “life styles” of plant

#### For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 5*.

#### Outline

## 15 Questions and answers

### Previous final question: the answer

Please describe the difference(s) between heartwood and sapwood

- Heartwood is darker (cells are compressed), sapwood lighter
- Heartwood is non functional, no living rays; sapwood functional, living rays present

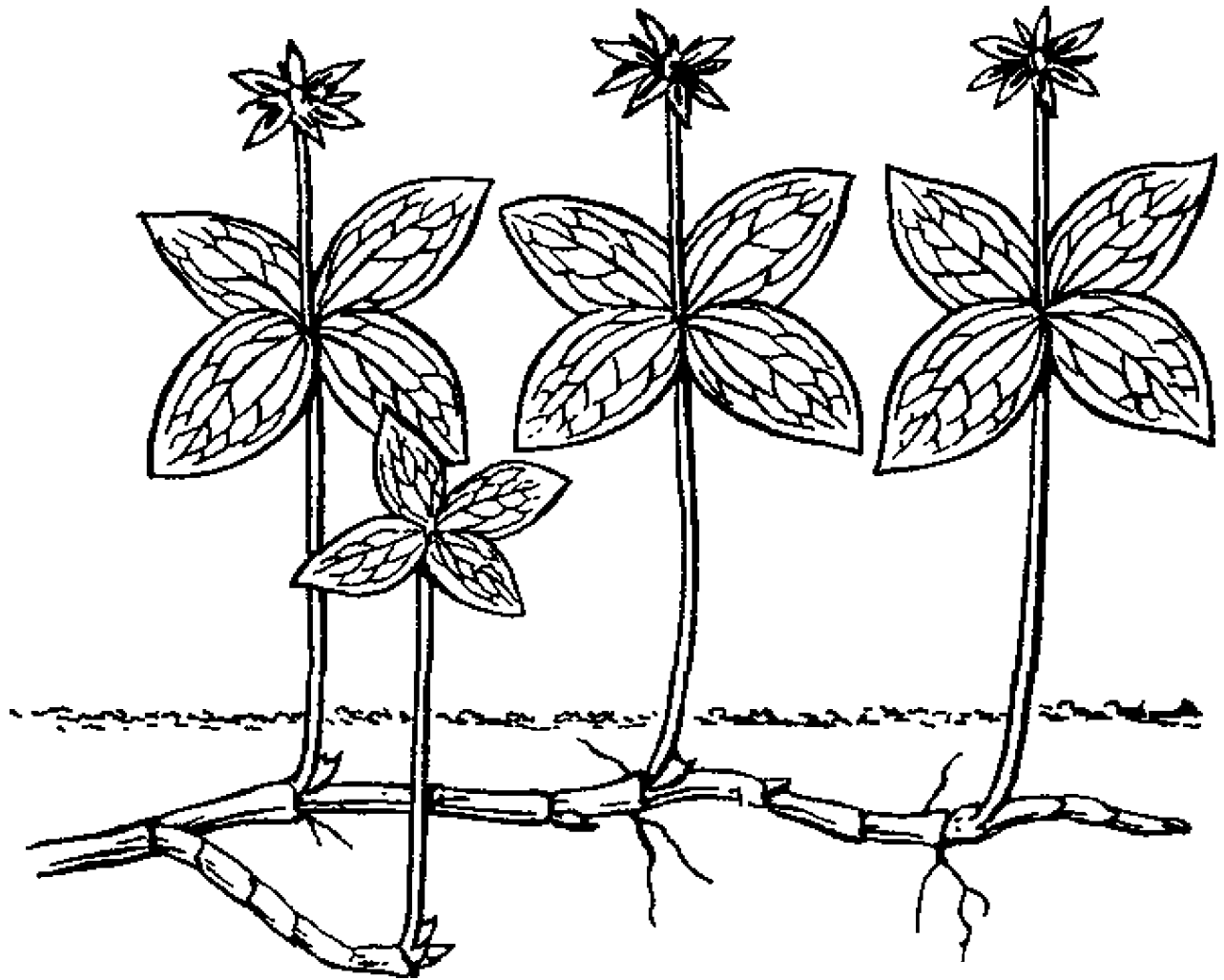
## 16 Stem and shoot

### 16.1 Modifications of stem / shoot

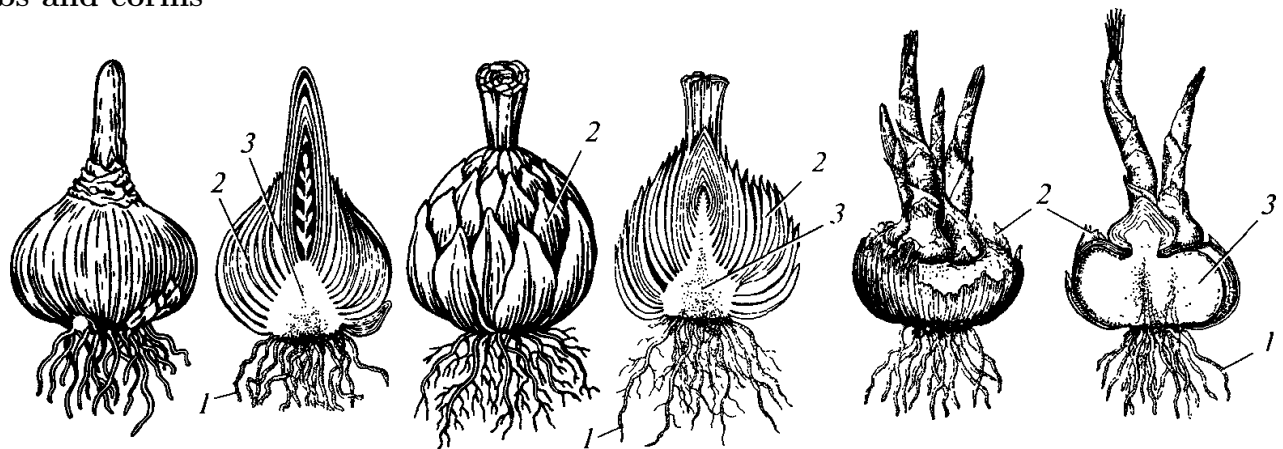
#### Modifications of shoots and stems

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

#### Rhizome



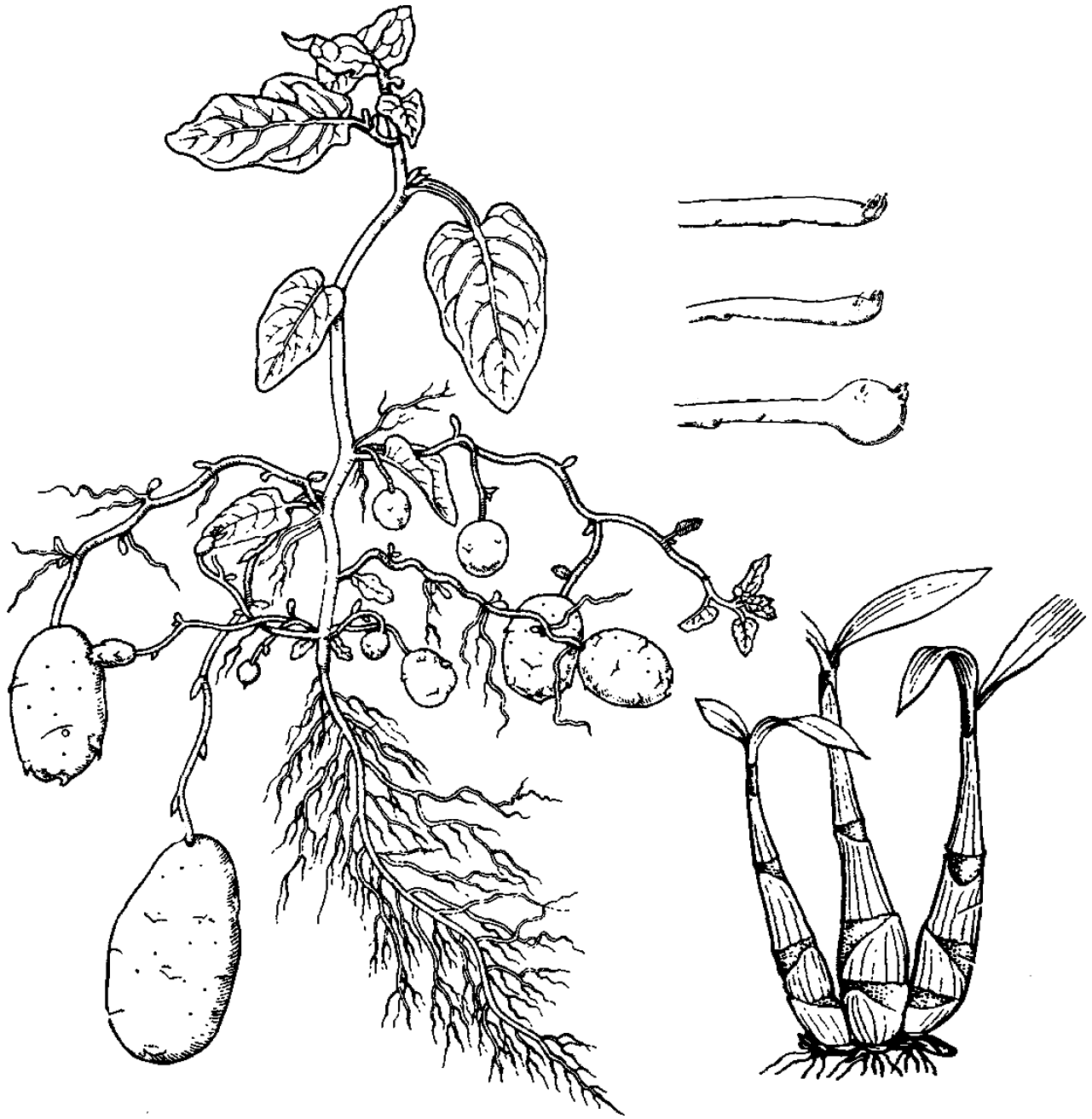
Bulbs and corms



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

Tubers: potato and orchids





Thorns



Cladophylls: leafy stems



Traps of bladderwort (*Utricularia*)





## External function and modifications

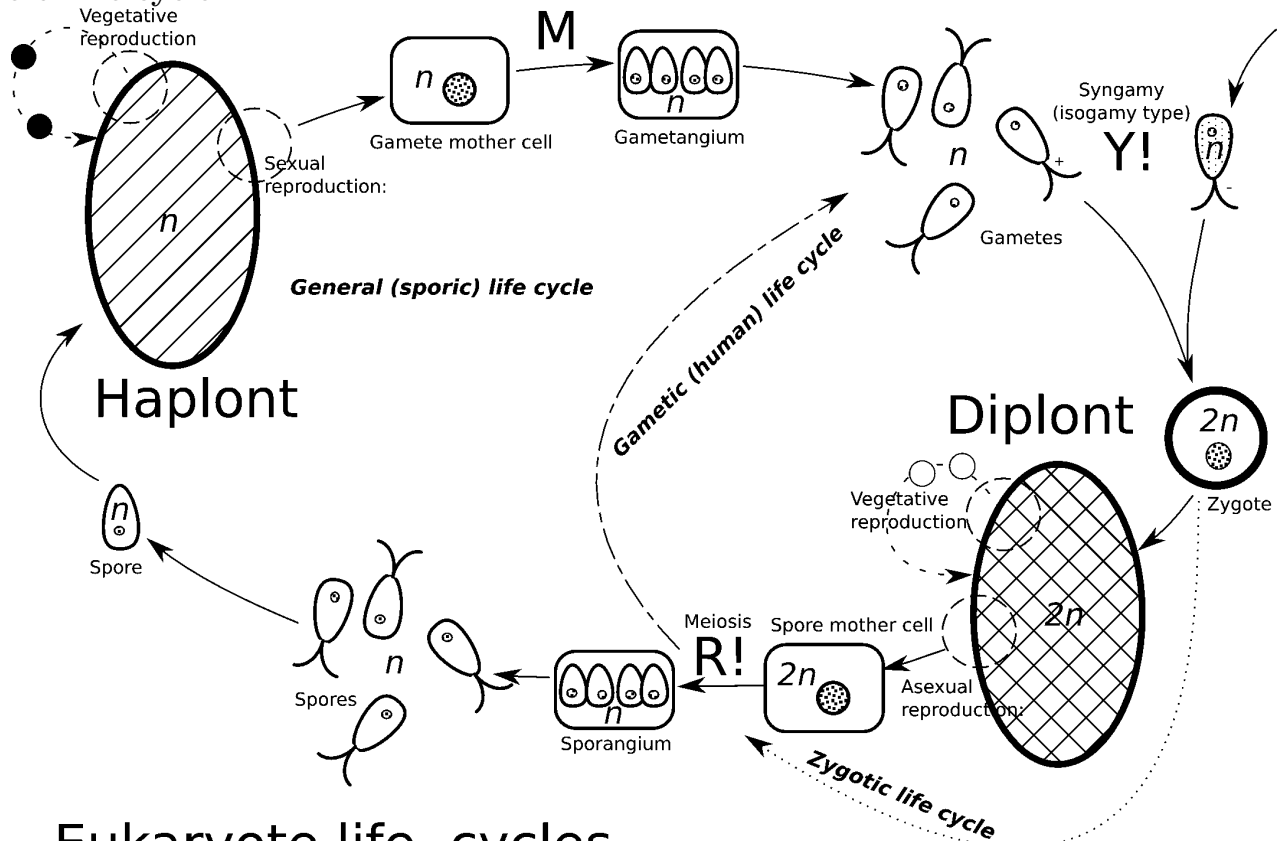
Function	Stem	Leaf	Root
Expansion	Rhizomes, stolons	Plantlets	Adventive buds
Storage	Bulbs, corms, tubers	Succulent leaves	Storage roots
Photosynthesis	Rhizomes, stolons, bulbs, corms, tubers	DEFAULT	Some aerial roots
Defense	Thorns, spines	Spines, scale	Root spines
Support	DEFAULT	Leaf tendrils	Haustoria, aerial and contractile roots
Interactions	Traps (bladderwort)	Traps, “sticky tapes”, urns	Mycorrhizae, nodulated roots

Each external function requires a specific modification of organ.

## 17 Seed plants

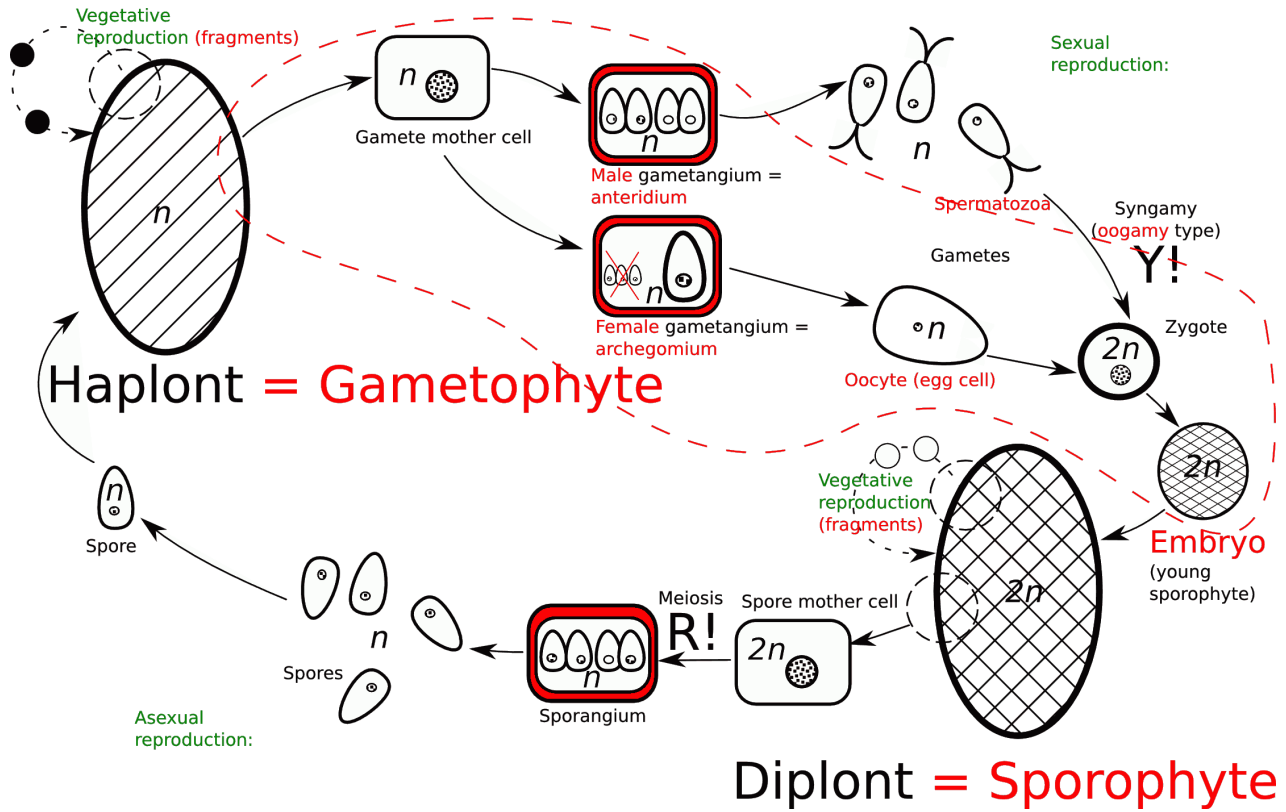
### 17.1 Seed

#### General life cycle

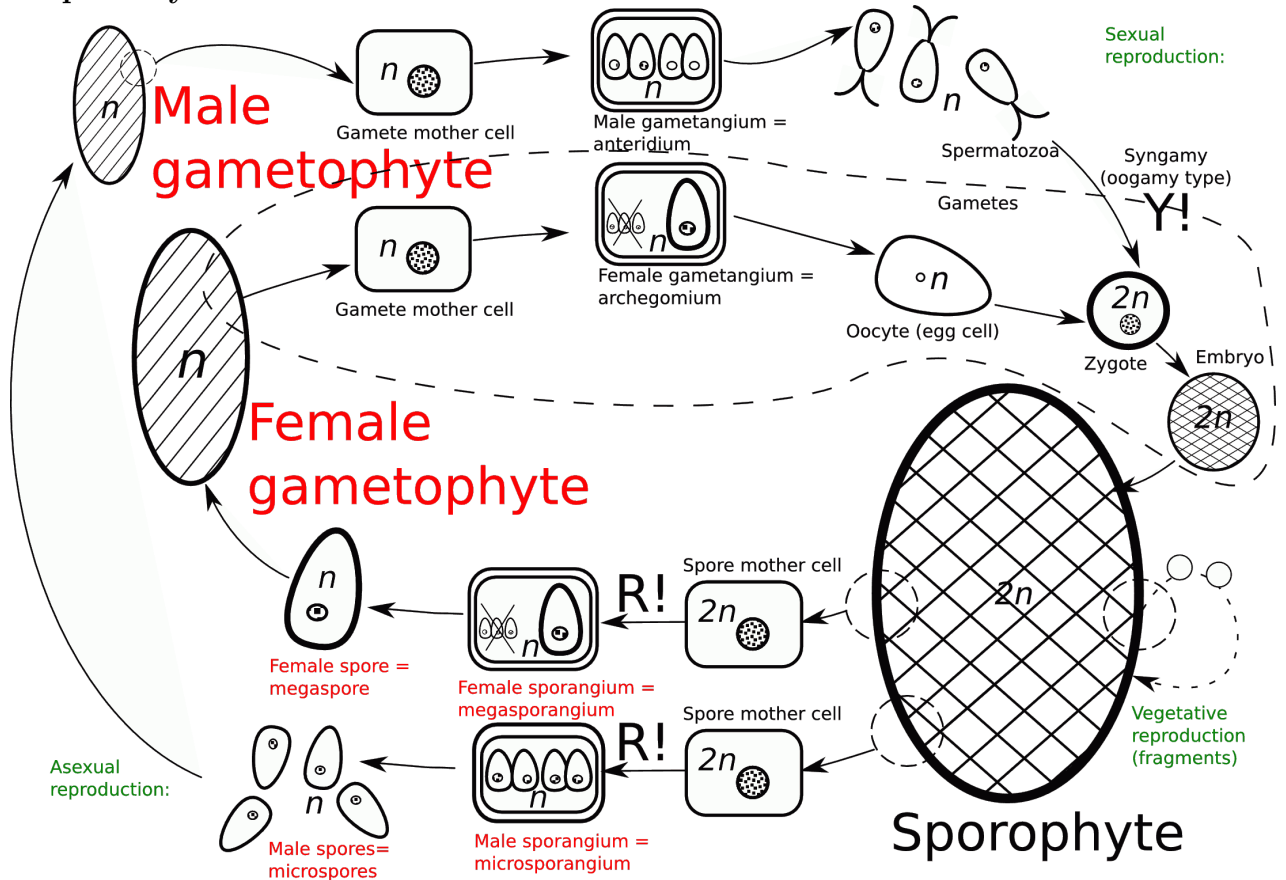


## Eukaryote life cycles

### 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**

### Final question (2 points)

What is a difference between bulb and corm?

### Summary

- Storage, defense and underground growth result in extensive modification of shoot
- Heterosporous plants have two kinds of spores: female (megaspores) and male (microspores)
- Seed plants have compact life cycle where almost all stages happen on mother sporophyte

### For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 5, 24*.

### Outline

## 18 Questions and answers

### Previous final question: the answer

What is the difference between bulb and corm?

- Bulb has more leaves, corm has bigger stem

## 19 Seed plants

### 19.1 Seed

#### 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 plant life cycle

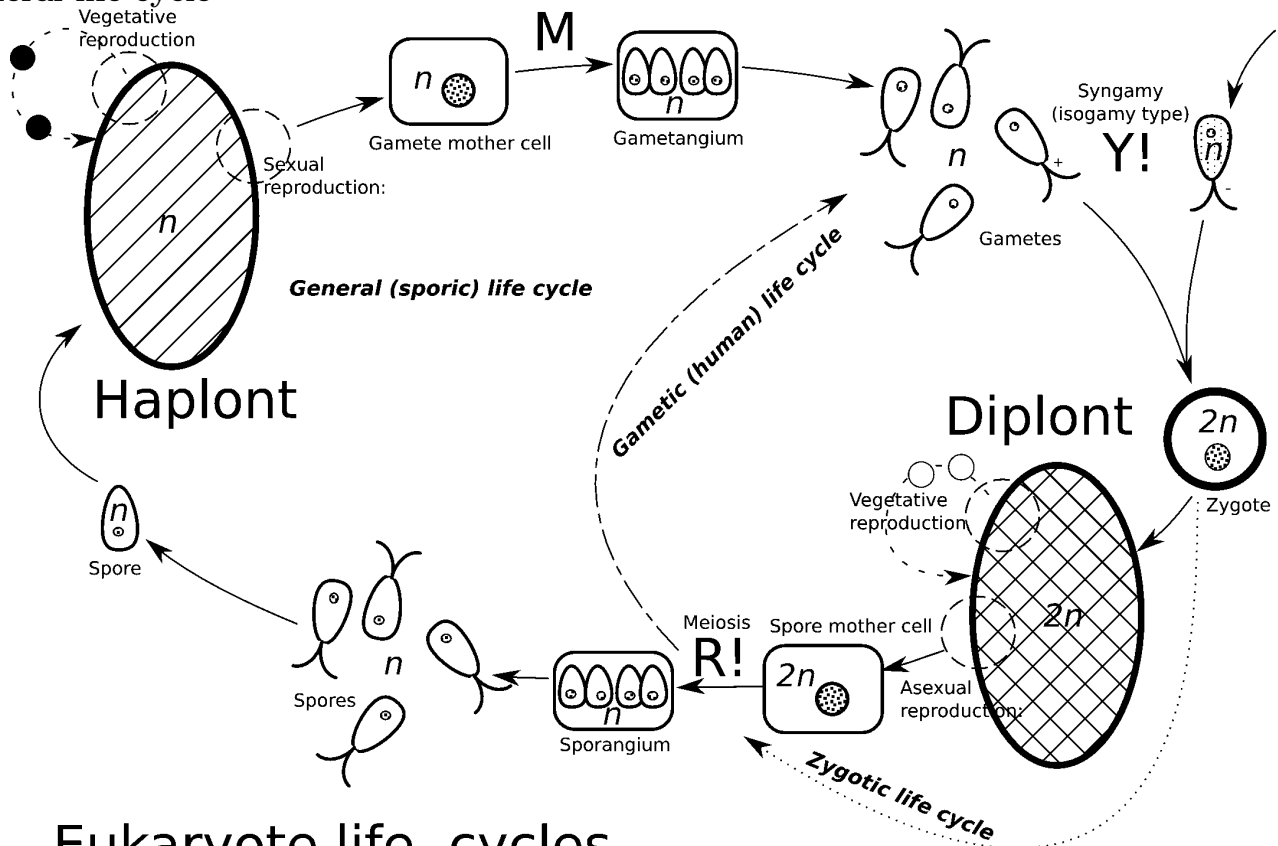
### Terms covered:

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

## The seed

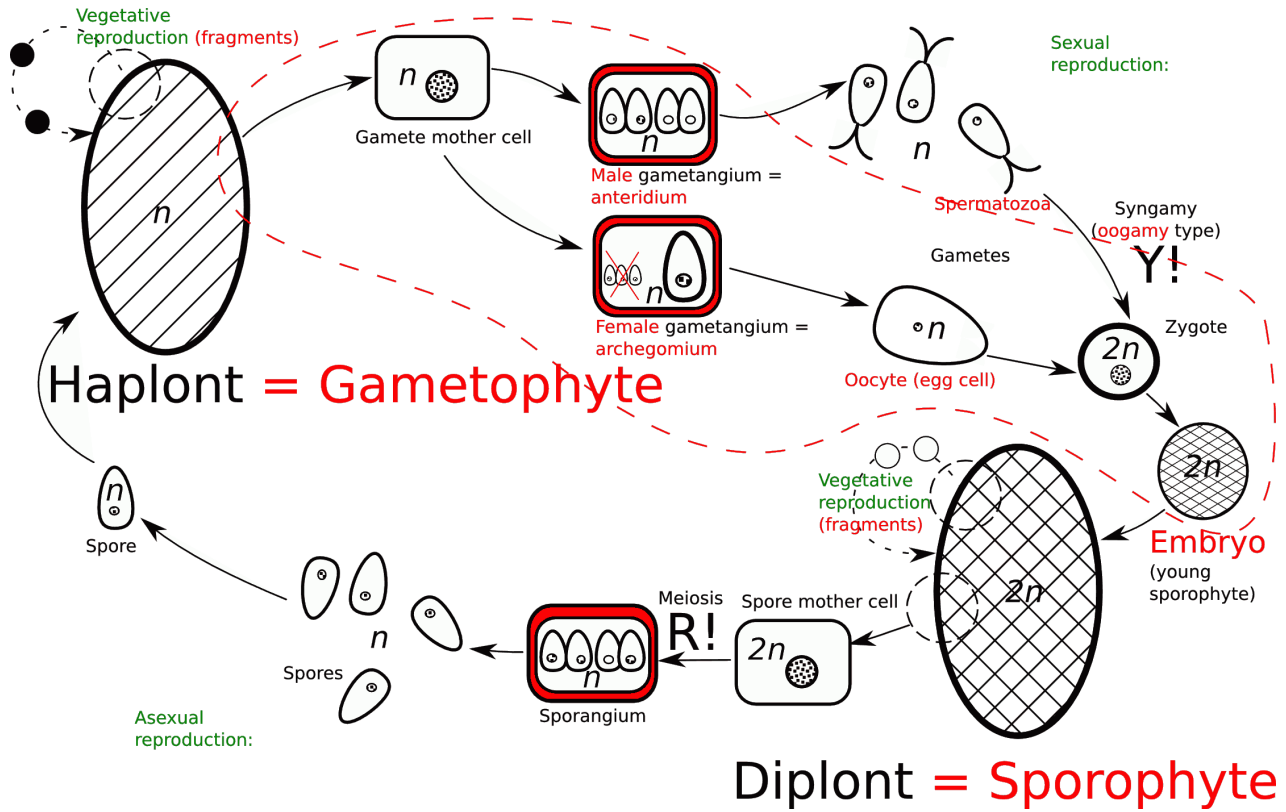
- Seed is a **chimeric organ** with three layers: (1) mother sporophyte tissue (integument + nucellus), (2) female gametophyte tissue (endosperm) and (3) daughter sporophyte (embryo)
- Biggest disadvantages of having seed are: (a) low probability of fertilization (pollination needed) and (b) overall slowness of cycle

## General life cycle

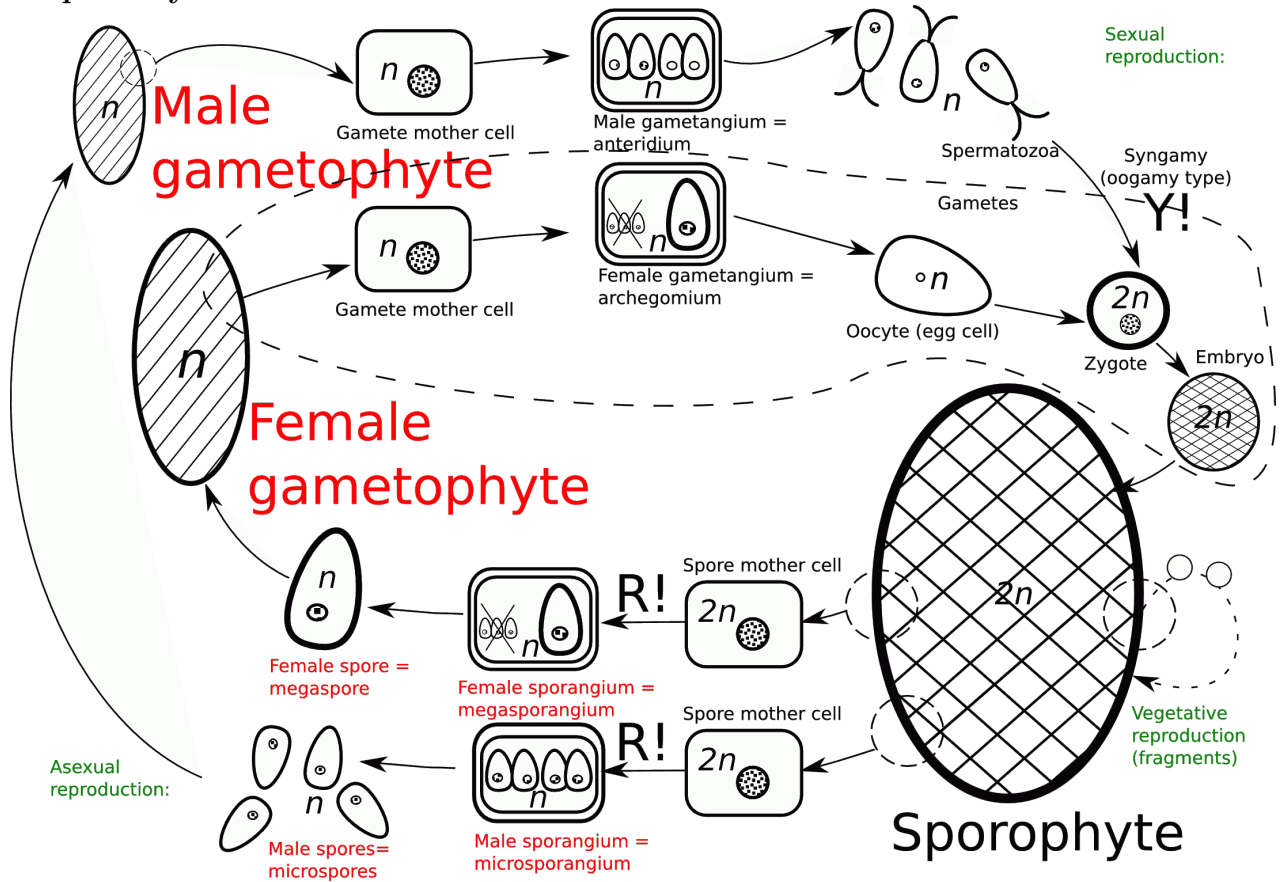


## Eukaryote life cycles

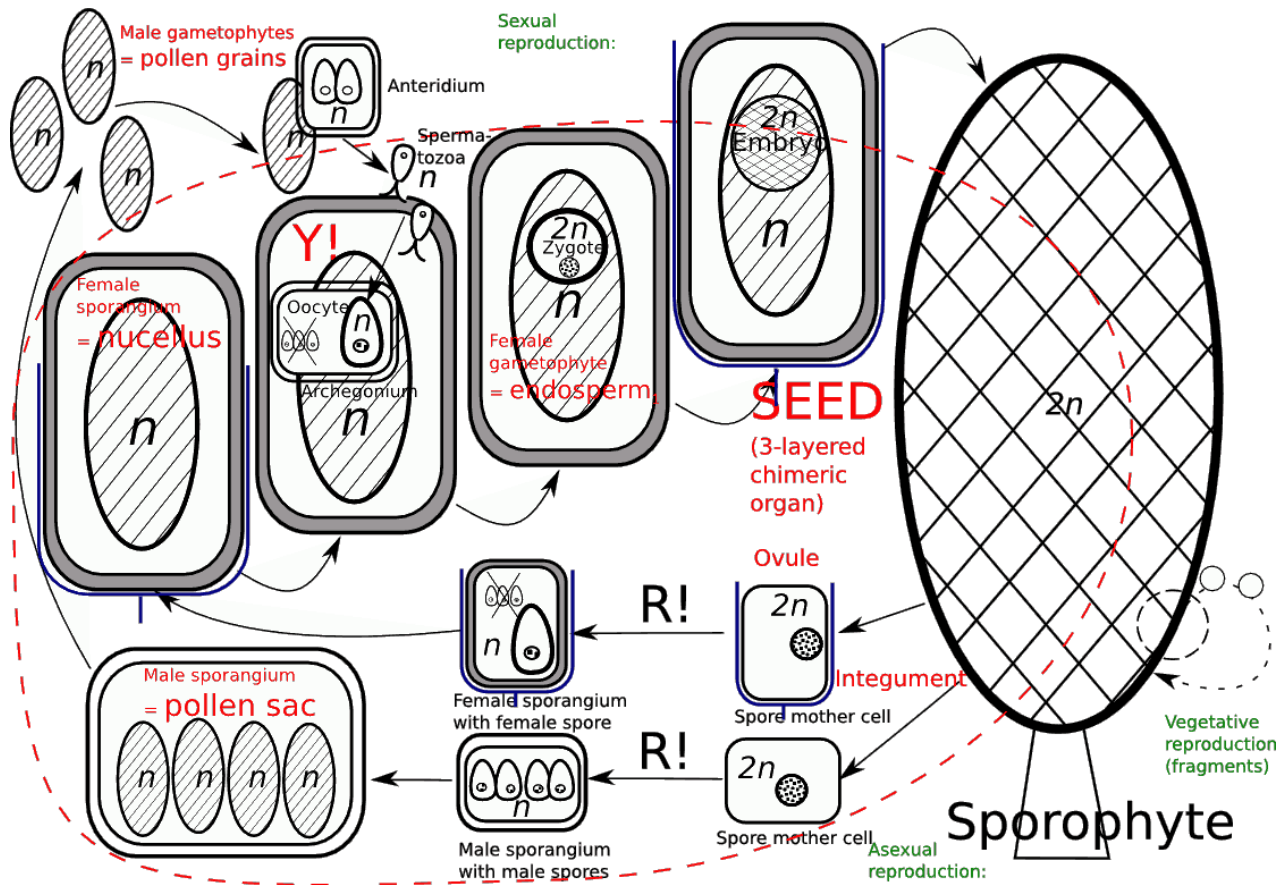
## Life cycle of land plants: differences



### Heterosporic cycle: differences



### Life cycle of seed plants: differences



## 19.2 Diversity of seed plants

### Spermatophyta: seed plants

- $\approx 600$  species of non-angiosperms and  $\approx 250,000$  species of angiosperms
- 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<sub>1</sub> (female gametophyte) or endosperm<sub>2</sub> (second embryo)
- Have axillary buds
- Homiohydric 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

### Final question (2 points)

What is a seed?

### Summary

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

### For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 24*.

### Outline

## 20 Questions and answers

### Previous final question: the answer

What is a seed?

- Chimeric organ: 3 genotypes
- Mother sporophyte ( $2n$ ) + female gametophyte ( $n$ ) + embryo ( $2n$ )
- Seed coat + endosperm<sub>1,2</sub> + embryo

## 21 Seed plants

### 21.1 Diversity of seed plants

#### Spermatophyta classes

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

*Italicized text below is not necessary to remember*

## Ginkgoopsida

- *Smallest class, only one species (!), Chinese tree Ginkgo 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 multi-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  $\approx 300$  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, with 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)

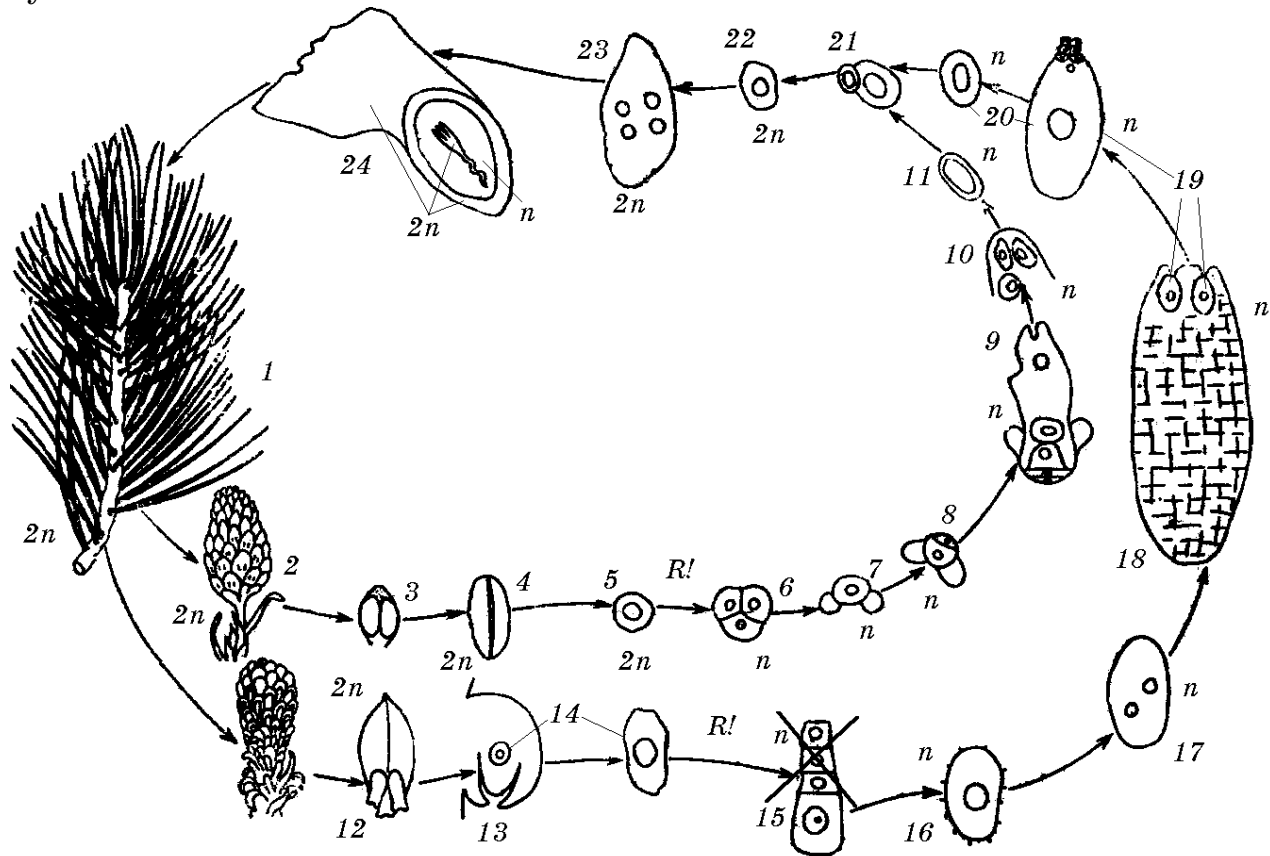


## 21.2 Conifers

### Pinopsida

- *Three orders, several families and  $\approx 300$  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 (spermata), 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



## 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





## 21.3 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 and polyembryony is widespread, Ephedra even has a double fertilization (like angiosperms). Only one embryo survives, other are eaten (endosperm<sub>2</sub>). Also have endosperm<sub>1</sub> (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 (!) dioecious plants*
- *Fructifications are cone-like; male one is similar to flower and contain sterile ovule (!)*
- *Seeds are wind-dispersed*



*Welwitschia*



*Welwitschia*



*Welwitschia* female cones





*Welwitschia* male cones





*Welwitschia* 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 monoecious 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



## 21.4 Flowering plants

Flowering plants are “Spermatophyta 2.0”

- Reduction of gametophyte: 3-celled pollen and 7-celled embryo sac
- No archegonia and anteridia
- Spermata, 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

**Final question (2 points)**

How to optimize the life cycle of seed plants? Name at least two possible optimizations.

## Summary

- Starting from **Pinopsida**, seed plants lost flagellate spermatozoa and micropylar chamber, and develop pollen tube
- Three genera of **Gnetopsida** are very divergent and morphologically close to angiosperms whereas molecular data place them close to conifers
- **Angiosperms** optimized their life cycle using (a) reduction, (b) signaling second embryo and (c) sophisticated pollination

## For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 24, 25*.

## Outline

## 22 Questions and answers

### Previous final question: the answer

How to optimize the life cycle of seed plants? Name at least two possible optimizations.

- Reduction of gametophytes
- Pollination
- Pollen tube
- Spermatia
- Endosperm after fertilization
- More ovules
- Ovules under cover



## 23 Seed plants

### 23.1 Life cycle of flowering plants

Flowering plants are “Spermatophyta 2.0”

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

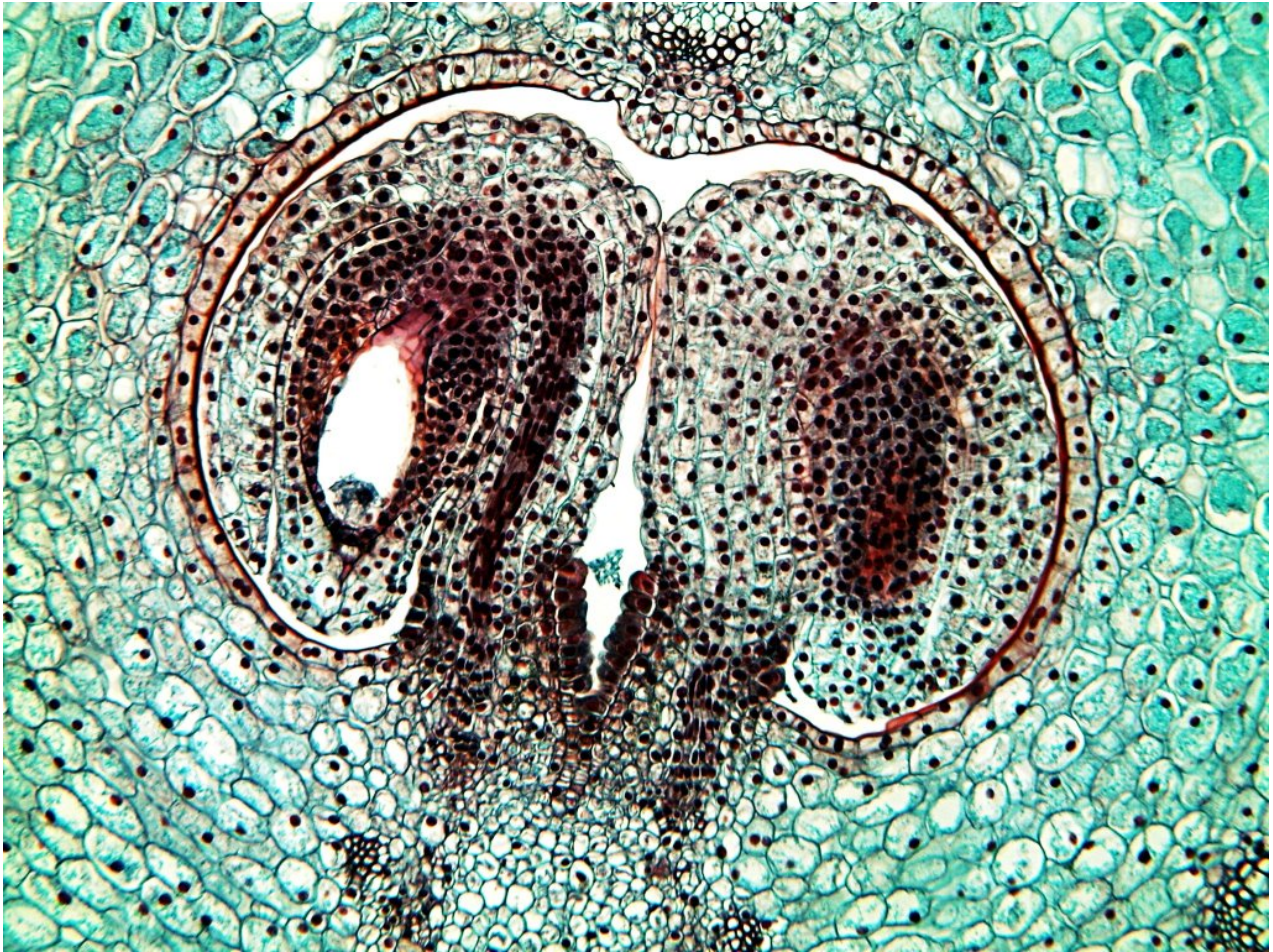
Note: angiosperms = flowering plants = class Magnoliopsida

#### Life cycle of angiosperms

Terms covered:

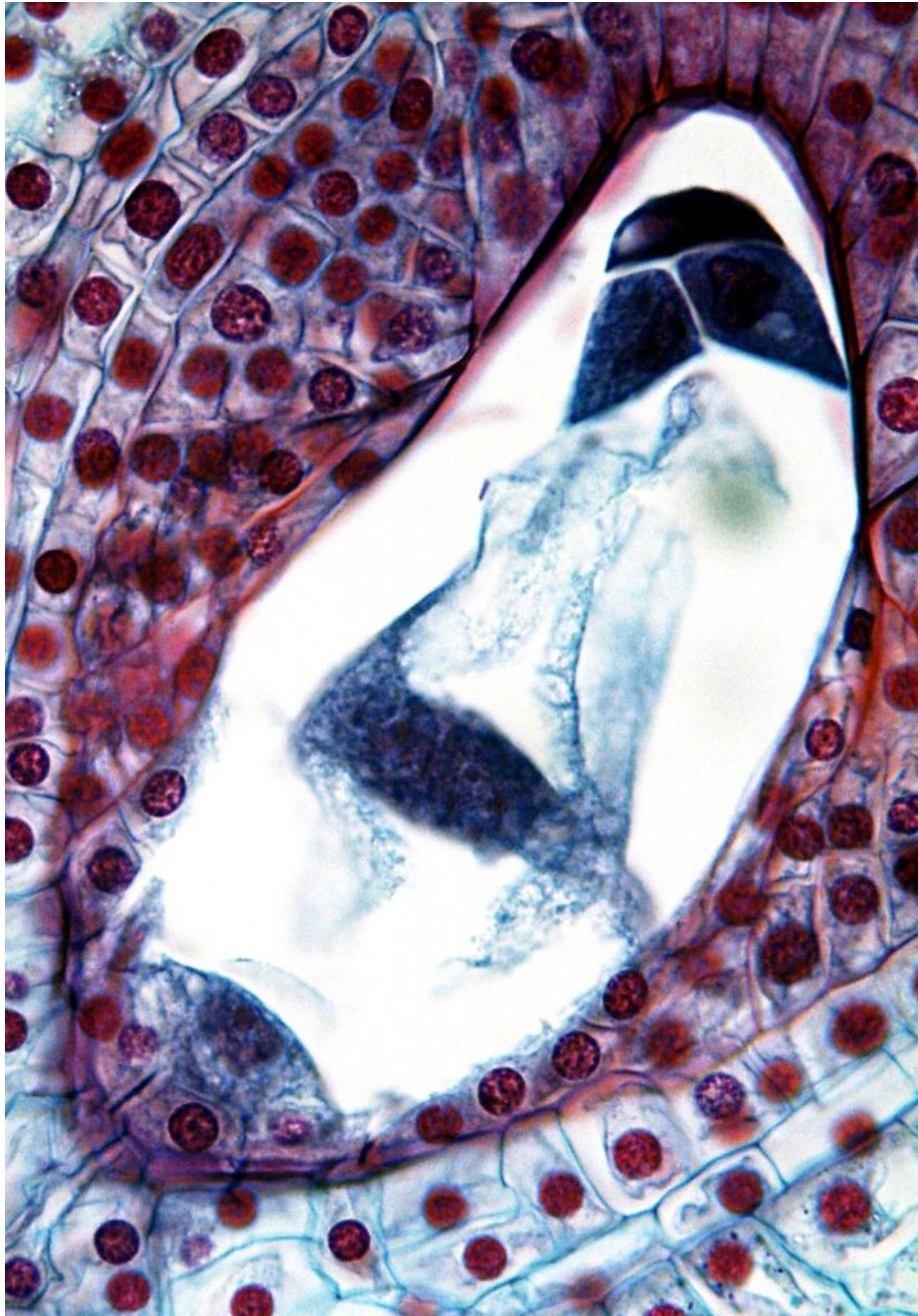
- Embryo sac, central cell
- Spermata (sperms without flagella), pollen tube
- Double fertilization
- Pistil and ovule → fruit and seed

Ovules (*Lilium* sp., lily)



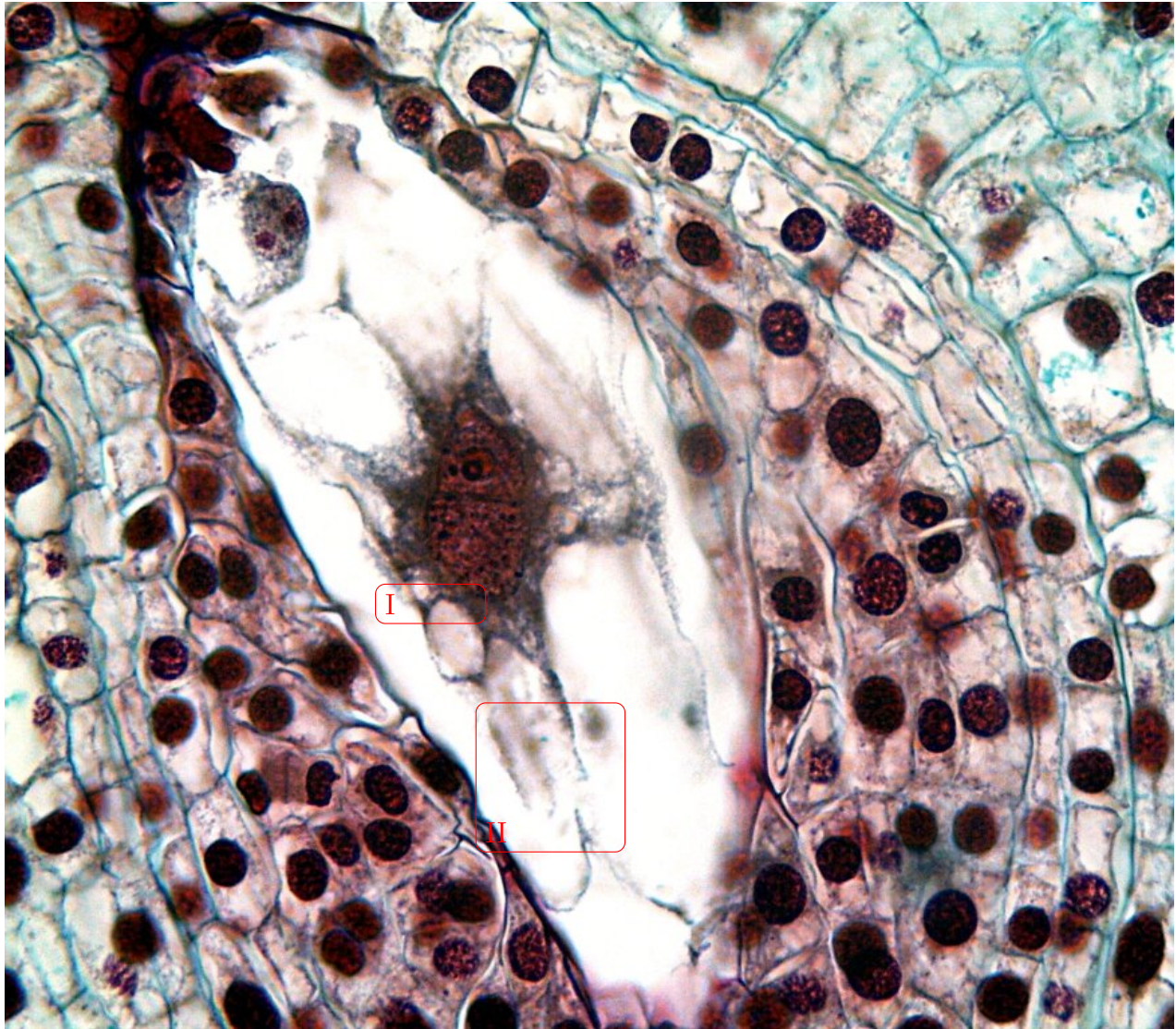
Embryo sac (*Lilium* sp., lily)





Double fertilization (*Lilium* sp., lily)

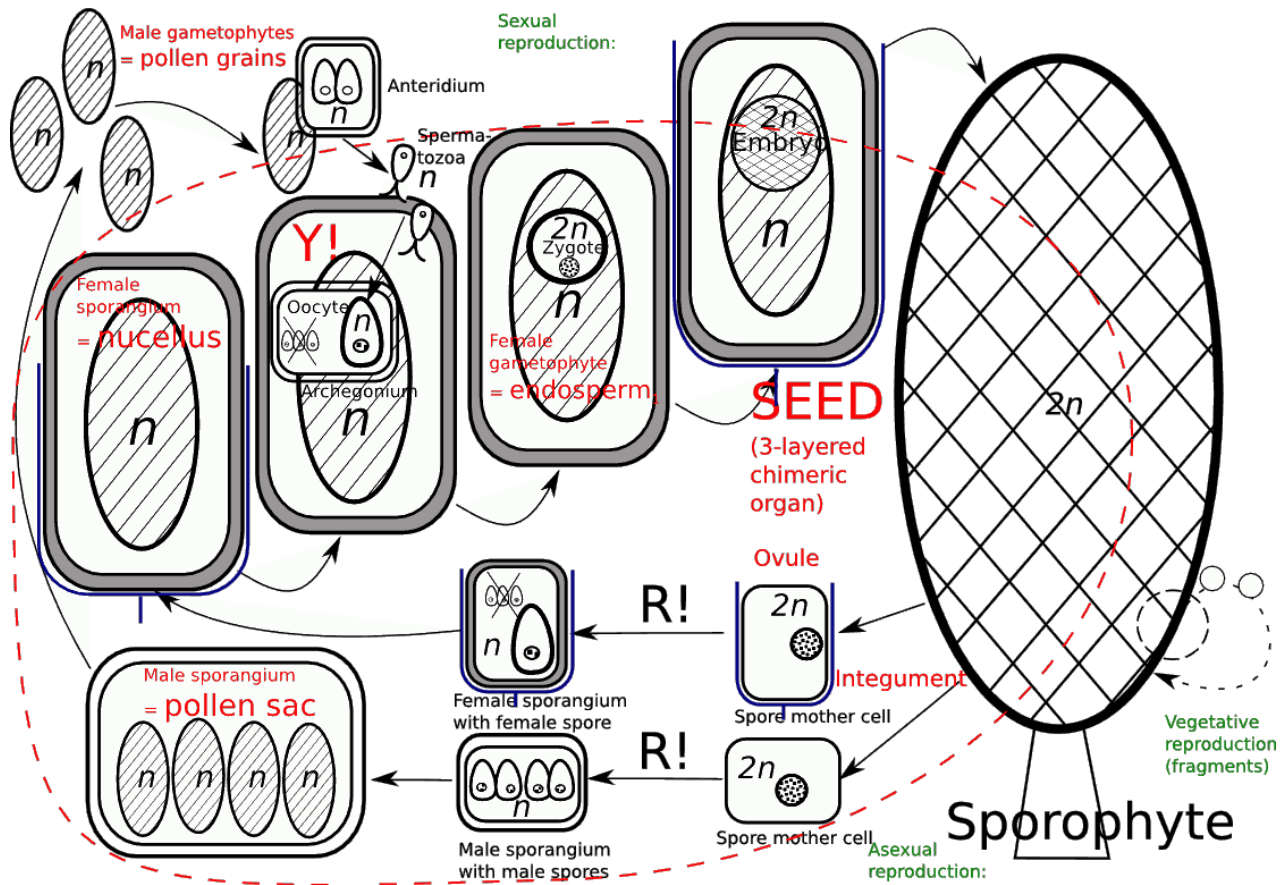




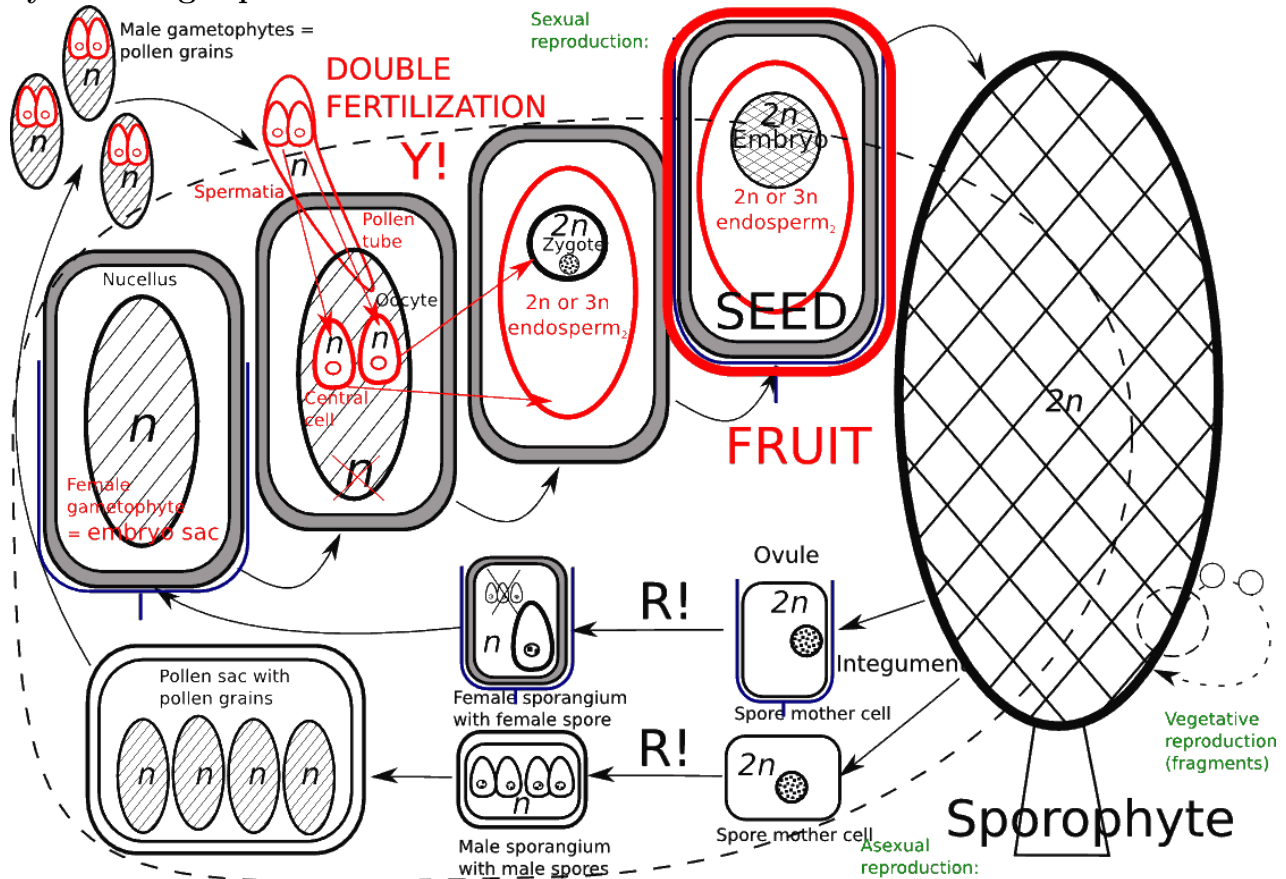
### Life cycle of angiosperms: sources of optimization

- Reduction of everything, especially of haploid stages
- Signal role of second embryo (source of endosperm<sub>2</sub>)
- Well-developed pollination
- Pistil and fruit

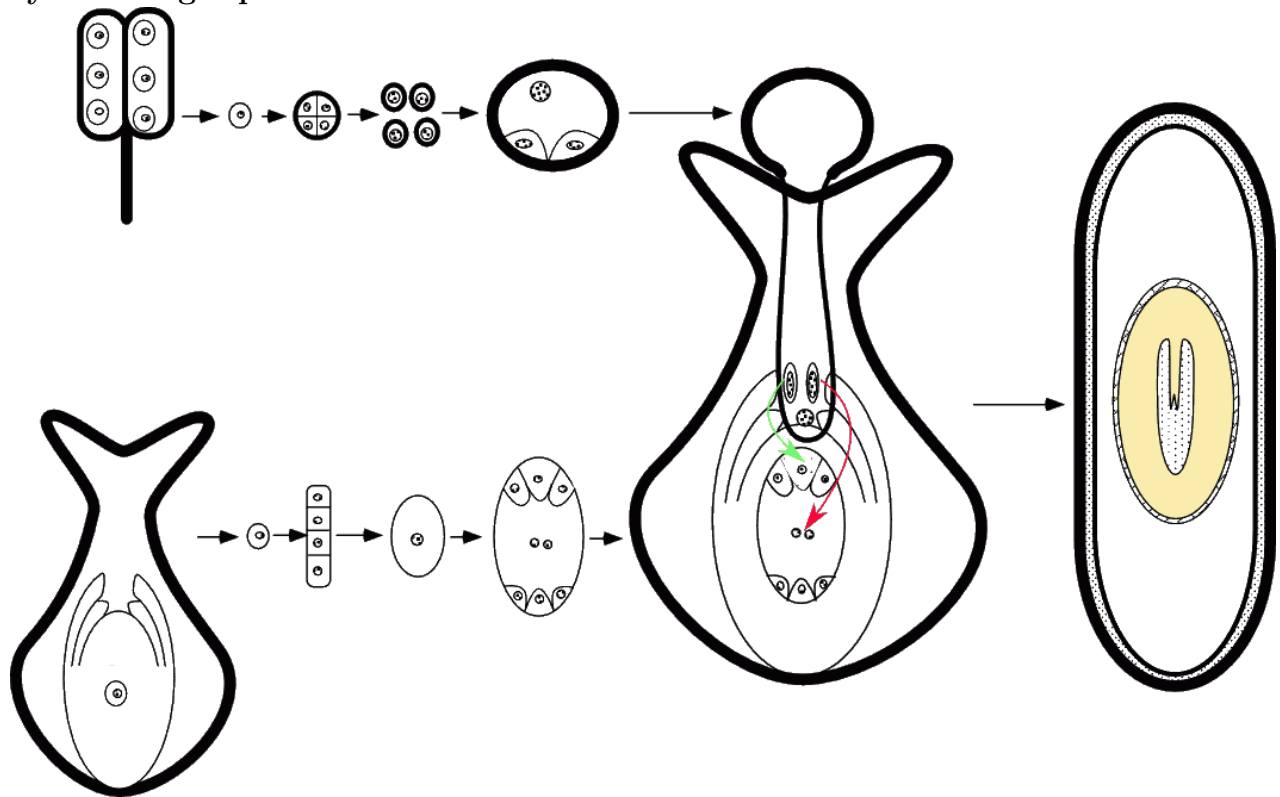
### Life cycle of “gymnosperms”



### Life cycle of angiosperms: differences

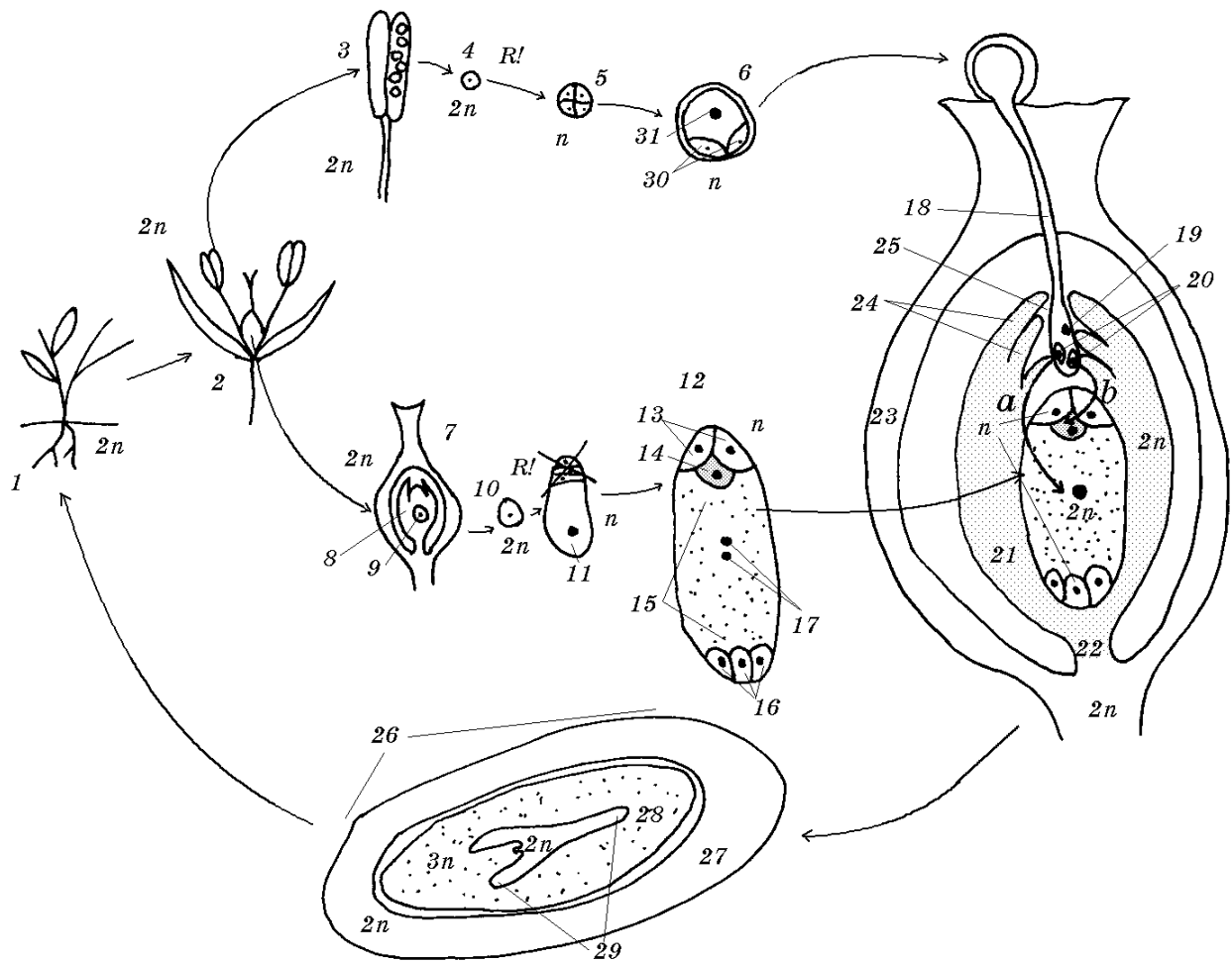


# Life cycle of angiosperms: relations between structures



## Life cycle of angiosperms: another view





## 23.2 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

- Fruit
- Parcellation

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

### Final question (2 points)

What is a double fertilization?

### Summary

- **Angiosperms** optimized their life cycle using (a) reduction, (b) signaling second embryo and (c) sophisticated pollination

### For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 24, 25*.

### Outline

## 24 Questions and answers

### Previous final question: the answer

What is a 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<sub>2</sub> ( $3n$  or sometimes  $2n$ )

In all, the second fertilization is a **signal** that first fertilization has been occurred. Endosperm<sub>2</sub> develops from the “signalized” female gametophyte.

## 25 Seed plants

### 25.1 Flower

#### Definition of flower

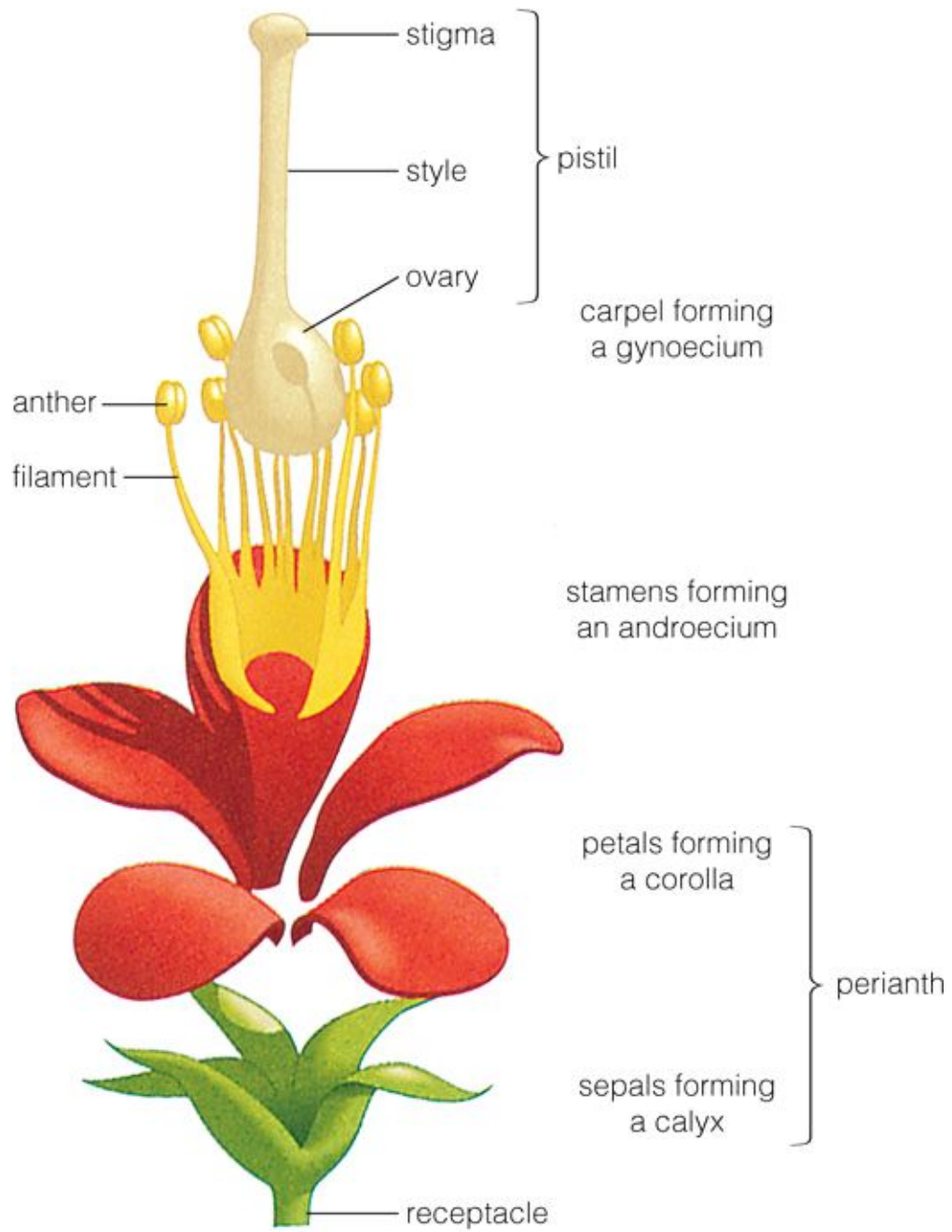
- Compact generative shoot (= floral unit, FU) with three zones
- Three main zones: sterile (perianth), male (androecium) and female (gynoecium)
- General characters: sex, merosity, symmetry, position of gynoecium

## Structure of flower

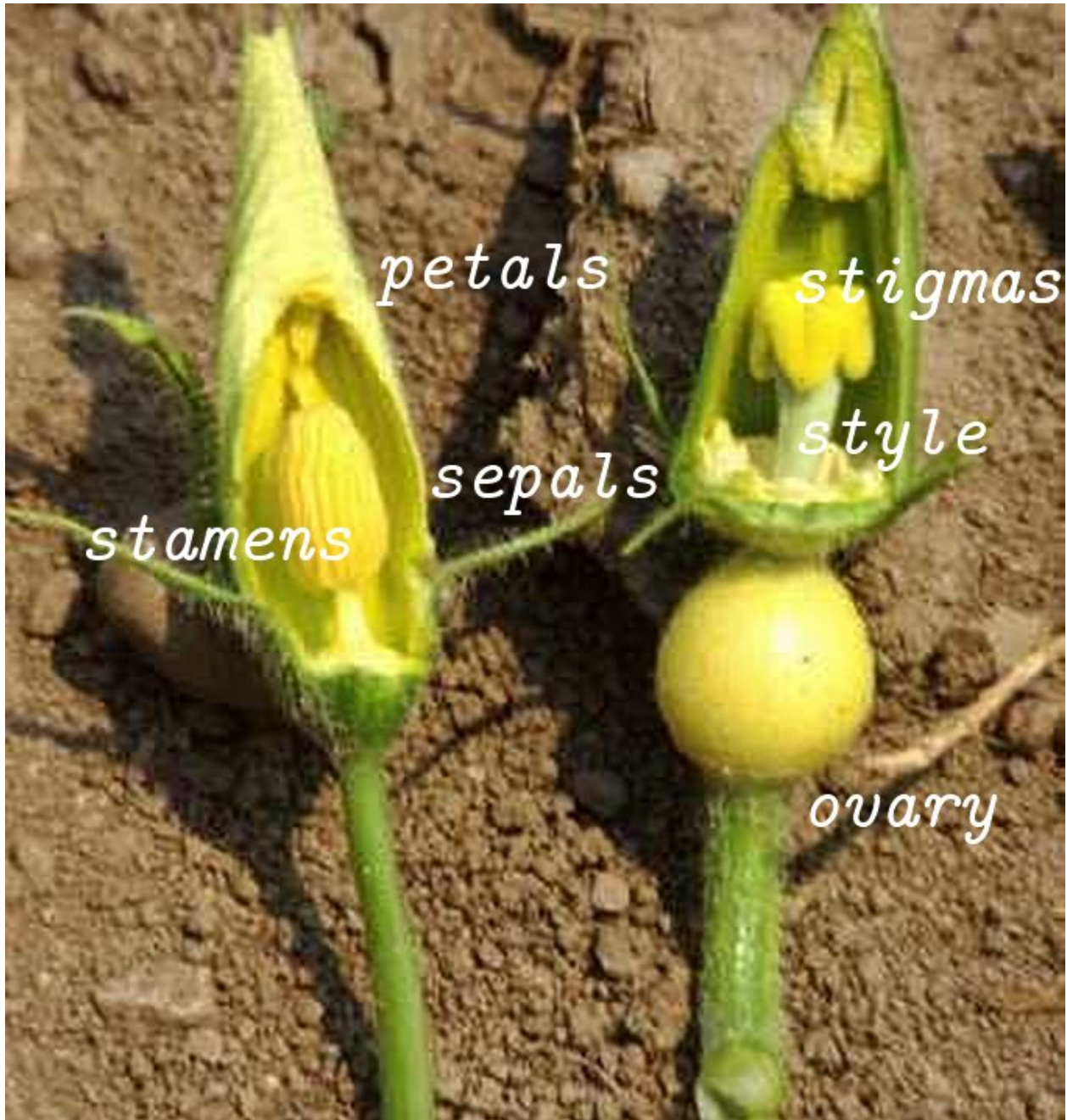
- Perianth
  - Simple perianth (consists of tepals)
  - Double perianth
    - \* Calyx (consists of sepals)
    - \* Corolla (consists of petals)
- Androecium (consists of stamens)
  - Filament
  - Anther (consists of pollen sacs)
- Gynoecium (consists of pistils)
  - Ovary (consists of carpels)
  - Style
  - Stigma

## Structure of flower





Pumpkin (*Cucurbita pepo*) flower

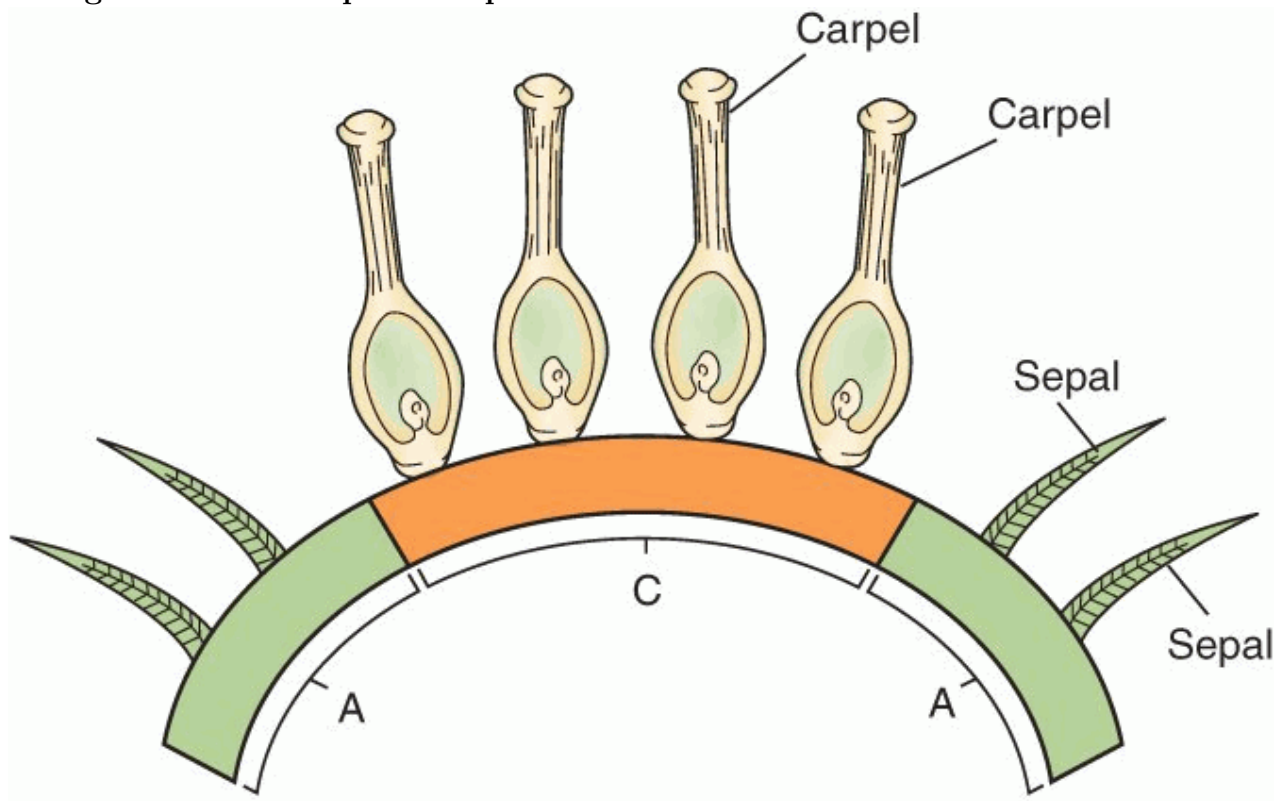


## 25.2 Flower development: ABC model

### ABC-genes

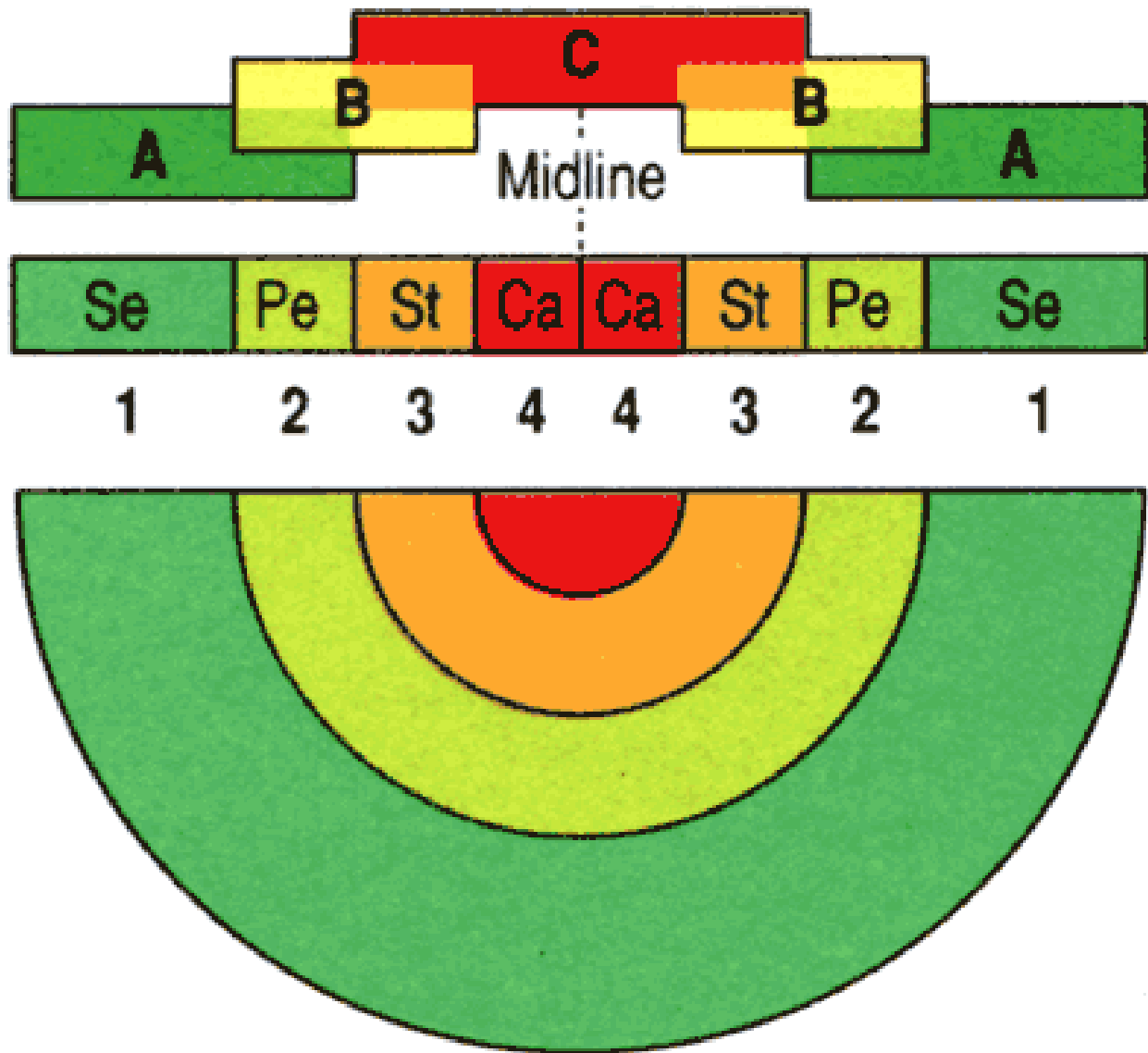
- There are 3 classes of genes expressed in overlapping, concentric rings.
- The A class (like *apetala2* gene) is expressed in the outermost ring and C (like *agamous*) is expressed in the center; B (e.g., *apetala3*) is expressed at the boundary of A and C.
- If A is expressed in a cell, it goes on to form a sepal.
- If C is turned on, it forms a carpel.
- Petals are formed where both B + A are active.
- Stamens are formed with the combination B + C.

A and C genes “make” sepals and pistils

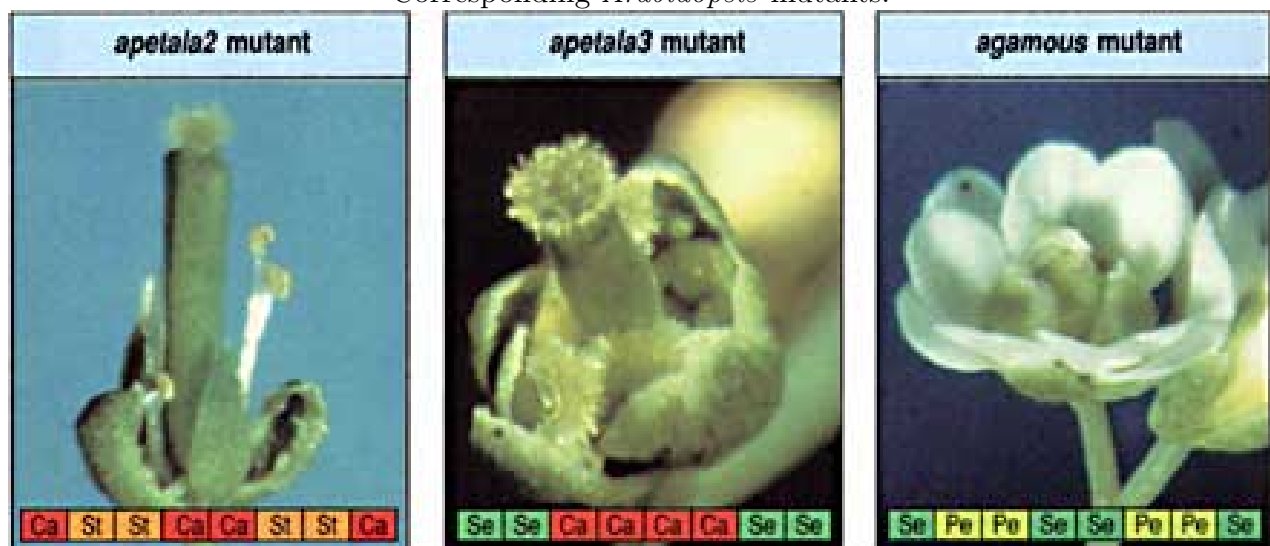


B genes “transform” them into petals and stamens





Corresponding *Arabidopsis* mutants:

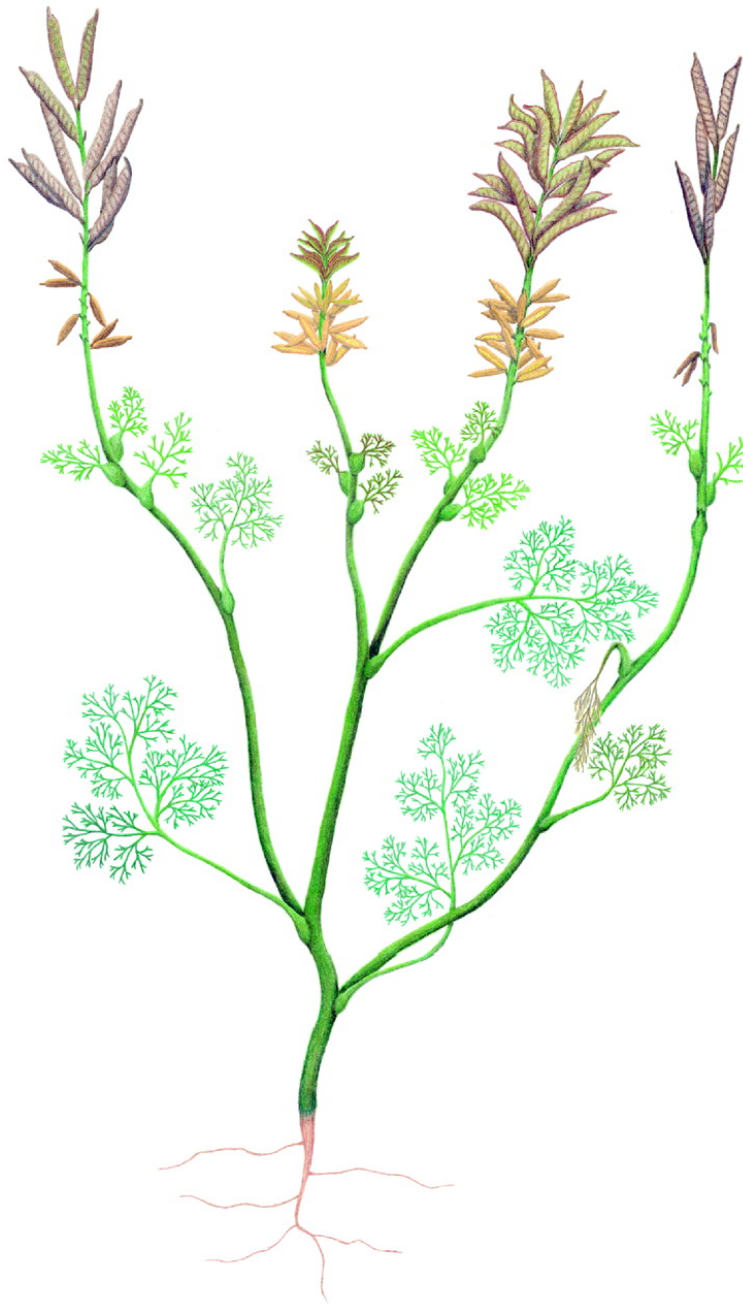


## 25.3 Primitive flowers

### *Archaeofructus*

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

### *Archaeofructus* reconstruction

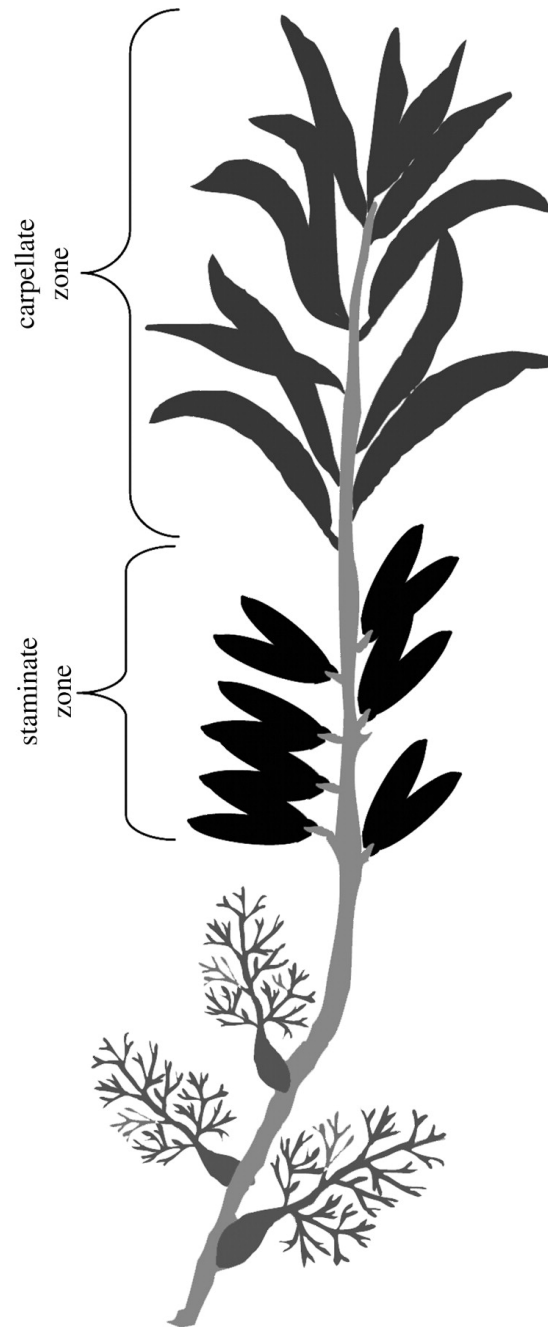


### *Archaeofructus* reconstruction, 3D



*Archaeofructus*, scheme of “flower”





### *Amborella*

- Small forest shrub of New Caledonia (big island in Pacific ocean)
- Have irregular flowers, stylar canal, unusual embryo sac (with three synergids and no antipods)

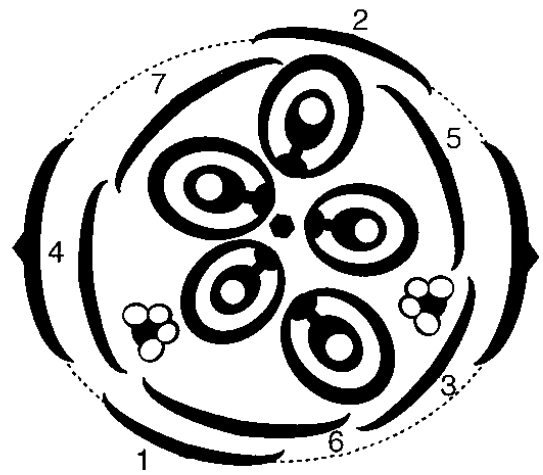
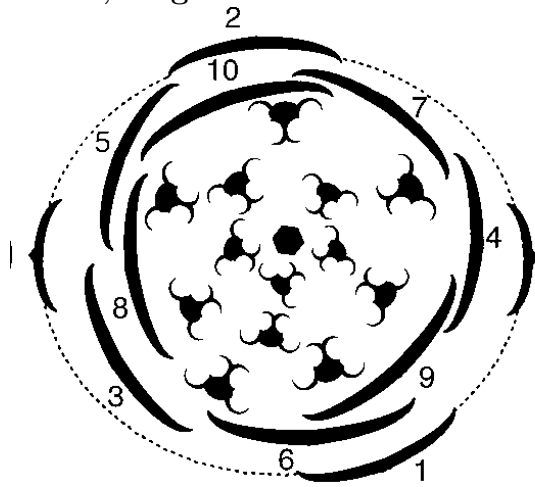
### *Amborella*, branch with male flowers



*Amborella*, male and female flowers

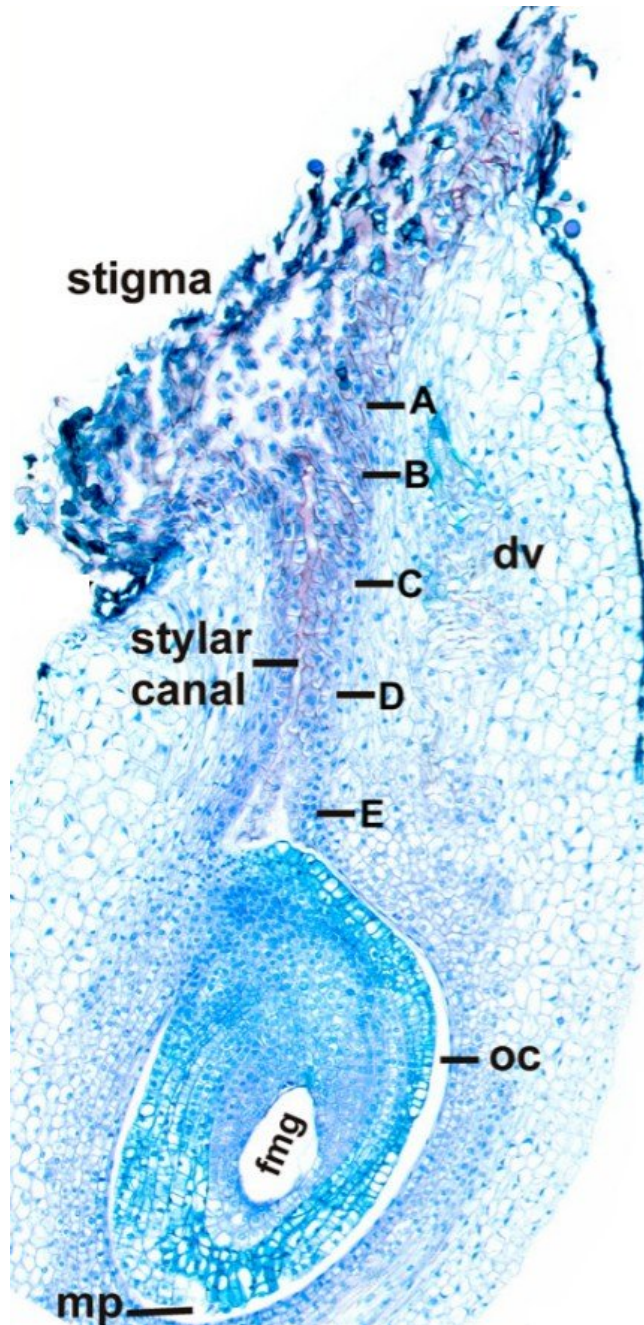


*Amborella*, diagrams of male and female flowers



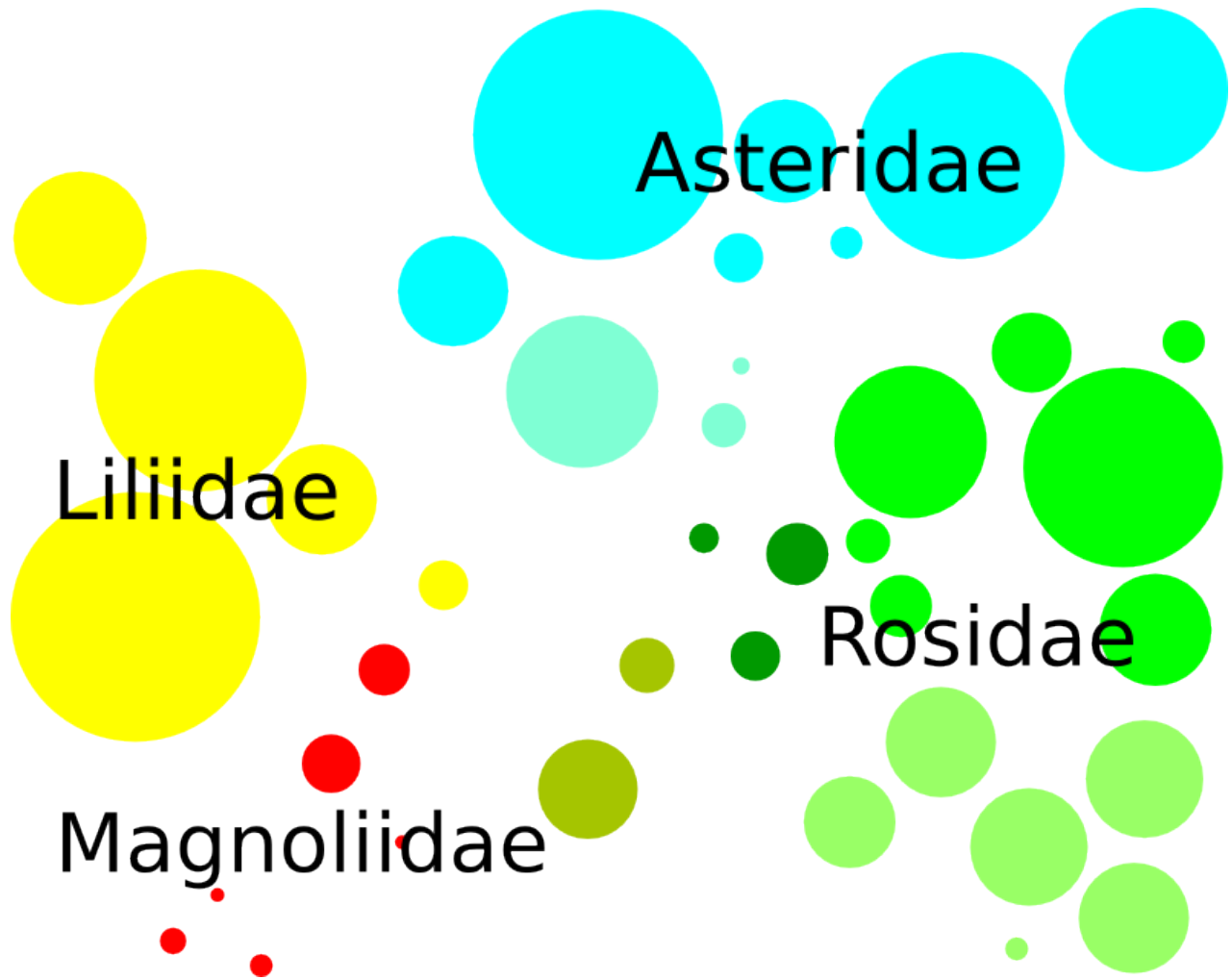
*Amborella* styler canal



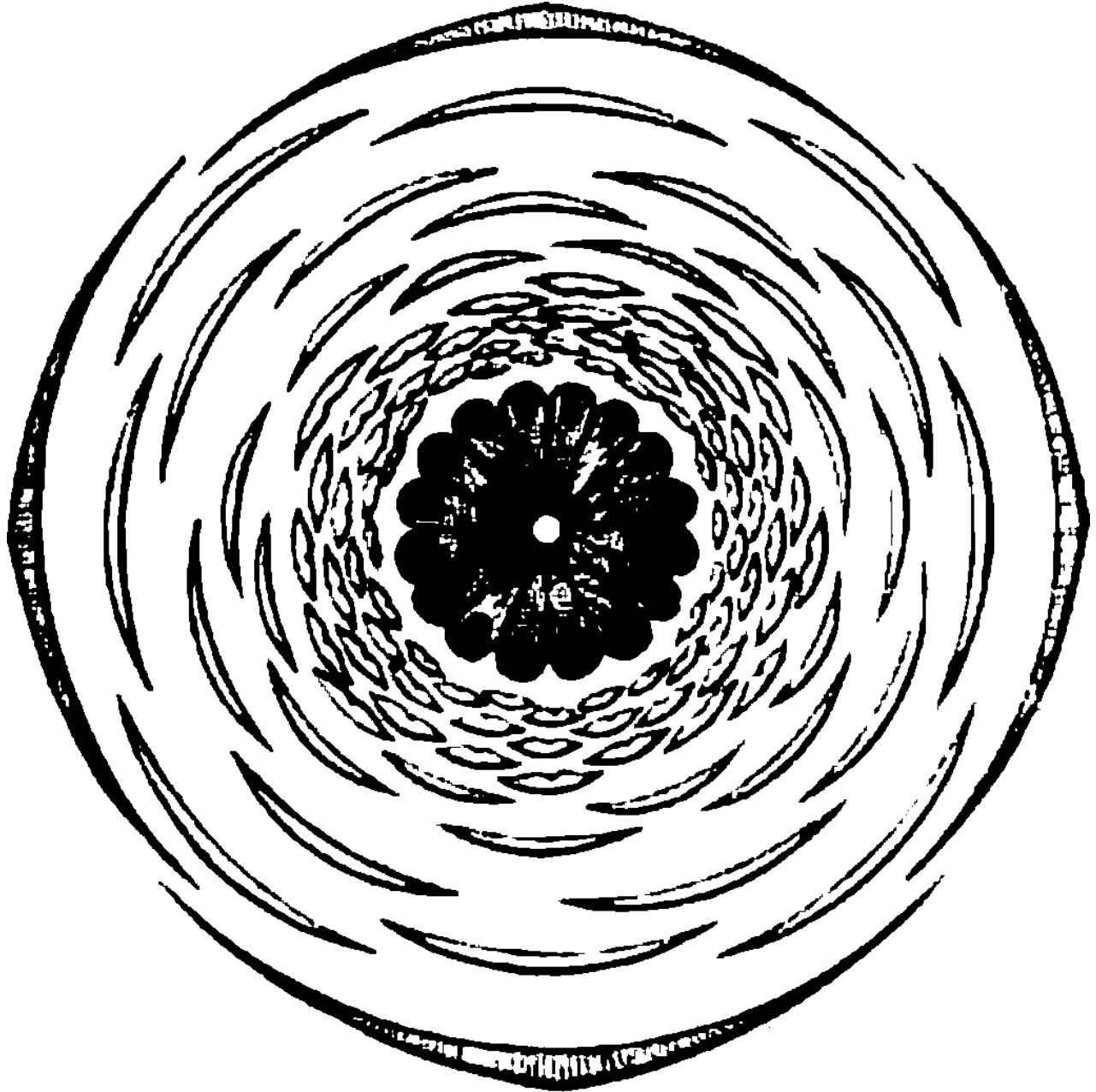


## 25.4 Four subclasses of angiosperms

Angiosperms: subclasses and orders



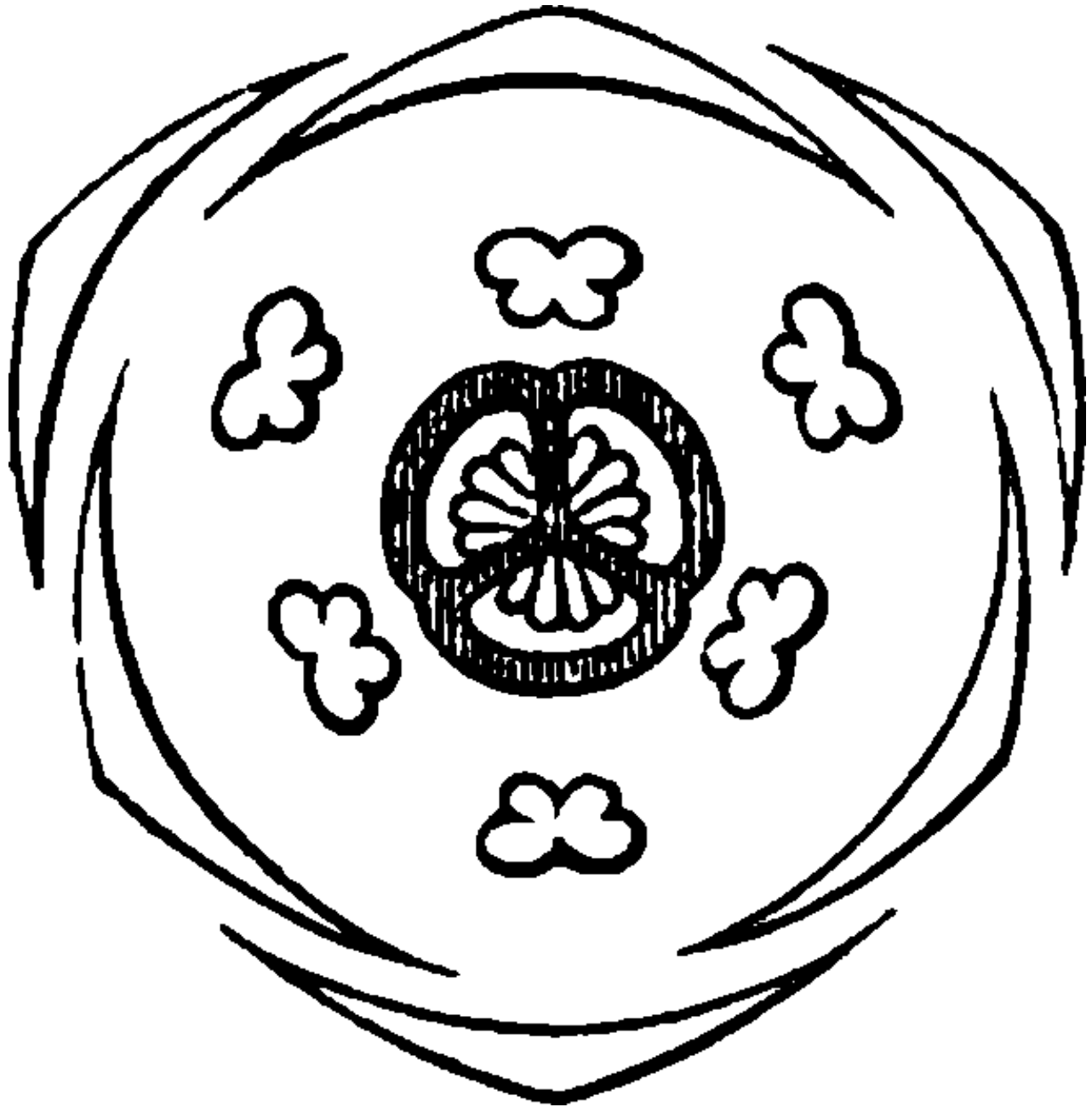
Magnoliidae portrait



*Nymphaea* sp. (water-lily)

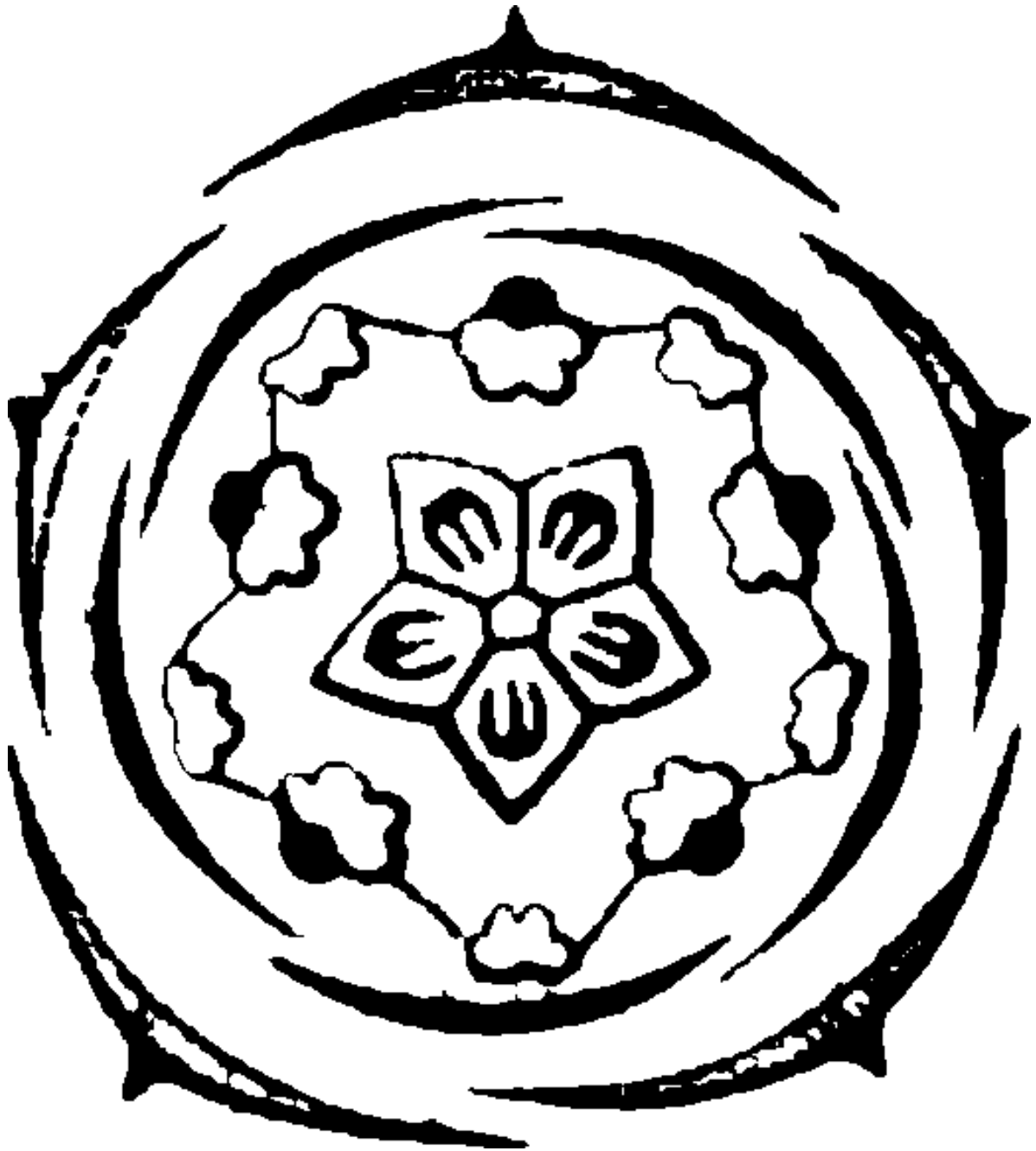
Liliidae portrait





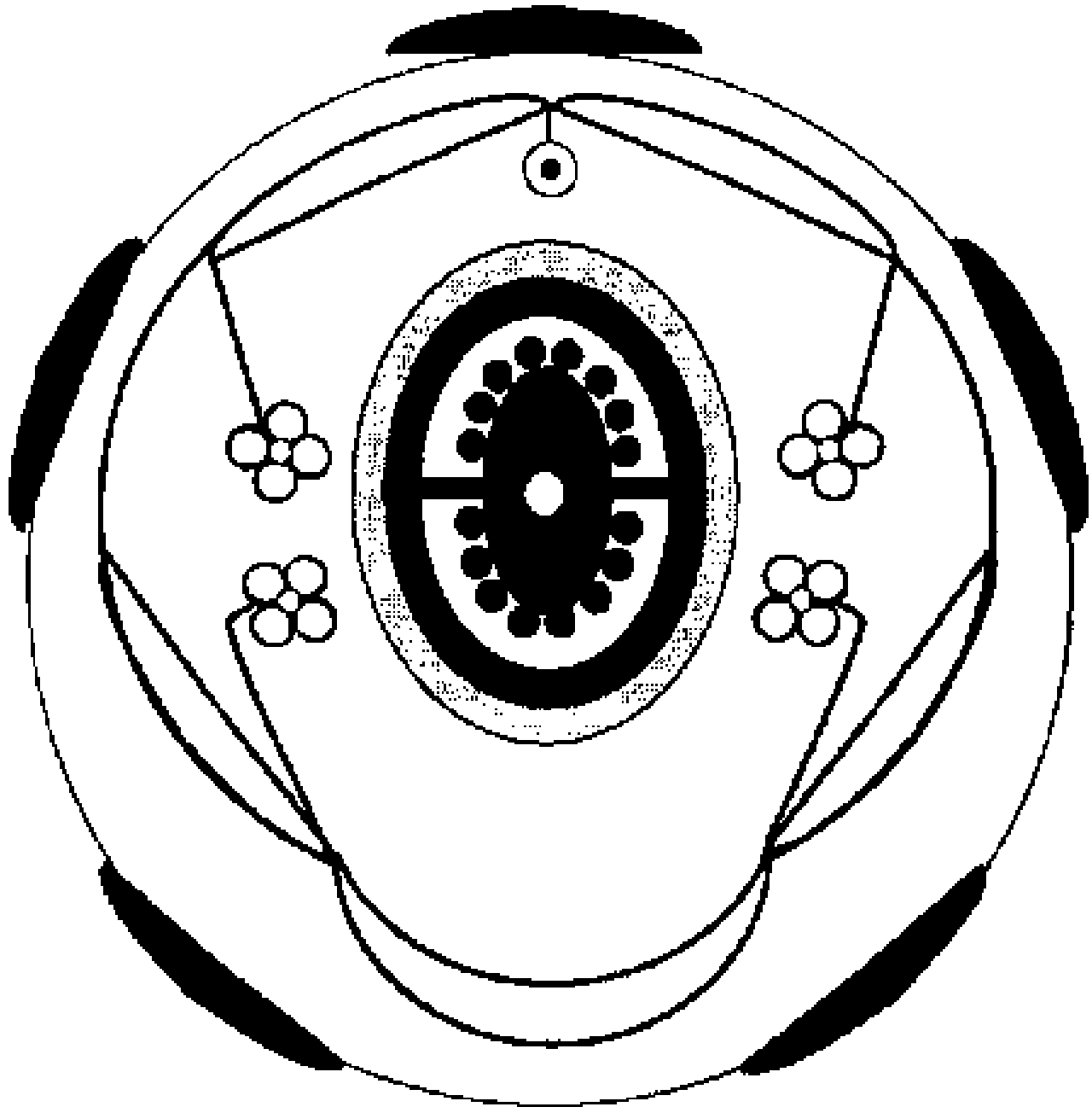
*Acorus calamus* (calamus, or sweet flag)

Rosidae portrait



*Geranium* sp. (wild geranium)

Asteridae portrait



*Penstemon* sp. (beard-tongue)

## 25.5 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

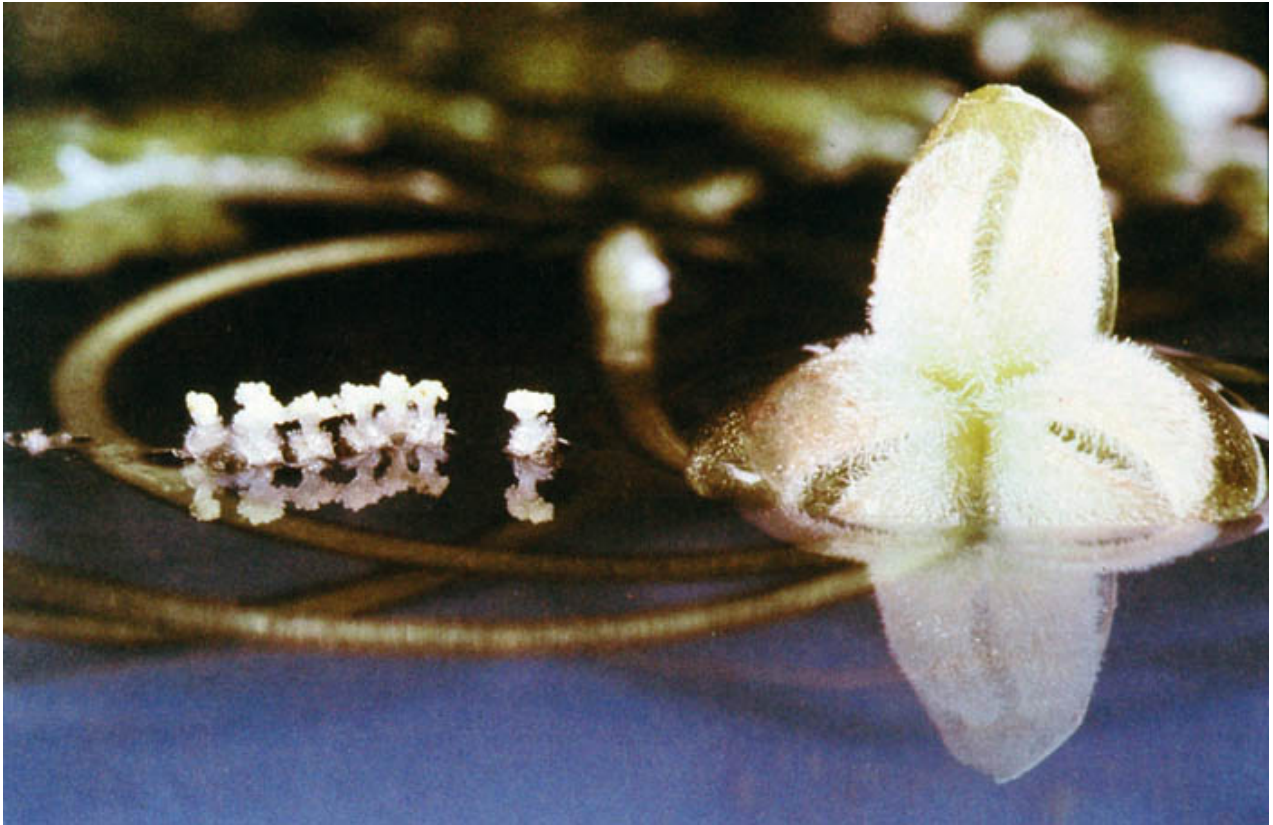


- Self-pollination (only slightly better than apogamy)
- Cross-pollination: abiotic (gravity, wind, water) and biotic (insects, birds, bats, sometimes even possums)
- Every pollination type has associated **pollination syndrome**

**Wind pollination: hazelnut**



**Water pollination: vallisneria**



Bat pollination: cacti





## 25.6 Inflorescences

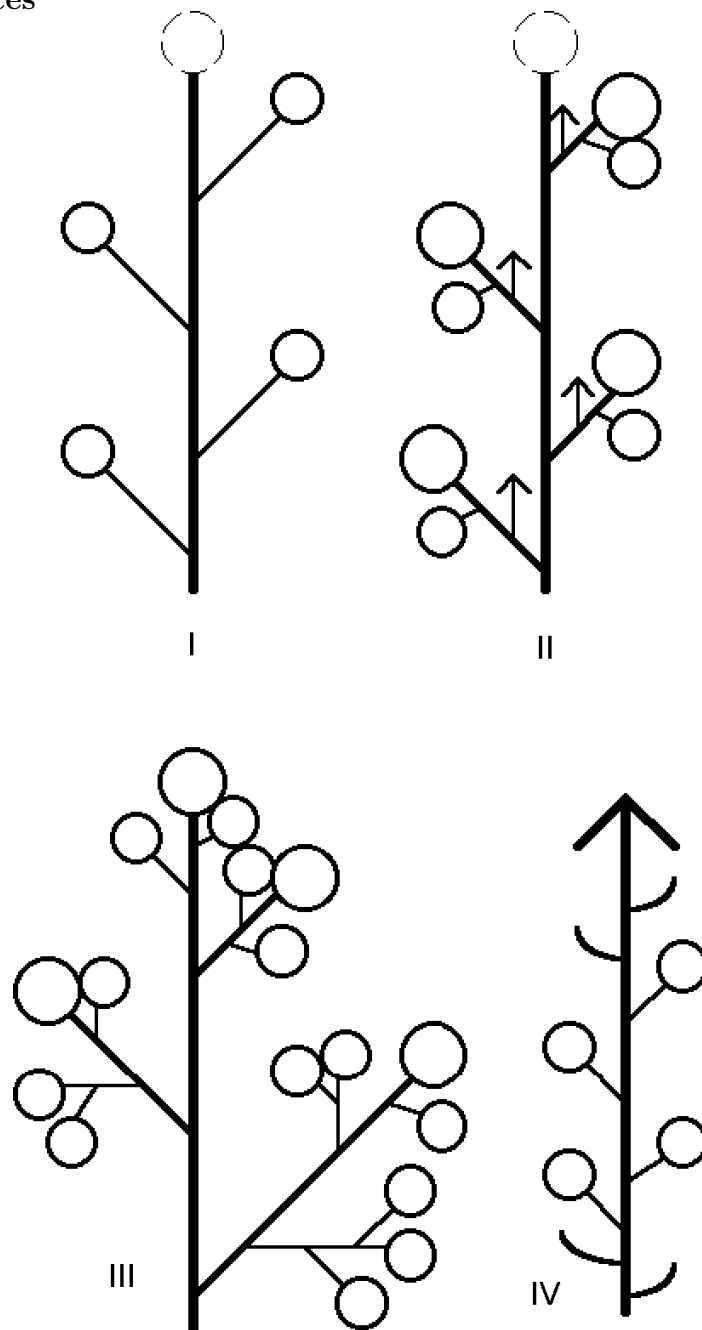
### Types of inflorescences

Inflorescence is an isolated generative shoot bearing flowers

- Model I. Raceme and its derivatives
  - Simple: raceme (developed main 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 derivatives
  - 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



## Final question (2 points)

What is a flower?

## 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

## For Further Reading

## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapters 13 and 25*.

## Outline

## 26 Questions and answers

Previous final question: the answer

What is a flower?

- Compact reproductive shoot (FU) with sterile, male and female zones

## 27 Seed plants

### 27.1 Seeds

#### Definition

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

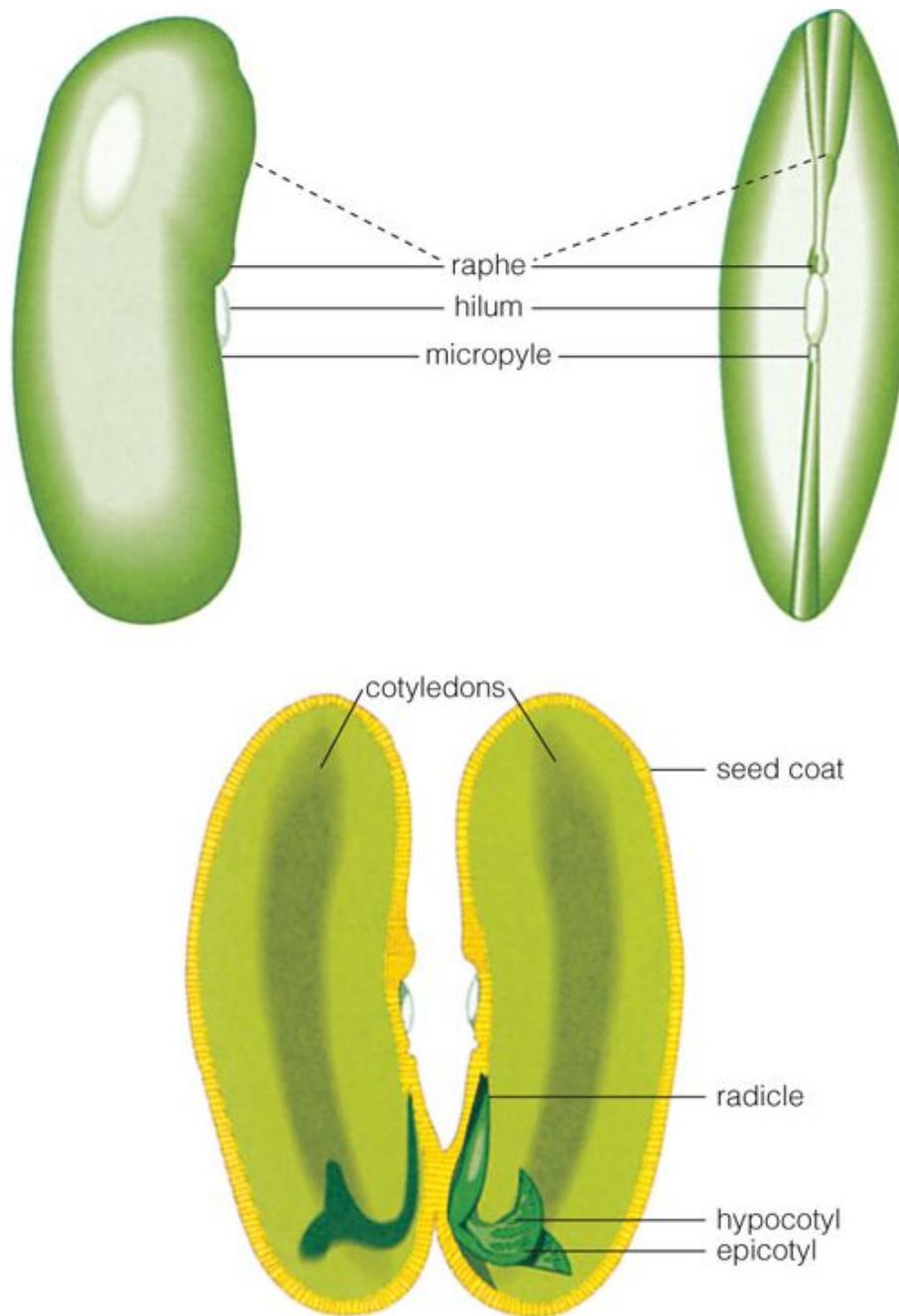
#### Origin of seed layers

Layer	Ploidy	Origin
Seed coat	$2n$	Integument of ovule
Endosperm <sub>2</sub>	$3n$ , sometimes $2n$	Fertilized central cell of embryo sac
Embryo	$2n$	Fertilized egg
Endosperm <sub>1</sub>	$n$	Female gametophyte (gymnosperms!)
Perisperm	$2n$	Nucellus of ovule

#### Seed structure variations

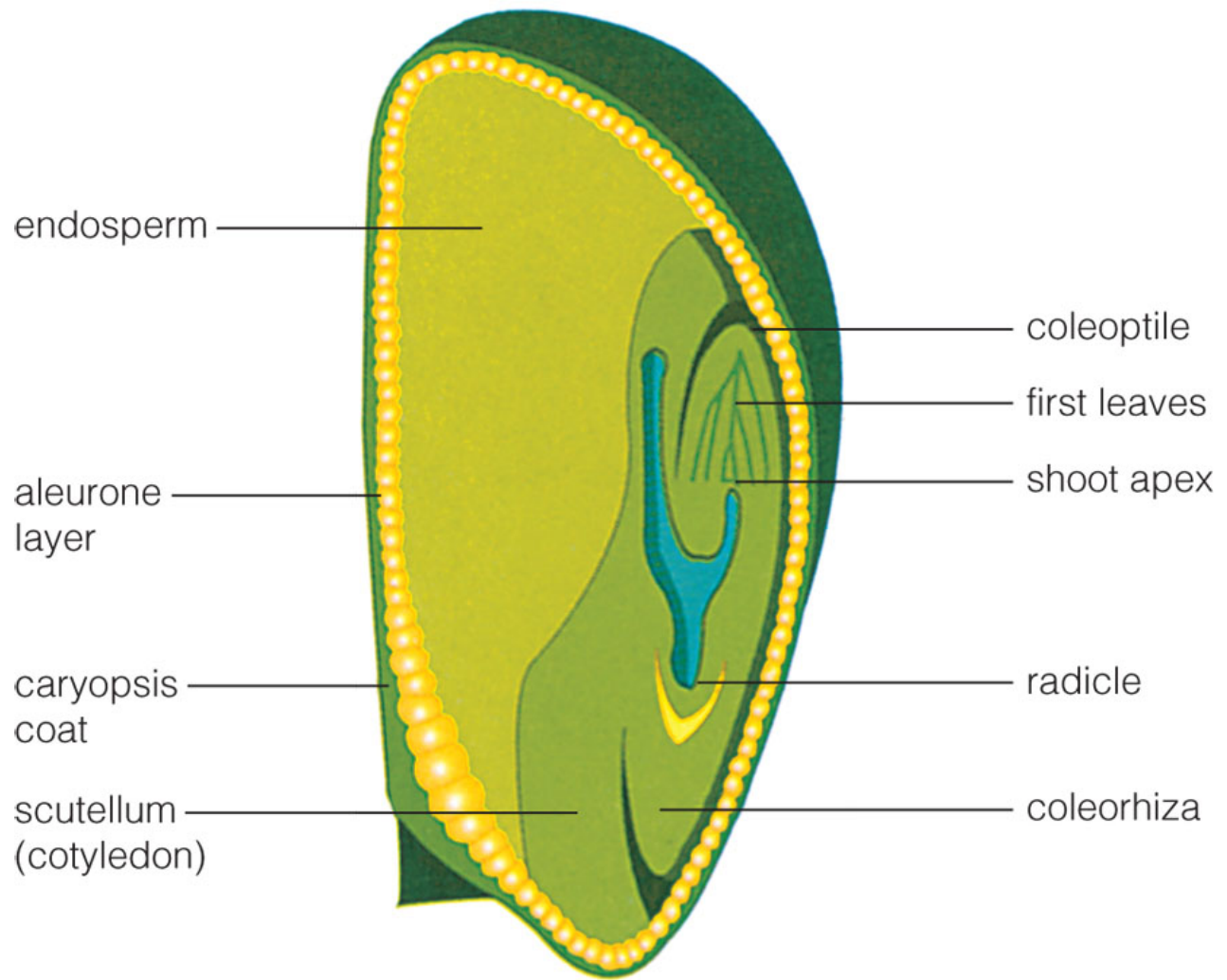
- Seed with endosperm (onion): cotyledon(s): embryonic leaves, radicle: embryonic root, apex: embryonic bud
- Seed without endosperm (beans and other Leguminosae): cotyledons, radicle, hilum, raphe
- Grass (Gramineae) seeds: coleoptile, coleorhiza, scutellum

## Bean seed



## Grass seeds





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## 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**

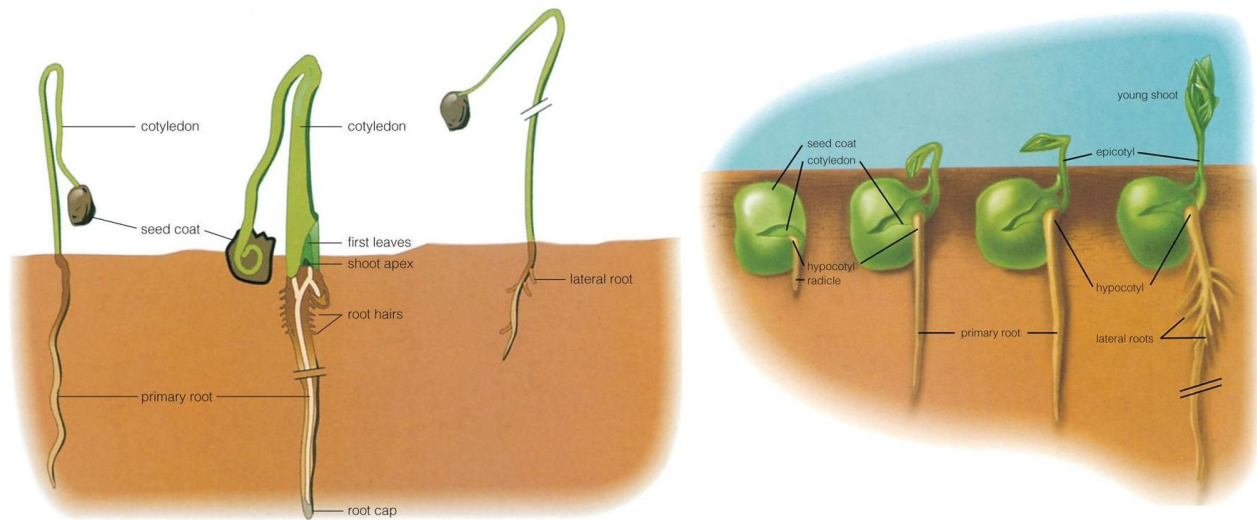


## Germination

- 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



## 27.2 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.

### Multiple fruit of *Fragaria* sp. (strawberry)





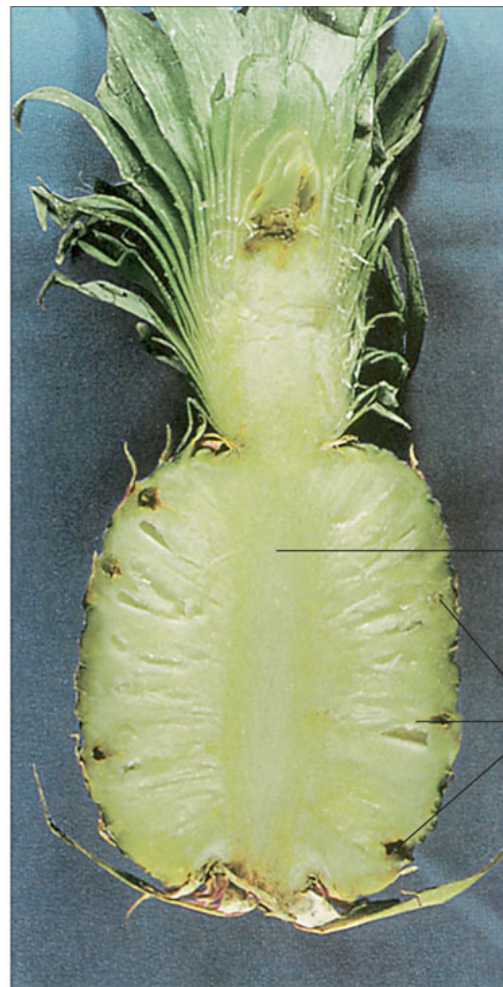
Multiple fruit of *Rubus* sp. (raspberry)



Compound fruit of *Ananas comosus* (pineapple)







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Compound fruit of *Ficus carica* (fig tree)



Schizocarp of *Zizia*

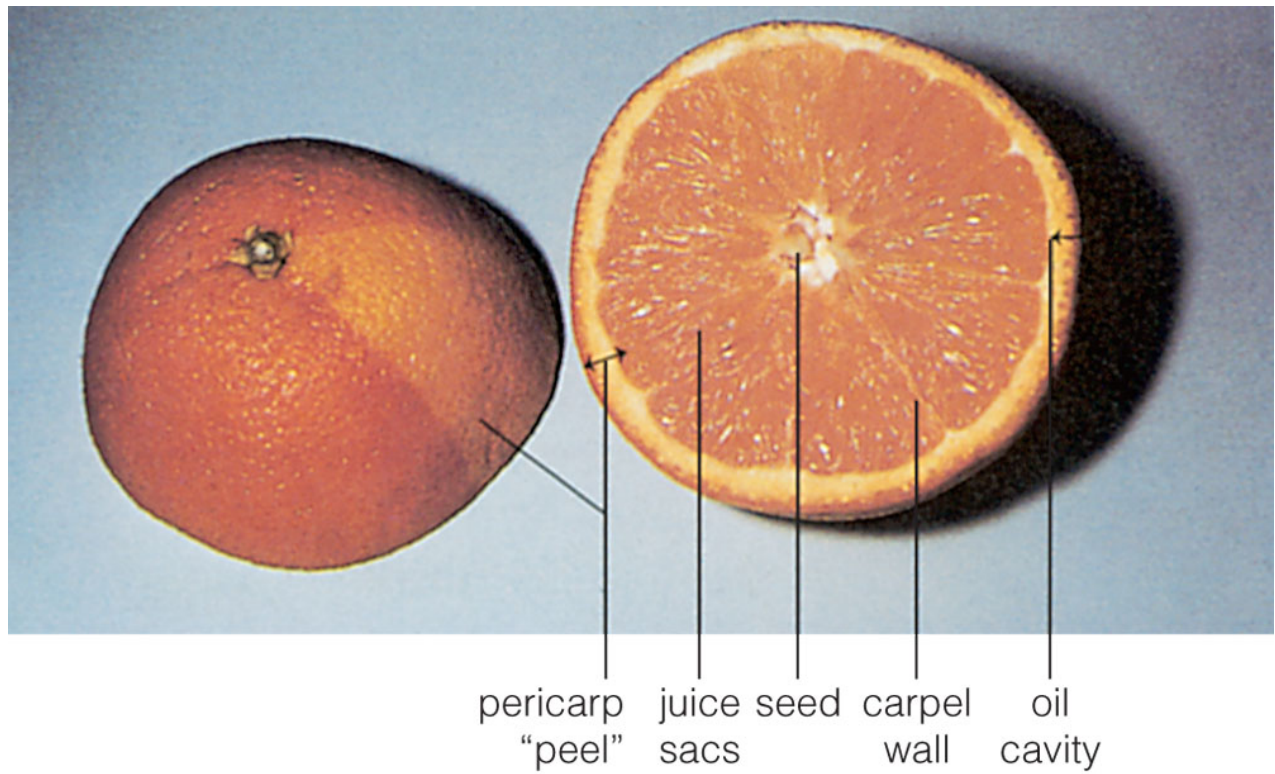


### Trivial classification: examples

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 of *Citrus*



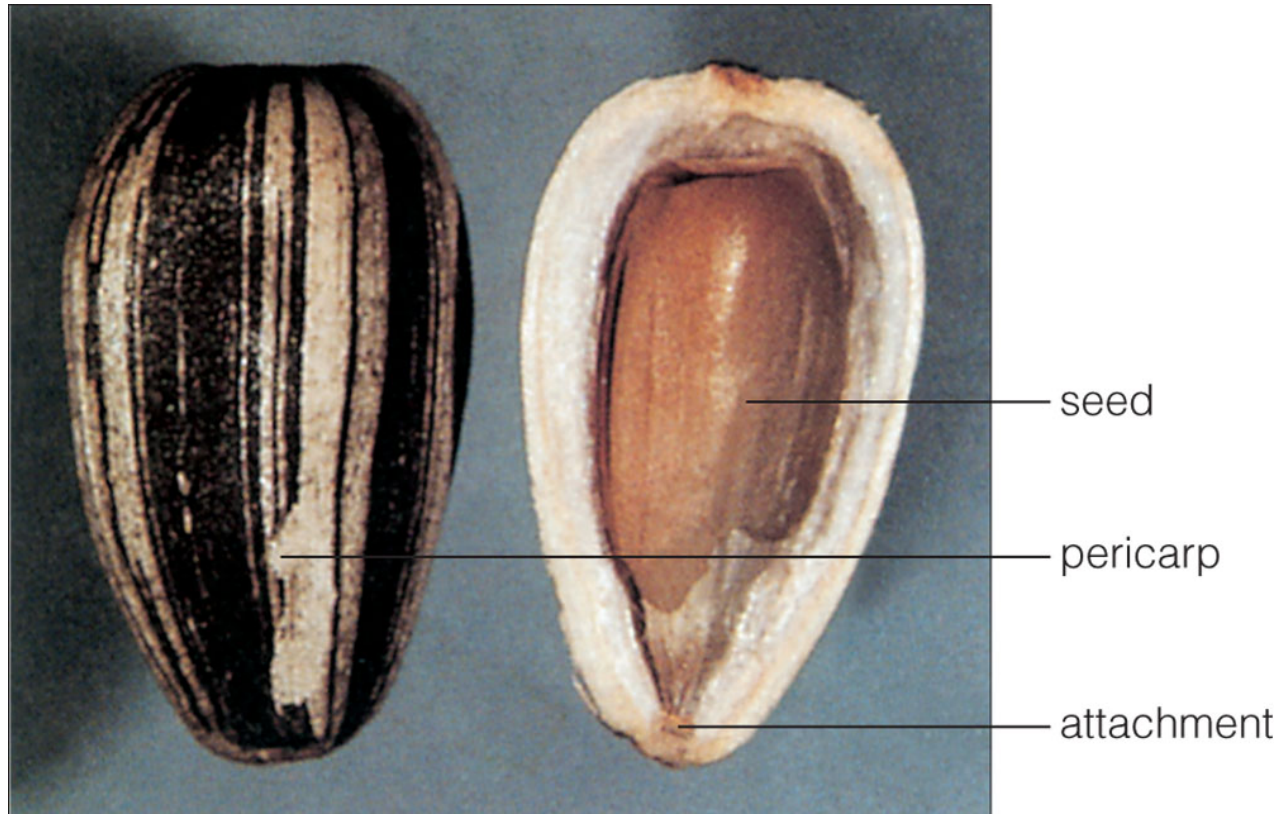


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Simple, dry, dehiscent: legume of *Erythrina*



Simple, dry, indehiscent: achene of *Helianthus*



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### Short anonymous absolutely voluntary survey

1. What do you **like** most in Biology 154?
2. What do you **dislike** most in Biology 154?
3. **Which lab** do you remember most of all?
4. Please grade (1—bad, 5—excellent):
  - (a) Lectures
  - (b) Labs
  - (c) Final questions
  - (d) Exams

### Summary

- **Seed** is a chimeric organ consists of seed coat, endosperm and embryo
- **Fruit** is a ripened ovary, flower or inflorescence

### For Further Reading



## References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2010—onwards. Mode of access: [http://ashipunov.info/shipunov/school/biol\\_154](http://ashipunov.info/shipunov/school/biol_154)
- [2] Th. L. Rost, M. G. Barbour, C. R. Stocking, T. M. Murphy. *Plant Biology*. 2nd edition. Thomson Brooks/Cole, 2006. *Chapter 14*.

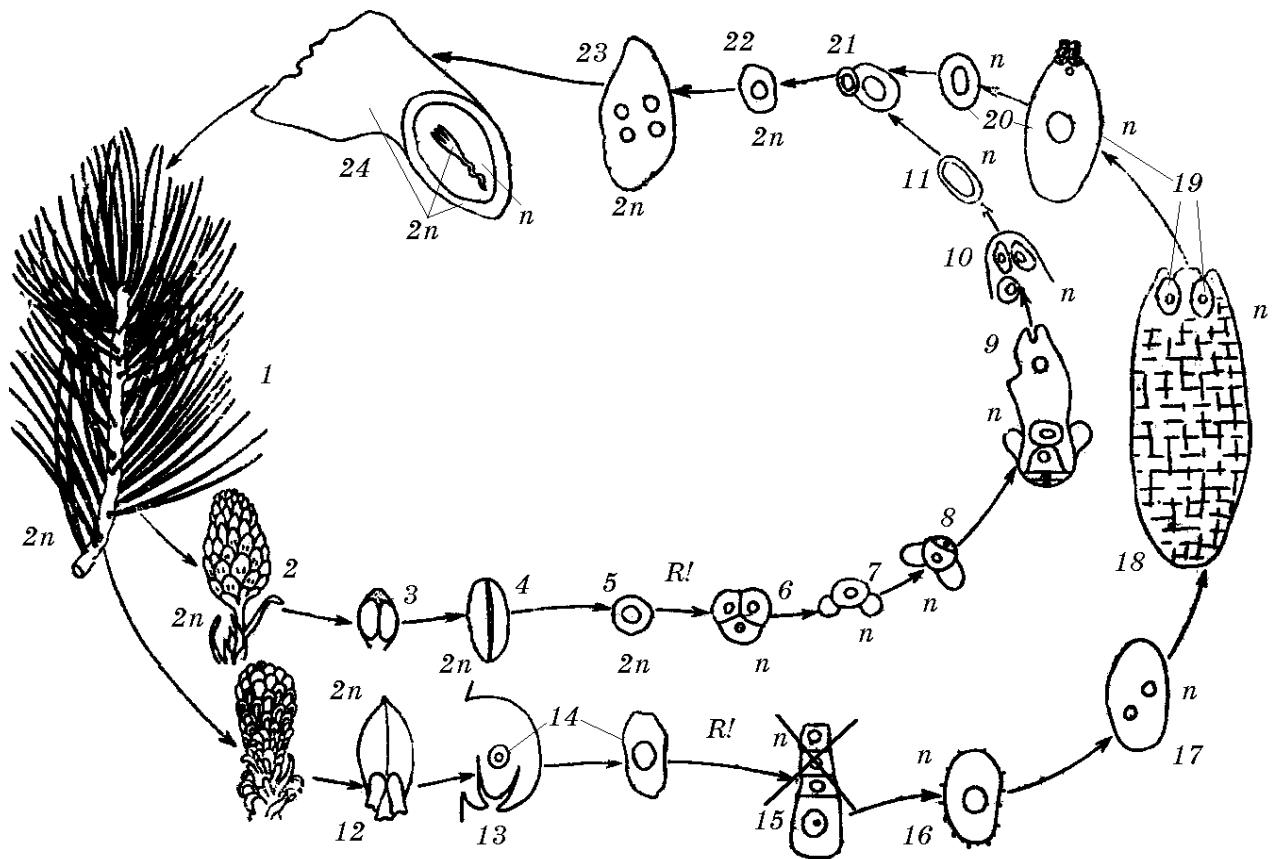
# Example questions for the exam

Start time \_\_\_\_\_

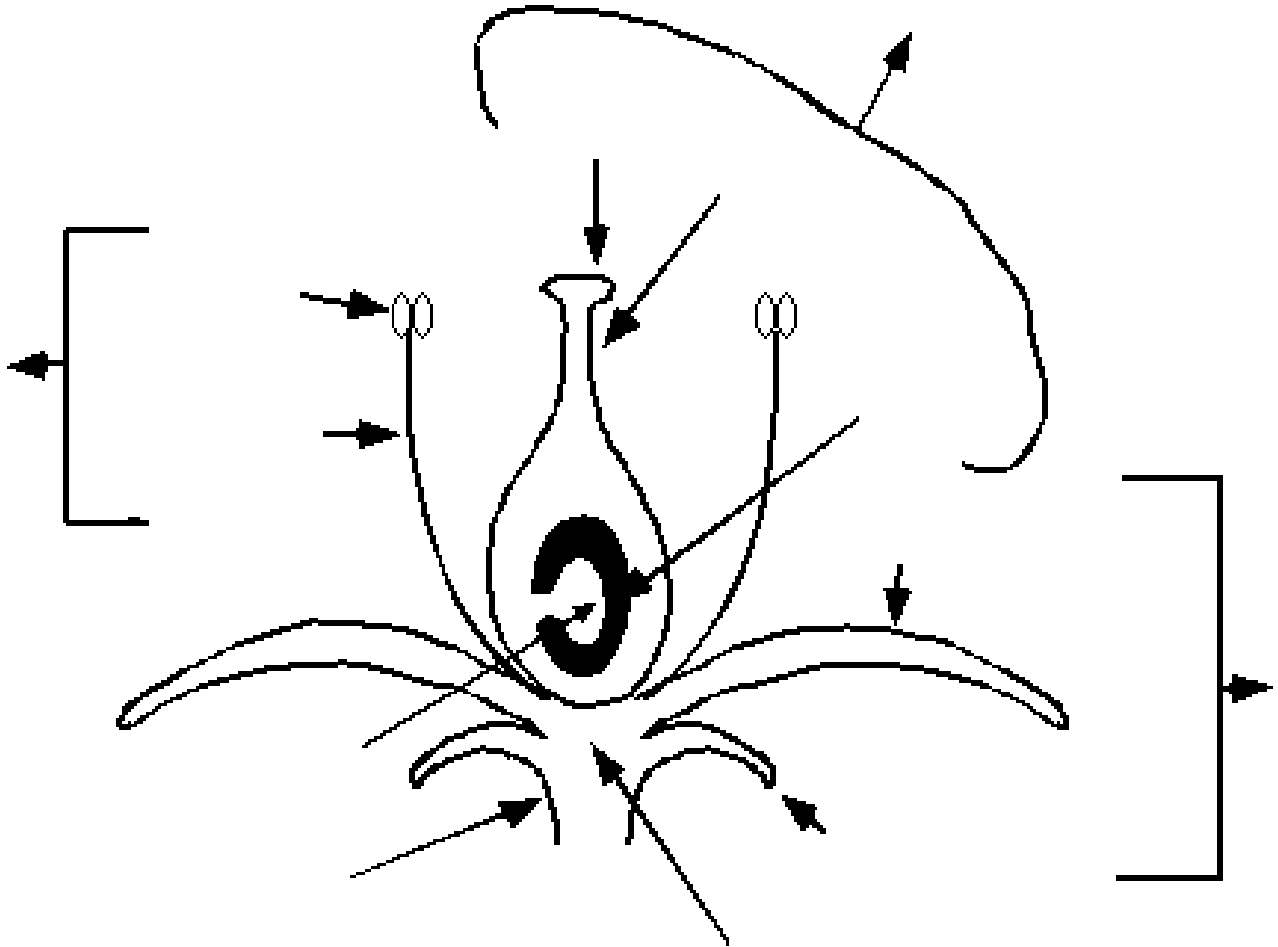
End time \_\_\_\_\_

## 28 Short answers

1. Label the life cycle below (*every correct label = 1 point, you may provide own labels*):



2. Label all arrows on the picture (*every correct label = 1 point, you may provide own labels*):



## 29 Multiple choice

Every question in this section costs either 1 or 0. Please **mark** the appropriate answer on the **scantron**.

- |   |  |
|---|--|
| <p>1. One of the four plants below is a root crop. Find it.</p> <ul style="list-style-type: none"> <li>(a) cauliflower</li> <li>(b) potatoes</li> <li>(c) orange</li> <li>(d) radishes</li> </ul> | <ul style="list-style-type: none"> <li>(a) pollination</li> <li>(b) meiosis</li> <li>(c) anchorage</li> </ul>  |
| <p>2. The pericycle:</p> <ul style="list-style-type: none"> <li>(a) presents only in roots</li> <li>(b) sometimes presents in stems</li> <li>(c) both of the above</li> </ul>                     | <p>4. Flowers pollinated by wind should:</p> <ul style="list-style-type: none"> <li>(a) open at nights</li> <li>(b) produce lots of pollen</li> <li>(c) both of above</li> </ul> |
| <p>3. Roots are not involved in the following activities except:</p>  | <p>5. Which is NOT part of a fruit?</p> <ul style="list-style-type: none"> <li>(a) sporogon</li> <li>(b) pericarp</li> <li>(c) endosperm</li> </ul>                              |



- |  |           |
|--|-----------|
| 6. Which of the following is a microsporangium of seed plants? | (b) axis  |
| (a) pollen sac   | (c) ovule |

## Answers

1D, 2C, 3C, 4B, 5A, 6A