# Introduction to Botany. Lectures 33–37

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# Outline



# Outline



# Questions and answers

## Quiz

# Seed plants

## Diversity of seed plants

# Spermatophyta: seed plants

- $\approx$ 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 $\approx$ 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, 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)

# Seed plants

## “Higher” seed plants

# Spermatophyta classes

“Lower”:

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

“Higher”:

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

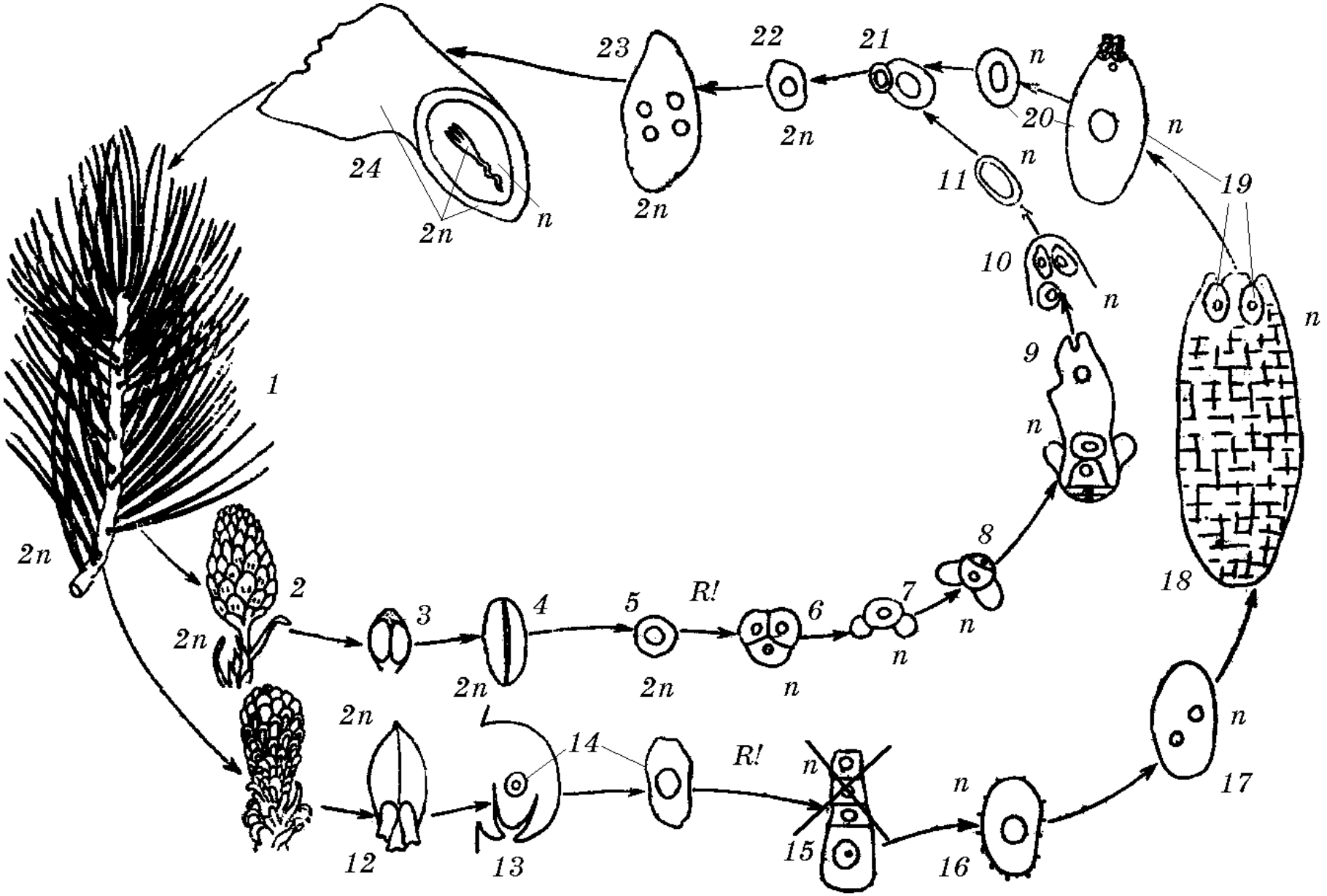
# Seed plants

## Conifers

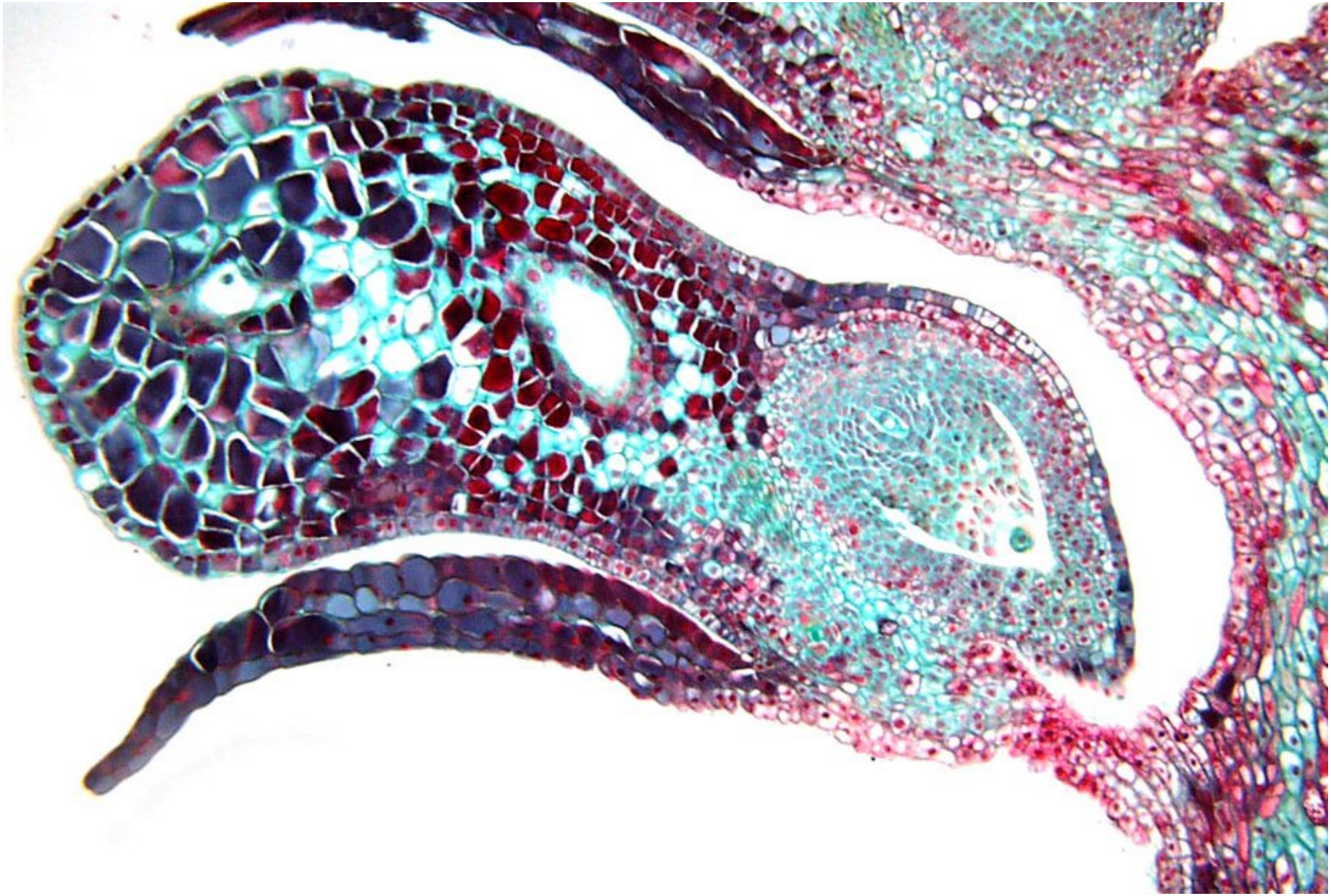
# Pinopsida

- 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 (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

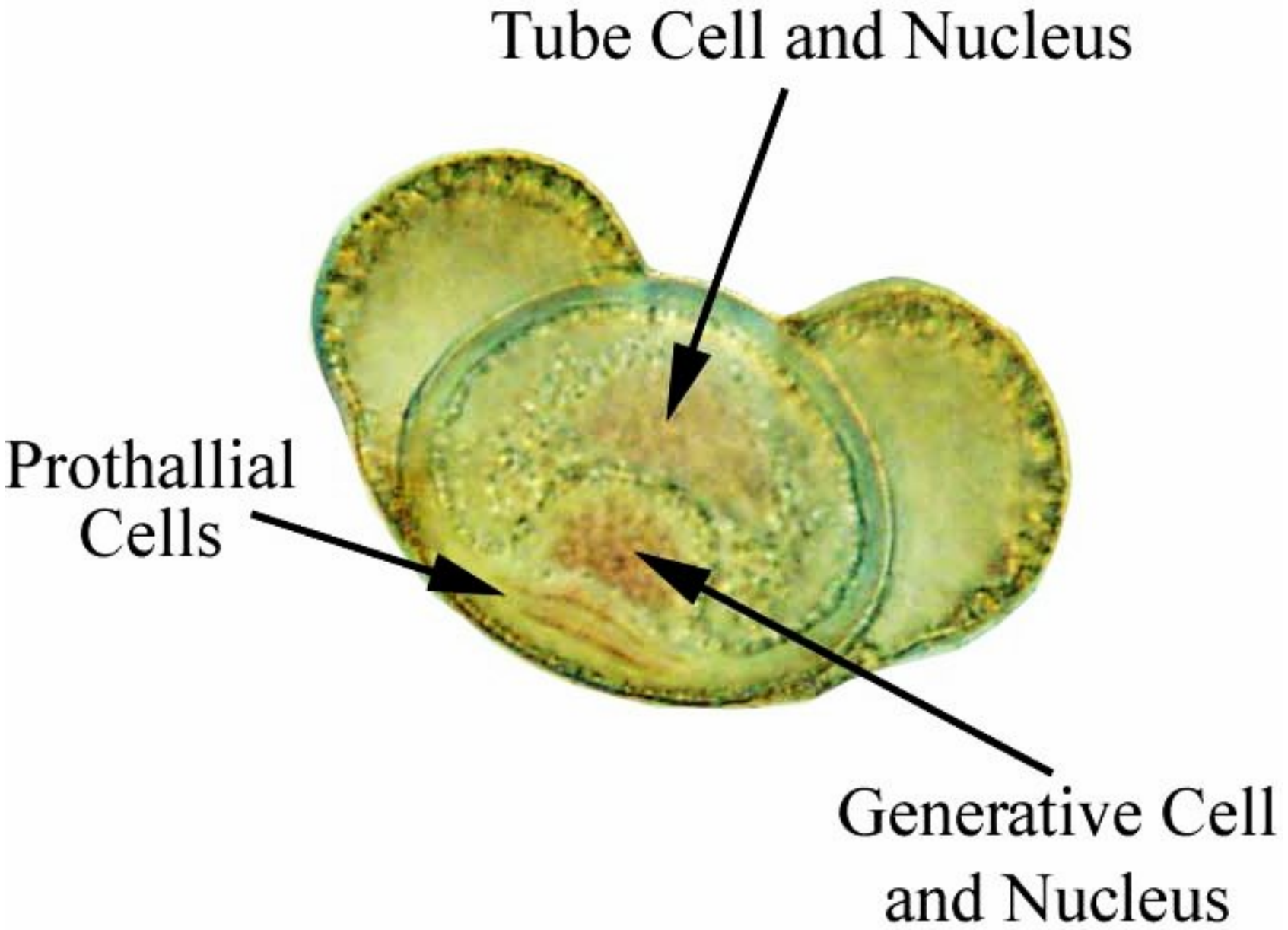
# Life cycle of conifers: another view



# 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

# Seed plants

## 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 ($\text{endosperm}_2$). Also have $\text{endosperm}_1$ (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

# Seed plants

## 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

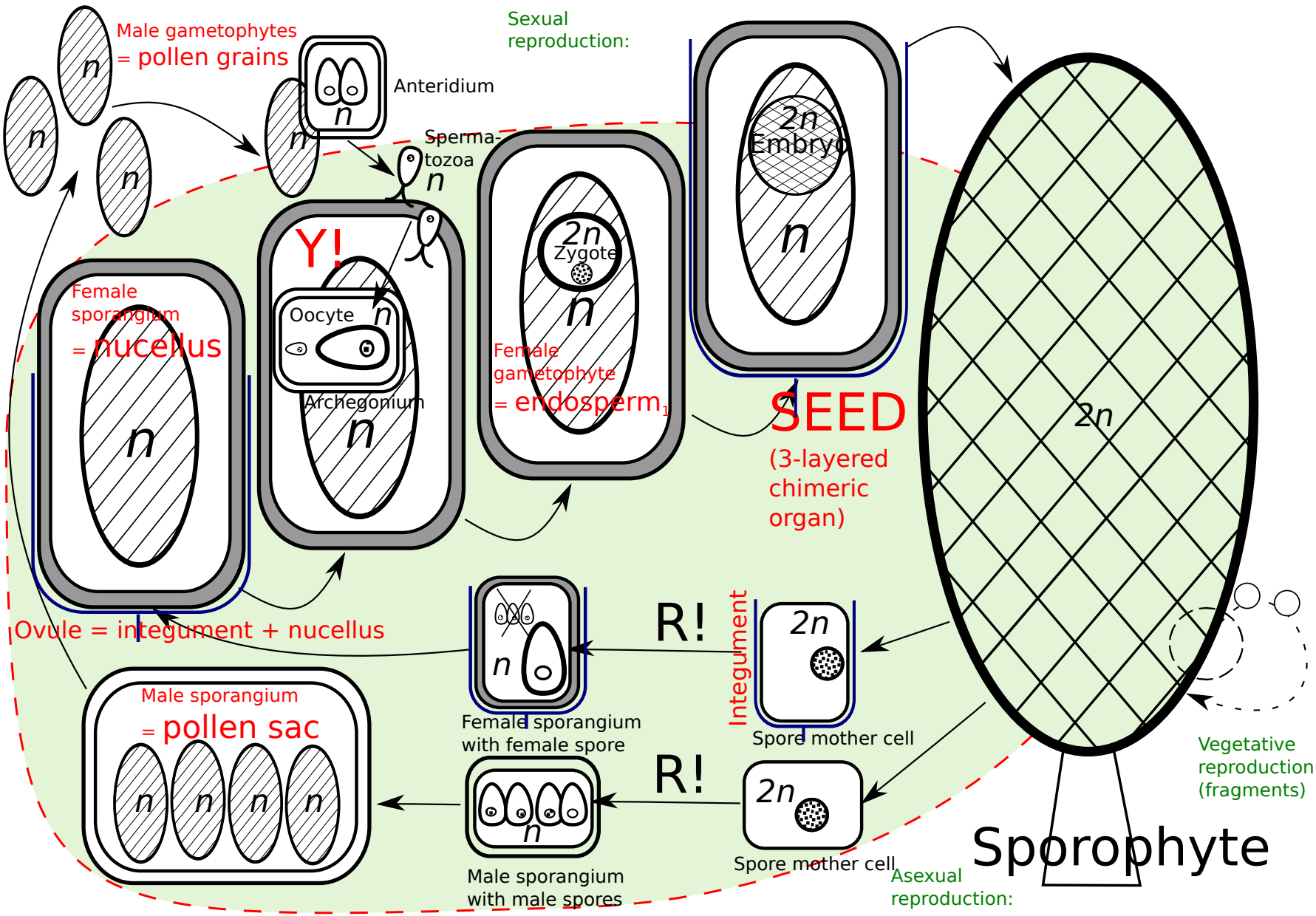
**Note: angiosperms = flowering plants = class Magnoliopsida**

# Life cycle of angiosperms

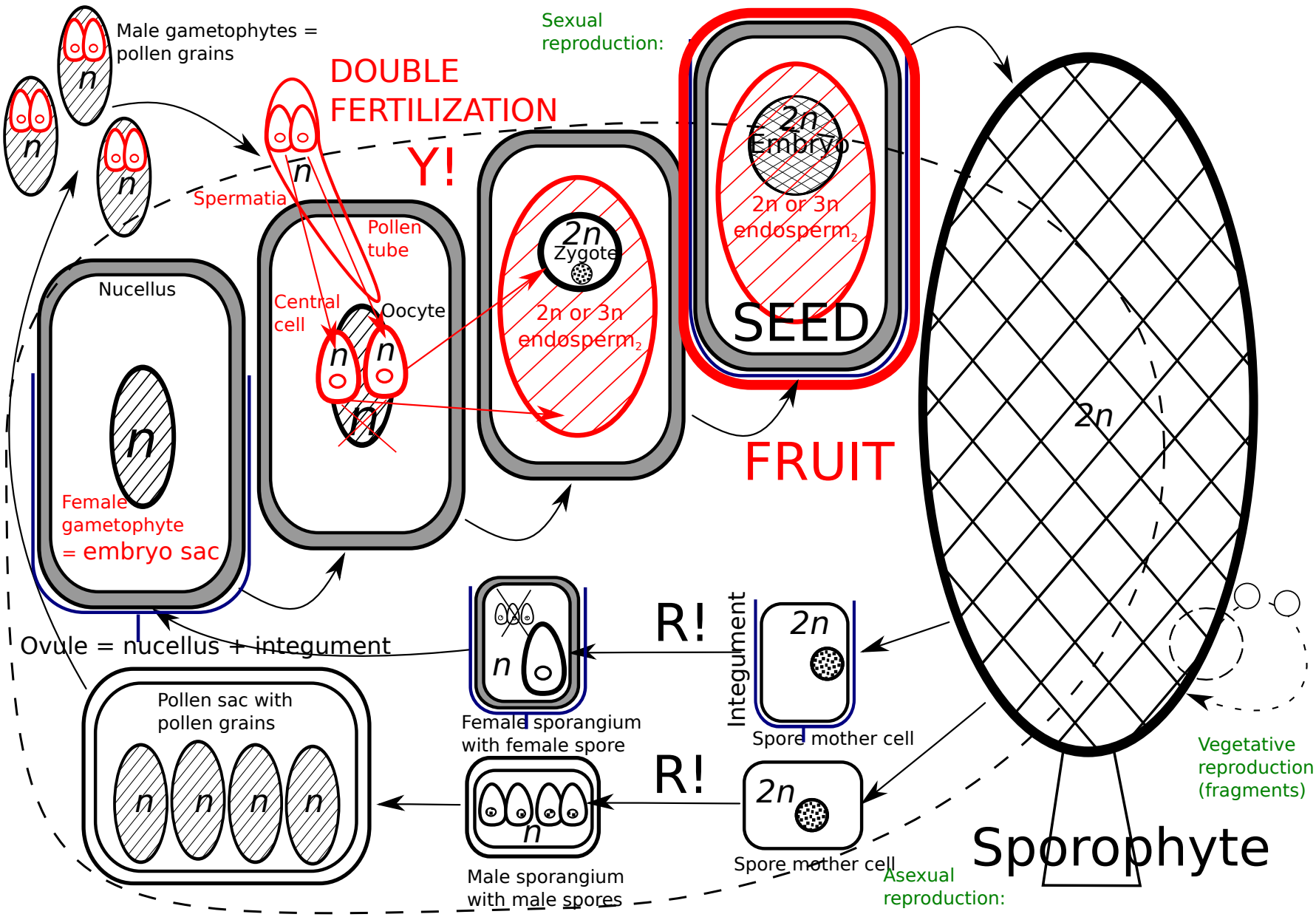
Terms covered:

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

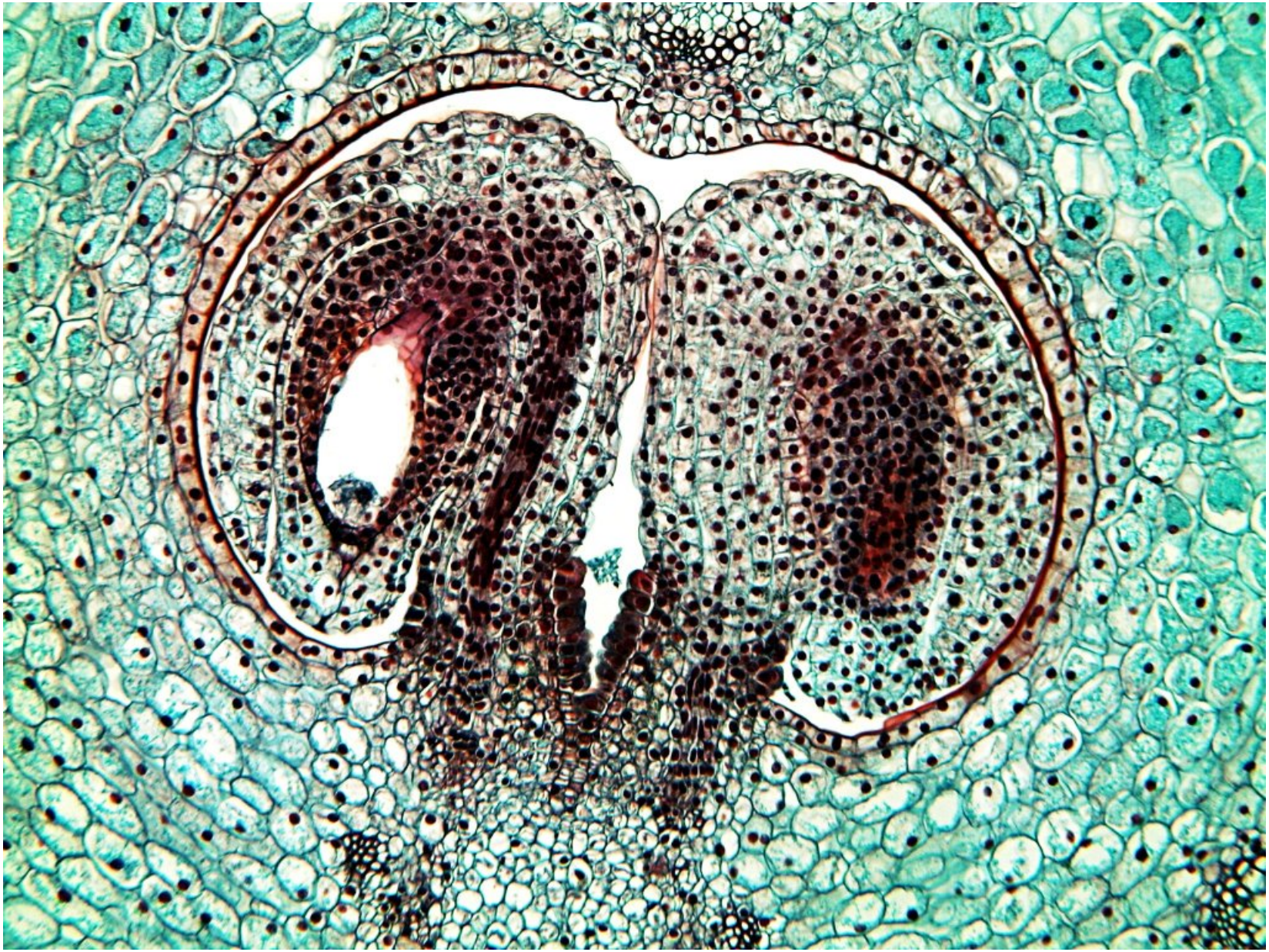
# Life cycle of “gymnosperms”



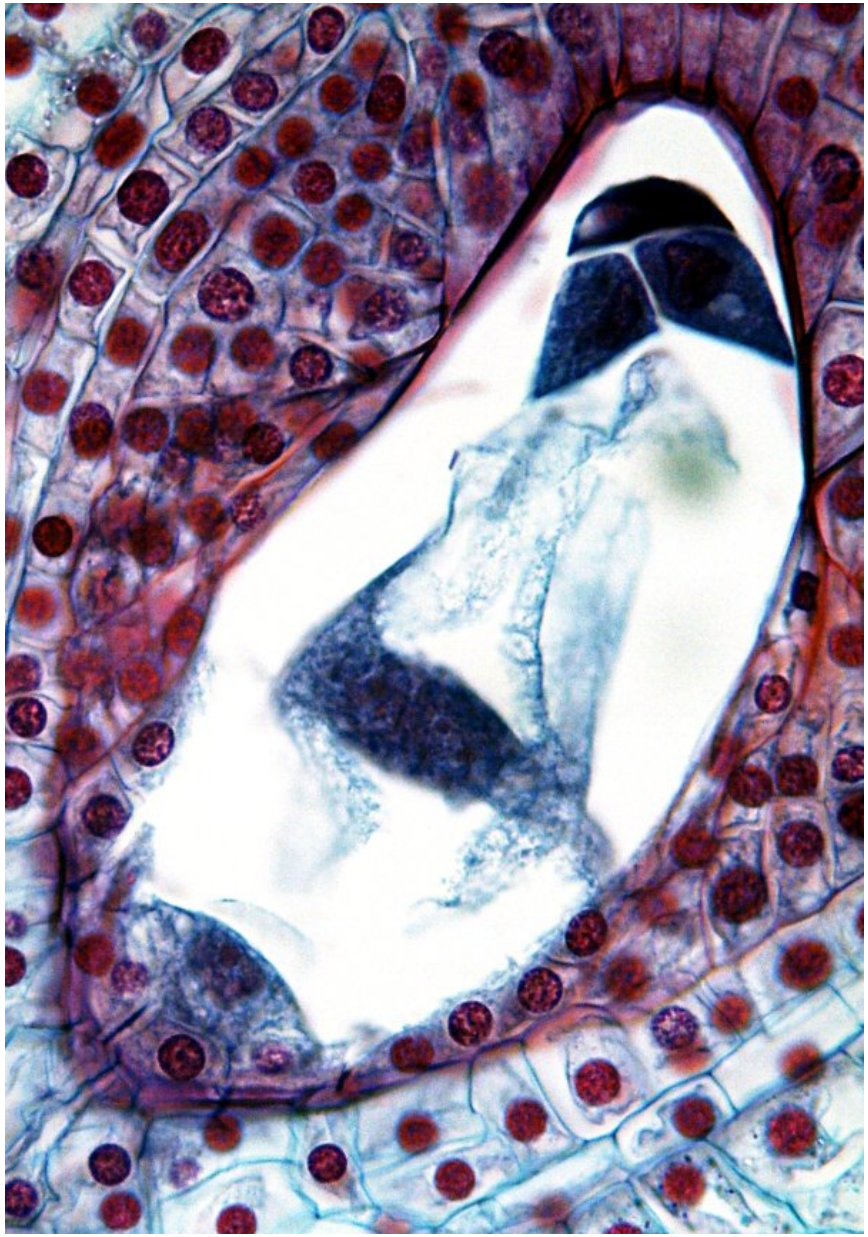
# Life cycle of angiosperms: differences



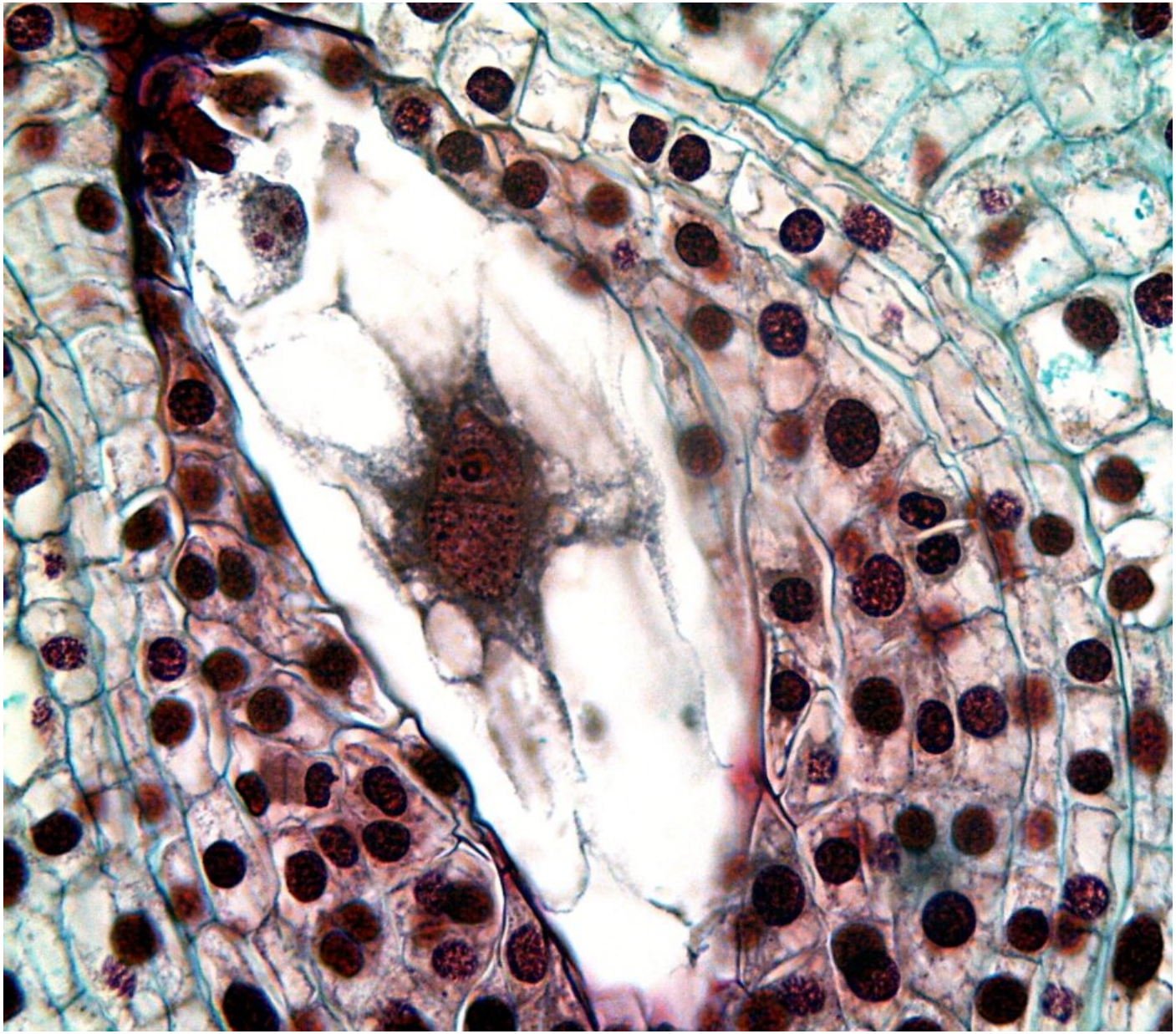
# Ovules (*Lilium* sp., lily)



# Embryo sac (*Lilium* sp., lily)



# Double fertilization (*Lilium* sp., lily)



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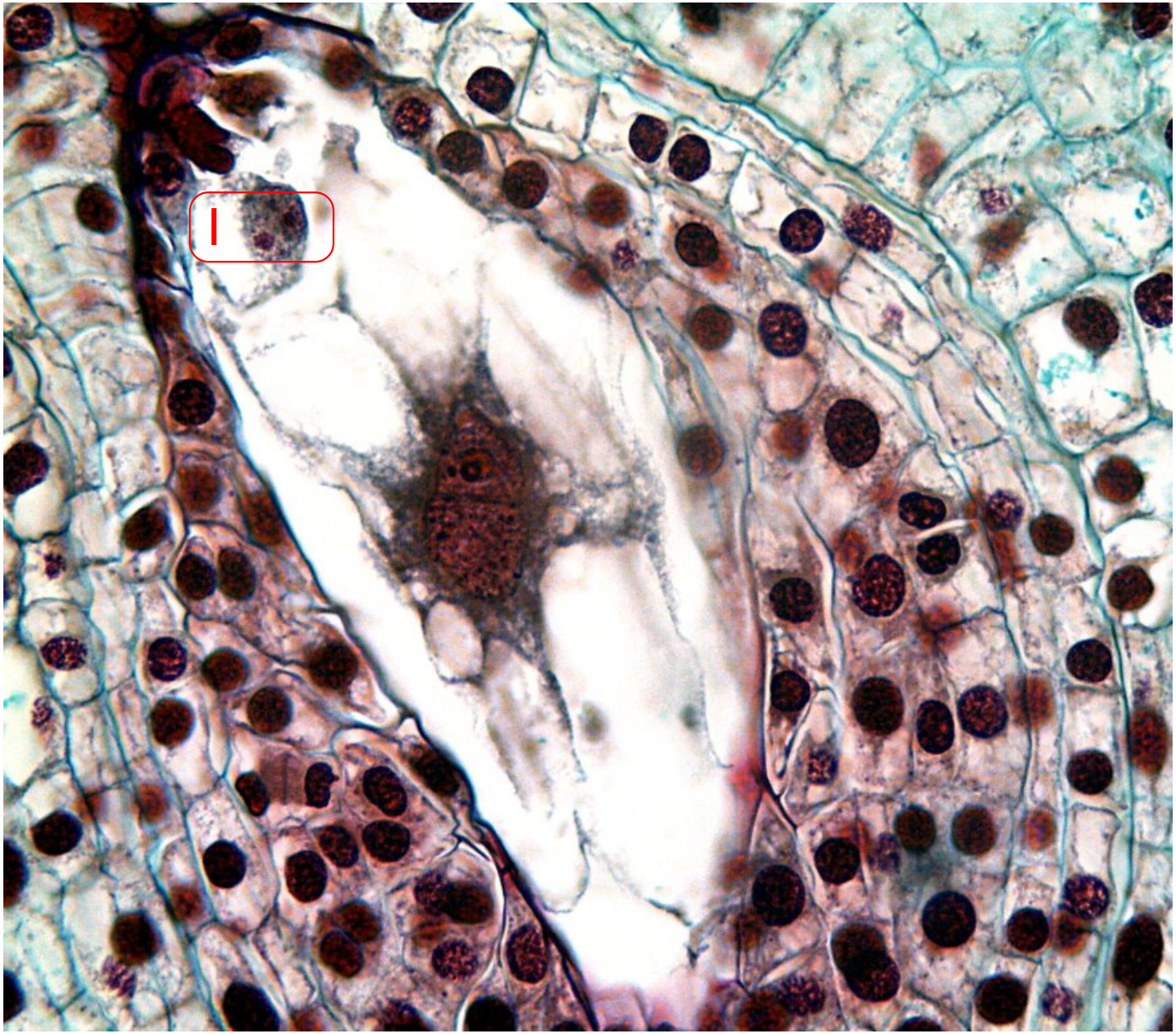

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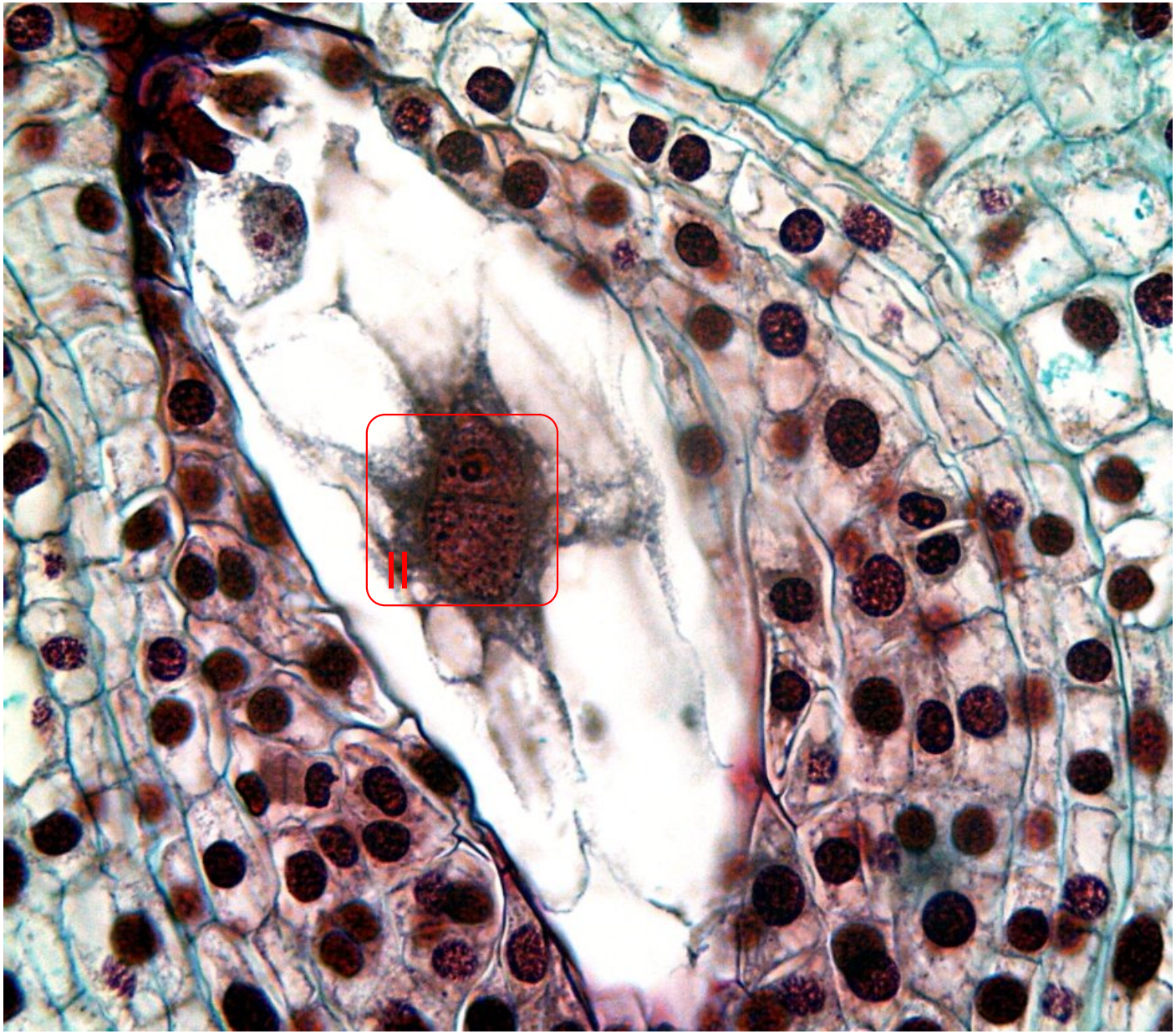
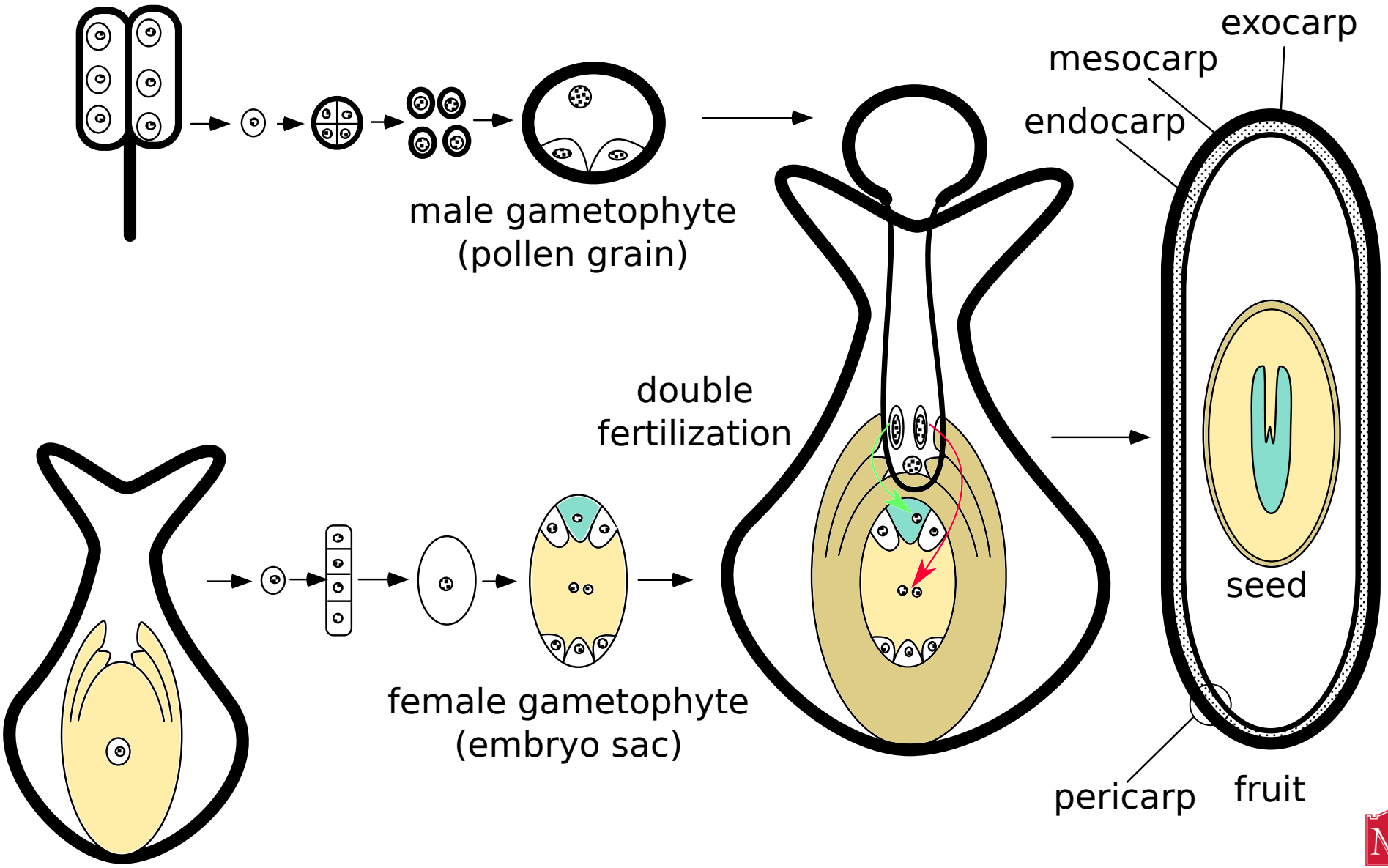
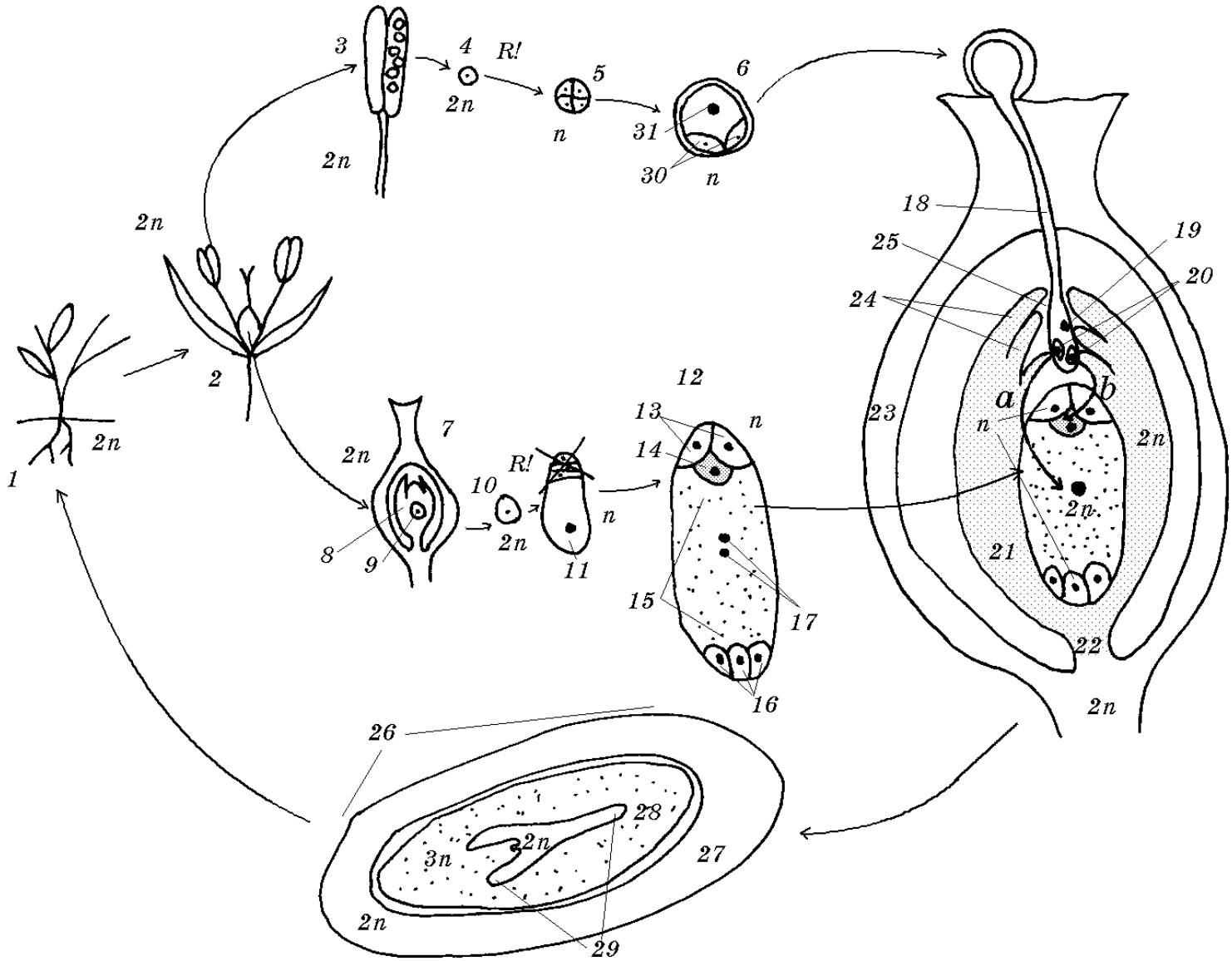


# Angiosperms: relations between structures



# Life cycle of angiosperms: another view



# Seed plants

## 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

# Seed plants

## Flower

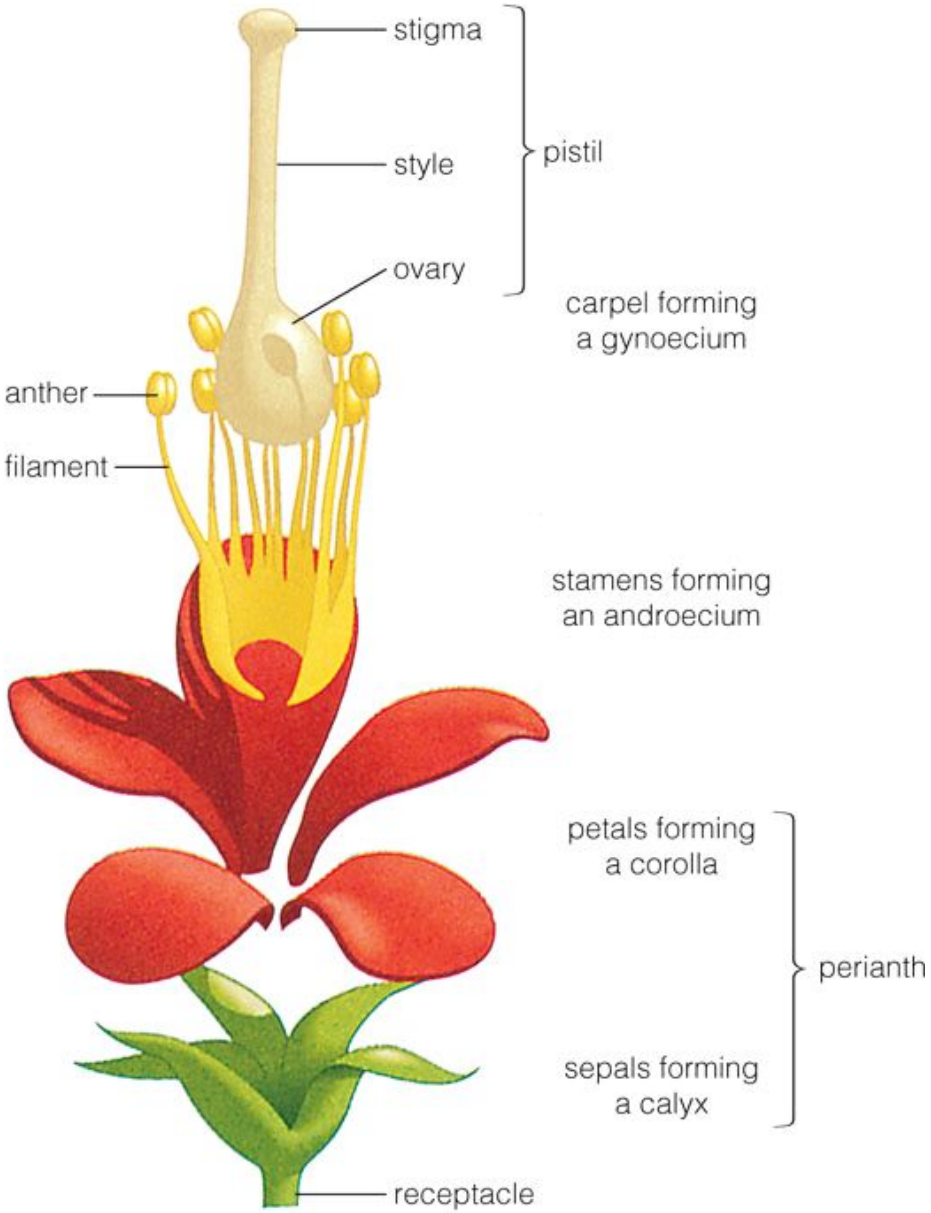
# Definition of flower

- 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

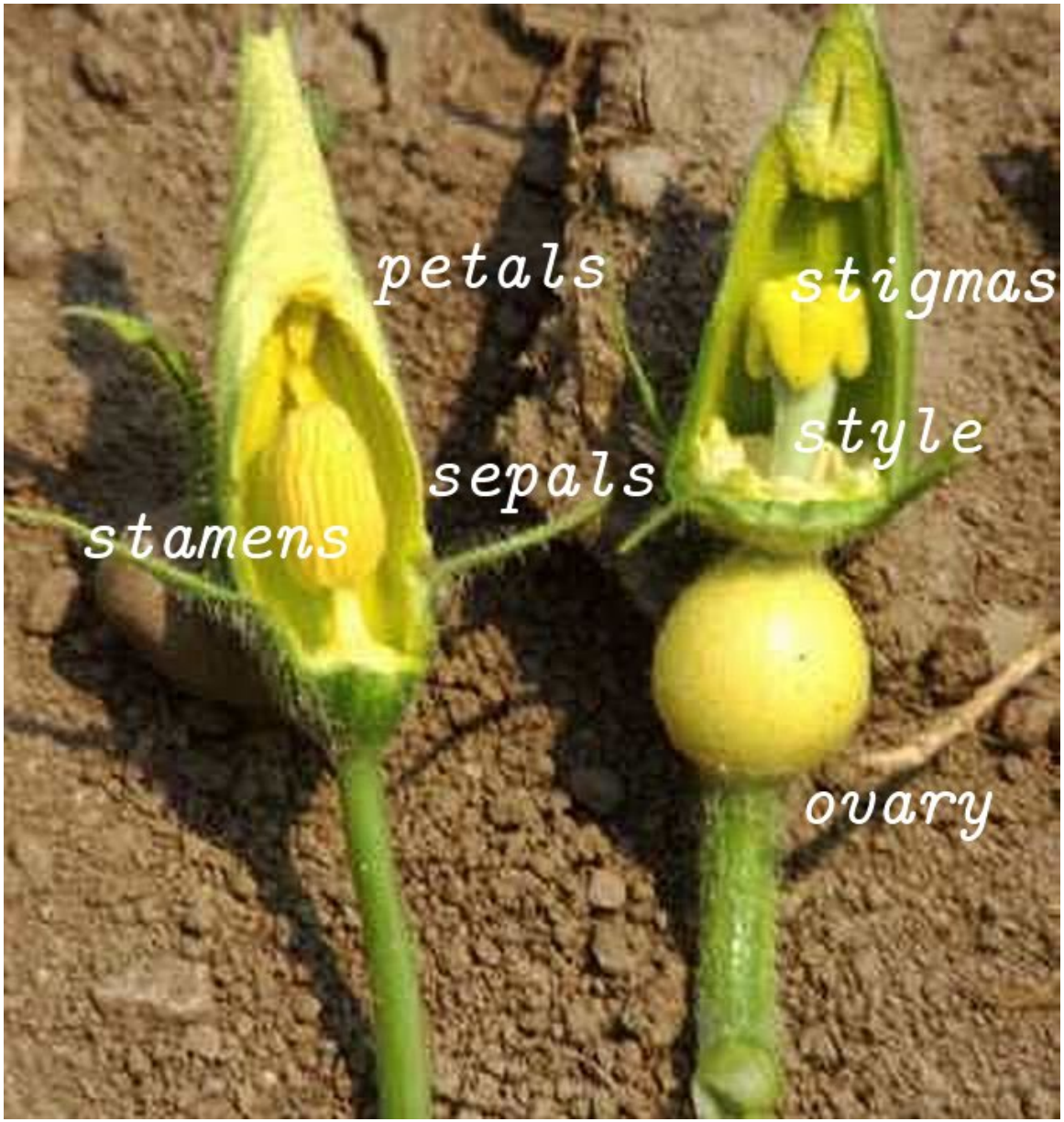
# Structure of flower

- 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



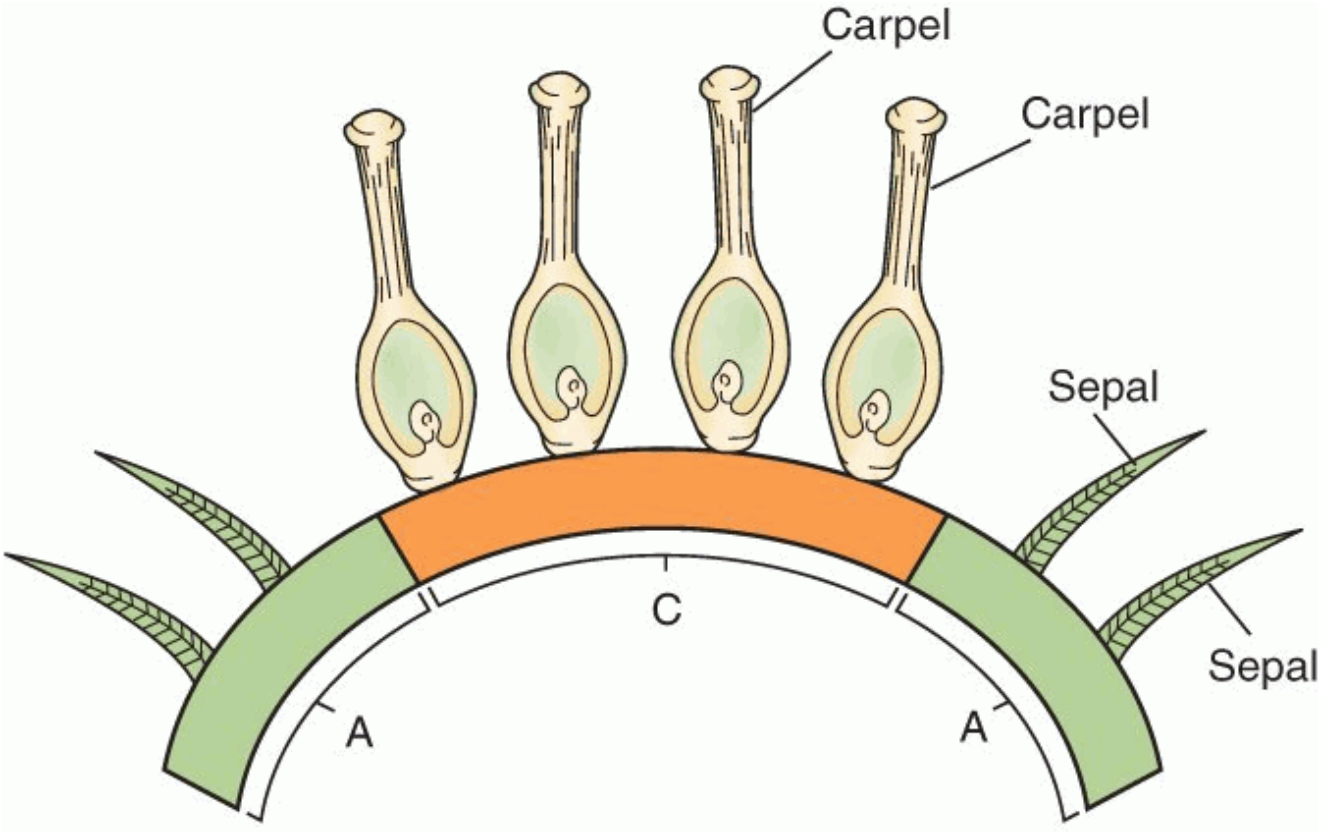
# Seed plants

## Flower development: ABC model

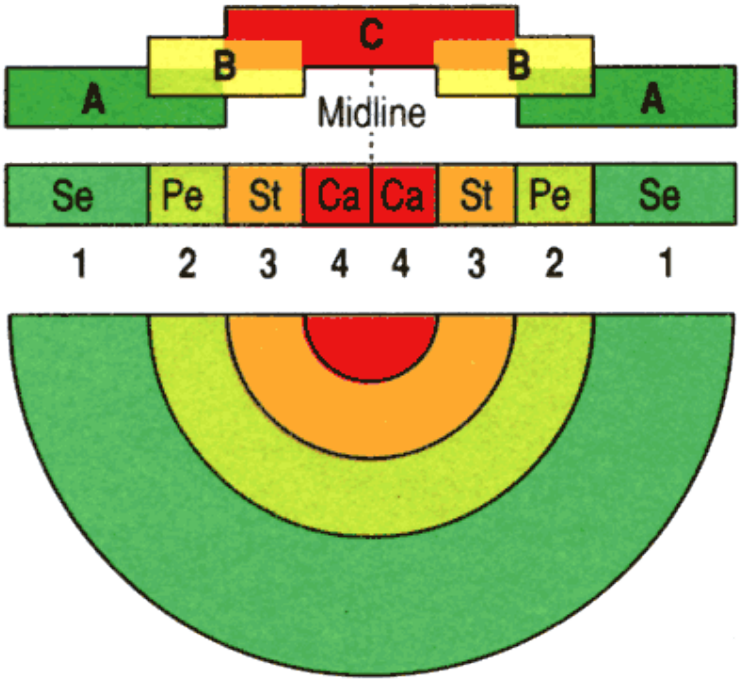
# ABC-genes

- 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 $\rightarrow$ calyx
  - A + B $\rightarrow$ corolla
  - C + B $\rightarrow$ androecium
  - C alone $\rightarrow$ gynoecium

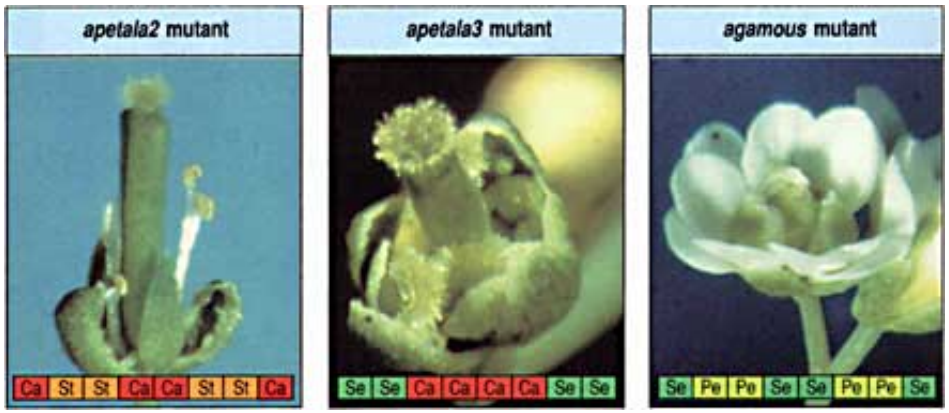
# A and C genes “make” sepals and pistils



# B genes “transform” them into petals and stamens




Corresponding *Arabidopsis* mutants:



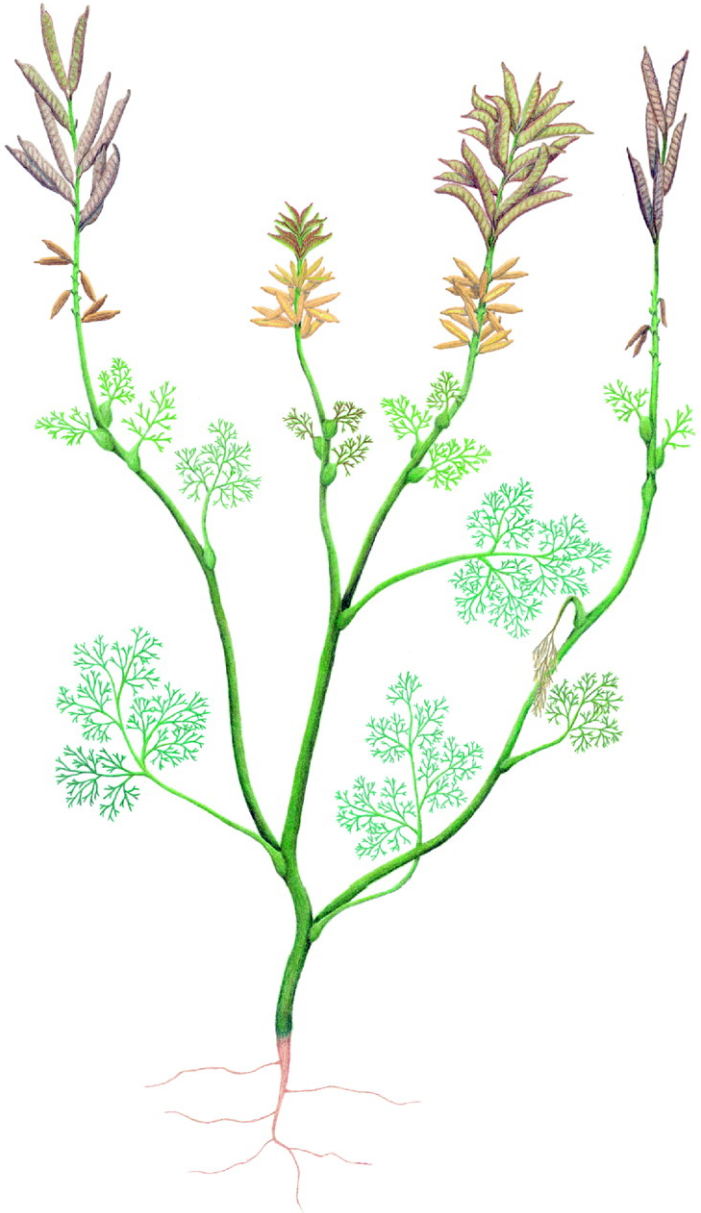
# Seed plants

## Primitive flowers

# *Archaefructus*

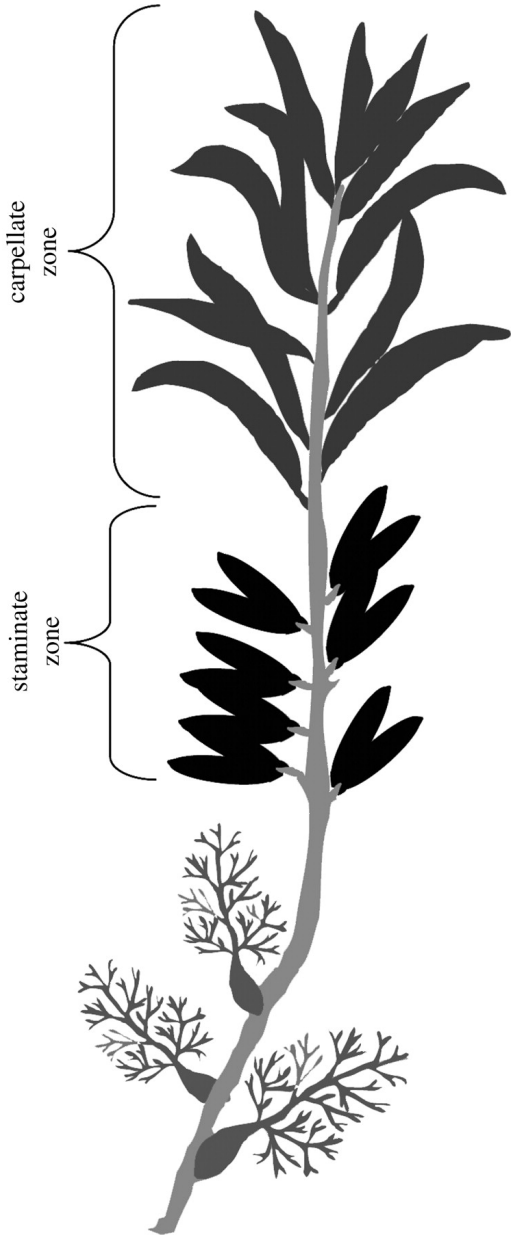
- Fossil water plant from lower Cretaceous of China
- Very primitive fructifications which are not yet compacted in flower
- Multiple free carpels, paired stamens

# *Archaefructus* reconstruction



# *Archaefructus* reconstruction, 3D

# *Archaefructus*, scheme of “flower”



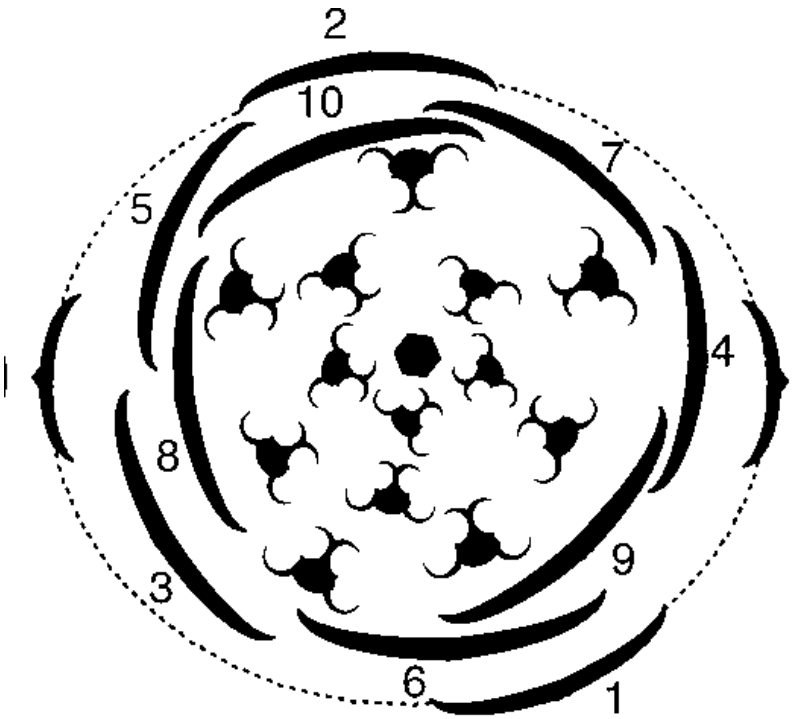
# *Amborella*

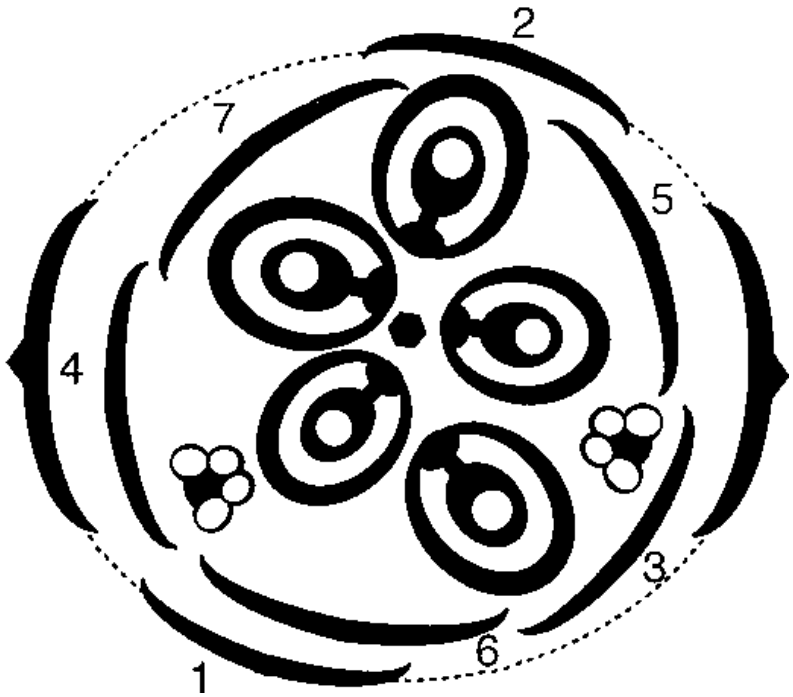
- Small forest shrub of New Caledonia (big island in Pacific ocean)
- Have irregular flowers, stylar canal, unusual embryo sac (5 cells)

# *Amborella*, branch with male flowers

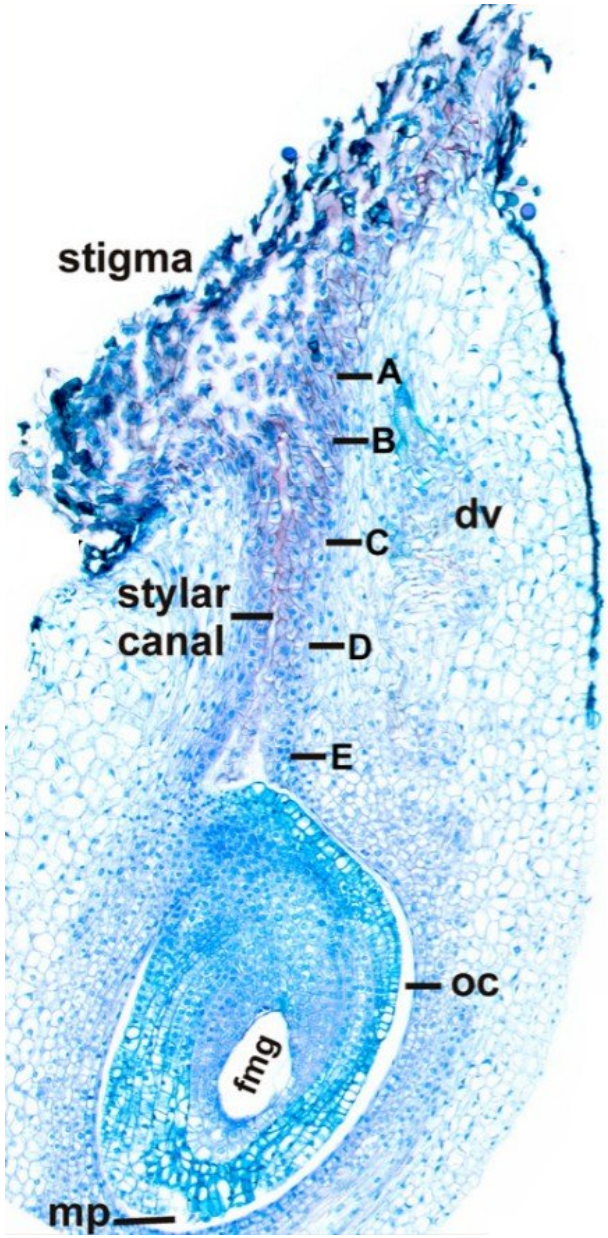
# *Amborella*, male and female flowers


# *Amborella*, diagrams of male and female flowers



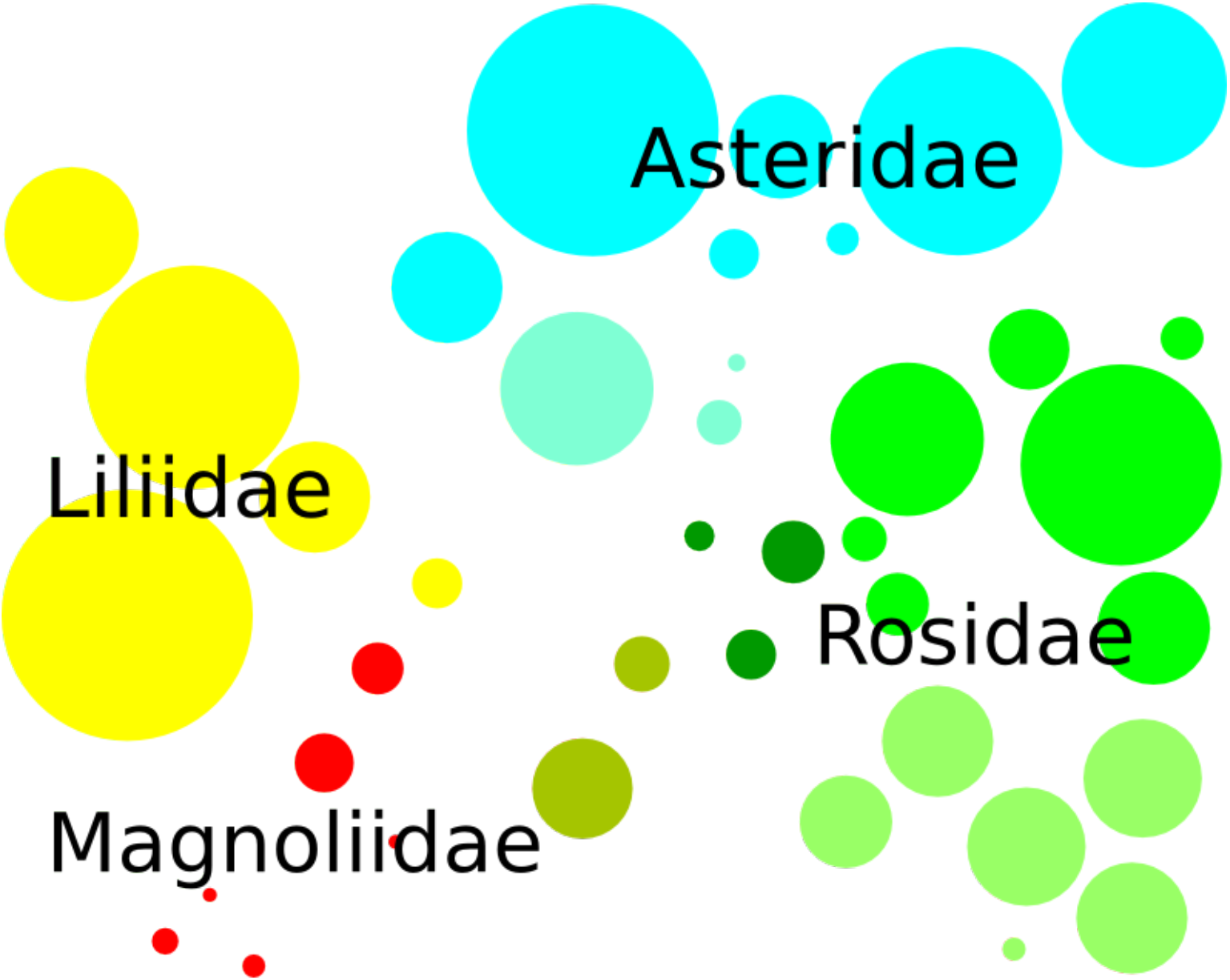
# *Amborella* stylar canal



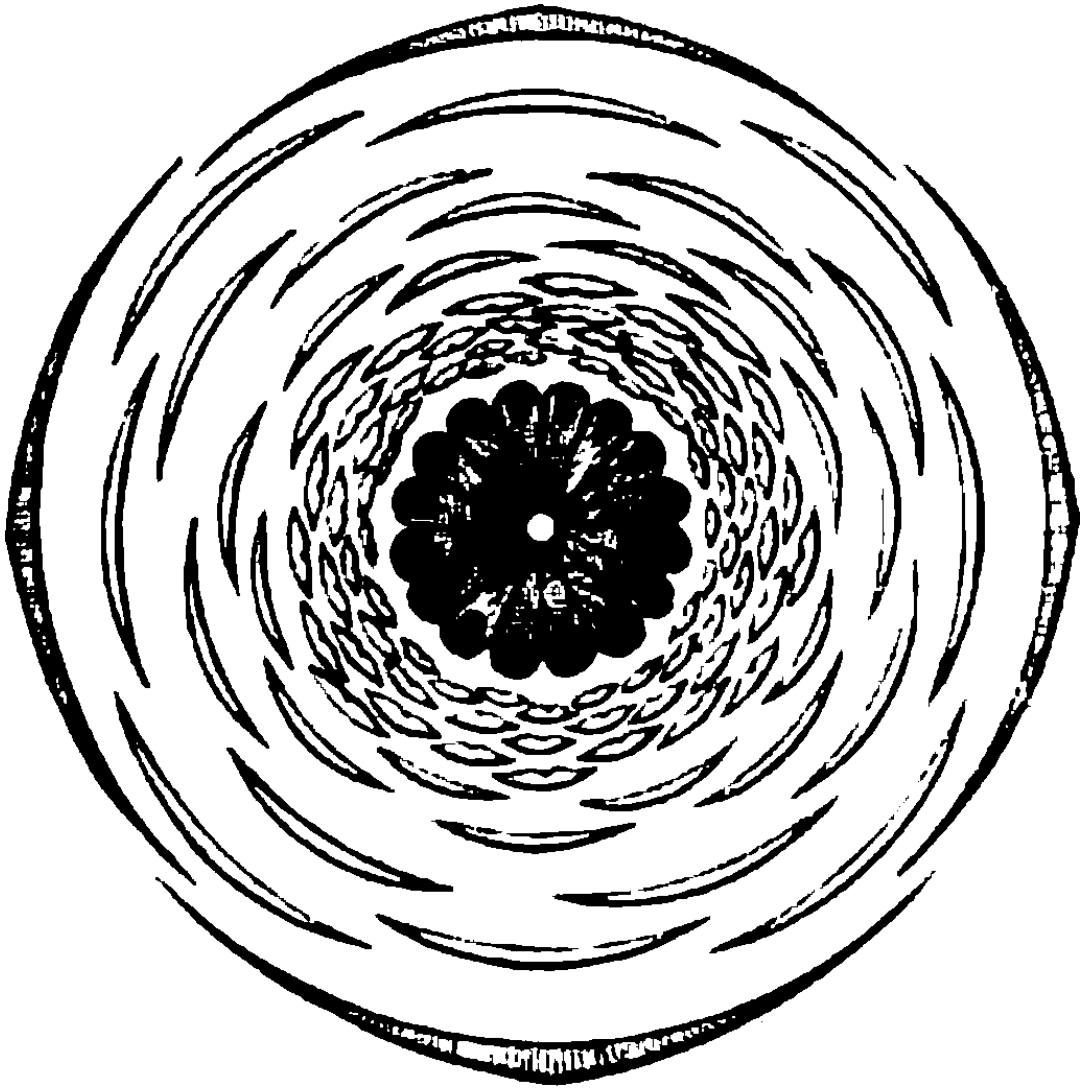
# Seed plants

## Four subclasses of angiosperms

# Angiosperms: subclasses and orders

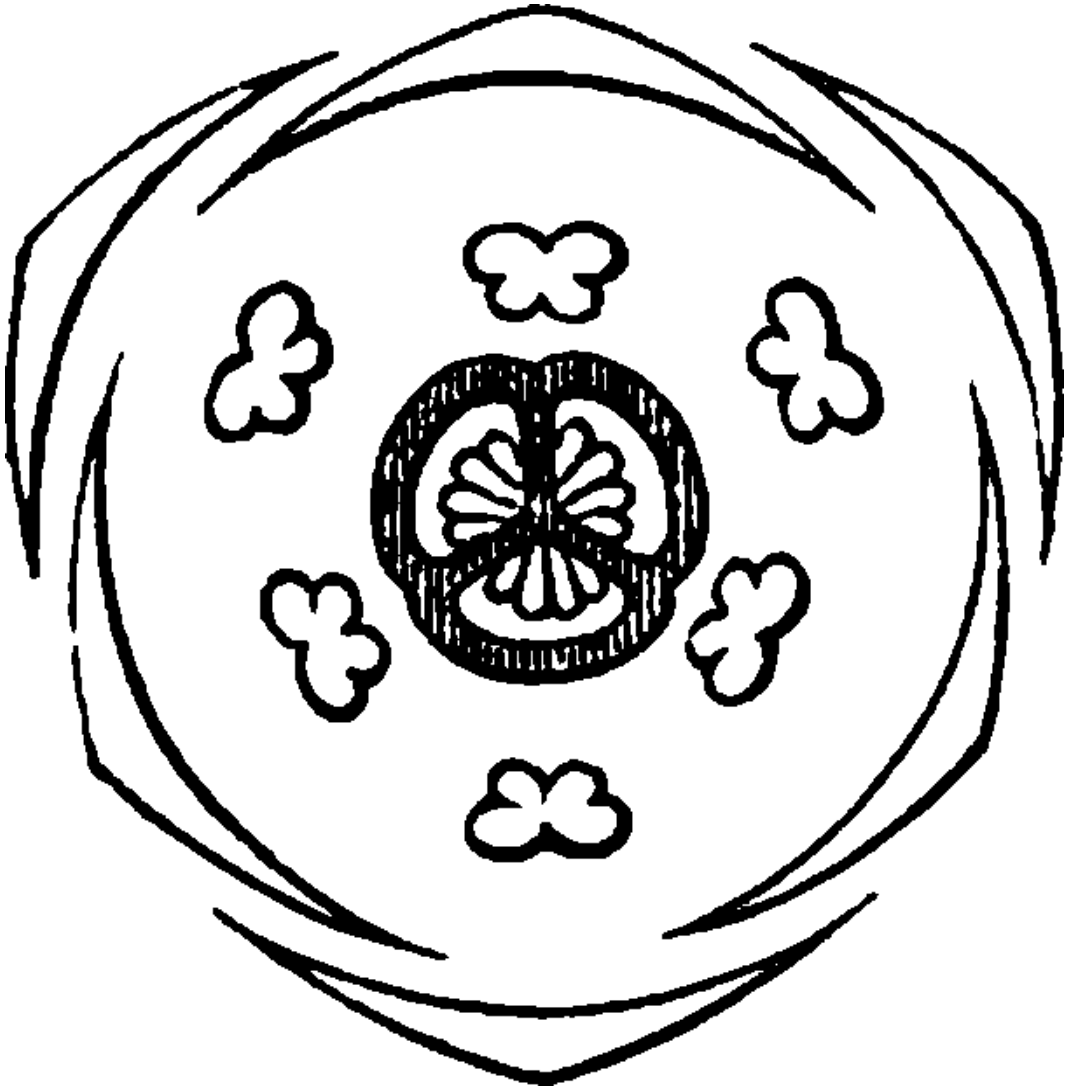


# Magnoliidae portrait



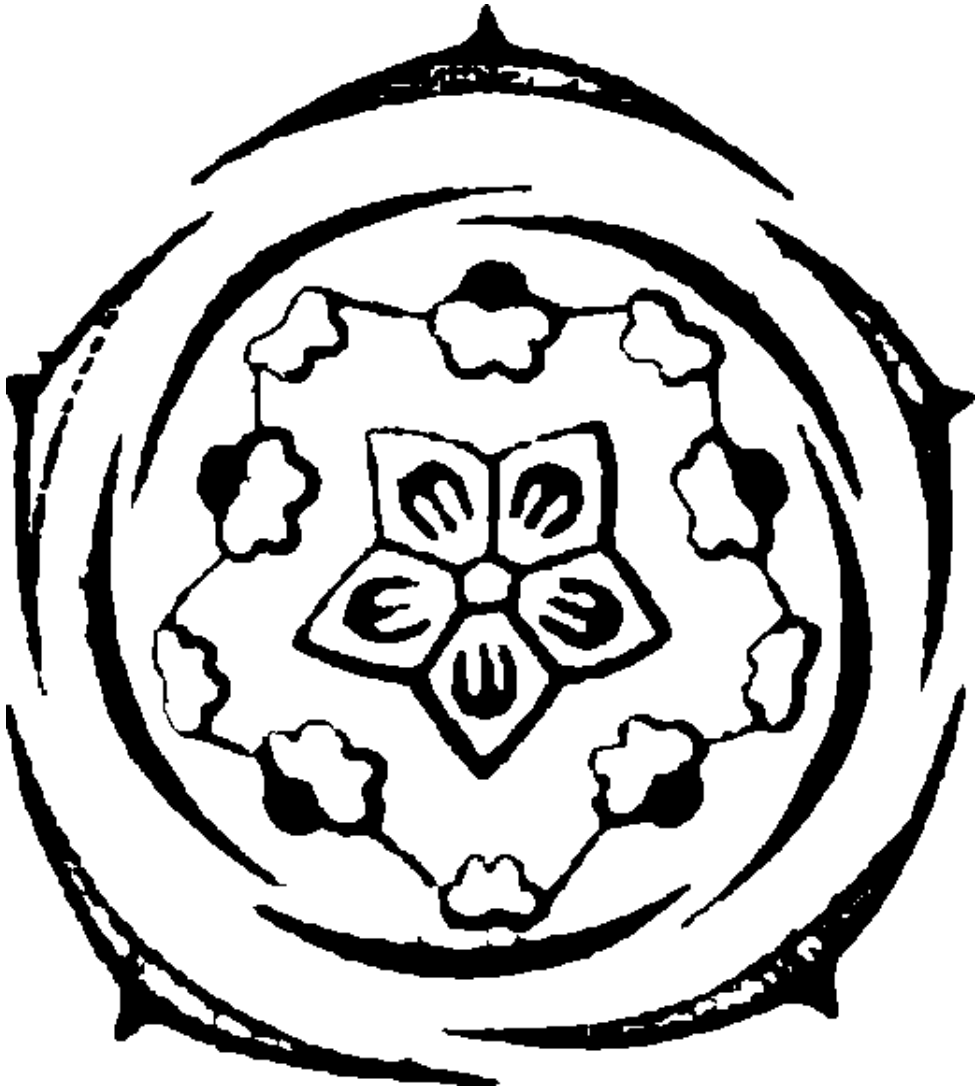
*Nymphaea* sp. (water-lily): multiple, disorganised

# Liliidae portrait



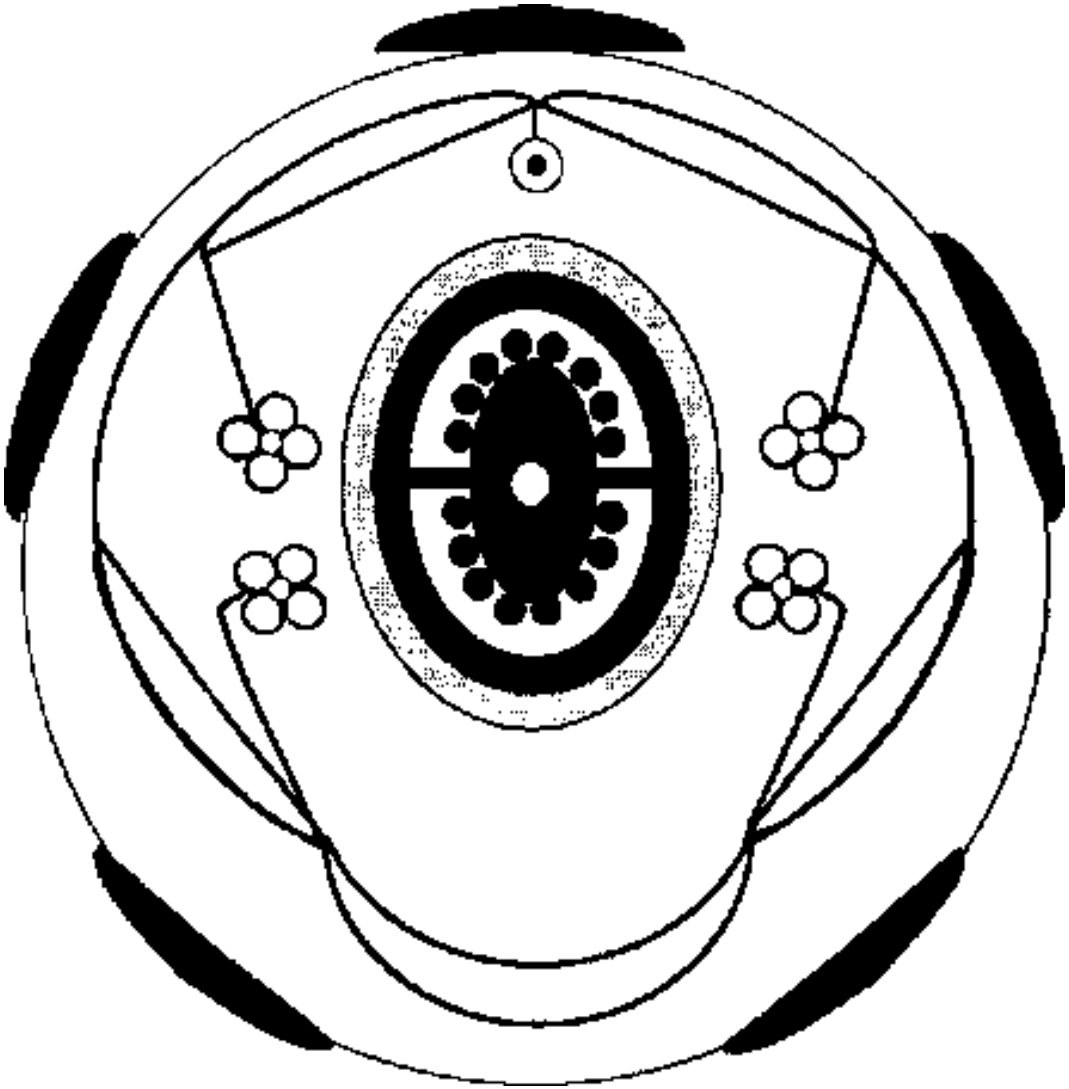
*Acorus calamus* (calamus, or sweet flag): trimerous

# Rosidae portrait



*Geranium* sp.: pentamerous or tetramerous, petals free

# Asteridae portrait



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

# Seed plants

## Pollination

# How to avoid pollination: apomixis

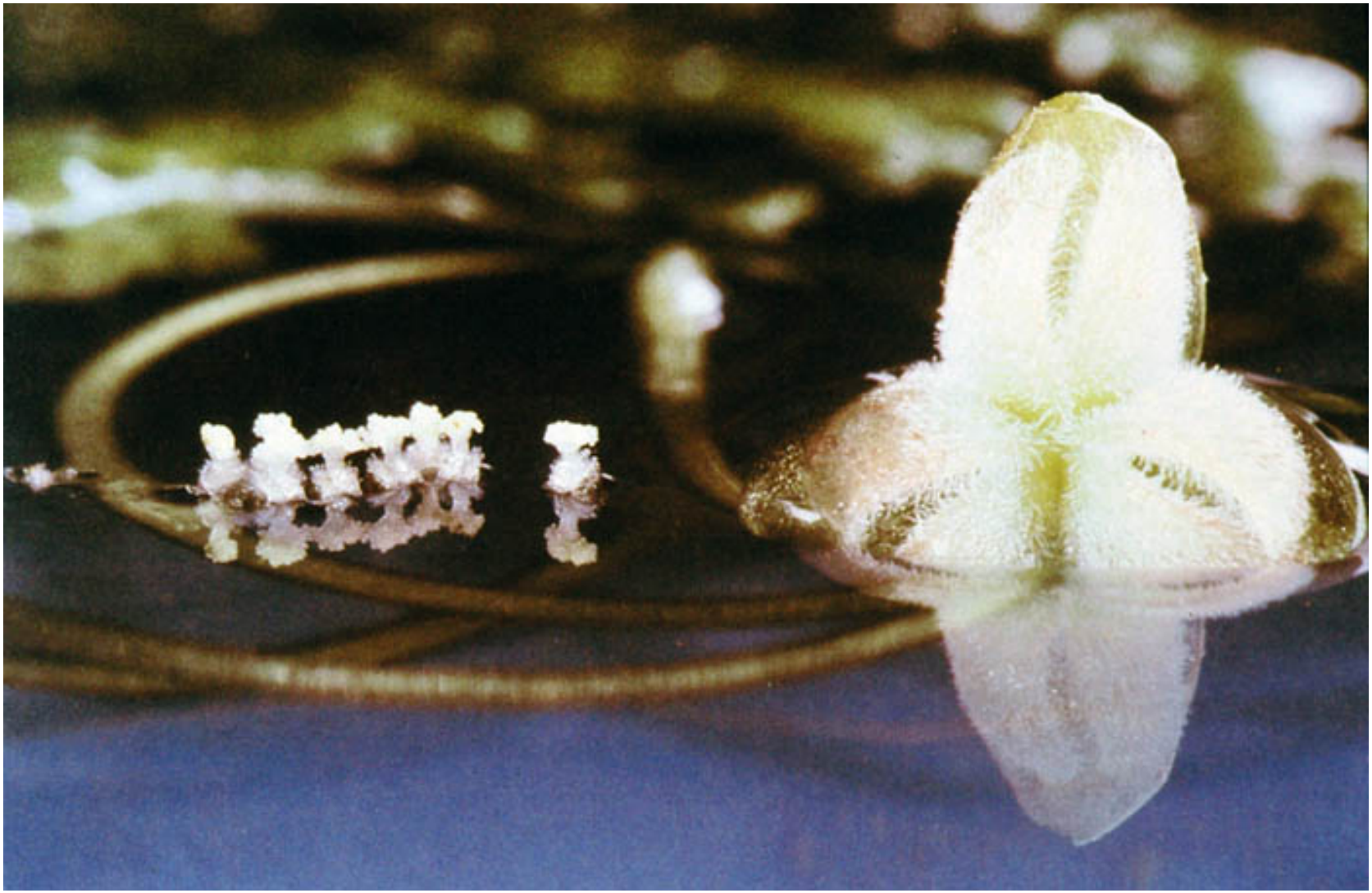
- Apomixis is a reproduction with reproductive organs but without fertilization
- **Apospory**: embryo develops from maternal diploid tissue, without meiosis; here asexual reproduction becomes vegetative
- **Apogamy** (i.e., parthenogenesis): embryo develops from unfertilized gamete after diploidization;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

# Seed plants

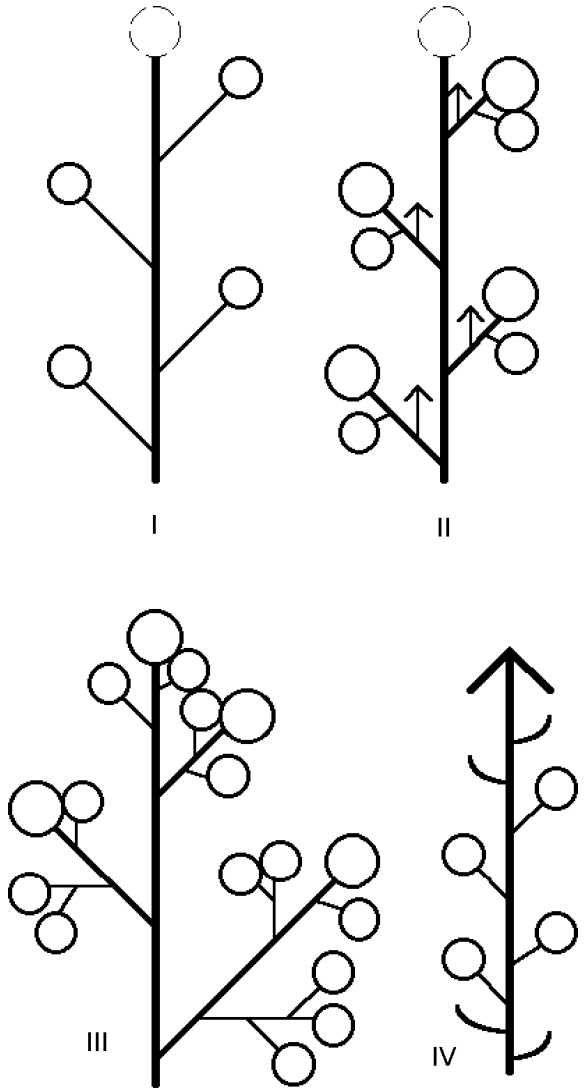
## Inflorescences

# 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



# Seed plants

## Seeds

# Definition

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

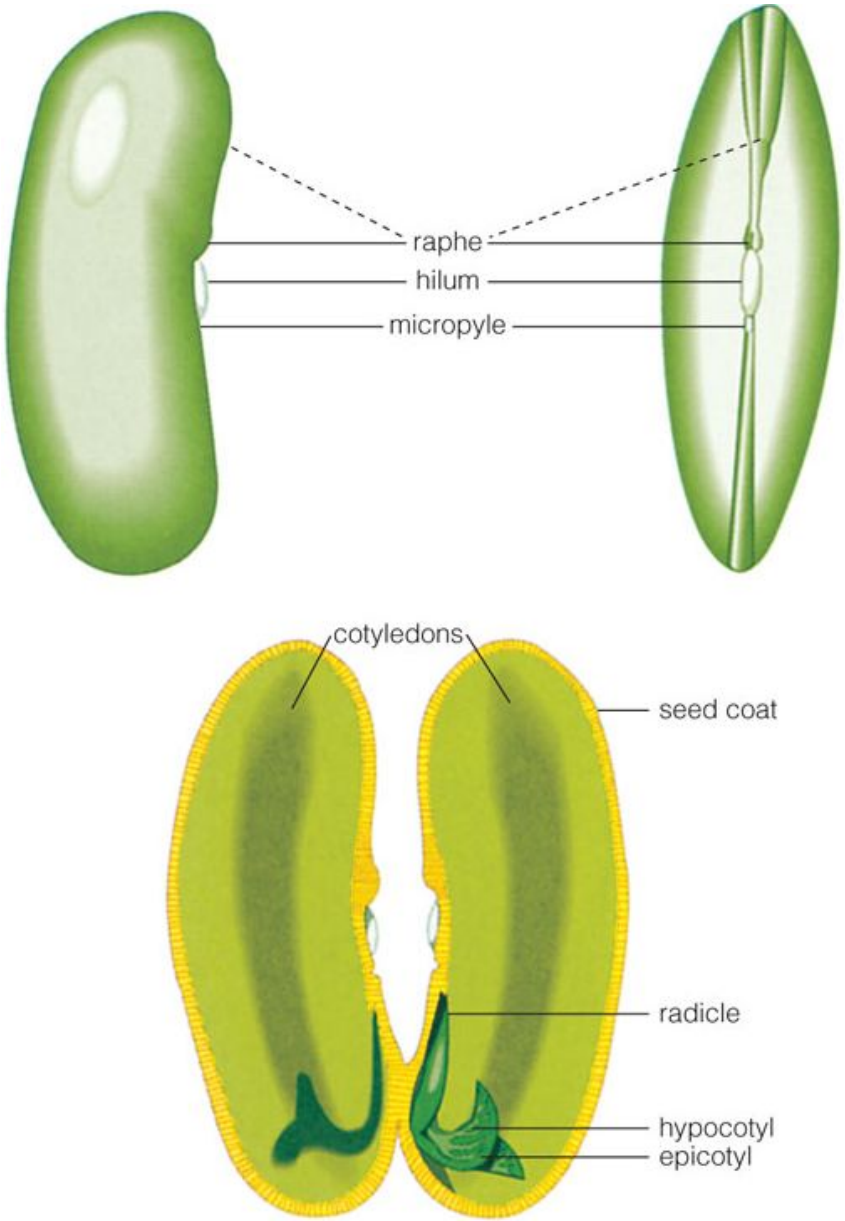
# Origin of seed layers

| Layer | Ploidy | Origin |
|---|---|---|
| Seed coat | $2n$ | Integument of ovule |
| $\text{Endosperm}_2$ | $3n$, sometimes $2n$ | Fertilized central cell of embryo sac |
| Embryo | $2n$ | Fertilized egg |
| $\text{Endosperm}_1$ | $n$ | Female gametophyte (gymnosperms!) |
| Perisperm | $2n$ | Nucellus of ovule |

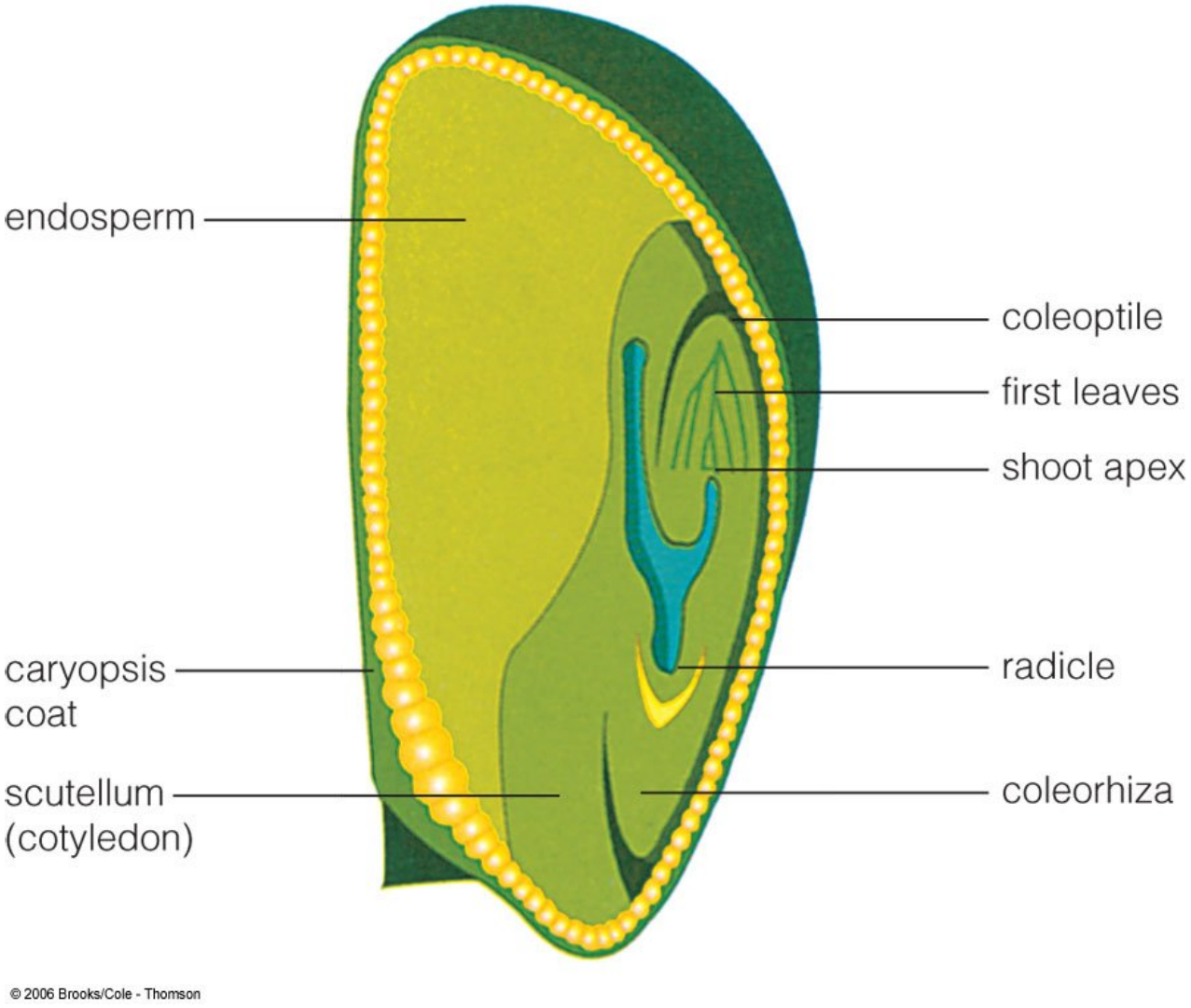
# Seed structure variations

- 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


endosperm
coleoptile
first leaves
shoot apex
caryopsis coat
radicle
scutellum (cotyledon)
coleorhiza
© 2006 Brooks/Cole - Thomson

# Cotyledons

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

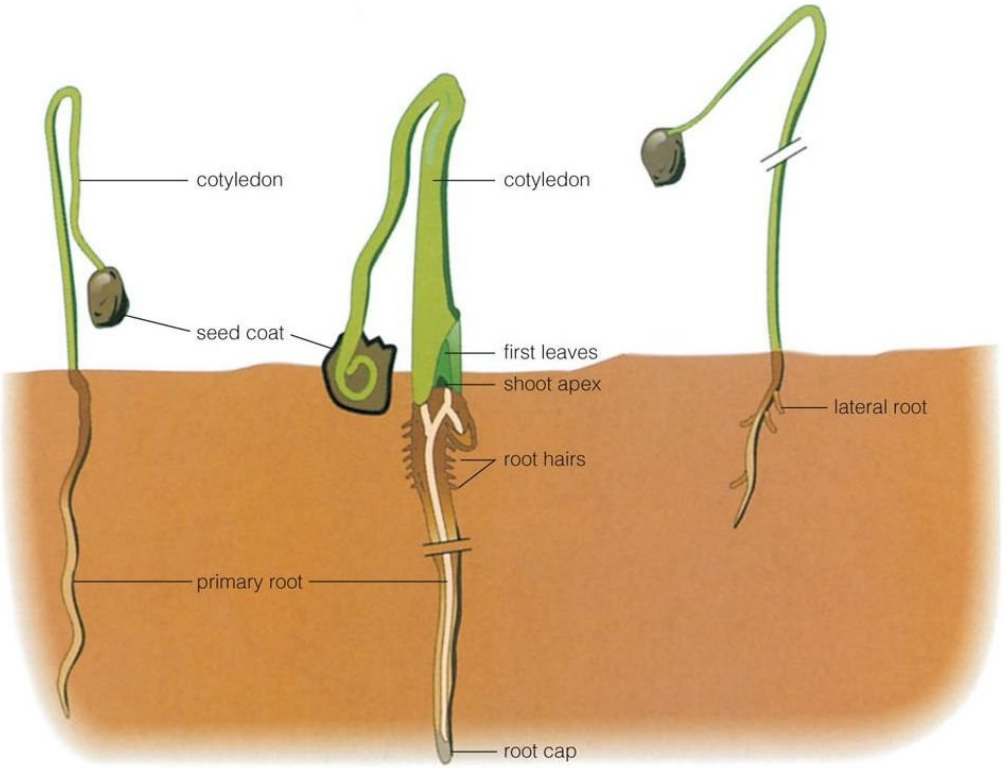
# *Pinus* sp.: multiple cotyledons

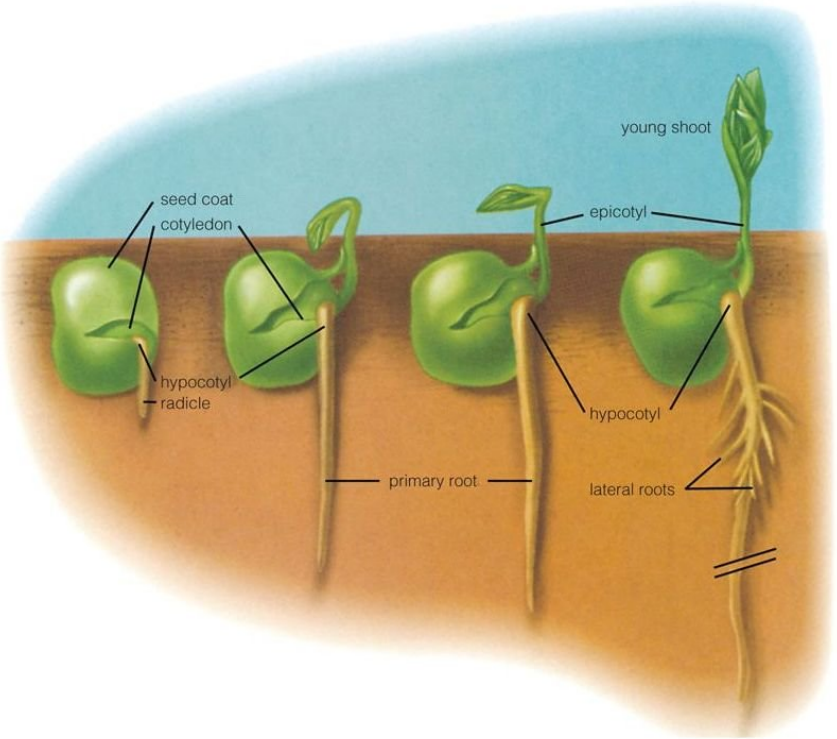
# Germination

- 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



# Seed plants

## Fruits

# Definition and origin

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

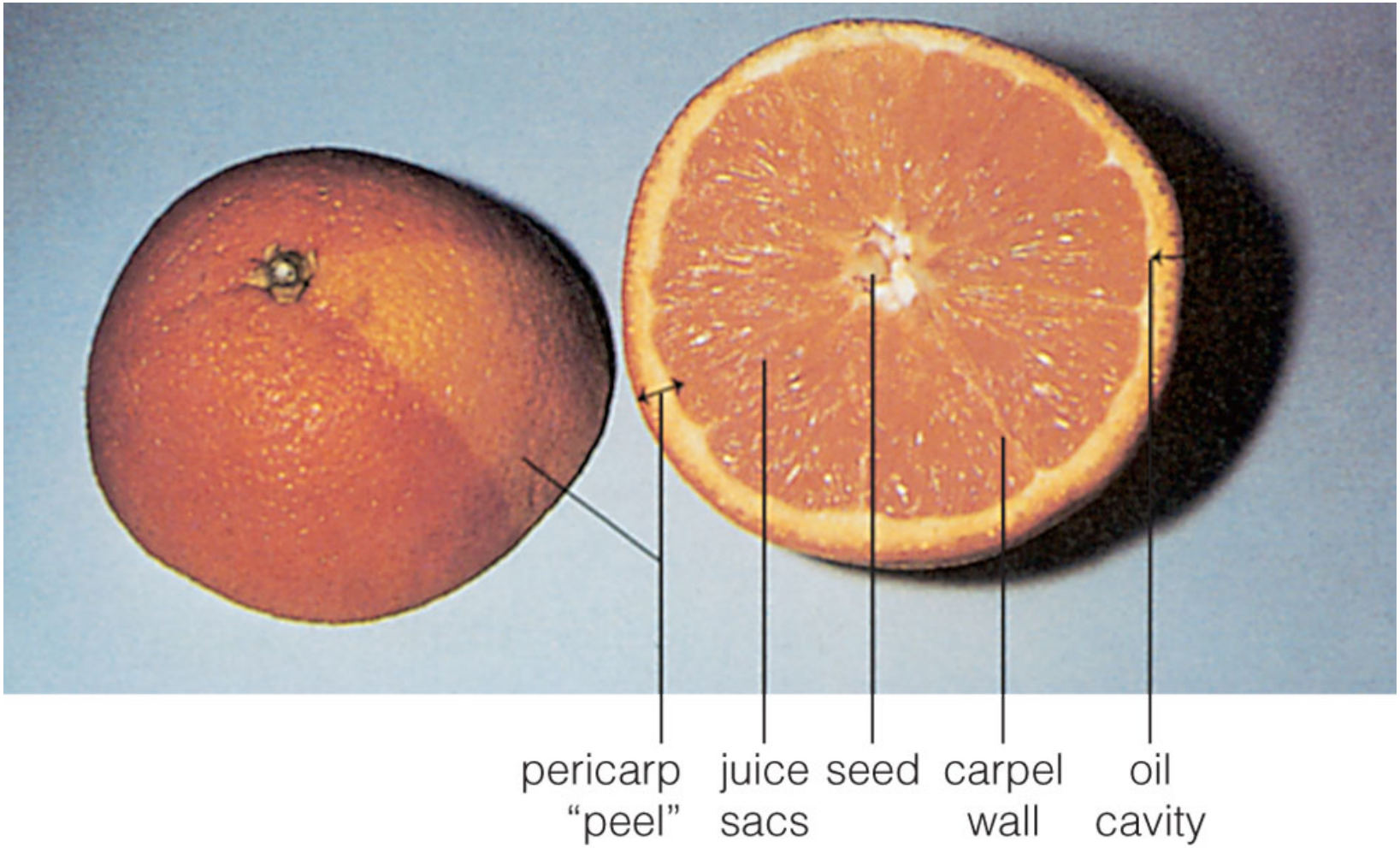
# Trivial classification: criteria

- **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

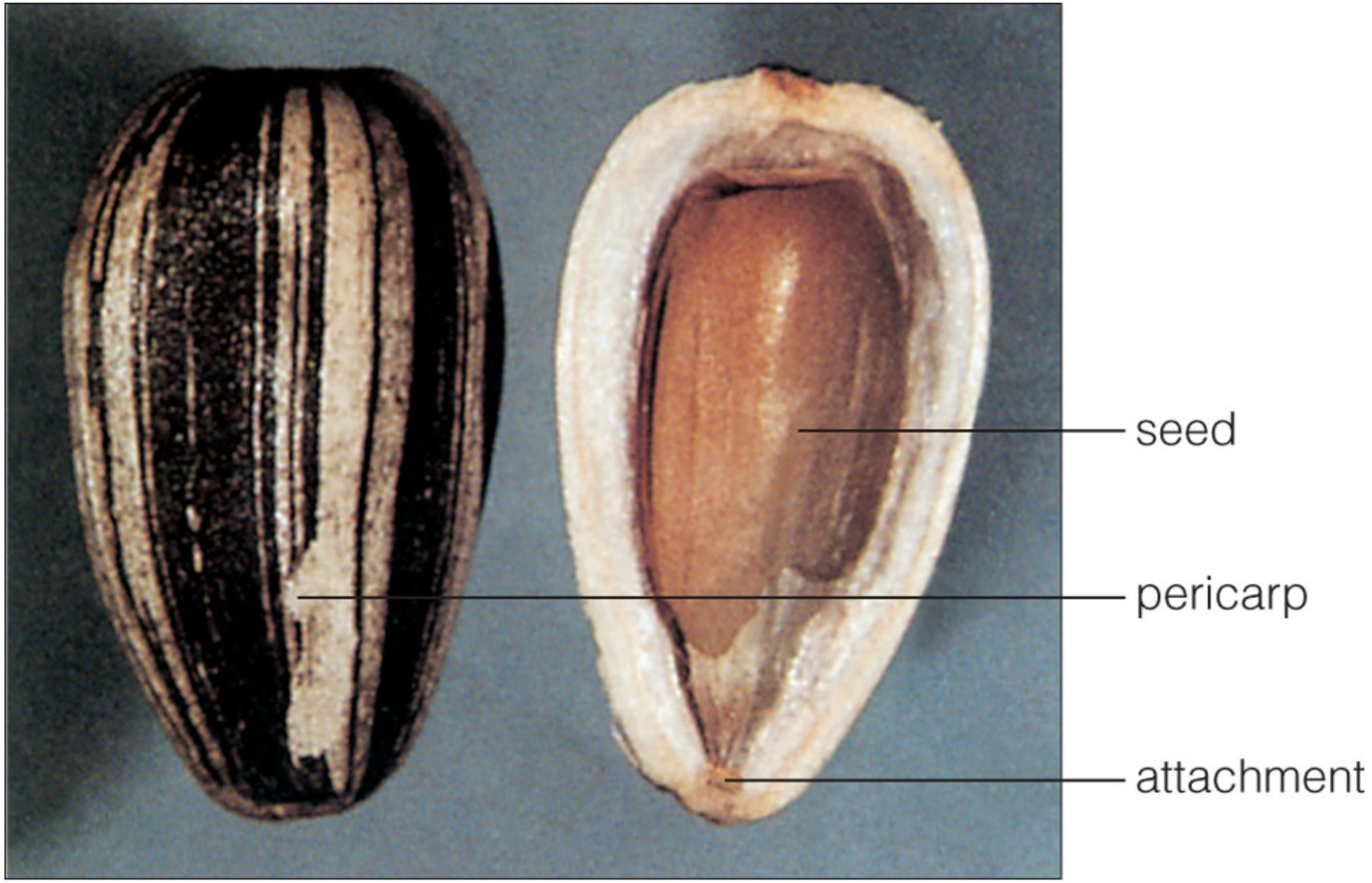
| Type | Consistency | Opening | Example |
|---|---|---|---|
| Simple | Fleshy | Indehiscent | Drupe (one seed), Berry (multiple seeds), Hesperidium (citruses), Pome (apple, pear: from inferior ovary) |
| Simple | Dry | Dehiscent | Legume (pod), Capsule, Silique (fruit of cabbage family) |
| Simple | Dry | Schizocarpic | Regma (spurge), Samara (maple), Schizocarp (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*

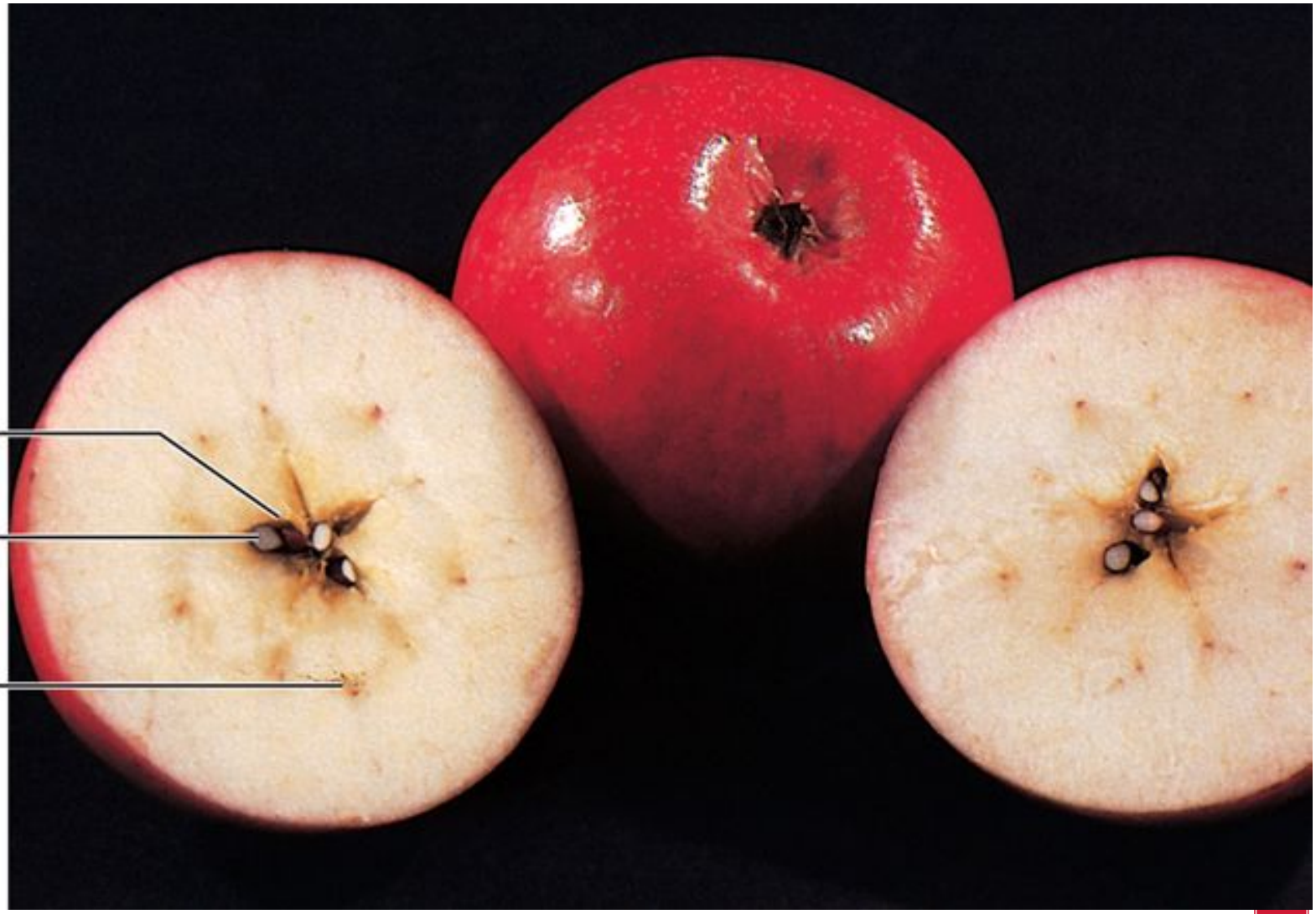


# Simple, dry, dehiscent: **pod** of *Erythrina* legume

# Simple, dry, indehiscent: **achene** (not “seed”!!!) of *Helianthus*



# Simple, fleshy, indehiscent: **pome** of *Pyrus*



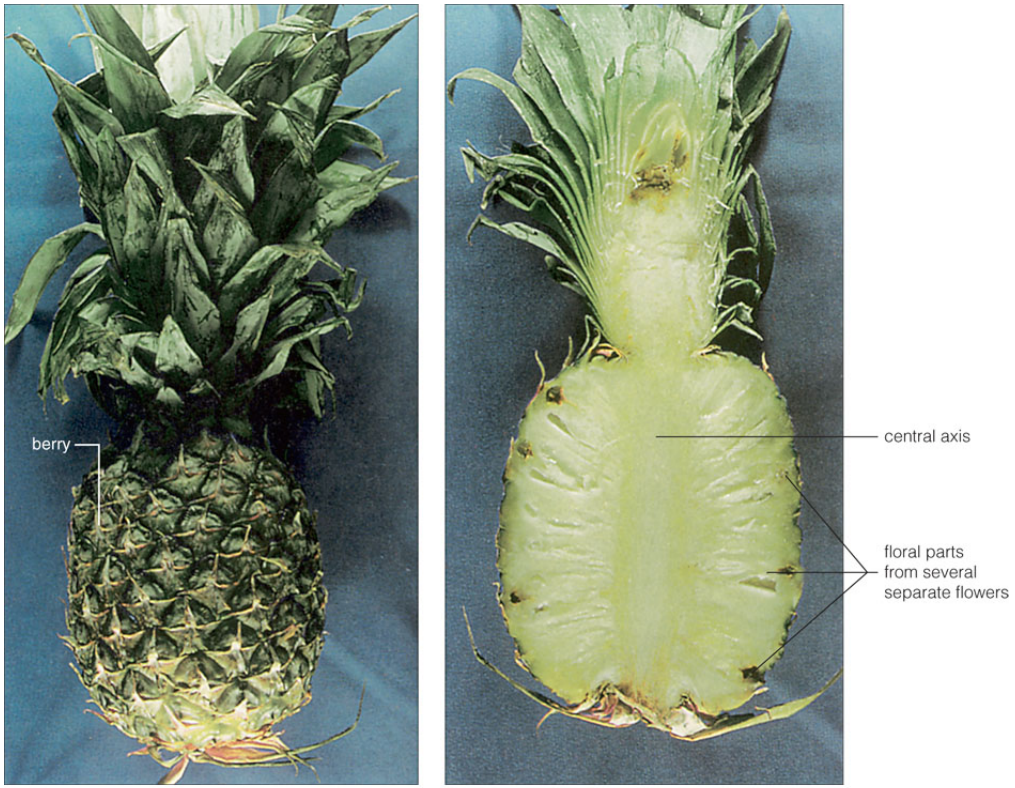
# Samara of *Acer*

# 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)

# Final question (2 points)

TBA

# For Further Reading

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