Phylum Chordata – Vertebrates
Amphibia

~6,000 species

one of the most significant events in vertebrate evolution was the gradual movement from water to land

1st *vertebrate* group to make transition onto land (=**tetrapods**)

bacteria → arthropods → plants → amphibians → reptiles
& algae 420MY 400MY 370MY 280MY

modern amphibians still retain a unique blend of aquatic and terrestrial characteristics

Life in Water versus Life on Land

whereas fish are adapted to an aquatic lifestyle; all other vertebrate groups are adapted to life on land

→basic differences between water and land:

1. **air contains 20x's more oxygen** than water also with faster diffusion rate

   but respiratory surfaces must be kept moist

2. **air is 800x's less dense** than water

density of water = 1g/cm^3
density of air = 0.001g/cm^3

water is harder to move through but does buoy up the body

land animals need strong limbs and remodeled skeleton to get around

appendages must be able to support body

3. **air fluctuates more in temperature**

ocean temperatures are constant

land has harsh seasonal cycles of freezing and drying

4. **land offers numerous new, unoccupied habitats and untapped food resources**:

eg. terrestrial arthropods and plants

5. **virtually no predators** on land yet

New adaptations for land life:

some other adaptations that made their appearance *after* the transition onto land:

→there was an increase in the number of **blood vessels** supplying the respiratory organs

→development of a **pumping mechanism** to get air into and out of lungs

→the **ear** became more important as a sense organ

→need **lacrymal glands** to keep eyes moist

→need **new method of prey capture**; cant use suction effectively

→ **moveable tongue** now used to manipulate food in mouth

Origin of Tetrapods (4-legged Vertebrates)

by Devonian (~400 MY ago) bony fish had developed a significant presence in freshwater habitat

~360MY ago the earth was becoming dryer with alternating droughts and floods

during these dry periods freshwater ponds & pools often dried up

lungfish in Siam today spends up to 4 months per year buried in damp soil, 2-3 ft deep

fishermen collect them with spades

some bony fish (=lungfish) living in these freshwater habitats had lung-like sacs that allowed them to breath air for short periods of time as well

reinforcements in their fins later enabled them to support their weight better in shallow water and, for short periods, on land

→ lungs and limbs were originally adaptations for fish to continue to survive in water

amphibians are descendants of these fishes

genetic studies have recently (2007) shown that fingers first appeared in lobe finned fish and have identified the genes that produced "fingers" from fish fins before the origin of amphibians (tetrapods)

The First Amphibians

the earliest amphibians (***Tiktaalik***, 375 MY; ***Ichthyostega***, 360 MY) share many features with these fish (***Eusthenopteron***):

1. both ~ 1 M long and lived during Devonian
2. skull structure was very similar
3. had "third eye" (**pineal eye**)
4. had middle ear that could hear sound vibrations in **air**

   Ichthyostega actually had an ear design that allowed it to hear better underwater than on land

   → probably spent considerable time in water
5. had similar short conical teeth (=labyrinthodont); probably predators
6. had short stocky but flexible appendages with digits
7. tail had tail fins with fin rays
8. had bony **operculum** (but no internal gills)
9. had **lateral line system**

but transition wasn't complete

→ most amphibians still need moist environment

→ most must return to water for reproduction

eggs must be laid in water

immature stage is aquatic

once the first amhibians appeared the climate became warmer and more humid (carboniferous)

land was covered with vast fern forests

primitive insects, some flying insects

amphibians were the dominant land animals in the carboniferous (300MY ago)

= Age of Amphibians

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most amphibians today move from pond to pond for food during droughts

live and breed in protected moist areas:

under longs and rocks
under litter on forest floor
in flooded tree holes

some modern amphibians have adapted to a dryer land existence:

a few don't require water for reproduction

largest:

largest frog:

African bulfrog, *Gigantorana goliath*

→ 30 cm (~1') long, nose to anus; 7.5 lbs; eats prey as big as rats & ducks

[largest US bulfrog gets to 20 cm (<8")]

largest salamander:

Chinese giant salamander

→ up to 6' long 55 lbs (lives 50 yrs iin captivity)

Japanese giant salamander

→ can get up to 4.5' long

smallest: cuban frog

→ less than 1 cm (.5")

Body Form

three main basic body forms:

eg. **salamanders**: head-trunk-tail

eg. **frogs**: fused head-trunk, no tail

eg. **caecilians**: long slender snake-like body

no limbs, no post-anal tail

Skin

most with thin moist, glandular skin without scales

(~1.5-4 mm vs humans 30-80x's thicker)

doesn't provide much protection from abrasion, dehydration or predators

thinness of skin and vascularization allows it to be used for **respiration** if kept moist

often with many **glands**:

eg. mucous glands

make skin slippery → harder for predators to get a hold

eg. poison glands

usually concentrated in areas behind eyes

when stressed poison gland secretes toxin

skin is often brightly colored

→contains **chromatophores** in dermis

many can adjust their color for camoflage

many toxic amphibians are brightly colored as warning coloration

less toxic species use color for camoflage

darkening of skin color controlled by light sensitive **pineal eye** which is connected to pineal gland

→ triggers release of **MSH** from **pituitary gland**

Support & Movement

stronger skeleton, mostly of bone, supports body weight on land

but legs don't support body very well

limbs are low to the ground

→body touches ground at rest

legs are not very flexible

still move in very 'fish-like' fashion

skeleton provides rigid framework for muscle action; esp leg muscles

→ muscle mass shifted from trunk to legs

strengthened rib cage and axial skeleton to support internal organs

abdominal organs hang down from axial skeleton which bears most body weight

limbs with toes for easier land locomotion

as the first vertebrates with "legs & feet" there was apparently some experimentation with the number of digits

early fossils are found with 5,6,7, or 8 toes

most modern amphibians have 4 toes on forelimbs and 5 toes on their hindlimbs

(almost all later tetrapods had five digits on all limbs)

→ made up of the same set of bones found in all land vertebrates

most **muscles** have lost the "segmentation" seen in fish

instead muscles are modified into "**opposing pairs**" to flex/extend or abduct/adduct limbs, etc

some of the trunk muscles still retain some of the "segmentation"

swimming:

aquatic forms have fish-like undulating swimming motion

gliding frogs:

eg. *Polypedates* spp (Africa and SE Asia)

large webbed feet

can glide horizontally 30-40' from a height of 40'

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another new structural innovation in land animals is the presence of a "**neck**"

the added flexibility with an additional set of muscles made the head much more flexible

necks are also found in some ancient fish species but most fish lack a flexibe neck

Feeding and Digestion

most amphibians are **predators** (carnivores)

eat mostly insects

but some eat small mammals, birds, snakes, fish & other frogs

some aquatic forms filter zooplankton from water

most have long flexible **tongues** for capturing prey

tongue of frogs is connected to front of mouth

free end produces sticky secretions to adhere to prey

can very quickly catch insects

[some take <.5 sec to catch prey with tongue]

some amphibians have teeth to hold onto prey and prevent its escape

food swallowed whole, not chewed

Respiration

adapations necessary for shifting from extracting oxygen from water to extracting it from air required major changes in both the respiratory and the circulatory systems

amphibians can get oxygen in several ways:

a. **lungs**
b. **through skin** (cutaneous breathing)
c. **mouth** (buccal breathing)
d. **gills**

a. lungs

most amphibians have lungs

the lungs are derived from the lungs of fish

very simple lungs; essentially hollow air sacs

→ amphibian lungs are not very efficient

[mammal lungs are >15 x's more efficient]

nostrils are now used for breathing as well as chemosensory

nostrils open directly into mouth cavity

→ cant eat and breath at the same time

and **no diaphragm** (breathing muscle)

→ amphibians must **gulp** air to force it into lungs

in most amphibians the lungs are not adequate for getting the oxygen they need

most amphibians rely on additional structures to supplement their lungs

b. skin

thinness of **skin** and blood vessels present allow it to be used as respiratory surface

even when lungs are used for oxygen; most carbon dioxide is lost through the skin

c. mouth

can also use **mouth lining** for respiration

some salamanders have dispensed with lungs and

gills and use cutaneous or mouth respiration only

d. gills

most amphibian larvae are aquatic and have **gills** for respiration

some aquatic amphibians retain gills as adults

Circulation

air breathing also requires a restructuring of the circulatory system

the amphibian circulatory system is improved over that of fish

have **3 chambered heart**; 2 atria, 1 ventricle

two complete **circuits** of blood flow

pulmonary circuit & **systemic circuit**

picks up O_2 in lungs and returns to heart

then sends oxygenated blood to rest of body

→ much more efficient; heart is a double pump

but not completely separated

there is some mixing of oxygenated and unoxygenated blood in ventricle

Nervous System & Senses

the vertebrate brain is made up of 4 distinct functional areas:

cerebrum - higher brain functions, integration

cerebellum - coordination of movement

diencephalon - coordination of nervous and endocrine systems

brain stem - automatic internal functions

amphibian brain is about same size as fish relative to body size

cerebrum (higher brain processing & sensory integration), esp optic centers, are relatively larger in amphibians than fish

cerebellum (controls movement) is relatively smaller than fish

Senses:

a. lateral line

many aquatic species have retained the lateral line system

in air there is not sufficient density to activate receptors in lateral line

senses of **smell** and **hearing** became more important than lateral line on land

b. use **touch**, **pressure** and **temp** are sensed mainly by free nerve endings in skin

c. vision

vision is dominant sense in many amphibians

no longer a fixed open stare as in fish

eye is similar to ours with a few differences:

eye muscles to move eyeball in socket

has **lacrimal gland** and **eyelids** to protect from drying

lower lid has a nictitating membrane
→ sweeps over eye when blinking

accommodation (focus) by moving lens in and out
→ not changing its shape as we do

retina has rods & cones → color vision

much visual processing occurs in the eye before signals reach the brain

c. smell

smell has become more important

receptors still located in "nose" area

smell due to olfactory epithelia in nasal cavities

also have "**Jacobson's Organ**" in roof of mouth

d. hearing & sound

our ear is divided into outer, middle and inner portions

fish had only an inner ear

amphibians have both a **middle** and **inner** ear

→ **eardrum** is on outside of head, behind the eyes

middle ear helps to amplify in air sound

sound waves in air are very weak

a single ear bone (=**columella** (stapes)) (not 3 earbones as in us)

transmits sound vibrations from eardrum to inner ear

most amphibians have a **larynx** with vocal cords

frogs pass air back and forth over vocal cords

between **lungs** and **vocal sac** in floor of mouth

use sound to attract a mate

better developed in males than females

→ males do most of the calling

some sound is also transmitted through forelimbs, muscles and soft tissues to inner ear

→ esp low frequency "seismic" vibrations

→may warn of large predators

e. balance and equilibrium

like fish, amphibians have inner ear that detects position and acceleration via **otolith organ** and **semicircular canals**

Excretion & Salt/Water Balance

as in fish nitrogen wastes are eliminated as **ammonia** or **urea**

skin and kidneys are the main way salts and water are gained or lost

most amphibians cannot conserve water by producing a concentrated urine

a few desert frogs can produce **uric acid**

→ requires much less water to eliminate

most amphibians can store urine up to 1/3rd body wt in bladders and lymph sacs beneath skin

kidneys conserve salts by reabsorbing them from urine to compensate

some amphibians can actually absorb water through their skin

products from the digestive, excretory and reproductive systems drain into a **cloaca** before being released to the outside

Defense/Protection

amphibians have many enemies: snakes, birds, turtles, raccoons, humans

→ many frogs and toads in tropics are aggressive and will fight predators

some can give a painful bite

→ frogs tend to stay very still when threatened

only when they think they have been detected do they jump in water or grasses to get away

when held, they remain motionless to catch us

offguard, then jump while voiding urine

→ most frogs can also inflate their lungs making them difficult to swallow

→ all amphibians have **poison glands** in their skin

some toxins are lethal

eg. **Poison Dart Frog**

brightly colored (warning); one of the deadliest frogs

→ poison from a single frog could kill several humans

Choco indians of Central and South America catch them and roast frogs over open fires then collect the highly toxic mucus which exudes from the frog's skin as they die.

use the poison on the tips of their blowgun darts

eg. large **toad** of Panama Canal Zone can squirt a poison that will blind

its skin is collected for fine leather

some frog toxins are hallucinogenic

(frog licking)

→ a few amphibians use **poisonous spines** to to protect themselves

eg. **sharp ribbed newt** when threatened can arch their back in such a way that the sharp ends of their ribs actually penetrate and poke out of the skin. As the ribs pass

through the layer of skin they are coated with a toxic milky liquid to become **venomous spines**

eg. **hairy frog** does a similar thing but uses its toe bones as the spines that it uses to slash at its attacker

→ one ancient group of African frogs has **poisonous fangs** that it uses to eat other animals including other frogs

Reproduction & Development

dioecious; rarely show sexual dimorphism

mating is controlled by seasonal conditions

most amphibians breed soon after spring emergence from hibernation

breeding season usually lasts for several weeks

no transfer organs or copulation; most amphibians have **external fertilization**

eg. in **salamanders** male deposits **spermatophore** on leaf or stick and maneuvers female over it

fertilization occurs as eggs are released

aquatic species lay eggs in clusters or stringy masses

terrestrial species may deposit eggs in clusters

under logs or in moist soil

in some salamanders, the adults guard eggs

eg. **frog** breeding is like an orgie

most larger frogs are solitary except during breeding season

males often take possession of a perch near water

then males call to females

each species has its own unique call

amplexus: male frog holds onto female

female deposits eggs in water anchored by sticky jelly

male deposits sperm over eggs

males will grab almost anything

often jump salamanders or other male frogs

have special release call to get males off

sometimes several males will jump on a female

many females drown from the weight holding them under water

in most amphibians there is some parental care of the eggs until they hatch by either the male or female

some amphibian species reproduce by **parthenogenesis**

Metamorphosis

salamanders, eggs typically hatch into tadpoles in ~ 1 week

with gills, suckers and spiracle

→larvae resembles adult

aquatic forms retain gills (paedomorphosus)

eg. *Necturus*, mud puppies

terrestrial forms lose gills and develop lungs

embryos of salamanders resemble adults

→ undergo less pronounced metamorphosis

some retain gills as adults

frogs hatch as herbivorous **tadpole larvae**

most frogs undergo **metamorphosis** into adult in a year or less

legs appear
tail is reabsorbed (in frogs)
lungs develop

one genus of tropical terrestrial frogs the eggs hatch dirctly into "froglets"

no aquatic stage

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frogs & toads have a variety of **unique reproductive behaviors**

a few tree frogs build nests: cuplike crates along streambank

another makes waterproof depressions in tree hollows using beeswax

some brood young in stomach

eg. Surinam toad; *Pipa*

completely aquatic

fertilized eggs are deposited on the back of female

the eggs sink into the spongy skin forming separate incubation chambers

each chamber is covered by thin sheet of skin

larvae undergo metamorphosis in these chambers and emerge as adult toads

eg. midwife toad

female lays eggs fastened together like beads on a string

male thrusts hind legs into the egg mass and wraps them around his body

male then takes eggs to his burrow

he comes out only at night to search for food

when larvae are about to emerge he finds a pool of water to jump in and the larvae swim away

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a very few amphibians have **internal fertilization** and bear live young

eg. the snakelike caecelians have internal fertilization, most bear live young

fetuses feed on secretions and tissues they scrape from lining of mom's oviduct

eg. the Alpine salamander, *Salamandra atra*, lives in Swiss Alps at ~4500' and has the longest gestation period of any land animal:

2 young are born ~ 3 years after fertilization

Hibernation

during winter most temperate frogs **hibernate** in mud at bottoms of pools and streams

use energy from glycogen and fat stores

toads tend to hibernate in humus on forest floor

some can survive freezing

eg. woodland frog is the only vertebrate able to survive being frozen

they live north of the arctic circle

up to 65% of its body water may be frozen

heart stops completely

glucose in blood acts as antifreeze

what freezes is the water outside its cells, not water inside cells

Migration

some amphibians have a strong homing instinct

they migrate to ponds to mate

→ return to the same pond each year for mating

guided by olfactory cues

Kinds of Amphibians

3 main orders:
- "with tail" (O. Caudata)
- "without tail" (O. Anura)
- "without feet" (O. Apoda)

A. Salamanders & Newts (Order Urodela or Caudata)

3 species of salamanders in Travis County
including the Barton Sprigs salamander, *Eurycea sosorum*

least specialized, resemble ancestor

limbs at right angles to trunk

→ walk with "S" motion of trunk

most have aquatic larva that metamorphoses into terrestrial adult

mainly in N America

mostly nocturnal

some up to 4' long

live in cool damp places

including along mountain streams

→ most cold tolerant of all amphibians

a few are arboreal and avoid water

both larvae and adults are **carnivores**

eat worms, small arthropods & molluscs

some have teeth in roof of mouth

some with prehensile tongue up to half body length

some without lungs or gill → breath through skin

some reproduce without metamorphosis

examples:

eg. Barton Springs salamander

eg. Hellbender (*Cryptobranchus alleganiensis*)

one of world's largest salamanders (to 2.5' (75 cm))

can live for 30 years

confined to clear stream and rivers in the Applachian mountains

wrinkly skin through which it breaths secretes a mildly toxic mucus to protect its thin skin from pathogens

→sometimes called a "snot otter"

feed on crayfish - swallow them whole

once extremely common is now an endangered species some states

has declined 77% in past 30 years

illegally caught and sold in pet stores in China and Japan for up to $1700 each

B. **Frogs and Toads** (order Anura (="no tail"))

17 species of frogs in Travis County

by far the most successful & widespread group

5283 species or 88% of all living amphibians

an ancient group

→ known from Triassic (250 MY)

hind legs specialized for jumping

occupy a great variety of habitats

especially common in tropical swamps and forests

but found in all habitats; even dry areas

frogs are more aquatic and generally live in or near water

toads are more terrestrial and only move to water to reproduce

more dependent on lungs than other amphibians

those that are completely aquatic usually lack tongue

highly specialized for jumping locomotion

some can glide like flying squirrels

eg. flying frog of tropical Asia

most have long flexible tongues attached to the front of the mouth for capturing prey

tree frogs have large, adhesive pads on the ends of their toes

C. Caecilians (O. Gymnophiona; Apoda)

~173 species

elongated, limbless, burrowing or aquatic animals

10 cm to >1.5 M long

in tropical forests of central and south America, Africa, India

skin is smooth and slimy

but some with small calcified dermal scales under skin

also skin has folds that make them look like large segmented earthworms

small eyes → most ar blind as adults

sensory tentacles on snout

feed on worms and small invertebrates

skin has squirt gland that secretes irritant

→causes sneezing in humans

internal fertilization, most viviparous

fetuses feed on secretions and tissues they scrape from lining of moms oviduct

Ecology & Human Interactions with Amphibians

A. Beneficial Effects of amphibians

→Frogs eat **disease-carrying insects**

→Frogs are **critical links** between predators and the bottom of the food chain (algae, plants, detritus, and such)

B. As Food

not a major part of human diet
→frog legs

Americans devoured more than 6.5 million pounds of frog legs a year (1984)

led to the death of some 26 million frogs annually.

Ninety percent came from India and Bangladesh, which banned exports after frog declines led to growing hordes of mosquitoes, malaria, and increased use of pesticides.

Now Indonesia supplies most of the frogs for restaurants

C. Education & Research

most commonly dissected laboratory animal:
in science classes and research

3-9 M US for education alone
6 M in high schools alone

3 M frogs (8% of all lab animals) are used for research

→ much of our medical knowledge came from frog dissections

→ embyrological studies

→ isolation of pharmaceuticals

D. Poisons

several species of tropical frogs secrete potent neurotoxins

distasteful
induces paralysis

often brightly colored

natives in Brazil and Costa Rica use toxin to make poison arrows

some of these toxins are hallucinogenic

leads to "frog licking"

eg. Poison Dart Frog

one of the deadliest frogs

→ poison from a single frog could kill several humans

E. As environmental Indicators

amphibians are extremely sensitive to environmental indicators

in 80's & 90's noted declines

→ since 80's 120 species have become extinct

today one third of the worlds 6,000 amphibian species are threatened

→ one of largest extinction spasms in vertebrate history

unsure of exact causes of declines:

Probable causes of decline:

1. The number one cause of amphibian decline is habitat loss

   most amphibians feed and breed in wetlands,

   In the past half-century the lower 48 states have lost more than half of their estimated original wetlands.

2. pollution

deformities from animals in polluted water

3. fungal skin infection

most recently has been tied to worldwide spread of a primitive mold pathogen

this is the first mold known to attack vertebrates.

can kill within days

→ *Batrachochytrium dendrobatidis* (chytridiomycota)

(including in and around central Texas)

spreads very rapidly; don't know how it kills frogs

Barton springs salamander has natural antibiotics in its skin that seem to protect it from the pathogen)

scientists have mobilized to collect and save representative species in safe haven protected from fungus

4. deadly virus is the likely culprit in several recent die-offs of frogs,

5. Increased exposure to ultraviolet radiation may

damage the eggs

6. possibly caused by acid precip, deforestation urbanization, climate change

the largest captive breeding program ever, "Amphibian Arc" has begun to save the 500 most endangered amphibians that cannot be protected in the wild