Phylum: Chordata

- Deuterostomes
  - radial and indeterminate cleavage
  - Enterocoelous
  - anus from blastopore
- Bilateral Symmetry
- Both invertebrates and vertebrates
  - Contain four anatomical features
Phylum: Chordata

- Notochord
- Dorsal, Hollow Nerve Cord
- Pharyngeal Slits
- Muscular, Postanal Tail
Subphylum: Urochordata

- Tunicates
- Sessile
- Only contains Pharynx with slits as an adult
Subphylum: Cephalochordata

- Lancelates
- Contains all four chordate characters as an adult
- Closest relative to vertebrates (*Amphioxus*)
- Paedogenesis
SubPhylum: Vertebrata

- Backbones
- Contains all four chordate characters as an adult with modification
- Neural Crest
  - bones and cartilage of the skull
Vertebrate Adaptations

- Living Endoskeleton
  - better for larger animals
- Pharynx and Efficient Respiration
  - increased metabolic rate
- Advanced Nervous System
  - developed system for distance reception
- Paired Limbs
  - increased movement
Chordate Evolution

- Vertebrae
- Jaws and two sets of paired appendages
- Teeth
- Lungs
- Legs
- Amniotic Egg
- Hair, feathers
Introduction to Fishes

“Fish”: poikilothermic, aquatic chordate with appendages developed as fins (when present), whose chief respiratory organ are gills and whose body is usually covered in scales
- Paraphyletic group because of tetrapods

All fishes...
- have distinct head region (eyes, mouth, etc.) and brain protected by braincase

Most fishes...
- live in water
- breathe with gills rather than lungs
- are unable to regulate their body temperature
- are covered in scales
- have paired limbs in the form of fins
Diversity of Fishes

- More fish species than birds, reptiles and mammals combined
  - 27,900 species described
  - 58% live in salt water, 41% in freshwater, and 1% move between salt and freshwater

Life span
- Pygmy goby < 60 days
- Rockfish >200 years

Size
- Minnow ≈ 0.3 in
- Whale shark > 65ft
Modes of Reproduction

- **Oviparous**: lay eggs that hatch outside of the mother’s body
  - Some sharks and most fish

- **Ovoviviparous**: mother retains fertilized eggs within the oviduct, but does not provide nourishment to the eggs
  - Few sharks

- **Viviparous**: young develop within mother’s uterus and receive nourishment via the placenta, uterus or by eating other eggs, before being born (live birth)
  - Some sharks and fish
Respiration in Fishes
Osmoregulation in Fish

- **Osmoconformers**: isotonic (same solute concentration) to surrounding water
  - Most marine invertebrates, hagfish, elasmobranchs

- **Osmoregulators**: actively regulate body osmolarity (solute concentration)
  - Most fish
Endothermy in Fish

Some tuna, billfish, and sharks

- Countercurrent heat exchange
  - Maintains elevated swim muscle temperature
- Thermogenic organs

Evolutionary advantages:

- Expansion of thermal niche
- Stabilize temperature of internal tissues
- Increased metabolic rates
- Increased neural processing and vision
Evolution of Vertebrate Excretory System

**Pronephros**: simple nephron which collects filtrate from coelom through ciliated nephrostomes before filtration in the pronephric duct
- Found in jawless fish (Agnatha) and larval amphibians

**Glomerulus** (Glomus): cluster of capillaries
Evolution of Vertebrate Excretory System

**Mesonephros:** collection of mesonephric tubules which form capsules around glomeruli where filtration occurs

- Found in fish, adult amphibians, and embryonic mammals
- Develops into **reproductive organs** in male mammals
- Ureteric bud develops into **metaneophros** (kidney in birds, reptiles and mammals)
Superclass Agnatha, Order Myxiniformes

**Hagfish**
- Jawless (Superclass Agnatha)
- Reduced vertebrae with cartilaginous braincase
- Marine scavengers
- Produce slime
- Lack scales and paired appendages
- Reduced brain, eyes, ears, and nasal opening
- Tie themselves in a knot to release slime or provide leverage when feeding
Superclass Agnatha, Order Petromyzontiformes

**Lampreys**
- **Jawless** (Superclass Agnatha)
- Rudimentary vertebrae and cartilaginous skeleton
- Marine and freshwater
  - **Anadromous**: migrates to fresh water to spawn
- **Ammocoetes larvae**: filter feeders, buried in sediment
- Most are **parasitic**
- Lack scales and paired appendages
Evolution of Jaws

- Jaws likely developed from gill arches used in filter feeding
- Lead to the diversification of food types (carnivory and herbivory)
- Allowed for active defense from predators
  - De-emphasis on armored plates
    - Development of paired appendages
Class Chondrichthyes (kon-DRIK-thee-EEZ)

- First appeared in mid-Devonian
- Cartilaginous skeleton
- Placoid scales
- Teeth derived from placoid scales are not fused with jaw
  - Replaceable (every few day)
- Large, buoyant livers
  - Lack gas bladder or lungs
- Spiral valve intestine
- Highly developed sensory organs
  - Ampullae de Lorenzini
- Internal fertilization
  - Claspers

Placoid scales

Ampullae de Lorenzini

Spiral valve

Claspers
Class Chondrichthyes

Subclass Elasmobranchii

- Sharks (8 orders, ~360 species)
  - Most are large (> 1m)
  - Most are active marine predators
- Skates, Rays, Electric rays, Sawfish (4 orders, ~550 species)
  - Flattened bodies
  - Bottom dwelling predators

Subclass Holocephali

- Chimaera (rat fish) (1 extant order, ~50 species)
  - Feed on benthic invertebrates in deep ocean
Class Chondrichthyes, Subclass Elasmobranchii

- **Sharks**
  - Charcharhiniformes (210 species)
    - Tiger, Hammerhead, Blacktip
    - Two dorsal fins, an anal fin, and 5 gill openings
    - Nictitating membrane
  - Lamniformes (16 species)
    - Mako, Great white, Thresher, Basking
    - Elevated body temp
    - Two dorsal fins, an anal fin, and 5 gill openings
    - Nictitating membrane
Class Chondrichthyes, Subclass Elasmobranchii

Order Rajiformes (Skates)
- Thorns on back
- **No stinging spine**
- **Two lobes** on pelvic fin
- Lay eggs (Oviparous)

Order Myliobatiformes (Rays)
- **No thorns** on back
- Stinging spine
- **One lobe** on pelvic fin
- Live birth (viviparous)
Class Chondrichthyes, Subclass Holocephali

Chimaera (ratfish)

- Oviparous
- Upper jaw attached to braincase
- Teeth modified as crushing plates
  - Diet of benthic invertebrates
- Poisonous spine before first dorsal fin
- Move by flapping pectoral fins
- Lack scales
Osteichthyes (AH-stee-IK-thee-eez)

**Bony fishes**
- Ossified (bony) endoskeleton
- Pair of lungs or swim bladder
- Bony fin rays
- Ganoid, ctenoid, or cycloid scales (no placoid)
- **Operculum**: bony gill cover

**Divided into two classes**

**Class Sarcopterygii** (sar-KOP-tuh-RIJ-ee-eye)
- **Lobe-finned fishes**
  - Pectoral and pelvic fins made of rod-shaped bones surrounded by muscle

**Class Actinopterygii** (ACK-tih-NOP-tuh-RIJ-ee-eye)
- **Ray-finned fishes**
  - Elongated, flexible fin rays
  - Single dorsal fin
Basic Anatomy of a Bony Fish

**Lateral line**: sensory organ used to detect vibrations and movements

**Swim bladder (gas bladder)**: internal air filled organ that aids in *buoyancy*
Lateral Line
Class Sarcopterygii, Order Coelocantiformes

Coelocanths
- Three lobed caudal fin
- Fleshy operculum
- Jointed skull
- Viviparous
- **Rostral organ**: electroreceptive organ located in the front of the braincase
- Believed to have gone extinct 65mya
  - Re-discovered in 1938
  - Populations near Indonesia and South Africa
Class Sarcopterygii, Subclass Dipnoi

**Lungfish**

- All freshwater fish
- **Lungs**
  - Breathe air
  - Homologous to tetrapods
- Slender fins
  - Single, long tapered caudal fin
- Omnivorous diet
- Can survive dry conditions by estivating in mucus-lined burrow for up to 4 years!
- Largest genome among vertebrates
- Estivation
Class Actinopterygii, Order Acipenseriformes

Sturgeons and Paddlefishes

- Primitive characteristics
  - Mostly cartilaginous skeleton
  - Heterocercal tail
  - Spiral valve intestine
  - Lack of vertebral centra
  - Marine, freshwater and anadromous

- Caviar
- Barbels
  - 4 in Sturgeons
  - 2 in Paddlefish
- Lack scales
Class Actinopterygii, Infraclass Holostei

- Brackish waters
- Highly vascularized swim bladder
  - Can breathe air
- Veracious predators
  - Stalk prey

**Order Amiiformes (Bowfins)**
- Single extant species
- Gular plate
- Swims via dorsal fin

**Order Lepisosteiformes (Gars)**
- Ganoid scales
- Heterocercal tail
Class Actinopterygii, Infraclass Teleostei

- 96% of all living fishes (38 orders and 426 families)
  - Occupy nearly all freshwater and marine habitats
  - Most diverse group of all vertebrates
- Significant variation in body plans, foraging and reproductive behaviors
  - Only herbivorous fishes
- Diverged in the Mesozoic Era
- Uroneural bones
  - Homocercal caudal fin
- Mobile pre-maxilla bone
  - Jaw protrusion
Class Actinopterygii, Superorder Elopomorpha

**Leptocephalus larvae**: flat, ribbon-shaped, transparent larvae
- Large size
- Long life

**Order Anguilliformes**
- True eels
- Elongated fish with dorsal and anal fins fused with caudal fin

**Order Albuliformes**
- Bone fish
- Hard, bony scales

**Order Elopiformes**
- Tarpon
Class Actinopterygii, Superorder Osteoglossomorpha

Bony tongues

- Teeth on the tongue bite against bones on the roof of the mouth
- Mostly tropical

- Arapaima and Arowana
  - Some of the largest fresh water fishes

- Elephant fish
  - Produced and detects weak electrical fields
  - Large brain
Class Actinopterygii, Superorder Clupeimorpha

Anchovies and Sardines

- Inner ear to gas bladder connection
  - Physostomes
    - Quickly adjust pressure in gas bladder
    - Improves hearing of low frequency sounds
- Most are marine, open water schooling species
  - Filter feeders
- Important commercial fish
- Food source for many predators including marine mammals, seabirds, and large predatory fish like tuna and marlin
Minnows, Catfish, Knifefish, Piranha

- Dominant freshwater fish species
- **Weberian apparatus**: set of bones that connect the inner ear to the gas bladder
  - Improved hearing
- Response to **alarm signals** of conspecifics
Class Actinopterygii, Superorder Osteiophysi

**Cypriniformes**: Minnows, Carp, Shiners
- 2nd largest order of fish
- Early pharyngeal dentition
- Invasive species in many freshwater habitats

**Characiformes**: Piranha, Tetras
- Mostly tropical
- Mouth teeth and replacement dentition
- Adipose fin

**Siluriformes**: Catfish
- Barbels
- No scales
Class Actinopterygii, Superorder Protacanthopterygii

**Order Salmoniformes: Salmon and Trout**
- Freshwater, **anadromous**
- Adipose fin
- Ecologically and commercially important species
- Reduced populations
  - Alteration to river systems (Dams)
    - Fish ladder
  - **Overfishing**

**Order Escoiformes: Pike**
- Fins far back on body
- Freshwater
- Voracious predators
  - Cannibalistic
Class Actinopterygii, Superorder Stomiatii

**Order Osmeriformes**: Smelt
- Small, silvery, elongate fishes
- Single soft rayed dorsal fin
- Freshwater, marine, anadromous
  - Delta smelt and Candlefish

**Order Stomiiformes**: Dragonfish, hatchetfish
- Deep sea
- Bioluminescence
  - Photophores
Lanternfish

- Deep sea fishes
- Laterally compressed, with large eyes
- Bioluminescence
  - Photophores
- Majority of deep sea biomass (65%)
- Diel vertical migration
  - From ~10,000ft deep to ~30ft deep
- Important food source for marine predators
  - High lipid content
Spiny-rayed fishes

- Spiny rays on first dorsal fin, pelvic and anal fin
  - Two dorsal fins (1\textsuperscript{st} spiny, 2\textsuperscript{nd} soft)

- Ascending process of premaxilla
  - Improved jaw protrusion

- Pharyngeal dentition
  - Specialized depending on food type
Class: Actinopterygii, Superorder: Acanthopterygii

- Pelvic girdle attached to pectoral girdle
- Pelvic fin with anterior spine and 5 soft rays
- Ctenoid scales
Superorder: Acanthopterygii, Order Gadiformes

**Cod, Haddock, Pollock**
- Benthic marine
- Nocturnally active
- Barbels
- Three dorsal fins, two anal fins
- Commercially important
  - Fish and chips!
- Populations declines due to overfishing
Superorder: Acanthopterygii, Order Syngathiformes

Pipefish, Seahorses, Seadragons

- Fused jaws form long snout
  - Pivot feeding (Supa fast!)
- Plates of body armor
- Lack pelvic fins
- Prehensile tail
- Males carry eggs in pouch or on tail
Superorder: Acanthopterygii, Order Scombriformes

Tuna, Mackerel, Bonito

- Large, fast marine predators
  - Most are schooling
  - Open ocean (pelagic)
- Two dorsal fins and strong caudal fin
- **Finlets** behind dorsal and anal fins
- Regional **endothermy**
- Non-protrusable jaw
- Commercially important food
- Populations declining
  - Overfishing
Superorder: Acanthopterygii, Order Perciformes

**Wrasses, Bass, Cichlids, and Perch**

- Largest vertebrate order
  - Contains ~ 40% of all fish species
- Abdominal pelvic fins and lateral pectoral fins
Superorder: Acanthopterygii, Order Scorpeniformes

**Rockfish and Sculpin**
- Bony ridge/spines on cheek
- Most have spines on head
- Round pectoral and caudal fins
- Carnivorous
- Live near bottom
- Long lived

Spines on cheek
Superorder: Acanthopterygii, Order Plueronectiformes

Flatfishes (flounders, soles, halibut)
- Bilaterally symmetric larvae metamorphose into flat formed adults
  - Left-eyed or right-eyed
- Benthic carnivores
  - Camouflaged
- Commercially important
Superorder: Acanthopterygii, Order Tetradontiformes

**Triggerfish, Pufferfish, Mola Mola**

- Teeth in the **outer jaws**
  - Derived from jaw bone (not true teeth)
  - Four in some pufferfish
- Mostly tropical reefs
- Often eat animals inaccessible to other fishes
  - Sponges, sea jellies, sea urchins, corals
- Mola mola’s can have >300,000,000 eggs!
Superorder: Acanthopterygii, Order Antheriniformes

Silversides (Topsmelt, Grunion)
- Two separate dorsal fins are common
- Single spine on anal fin
- Weak or absent lateral line
- Surface-dwelling fish
- Beach spawning in grunion