

**Physics is everywhere -
in the atom, in the universe,
in the TV set and ...**

**Physics is everywhere -
in the atom, in the universe,
in the TV set and ... in the
human body**

Physics of the Body

(bones, ears, eyes)

Urbana, November 2006

Klaus Schulten
with

Zhongzhou Chen, Jordi Cohen, Emma Falck, Jen Hsin, Eric Lee, Marcos Sotomayor



Jordi Cohen
bone doctor

Eric Lee
bone smasher

Zhongzhou Chen
acoustics engineer

Emma Falck
opera singer

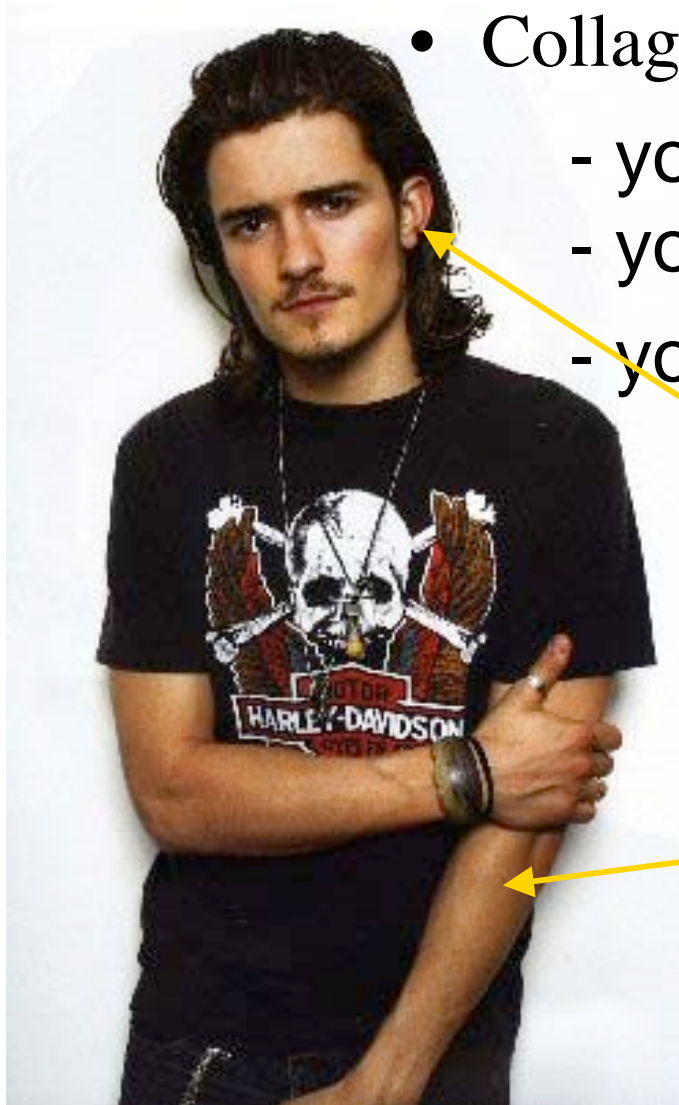
Jen Hsin
eye donor

Marcos Sotomayor
eye doctor

The human body takes advantage of the laws of physics as the talk will illustrate in three ways. Dissecting a cow's eye we show the wonderful lense of the eye working as a perfect magnifying glass; the retina of the eye, easily seen, with more nerve cells than the US has citizens that outdo digital cameras in having a higher pixel resolution. We tinker with simple electronics to show that the ear, likewise, is a sensitive physical instrument, learning to sing a pure harmonic tone, that the ears of older people cannot hear many sounds without them realizing it, and that indeed the human ear can be fooled to hear great sound even though much of the real sound is cut away as done in our iPods everyday. We also look at the skeleton with an electron microscope

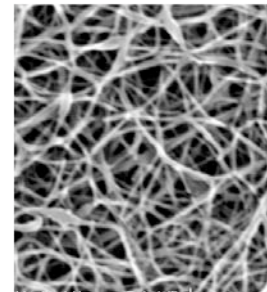
Collagen holds your body together

- Collagen provides shape and elasticity to:
 - your ears
 - your skin
 - your **bones**
 - your nose tip
 - your tendons



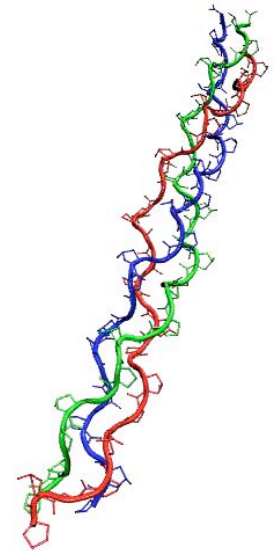
cartilage of ear

bone of arm



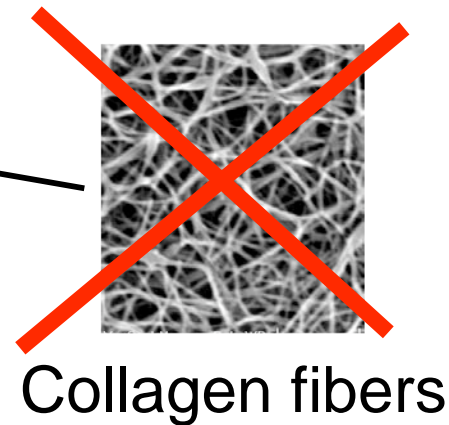
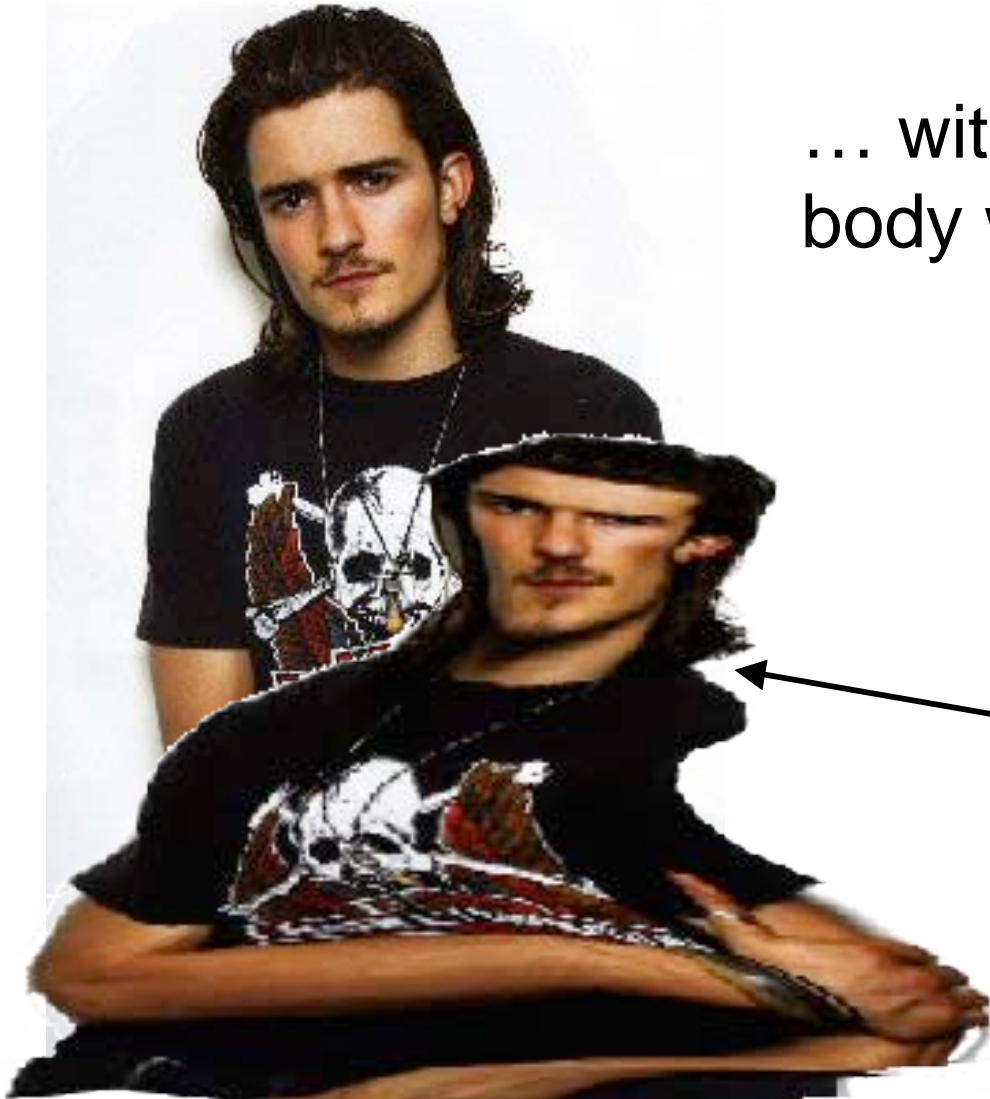
collagen fibers

tropocollagen molecule



Collagen holds your body together

... without collagen, your body would lose its shape!



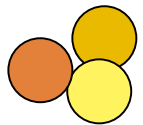
Collagen fibers

What are bones made of?

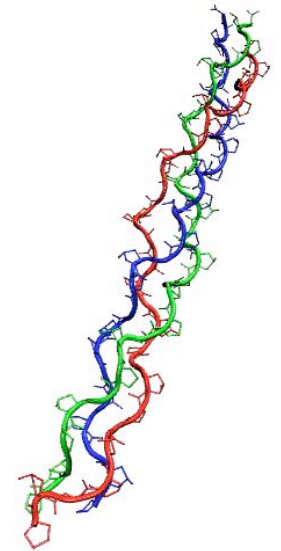
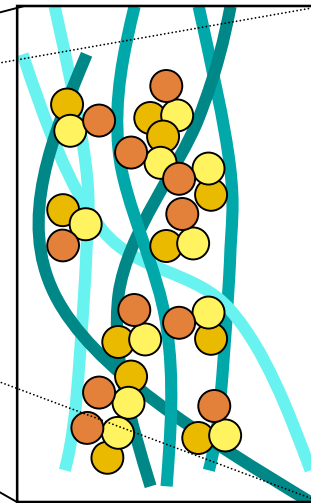
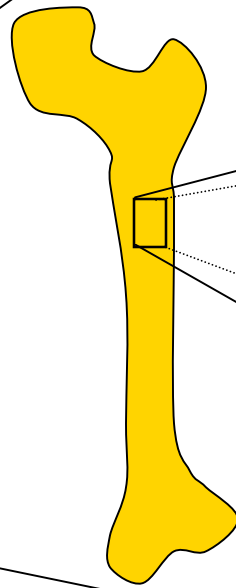
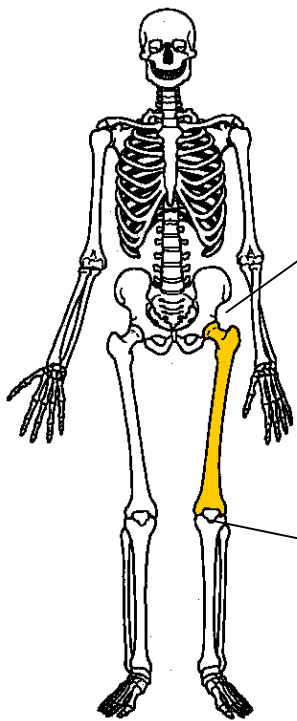
- Bones are made of mineralized collagen fibers:



30% collagen fibers (*for shape*)



70% minerals: calcium phosphate (*for strength*)



tropocollagen molecule

Let's look at bones up close

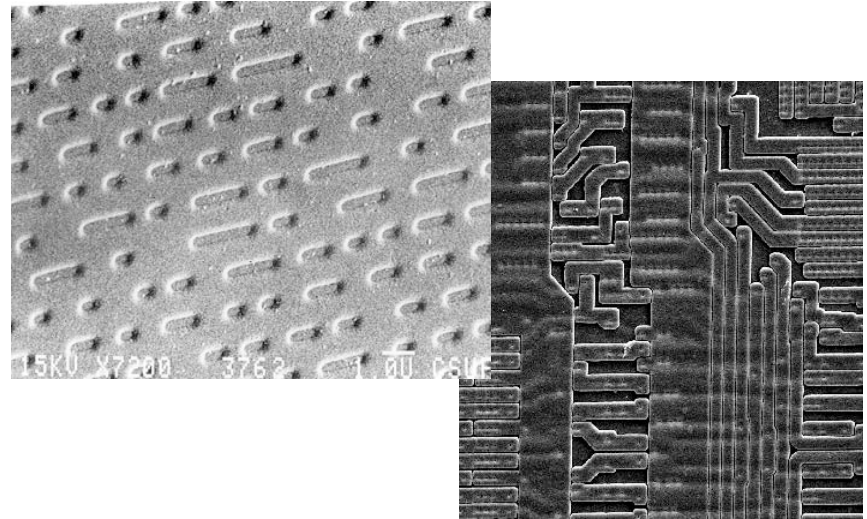


How can we visualize bone structures?

With a scanning electron microscope!



Usually used on inert materials:
surface of a CD, microchip



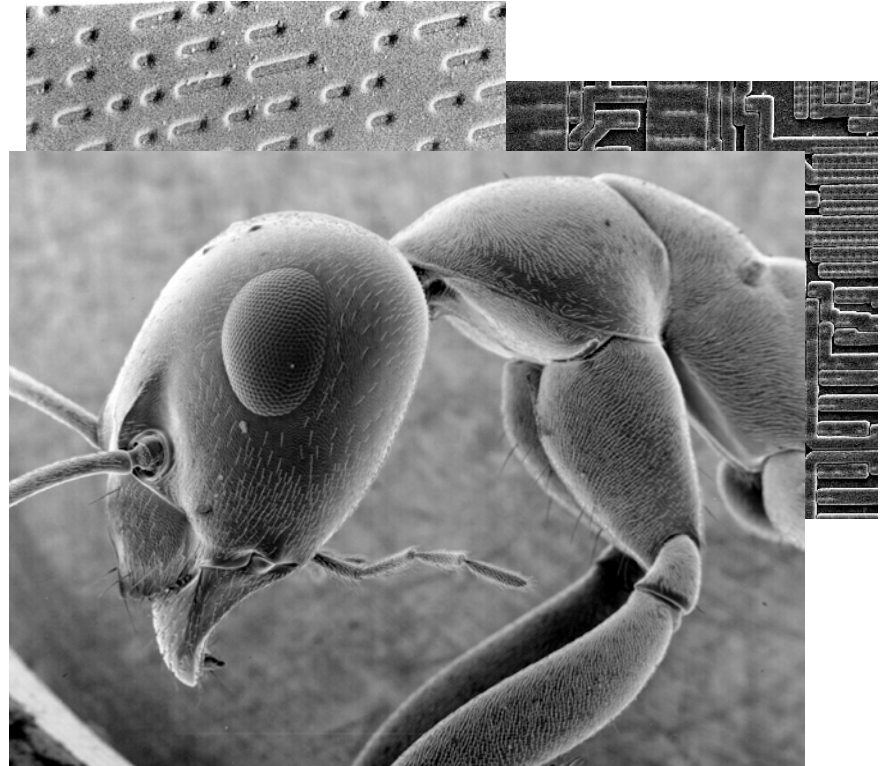
But can also be used on living things...

How can we visualize bone structures?

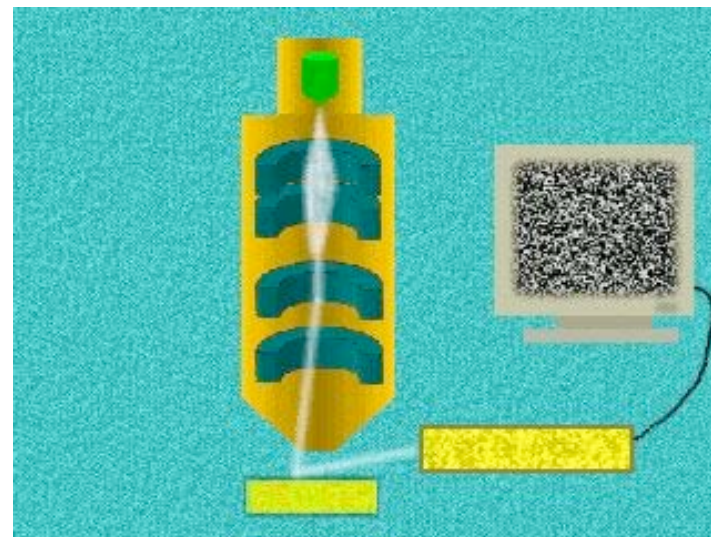
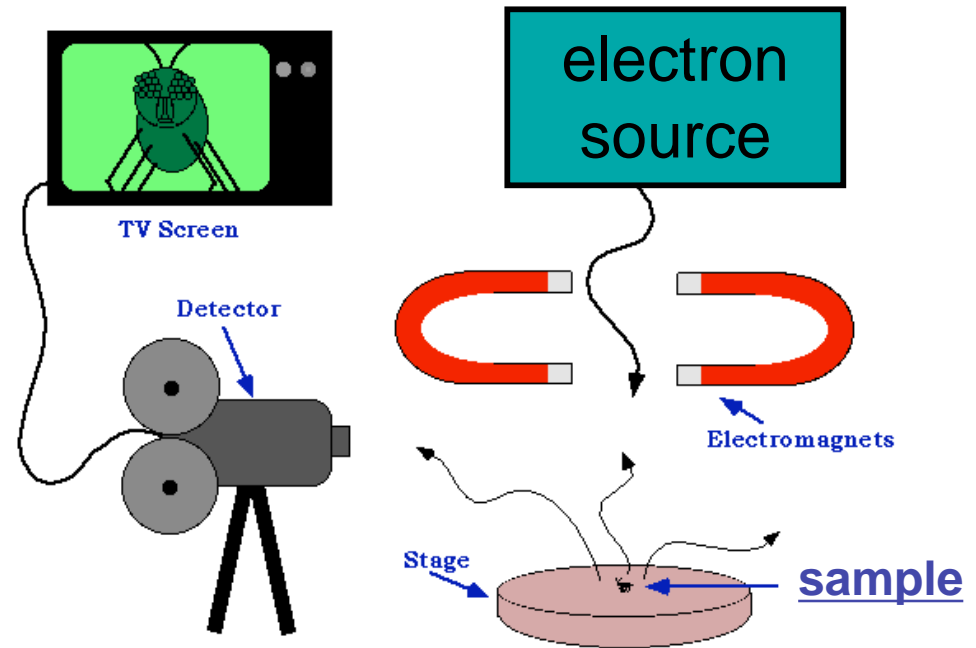
With a scanning electron microscope!



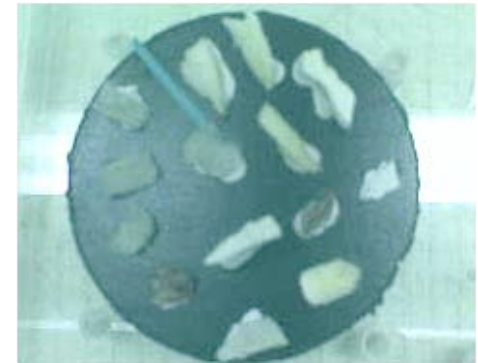
Usually used on inert materials:
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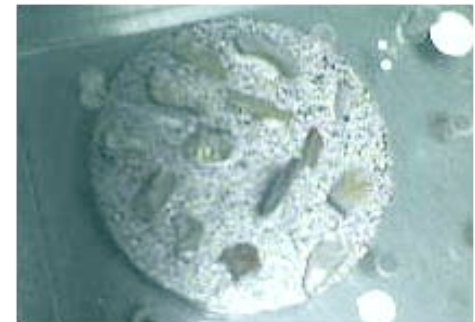
How Does an Electron Microscope Work



Let's Have a Look at Bone!



Prepared bone fragments



... covered with metal
(gold-palladium)

Compact Osteonal Bone

(the outer hard shell of bone)

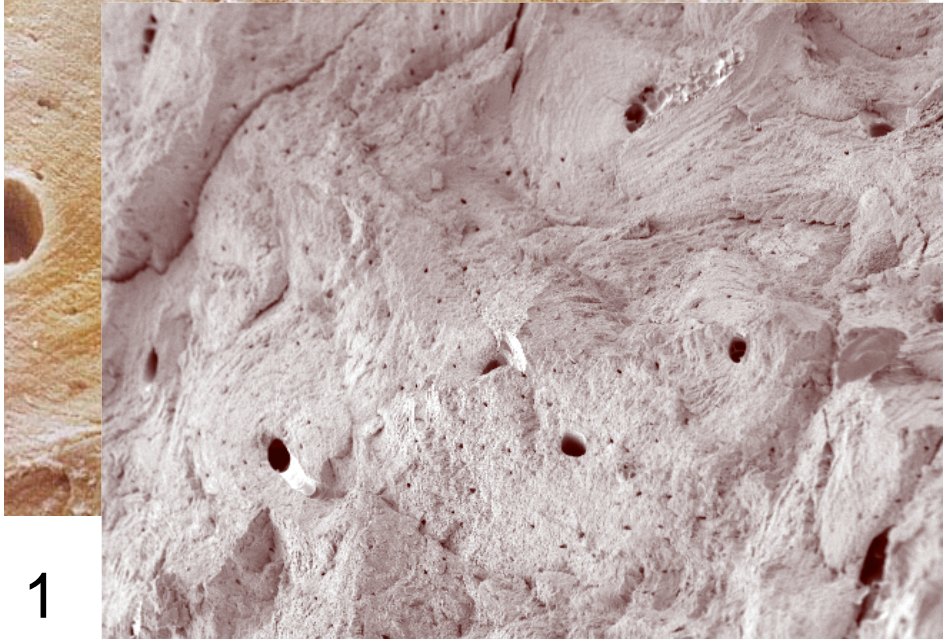
- “Outer” bone
- Very solid and hard to crack
- Very slow to build
- Found in... outer shell of every bone in your body



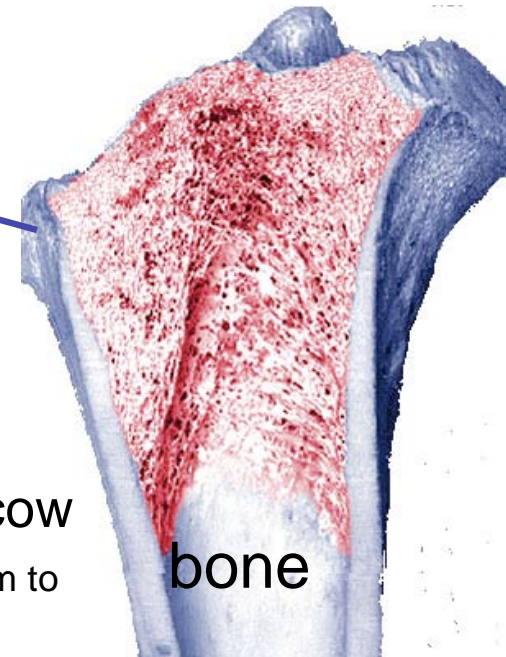
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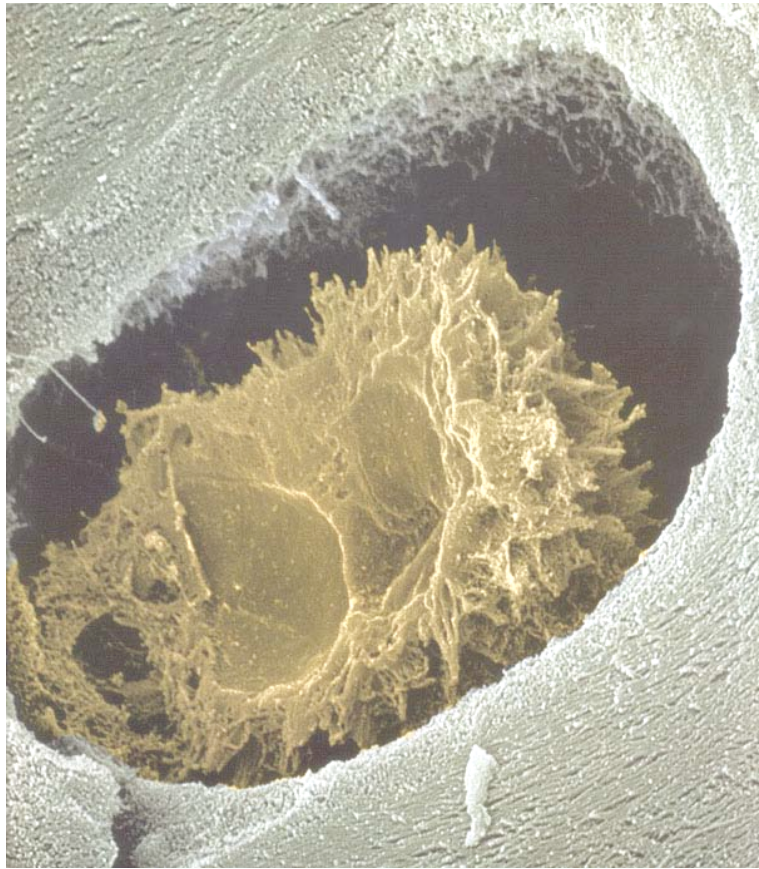


top view cow
spine, zoom to
osteocyte



bone

Osteocytes: the bone builders



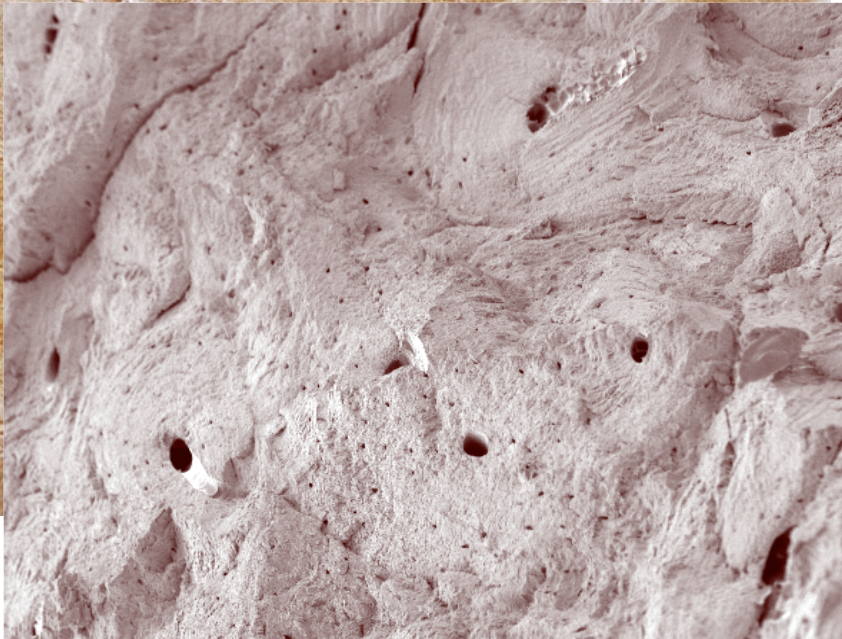
- Constantly mineralize, dissolve and rebuild bones
- They live in tunnels and cavities inside bones

Bone builder cell inside bone

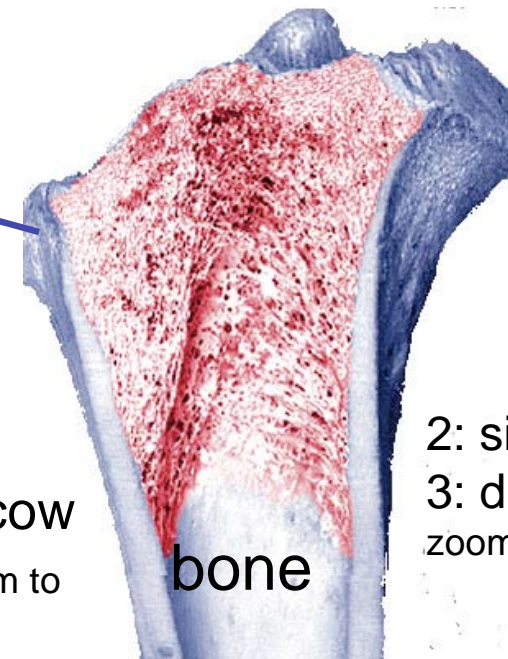
Compact Osteonal Bone

(the outer hard shell of bone)

- “Outer” bone
- Very solid and hard to crack
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top view cow
spine, zoom to
lacunae



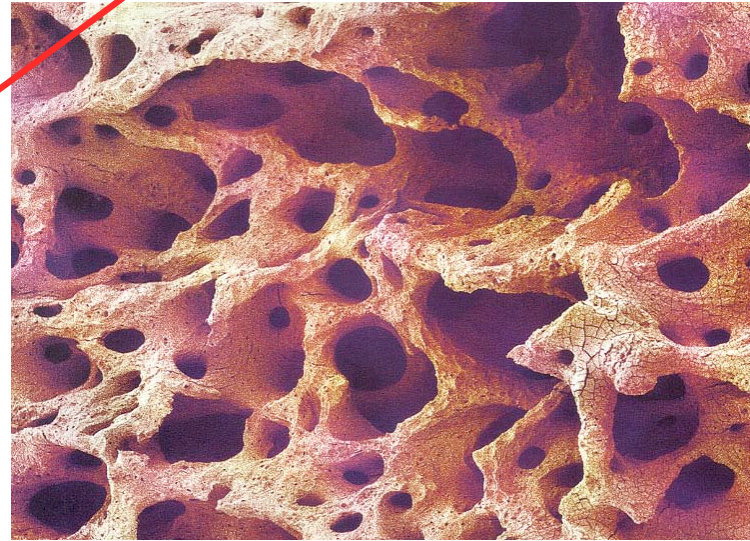
2: side view,
3: diagonal
zoom?

Spongy (soft, trabecular) Bone

This is the place where blood cells are born.



spongy bone



- Inside of bones
- Not very solid, but it's light!
- Propagates stress well
- Open space used to make red blood cells

compact bone



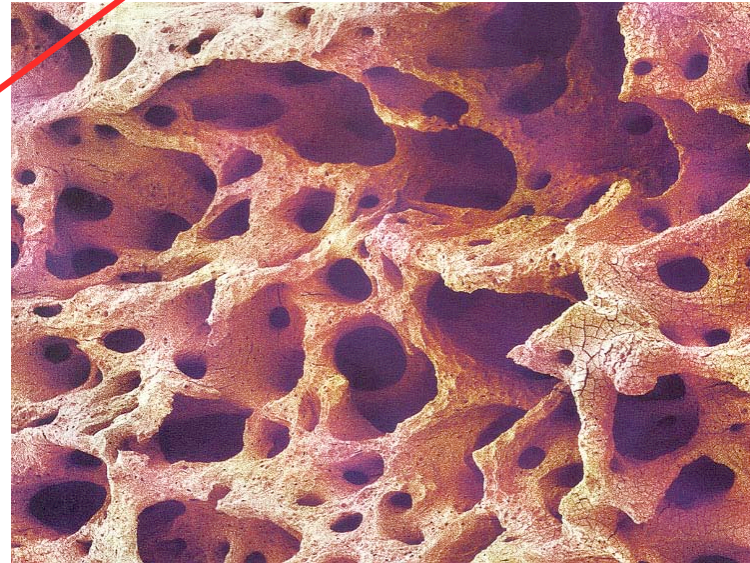
bridges also propagate stress to leave room for water and ships

Spongy (soft, trabecular) Bone

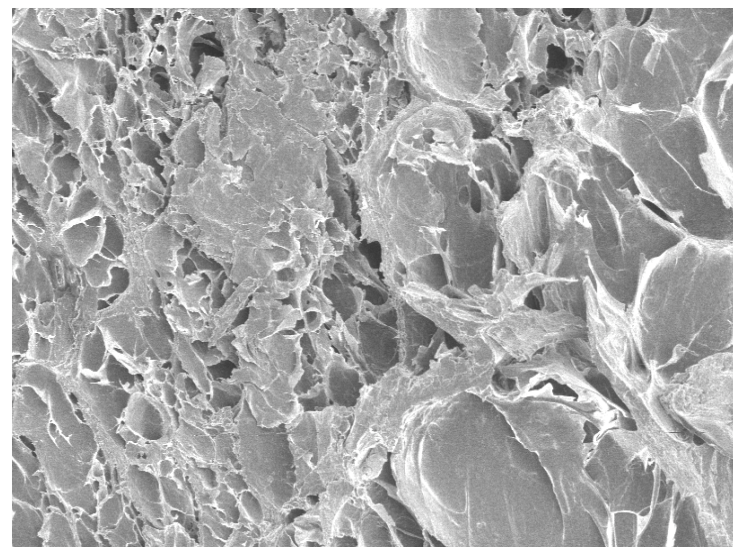
This is the place where blood cells are born.



spongy bone



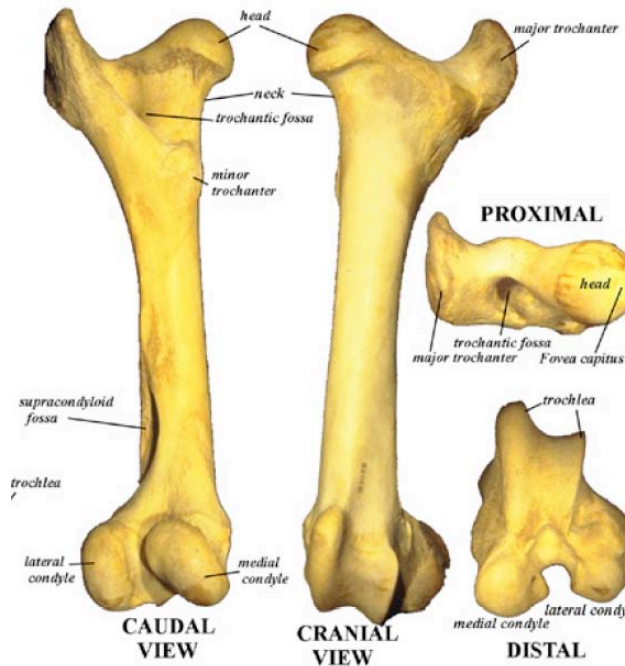
- Inside of bones
- Not very solid, but it's light!
- Propagates stress well
- Open space used to make red blood cells



4: spongy bone

compact bone

Compact Plexiform Bone



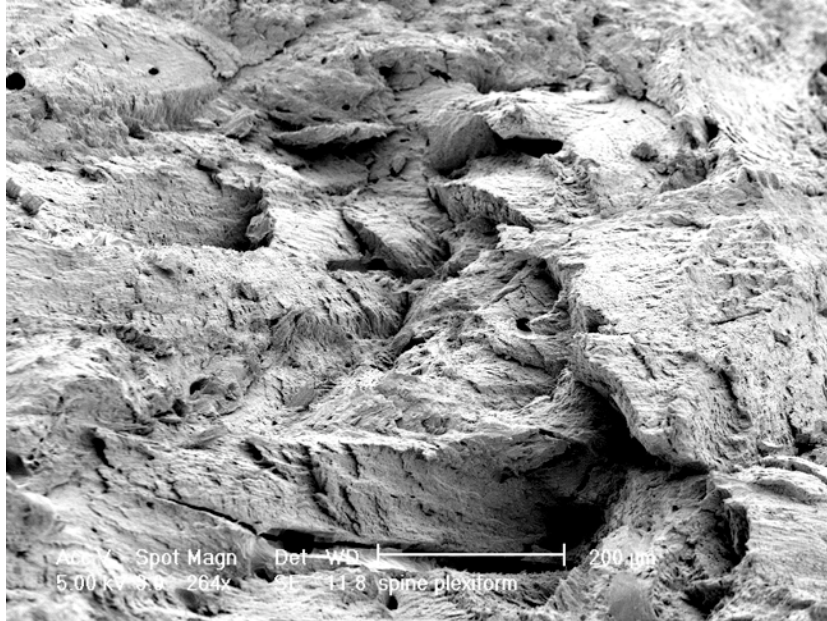
- most solid type of bone
- Grows very quickly
- But... cracks easily
- Found in... big bones of big fast-growing animals (e.g., sheep, cow)



Like plywood!



Compact Plexiform Bone



5: strong bone built from sheets

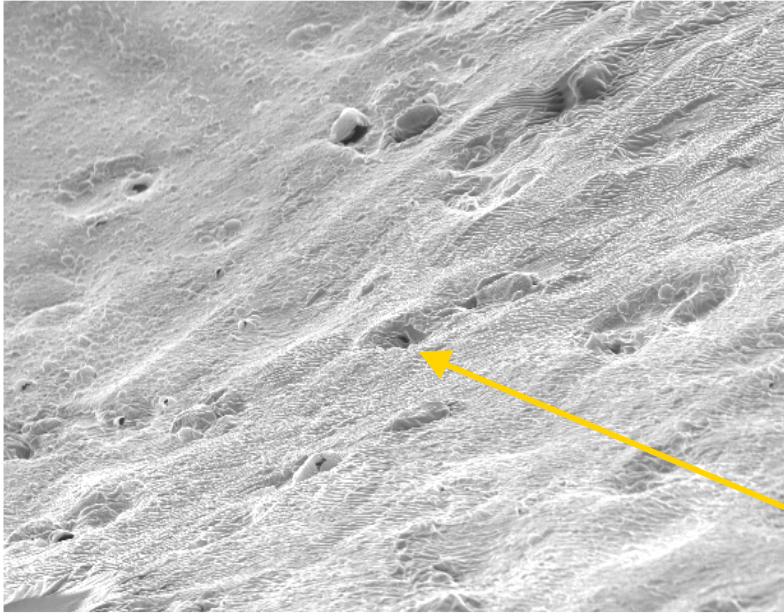
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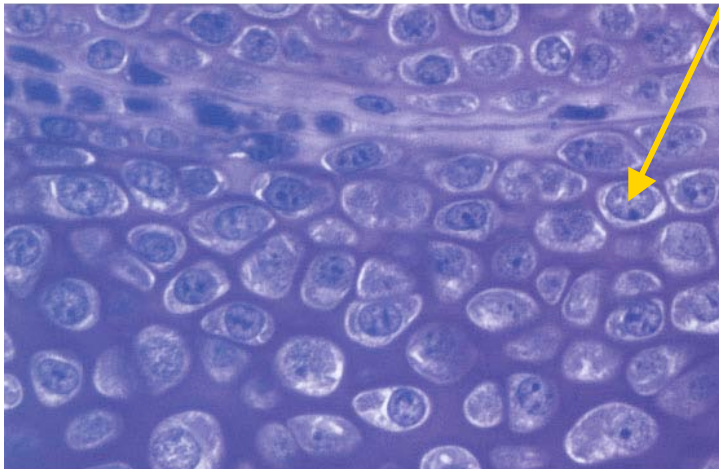


Cartilage: like “bone” without calcium



6: cartilage from chicken

Light microscope view

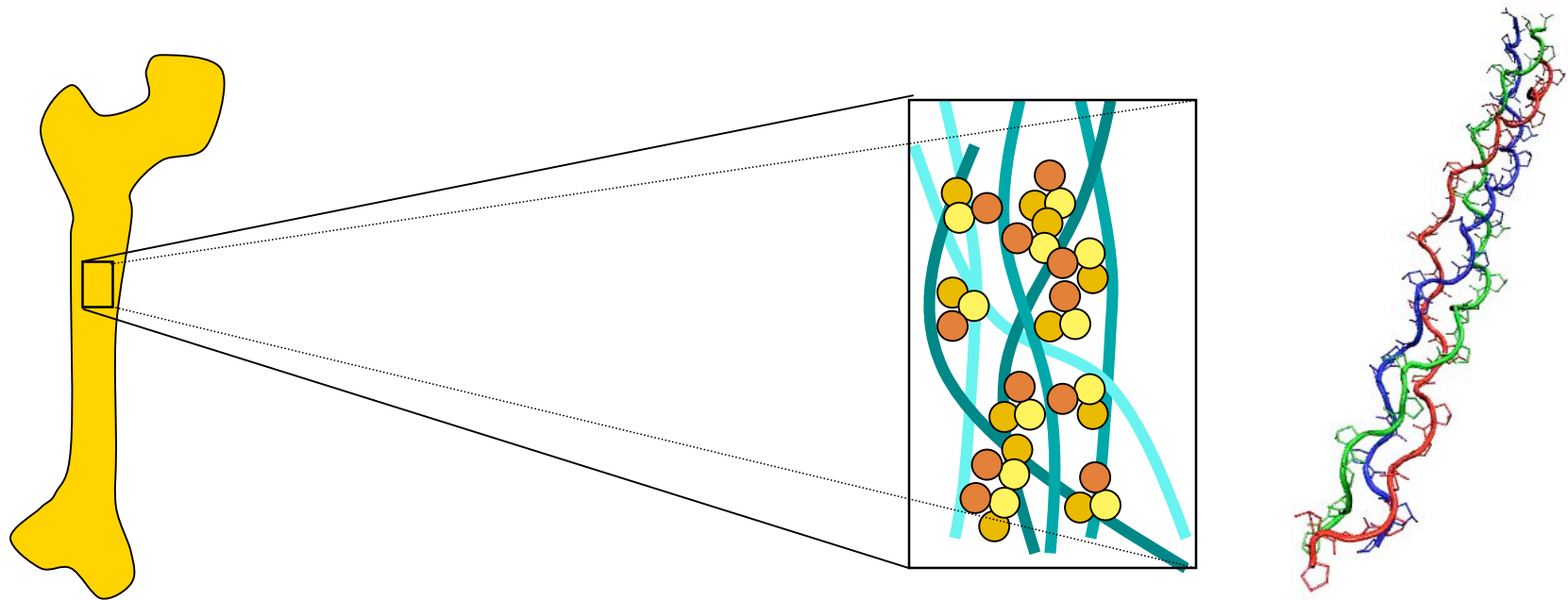


- Made of:
 - collagen fibers
 - Mixed with sugars and proteins
- Cartilage cells are embedded inside for maintenance
- Found in... joint, and your ear!

7: zoom to 25,000 x

Physics of the bone

- All bones are made of the same materials, but many bones have different physical properties.



tropocollagen molecule

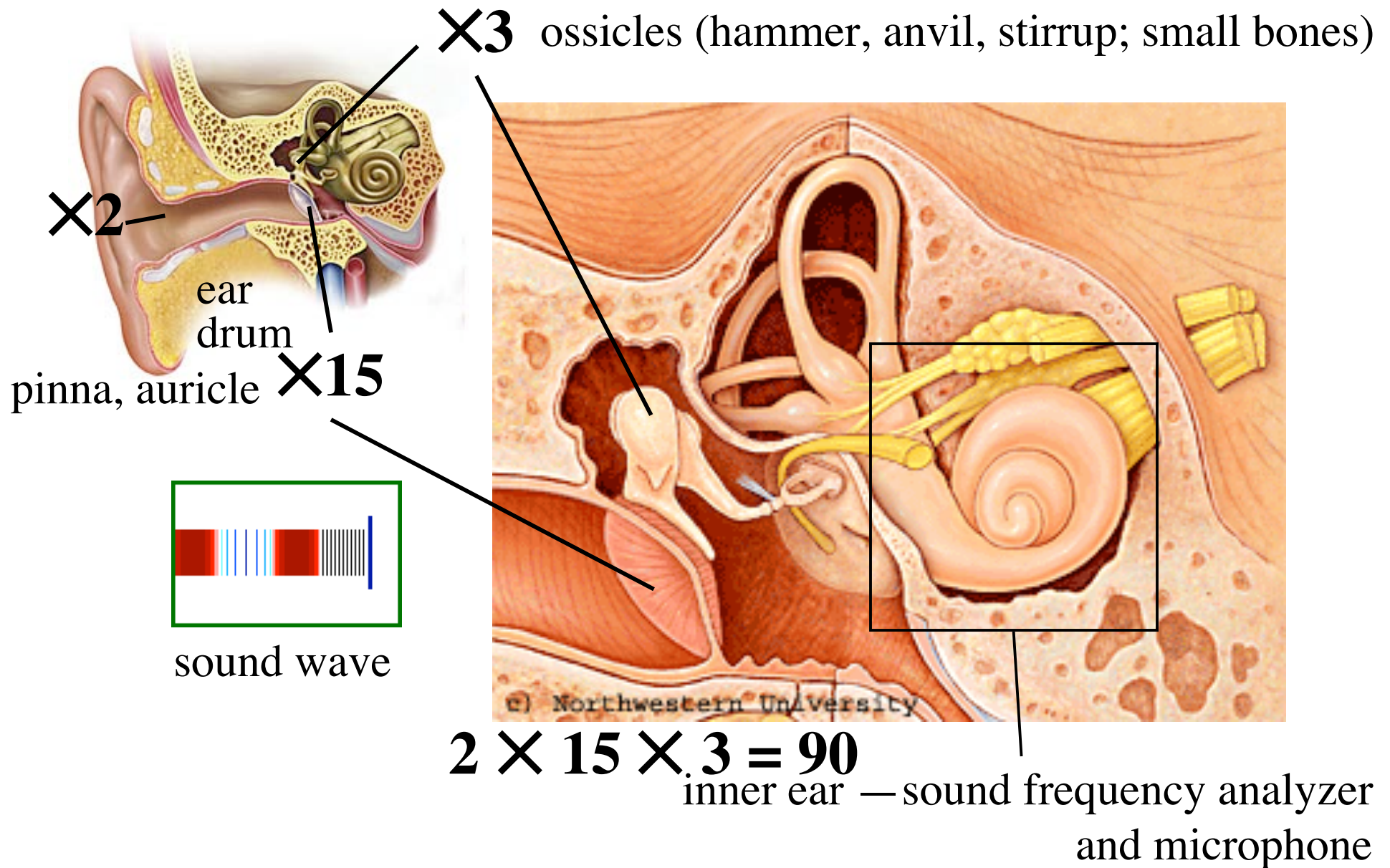


Physics of the Ear

How to repel teenagers and win the Ig Nobel Prize?



Outer and Middle Ears — Sound Amplifier



Characterizing Sound

- Loudness
- Pitch
- Timbre

1: play movie; 2: frequency generator 1 on, amplitude, frequency $f(t)$

Characterizing Sound

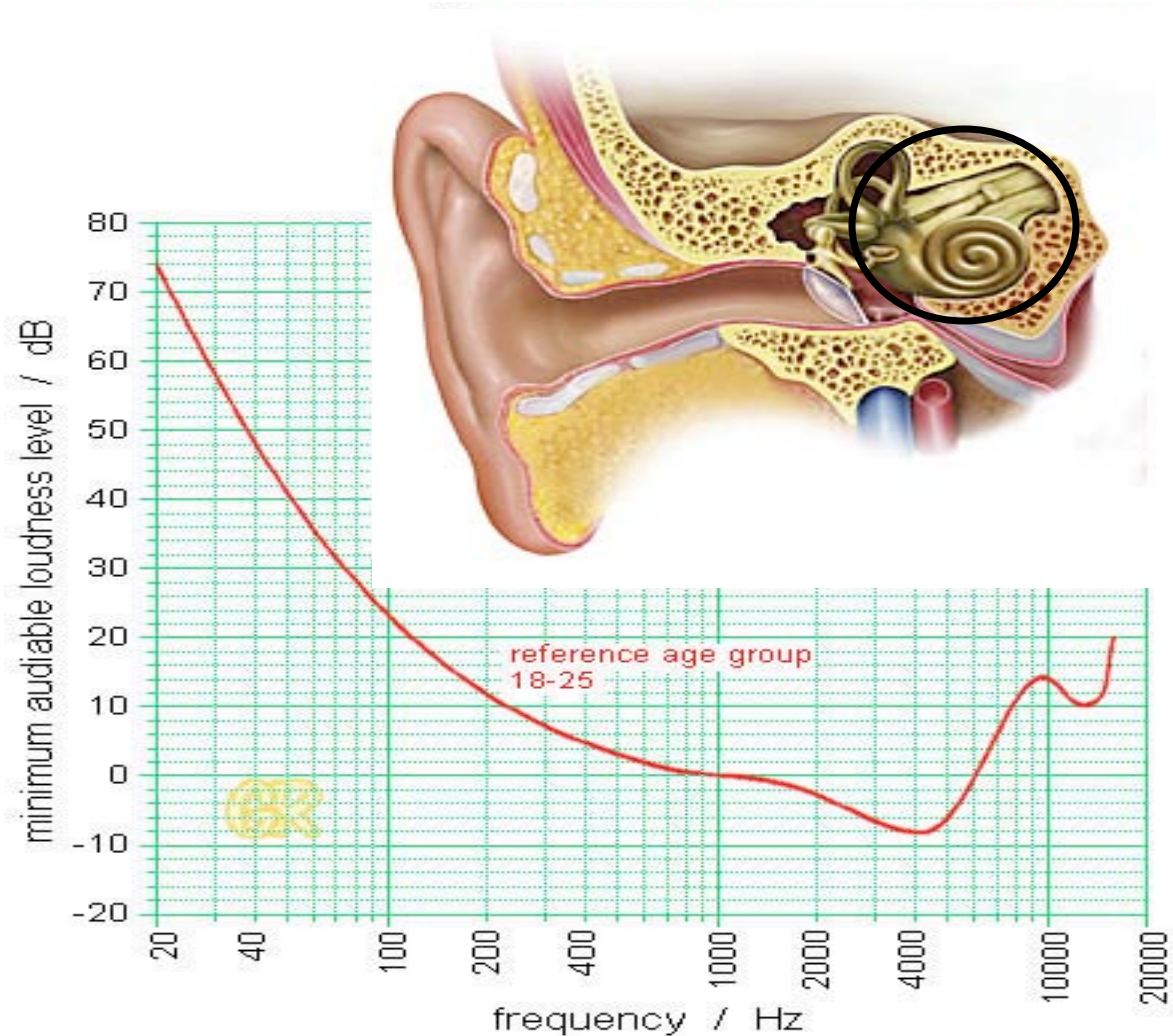
- Loudness
- Pitch
- Timbre



3: single frequency, w_1 ; 4: turn on frequency generator 2 with $w_1 + w_2$; 5: Emma; 6: vol.

Repelling Teenagers and More...

Presbycusis
—hearing
impairment in
older adults



Frequency Sensitivity of Human Ear for Young Adults

Frequency Sensitivity of the Audience

- Please raise your hand.
- When you no longer hear the sound, put your hand down.



Repelling Teenagers — Ultrasonic Youth Deterrents



trials have shown that teenagers are acutely aware of the Mosquito™ and move away from the area within just a couple of minutes...

Youth-only Ringtones



mosquitotone

GET THE OFFICIAL MOSQUITO
RINGTONE DIRECT TO YOUR
MOBILE PHONE!

text **MOZZY** or **MOZZIE**
to **87070**
and get the ringtone that's
sweeping the nation now!

16+. You must have the permission of the bill
payer. Check your phone for compatibility.
Tones are charged at 2 x £1.50 msgs.
Usual network costs apply.
Customer services 0871 872 9899.
E-mail help@ukcustomersupport.com

Not So Intelligently Designed

— Fooling the Ear

Nr. 3
Trio in B
D 898 - op. 99

Allegro moderato

Violino

Violoncello

Pianoforte

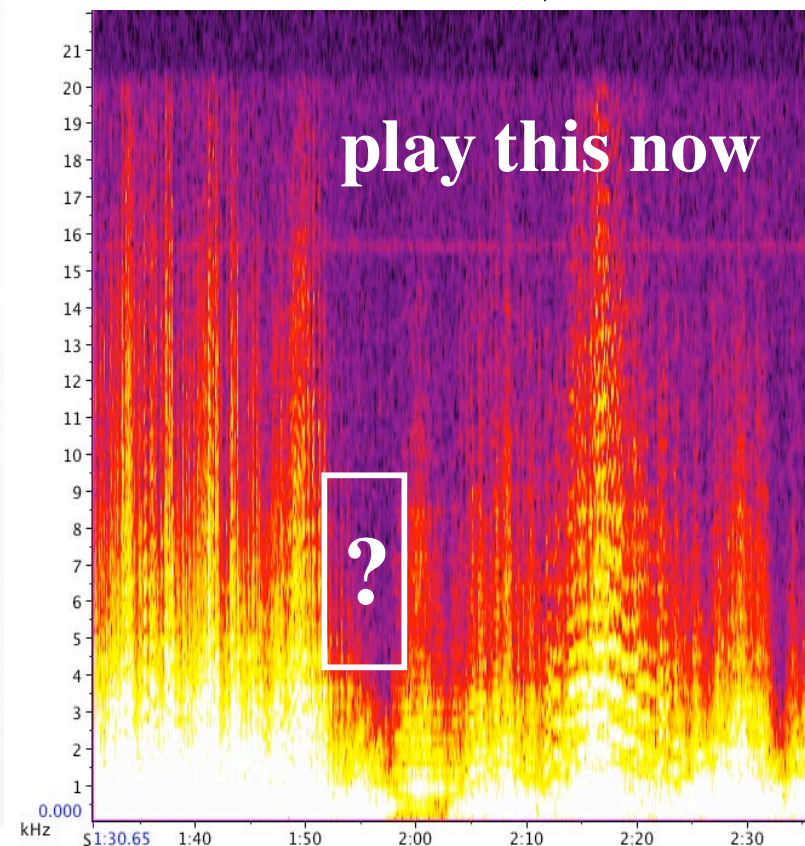
5

10

BA 5607

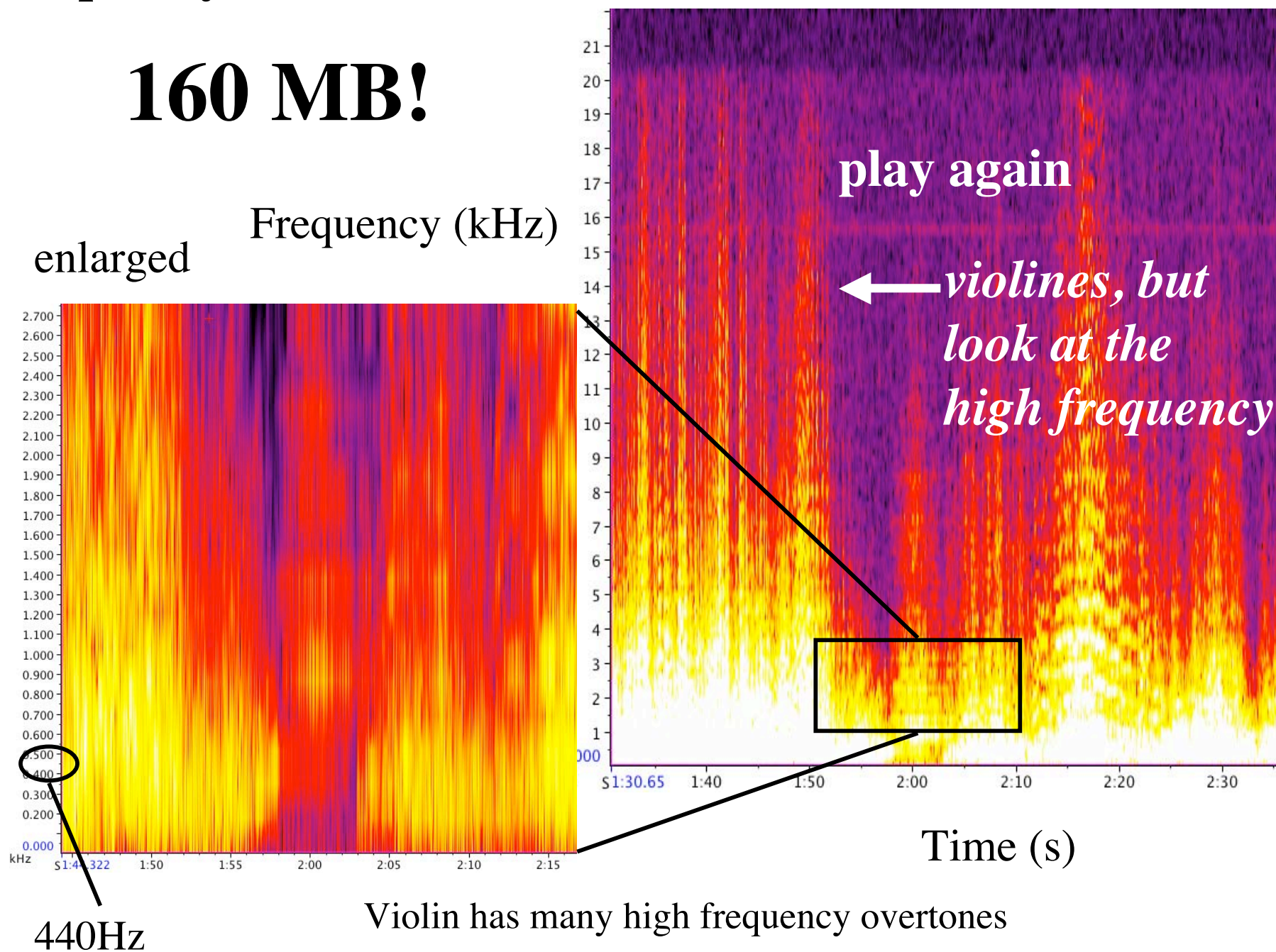
© 1975 by Bärenreiter-Verlag, Kassel

Frequency distribution over time of
Schubert Piano Trio, 160 MB



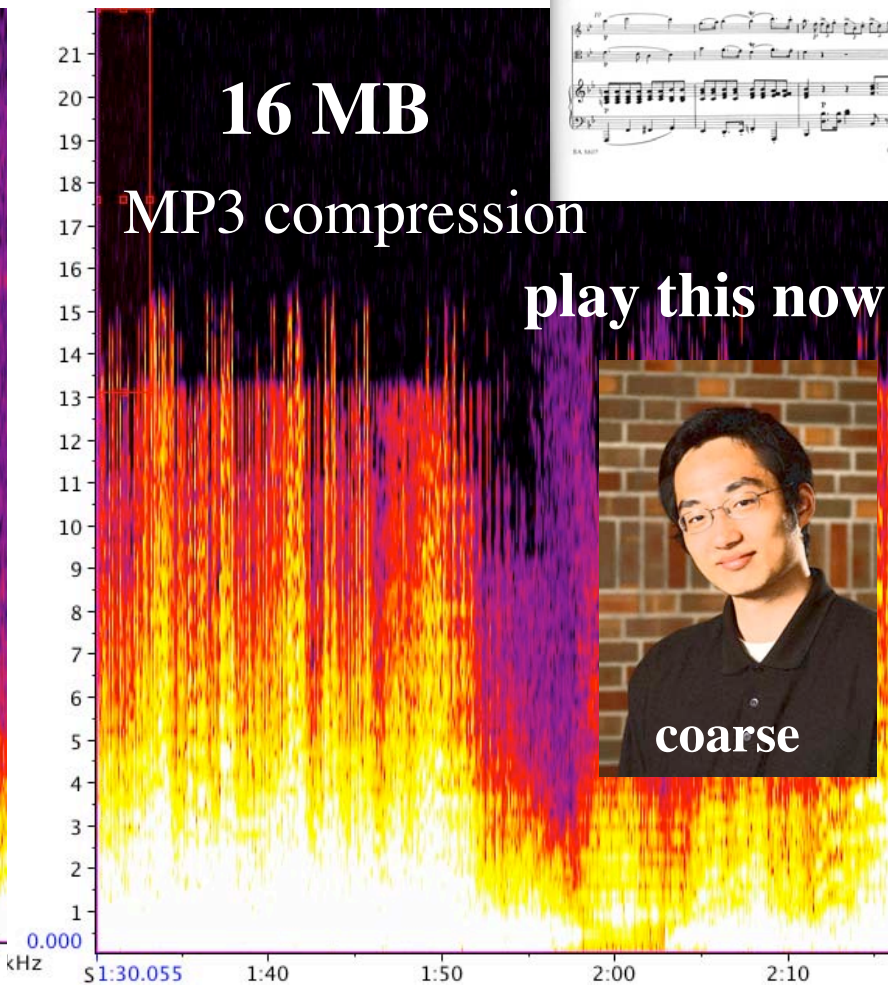
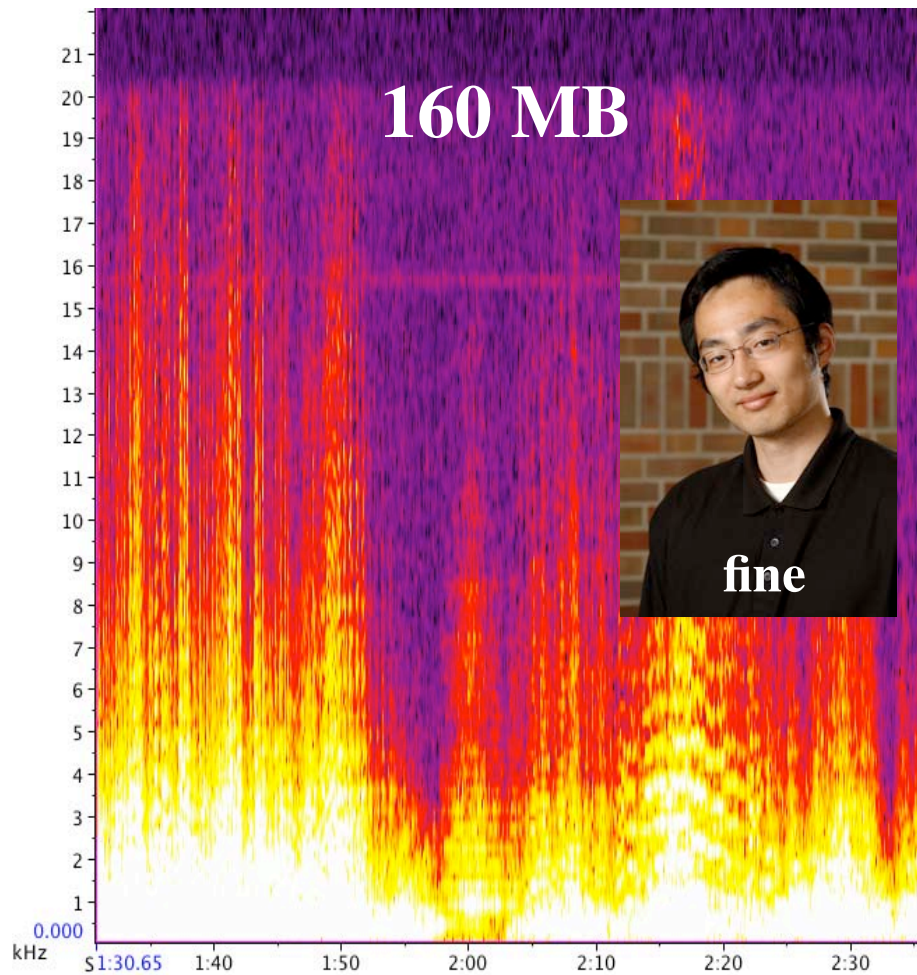
Frequency distribution over time of Schubert Piano Trio

160 MB!



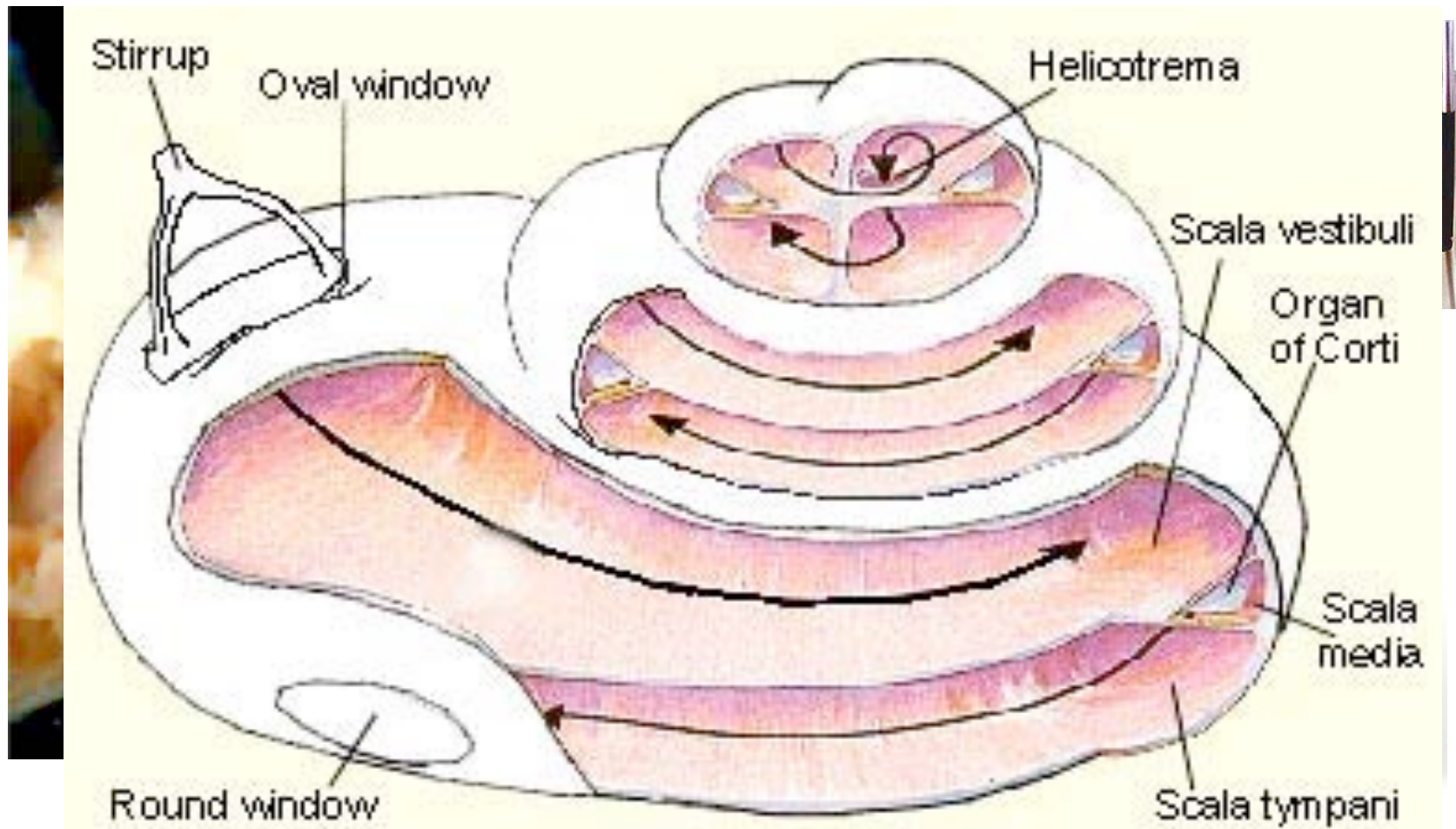
Not So Intelligently Designed

— Fooling the Ear, But More Songs on the iPod



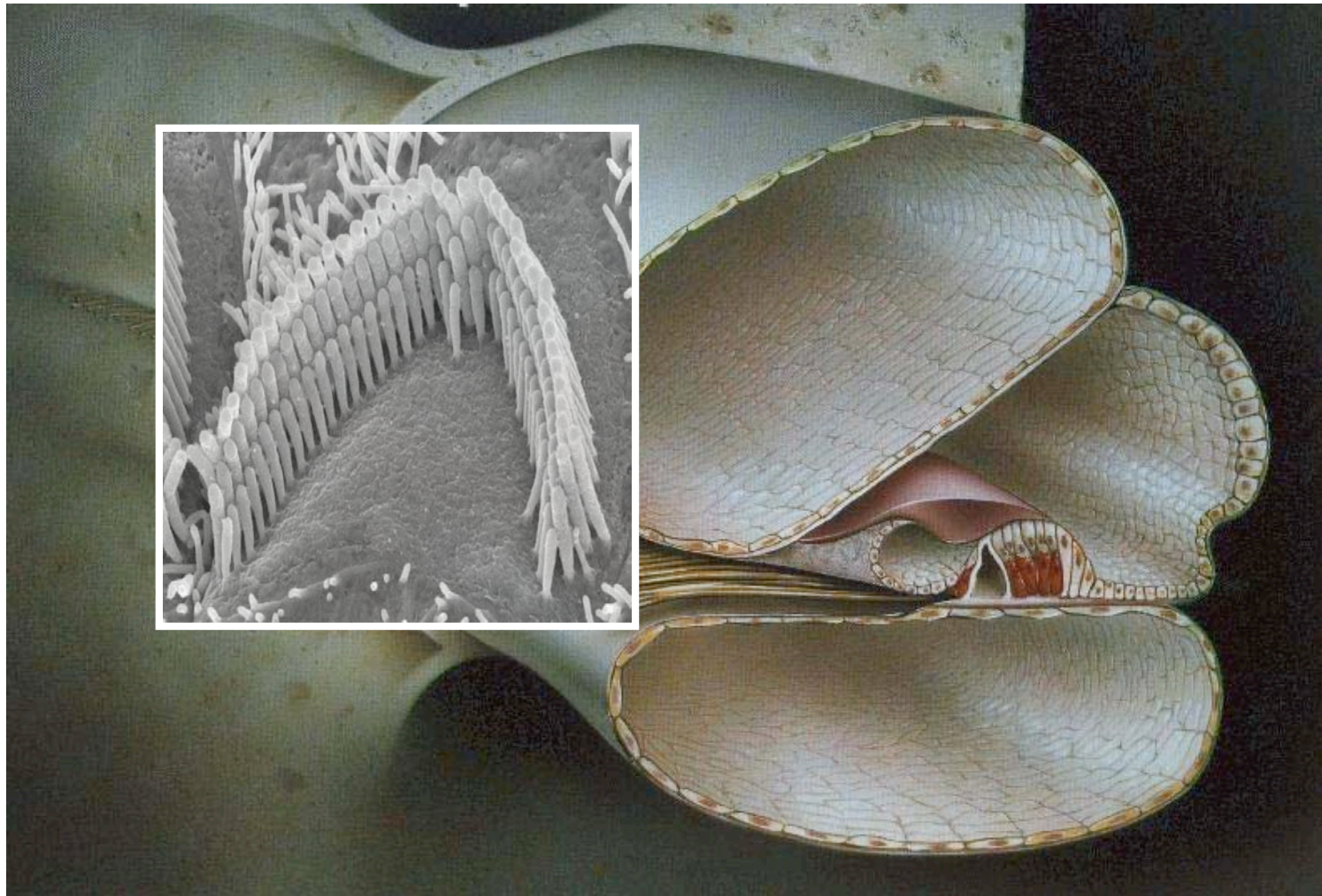
The Cochlea

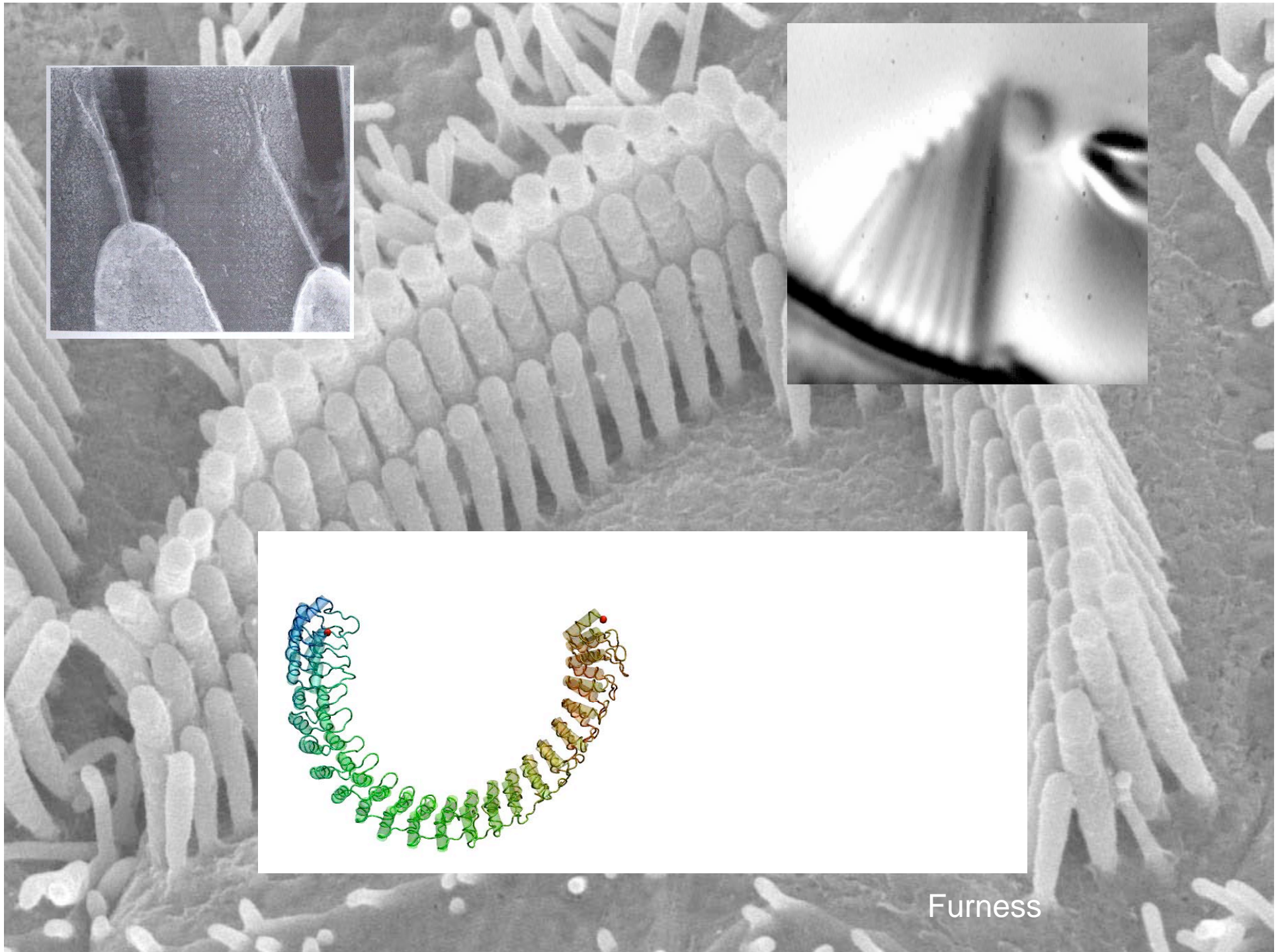
— Frequency Analyzer and Microphone



The Cochlea

— Frequency Analyzer and Microphone

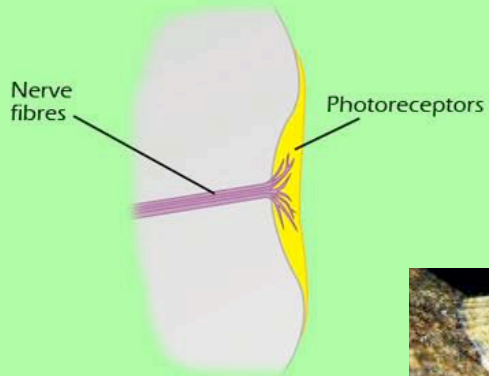




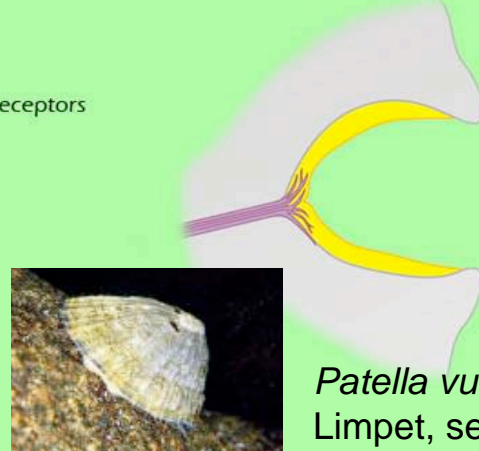
Furness

Evolution of the Eye!

a) Region of photosensitive cells

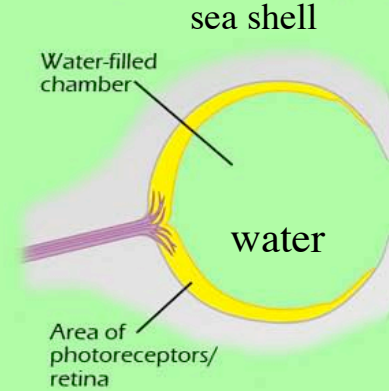


b) Depressed/folded area allows limited directional sensitivity



Patella vulgata
Limpet, sea shell

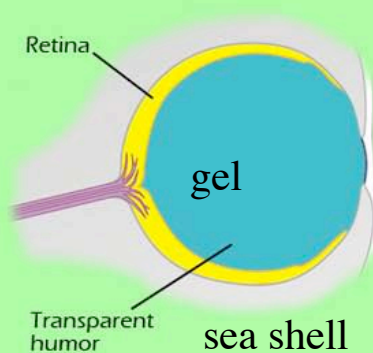
c) "Pinhole" eye allows finer directional sensitivity and limited imaging



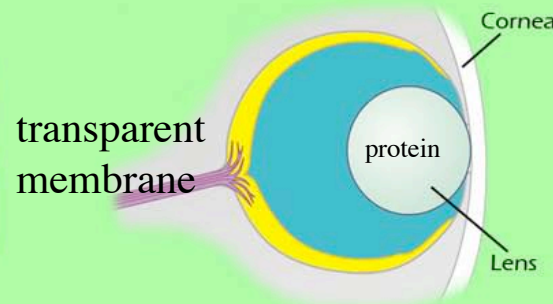
Nautilus



d) Transparent humor develops in enclosed chamber



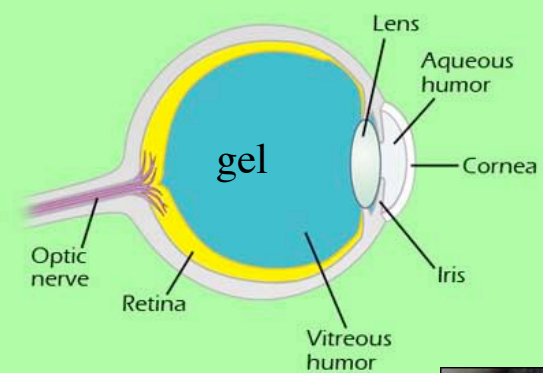
e) Distinct lens develops



Nucella, sea snail

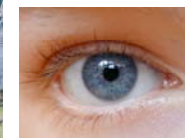


f) Iris and separate cornea develops

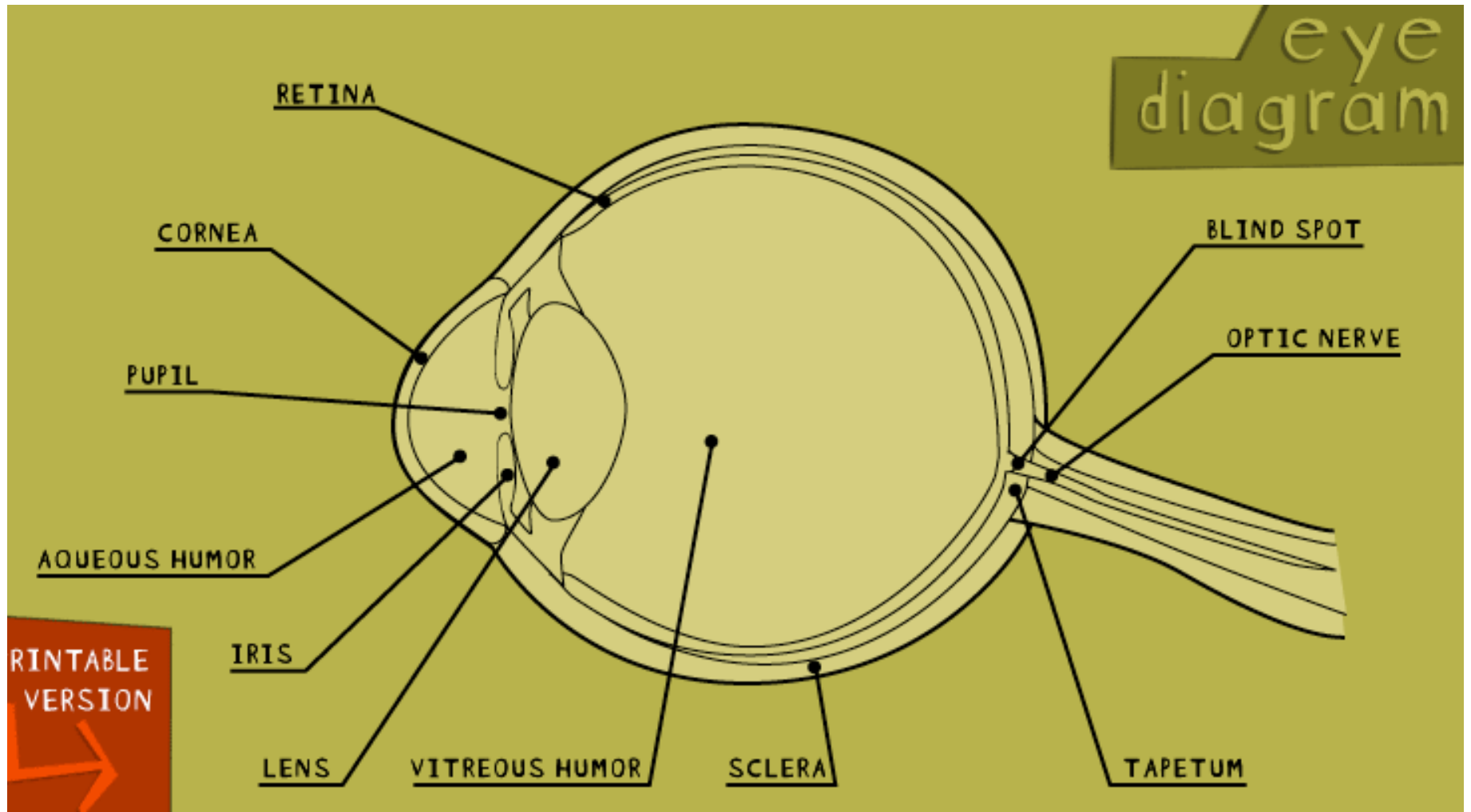


cow,
human,
monkey,
etc...

Haliotis tuberculata

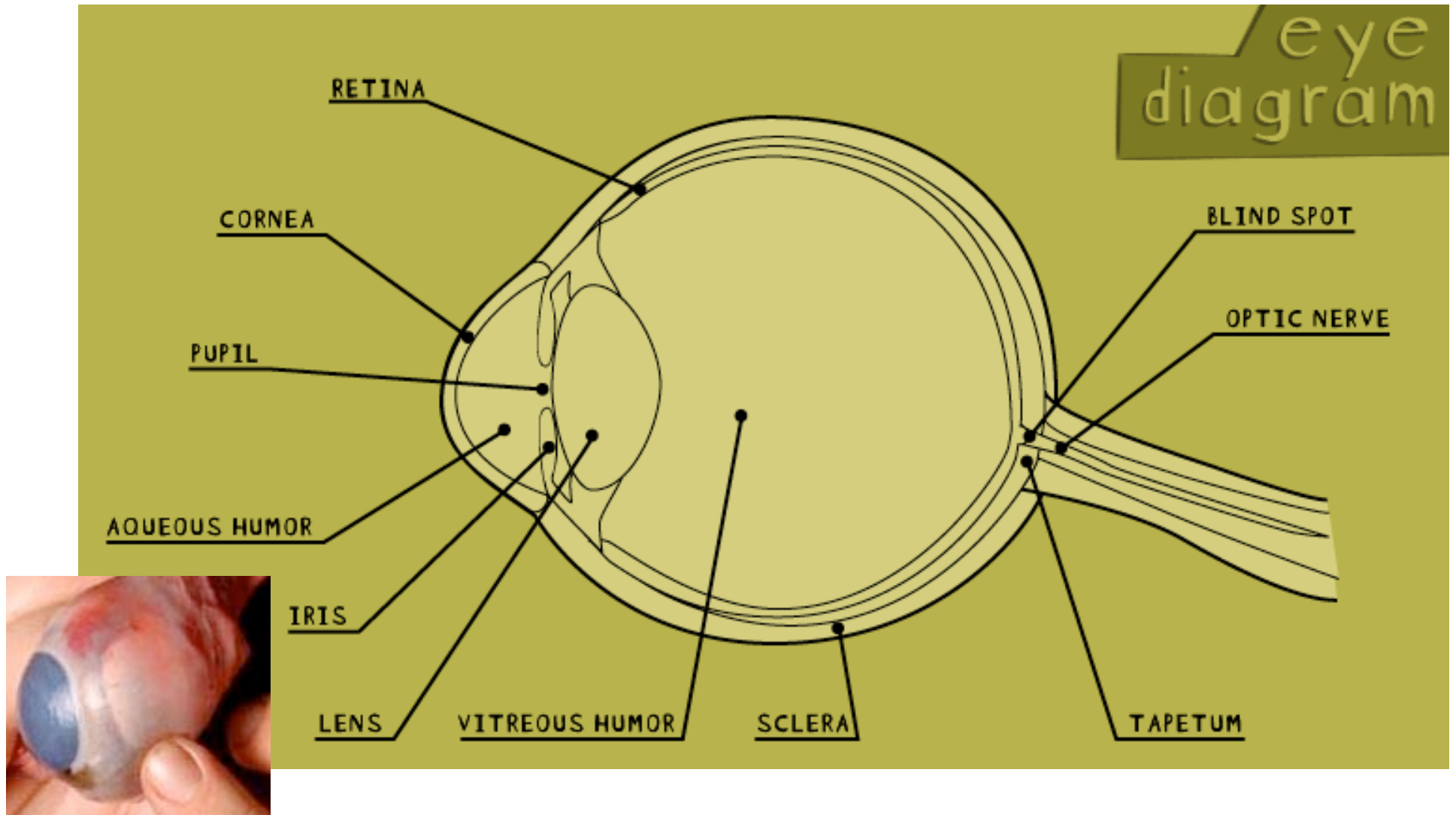


The Architecture of the Eye



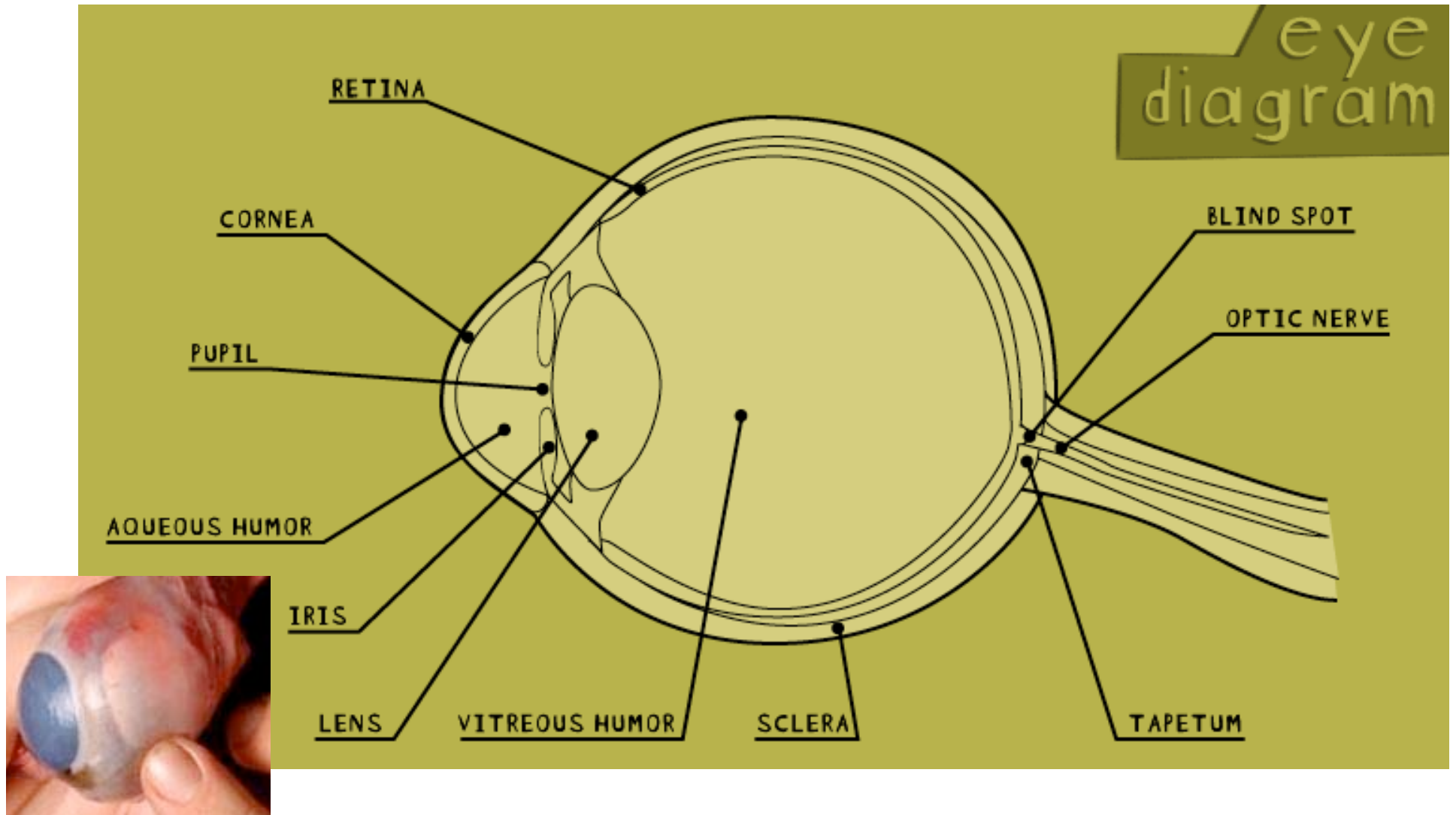
Let's take it apart! -- Dissecting a cow's eye

The Architecture of the Eye



Let's take it apart! -- Dissecting a cow's eye

The Architecture of the Eye



↑ Whose eye is this?

Let's take it apart! -- Dissecting a cow's eye

Lens -- it's a magnifier!

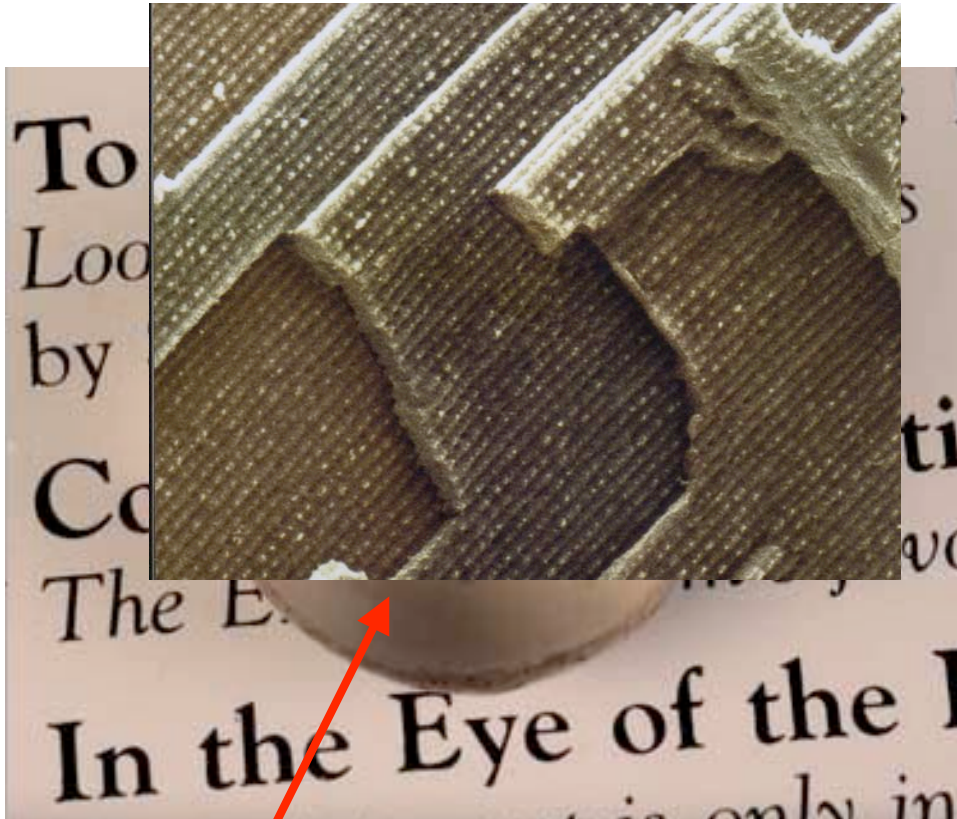


image is **bigger**
and **not inverted**

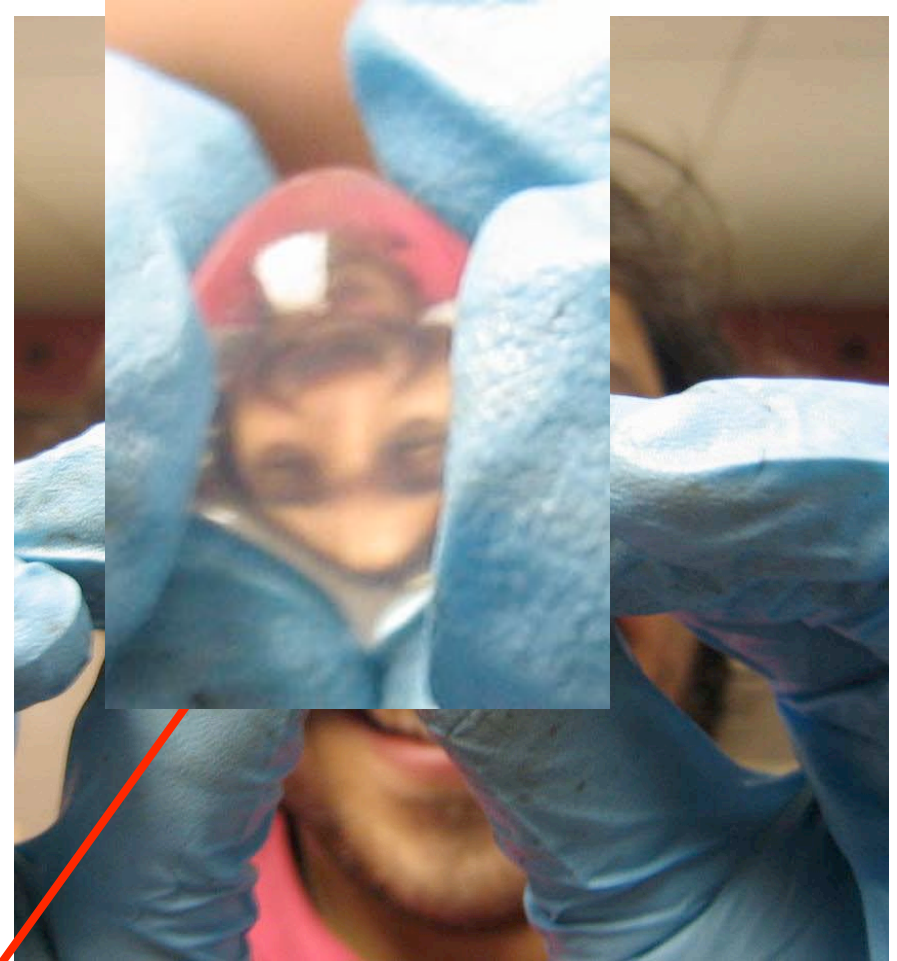
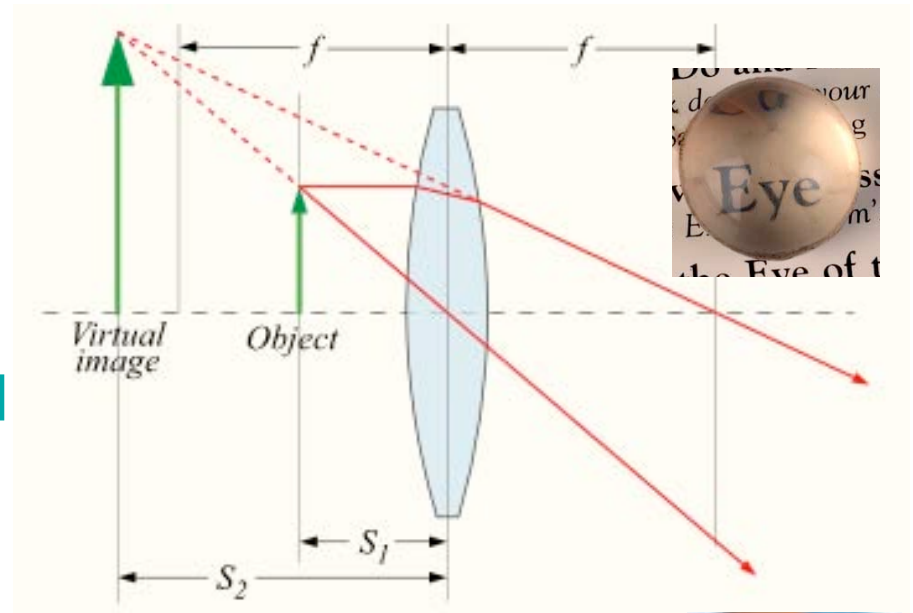


image is **smaller**
and **inverted**

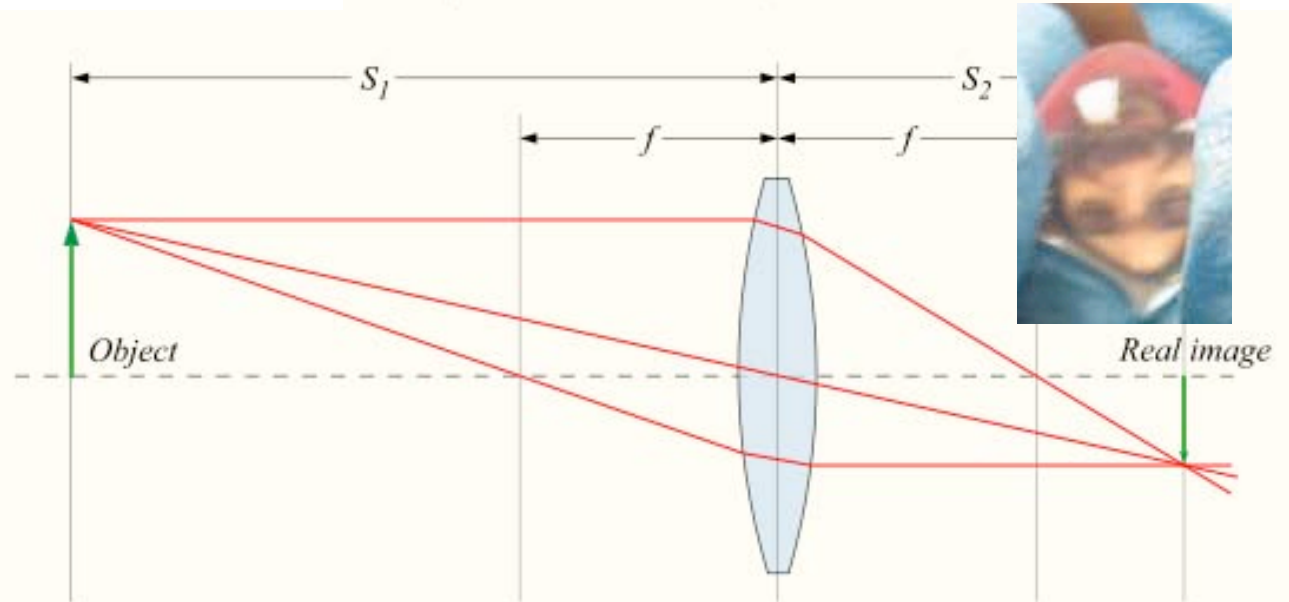
WHY?

Optics of a convex lens

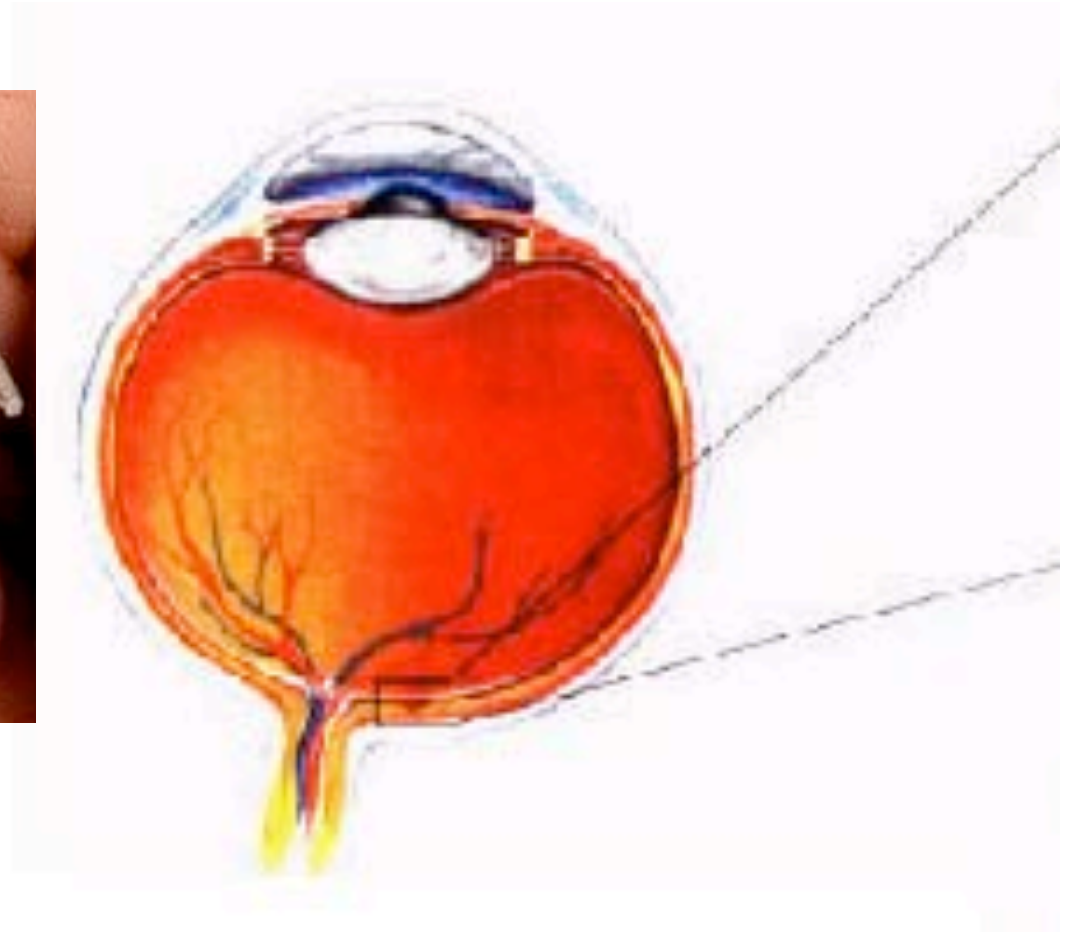
Put the object really **close** to the lens, we get an image that's **bigger** and **not inverted**

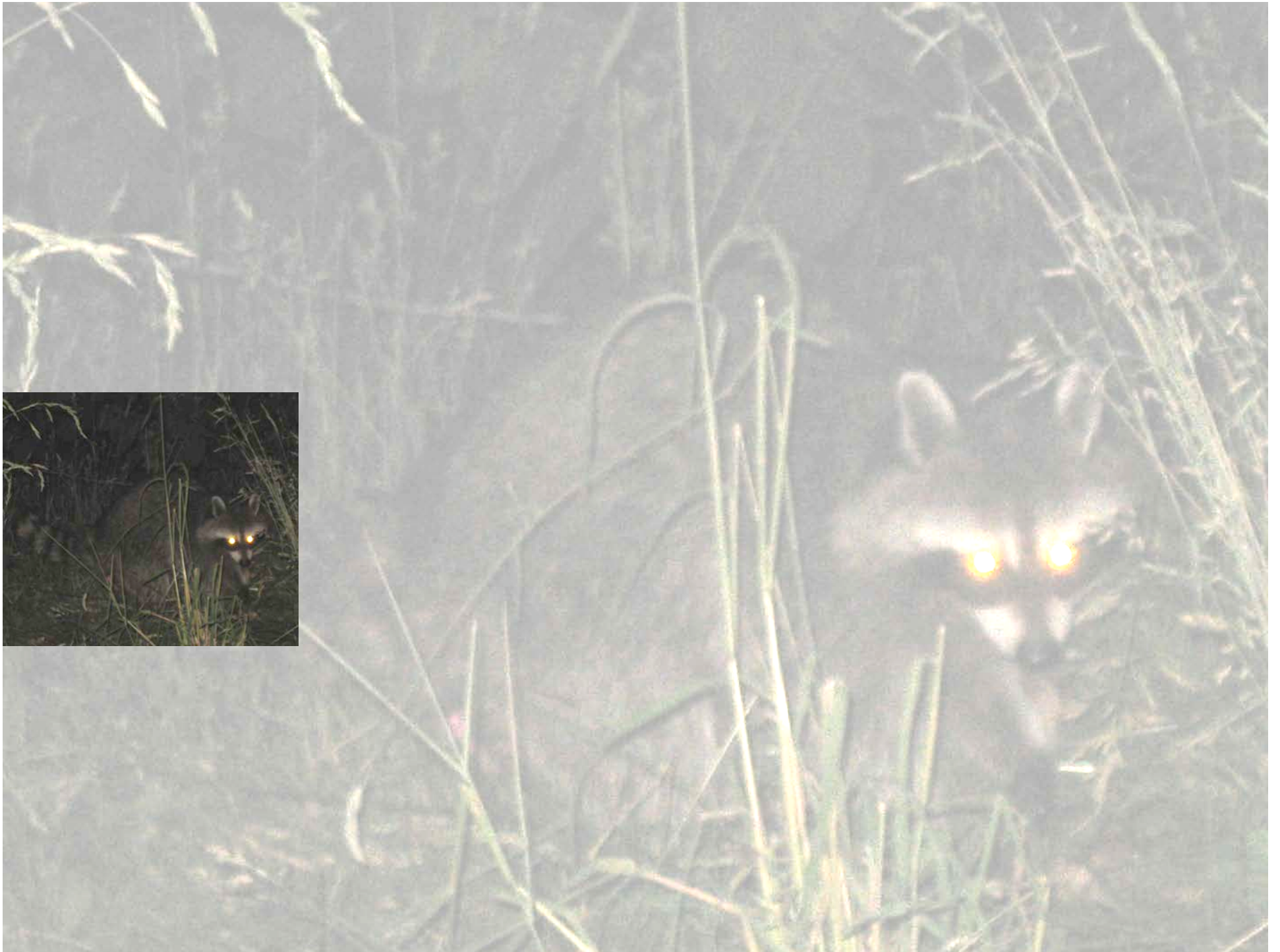


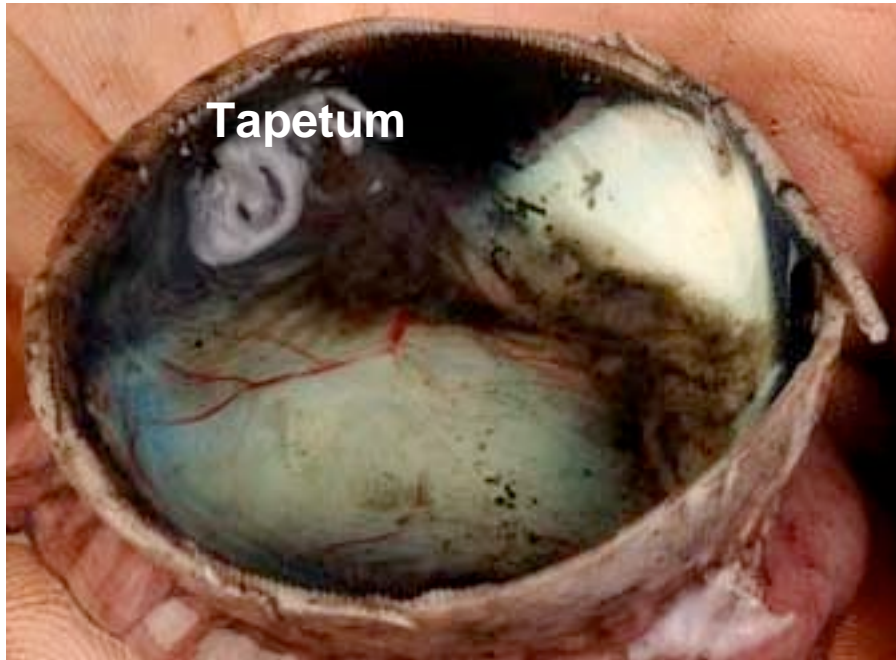
Put the object really **far away** from the lens, we get an image that's **smaller** and **inverted**



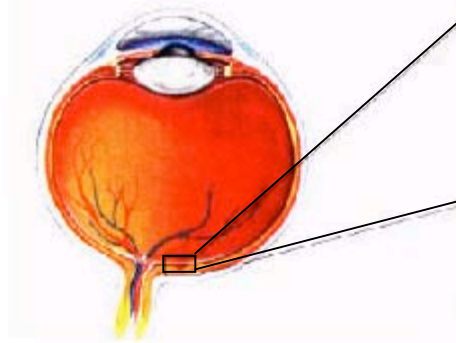
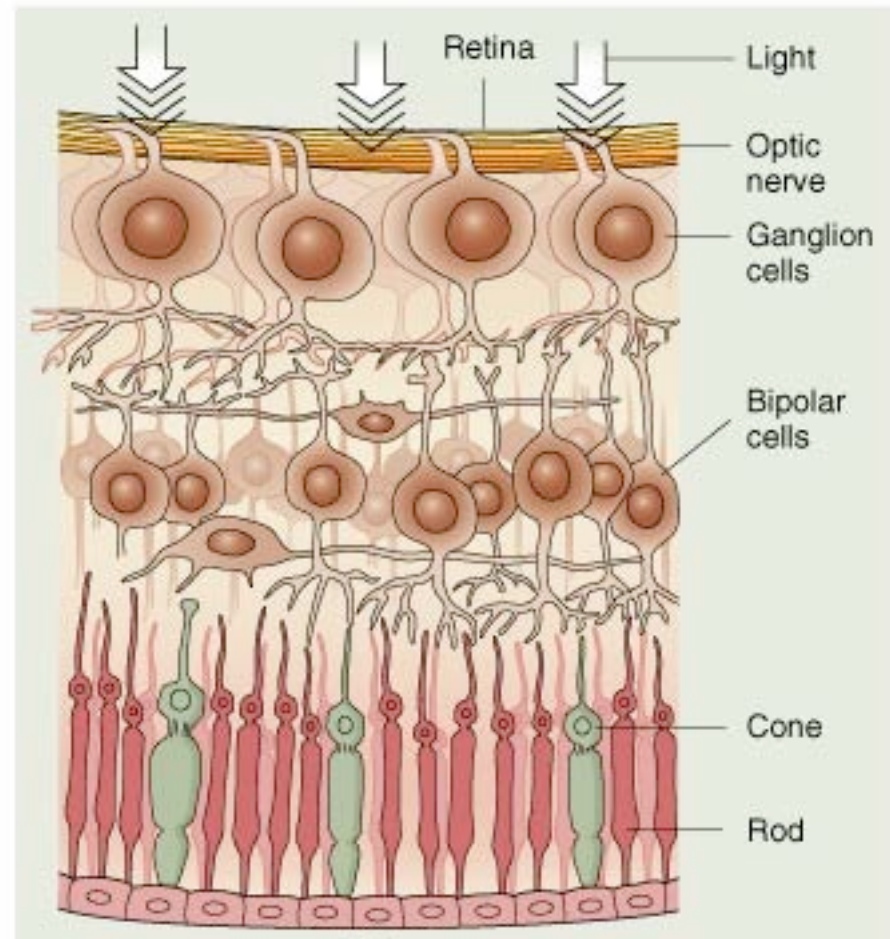
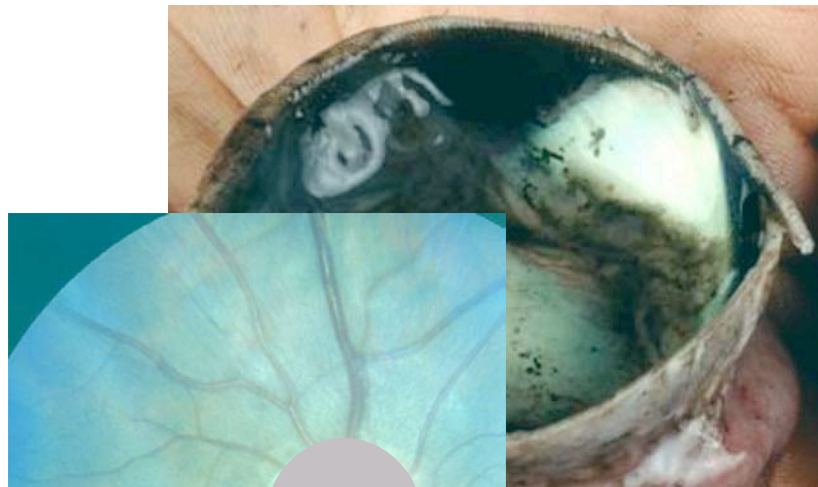
The Tapetum of the Eye







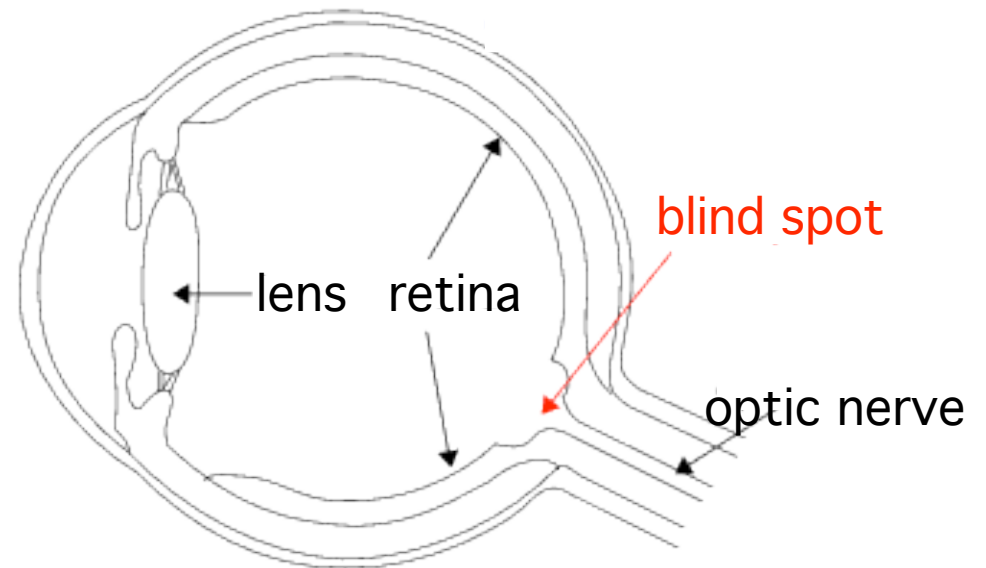
Retina -- it's a layer of light-sensitive cells



- * Rod cells sense **brightness**
- * Cone cells sense **color**

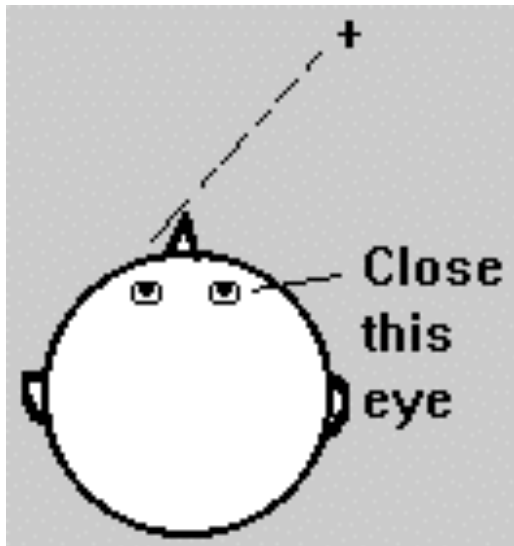
More rod and cone cells than citizens in the US!

Retina -- only attached to the eye in one spot



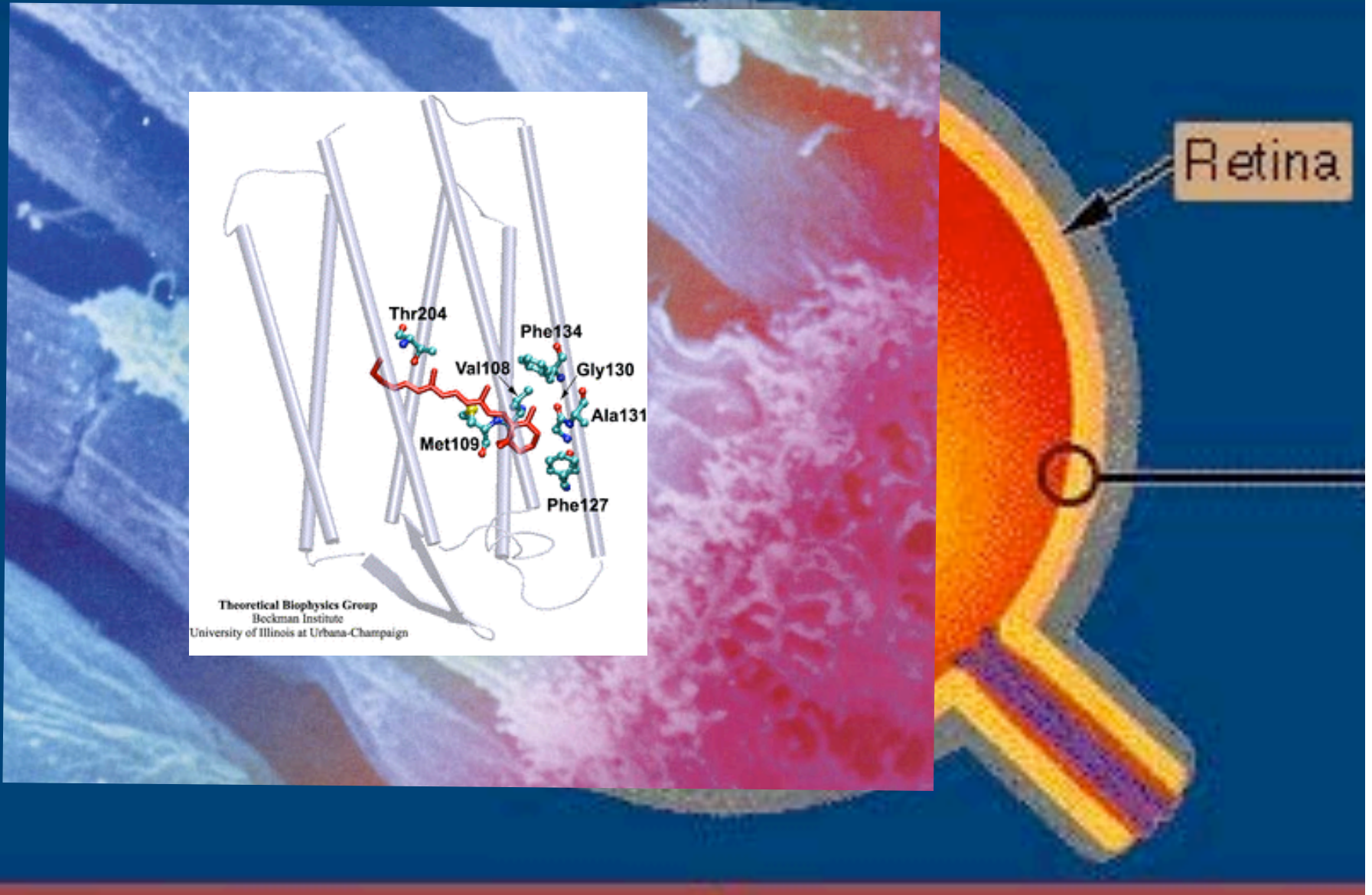
- * All the nerves from the retina join to form optic nerve at the blind spot
- * There are no light-sensitive cells at the blind spot
- * Cannot see anything that lands on blind spot

Blind Spot Test

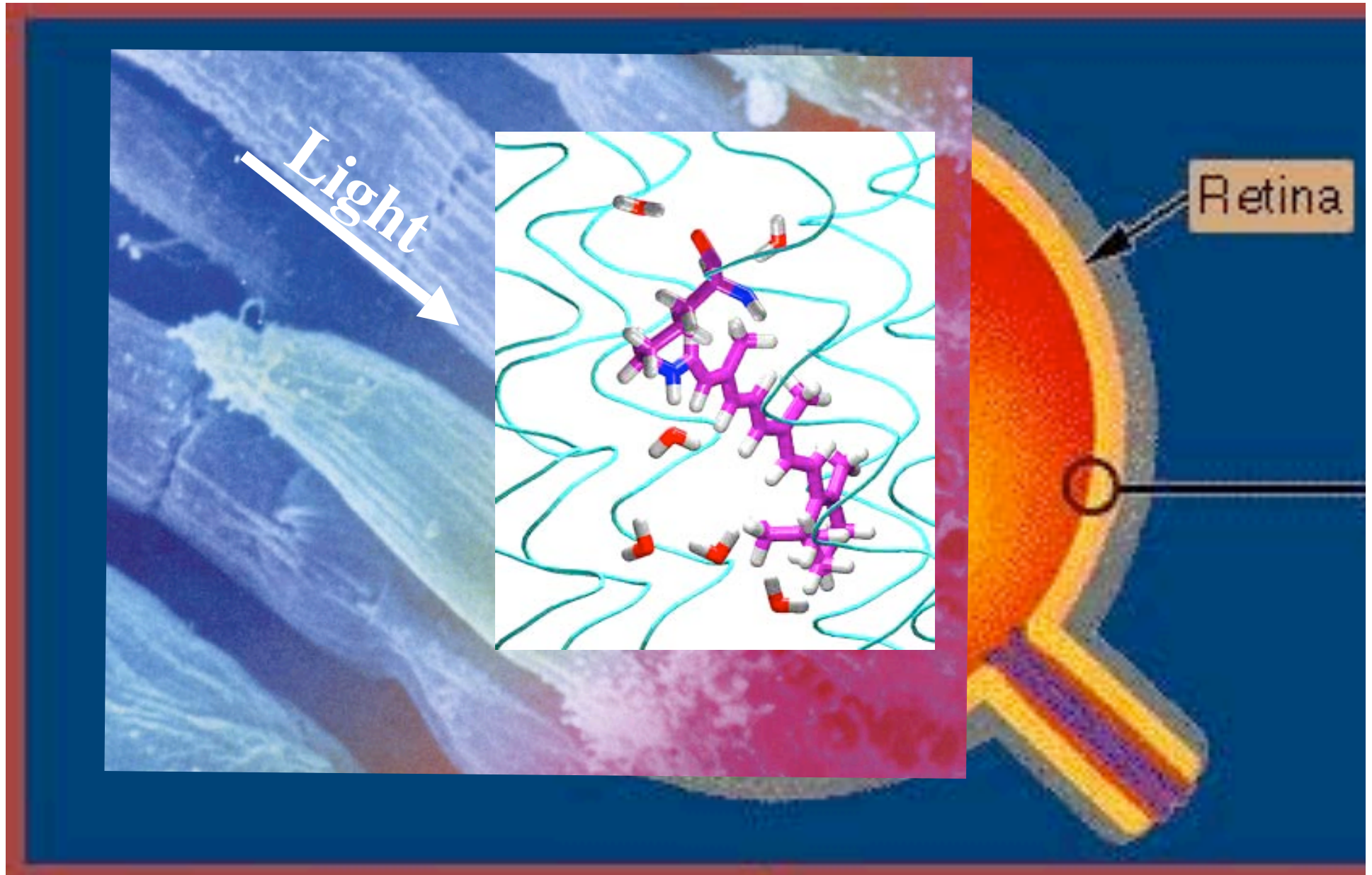


1. Hold the blind spot test paper at arm's length
2. Close your **right** eye
3. Look at the “**+**” symbol with your **left** eye
4. Slowly move the paper closer and closer, until the “**•**” symbol disappears.

Retina → Rod cell → Rhodopsin



Retina → Rod cell → Rhodopsin



The Eye is a Photoreceptor

