Themes 3

- send answer to iClicker Question 9A now.
- Size & Scale
  - ex. respiration
  - ex. terminal velocity
  - in general

Tim A see me

iClicker Question 9B

Due in lab **this** week:
⇒ pre-lab for Aipotu IV (lab manual p 51 and on-line)
⇒ Molecular Phylogeny lab report

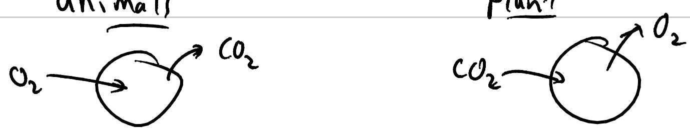
Exam 1: Monday 3/1 (info in Themes 2 handout)
- Last names A - G in McCormack Cafe (3rd floor above stairwell)
- Last names H - Z here (1 bonus point for going to correct place!)

BRING a scientific Calculator to the exam!

Application III size, scale & nutrition

ex. respiration : gas exchange

animals plant



plant or animal

* small organisms use diffusion only - no specialized respiratory organs

why?

- gases are exchanged through surface
  - ∴ max possible rate of exchange depends on surface area
- but gases are made/needed by interior
  - ∴ required rate of exchange depends on volume

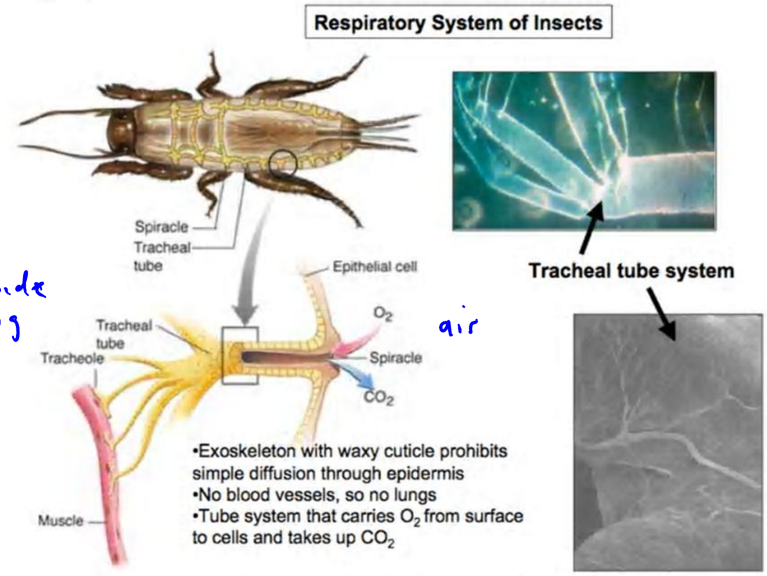
∴ larger organisms (lower $\frac{\text{surface}}{\text{volume}}$ ratio) need specialized respiratory organs (gills, lungs, etc.)

⁝ circulation (share the wealth ⁝ faster transfer)

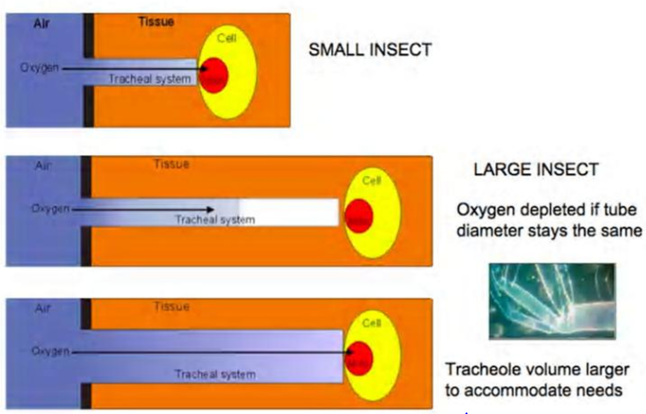
Size and Scale and Giant Insects

In the 1950's there were many science fiction horror movies about giant insects produced by nuclear radiation. For a variety of reasons, giant insects are impossible.

One important factor that likely limits insect size is respiratory capacity. As we will discuss in detail during the animal diversity lectures, insects breathe through pores in their skin using a system of tracheoles. This is shown below:



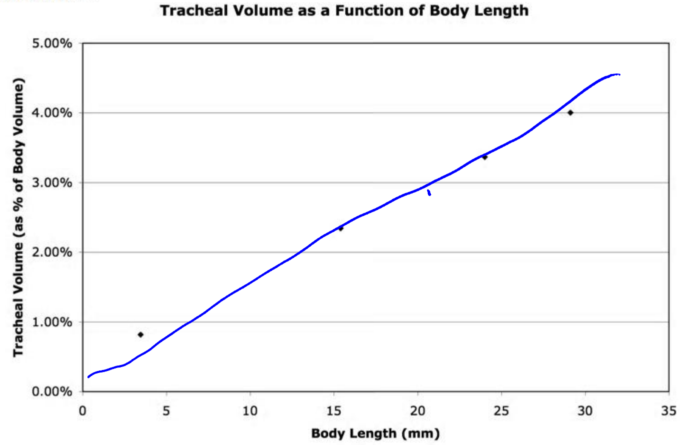
Larger insects require longer tracheal tubes to reach into their insides. In order to function properly, longer tracheal tubes must also be larger in diameter. This is illustrated below:



~proportional scaling

> proportional to account for length

In a recent paper (*Increase in tracheal investment with beetle size supports hypothesis of oxygen limitation on insect gigantism.* Proceedings of the National Academy of Sciences 104(32): 13,198 – 13,203; this paper is available free online; you don't have to read it, but you can if you want), Alex Kaiser *et al.* collected looked at four related beetle species of very different size and measured the percent of their body volume that was taken up by their tracheal system. Their data are shown below:



1) Would you expect the % of body volume devoted to the tracheal system to increase, decrease, or stay the same if larger beetles were simply scaled-up smaller ones?

eg. 10x ↑ total volume —prop. scaling→ 10x ↑ tracheal volume

same b/c scaling up keeps proportions of same measure

2) Why does the % of body volume devoted to the tracheal system increase in the larger beetles? larger bug → longer tracheal tubes (proportional scaling)

but long tubes must be wider (> proportional) ∴ larger % of body volume

3) Using these data, roughly how big could a beetle be?

biggest beetle Titan beetle (Titanus gigantus)
~170 mm (~25% tracheae)

Note: it is important to keep in mind the dangers of extrapolation. As Mark Twain wrote, in *Life on the Mississippi* (1883; Ch 17), "In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oolitic Silurian Period,' just a million years ago next November, the Lower Mississippi River was upwards of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three-quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding comfortably along under a single mayor and a mutual board of aldermen. There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact."

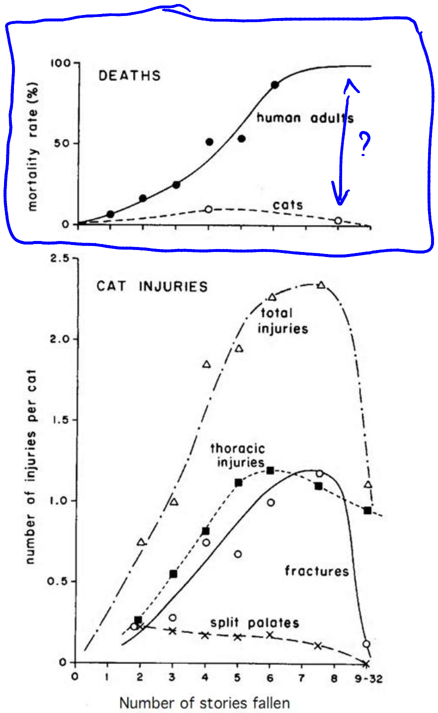
Bio 112:
Why cats have nine lives

Jared M. Diamond
[From *Nature* vol 332, pp. 586-587; April 14, 1988]

The famous adage that cats have nine lives stems in part from their ability to survive falls lethal to most people. This phenomenon has not received the scientific attention that it deserves. Filling this lacuna, a new study by W. O. Whitney and C.J. Mehlhoff (*J. Am. Vet. Med. Assoc.* 191, 1399-1403; 1987) applies principles of anatomy, physics and evolutionary biology to falling cats.

The authors were veterinarians at an animal hospital in New York City, where skyscrapers, open windows and paved ground combined to generate a database of 132 cats injured by falls of 2 or more stories, with a maximum of 32 stories and a mean of 5.5 + 0.3 (s.e.m.) (1 storey = 15 feet). Most victims landed on concrete after a free-fall. Omitting 17 cats that were euthanized by owners unable to afford treatment, 90 per cent of the cats (104 of 115) survived, whereas 11 died (mainly because of thoracic injuries and shock). The most remarkable feature of the results (see figure) is that incidence both of injuries and of mortality peaked for falls of around seven stories and decreased for falls from greater heights. For instance, the cat that free-fell 32 stories onto concrete was released after 2 days of observation in the hospital, having suffered nothing worse than a chipped tooth and mild pneumothorax.

Falling adult humans differ from falling cats in their much higher mortality rate, monotonic mortality/height relation, different causes of death, and different sublethal injuries (Warner, K.G. & Demling, R.H. *Ann. emerg. Med.* 15, 1088-1093; 1986). As illustrated in the figure, higher falls are increasingly lethal for humans, and few adults survive falls of more than six stories onto concrete. The principal causes of death are head injuries and hemorrhage from visceral injuries. Although forelimb fractures are slightly commoner than hindlimb fractures in falling cats, falling adult humans most often break their legs, and falling children their arms (Smith, M.D. et al. *J. Trauma* 15, 987-991; 1975).



Mortality rates for falling adult humans and cats (above), and number of total injuries and various types of injury per falling cat (below), as a function of number of stories fallen. (Based on the work by Waring and Demling and by Whitney and Mehlhoff.)

why do cats survive falls better than humans?

- they "fall slower" = have lower terminal velocity

when falling in air - speed up until reach terminal velocity

where force from air drag = force from gravity

depends on area & speed — depends on weight

& speed

∴ terminal velocity depends on $\frac{\text{weight}}{\text{drag}}$ ∴ $\frac{\text{volume}}{\text{area}} \sim \frac{x^3}{x^2}$

(gets bigger with bigger things)

∴ larger objects have higher terminal velocity

ex. humans ~ 200 mph

cats much lower

<u>in general</u>

- because size, area, & volume scale differently, large organisms <u>cannot</u> simply be scaled-up small organisms

∴ need alternative strategies / adaptations

ex. ① scale up out of proportion

ex. thick legs of elephants

high % of trachae in big bugs

② use stronger material

(ex worms don't need bones, but snakes do)

③ use different <u>method</u> ex lungs & gills vs. diffusion)

⇒ specialized tissues & organs

∴ need circulation to share benefits of