

Animals & Scale

Part 2



National Science Foundation
WHERE DISCOVERIES BEGIN

Size, Area, and Volume

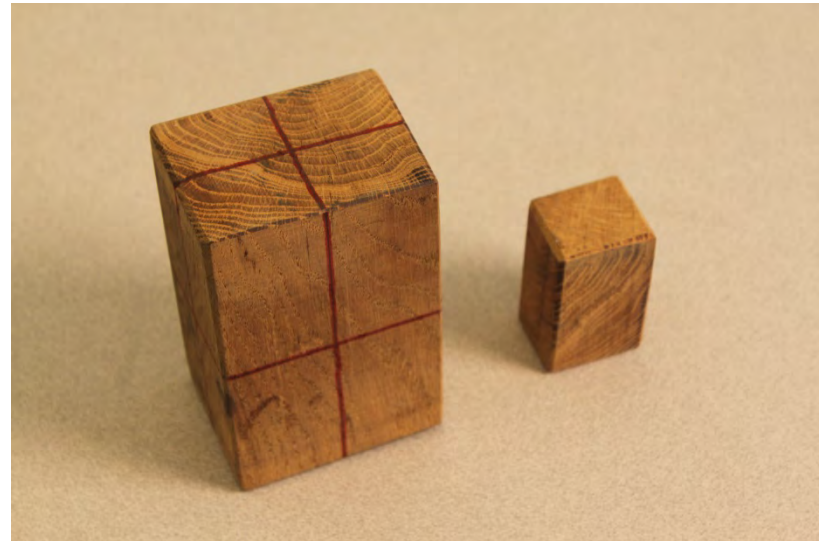
Area goes as:

$$(\text{Size}) \times (\text{Size}) = (\text{Size})^2$$

Volume goes as:

$$(\text{Size}) \times (\text{Size}) \times (\text{Size}) = (\text{Size})^3$$

Big cube is 2x the size
so it has 4x the area
and 8x the volume.



Burning and Dissolving

The time it takes to burn or to dissolve is a physical cue for size.

Burn or dissolve rate goes as area but total amount goes as volume.

Kindling is consumed quickly while large logs take longer to burn.



Cubes dissolve slower than grains.

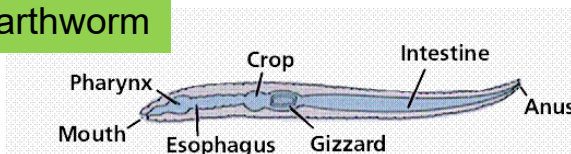


Internal Organs

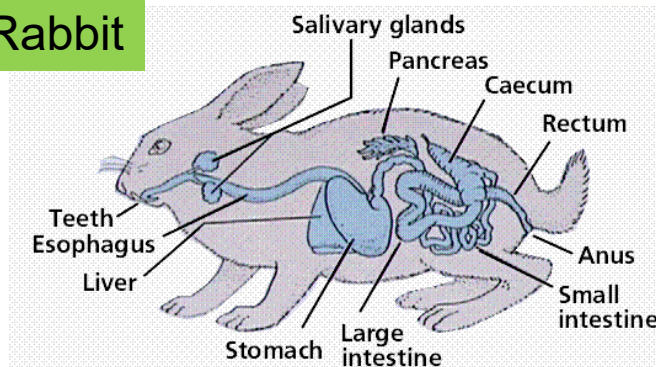
Complexity of internal organs, such as lungs and intestines, is a physical cue for animal size.

Absorption amount goes as area while consumed amount goes as volume

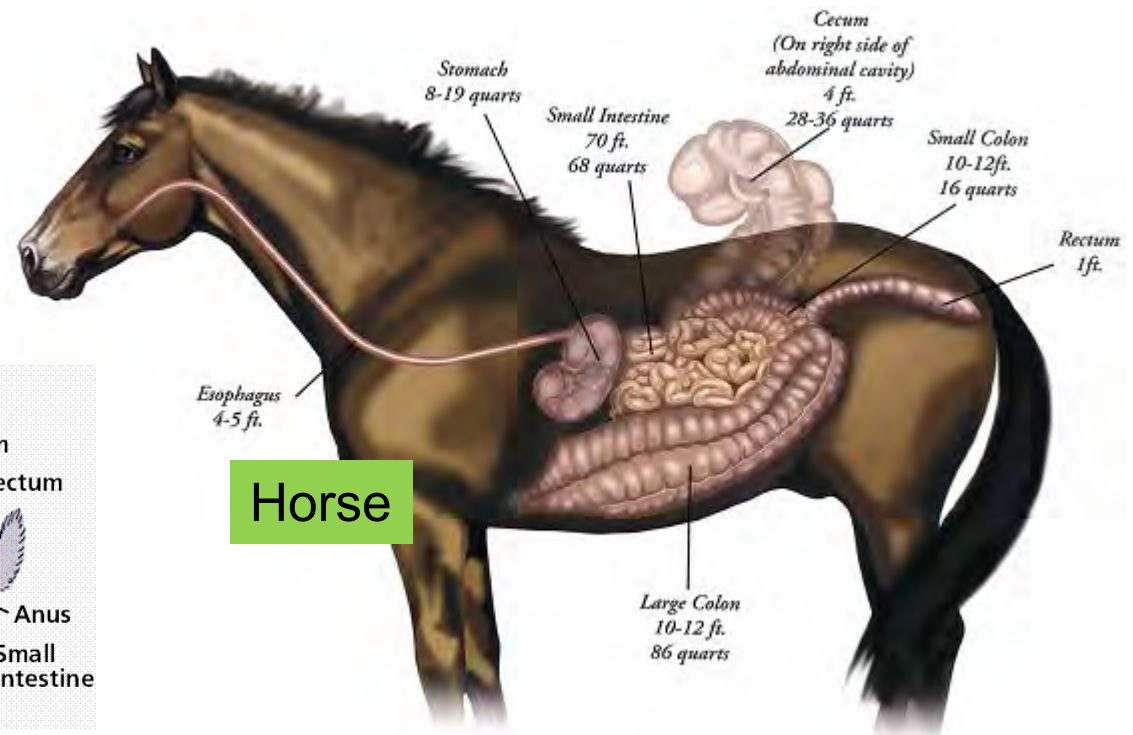
Earthworm



Rabbit



Horse



Eating

Food consumption per pound of body weight is a physical cue for animal size.

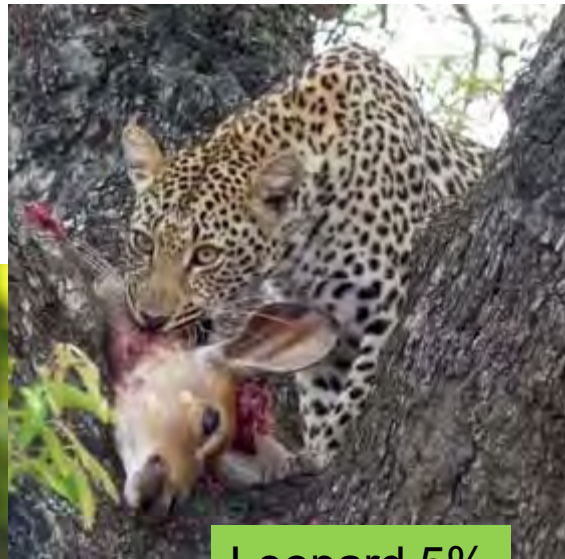
Caloric energy required goes as area while body weight scales as volume



Mouse 28%



Squirrel 18%



Leopard 5%



Zebra 2%

Heart Rate

Heart rate is a physical cue for animal size.

Oxygen required goes as area while heart size scales as volume.

Donkey: 37 beats per min.



Cat: 150 b.p.m



Mouse: 630 b.p.m



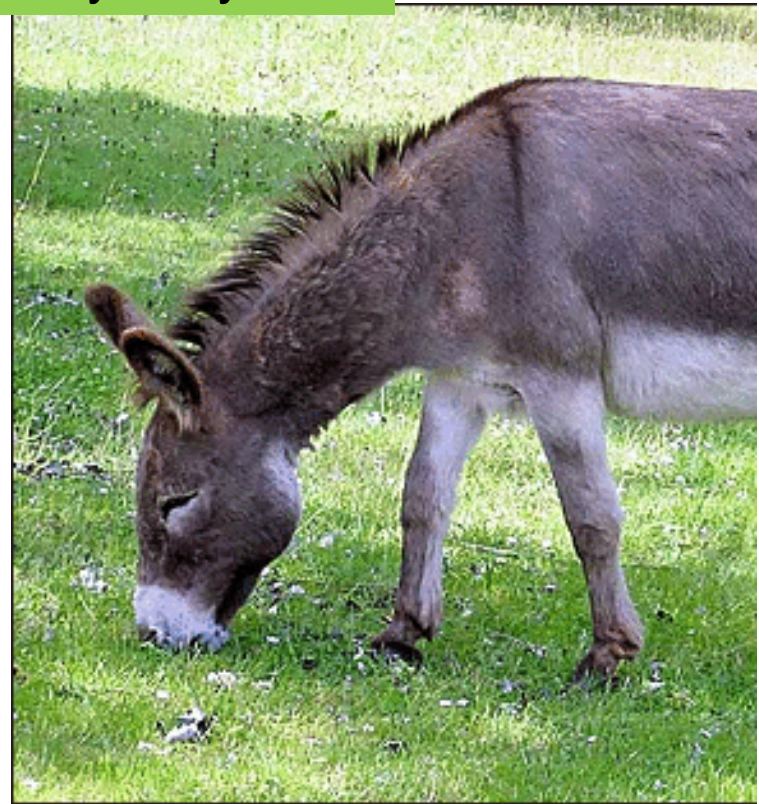
Smaller animals tend to be frisky due to faster “clock rate.”

Longevity

Longevity is a physical cue for animal size.

Total heartbeats per lifetime is about one billion.

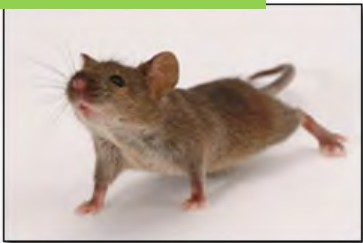
Donkey: 40 years



Cat: 10 years



Mouse: 3 years



Human longevity is roughly 30 years, without medicine.

Fur

Furriness is a physical cue for size.

Heat production goes as volume while heat loss goes as surface area.



Mice huddled for warmth



Large ears vent heat

Small animals have trouble staying warm while large animals have trouble staying cool.

Climate

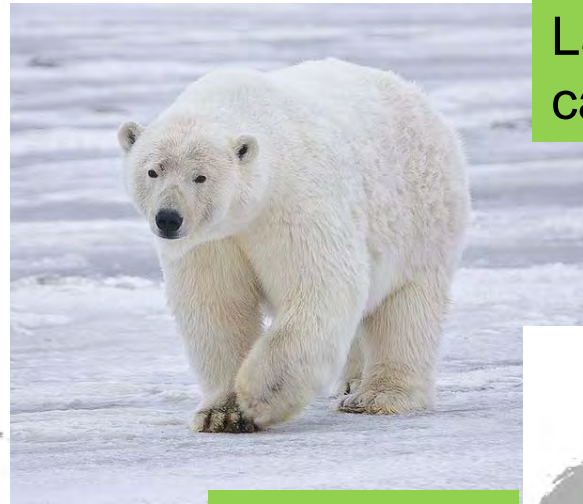
Heat production goes as volume while heat loss goes as surface area.

Climate is a physical cue for size.
Small mammals thrive in warm climates;
the Arctic has mostly large mammals.

Smallest mammal



Etruscan
pygmy
shrew



Largest land
carnivore

Polar bear



Pitch of Sound

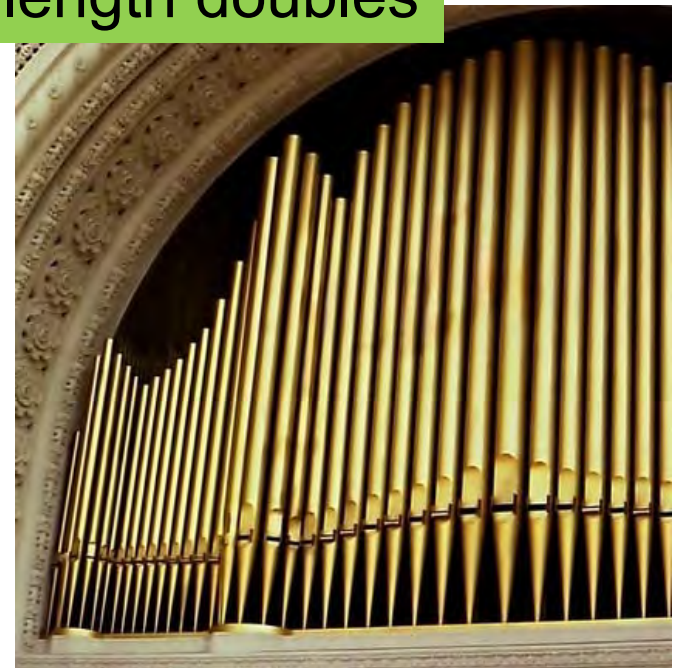
Pitch (frequency) of sound is a physical cue for size.

Frequency goes inversely with wavelength, which scales with pipe or string length.

Pitch drops one octave when pipe length doubles



Compare pitch of ukulele and cello



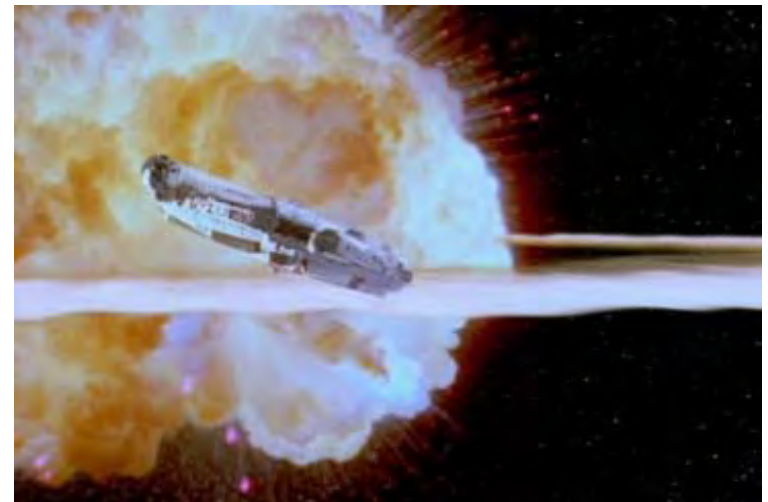
Loudness of Sound

Loudness (amplitude) of sound is a physical cue for size.

Loudness is proportional to physical volume



Compare sound of cat and lion



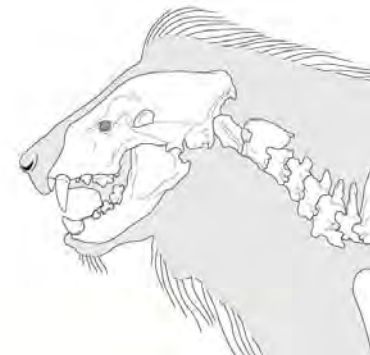
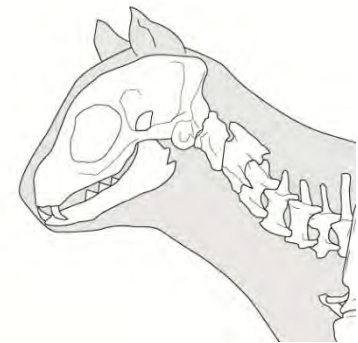
Loudness gives scale to an explosion, especially when it is far away

Eyes and Head

Required “processing”
capability goes as area

Facial features
and brain size
are physical cue
for animal size.

Small animals have
proportionally large
eyes, ears, mouths,
and brains.



Creating Magic

Deviating from the rules of physics makes a world magical and fantastic.



Concept art from *The Croods* and *How to Train Your Dragon*

Summary

- Small animals have simple internal organs.
- Small animals eat a lot, relative to their weight.
- Small animals have a quick heart rate, which tends to make them active and jittery.
- Small animals have a shorter life span.
- Small mammals need fur to stay warm and they tend to live in warmer climates.
- Small animals have squeaky voices and they cannot produce very loud sounds.
- Small animals have relatively large facial features, such as eyes and ears.