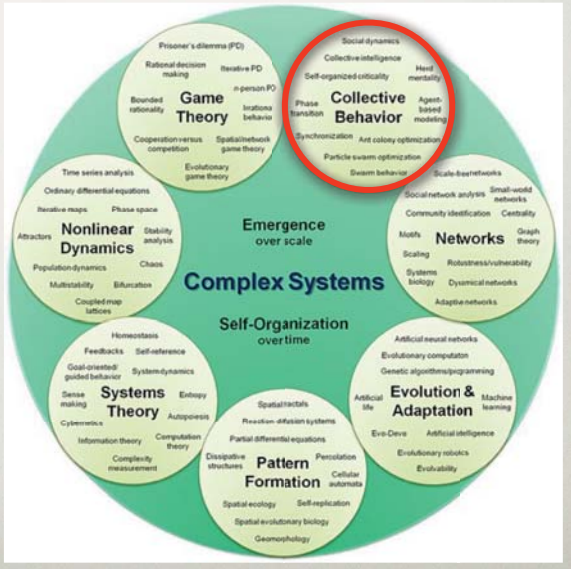
Biophysics of complex systems

Miklós Kellermayer

Complex systems

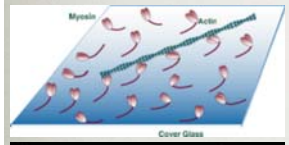
The whole is more than the sum of its parts.

Branch of physical and matematical modeling that studies how relationships between parts give rise to the collective behaviors of a system and how the system interacts and forms relationships with its environment.



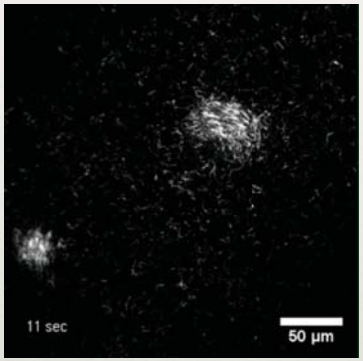
Collective behavior of propelled filaments

Low filament density

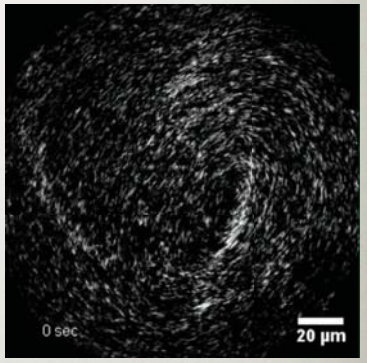


In vitro acto-myosin motility

Very high filament-density environments

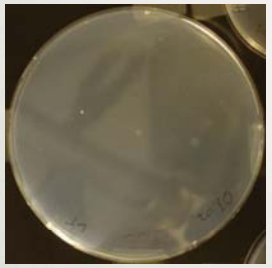


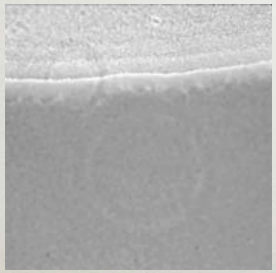
Cluster movement



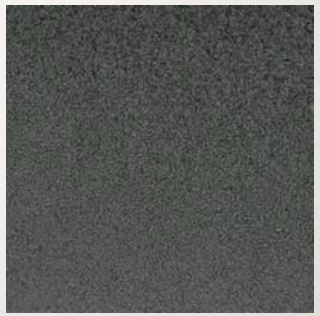
Swirling motion

Collective behavior of bacteria





Swarming (*Pseudomonas aeruginosa*)



Swirling (*Escherichia coli*)

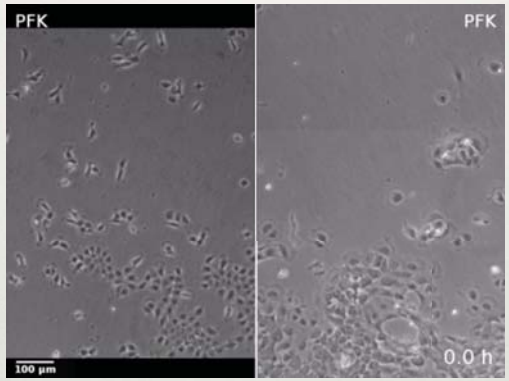
Quorum sensing: system of stimulus and response correlated to population density.

Involves signaling molecules (e.g., oligopeptides)

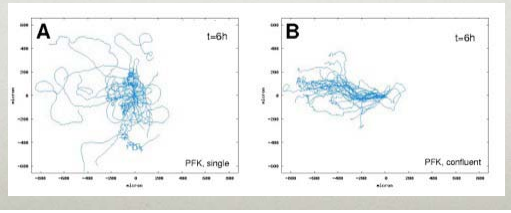
Quorum sensing functions as a decision-making process if individual components have: (a) a means of assessing the number of other components they interact with and (b) a standard response once a threshold number of components is detected.

Collective behavior of cultured eukaryotic cells

Fish keratinocyte low density



Fish keratinocyte high density



Overlaid cell trajectories

Collective behavior of groups of animals

School of fish

Flock of birds

Collective behavior of crowds

"Moshers" in mosh pit

Mexican wave

Common principles

- Self-propelled particles
- Correlation (length and time)
- Interaction mechanism
- Decision making
- Response behavior

Spontaneus collective motion of robots

Biophysical basis of physical examination

Miklós Kellermayer

Physical examination

- Inspection
- Palpation
- Percussion
- Auscultation

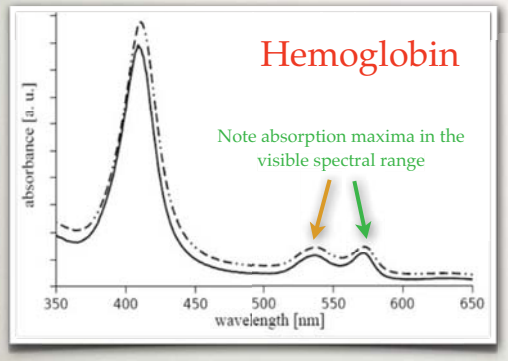
Inspection

What is it?
Visual examination of the patient

What do we visualize?
Behavior, morphology, structure, ***color***

Relationship to biophysics:
Absorption spectroscopy

Light absorption



From the general law of radiation attenuation:

$$J = J_0 e^{-\mu x}$$

$$\lg \frac{J_0}{J} = \mu x \lg e$$

$$\lg \frac{J_0}{J} \approx \mu$$

absorbance, optical density

$$\lg \frac{J_0}{J} = \varepsilon_\lambda c x$$

Lambert-Beer's Law

ε_λ = molar extinction coefficient

c = concentration

Examples

Cyanosis (rise in deoxygenated hemoglobin)

Icterus (jaundice, hyperbilirubinaemia)

Erythema (redness of the skin)

Palpation

What is it?

Examining the patient by touching

What do we palpate?

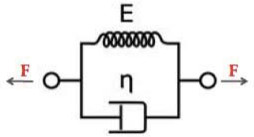
Size, shape, location, ***firmness***

Relationship to biophysics:

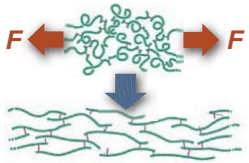
Biomechanics

Viscoelasticity

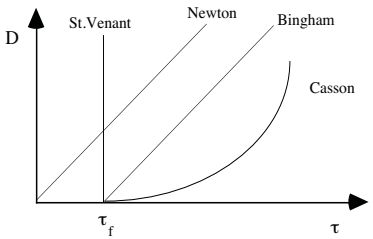
Spring-dashpot model



Schematic mechanism



Velocity gradient versus shear stress function of newtonian and non-newtonian fluids



Example: edema (pitting)

Percussion

What is it?

Examining the patient by locally striking (tapping) with short, sharp blows

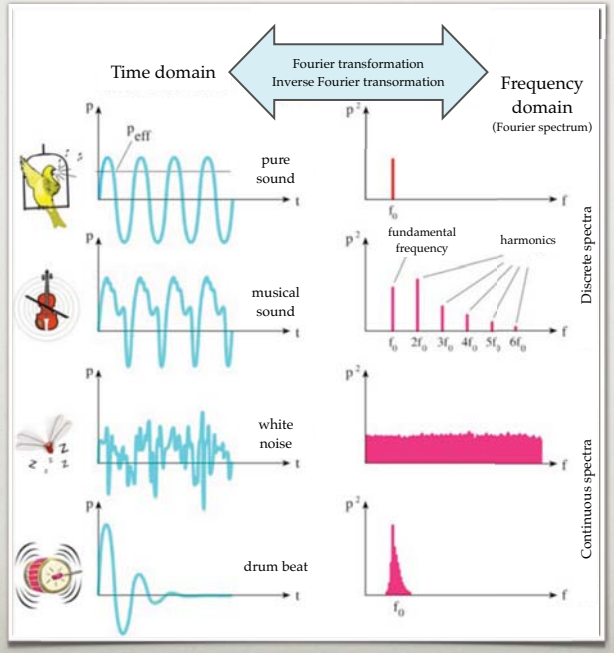
What do we examine by percussion?

Material content, shape, boundaries

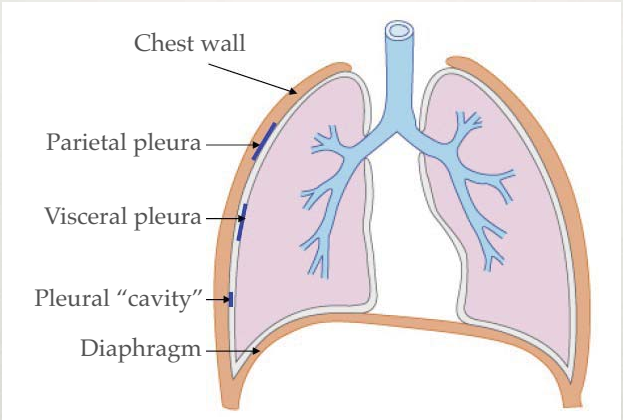
Relationship to biophysics:

Sound generation, propagation and detection

Sounds and their spectra



Respiratory system as a box



Boundaries of the diaphragm, heart, liver (and other, parenchymal organs) may be detected by palpation.

Auscultation

What is it?

Examining the patient by listening (with a stethoscope) for sounds (murmurs) within the body

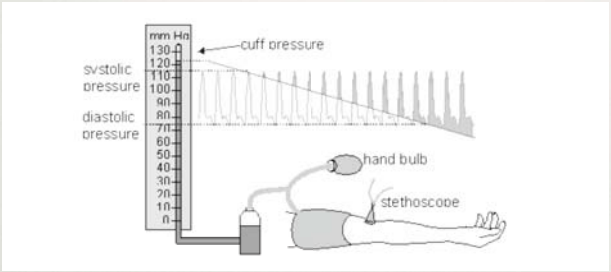
What do we examine by auscultation?

Loudness, pitch, tone, duration, temporal variation (rythm)

Relationship to biophysics:

Sound generation, propagation, fluid flow, turbulence

Korotkow's sound



1. tapping
2. swishing
3. knocking
4. muffling

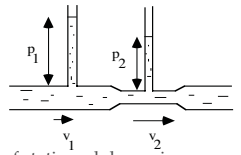
Reynolds number:

$$R = \frac{vr\rho}{\eta}$$

v=flow rate (m/s)
r=tube radius (m)
ϱ=density of fluid (kg/m³)
η=viscosity (Ns/m²)

Turbulent flow (R> ~1000) causing sound effects

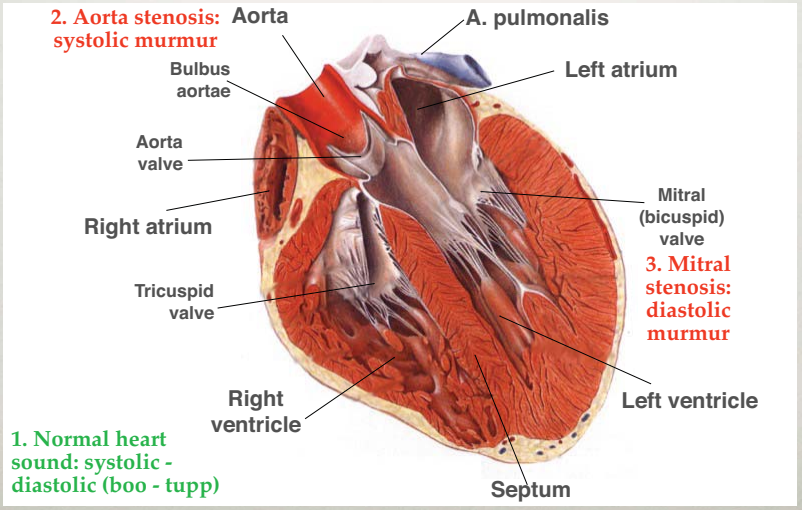
Bernoulli's law



Fluctuation of static and dynamic pressures resulting in rapid opening and closing of brachial artery

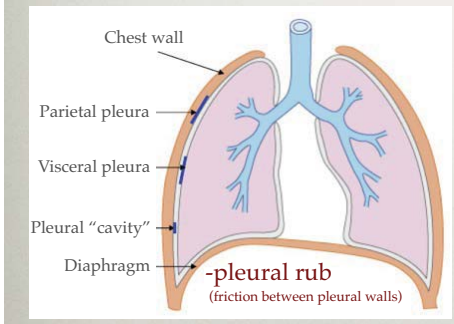
Heart sounds and murmurs

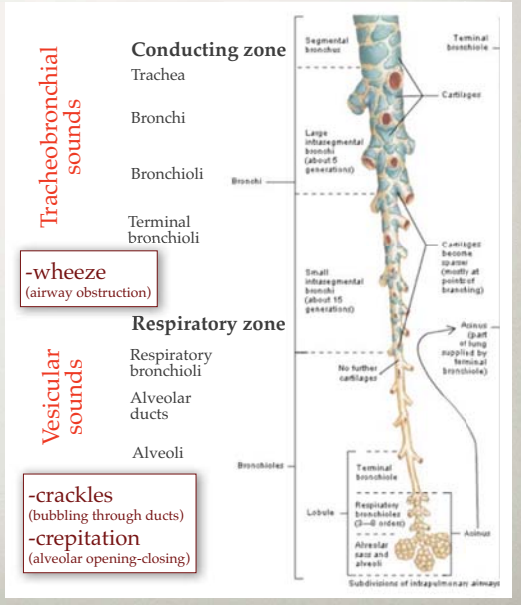
Sources: mechanical vibrations (e.g., valve closing), turbulent flow
Conductance: towards blood-filled compartments



Respiratory sounds

Sources: mechanical resonance (organ-pipe action), mechanical vibrations (rubbing), bubbling through fluid





Complex systems

- **Logic:** definition, physical description and modeling, examples
- The human body: collection of cells and tissues
- Groups: collection of individuals
- Collective behavior: motion, decision making, etc.
- Examples:
  in vitro motility assay
  Collective motion
  Tissue differentiation
  Quorum sensing

Physical examination

- Inspection
  What do we inspect: structure (shape), color
  Connection with spectroscopy - absorption
  Examples: rubor, icterus, cyanosis
- Palpation
  Connection with tissue mechanics and wave propagation
  Examples: oedema
- Percussion
  Connection with sound generation and propagation
  Examples: chest percussion (box sounds)
- Auscultation
  Connection with sound generation and propagation
  Examples: heart murmurs, Korotkow-sound, respiratory sounds,