Patterns and form:
from physical systems to living systems
• Questions in nonlinear/statistical physics
• Questions in physics inspired by living systems
• Questions in cell and developmental biology
Self-organisation of droplets
Self-organisation of droplets

Silicon oil

Frequency
50 Hz

Film of air

Couder et al. Nature. 2005
Self-organisation of droplets

\[ m \frac{d^2 \mathbf{r}}{dt^2} = F^b \sin \left( \frac{2\pi}{V^q} \frac{d\mathbf{r}}{dt} \right) \frac{d\mathbf{r}}{dt} - f' \frac{d\mathbf{r}}{dt} + F'^b \exp \left( \frac{-|\mathbf{r} - \mathbf{r}'|}{\lambda_A} \right) \sqrt{\frac{\lambda_F}{|\mathbf{r} - \mathbf{r}'|}} \sin \left( \frac{2\pi |\mathbf{r} - \mathbf{r}'|}{\lambda_F} \right) \]

Packing of thin
Packing of thin sheets

A simplified experimental system: conical packing

- Self-alignment / bundling
- Broad distributions of sizes

Deboeuf et al. EPL 2008
Indentation of a thin sheet

- Dynamics of patterns
- Prediction of patterns

Waves at the edge
Waves at the edge
Waves at the edge

Auxin application
Waves at the edge

Magnification factor
3.2

Eran Sharon et al 2002
Thin elastic sheet with

metric \( ds^2 = (1+g(y))^2 \, dx^2 + dy^2 \)

\( g(y) \): quantifies growth rate
Waves at the edge

Up to 5 generations of wrinkles with wavelengths \( \lambda, \lambda/3, \lambda/9, \lambda/27, \lambda/81 \).

Audoly & Boudaoud Phys Rev Lett 2003
Form and size of an organism

Duckweed
The genetics of form

Finding genes that control teeth morphogenesis
A number of discoveries in genetics and molecular biology
Building an organism

Assembly and stiffness of structural elements determines form
Building an organism

Optical microscopy
Stem cells

Arabidopsis
flower
primordium

Mechanical microscopy (AFM)
Stiffness

Atomic force microscope

Stem cells are stiffer
The mechanics of structural elements determines form

Microtubules in the shoot apex

Building elongated forms

Hamant et al. Science 2008
Building elongated forms

What controls the orientation of microtubules?

• A continuum mechanical model of the shoot apex
  ▶ Much stiffer epidermis
  ▶ Hydrostatic pressure (turgor)

• Prediction of force patterns
  ▶ Microtubules // main tension

Hamant et al. Science 2008
Building elongated forms

Cell wall reinforcement in the direction of maximal stress
Building elongated forms

Fission yeast

Outgrowth occurs when the outer wall breaks.

Spore (note the dark casing)
Spore with outgrowth (note breakage of casing)

Vegetative cell

Outgrowth occurs when the outer wall breaks.
Building elongated forms

Fission yeast cell

Mathematical model: coupling between structural elements and cell polarity

Coordination between biochemistry and biomechanics
Transition from sphere to elongated shape

Bgs4-GFP = cell wall synthesis

Bonazzi et al. Dev. Cell 2014
Developmental stability

Morphogenesis: organs with reproducible forms

The two hands?

Eric Biot
Developmental stability

Flowering plants: ideal systems to study robustness of form
Developmental stability

Growth is spatially heterogeneous

Developmental stability

Genetic screen for mutants in variability

Flowers from a single plant (Arabidopsis)

Mutation affecting robustness of flowers

Mutant: cell wall stiffness less heterogeneous.

Now: variability in gene expression and robustness of development

Spatiotemporal variability promotes flower robustness!
Conclusions

From simplified systems to living systems

Investigating morphogenesis:
tools from experimental/theoretical physics
in addition to genetics/molecular biology

There is biological information in variability

AND
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