Understanding floral pattern formation in yeast biofilms

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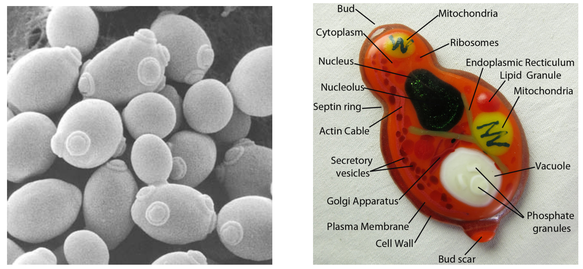
Yeast

- Single-cell fungi used in baking, brewing, probiotics, waste management, and biofuels (Figure 1).
- Similar cell anatomy to plants and animals.
- Model organism for researching how cells grow.

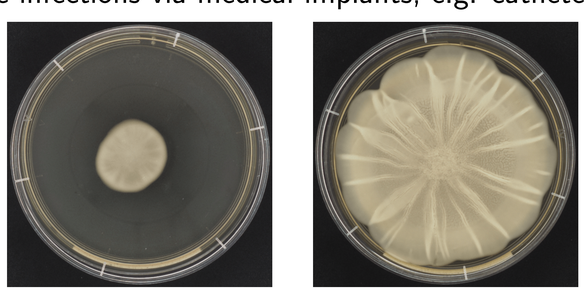


(a) Yeast cells. (b) Cell anatomy.

Figure 1: Bakers' yeast, *Saccharomyces cerevisiae*.

Biofilms

- Sticky communities of yeast cells and fluid (Figure 2).
- Help yeast survive by improving nutrient transport, and blocking harmful substances.
- Cause infections via medical implants, e.g. catheters.



(a) Circular. (b) Floral.

Figure 2: Initially circular yeast biofilms develop a floral pattern.

Pattern formation

- Three mechanisms thought to cause floral patterning:
  1. Nutrient (glucose) movement and consumption.
  2. Fluid flow.
  3. Cell adhesion and wrinkling.
- We want to understand the relative importance of each.
- Mathematical models allow us to separate the effect of each mechanism.

Mathematical model

- We relate cell density $n(\vec{x}, t)$ and glucose concentration $g(\vec{x}, t)$ with the partial differential equations

$$\frac{\partial g}{\partial t} = \nabla^2 g - ng, \tag{1a}$$

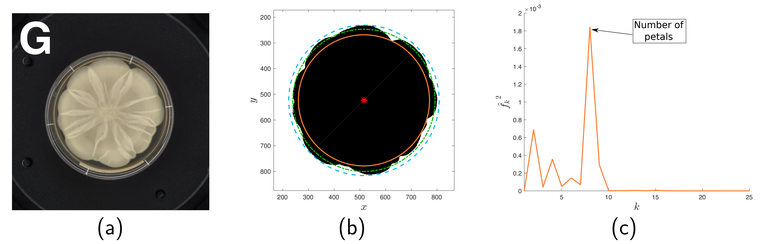
$$\frac{\partial n}{\partial t} = D\nabla \cdot (n\nabla n) + ng. \tag{1b}$$

- The terms in the equations represent
  - Rate of concentration change.
  - Consumption of glucose by cells.
  - Random movement of glucose via diffusion.
  - Biased cell spread via budding from existing cells.
  - Rate of cell spread relative to glucose movement.

Quantifying spatial patterns from images

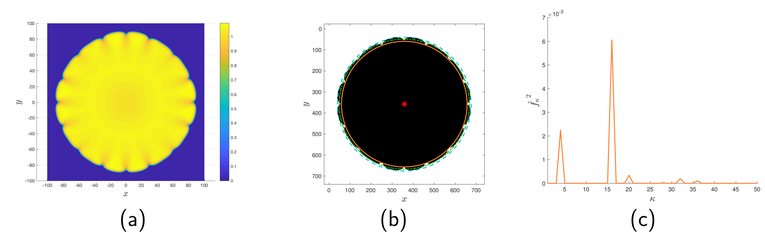
- We compare patterns in experimental photographs with plots of numerical solutions to our model.
- Two cells are likely to belong to the same petal if their angle from the biofilm centre is similar.
- We can count petals automatically by taking a discrete cosine transform of the angular pair-correlation function.

Comparing the model with experiments



(a) (b) (c)

Figure 3: Experimental pattern quantification. (a) Original image. (b) Processed image. (c) Power spectrum.



(a) (b) (c)

Figure 4: Mathematical model pattern quantification. (a) Numerical solution. (b) Processed image. (c) Power spectrum.

- Model can reproduce floral patterns.
- We conclude that glucose consumption and diffusion are important mechanisms in yeast biofilm pattern formation.