Robustness of epithelia tissue growth to cell mechanics

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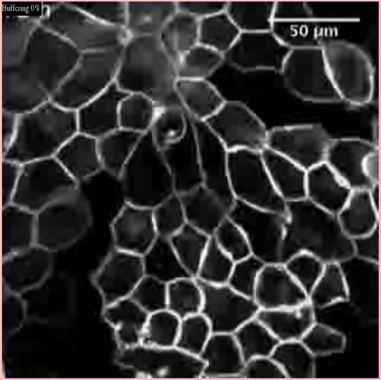
22 October 2015, IEU/UZH, Switzerland.

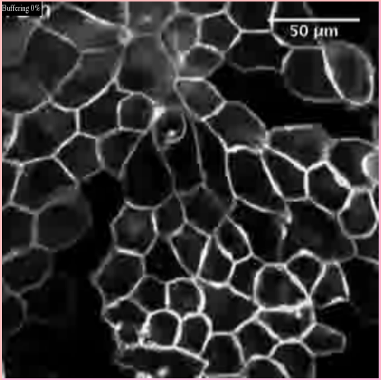
Tissue growth: cells as polygons, tissues as networks

Tissue, cells, Edges, and Vertices



1. Tissue as a network of cells.

Tissue, cells, Edges, and Vertices



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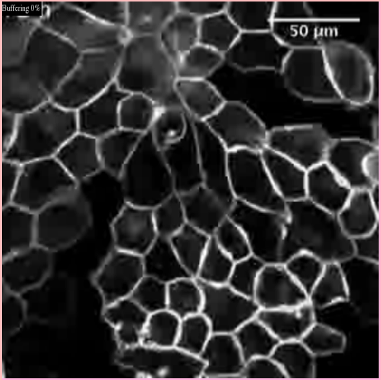

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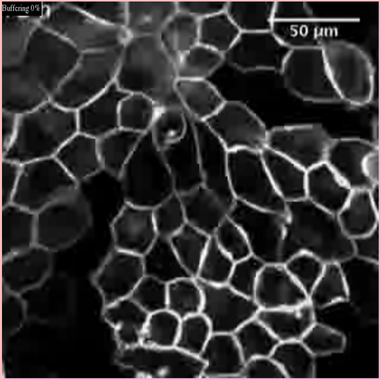
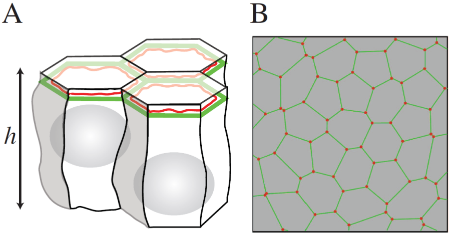
3. Each 2 Cells share 1 Edge.

Tissue, cells, Edges, and Vertices



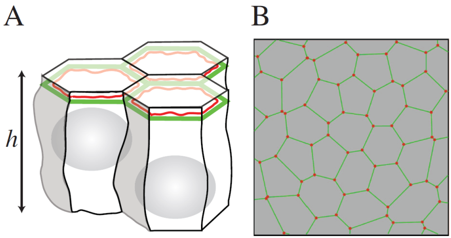
1. Tissue as a network of cells.
2. Cells as polygons.
3. Each 2 Cells share 1 Edge.
4. Each Edge is composed by 2 Vertices.

Junctional network



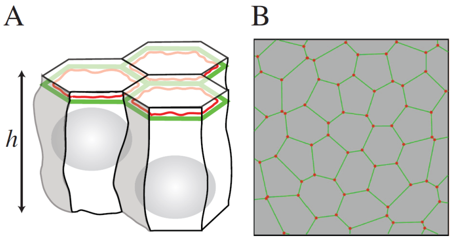
1. Epithelia cells are connected to each other via adhesive molecules.

Junctional network



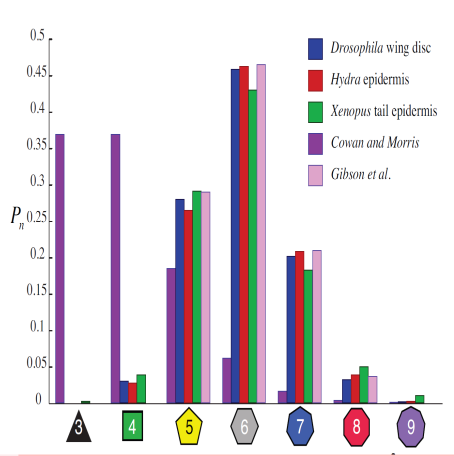
1. Epithelia cells are connected to each other via adhesive molecules.
2. Epithelia cells establish a **junctional adherent network** near their apical region.

Junctional network



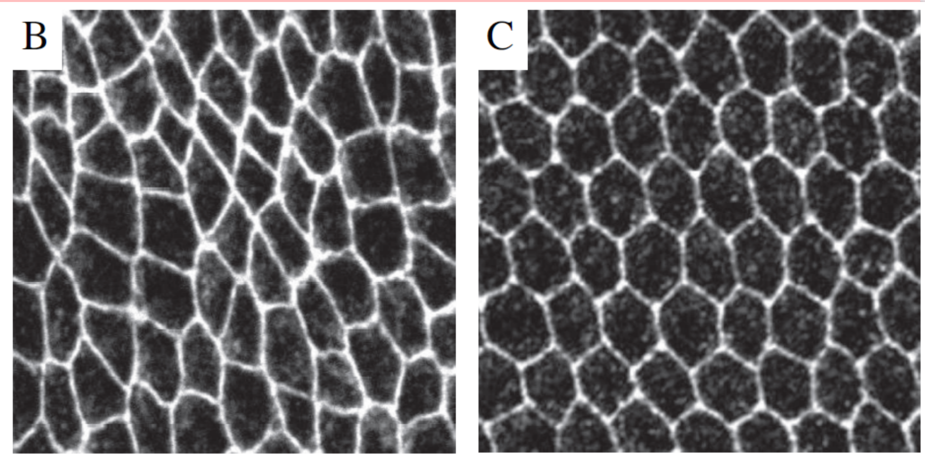
1. Epithelia cells are connected to each other via adhesive molecules.
2. Epithelia cells establish a **junctional adherent network** near their apical region.
3. Epithelia tissues are simpler to be studied (2-dimensional).

Different kind of tissues

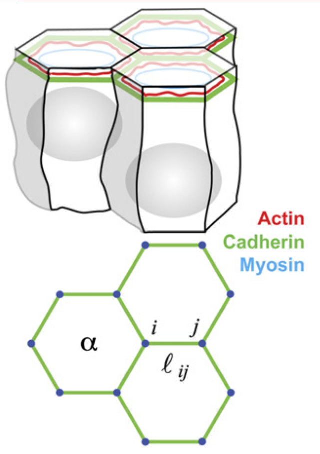


Different Developmental stages (Drosophila wings)

(B) pupal stage **(C)** before hair formation



Line Tension, Contractility, and Elasticity



- Edge's Line tension (Λ) is associated to Edge's length.
- Cell's Contractility (Γ) is associated to Cell's Perimeter.
- Cell's Elasticity (K) is associated to Cell's Area.

Force Balance Energy Function

$$F = \sum_\alpha \frac{K_\alpha}{2}(A_\alpha - A_\alpha^{(0)})^2 + \sum_{(i,j)} \Lambda_{ij} L_{ij} + \sum_\alpha \frac{\Gamma_\alpha}{2} L_\alpha^2$$

- Elasticity and Cell Area

Force Balance Energy Function

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- Elasticity and Cell Area
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- Line tension and Edge length
- Contractility and Cell Perimeter

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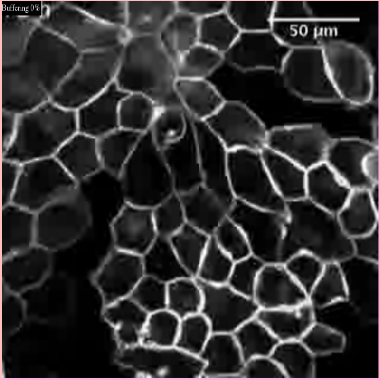
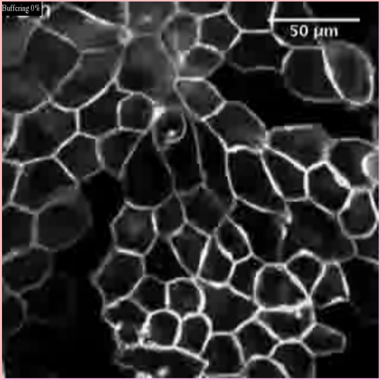


We keep the physical properties of the cells fixed during the simulation. So, in order to satisfy the **Minimal Energy's Assumption** theh positions of the vertices need to change.

Preferred Cell's Area $A_\alpha^{(0)}$

$$F = \sum_\alpha \frac{K_\alpha}{2}(A_\alpha - A_\alpha^{(0)})^2 + \sum_{(i,j)} \Lambda_{ij} L_{ij} + \sum_\alpha \frac{\Gamma_\alpha}{2} L_\alpha^2$$



$A_\alpha^{(0)}$ is the preferred area of cell α which is related to the volume, V_α and height, h_α of the cell: $A_\alpha^{(0)} = \frac{V_\alpha}{h_\alpha}$

Sequence of Events

1. **Relaxation** (Vertices change their position to guarantee the force balance to be equal to zero).

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2. **Cell Proliferation** (cells growth and cells division).

Relaxation

- 1 - Vertices change their position to guarantee the force balance equal to zero.

Relaxation

- 2 - The position of the vertices is defined by a *Verlet Function*[**?**] in which the accelleration is defined by the total force on the junctions of the tissue $(r(t+\Delta t) = 2r(t) - r(t-\Delta t) + a(t)\Delta t^2)$.

Relaxation

- 3 - Once the force is zero, the accelleration of the *Verlet Function* is also zero, and so the position of the vertices don't change from time step t to $t + \Delta t$.

Relaxation

- 4 - Relaxation is finished once the length of the tissue remains *steady* (the position of its vertices don't change) along 100 time steps ($\frac{sd(\sum_\alpha L_\alpha)}{mean(\sum_\alpha L_\alpha)} \approxeq 0$).

Regularness of the tissue

1. We define ***regularness*** as a dimensionless measure to say how regular the cells of a tissue are.

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2. Regularness is defined as: $Reg = \frac{sd(L_{ij})}{mean(L_{ij})}$ accross all the edges.

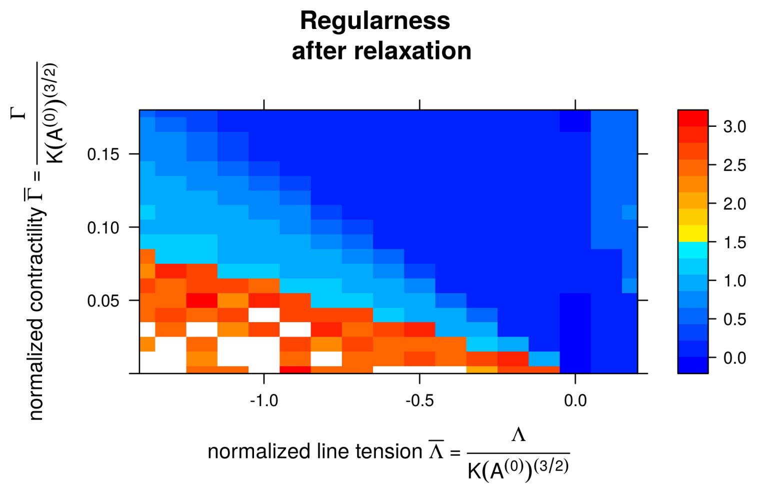
Regularness of the tissue

We define ***regularness*** as a dimensionless measure to say how regular the cells of a tissue are.

$$Reg \approxeq 0$$
$$(Lambda, Gamma) = (-0.25, 0.15)$$

$$Reg > 0$$
$$(Lambda, Gamma) = (-0.6, 0.08)$$

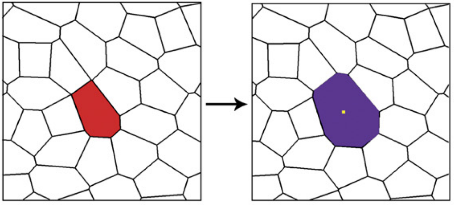
Phase space of Regularness



Cell Proliferation

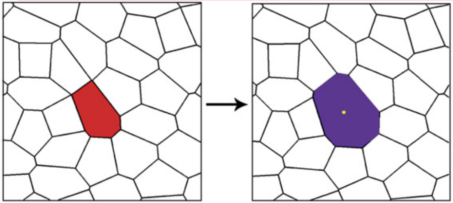
- Cell Growth.
- Cell Division.

Cell Growth



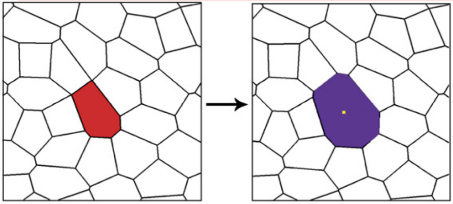
1. Cells are **randomly** triggered to increase their area.

Cell Growth



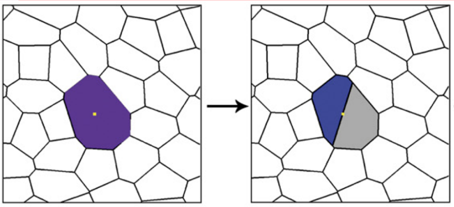
1. Cells are **randomly** triggered to increase their area.
2. They increase their area by 10% each time step.

Cell Growth



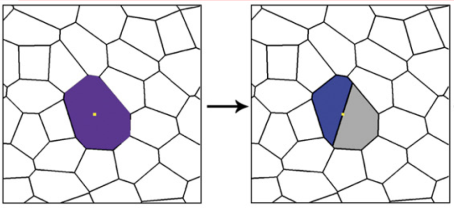
1. The increment of the area is given by changing the value of the preferred area parameter $(A_\alpha^{(0)})$ on the Force balance equation.

Cell Division



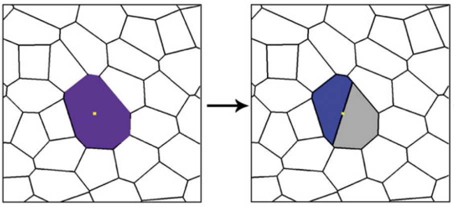
1. Once a cell α reaches the **double** of the area it had **before starting to increase**, it is subdivided into two cells with half the current area of cell α.

Cell Division



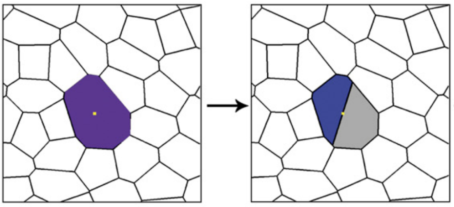
1. The division consists in creating a new edge e_i that **crosses the centroid** of the original cell α with a **random direction.**

Cell Division



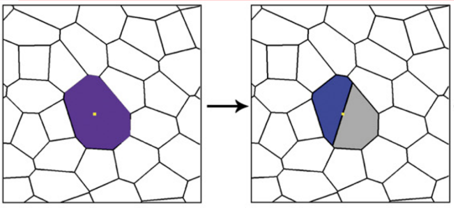
1. The former cell α is replaced by two new cells that share the edge e_i.

Cell Division



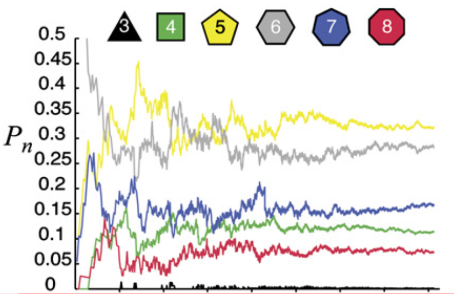
1. Edges in neighbour cells that are now connected to one of the vertices of e_i need to be splitted into two edges.

Cell Division



1. This procedure changes the *shape* of the cells in the neighbourhood of α, as well as it creates new cells to replace α that not necessarily have the same *shape* as α.

Steady state



1. The steady state of the cell division proccess is observed once the relative proportion of cells don't change along 100 time steps.

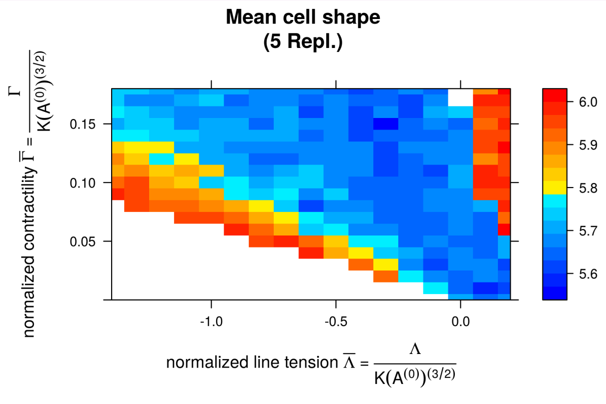
Change in shapes distribution

$$Reg \approx 0$$
$$(Lambda, Gamma) = (0, 0.15)$$

$$Reg > 0$$
$$(Lambda, Gamma) = (-0.6, 0.08)$$

Phase Space: Mean shape of cells

We observed the following Phase space of shape of cells after 10



replicates.

Next steps

1. Increase the number of replicates.

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1. Increase the number of replicates.
2. Change initial conditions of the tissues.
3. Change choice of cells to proliferate.
4. Change the way cells are divided.
5. Change the shape of the tissue.

Thank you!

- SystemsX Initiative.
- ***EpiphysX*** members: Andreas Wagner (UZH), Aziza Merzouki, Orestis Malaspinas, Bastien Chopard, Aurélien Roux, Michel Milinkovitch, Marcos Gonzalez-Gaitan (UNIGE)
- Chopard's Group members (UNIGE).
- Wagner's Group members (UZH).
- You, for the attention and patience.