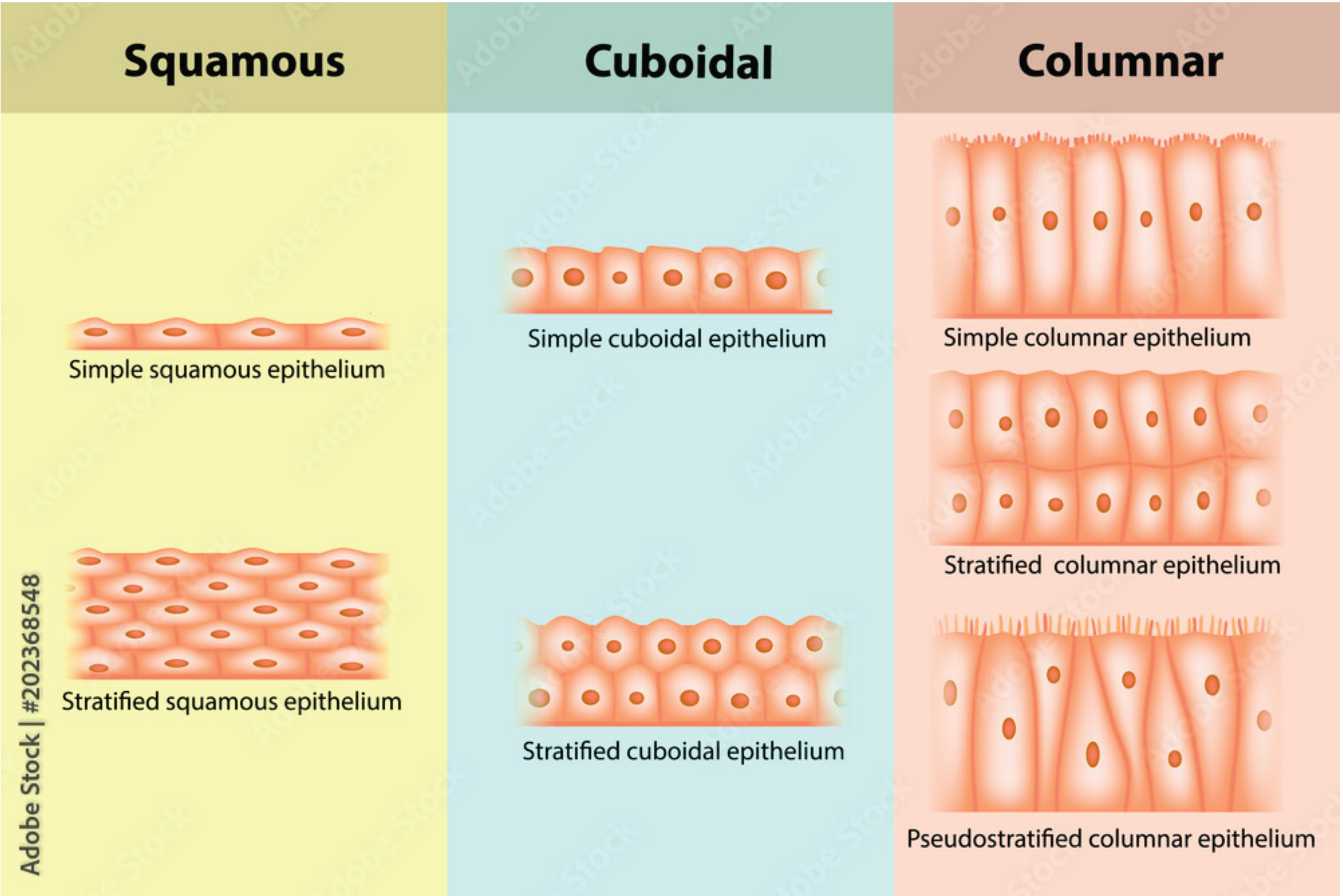
Master 2 ICFP - Physics of Multicellular Systems

Lesson 6

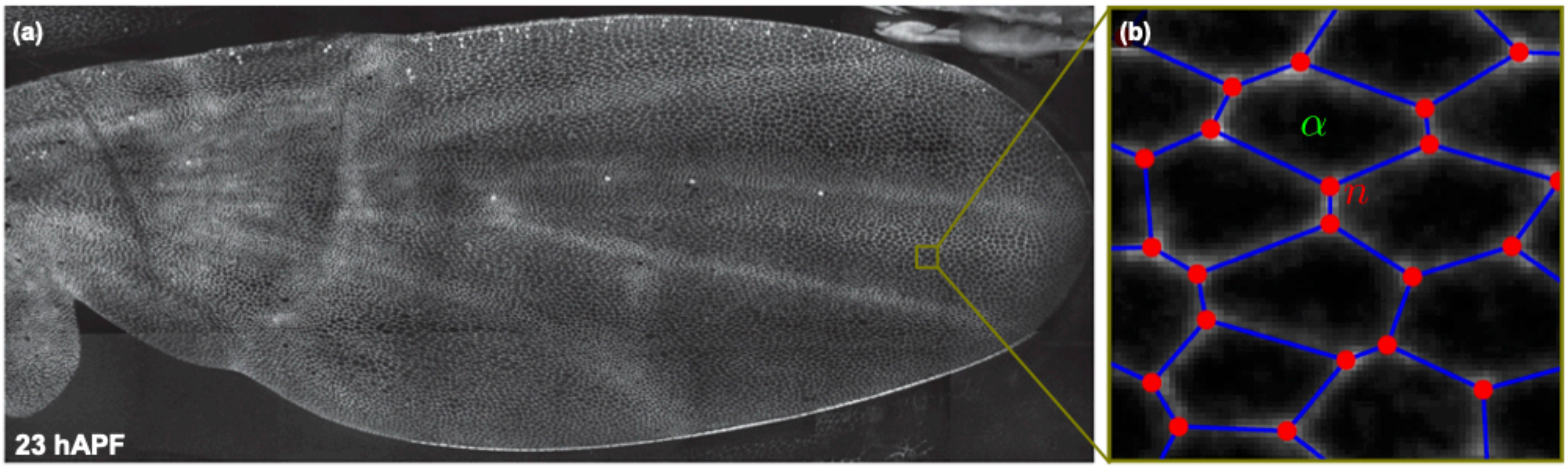
Vertex models of tissues

Hervé Turlier - March 6th 2023

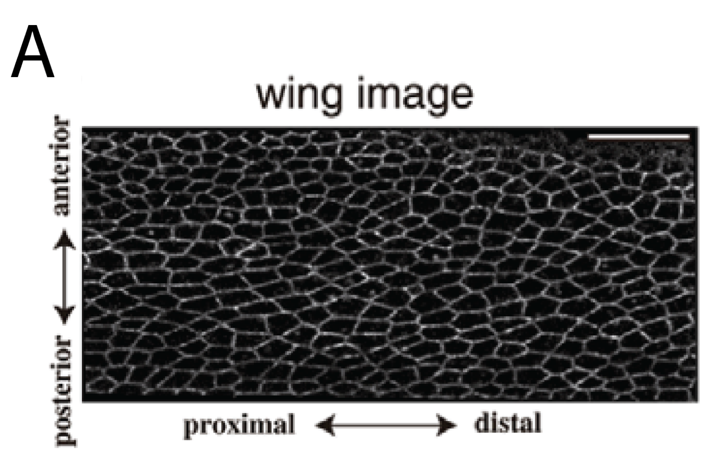
Epithelial tissues

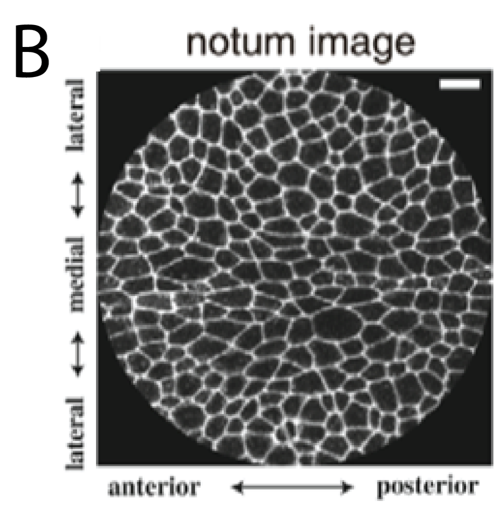


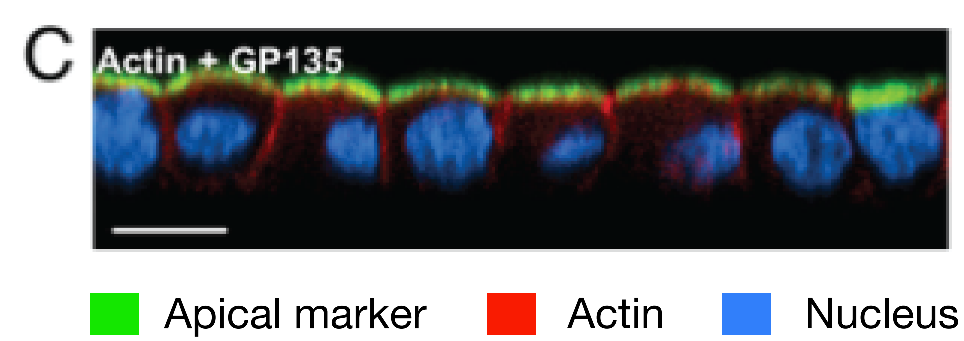
Epithelial monolayers



Merkel et al. *PRE* 2017





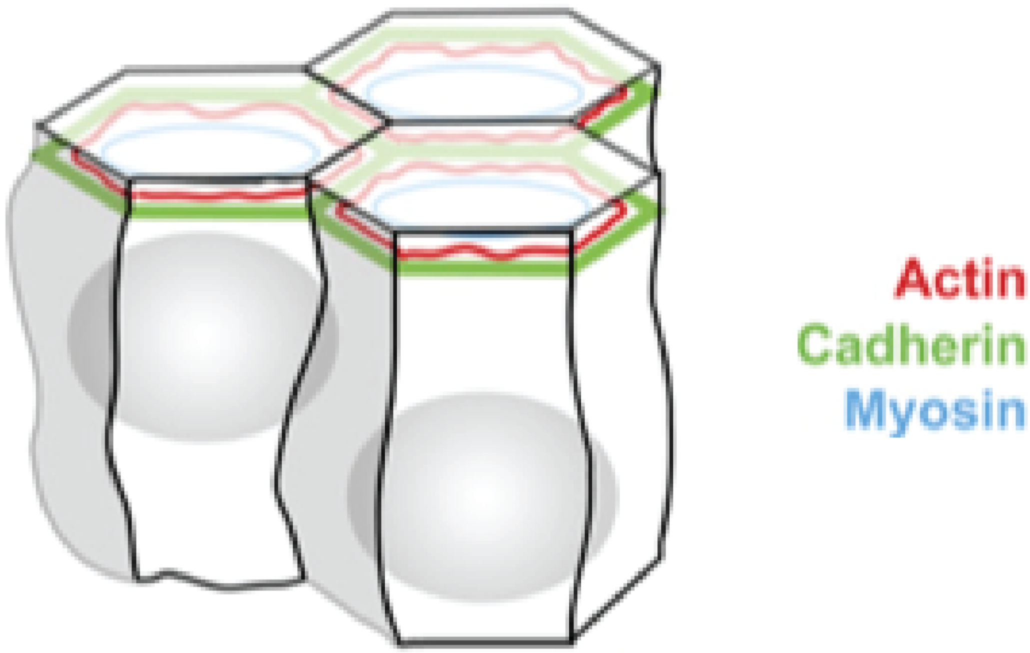


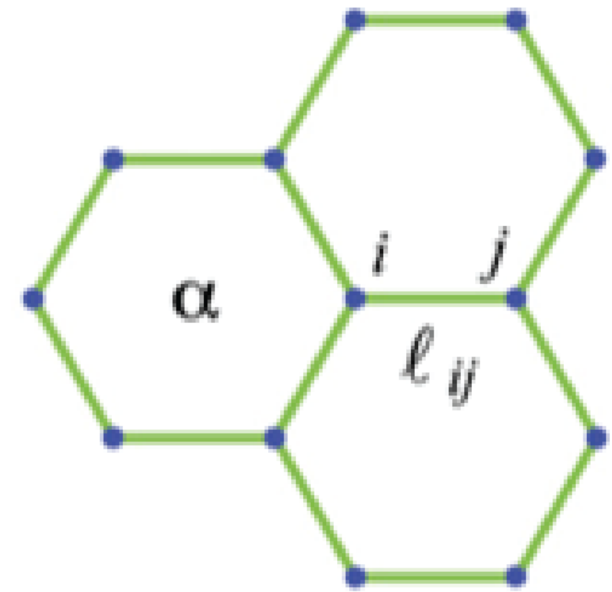
Ishihara et al. *EPJE* 2013

Harris et al. *PNAS* 2012

2D vertex model

Farhadifar et al. *Curr Biol* 2007





$$\mathcal{E} = \sum_{\alpha} \frac{\kappa_\alpha}{2} \left(A_\alpha - A_\alpha^0\right)^2 + \sum_{<i,j>} \Lambda_{ij} \ell_{ij} + \frac{1}{2} \sum_{\alpha} \Gamma_\alpha P_\alpha^2$$

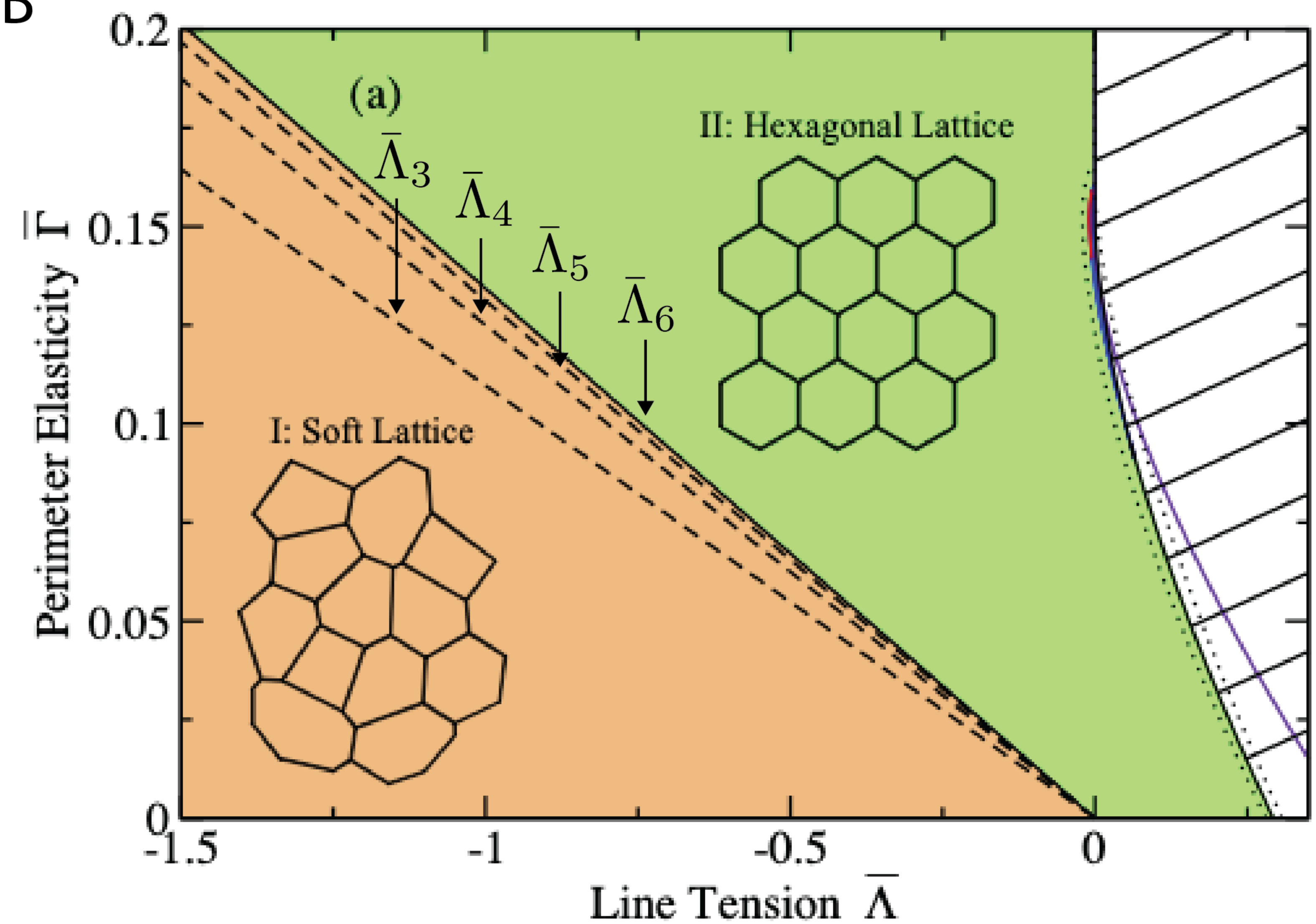
2D vertex model

Fundamental energy states - Staple et al. *EPJE* 2010

A

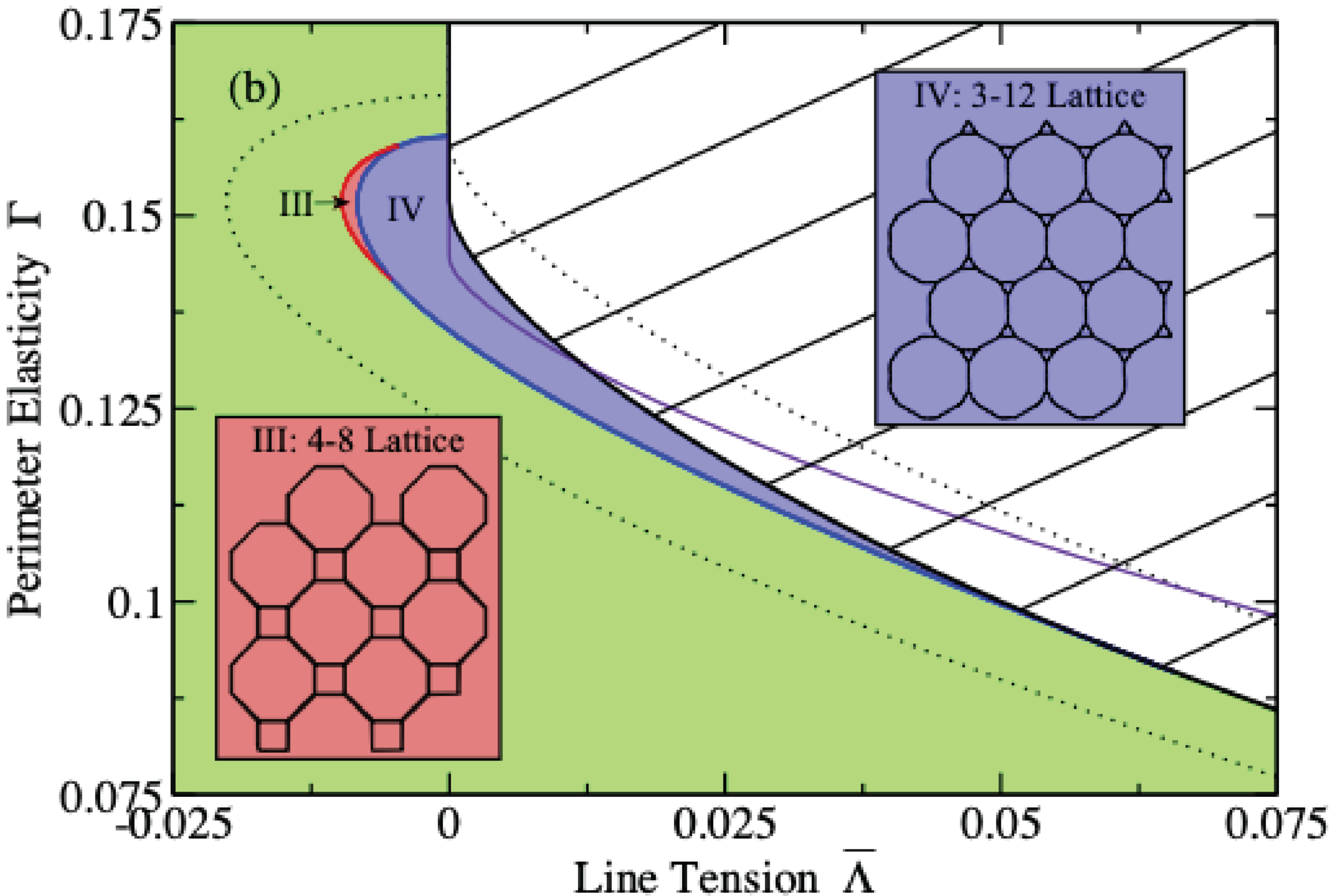
Parameter values		Ground state (identical cells)
$\bar{\Lambda} < -2^{5/2}3^{1/4}\bar{\Gamma}$	–	irregular polygons ($a = 1$, $p = p_0$)
$-2^{5/2}3^{1/4}\bar{\Gamma} \le \bar{\Lambda} < 2 \cdot 3^{-5/2}(\sqrt{3} - 12\bar{\Gamma})^{3/2}$	$\bar{\Gamma} < \sqrt{3}/12$	hexagonal lattice
$-2^{5/2}3^{1/4}\bar{\Gamma} \le \bar{\Lambda} < 0$	$\bar{\Gamma} \ge \sqrt{3}/12$	hexagonal lattice
$\bar{\Lambda} \ge 2 \cdot 3^{-5/2}(\sqrt{3} - 12\bar{\Gamma})^{3/2}$	$\bar{\Gamma} < \sqrt{3}/12$	collapsed lattice ($a = 0$, $p = 0$)
$\bar{\Lambda} \ge 0$	$\bar{\Gamma} \ge \sqrt{3}/12$	collapsed lattice ($a = 0$, $p = 0$)

B



2D vertex model

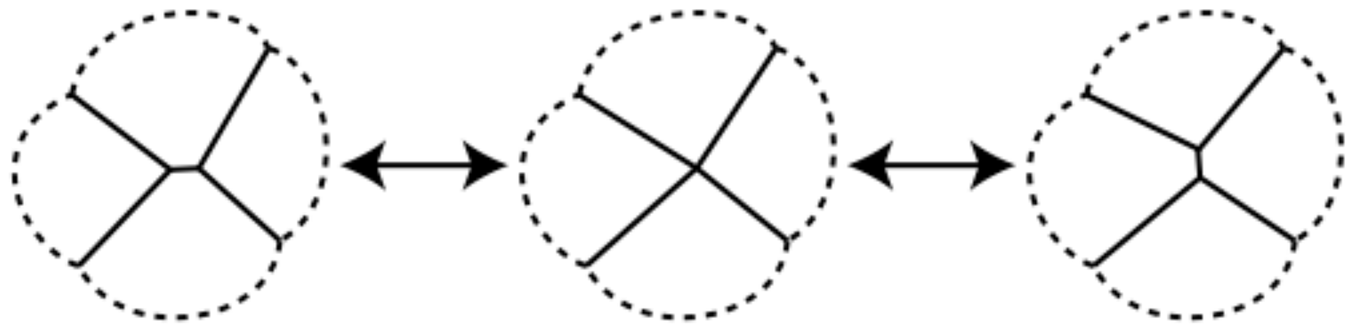
Fundamental energy states - Staple et al. *EPJE* 2010



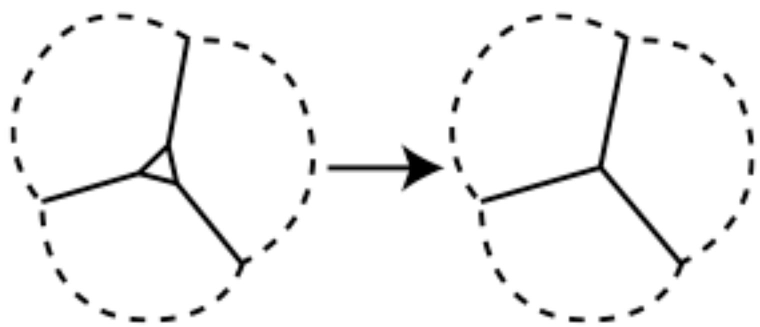
2D vertex model

Farhadifar et al. *Curr Biol* 2007

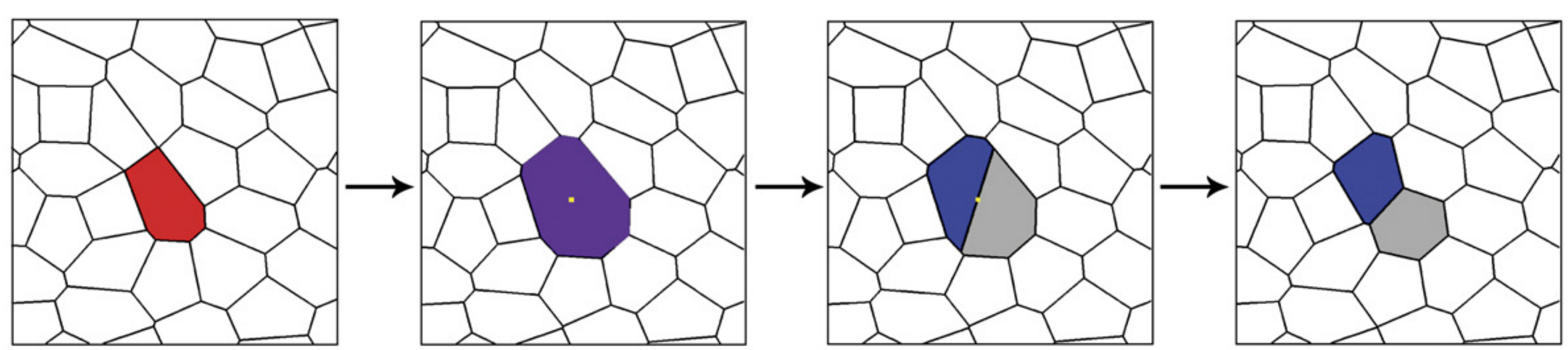
T1 transition



T2 transition

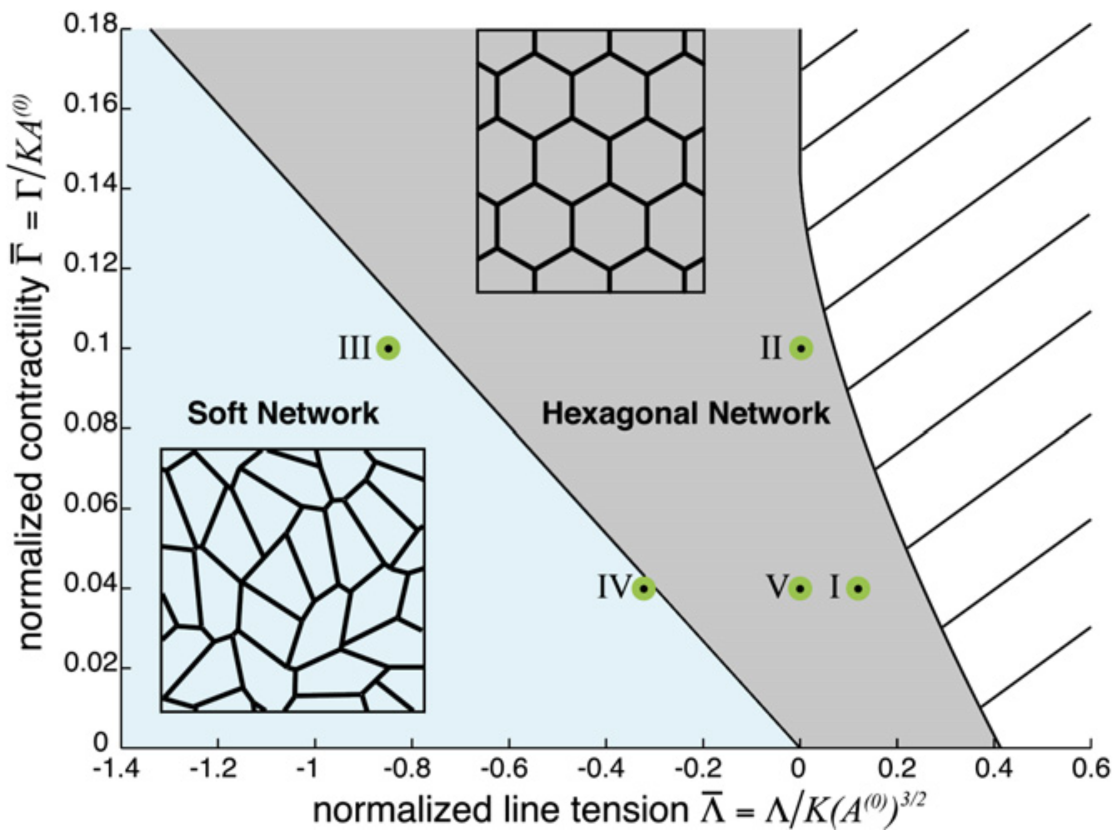


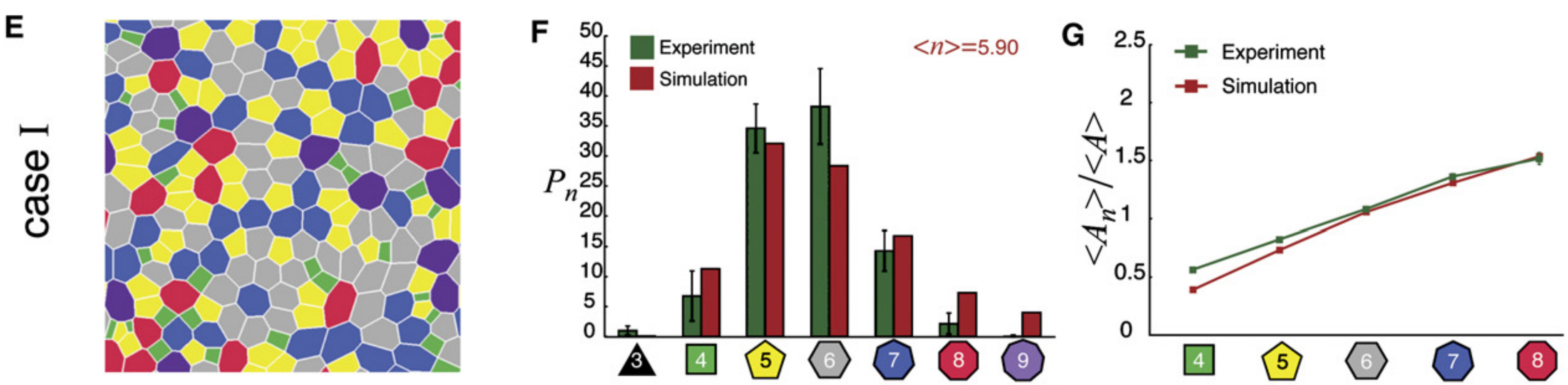
Cell division



2D vertex model

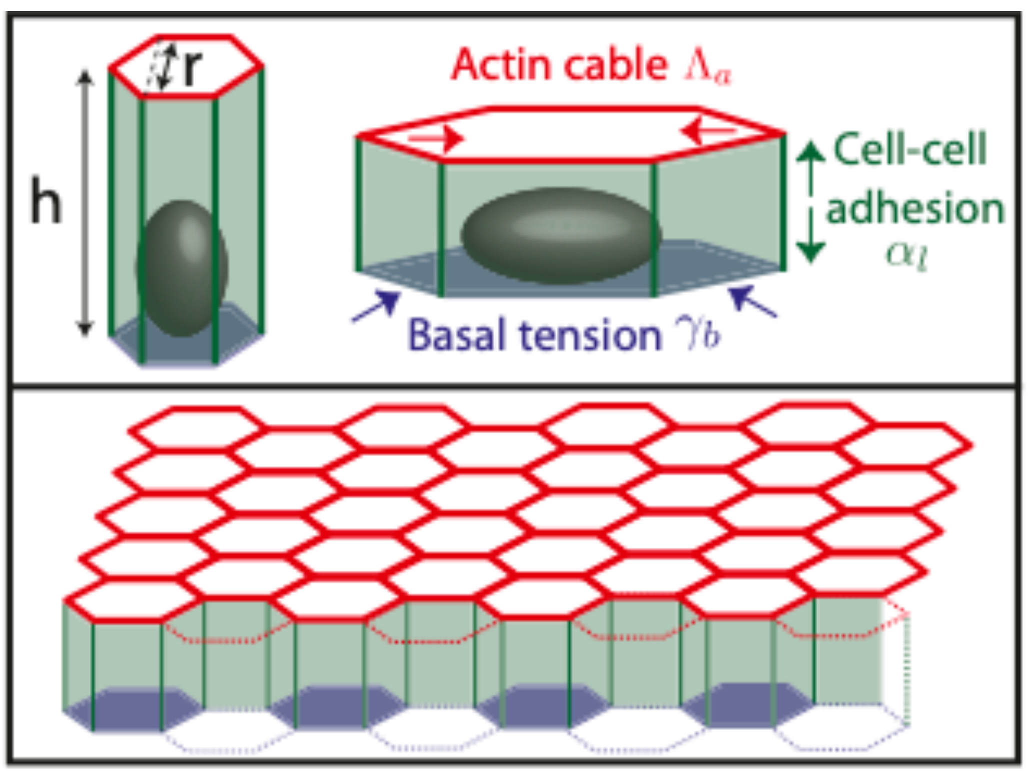
Farhadifar et al. *Curr Biol* 2007

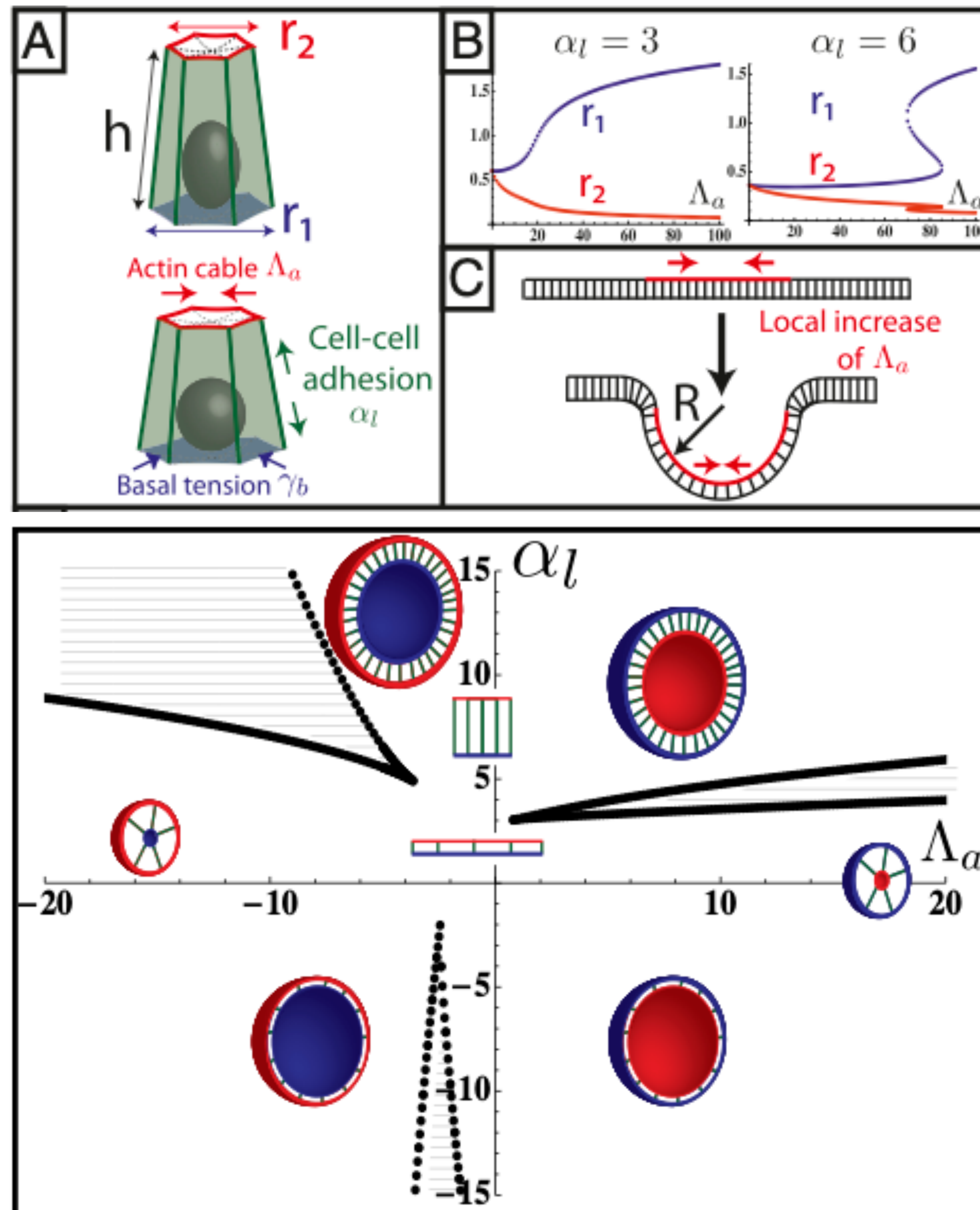




3D vertex models

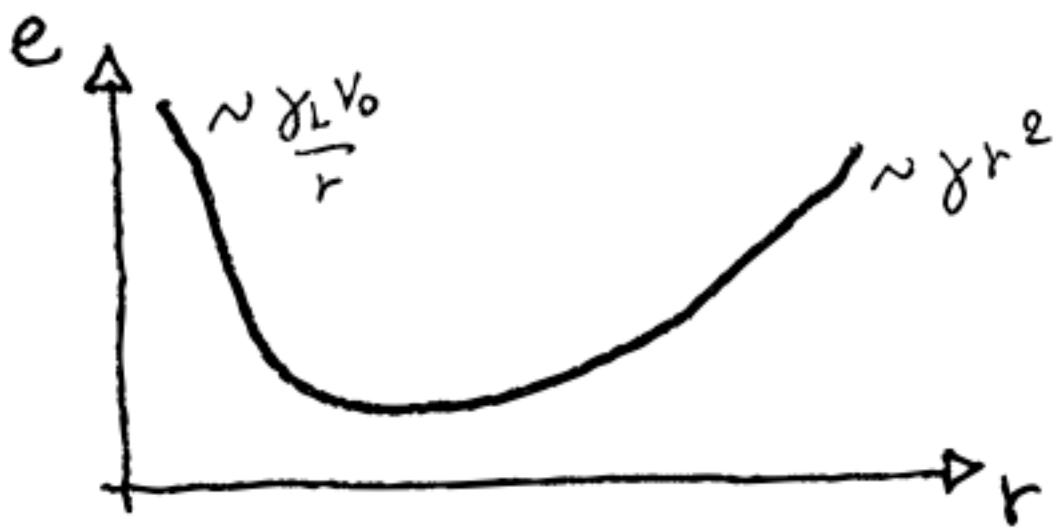
Analytical model - Hannezo et al. *PNAS* 2014

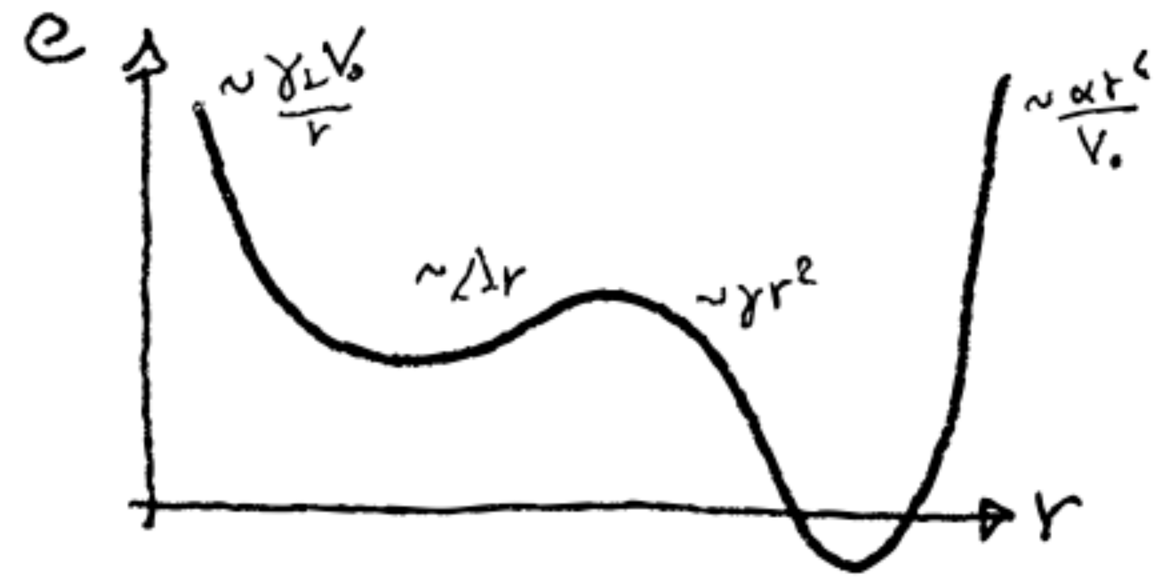


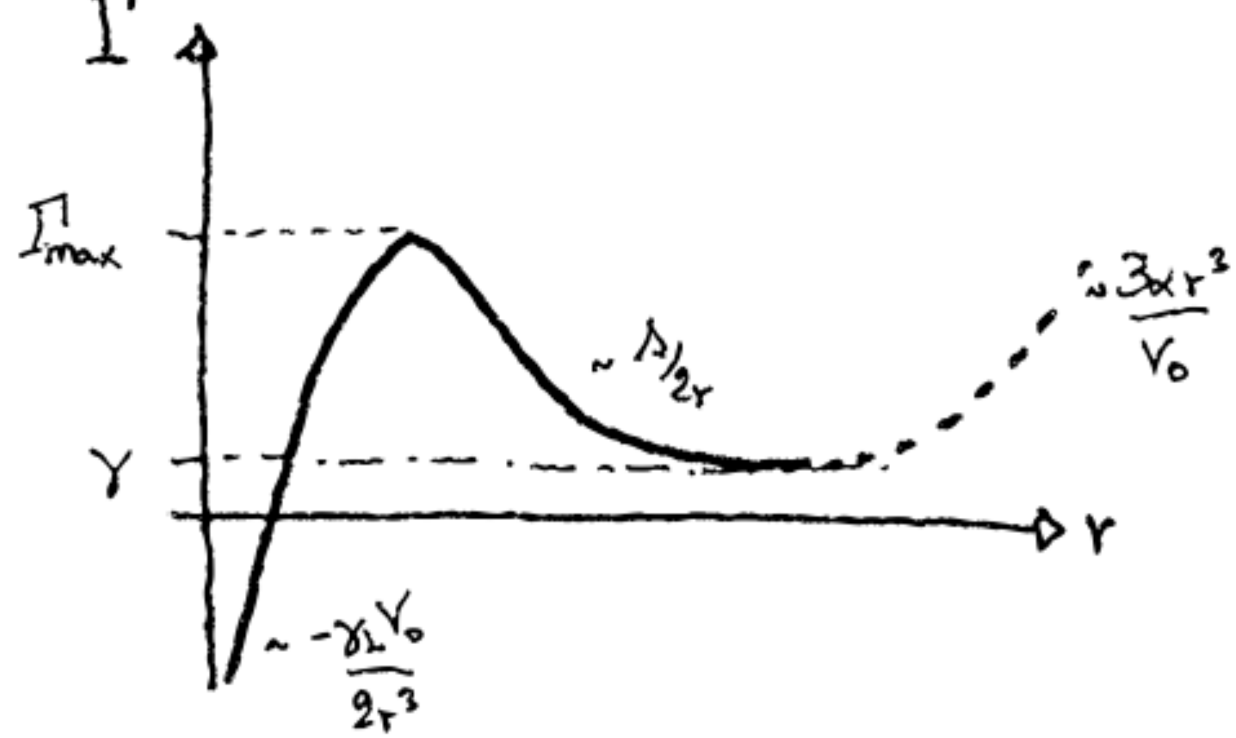


3D vertex models

Analytical model - Hannezo et al. *PNAS* 2014

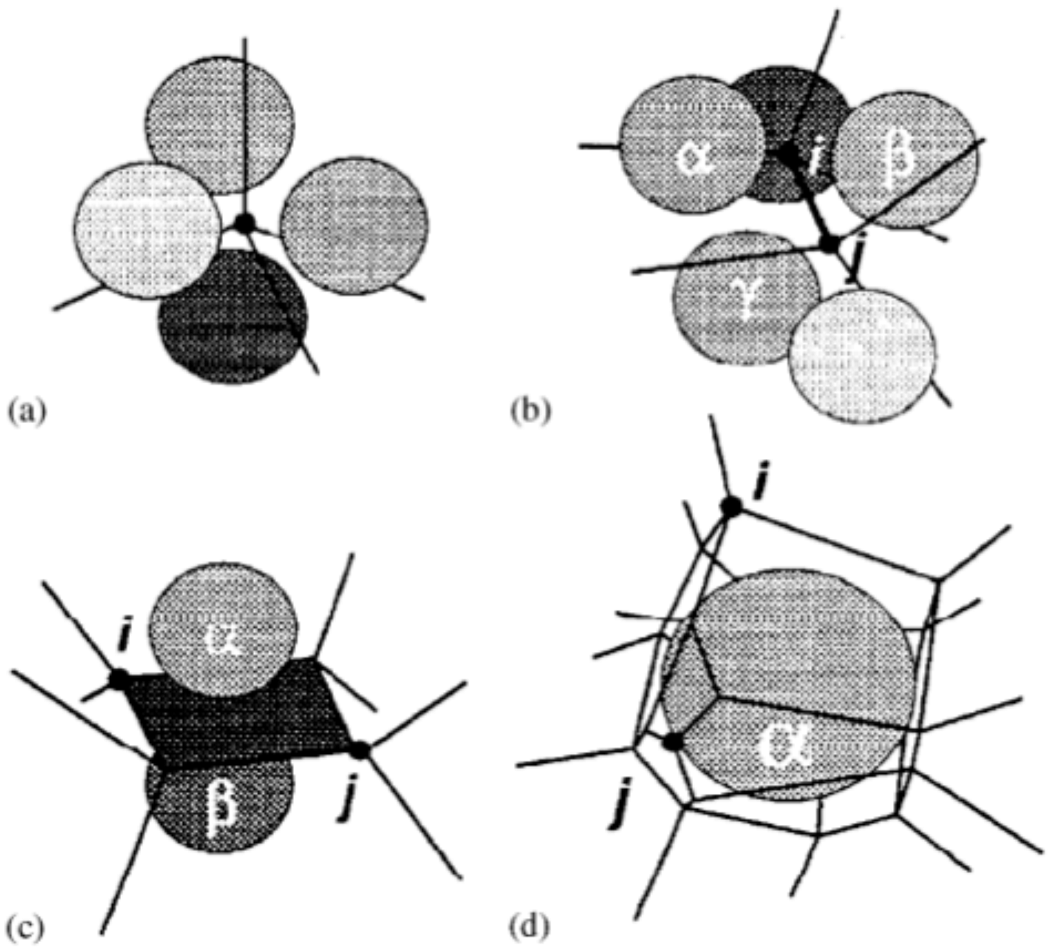


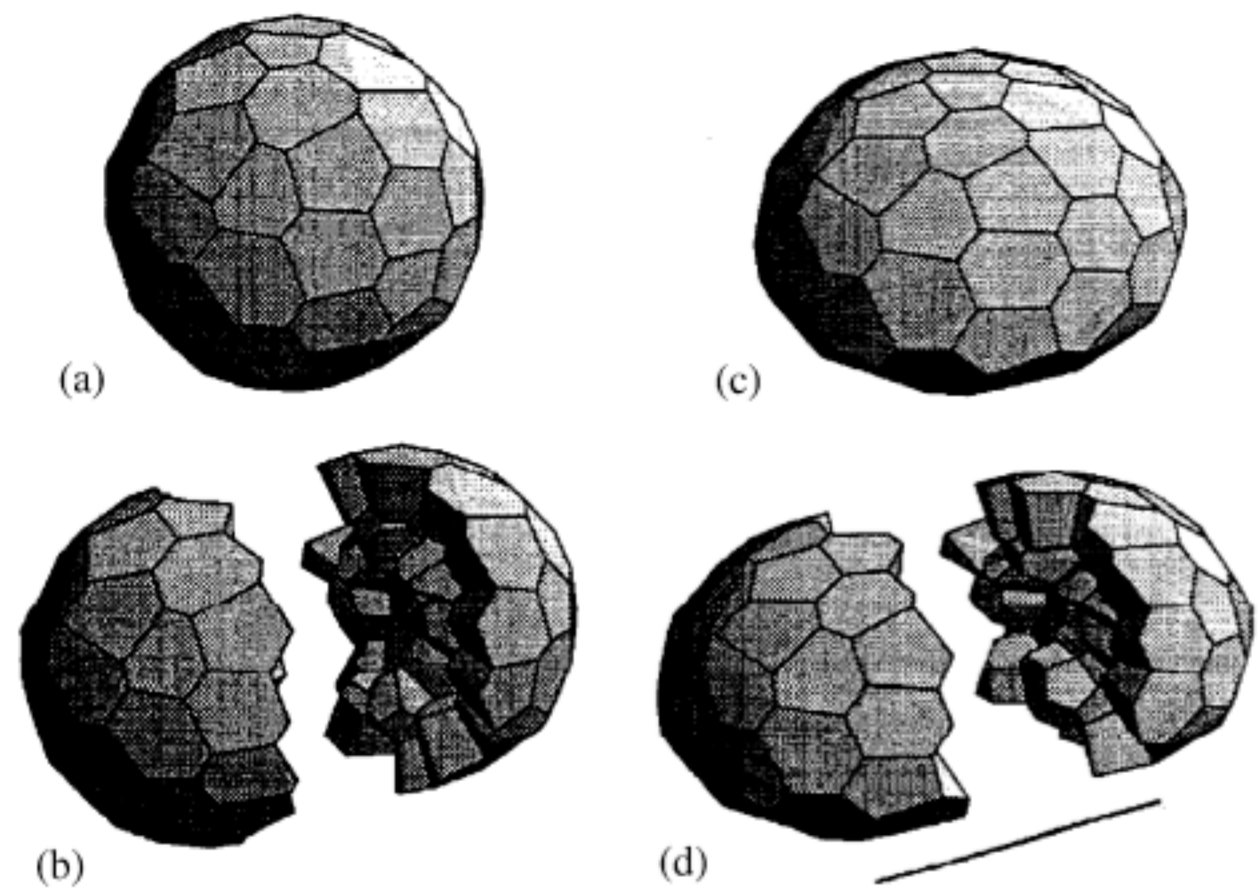




3D vertex models

Numerical models - Honda et al. *J Theo Biol* 2004



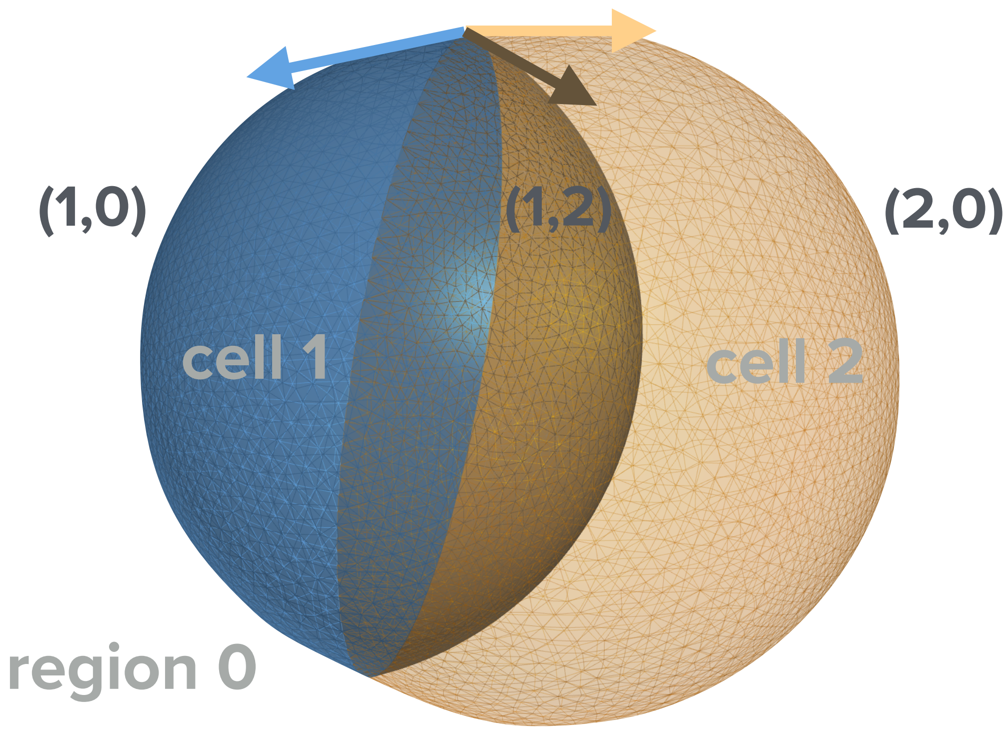


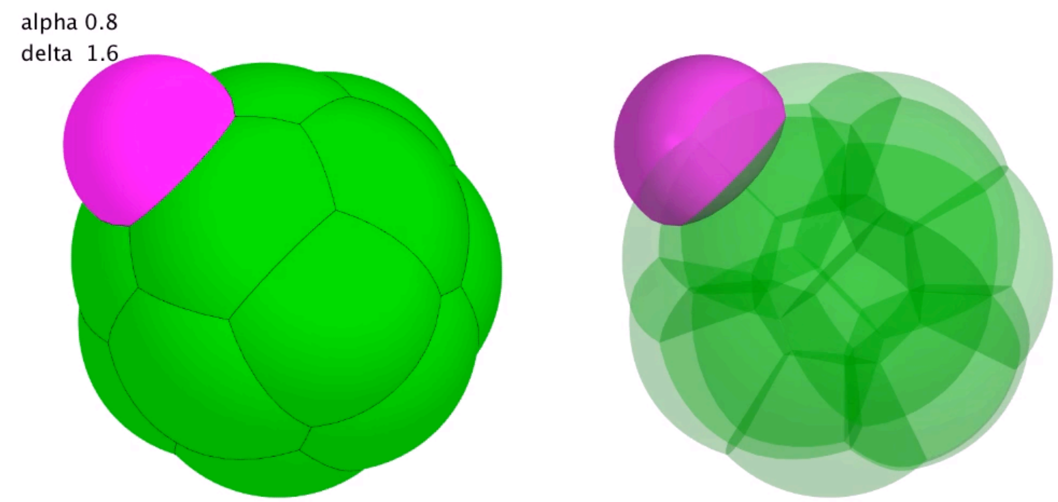
$$\eta \frac{d\boldsymbol{r}_i}{dt} = -\boldsymbol{\nabla}_i \mathcal{E}$$

$$\mathcal{E} = \sigma \sum_{<\alpha,\beta>} A_{\alpha\beta} + \sigma_0 \sum_{<\alpha,0>} A_{\alpha 0} + \kappa \sum_{\alpha} (V_\alpha - V_0)^2 + \rho \sum_{\alpha} z_\alpha V_\alpha + w_{\text{floor}} \sum_{\alpha} \frac{1}{1+e^{a z_\alpha}}$$

3D vertex models

Numerical models - Maître, Turlier et al. *Nature* 2016

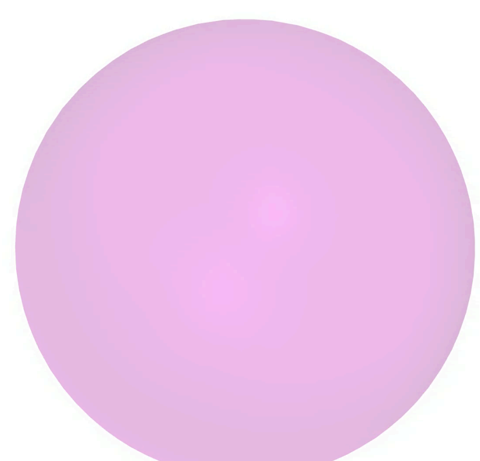


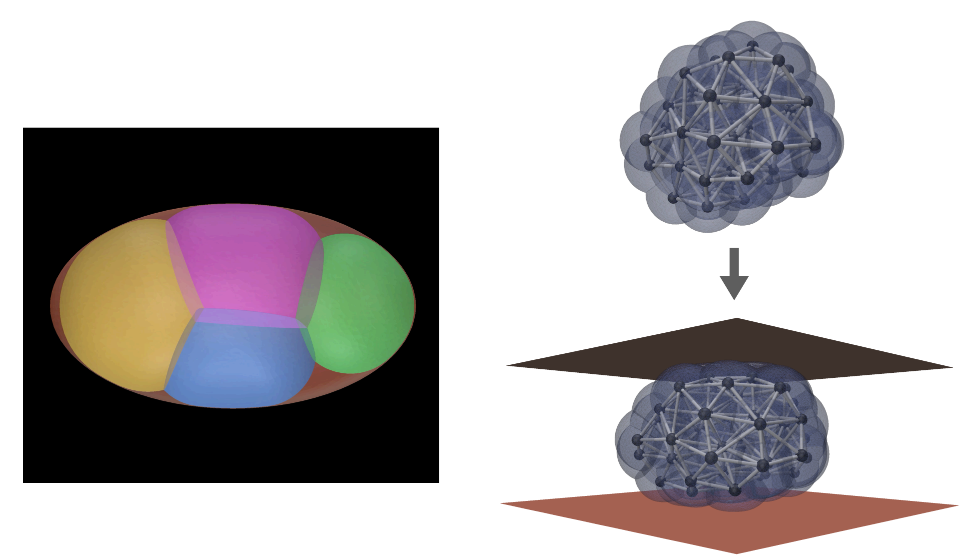


500 cells

Cell division

Confinement





Nicolas Ecker

3D vertex models

Numerical models - Okuda et al. *Sci Reports* 2018