Self-organized cable formation and force transmission in an active vertex model for epithelial tissues

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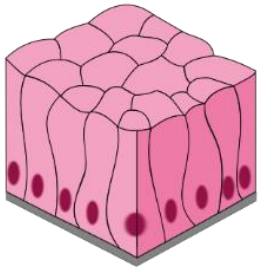
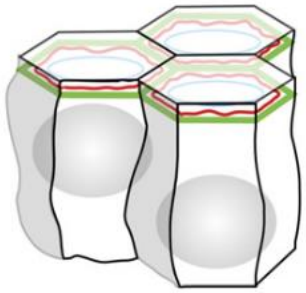
Epithelial tissues

The (epithelial) tissue may be modelled as a network of active edges.

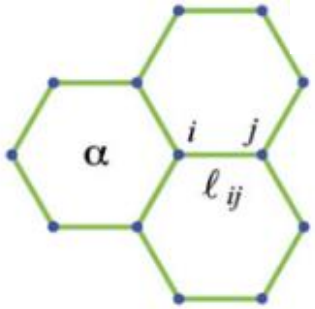
epithelial tissue



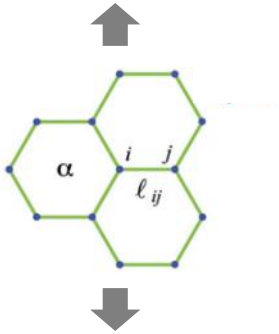
force-generating machineries

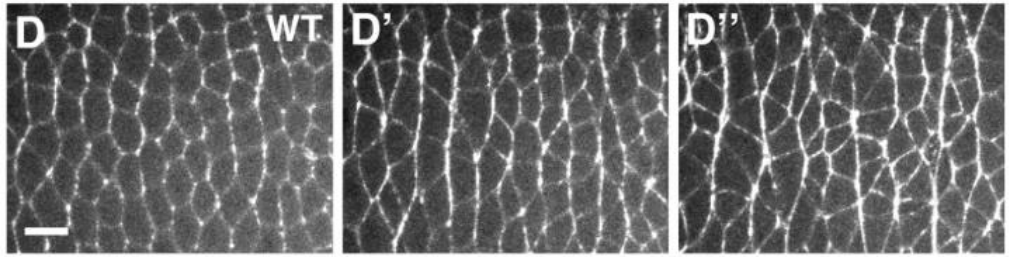


vertex model



The active edges are *mechanosensitive*.



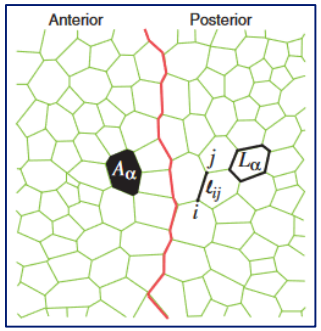


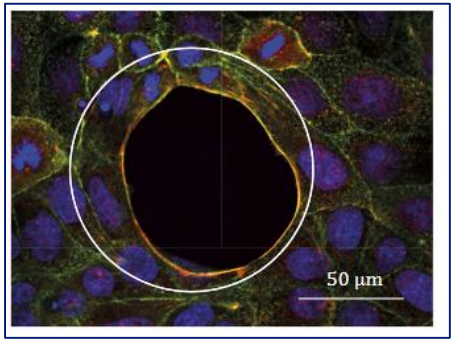
Farhadifar et al., *Curr Biol*, 2007;
Fernandez-Gonzalez et al., *Dev Cell*, 2009;
Sumi et al., *Dev Cell*, 2018;
Duda et al., *Dev Cell*, 2019.

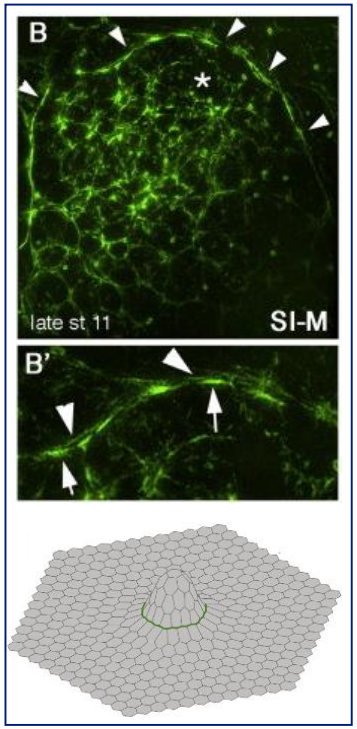
Actomyosin cables

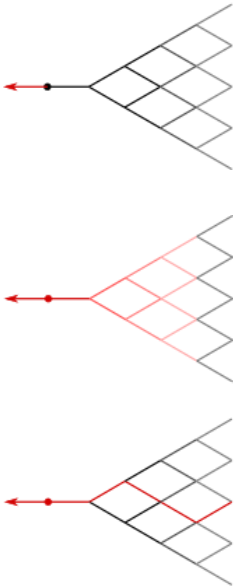
Supracellular actomyosin cables are ubiquitous in development.

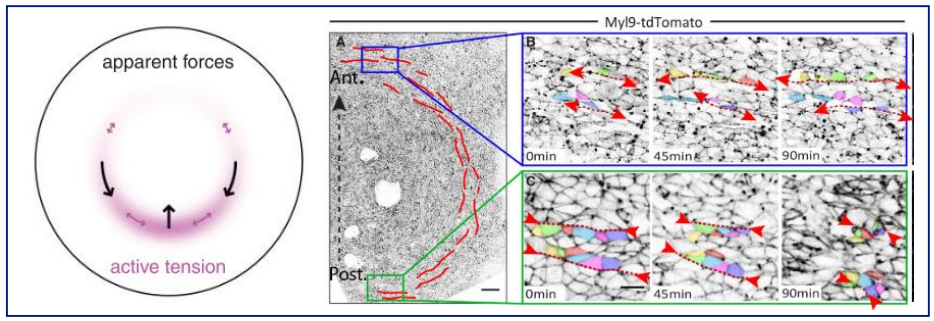
- Could mechanical feedback lead to the assembly/refinement of cables?









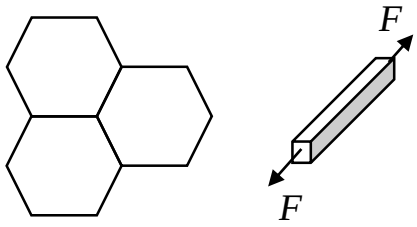


Landsberg et al., *Curr Biol*, 2009;
Nier et al., *Proc Natl Acad Sci USA*, 2015;
Röper, Dev Cell, 2012;
Murisic et al., *Biophys J*, 2015;
Saadaoui et al., *Science*, 2020

Viscoelastic active edges

- Short-time elasticity

$$F = \frac{k(l - l_0)}{l_0}$$



- Long-time yielding and active contraction

yielding

$$\frac{\dot{l_0}}{l_0} = w(F, m) = F - m$$

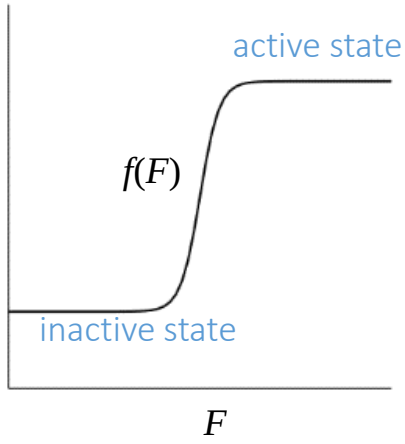
active contraction

- Myosin kinetics

mechanical feedback detachment

$$\frac{d}{dt}(ml_0) = \left[f(F) + \xi \left(\frac{l}{l^*} - 1 \right) - m \right] l_0$$

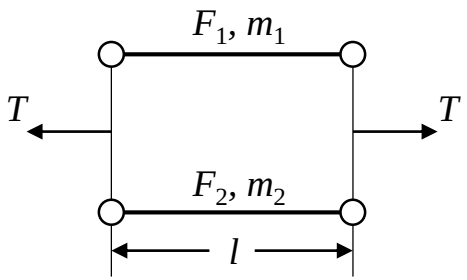
preferred length

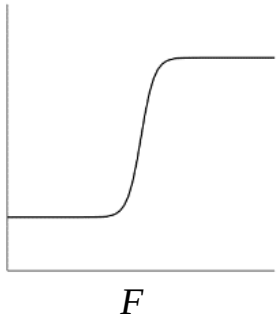


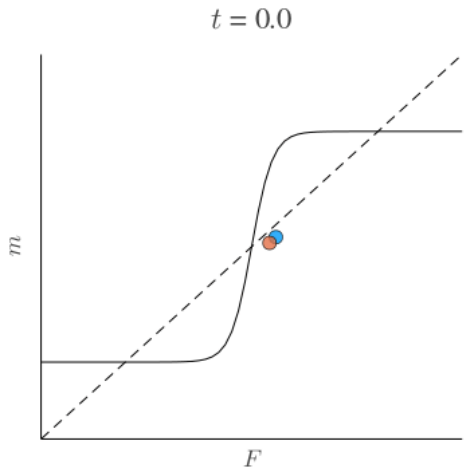
Noll et al., *Nat Phys.*, 2017

Symmetry breaking leads to tension focusing

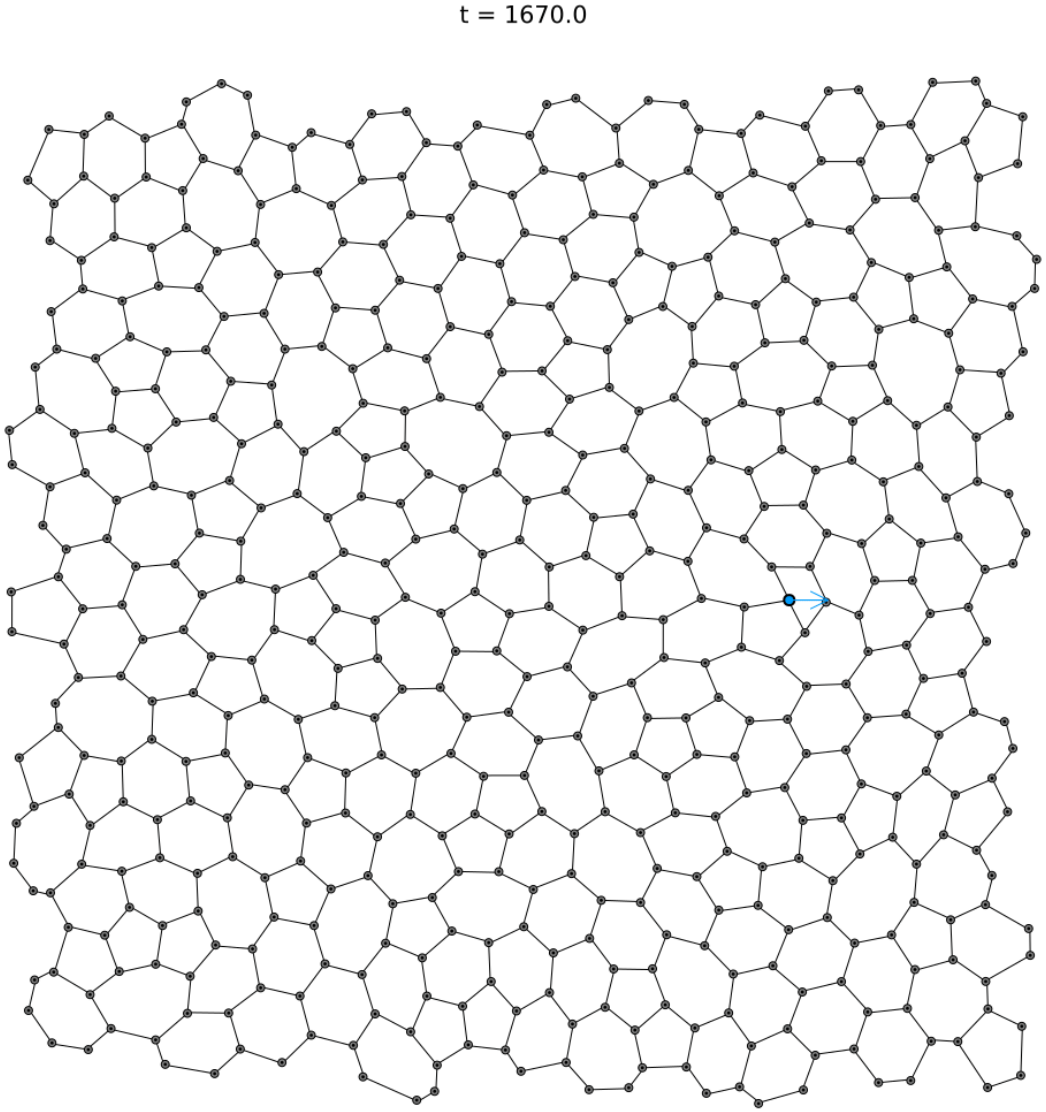
The symmetric steady state is unstable if the mechanical feedback is sufficiently nonlinear.







Self-organized cables in a 2D tissue



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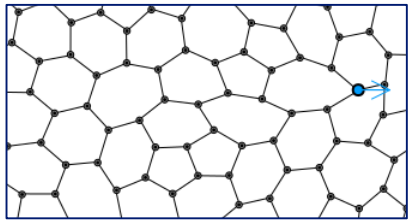
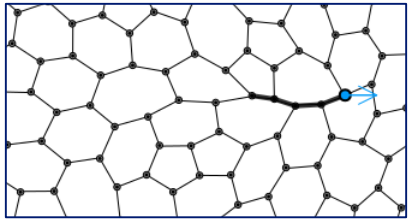
Properties of a finite cable

- The cable length can be modulated by the pulling force.

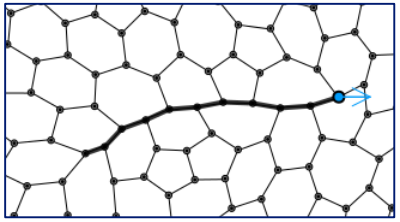
vertex 358, $P = 1.0$



vertex 358, $P = 1.4$

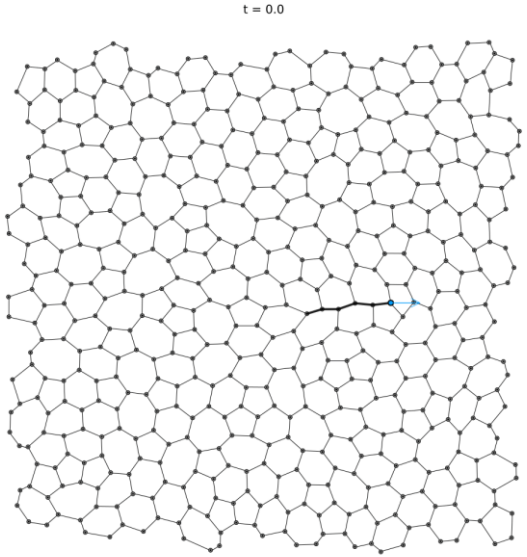


vertex 358, $P = 1.8$

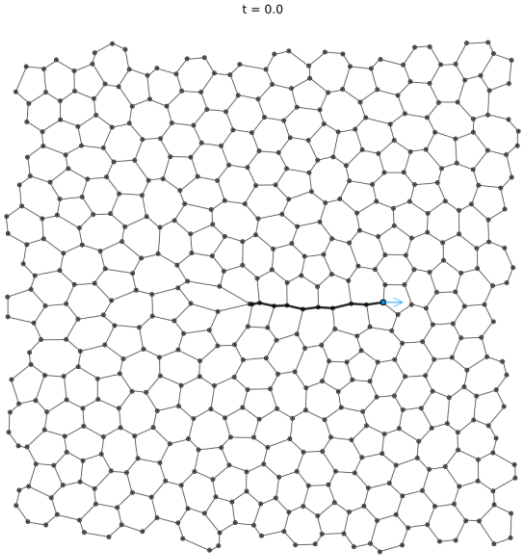


- Cables can be reversible

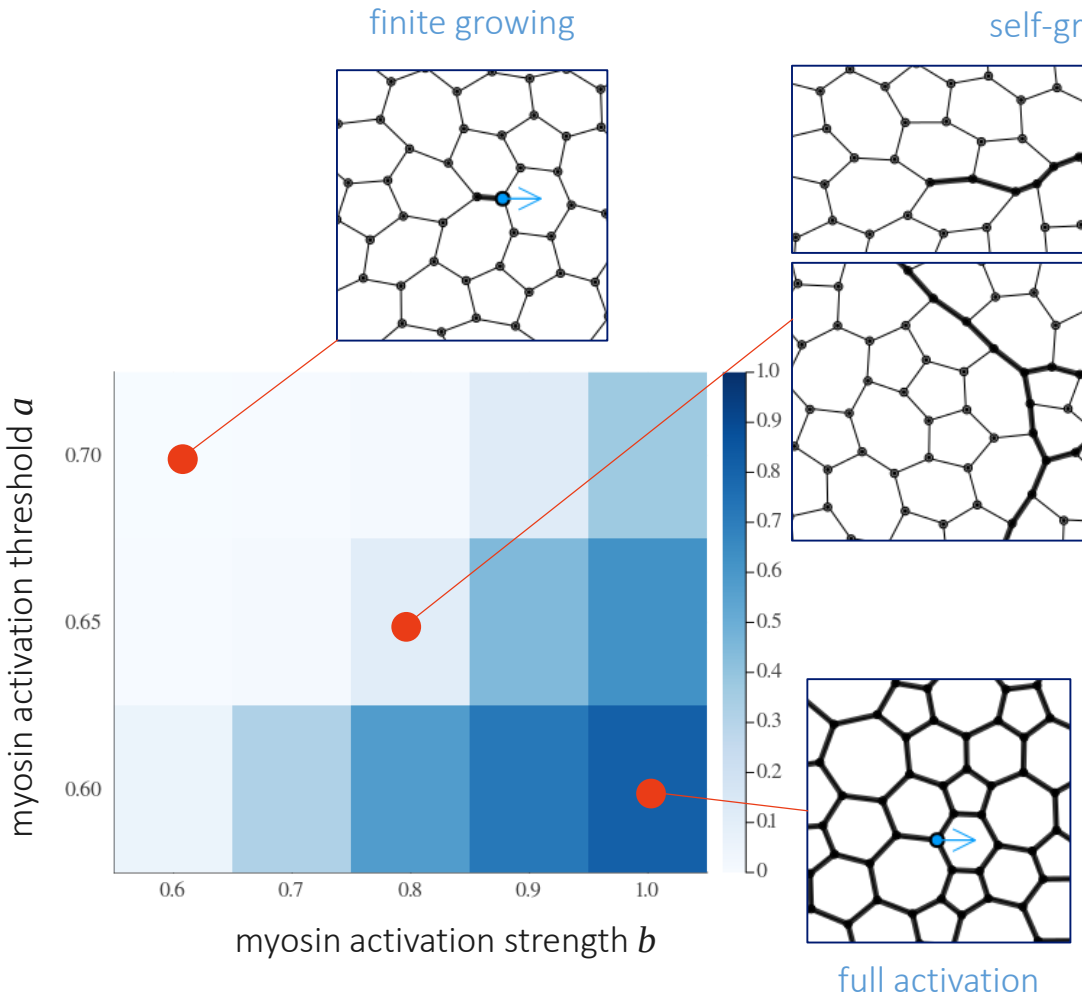
$\xi = \mathbf{2.0}$, $a = 0.7$, $b = 0.5$, $P = 1.5$

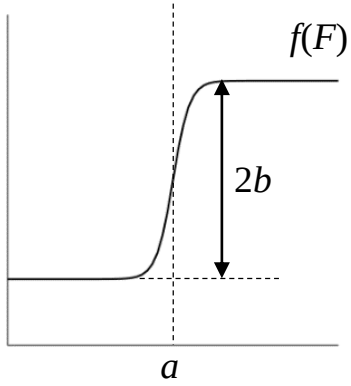


$\xi = \mathbf{0.2}$, $a = 0.52$, $b = 0.45$, $P = 1$



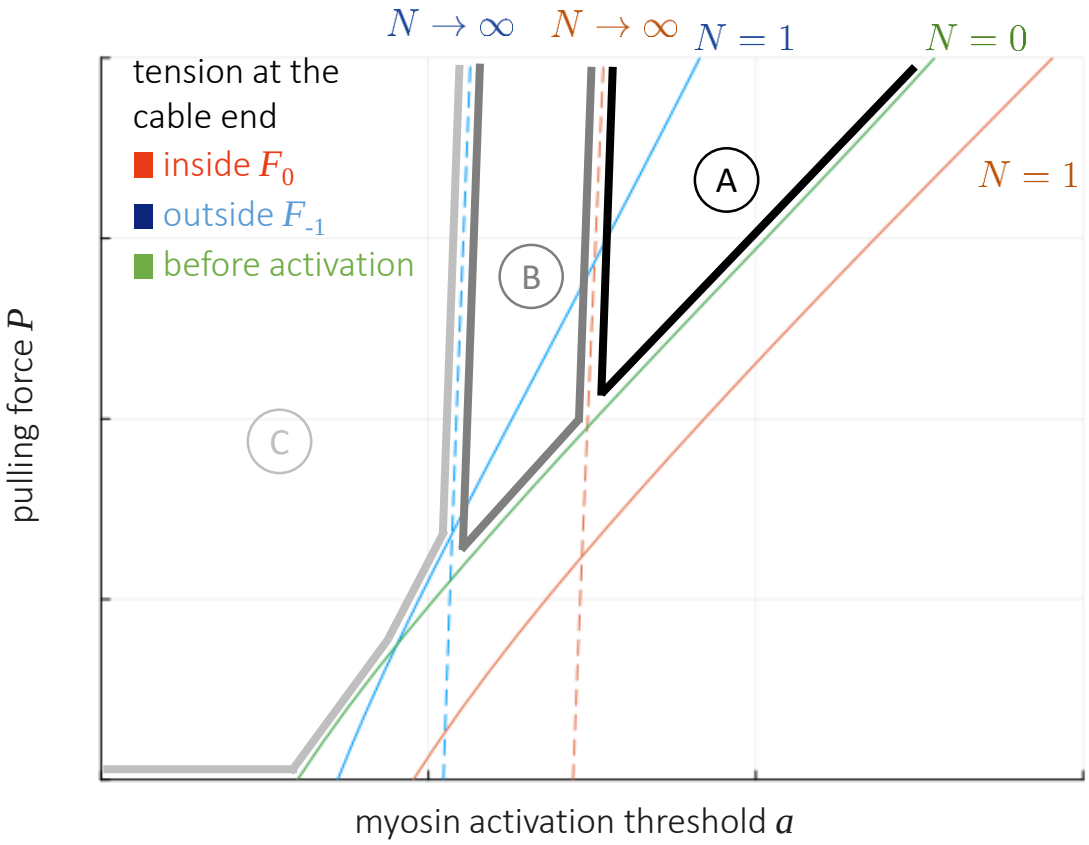
Spontaneous activation propagation



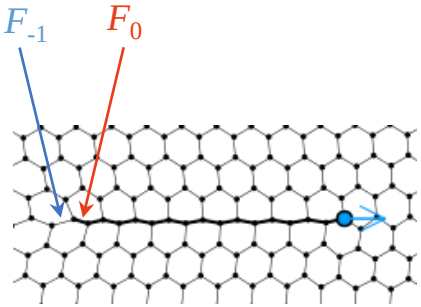


pull-stop simulation: increase the pulling force slowly until at least one edge is activated

Cable growth and reversibility



prescribing a cable of N edges with a pulling force P

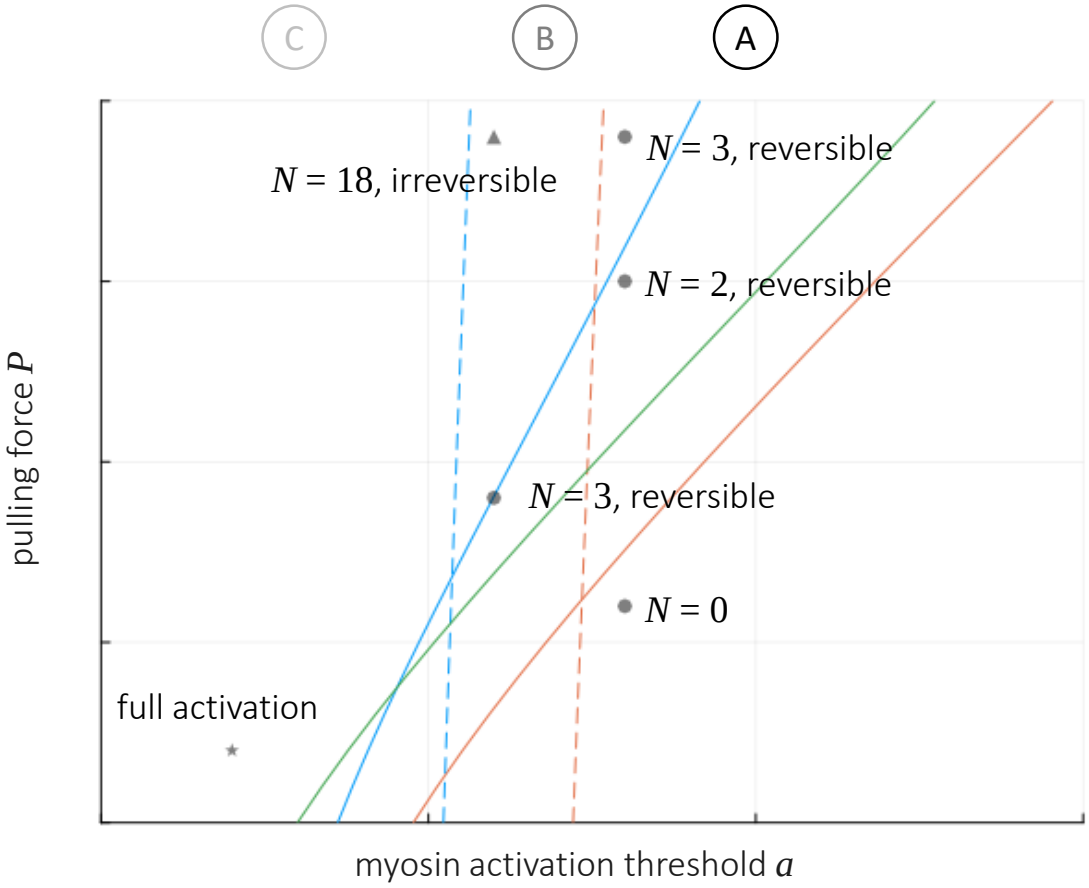


A finite cable, reversible

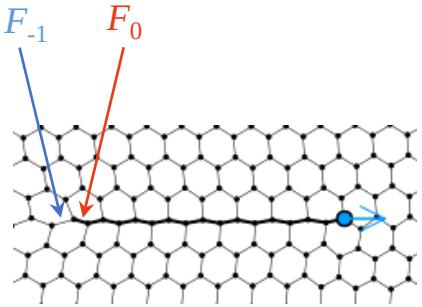
B finite cable, reversible if short

C infinite cable

Cable growth and reversibility



comparing with numerical simulations



A finite cable, reversible

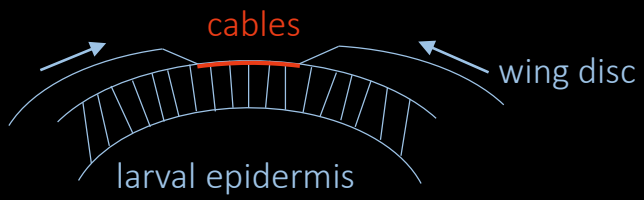
B finite cable, reversible if short

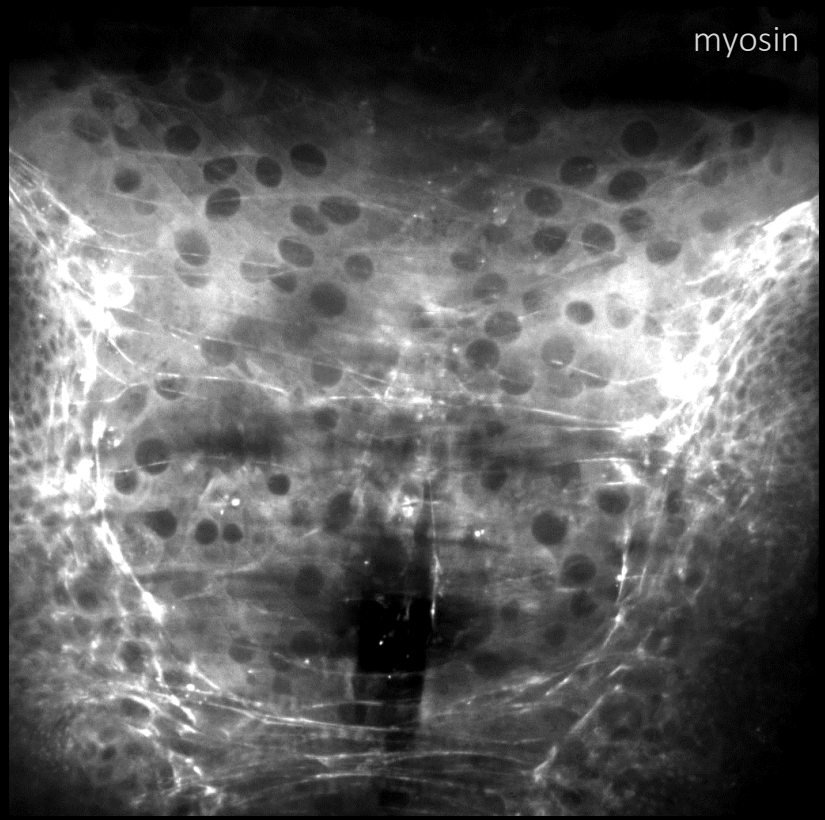
C infinite cable

Experimental evidence

Drosophila wing imaginal discs migrating on the larval epidermis

- Supracellular cables assemble in the larval epidermis.





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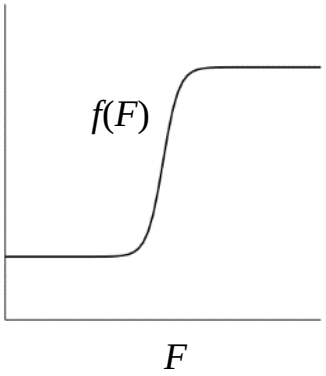
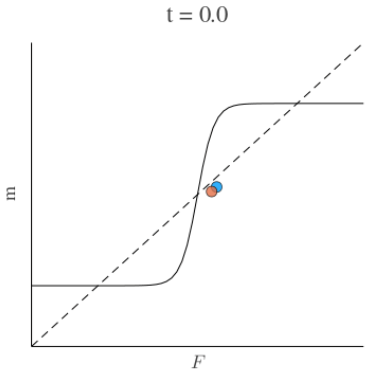
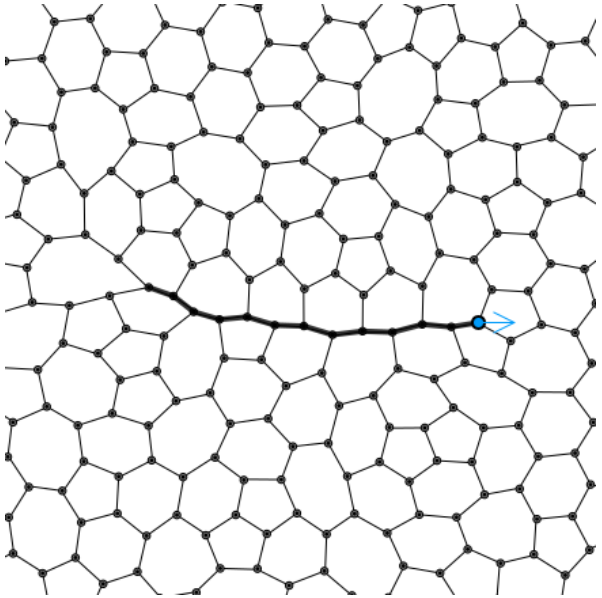
Summary

An active cellular network equipped with *nonlinear* mechanosensitive feedback

- The bistability allows for active/inactive states of edges.
- Symmetry breaking due to the mechanical feedback.
- Tensile cables: long-range, focused, reversible
- Mechanical self-organization







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