

# From cells to strategy: Emergent patterning in development

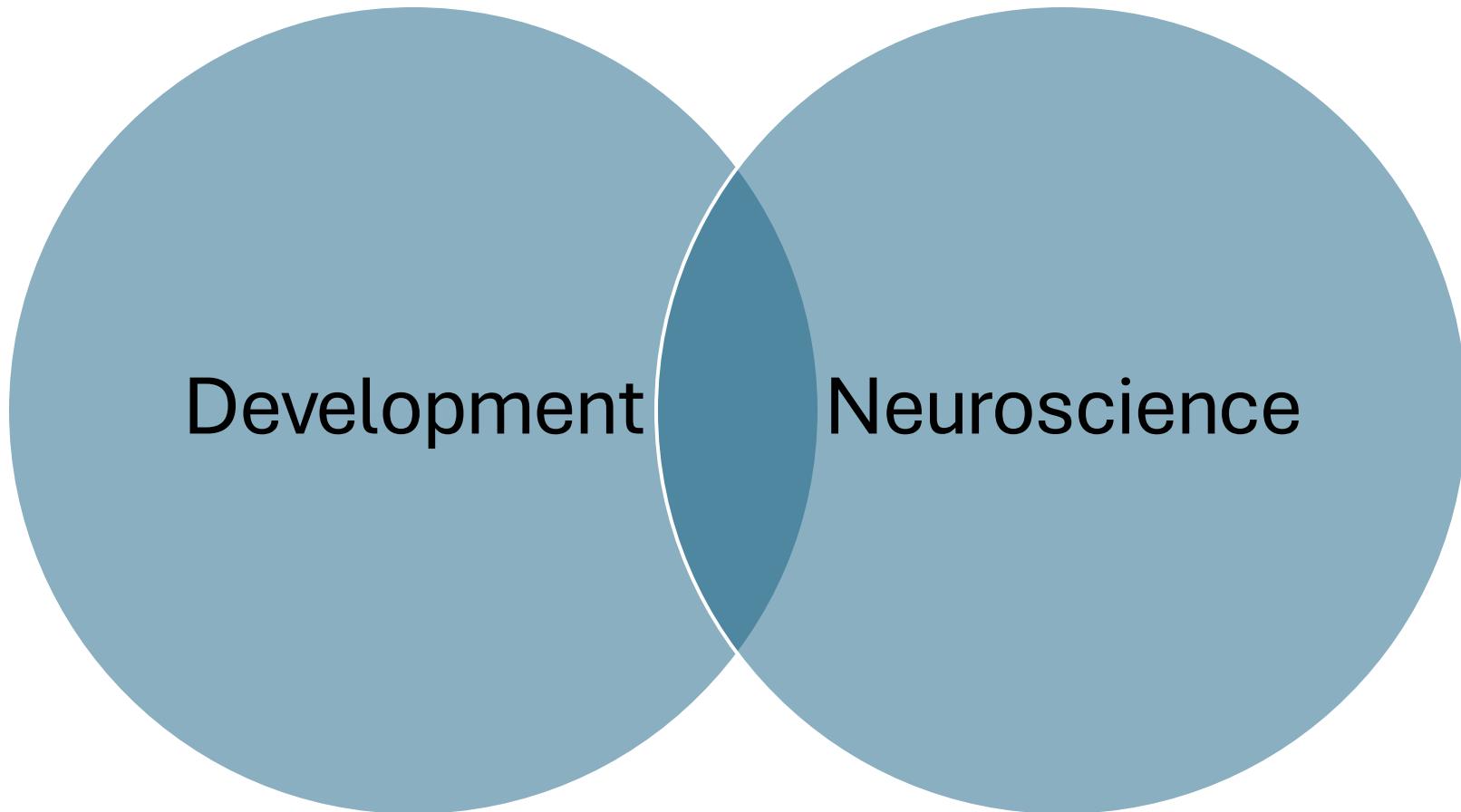
GSK Core class: Mechanistic Bio

2025-11-18



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# Neurodevelopment



# Core concepts

## Developmental Biology (Topics)

- Gene regulation
- Pattern formation
- Morphogenesis
- Organogenesis
- Stem cell biology

## Neuroscience (Concepts)

- Communication modalities
- Emergence
- Evolution
- Gene-environment interactions
- Information processing
- Nervous system functions
- Plasticity
- Structure-function relationship

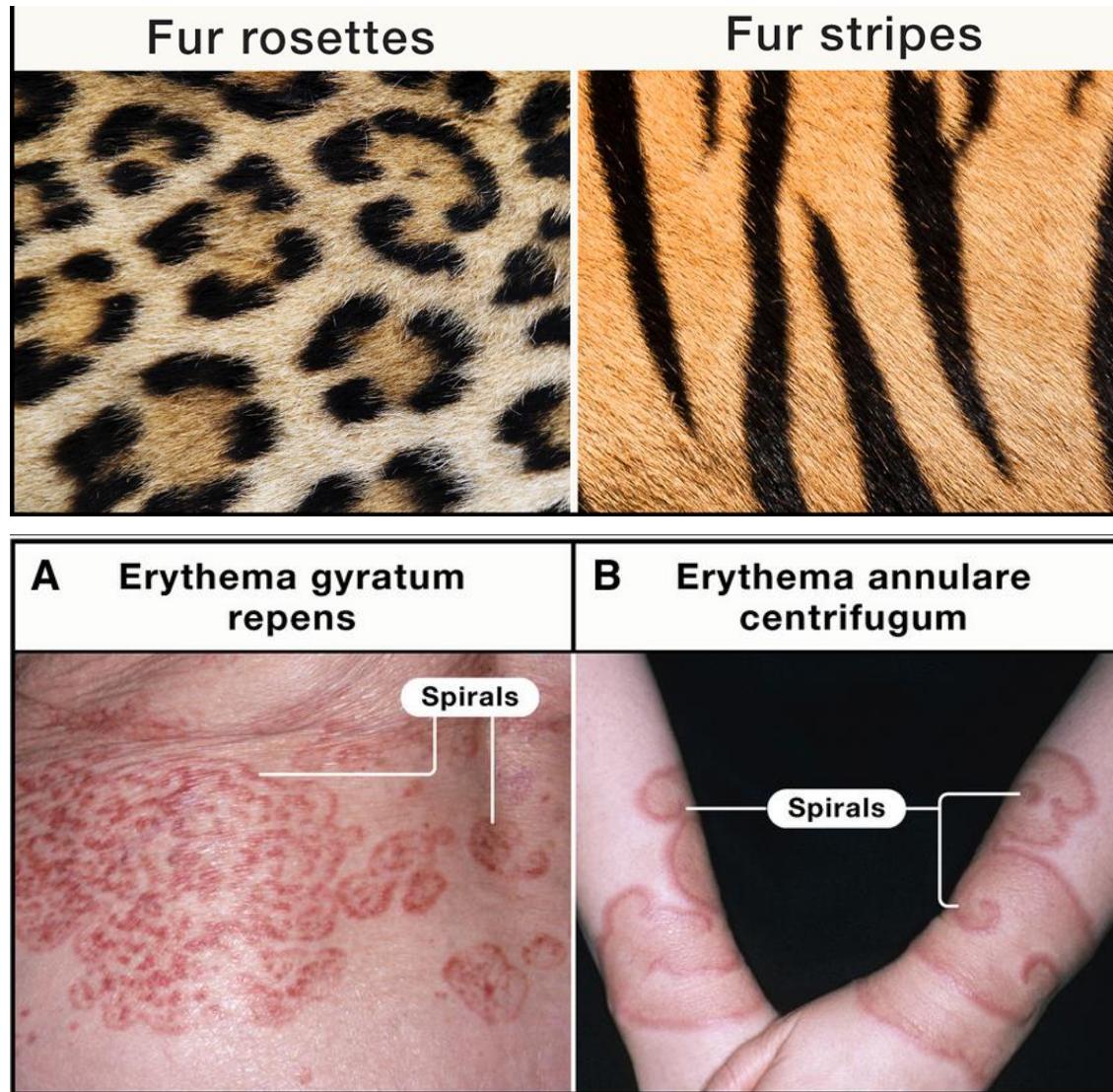
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# Core concepts

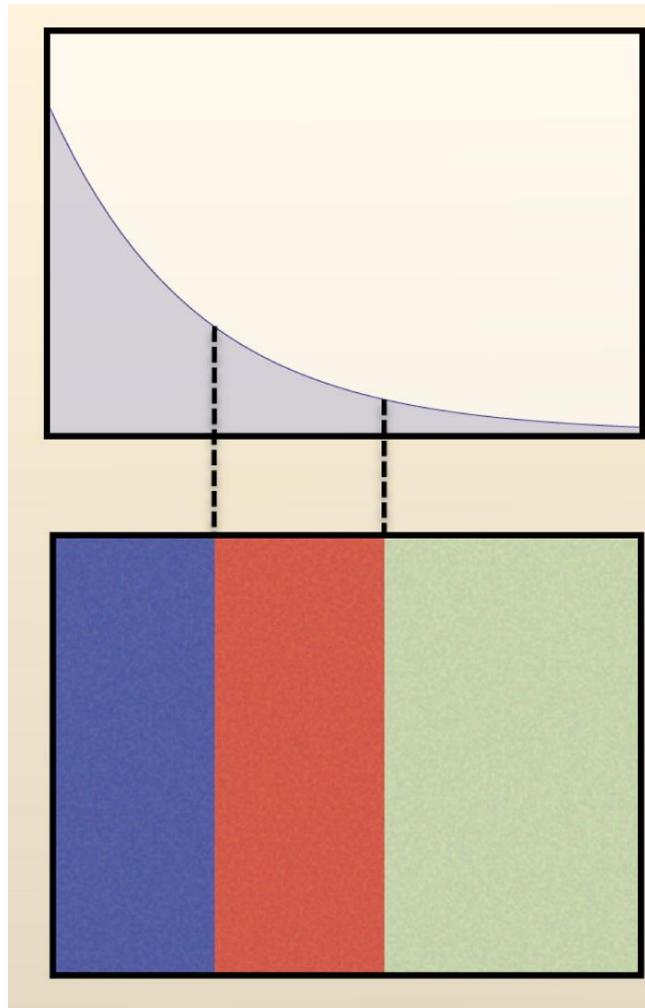
- **Patterning**: cell identity specification and spatial arrangement into complex tissue.
- **Morphogenesis**: the process by which an organism takes its shape.
- Organogenesis: the assembly of cells and tissues that perform specific physiological functions.
- Emergence: higher-level organization that arises from the collective interactions of the constituent parts.
- Evolution: similarities/differences between organisms are constrained by evolutionary backgrounds.

# Why study biological pattern formation?

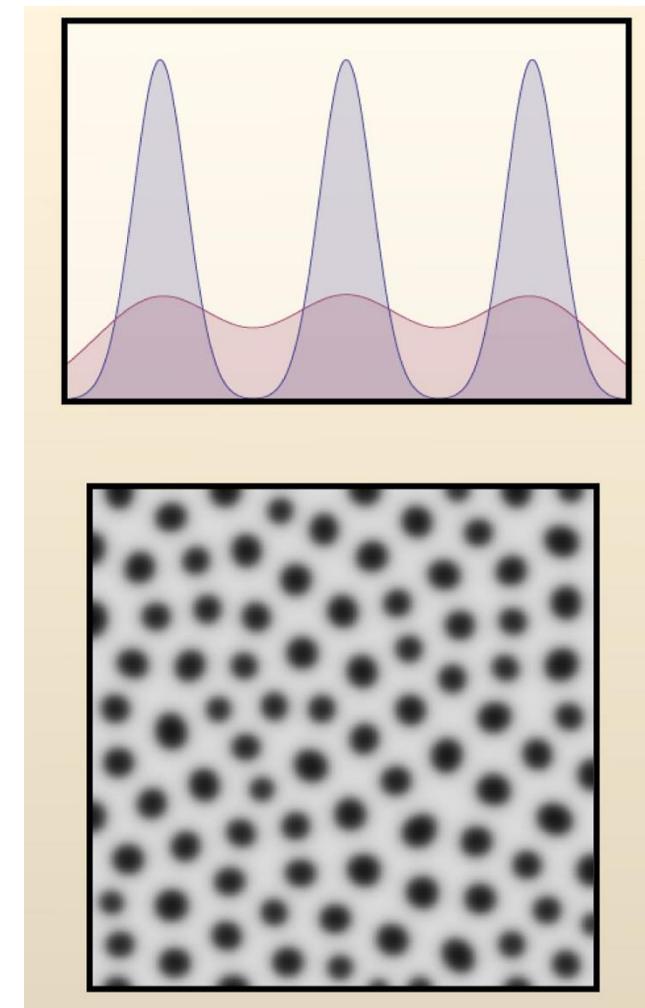


# Patterning: Two major historical threads

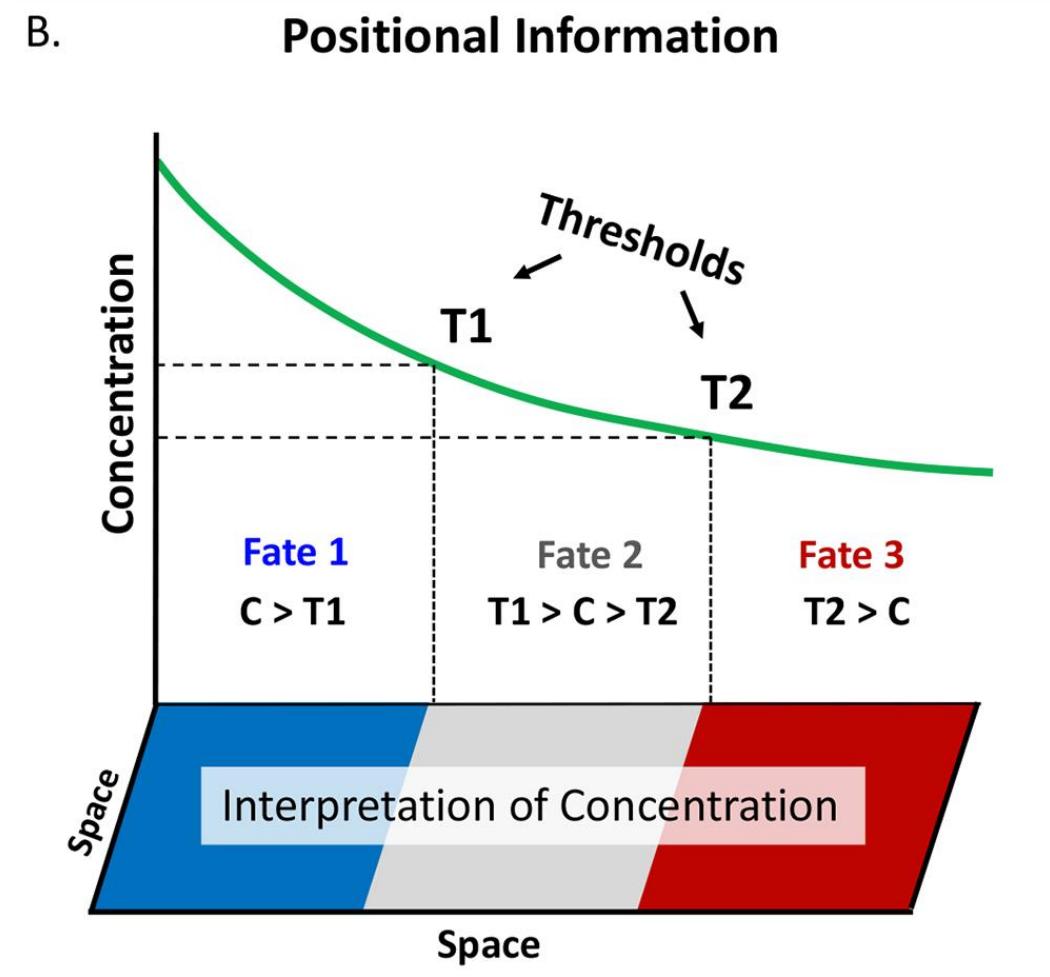
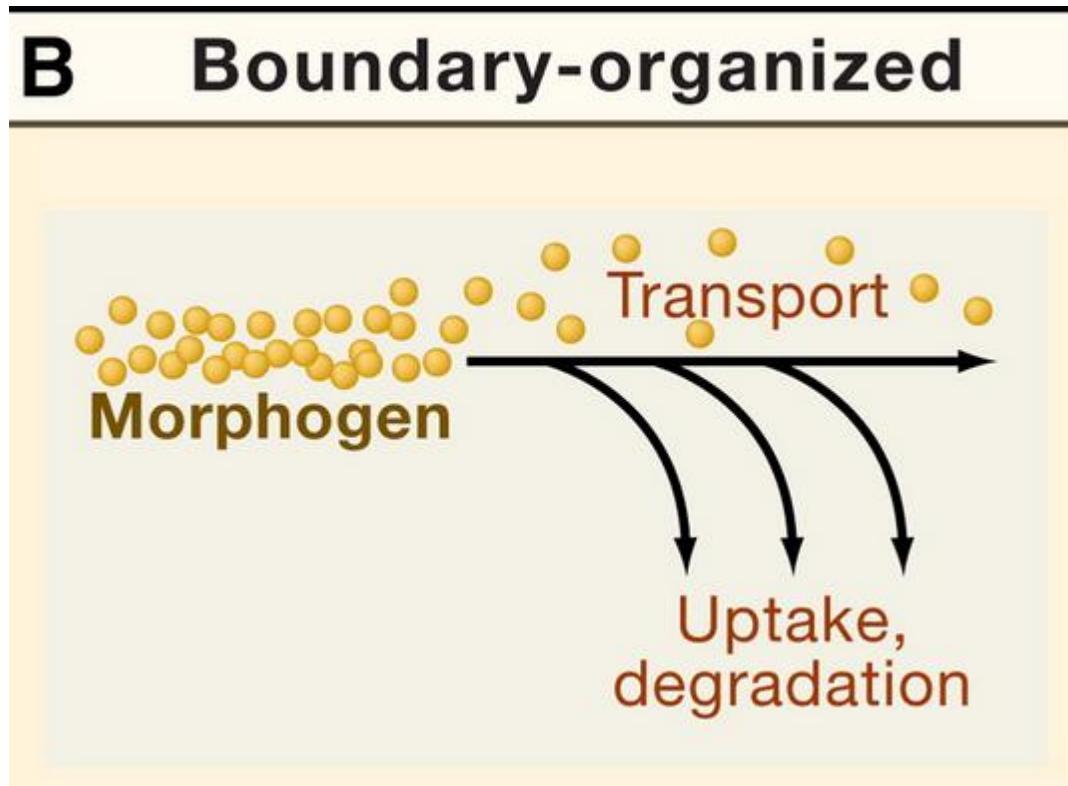
Wolpert "French Flag"  
Positional information



Turing: Reaction-Diffusion  
Local self-organization

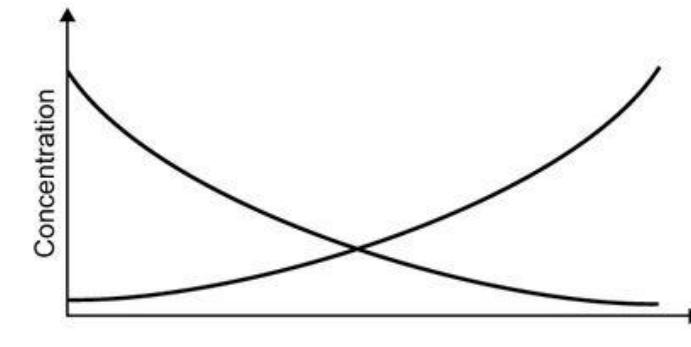
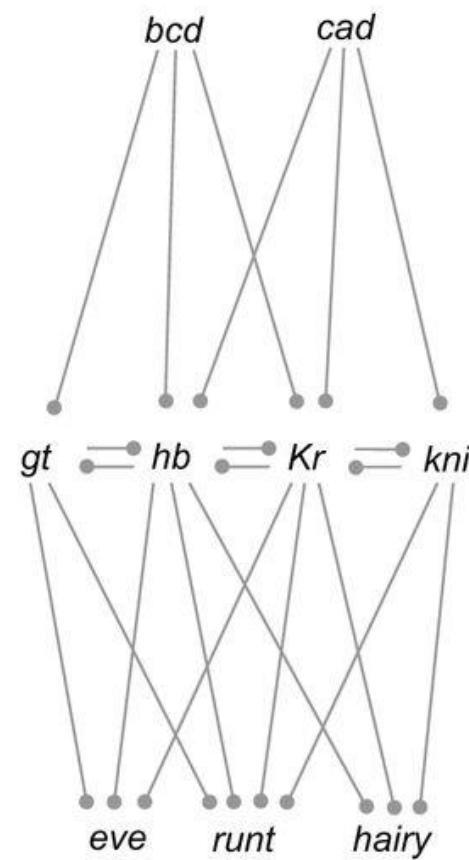
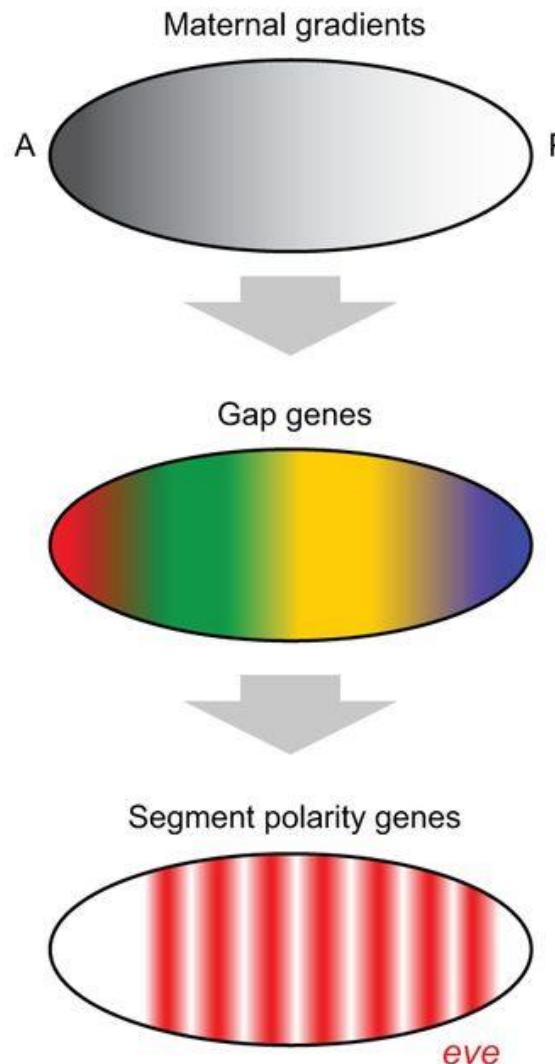


# Positional information: Gradients

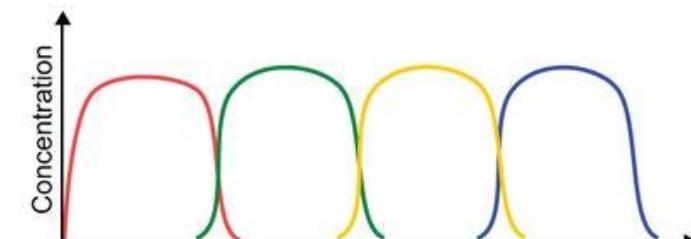


# PI: *Drosophila* embryo segmentation

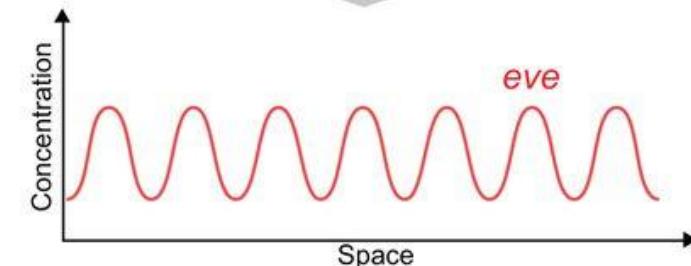
## A Wolpert – PI



Positional information

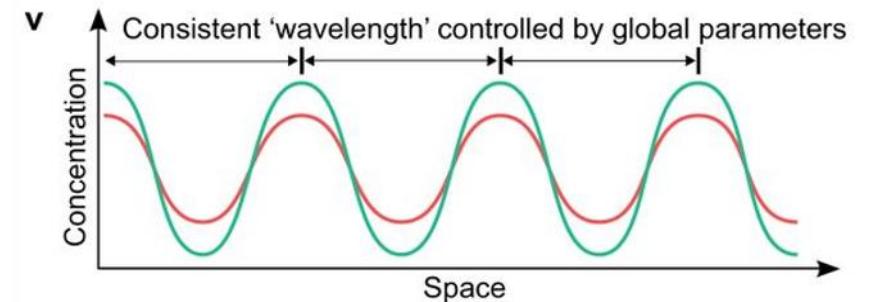
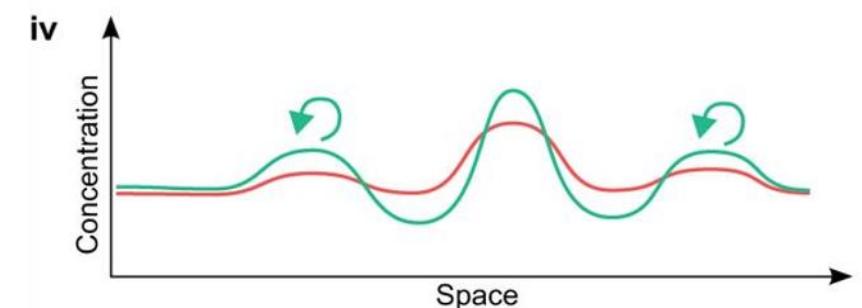
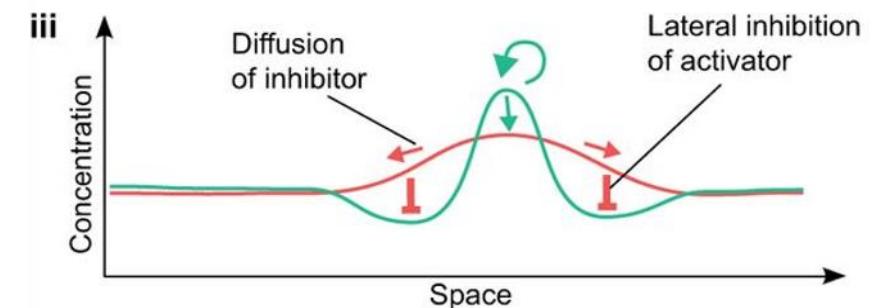
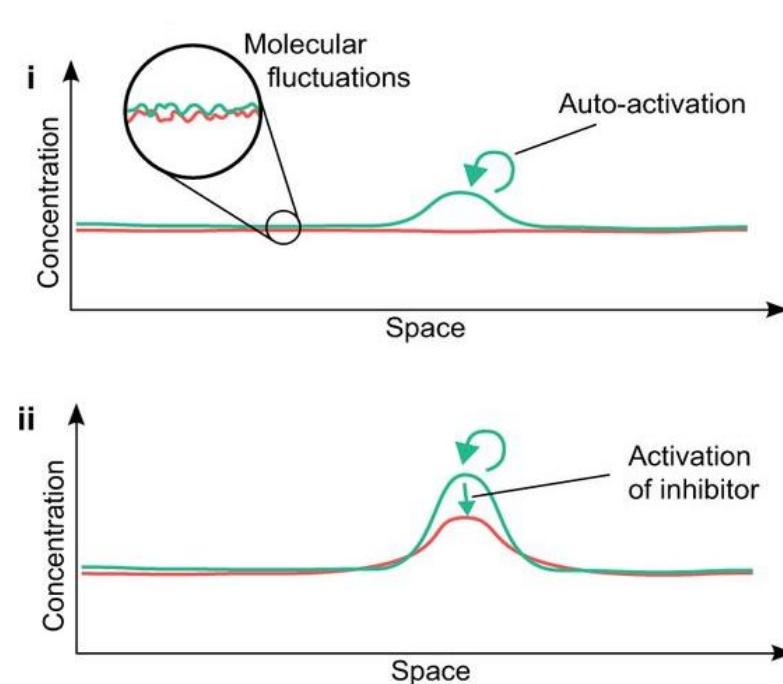
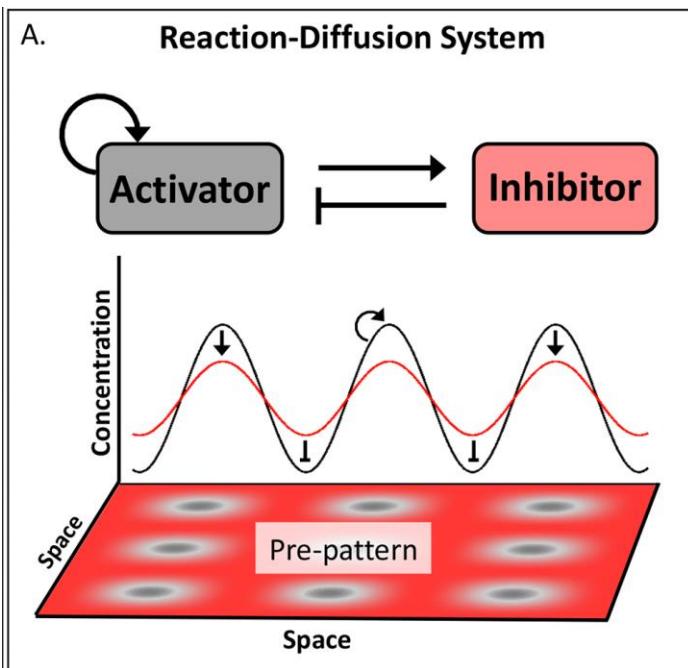


Positional information

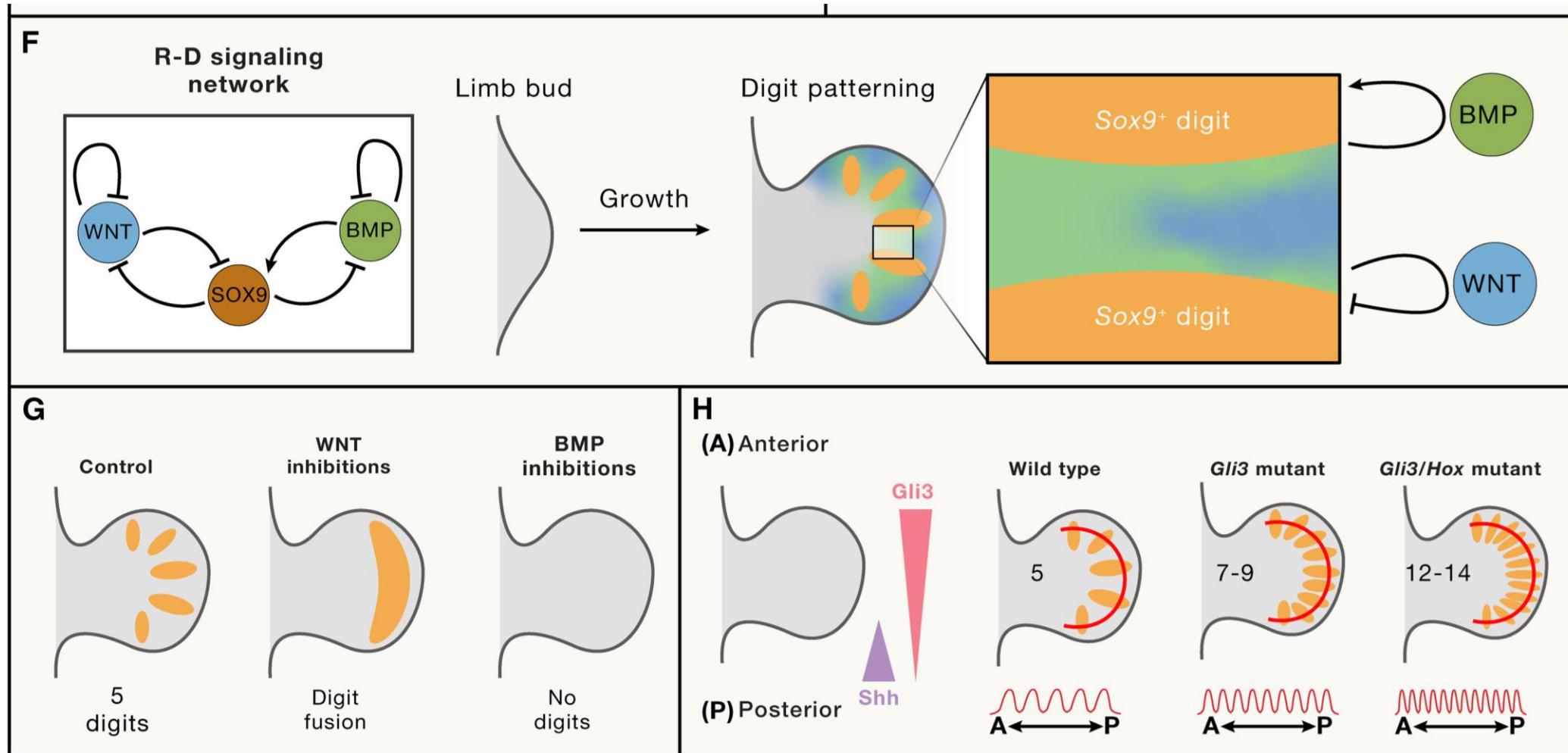


Space

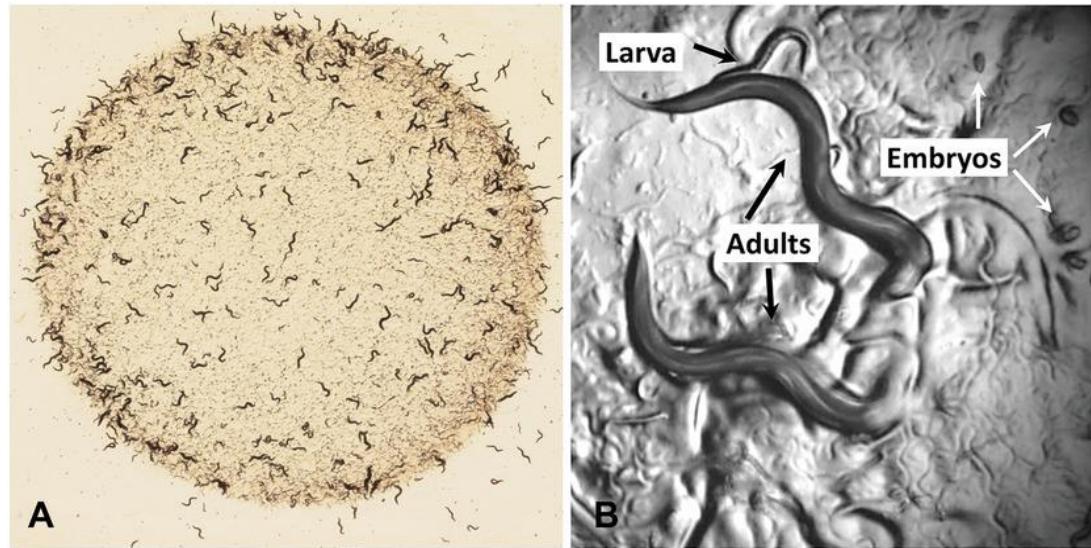
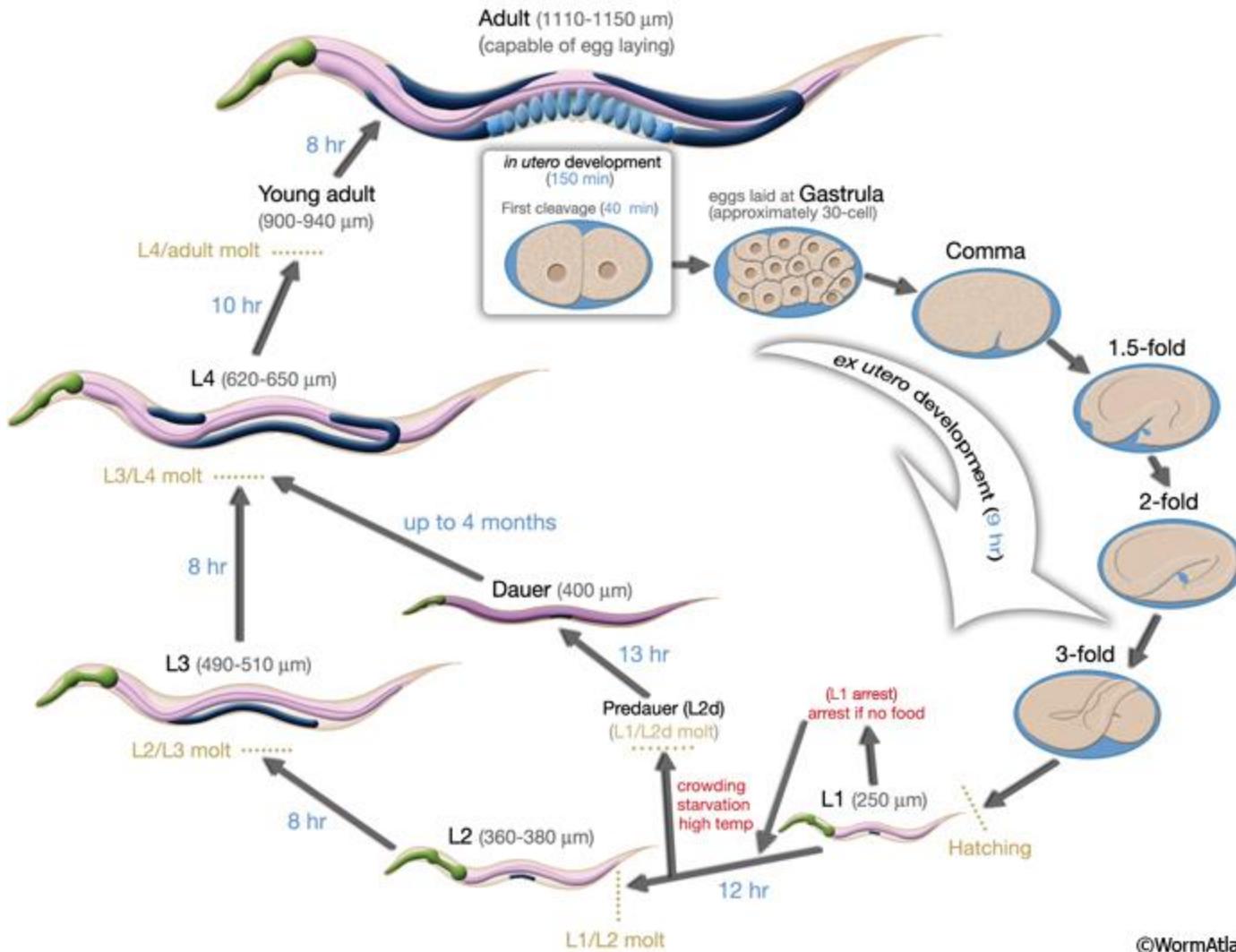
# Reaction-Diffusion: Periodic patterns



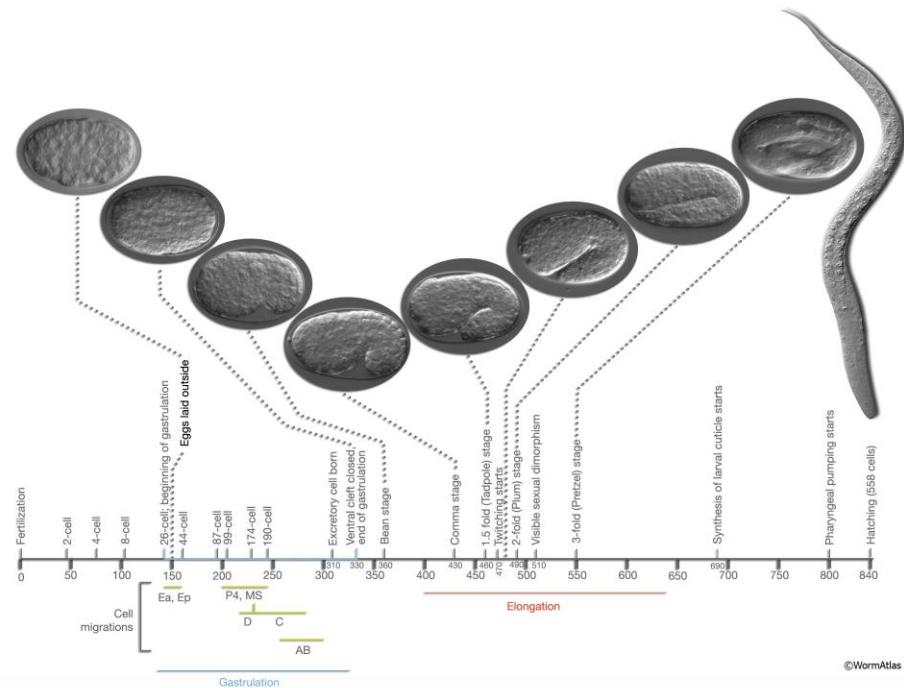
# RD: Limb bud



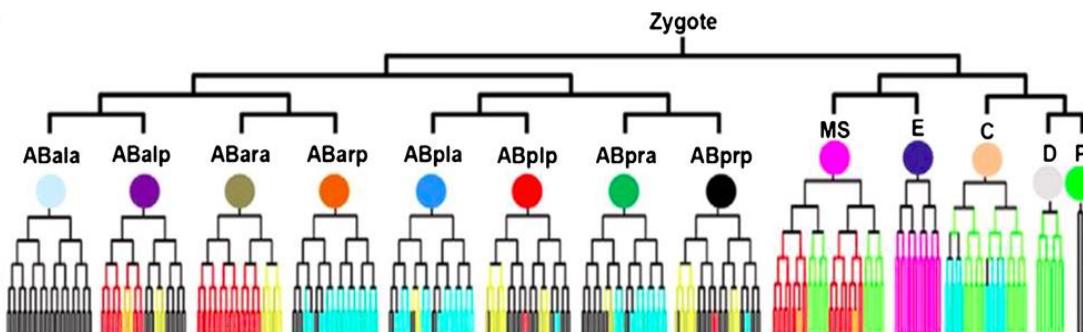
# Model organism: *C. elegans*



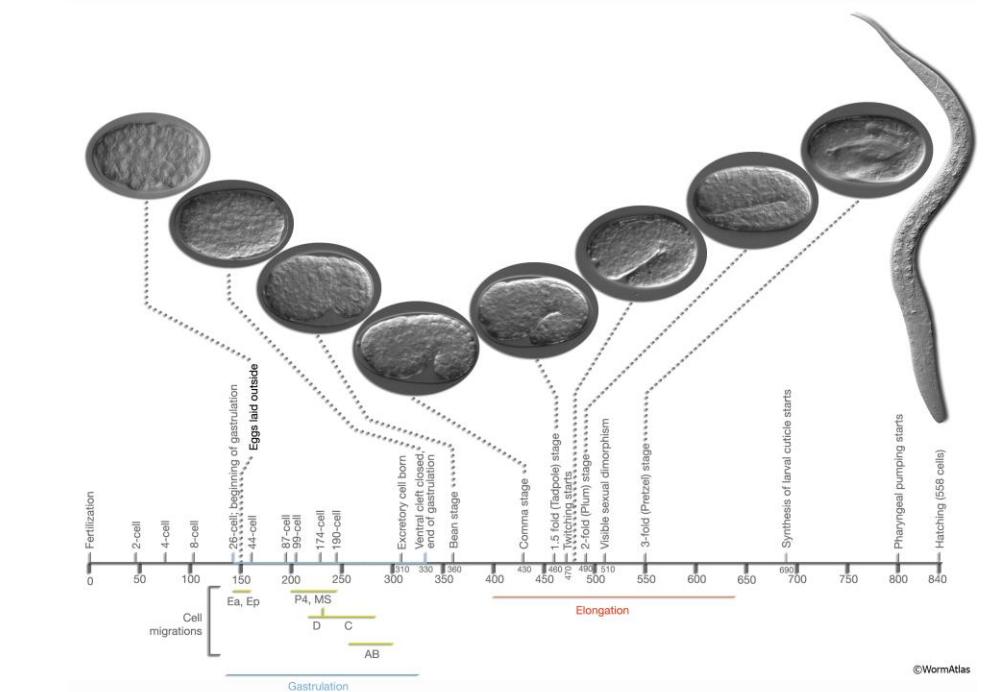
# Tracking *C. elegans* embryogenesis



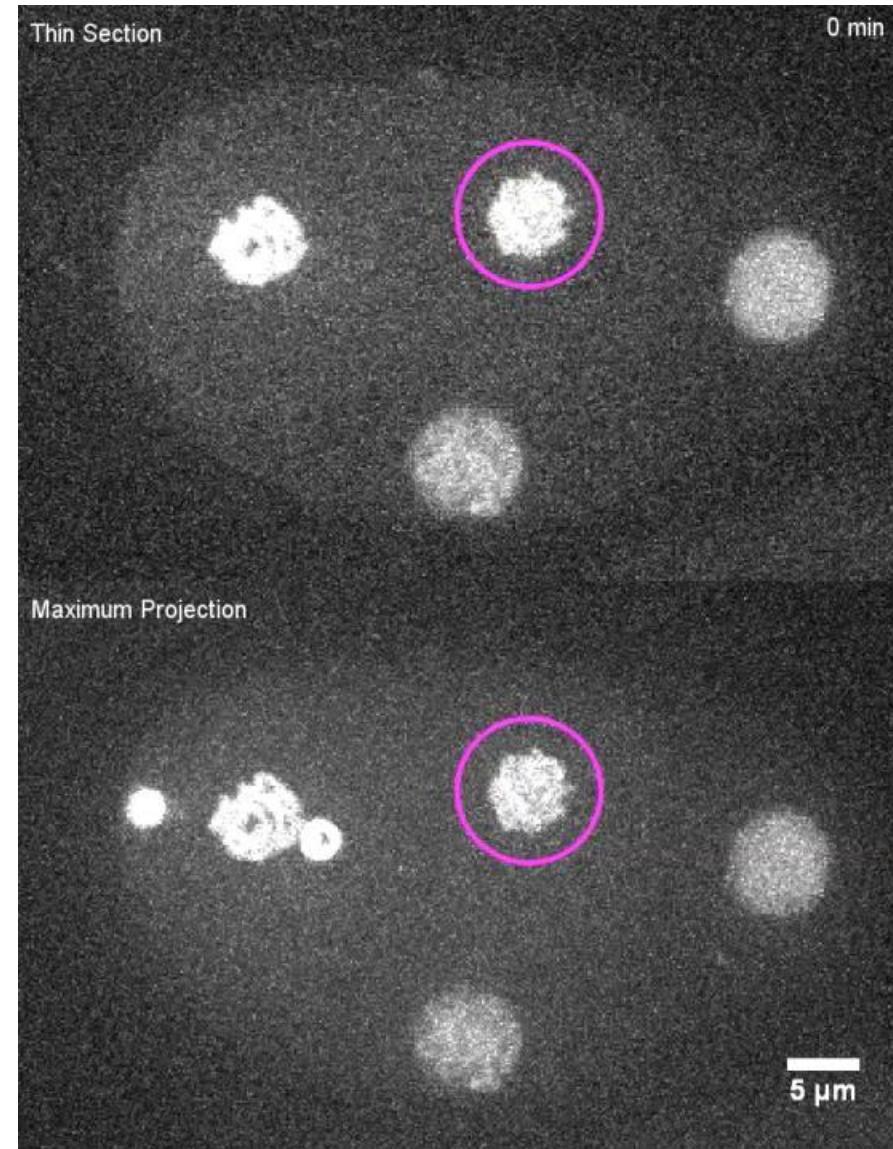
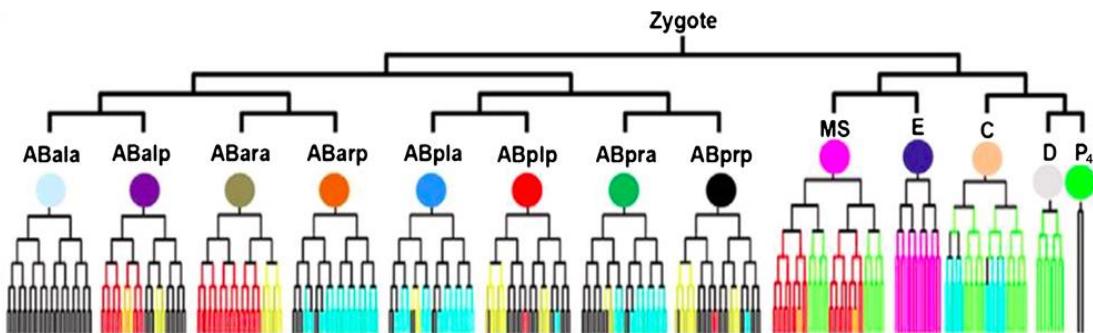
## Complete cell lineage



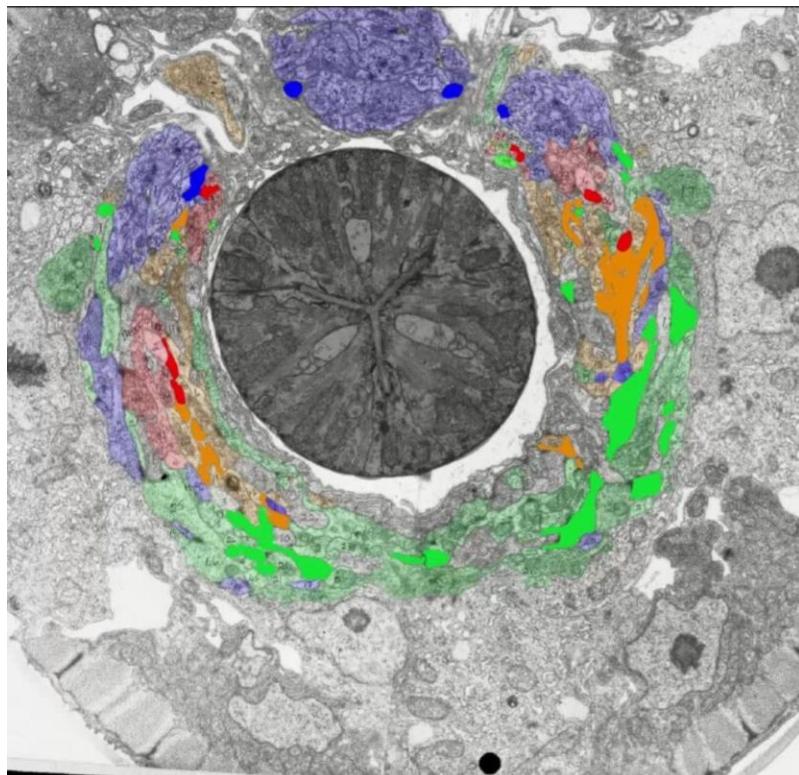
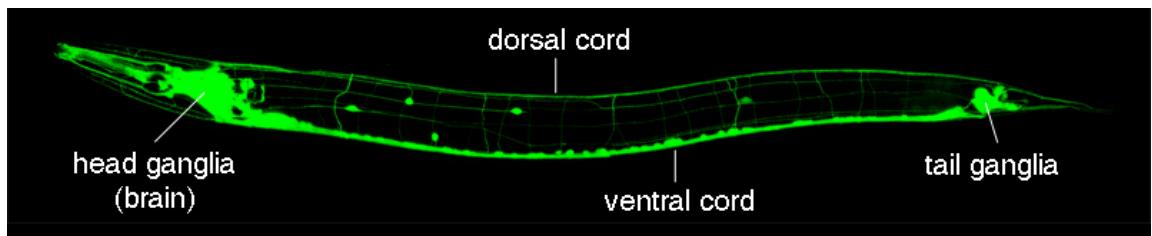
# Tracking *C. elegans* embryogenesis



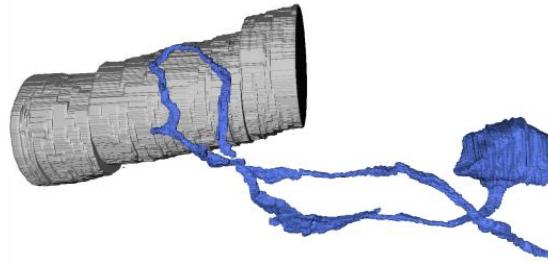
# Complete cell lineage



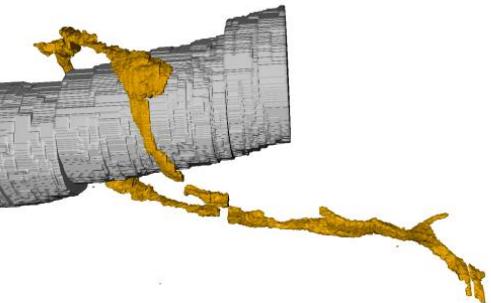
# *C. elegans* neuropil



SMBV



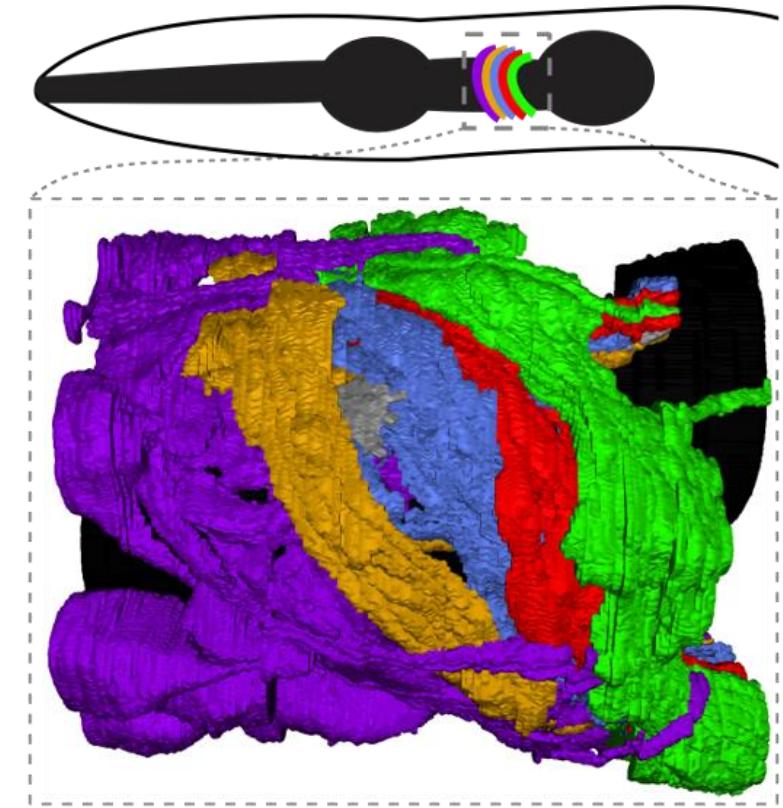
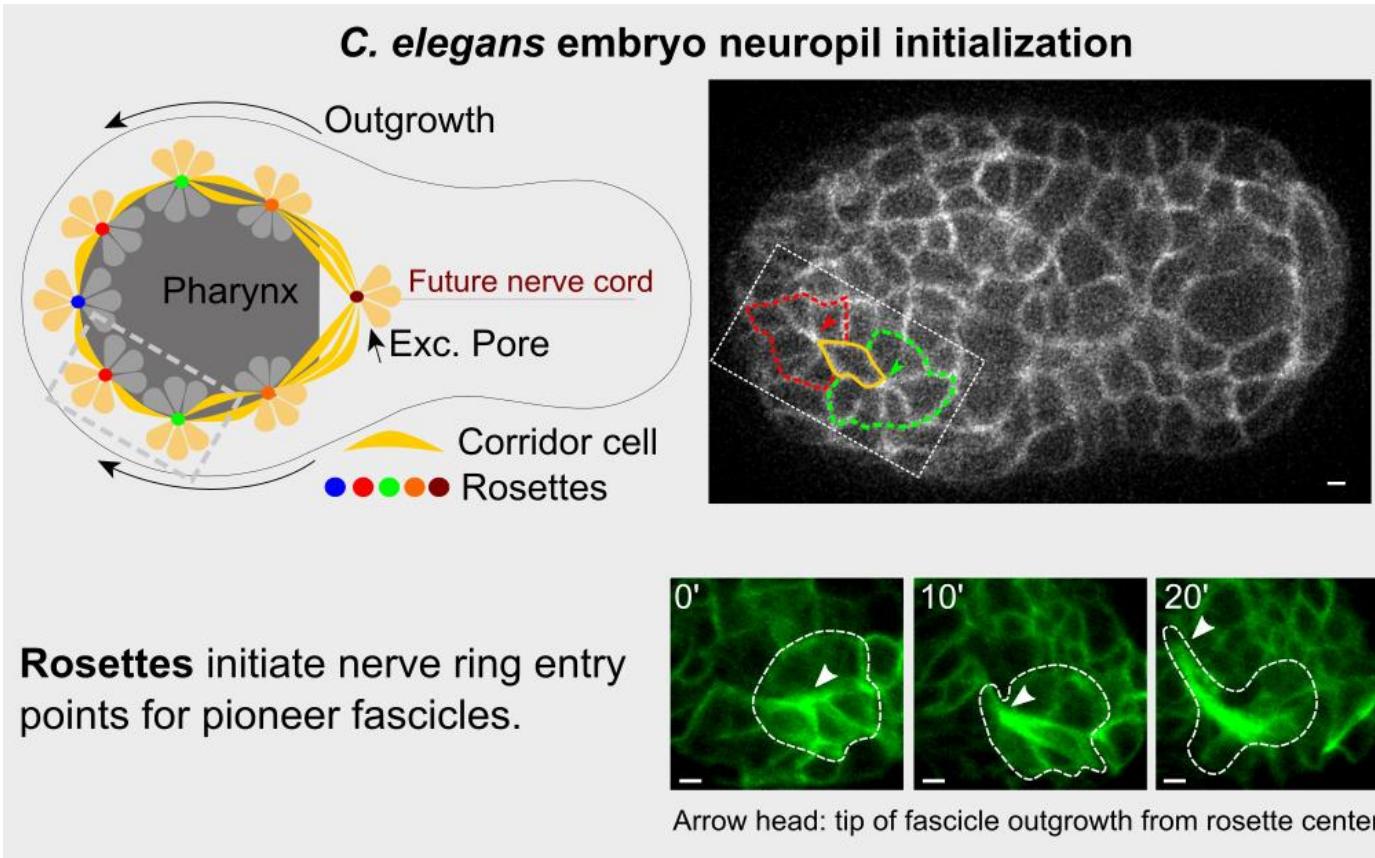
RIM



16  $\mu$ m  
Anterior



# How does neuropil emerge for early developmental events?



# Traditional computational methods

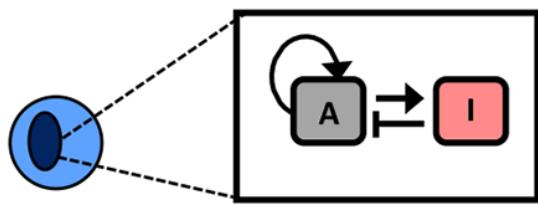
$$\frac{\partial A}{\partial t} = D_A \nabla^2 A + F(A, B),$$

$$\frac{\partial B}{\partial t} = D_B \nabla^2 B + G(A, B),$$

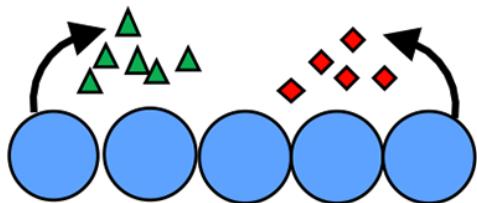
# Agent based modeling (ABM) in morphogenesis

C.

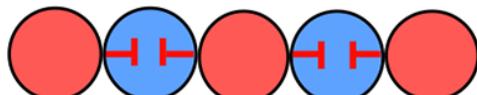
## *Cell-Agents as Reaction Sources*



## *Secretion & Consumption*

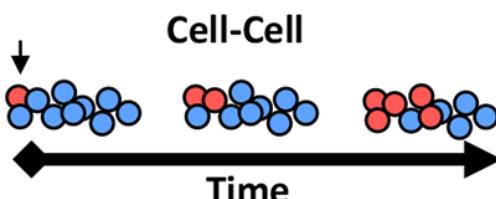
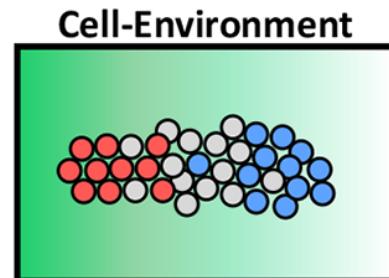


## *Lateral Inhibition*

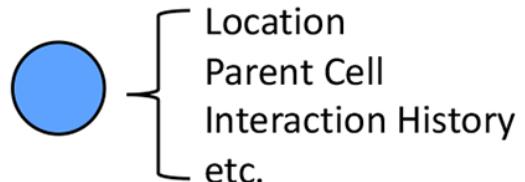


## **Agent-Based Modeling**

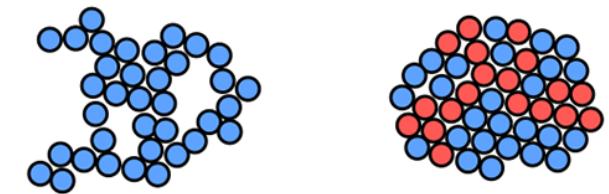
### *Autonomous Cell Decisions:*



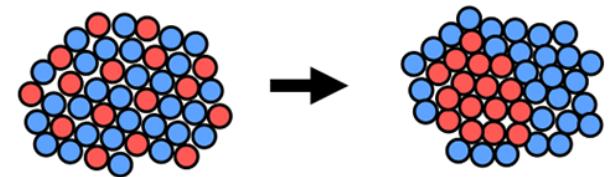
### *Single Cell Information*



### *Spatial Characterization & Heterogeneity*



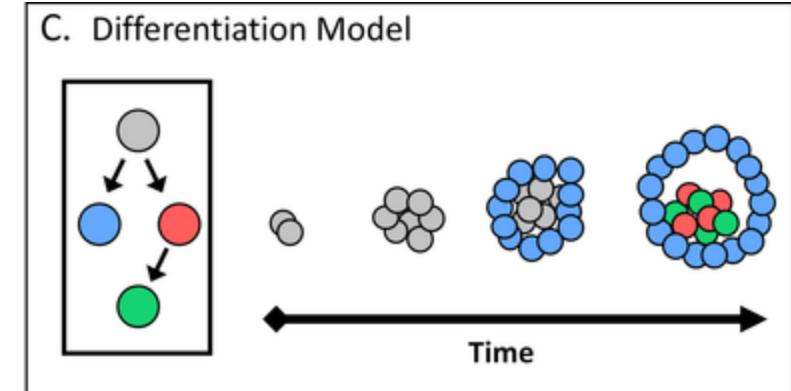
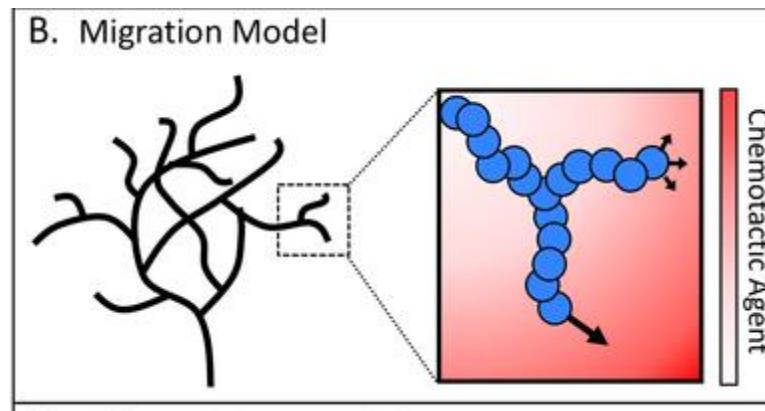
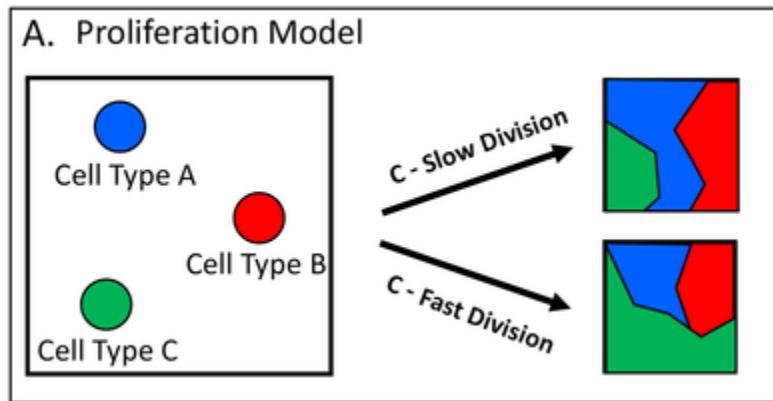
### *Emergence of Features*



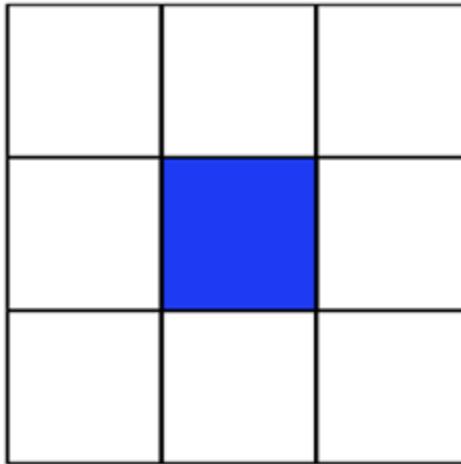
### *Mechanical Interactions*



# ABM: Applications



# ABM: Basic strategies



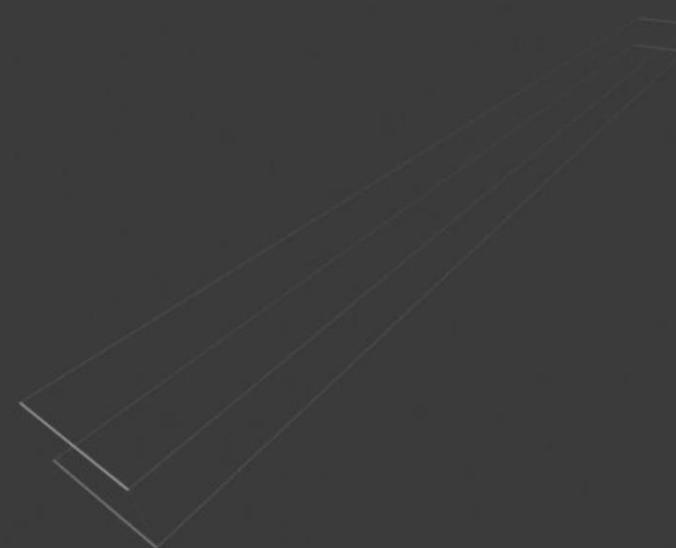
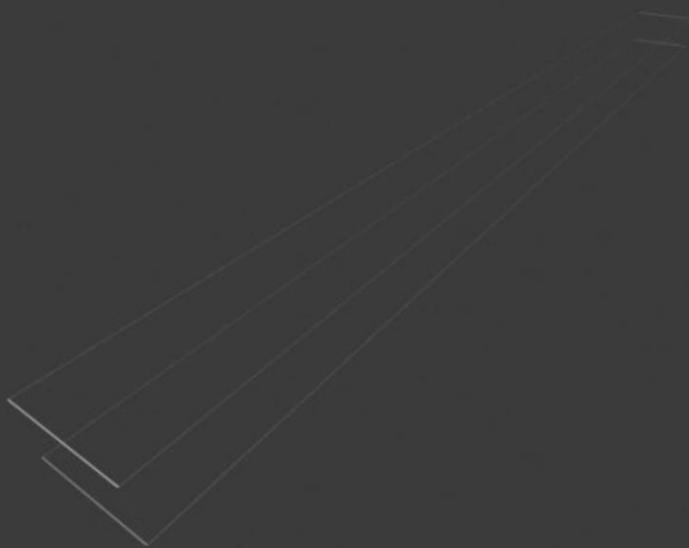
## Lattice

Cells are represented as a single grid point on a lattice. For a Euclidean grid, cell movement and interaction are usually constrained to the so-called von Neumann or Moore neighborhoods, which include either four or eight neighbors, as indicated below for the cells shaded in black:



Grids can also be represented as hexagons in 2D or dodecahedrons in 3D. Although triangles also offer regular tessellations, they are not typically used for ABMs.

# Use computational modeling



# Modeling as world building



# Two common modes of patterning

