

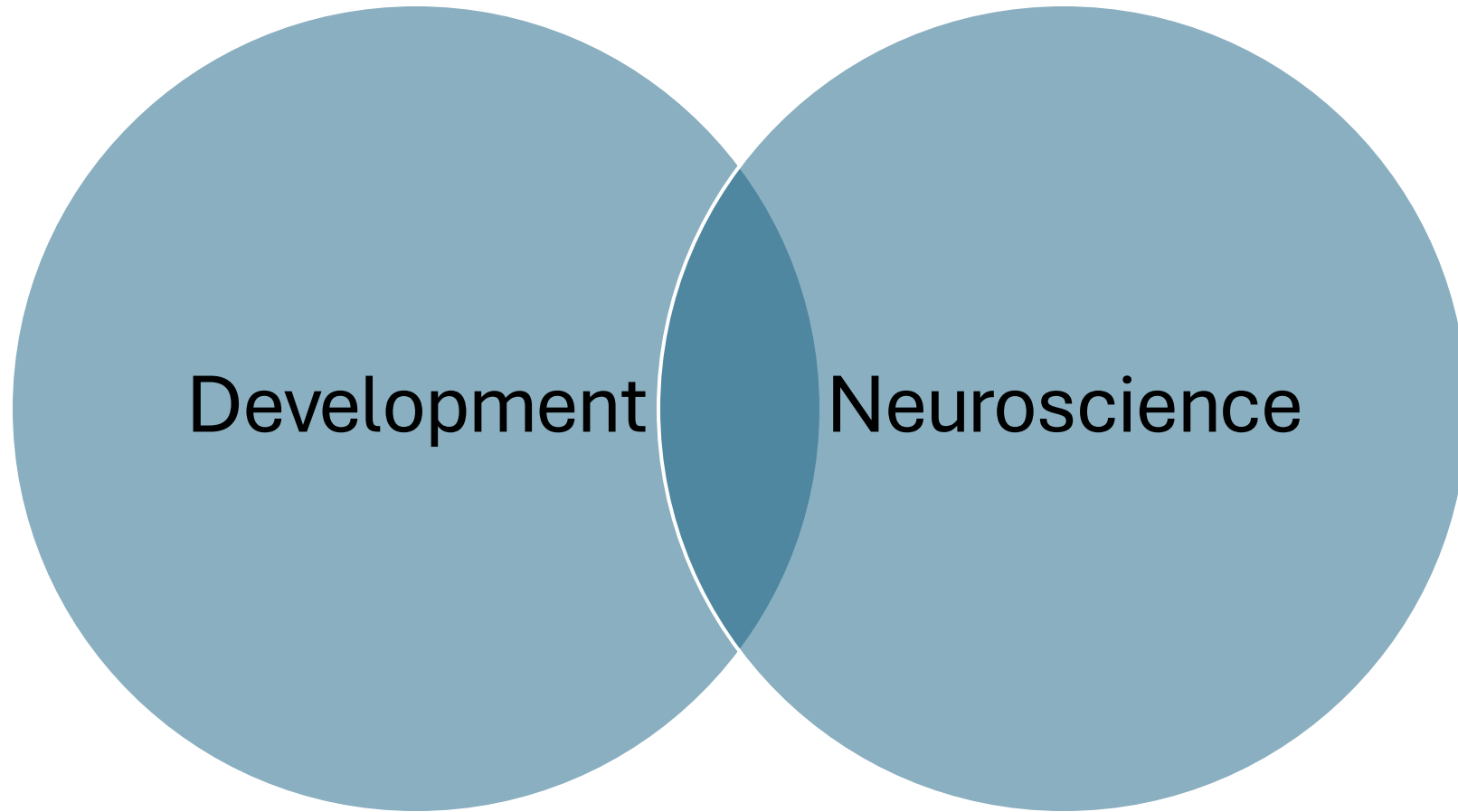
From cells to strategy: Emergent patterning in development

GSK Core class: Mechanistic Bio

2025-11-18



Neurodevelopment



Core concepts

Developmental Biology (Topics)

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

PMID: 38906136

Neuroscience (Concepts)

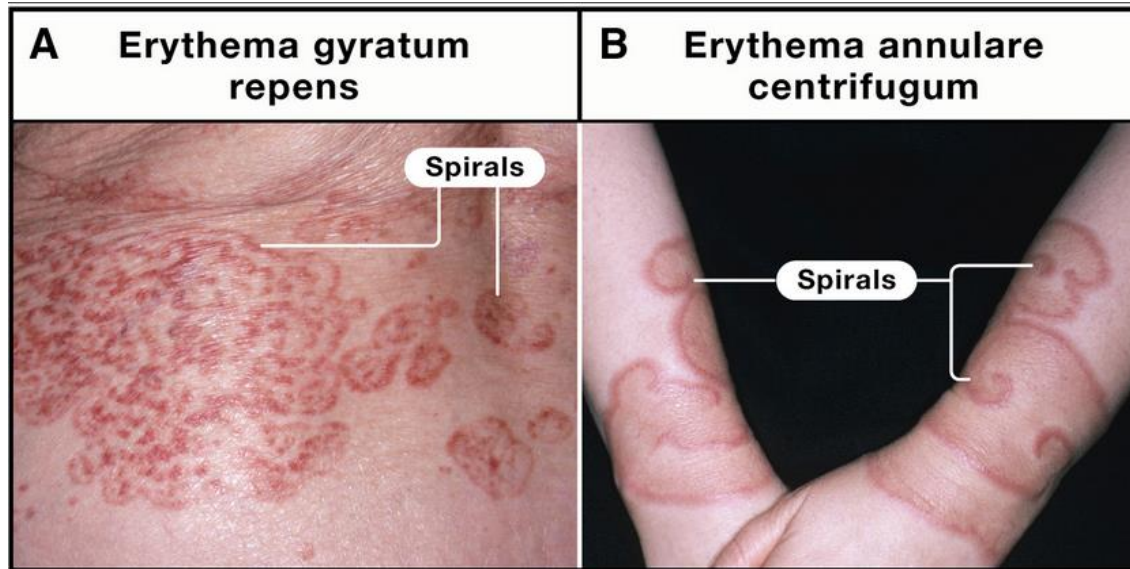
- Communication modalities
- Emergence
- Evolution
- Gene-environment interactions
- Information processing
- Nervous system functions
- Plasticity
- Structure-function relationship

PMID: 36862801

Core concepts

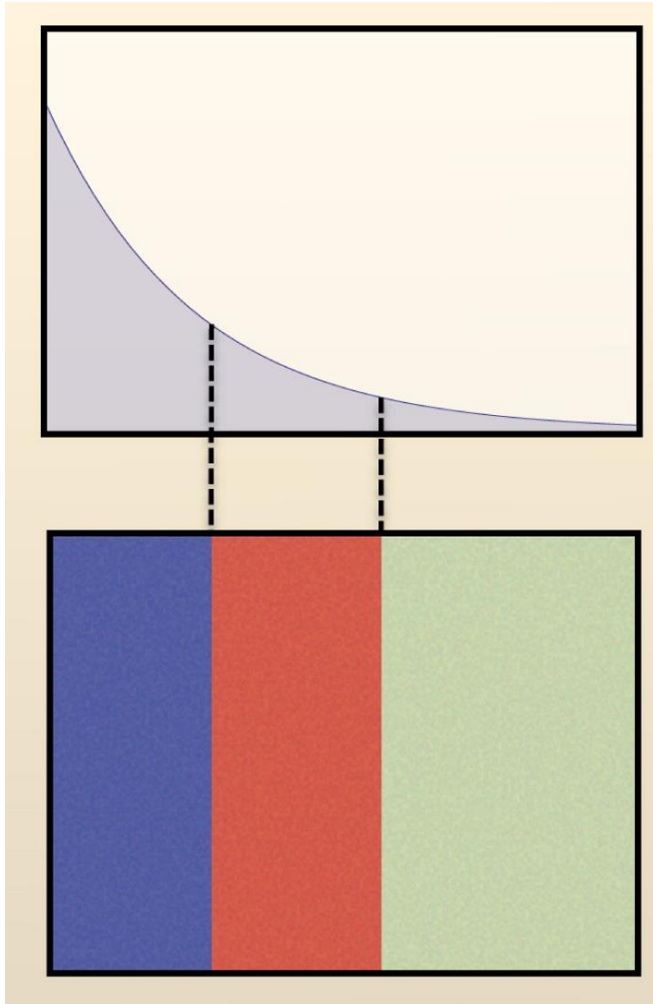
- **Patterning**: cell identity specification and spatial arrangement into complex tissue.
- **Morphogenesis**: the process by which an organism takes its shape.
- Organogenesis: the assembly of cells and tissues that perform specific physiological functions.
- Emergence: higher-level organization that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

Why study biological pattern formation?

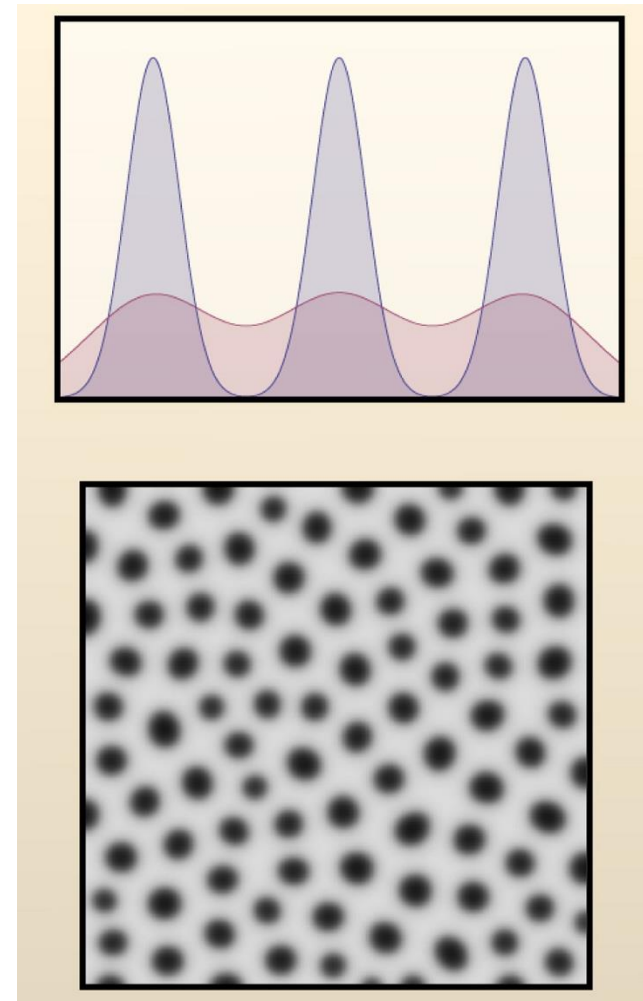


Patterning: Two major historical threads

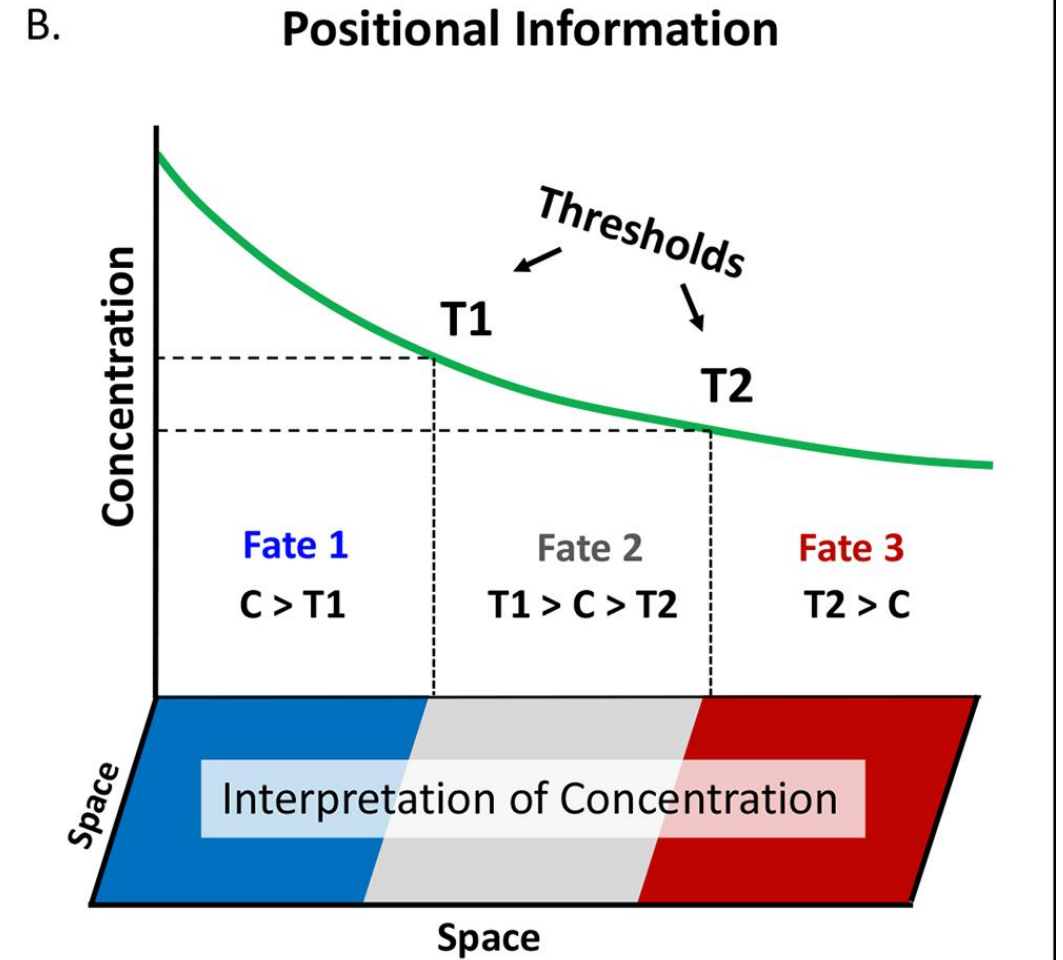
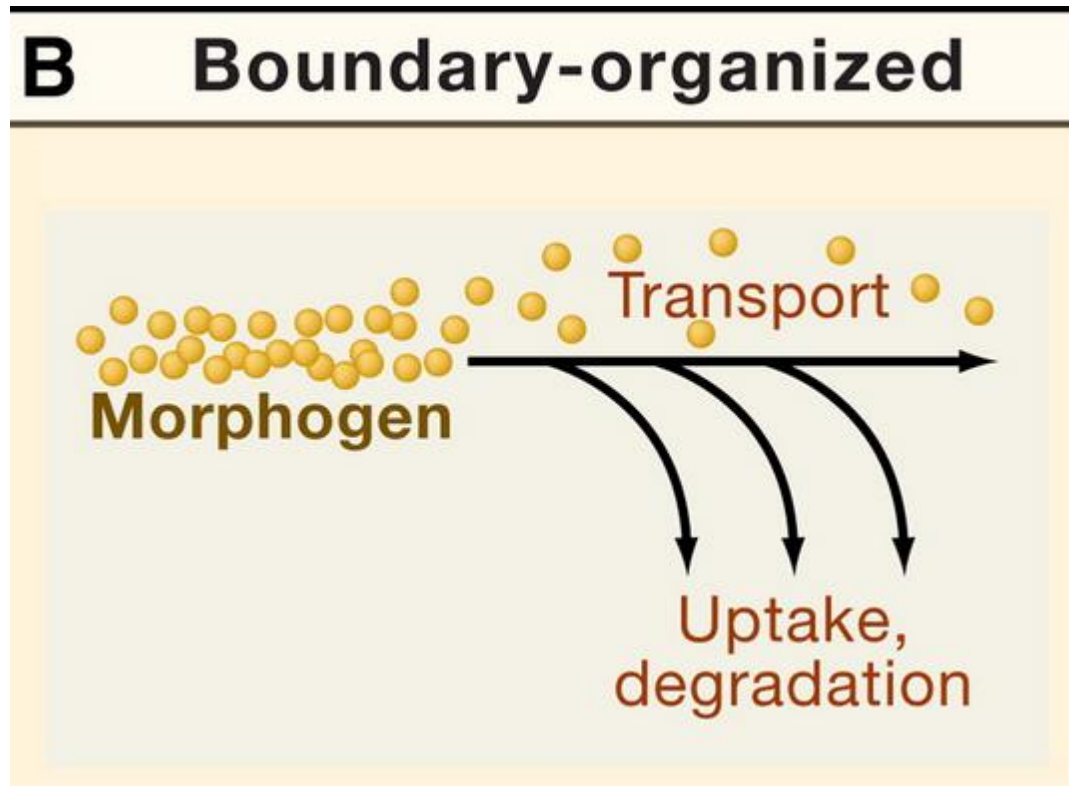
Wolpert "French Flag"
Positional information



Turing: Reaction-Diffusion
Local self-organization

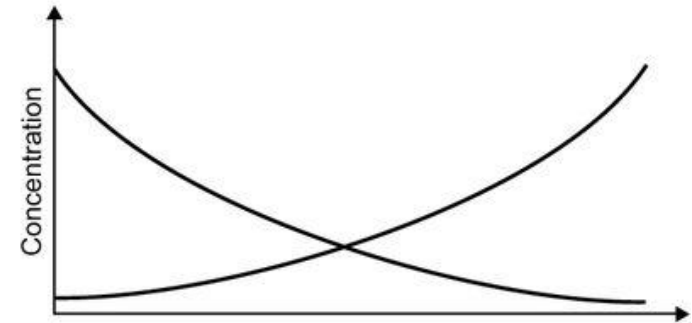
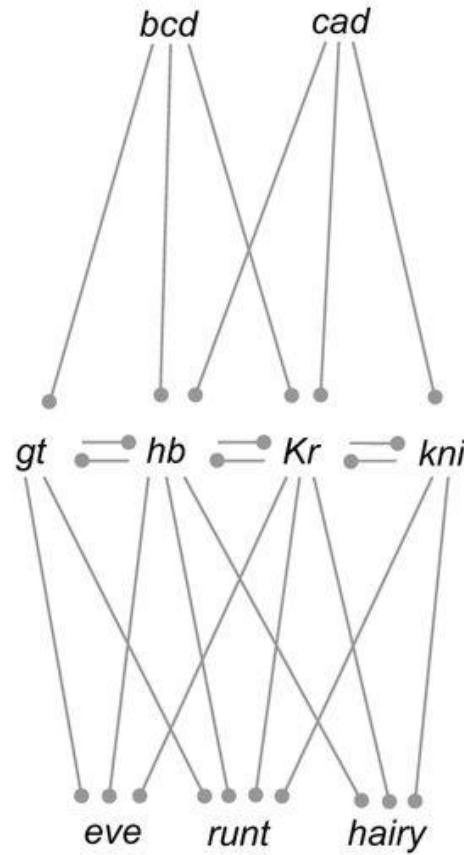
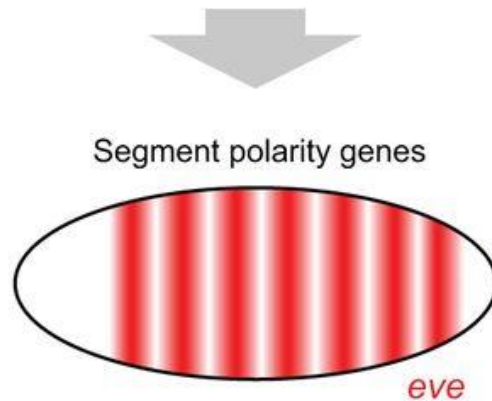
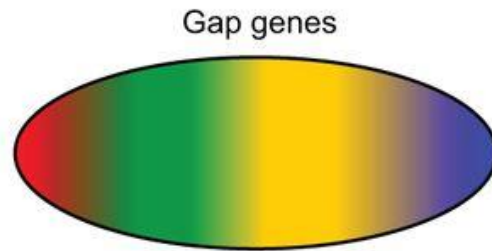
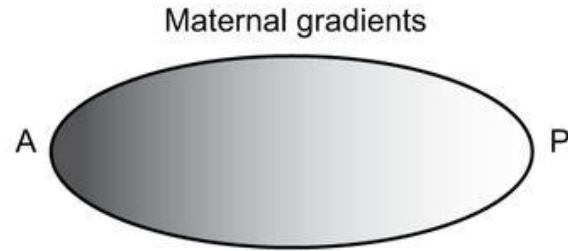


Positional information: Gradients

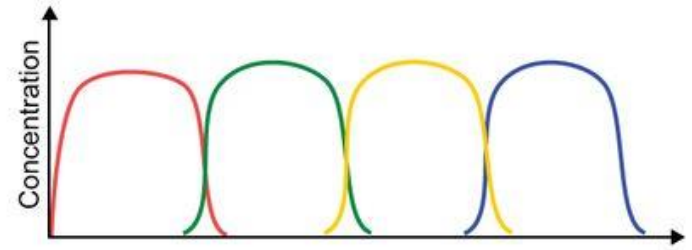


PI: *Drosophila* embryo segmentation

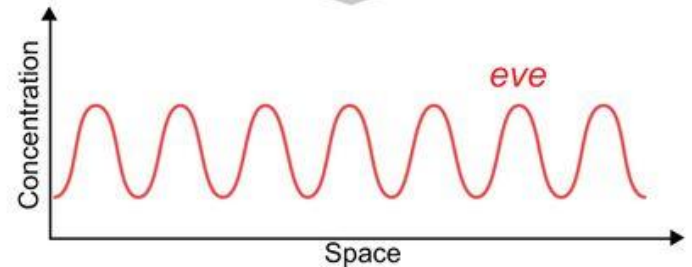
A Wolpert – PI



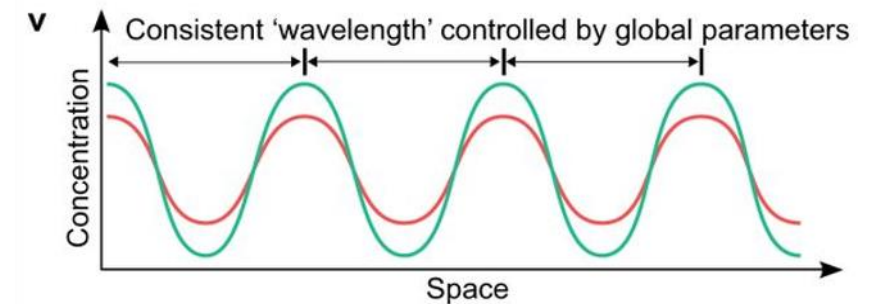
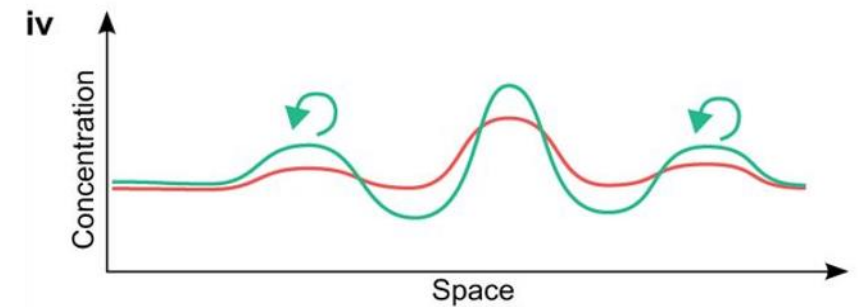
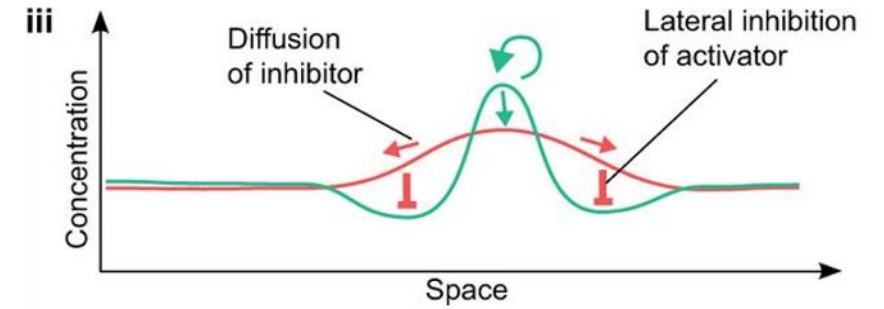
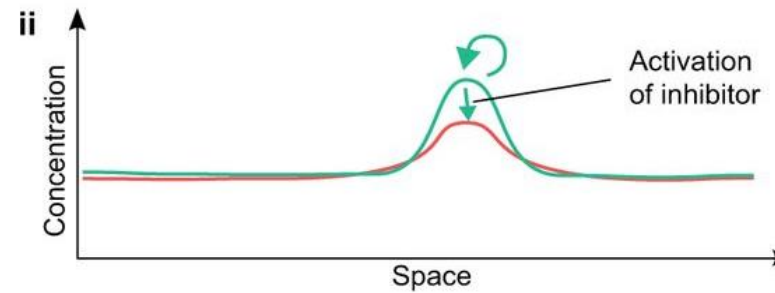
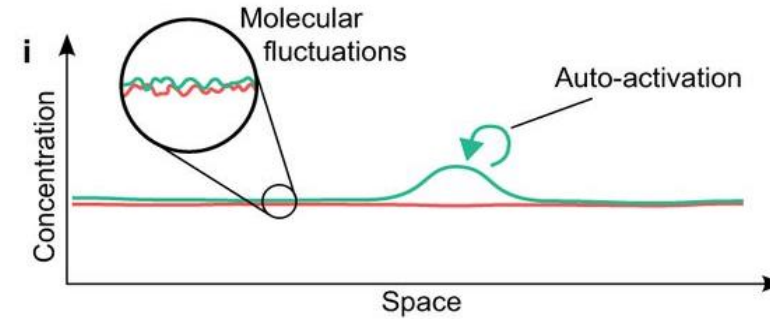
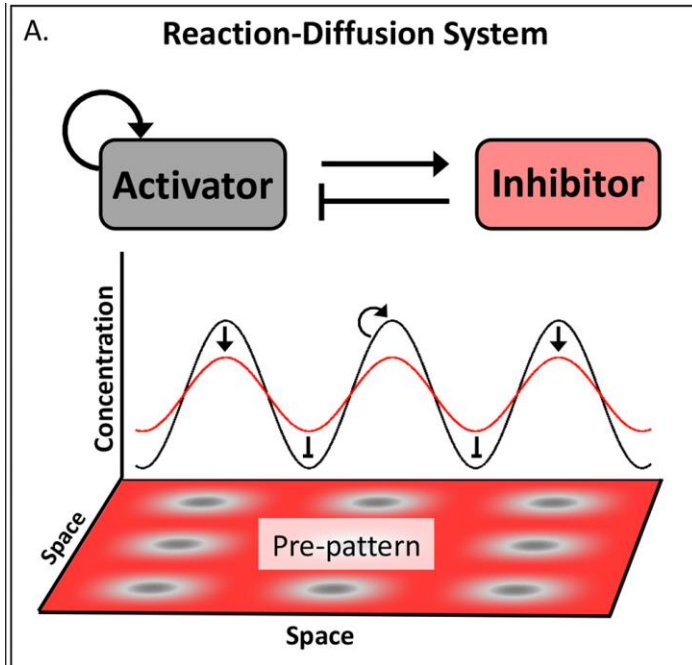
Positional information



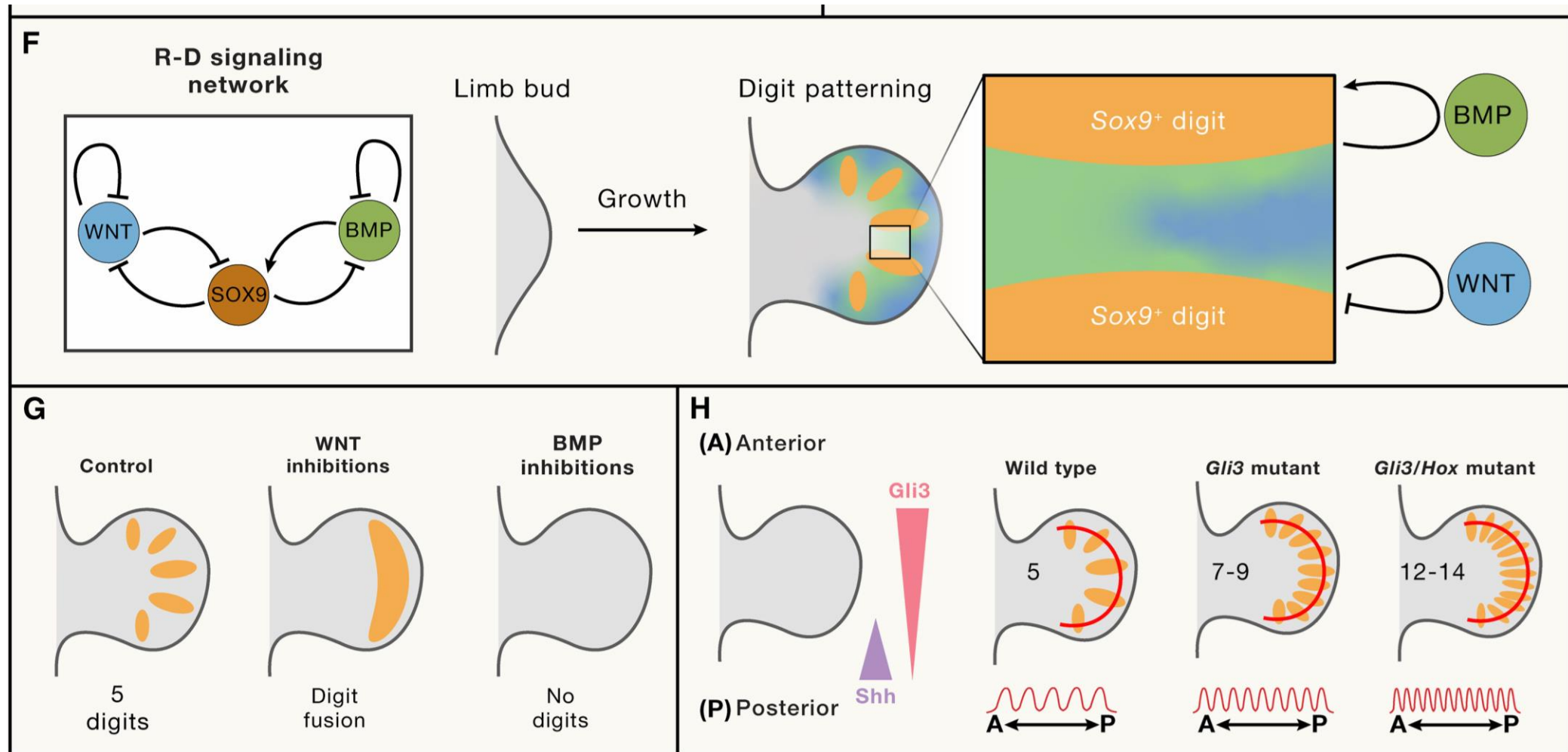
Positional information



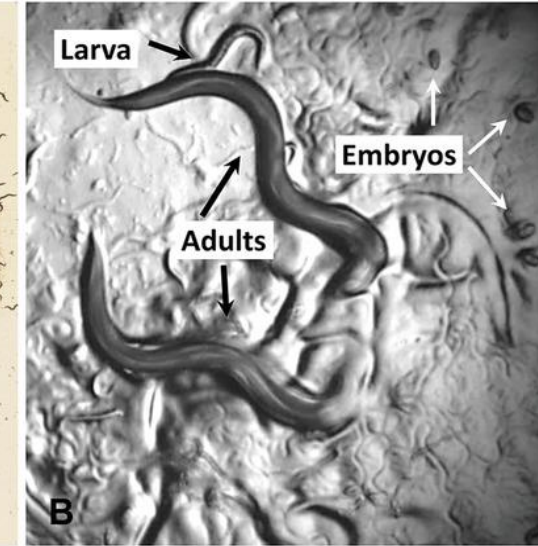
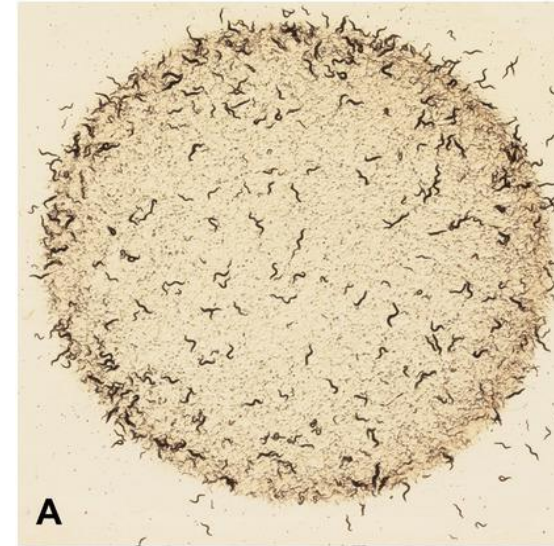
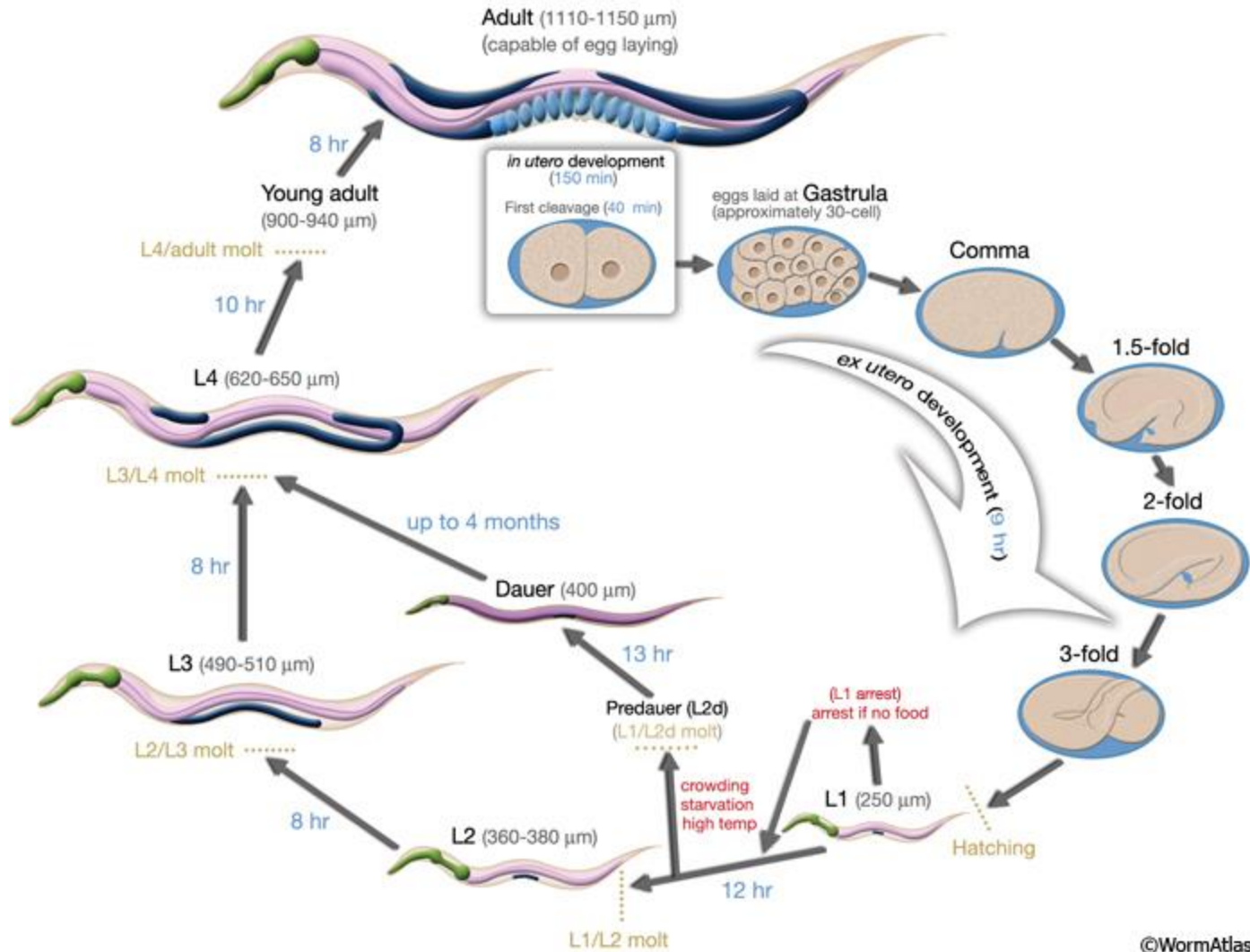
Reaction-Diffusion: Periodic patterns



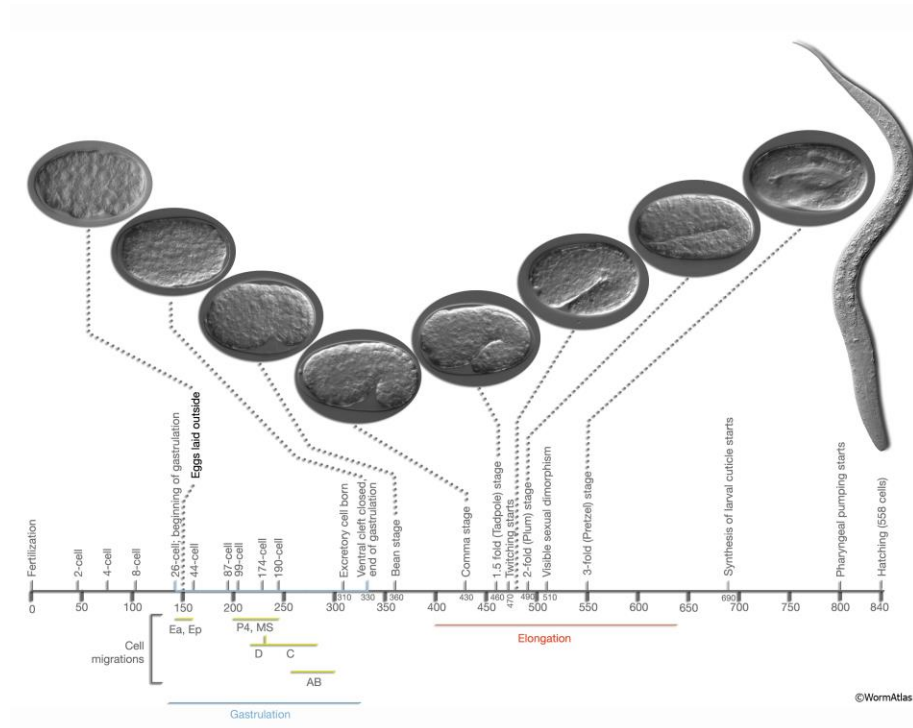
RD: Limb bud



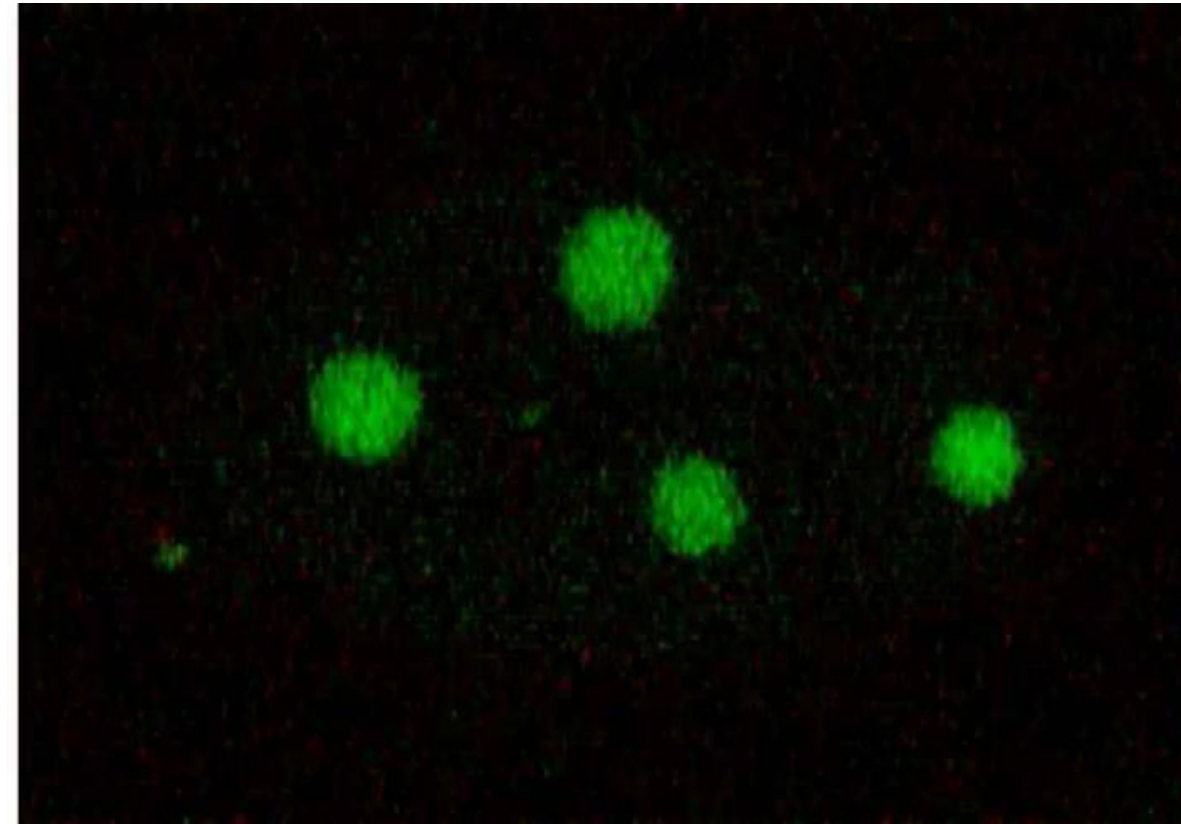
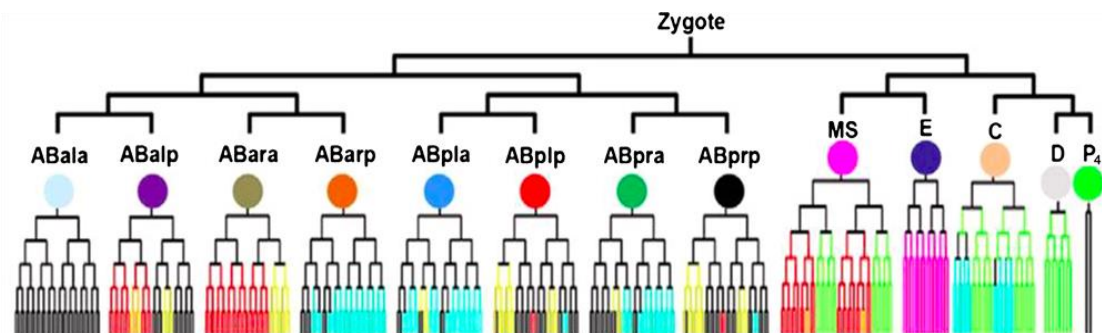
Model organism: *C. elegans*



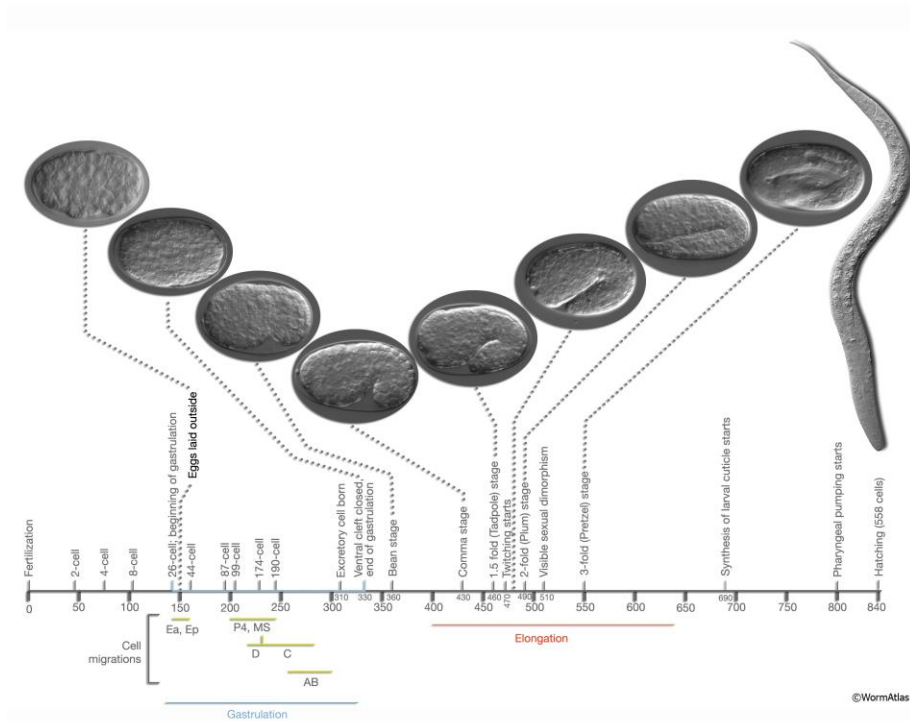
Tracking *C. elegans* embryogenesis



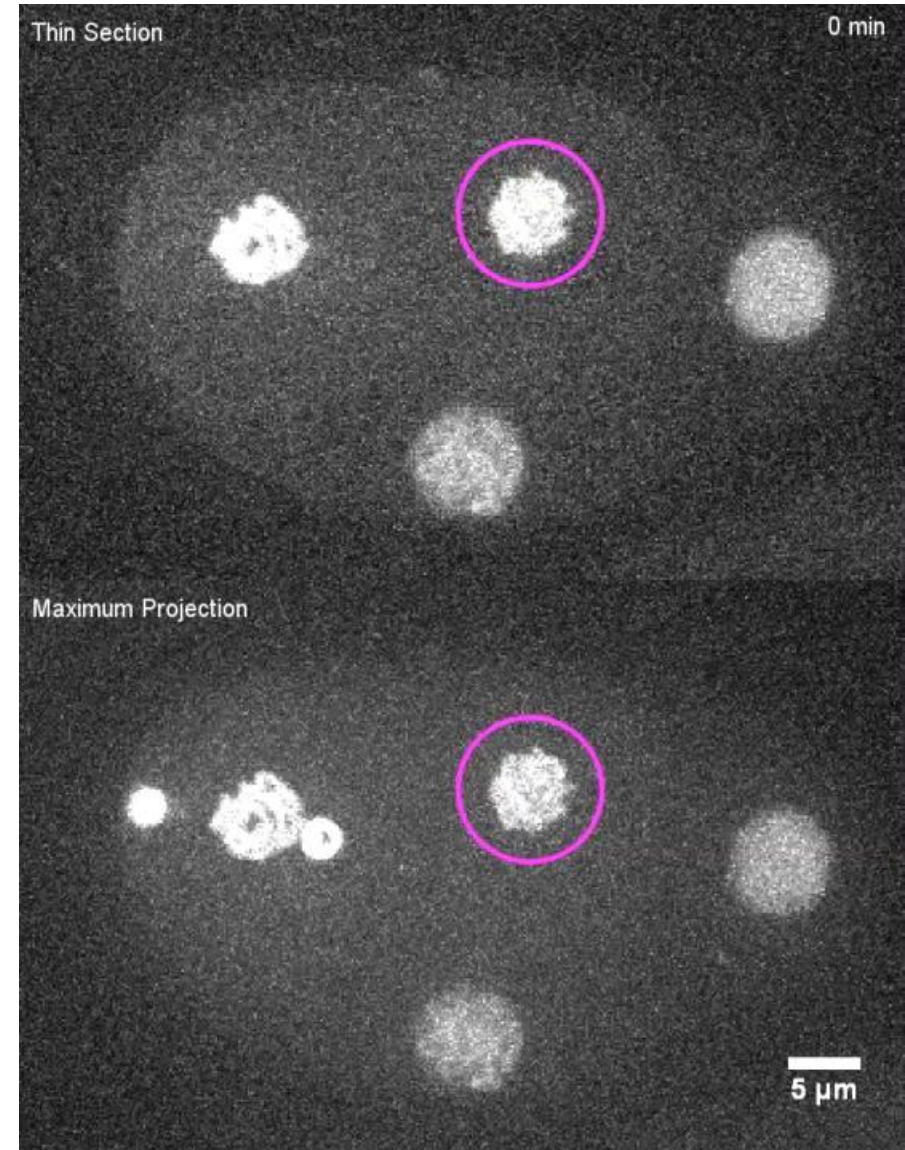
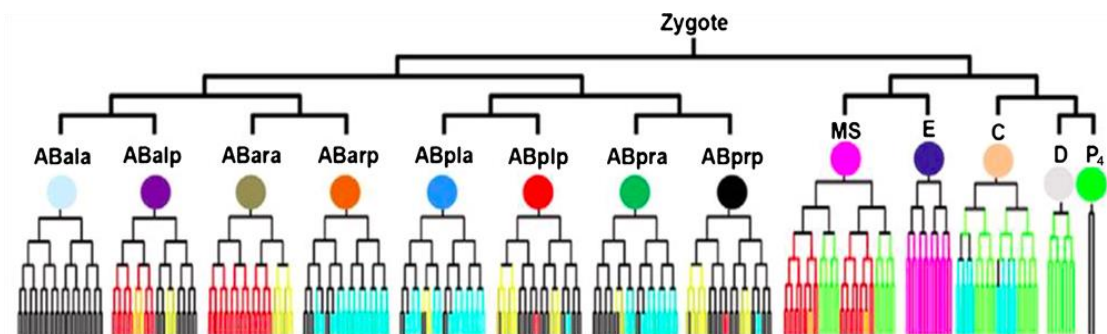
Complete cell lineage



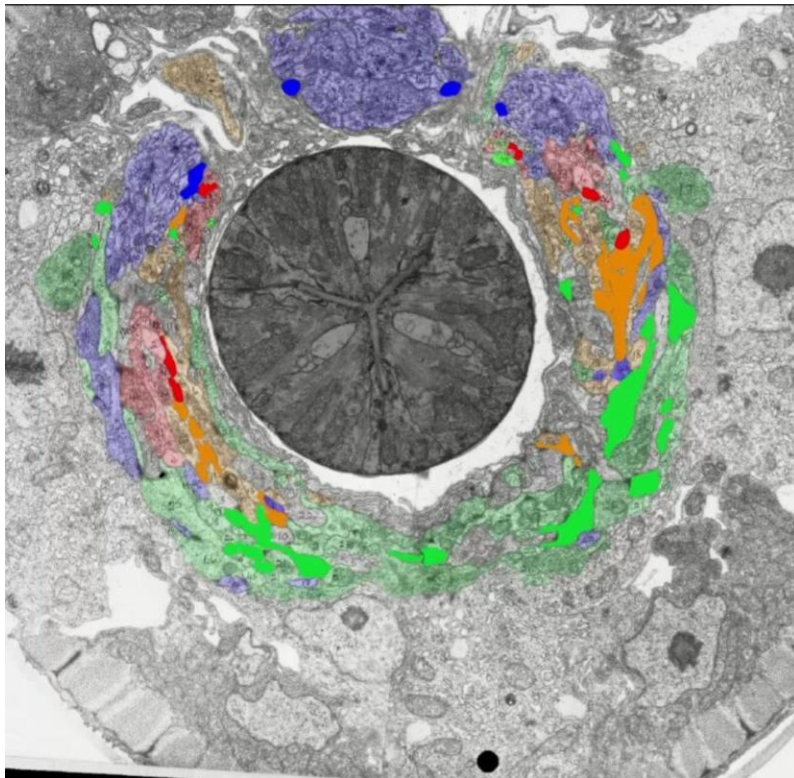
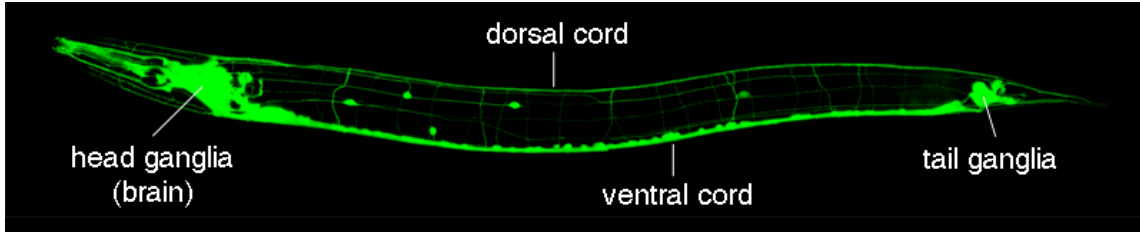
Tracking *C. elegans* embryogenesis



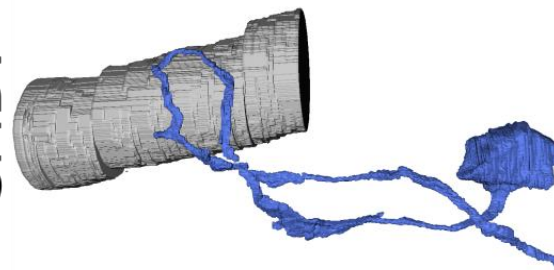
Complete cell lineage



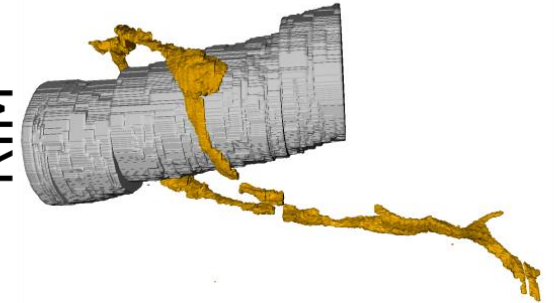
C. elegans neuropil



SMBV

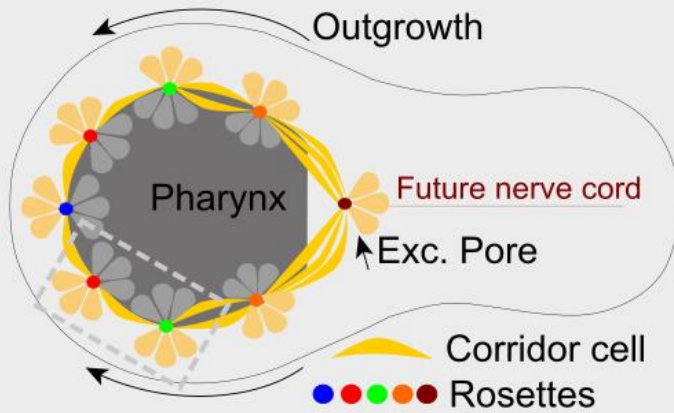


RIM

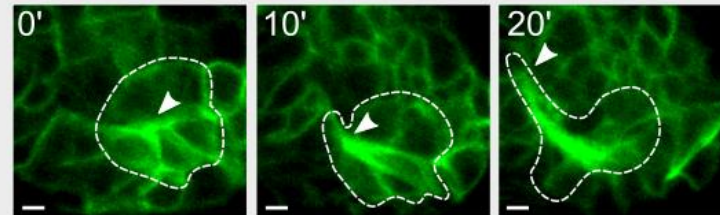
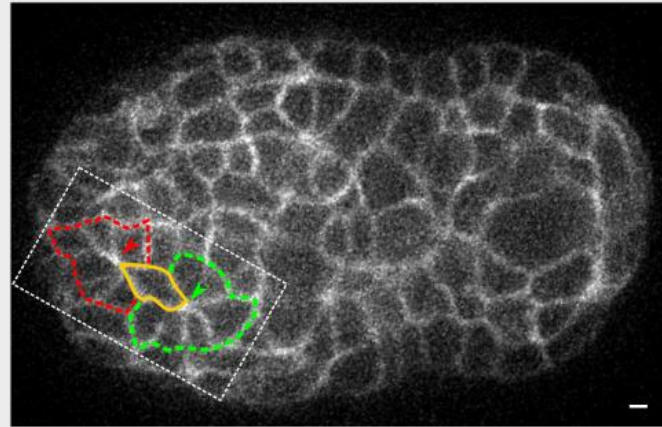


How does neuropil emerge for early developmental events?

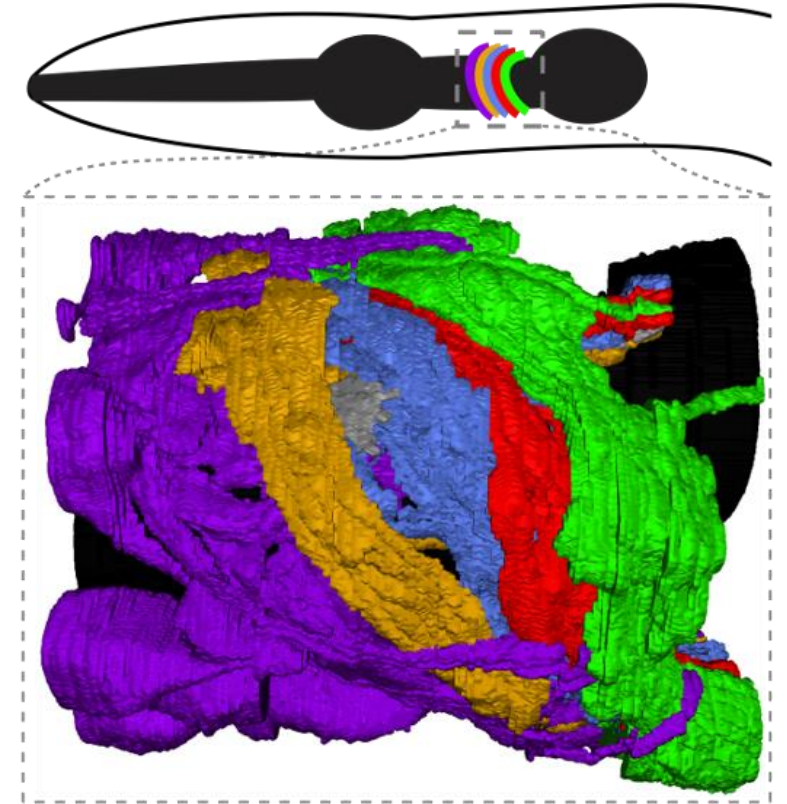
C. elegans embryo neuropil initialization



Rosettes initiate nerve ring entry points for pioneer fascicles.



Arrow head: tip of fascicle outgrowth from rosette center



Traditional computational methods

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

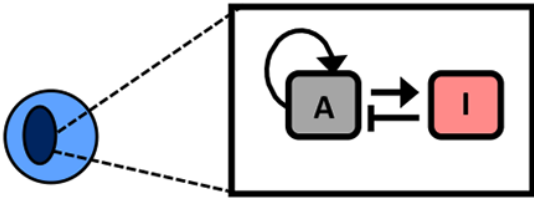
$$\frac{\partial B}{\partial t} = D_B \nabla^2 B + G(A, B),$$

Agent based modeling (ABM) in morphogenesis

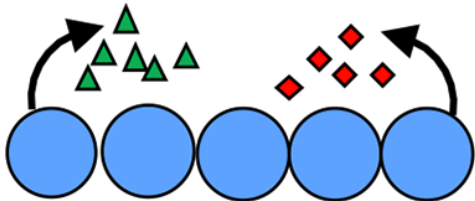
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Agent-Based Modeling

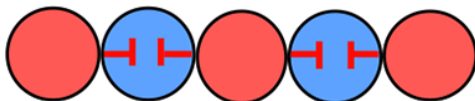
Cell-Agents as Reaction Sources



Secretion & Consumption

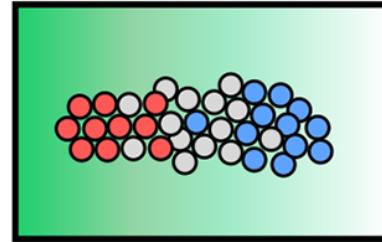


Lateral Inhibition

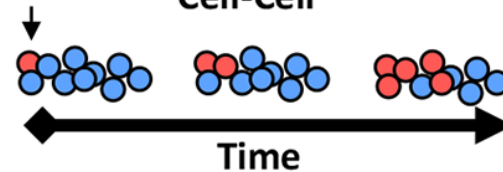


Autonomous Cell Decisions:

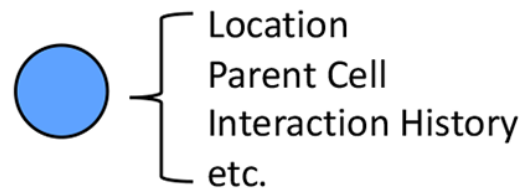
Cell-Environment



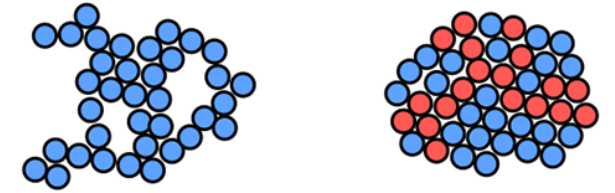
Cell-Cell



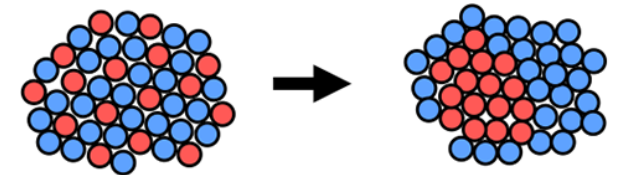
Single Cell Information



Spatial Characterization & Heterogeneity



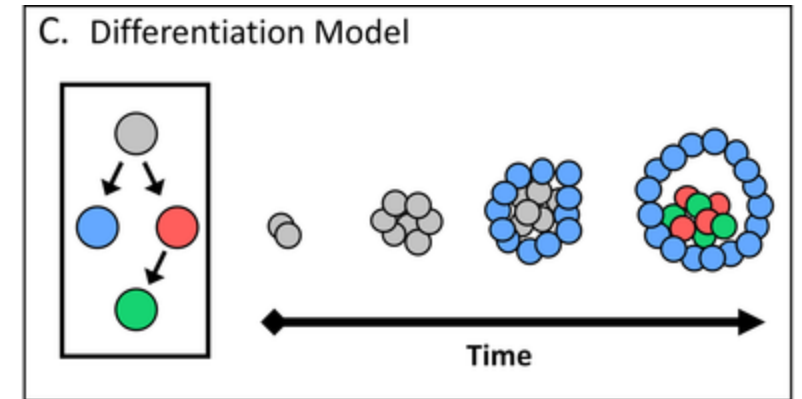
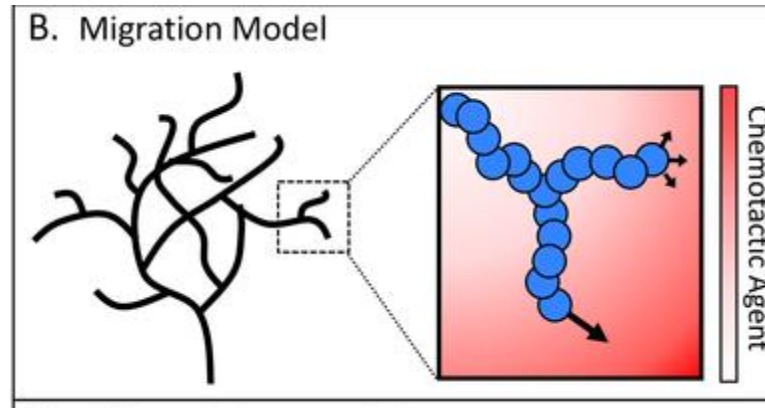
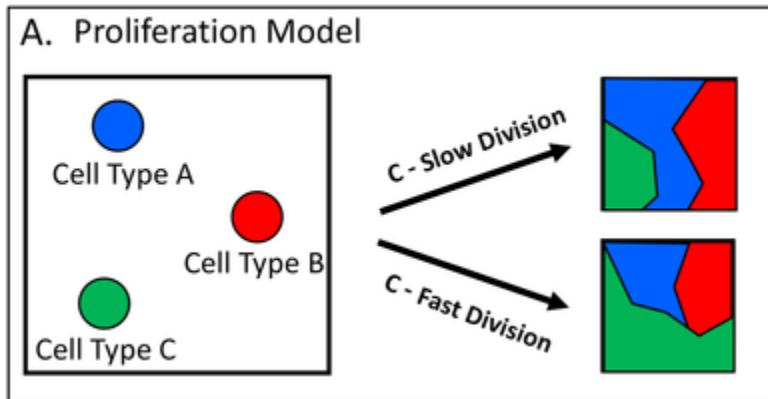
Emergence of Features



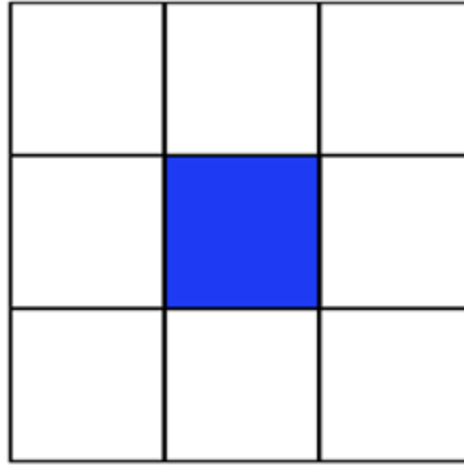
Mechanical Interactions



ABM: Applications



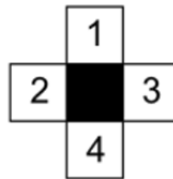
ABM: Basic strategies



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:

von Neumann

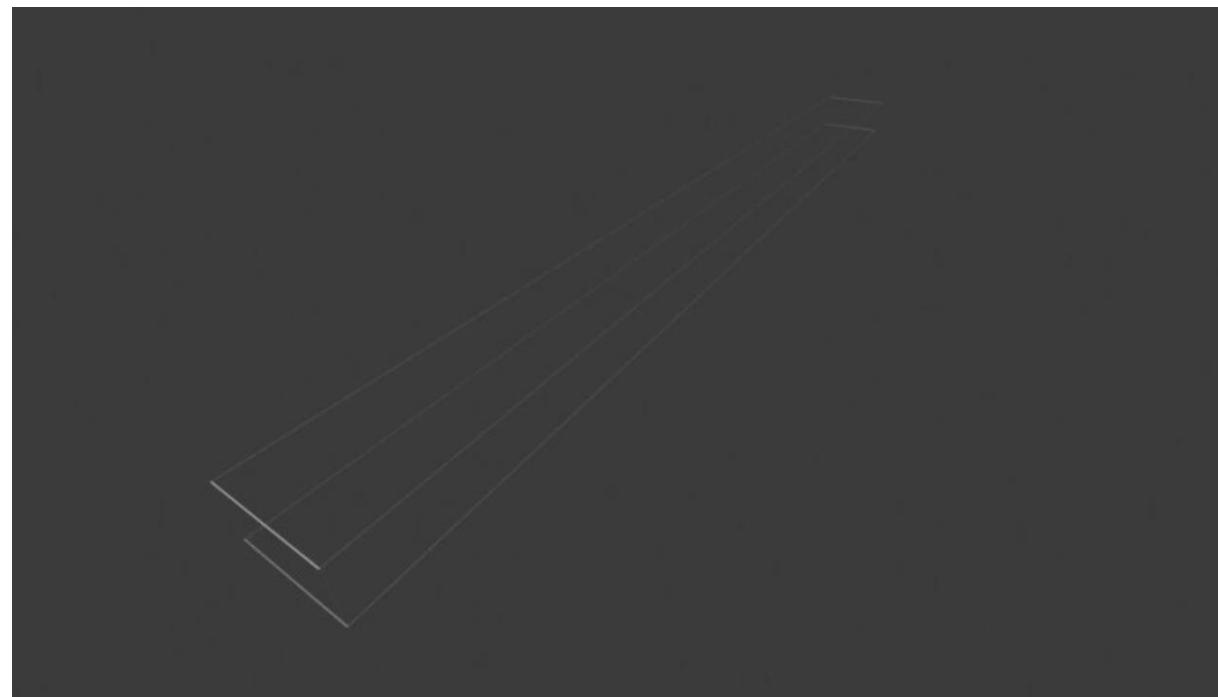
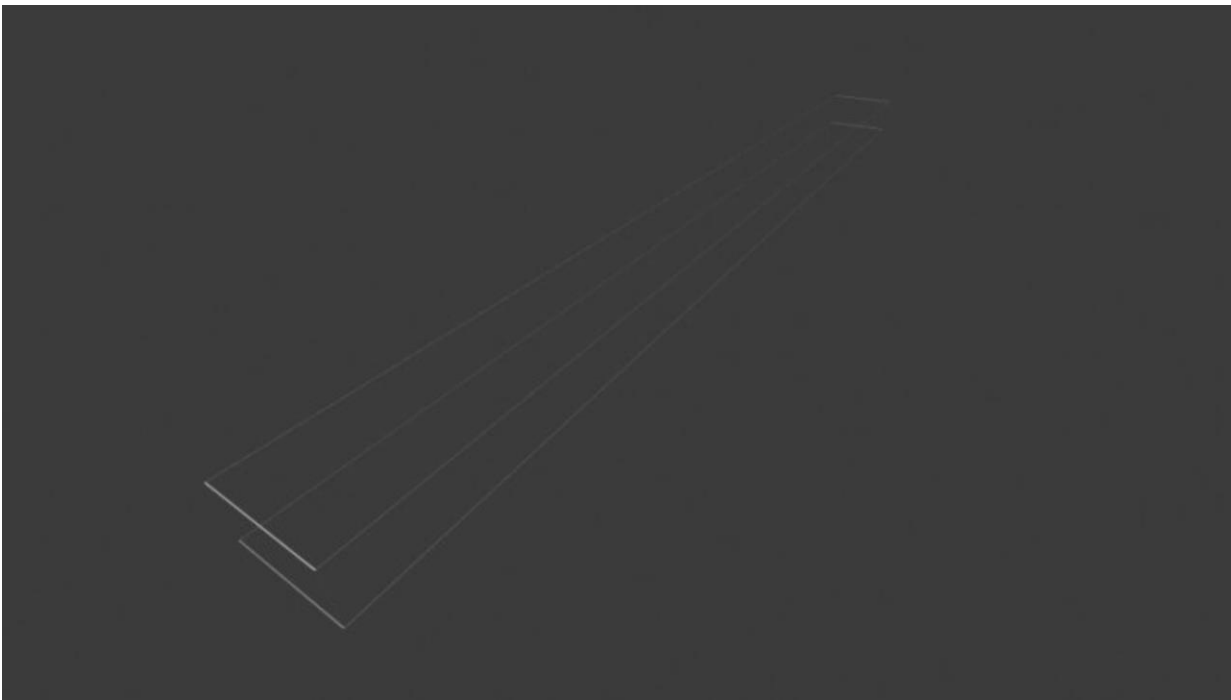


Moore



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

