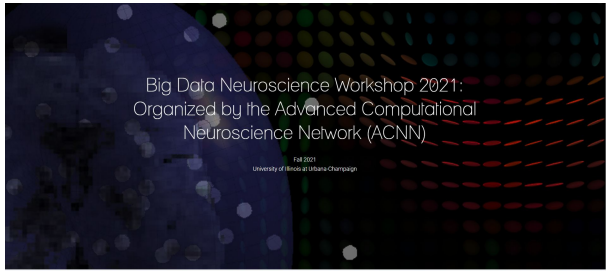
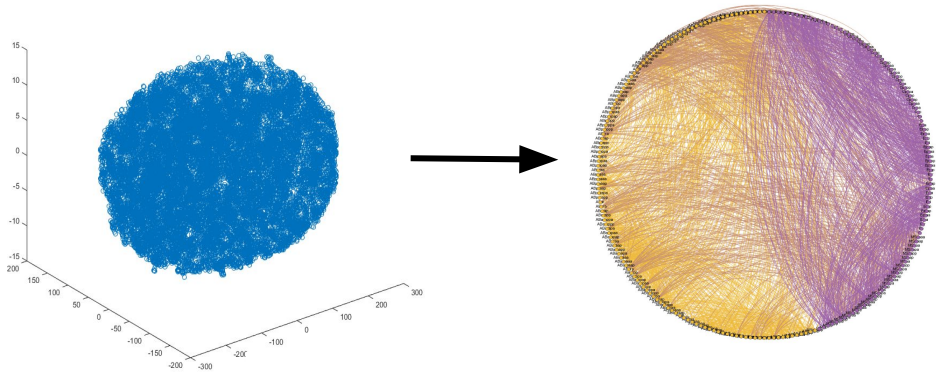
Generative Divergent Integration as a Theory of the Emergent Connectome

Big Data Neuroscience Workshop,
Beckman Institute, UIUC

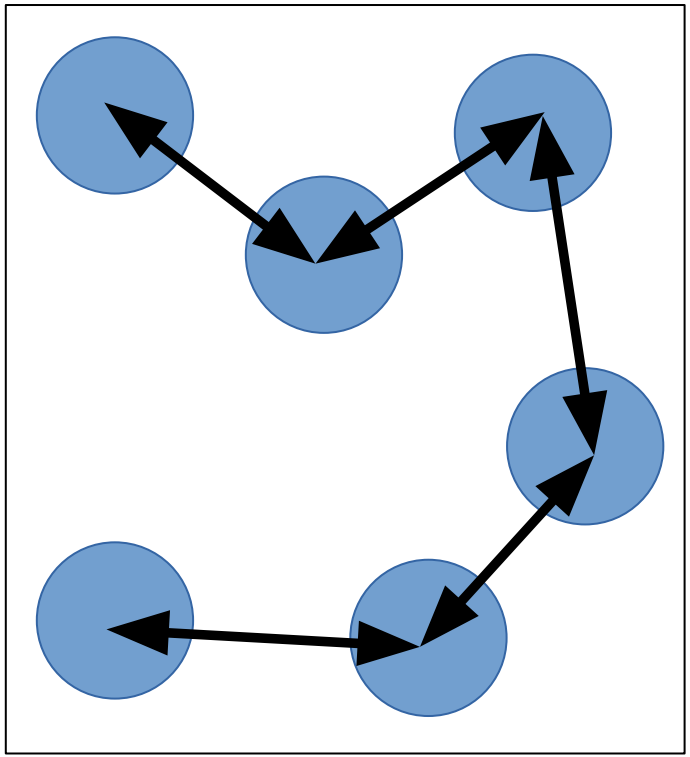




Bradly Alicea

@balicea1

Embryo Networks



x,y,z,t,θ

3-D space

time and context

x,y,z,t,θ

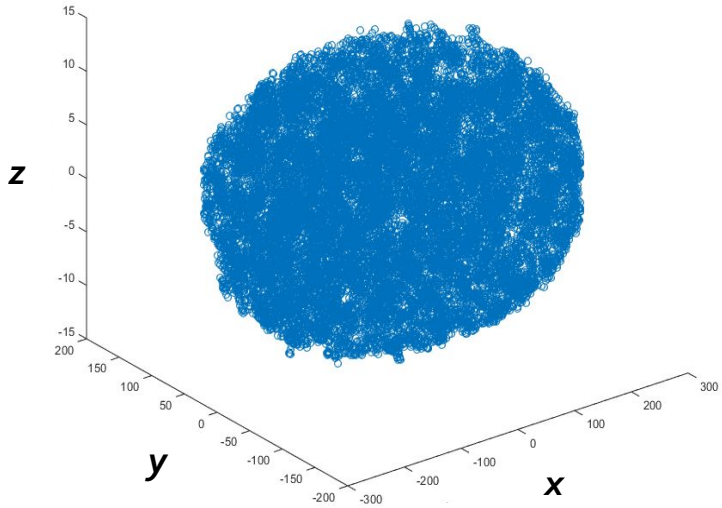
See our Jupyter Notebook for more information

GitHub

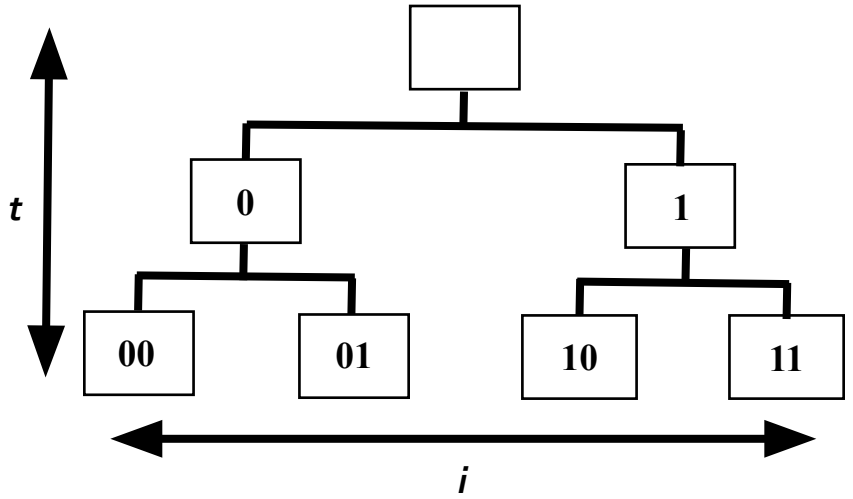
https://devoworm.github.io/

5-dimensional Data Structure

x, y, z, t, i



A generalized parameter space based on observations across *C. elegans* embryos (*x,y,z*)



A spatially-independent parameter space ordered by A-P axial order (*i*) and lineage time (*t,i*)

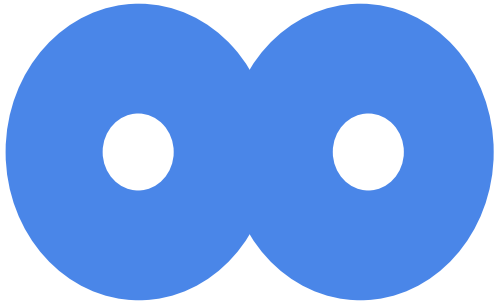
Cell Division

Graph diameter expands (growth in number of nodes)

Local connectivity increases (nodal density)

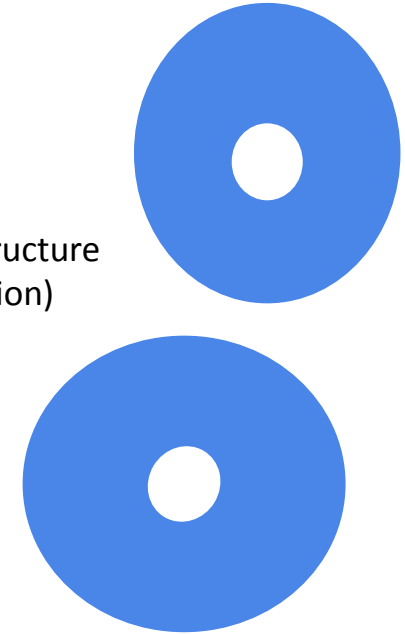
Global modularity increases (differentiation events, bifurcation)

Initial Condition



Expansion of Structure

Bipartite Structure (Bifurcation)

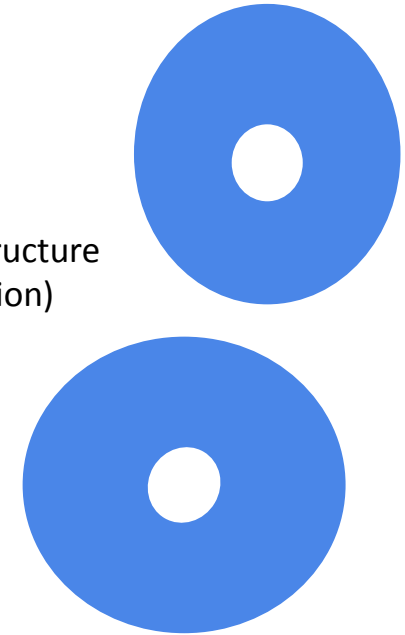


Cell Division

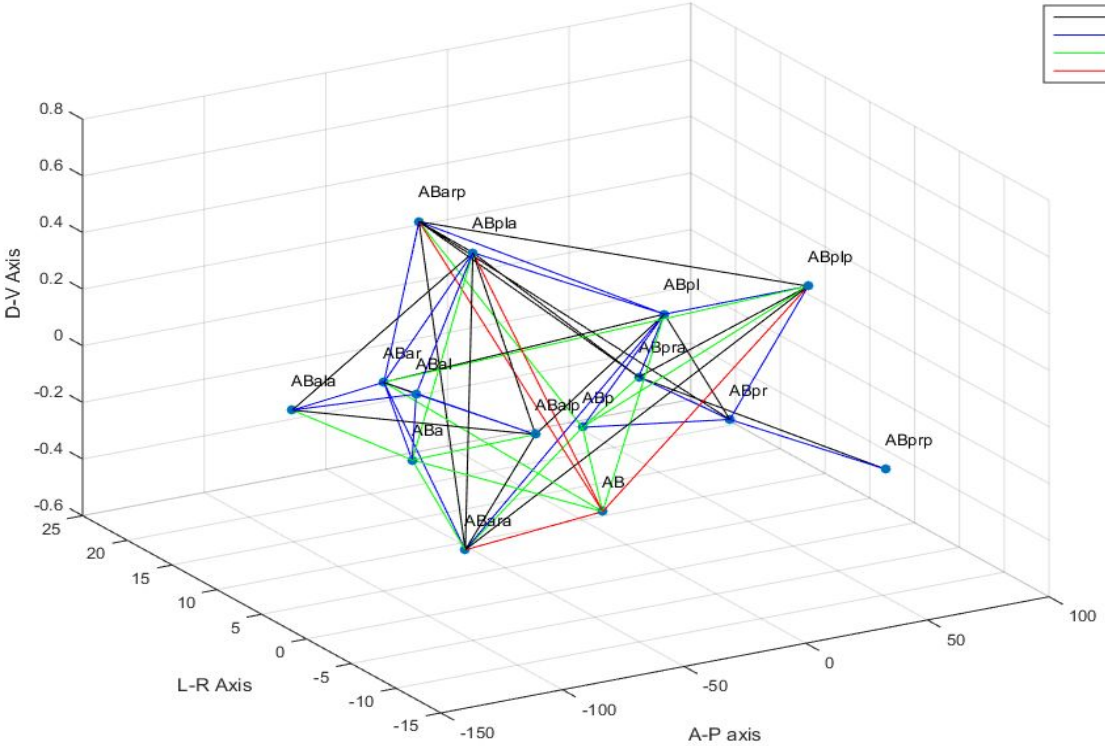
Bifurcation: single network to bipartite.

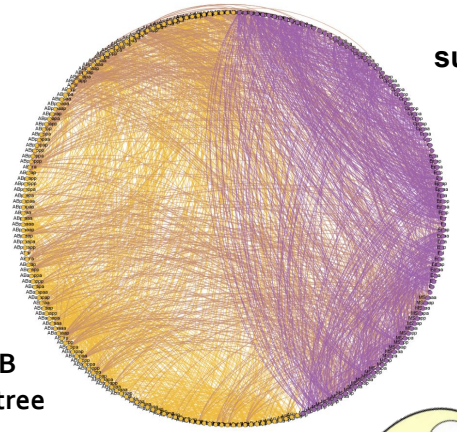
- how many parts does the network fragment into over time?

Bipartite Structure
(Bifurcation)



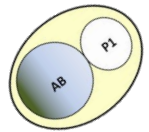
Spatial Connectivity (Interactome)



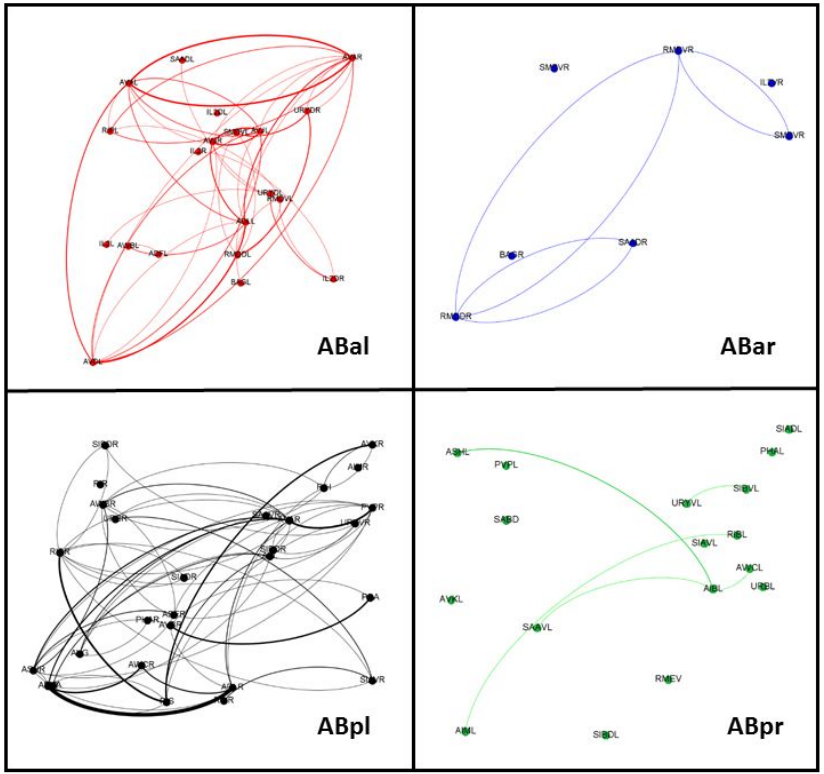


P1 subtree

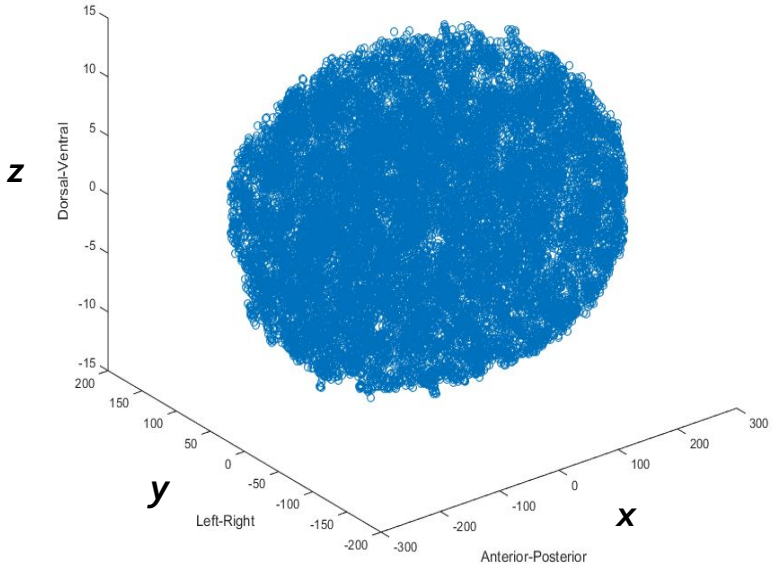
AB subtree

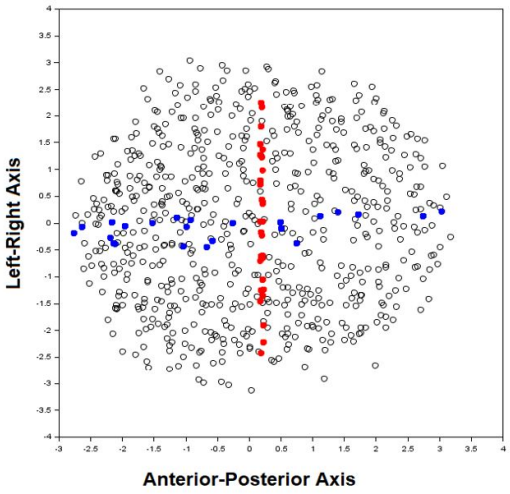


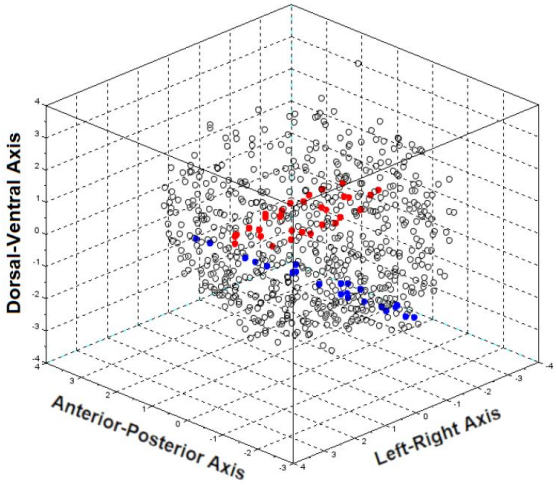
Spatial Connectivity (developmental lineages leading to Connectome)

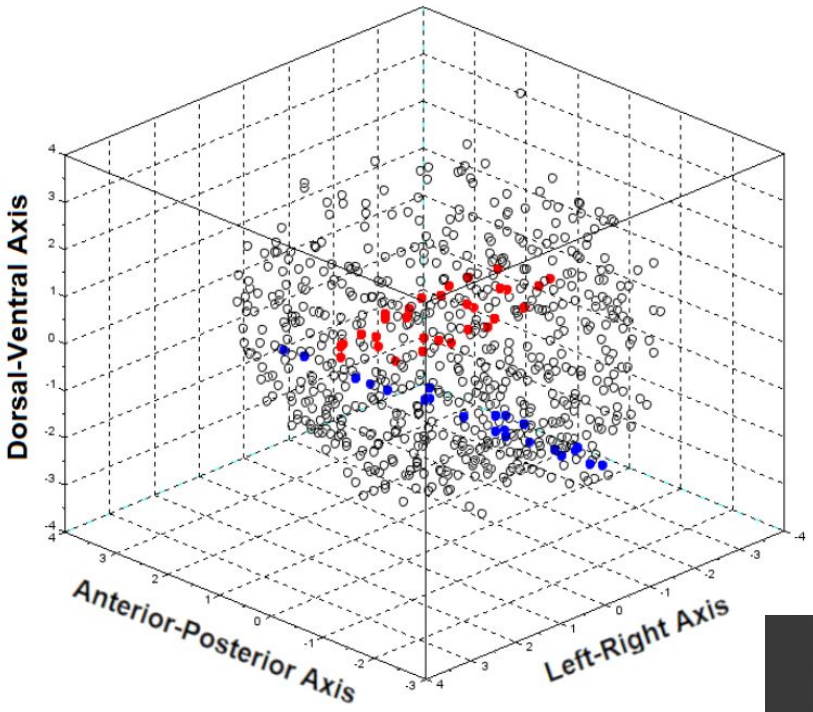


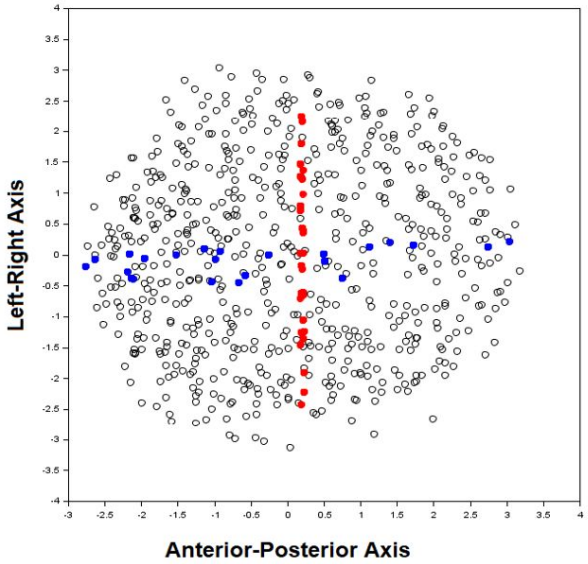
Where connectome neurons emerge in the embryo

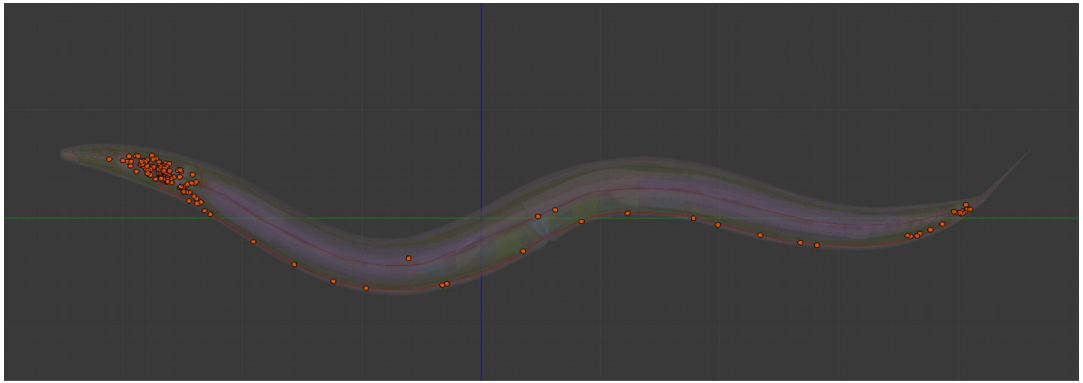






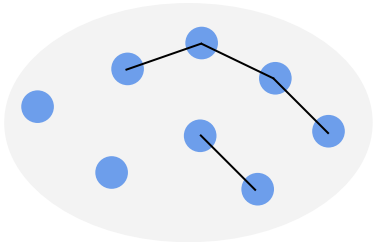

Dorsal-Ventral Axis
Anterior-Posterior Axis
Left-Right Axis


Left-Right Axis
Anterior-Posterior Axis

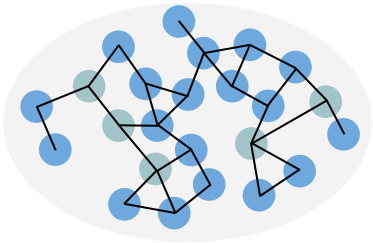


Generative Divergent Integration

8-cell example



24-cell example



Embryo network only. Connections between nodes:

For all developmental cells (blue), < distance *t* (threshold) between cell centroids.

Sparse connectivity due to larger cell size.

Embryo and Neuronal network. Connections between nodes:

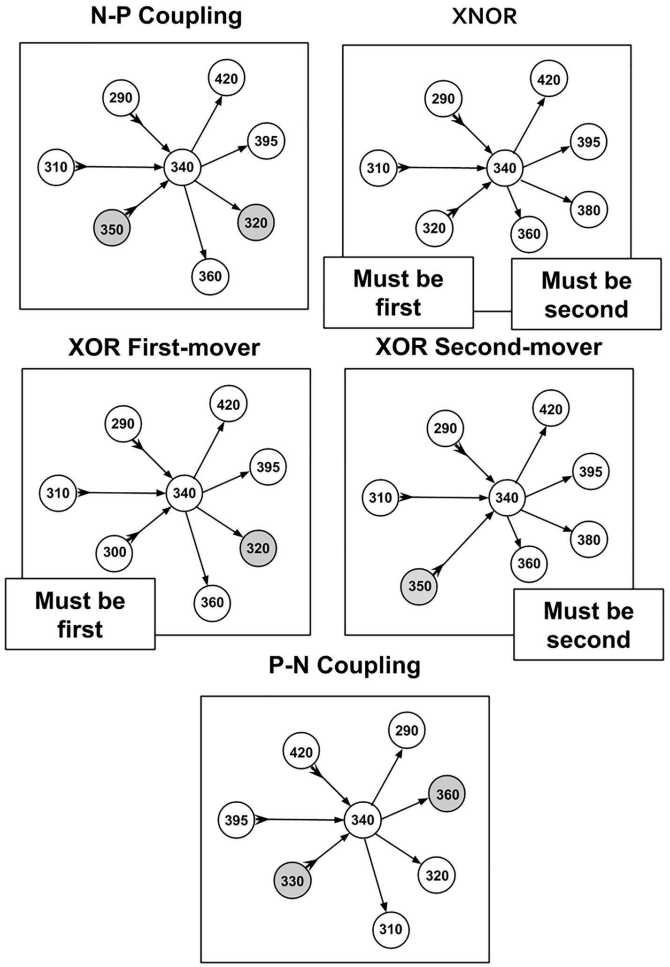
For all developmental cells (blue), < distance *t* (threshold) between cell centroids.

All neurons (green) that share gap junctions.

First-player Dynamics in Connectome Formation

Analysis of developmental synaptic connectivity data in *C. elegans*. Define connectogenetic strategies.

- potential pre- and post-synaptic relationships.
- yield various strategies for establishing connections.

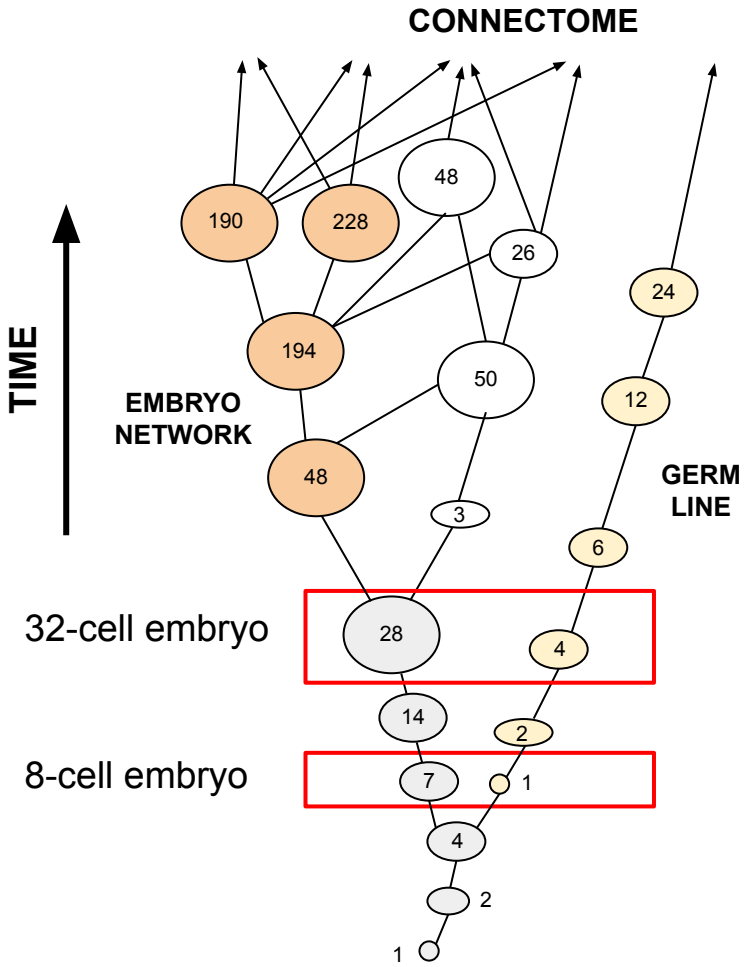


Alicea, *Frontiers in Cellular Neuroscience*, 14, 524791. (2020).

Density-Bifurcation Model

The process of increasing connectivity in development is as follows:

- cells divide and migrate, connectivity increases.
- cell migration enriches local communities and cliques.
- function of cells diverges (differentiation), two interconnected networks emerge.
- interconnected networks provide weak ties (functional interdependencies) between emerging tissues.



Divergent Integration As Hyper-lineage Tree

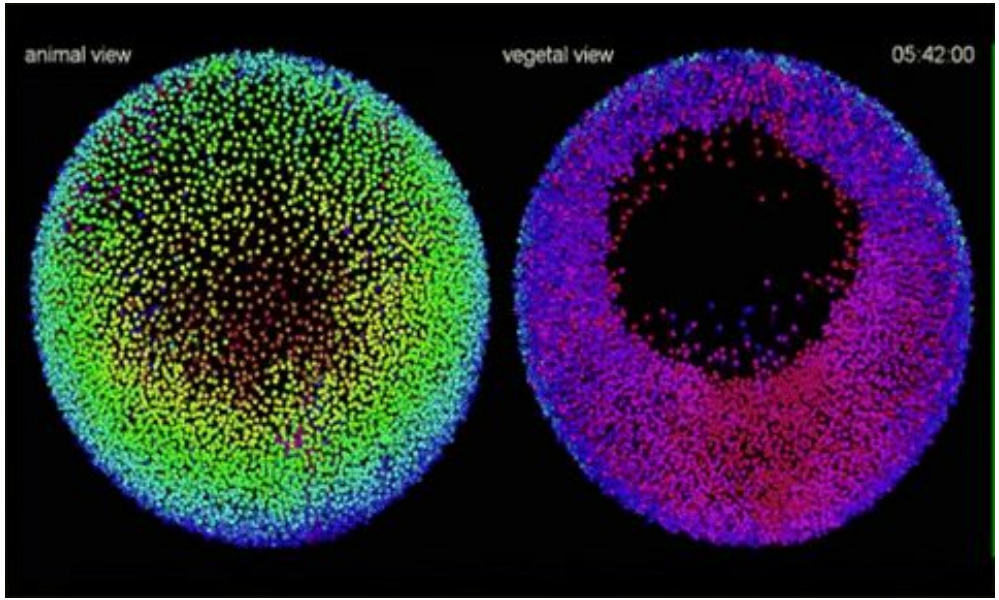
A Hypergraph of Embryogenesis and Connectogenesis

LEFT: *C. elegans*-like connectome (deterministic lineage tree, bilateral symmetry).

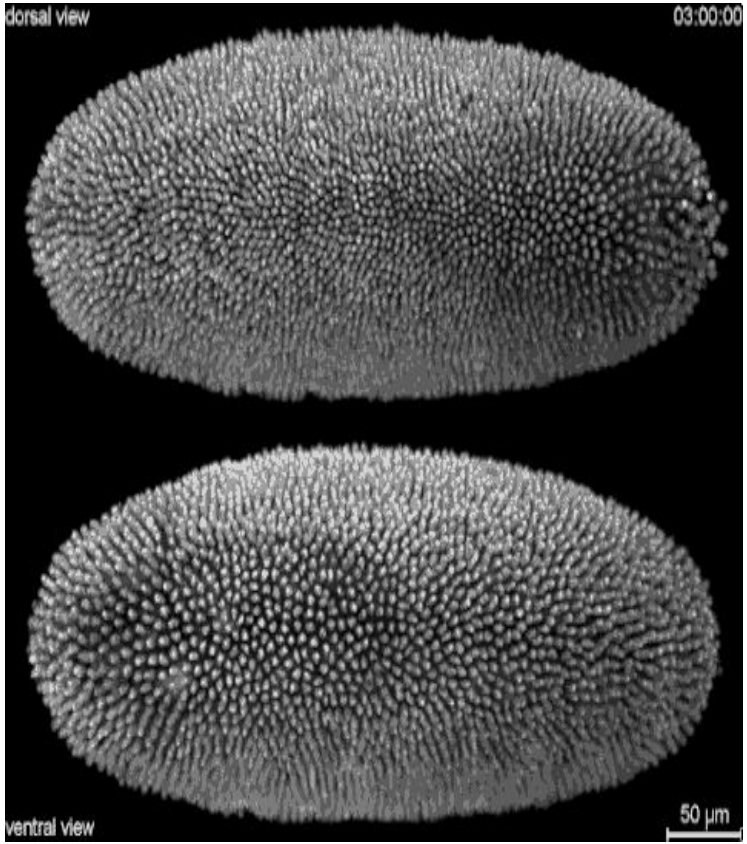
Stem (developmental) cells can move across subgraphs (ovals, *n* = size of network), but terminally differentiated cells cannot.

Future directions: capturing embryo dynamics

- time-series of static embryo networks with spatially-localized differentiation.



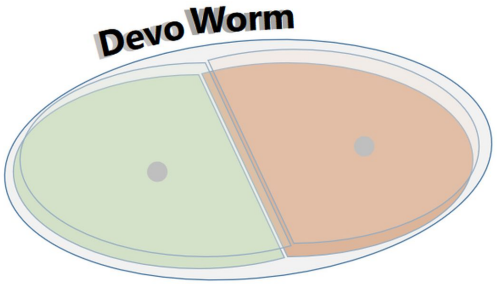
COURTESY: https://giphy.com/gifs/BAccmmPOGIAQo



COURTESY: https://txchnologist.com/post/109306942500/watching-embryos-develop-from-earliest-moments

Thanks for Your Attention

COURTESY: gfycat user orneryangelicgaur



http://devoworm.weebly.com