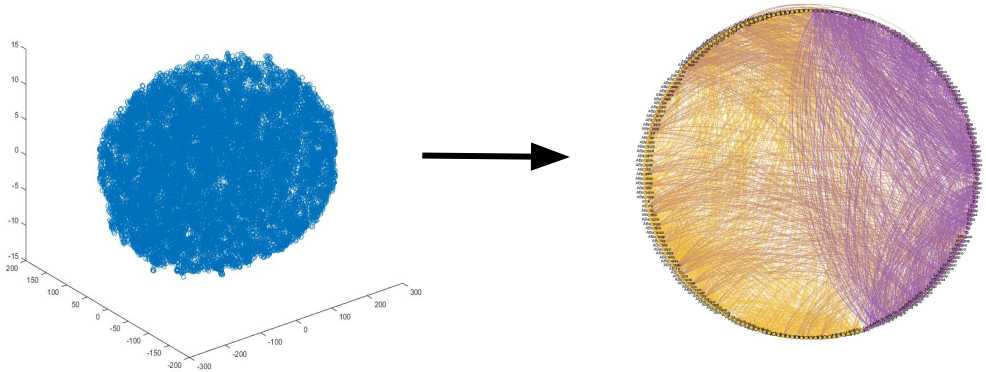
Embryo Networks as Generative Divergent Integration

NETWORKS 2021



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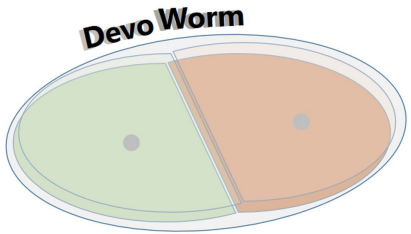
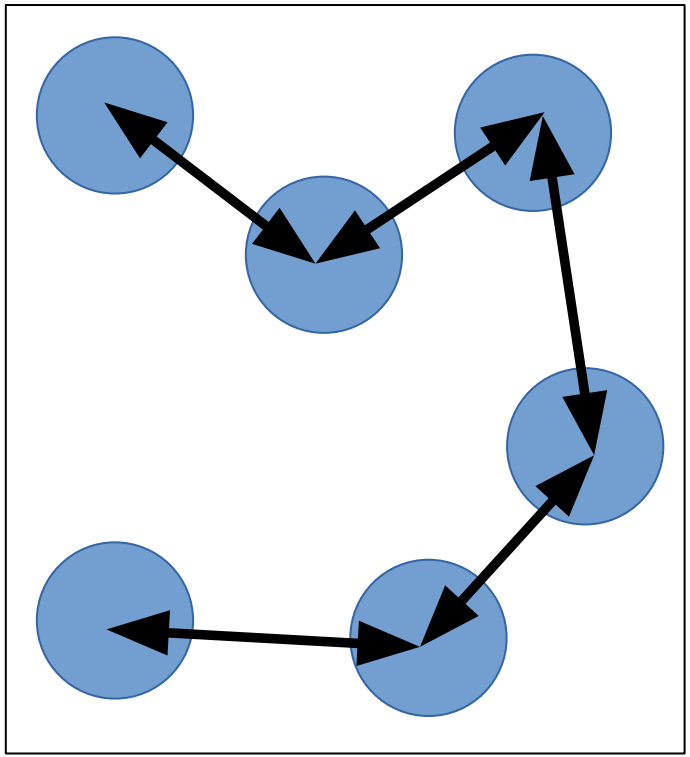


Embryo Networks



x,y,z,t,θ

3-D space

time and context

x,y,z,t,θ

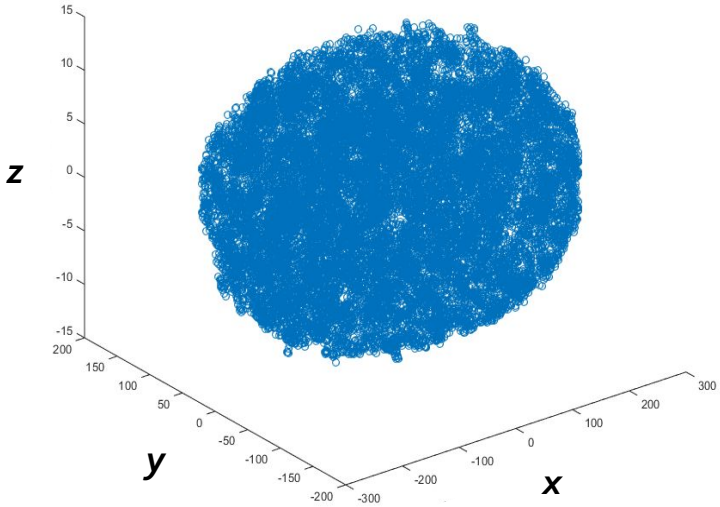
See our Jupyter Notebook for more information

GitHub

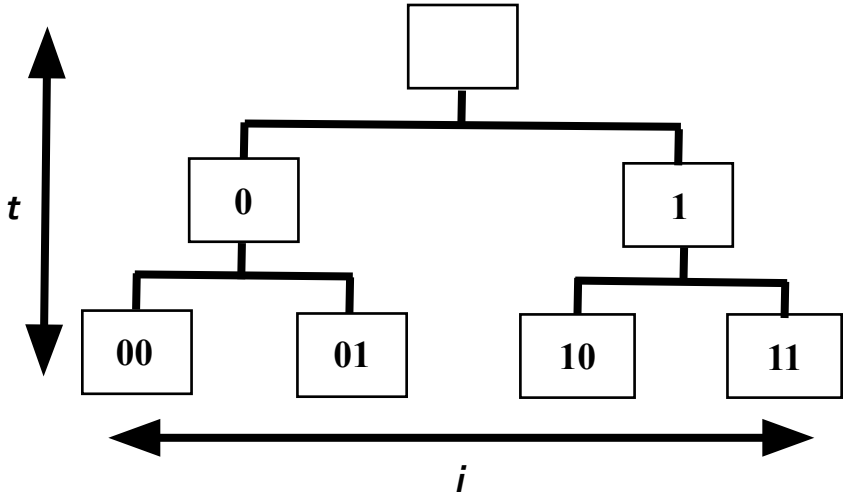
https://devoworm.github.io/

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*)

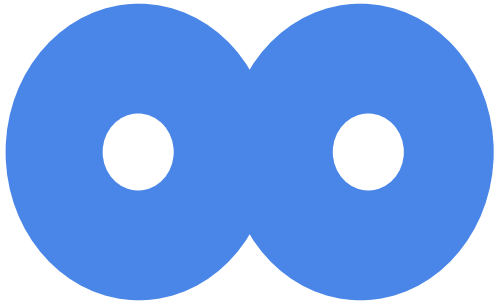
Cell Division

Graph diameter expands (growth in number of nodes)

Local connectivity increases (nodal density)

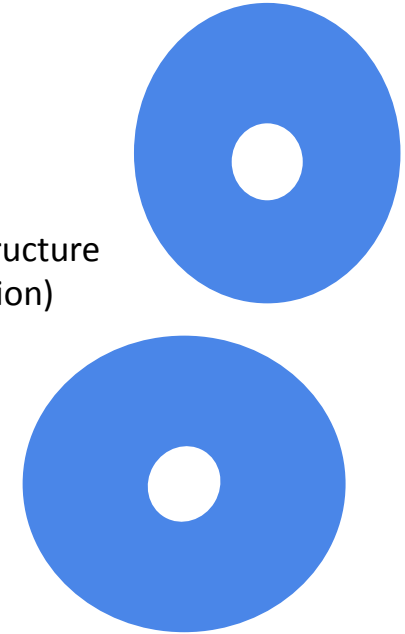
Global modularity increases (differentiation events, bifurcation)

Initial Condition



Expansion of Structure

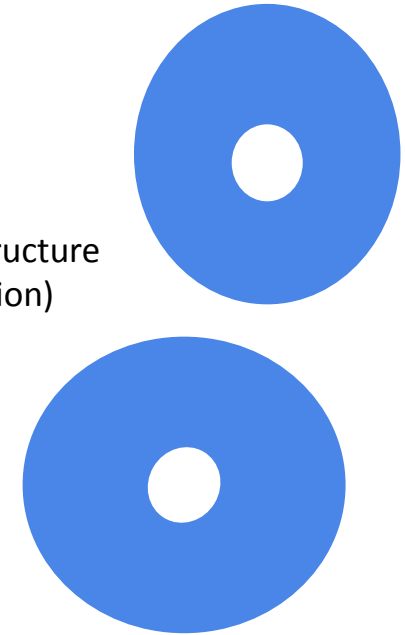
Bipartite Structure (Bifurcation)



Cell Division

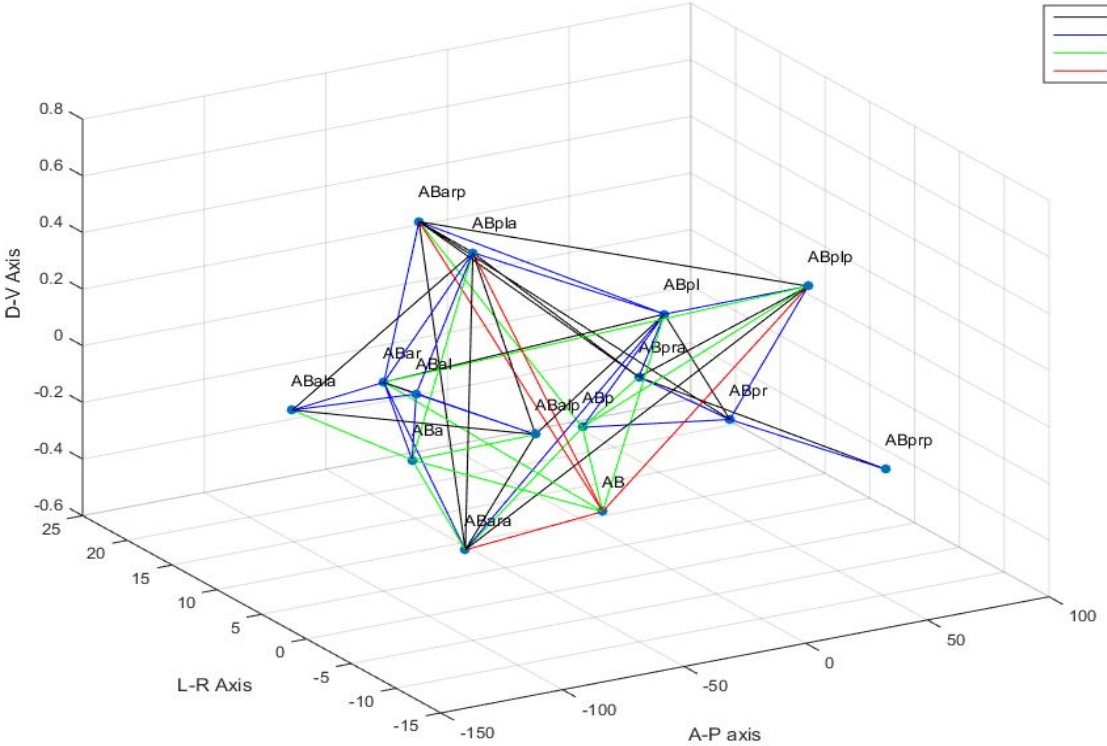
Bifurcation: single network to bipartite.

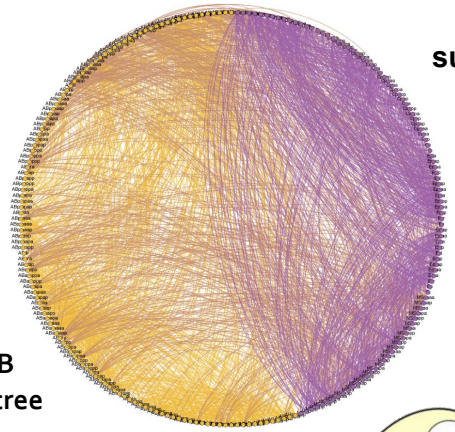
- how many parts does the network fragment into over time?



Bipartite Structure
(Bifurcation)

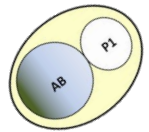
Spatial Connectivity (Interactome)



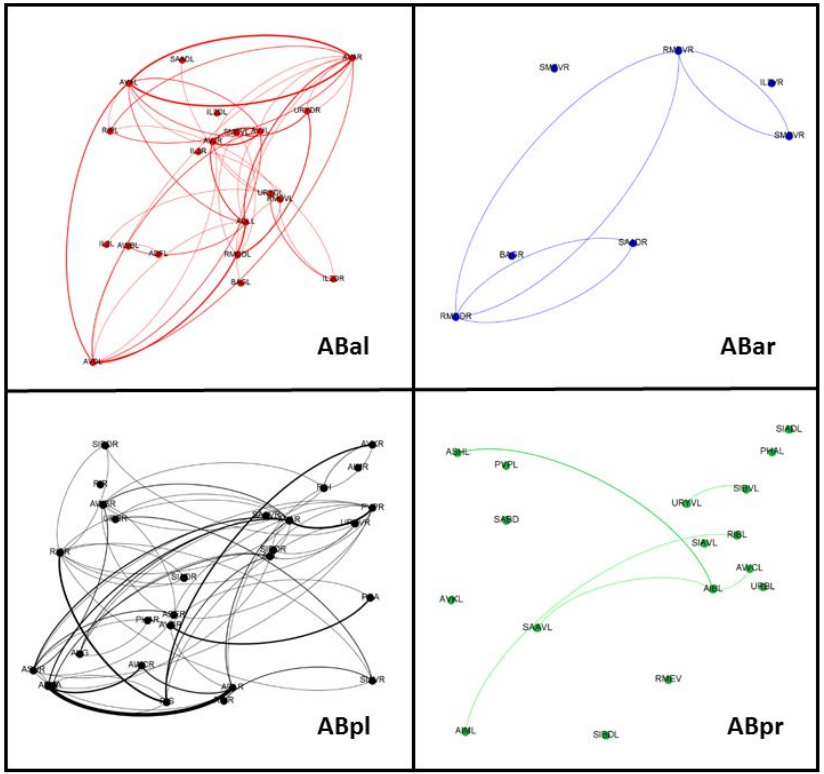


P1 subtree

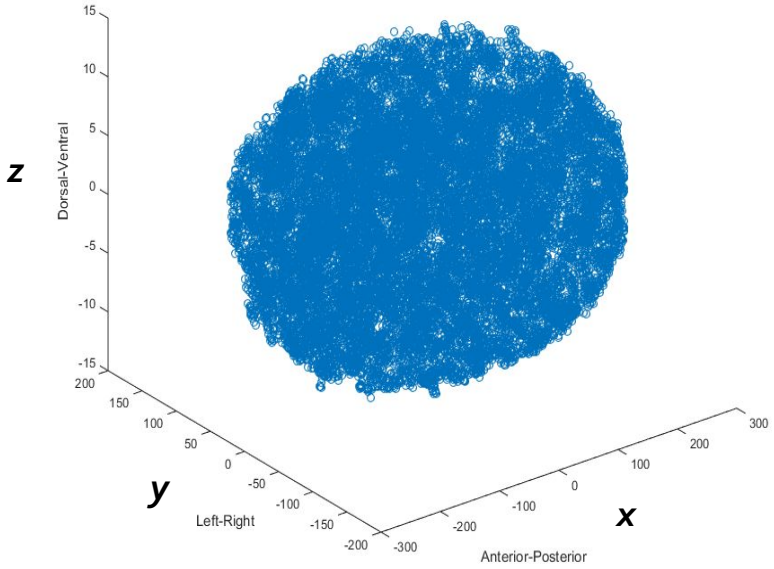
AB subtree

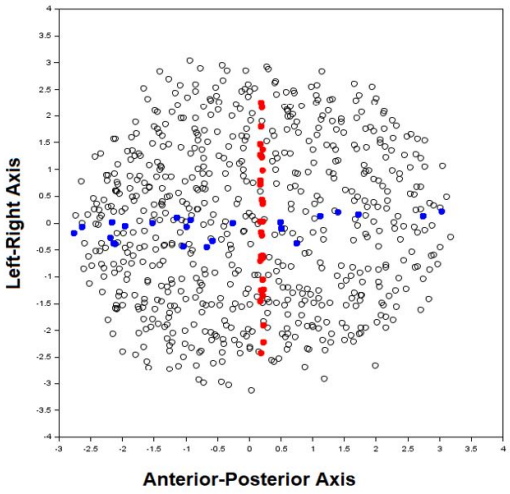


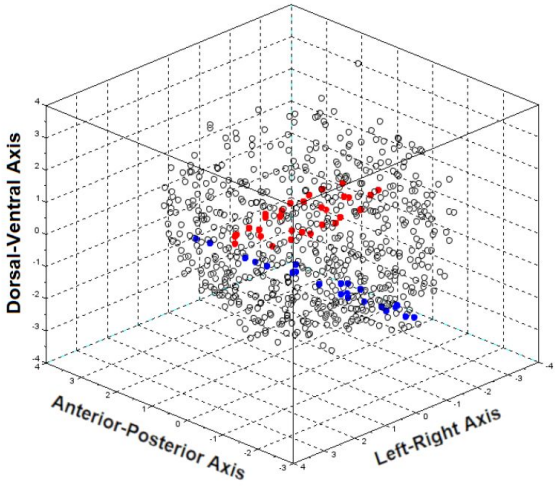
Spatial Connectivity (developmental lineages leading to Connectome)

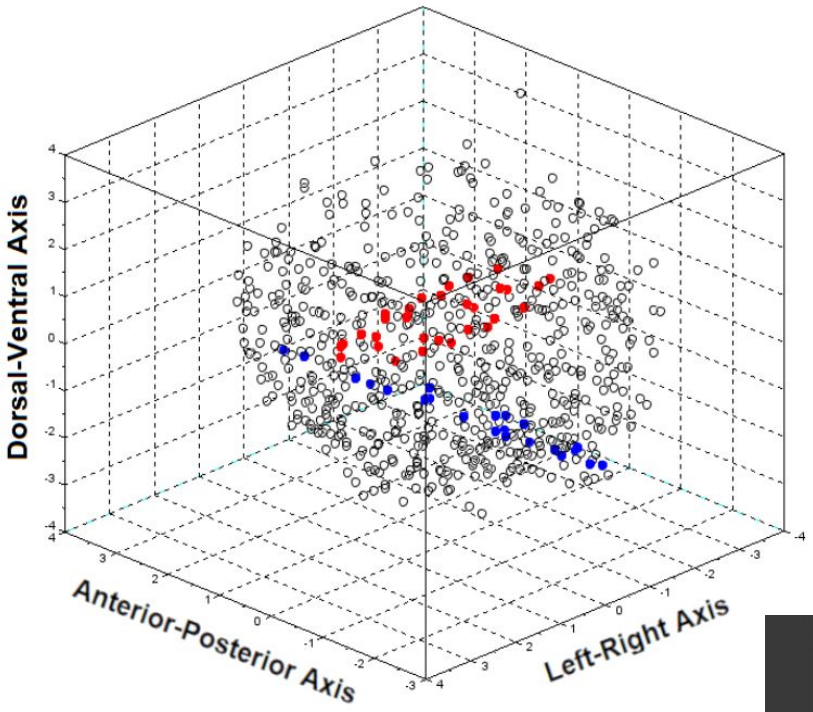


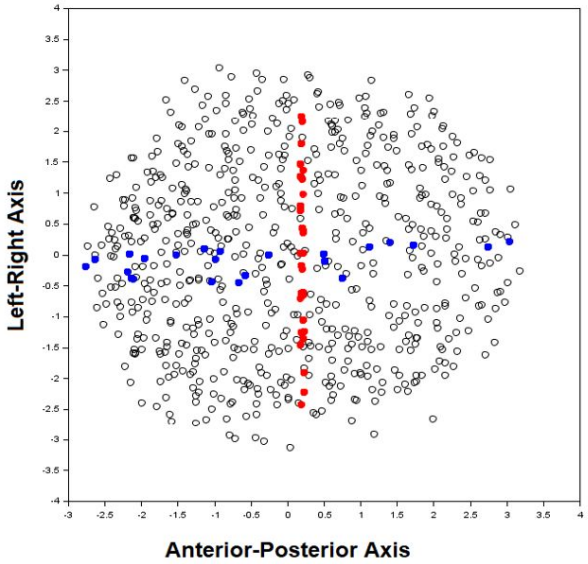
Where connectome neurons emerge in the embryo








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


Left-Right Axis
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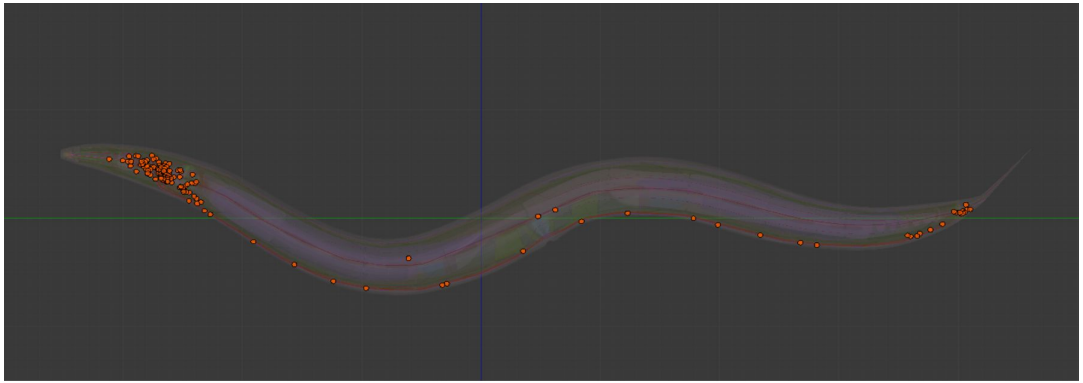
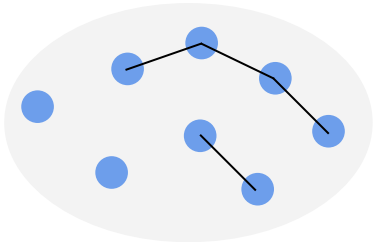
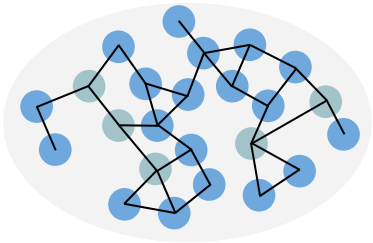


Generative Divergent Integration

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:

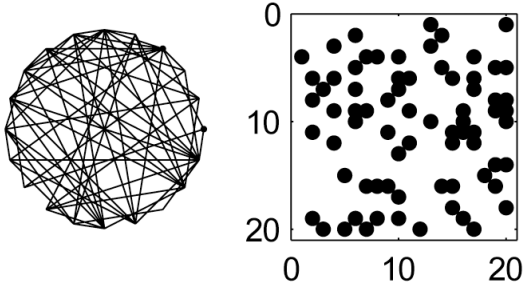
For all developmental cells (blue), < distance *t* (threshold) between cell centroids.

All neurons (green) that share gap junctions.

Developmental spatial connectivity and connectomes as complex networks?

Static Adult Network

Random



Scale-free

Small-world

Stobb et.al, Graph Theoretical Model of a Sensorimotor Connectome in Zebrafish. *PLoS One*, 7(5), e37292.

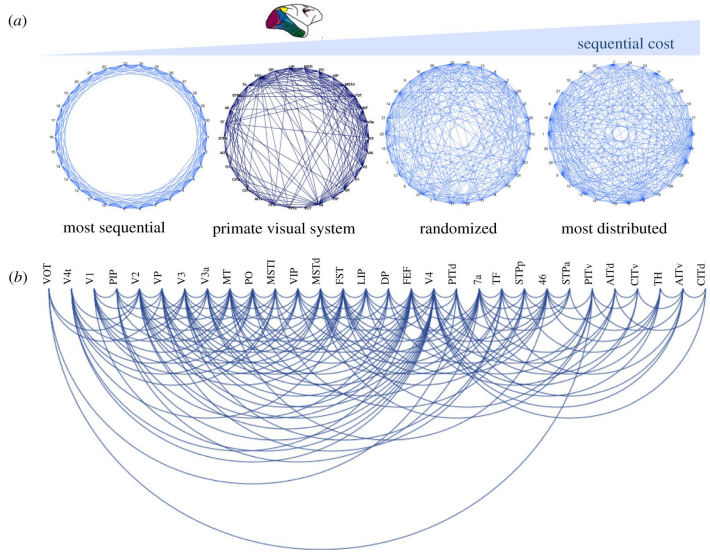
What if the correct model is not a complex (scale-free, small-world) network?

New World Network: small-world network with expansion
Brain Structure and Function, 221(4), 2361-2366 (2016).

Chimeric states: simultaneously coherent and incoherent.
Science Advances, eaah8535 (2019).

Small-world constrained by spatiotemporal sampling
Chaos, 20, 013134 (2010).

Network connectivity preferences influences later activity in ways that affect symmetry
PNAS, 116(41), 20360–20365.



Generalized Hierarchical Signatures
Phil. Trans. R. Soc. B, 375, 20190319 (2020).

New World Embryo Networks are Multilevel Networks

Proximity and Adjacency measurements:

- convex hull measurement over time (topological data analysis).
- differential network diameter (between time t_1 and t_n).

Expansion rate measurements:

- differential path length ratio (between time t_1 and t_n).
- differential clustering (between time t_1 and t_n).

New Types of Topologies

Feature-rich Networks:

- topological features to capture emerging tissues, fluid dynamics, and gene expression cascades.

Multiple Worlds:

- different processes and structures captured in a *n*-partite network with weak connectors.

Semi-integrated Networks:

- interrelated phenotypic modules and functional systems (brain and body).

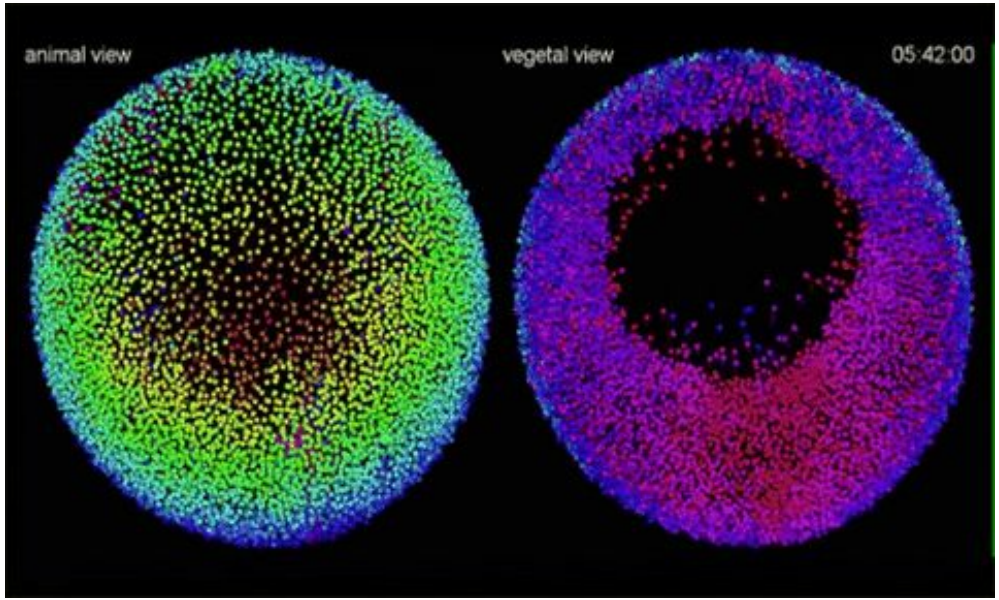
Density-Bifurcation Model

The process of increasing connectivity in development is as follows:

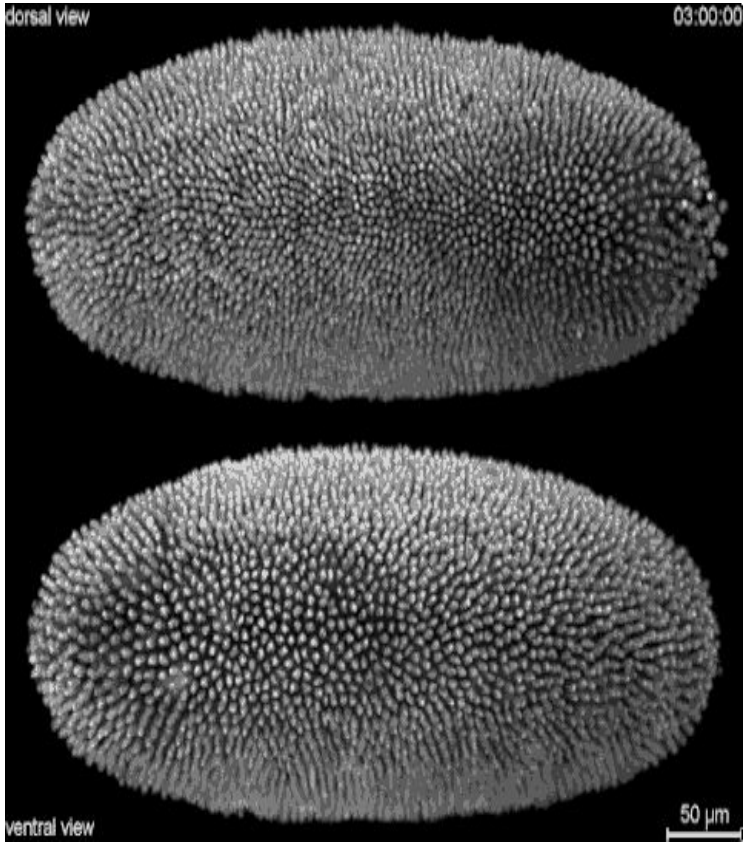
- cells divide and migrate, connectivity increases.
- cell migration enriches local communities and cliques.
- function of cells diverges (differentiation), two interconnected networks emerge.
- interconnected networks provide weak ties (functional interdependencies) between emerging tissues.

Future directions: capturing embryo dynamics

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



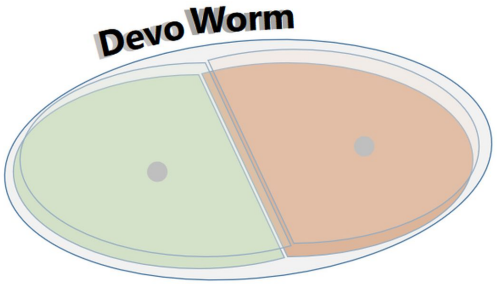
COURTESY: https://giphy.com/gifs/BAccmmPOGIAQo



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

Thanks for Your Attention

COURTESY: gfycat user orneryangelicgaur



http://devoworm.weebly.com