Circuitous Connectome Modeling for Developing Sensorimotor Complexity

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Poster Overview on YouTube:
https://tinyurl.com/Network-Science-Playlist

The structural and functional emergence of simple connectomes can yield great diversity and complexity, even in their tiniest forms (10^2 to 10^5 neurons).

MAP: openworm.org

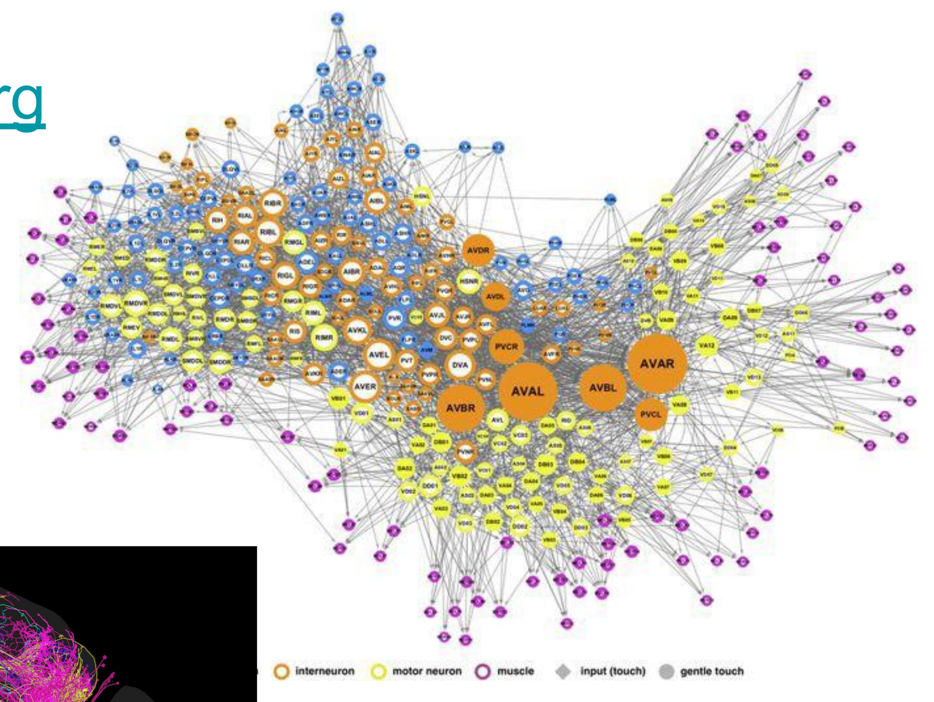
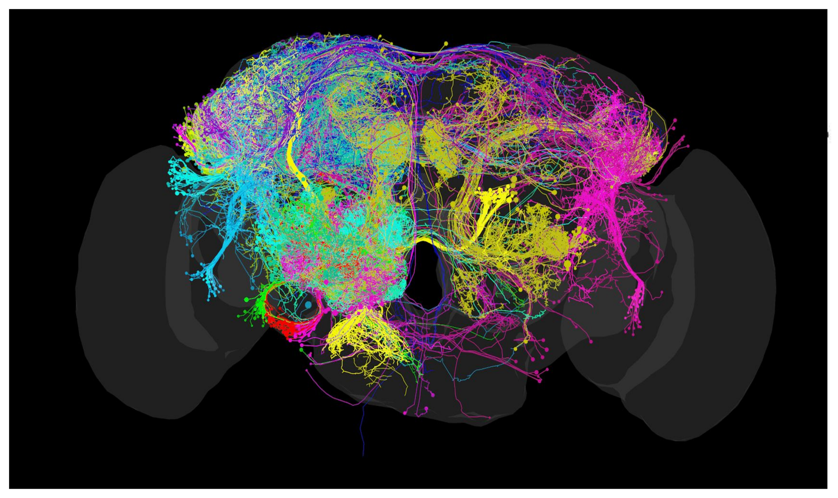
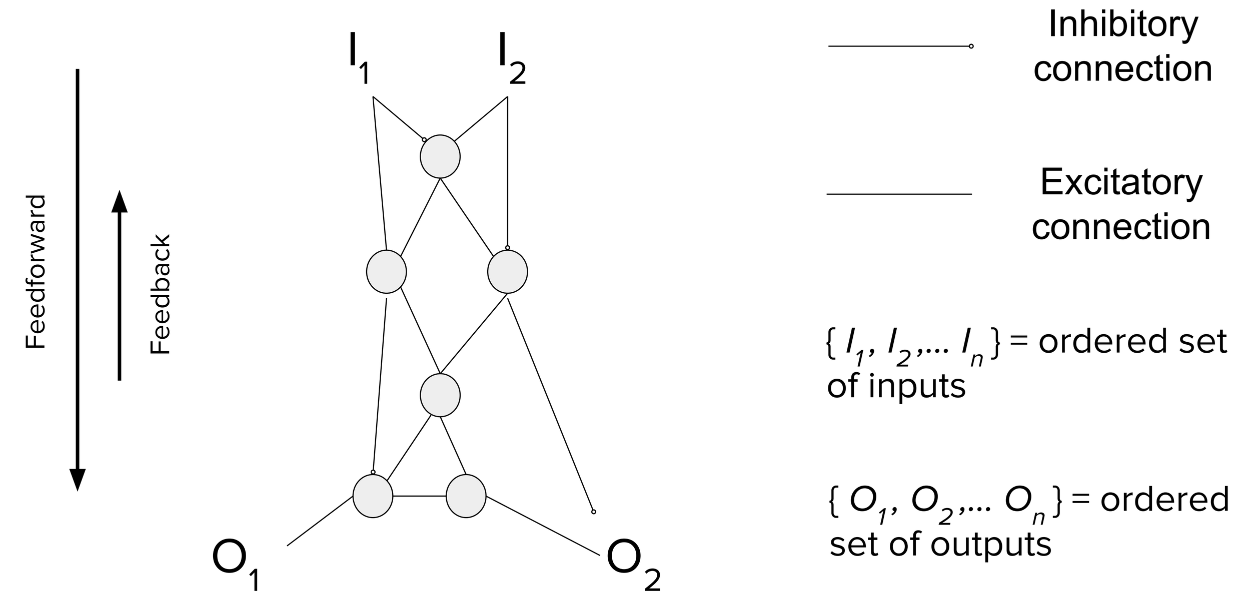


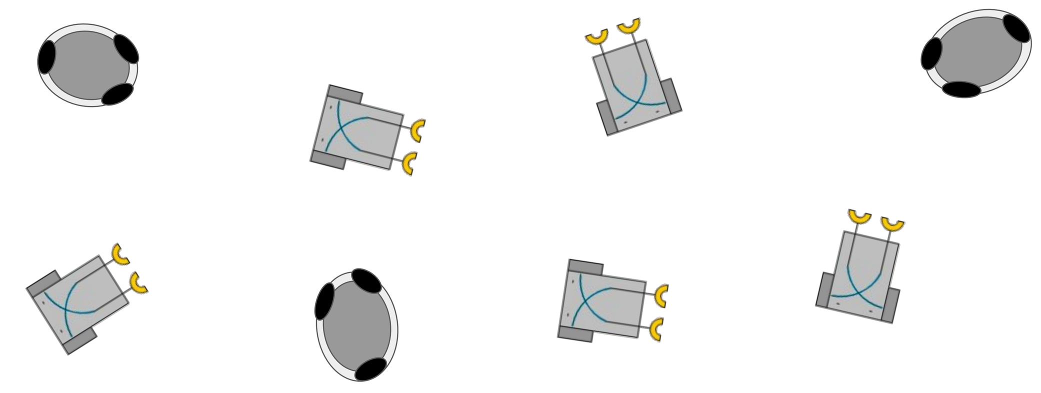
IMAGE: flyconnecto.me



Network phenotypes [1] → emergence of complex outputs:

mechanism for perception and action, an internal network that processes the signal between sensory input and action output, and an embodied phenotype that generates said action.

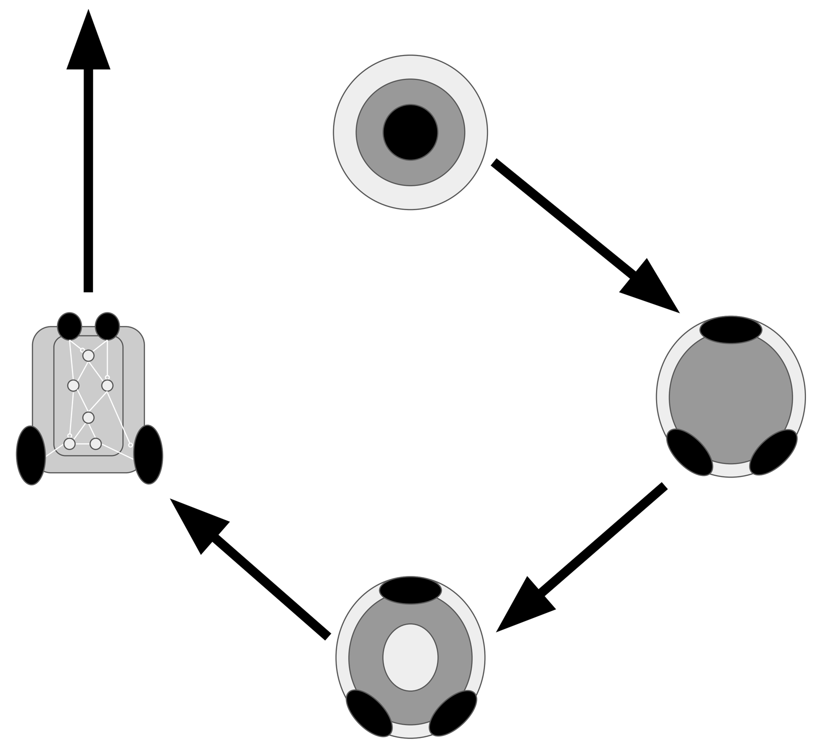




Developmental Braitenberg Vehicle (dBV) [1]

Input (sensory information), processing of the I/O signal (internal network)

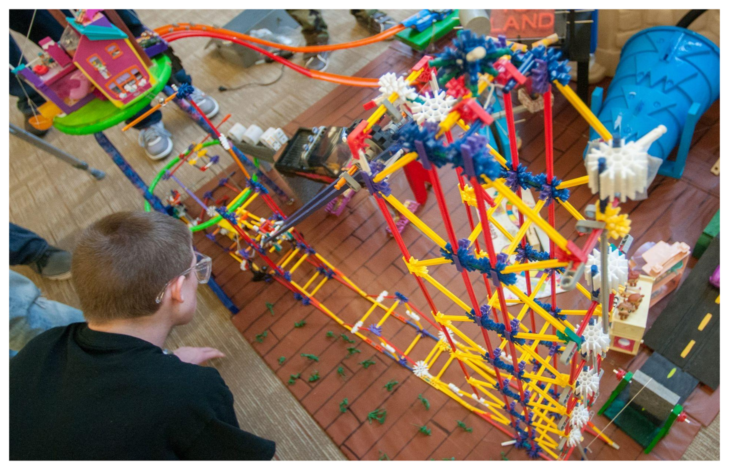
Output (effector action) in terms of both linear to combinatorial relations.

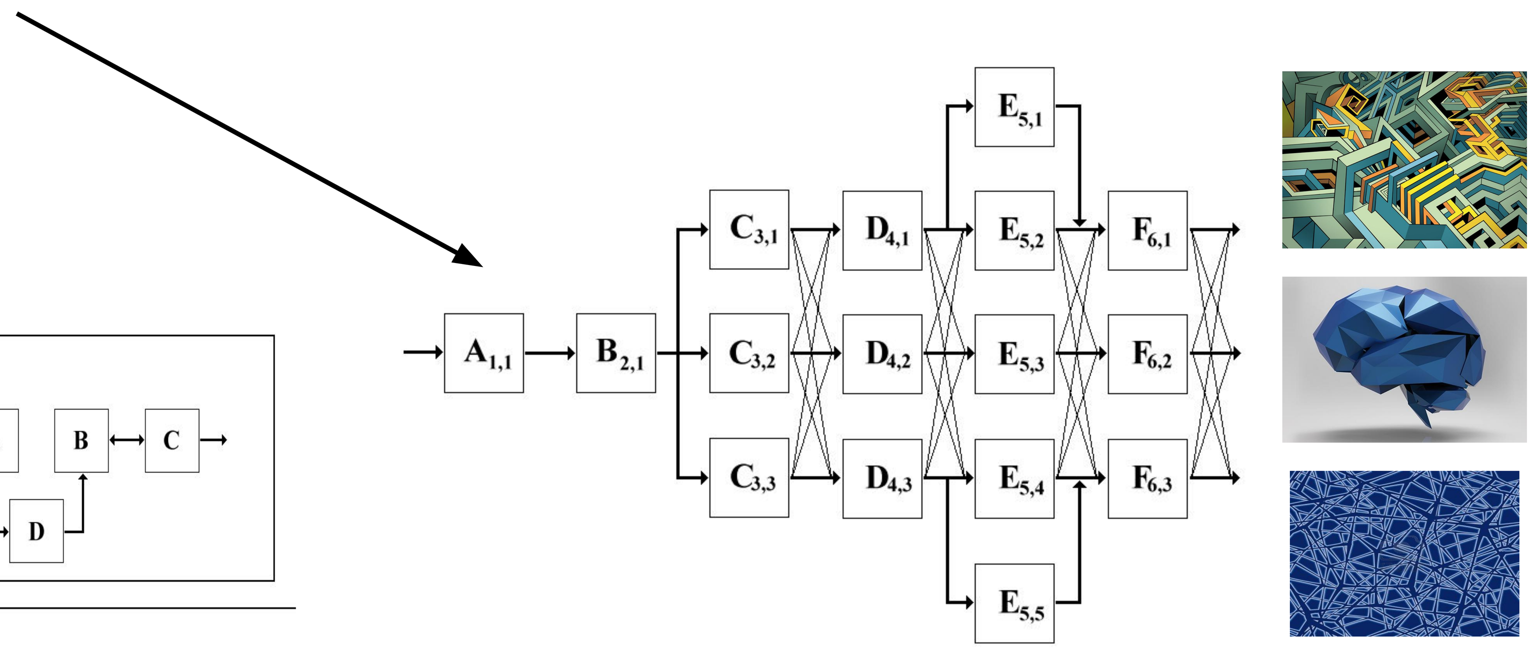


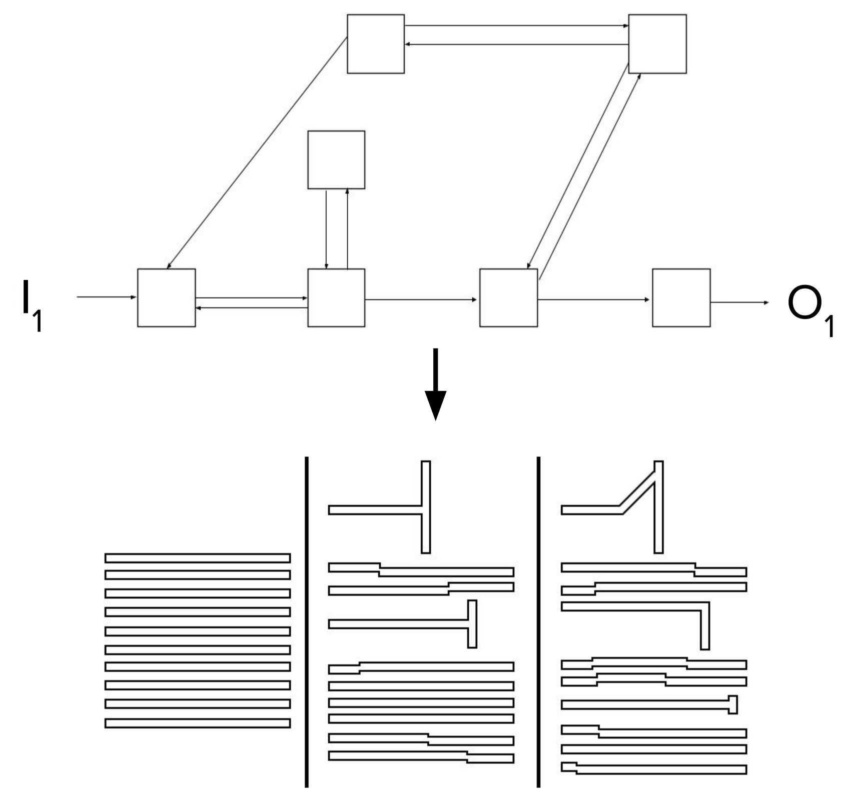
Hypothesis: that increasing functional complexity is marked by maximizing the circuitousness (or path length) between sensor and effector. This assumes the goal of internal networks is to convolve the signal between perception and action as much as possible.

Modeling increased phenotypic complexity in a suboptimal manner favors the emergence of redundancies, which in turn serve as the interface for new phenotypic components and modular subdivision of the internal network.

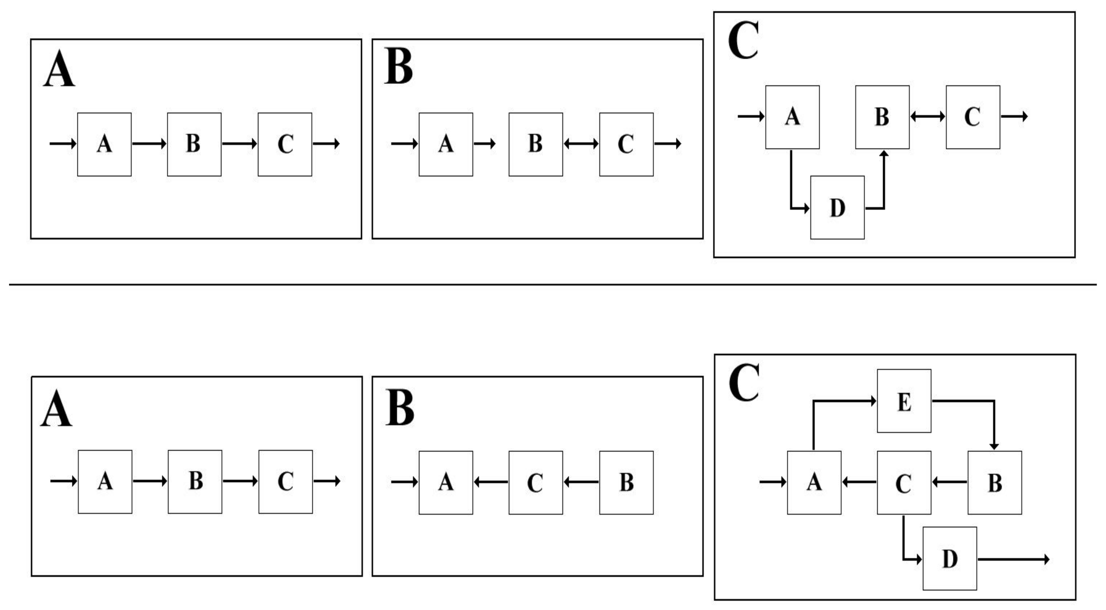
Biological Rube Goldberg Machines (bRGM) [2] = I/O network, nonlinear directed graphs can be produced that tend to maximize the number of steps (neurons) between input and output..







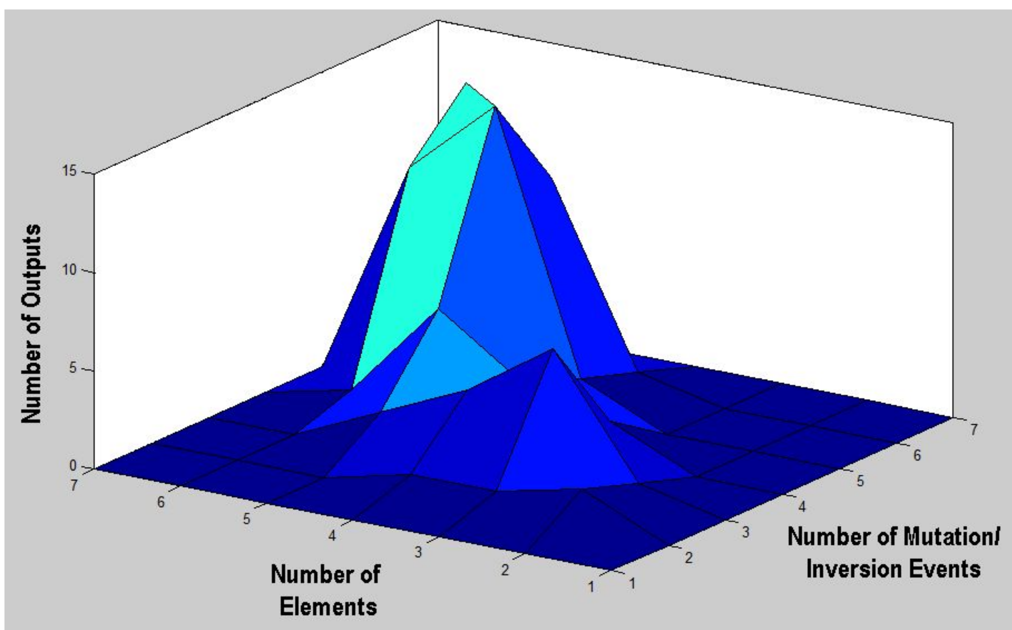
Increasing sensory experience (input) intersects with changing network parameter values (growth in network diameter and increasing path length from sensor to effector).

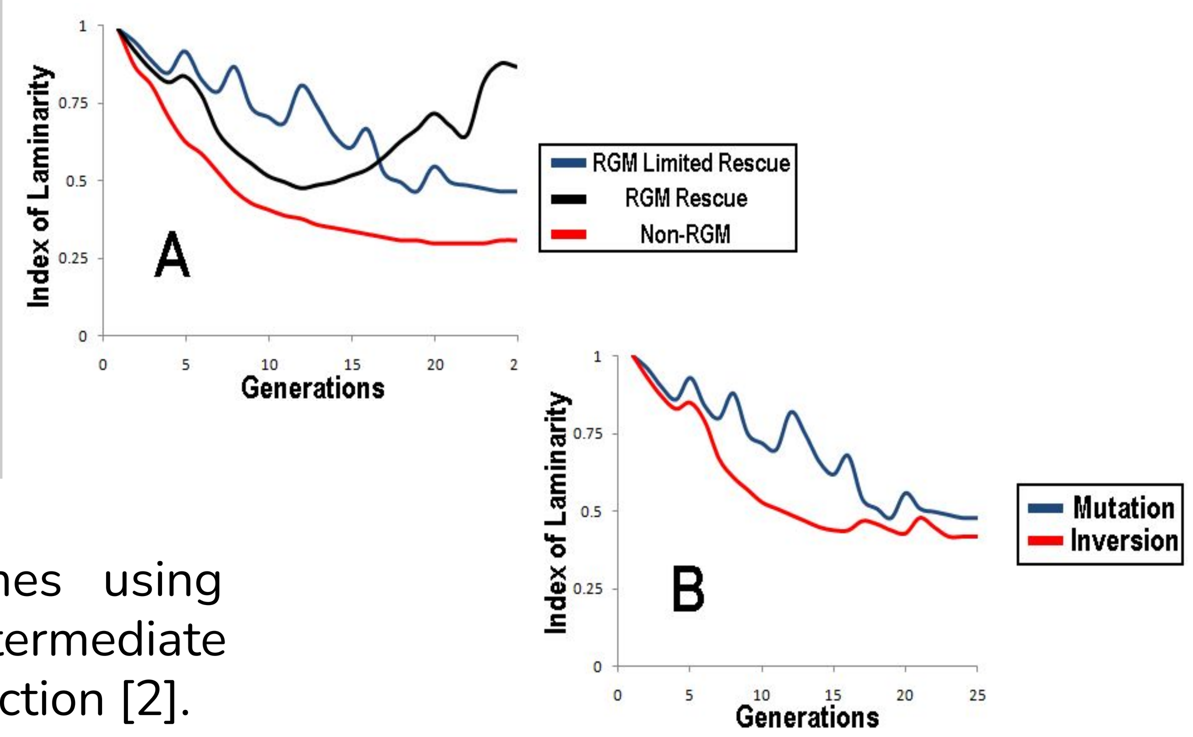


Two network growth scenarios.

TOP: mutation/co-option, where change occurs in a stepwise fashion.

BOTTOM: inversion, where change occurs in a motif-wise fashion.





Expected complexity of resulting connectomes using pseudo-data. The greater the amount of intermediate steps, the less laminar (smooth) the network function [2].

Maximizing circuitous path lengths is also consequential to the production of novel behaviors and ambiguities. As the network phenotype grows in complexity, the behavioral outputs may become more diverse and more unpredictable.

References:

[1] Dvoretskii, S. Gong, Z. Gupta, A. Parent, J. and Alicea, B. (2022). Braitenberg Vehicles as Developmental Neurosimulation *Artificial Life*, 28(3), 1-27.

[2] Alicea, B. (2012). The "Machinery" of Biocomplexity: understanding non-optimal architectures in biological systems. *arXiv*, 1104.3559.