Possible Origin of Division of Labor in Multicellular Organisms

An Agent-Based Model Simulation

We use an agent-based model to show how primitive signs of division of labor can appear spontaneously in a multicellular organism.

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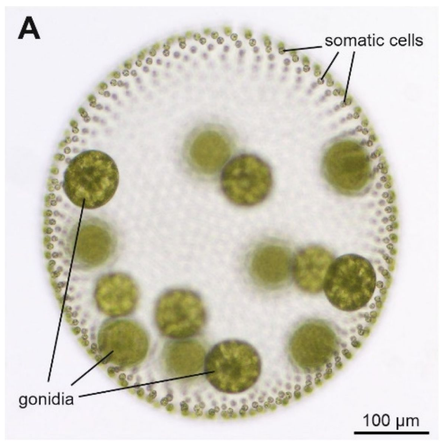
Introduction

Division of labor generally refers to specialized individuals performing complementary tasks within a group.

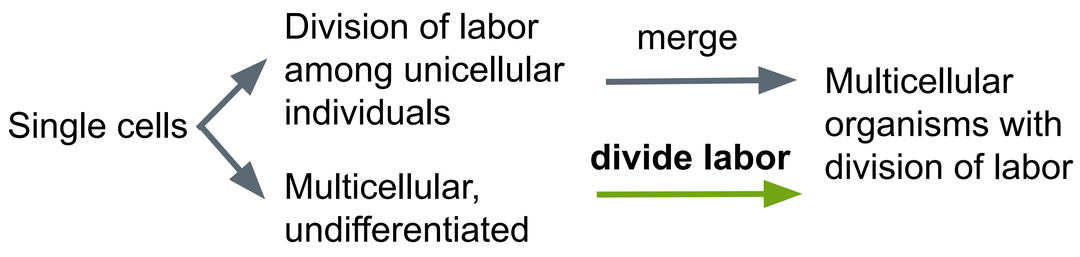
In multicellular organisms, it involves different cell types, with groups of cells carrying out distinct functions.

The appearance of multicellular organisms with division of labor among cells marks a major evolutionary milestone.



Somatic and germline cells in *Volvox*

Conceptually, there are two possible ways of this transition:



We focus on the second step of the second pathway[1]:

How does the transition from undifferentiated multicellularity to specialization of activities happen?

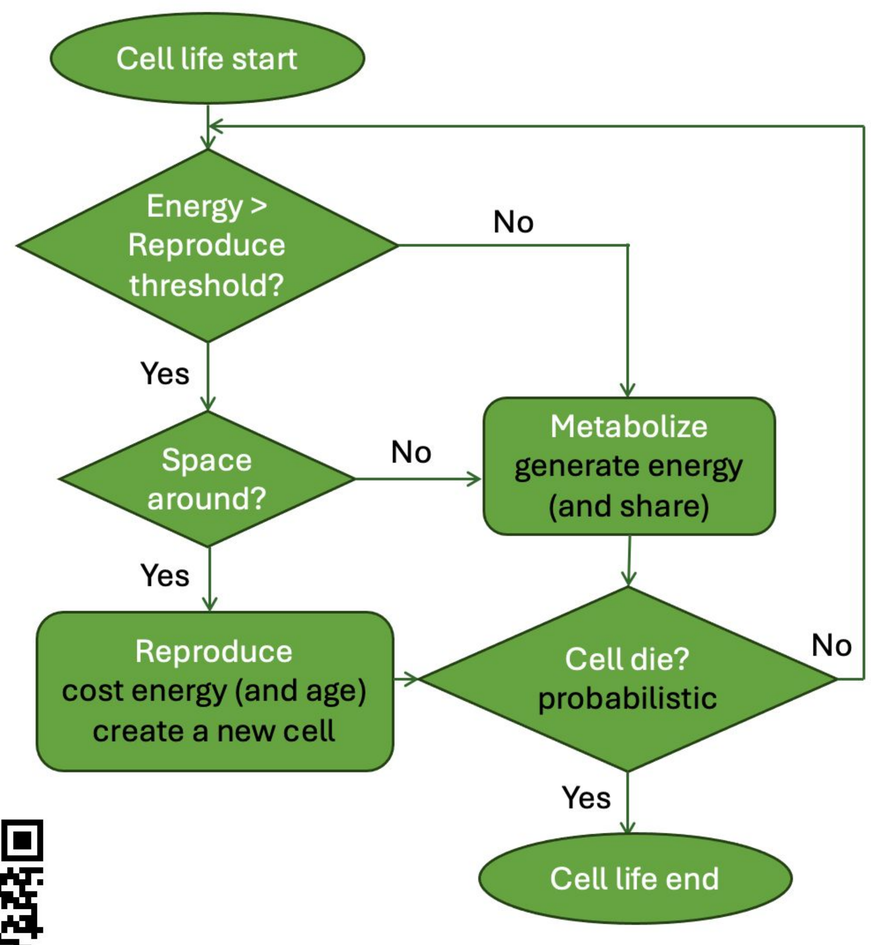
We propose that it can begin with an aggregative phenomenon that occurs when cells share resources and are constrained by lifespan and spatial limits.

This hypothesis is supported by our agent-based model: under certain conditions, some cells specialize in one activity throughout their lifespan without genetic changes or selective processes.

The Model

An agent-based model is a computational model that simulates agent behavior to demonstrate how group-level phenomena emerge from individual actions.

In our model, each cell follows this procedure:



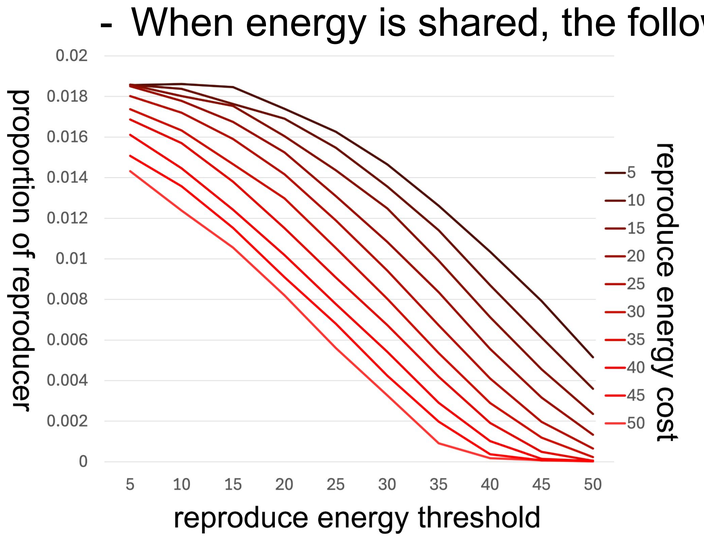
←**Play with the model!**

Results

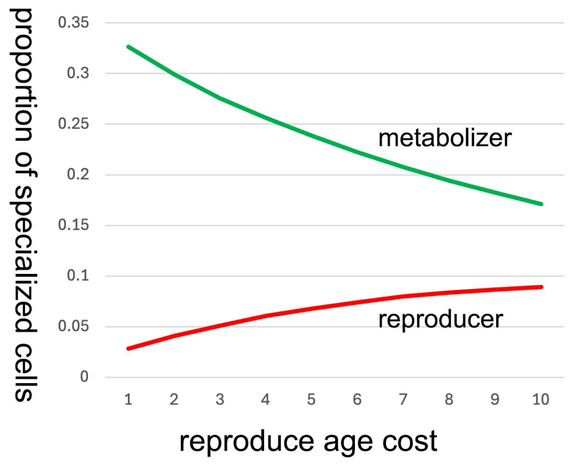
Two types of specialized cells occur:

- **Reproducer:** Cells that solely reproduce throughout their life.
- **Metabolizer:** Cells that solely metabolize throughout their life.

- The proportion of metabolizers remains stable across different energy parameters, regardless of whether energy is shared.
- Reproducers do not appear when energy is not shared.
- When energy is shared, the following pattern is observed:



metabolize efficiency = 20; reproduce age cost = 0; average lifespan = 15.



reproduce threshold = 50; reproduce energy cost = 50; metabolize efficiency = 50; average lifespan = 15.

Discussion & Conclusion

What gives rise to the specialized cells? The explanation is surprisingly simple:

	Metabolizer	Reproducer
Explanation	No space around to reproduce	Reproduce right after birth and die after a couple of reproduction activities
Evidence	Energy usually above threshold	Age usually very small
Assumption	Limited space for new cells[2]	- Energy shared among cells - Reproduction energy threshold and cost relatively low - Non-zero probability of dying early

Our model demonstrates how initial cell specialization can first develop. Further research is needed to understand how this contingent specialization stabilizes into regular functions, ultimately evolving into a full division of labor.

References & Acknowledgements

Picture A from: von der Heyde, Benjamin, Eva Laura von der Heyde, and Armin Hallmann. 2023. "Cell Type-Specific Promoters of Volvox carteri for Molecular Cell Biology Studies" Genes 14, no. 7: 1389.

[1] Research have shown what is likely to be the first step: the appearance of aggregates of undifferentiated groups of cells. See Koschwanez, J. H., Foster, K. R., & Murray, A. W. (2011). Sucrose utilization in budding yeast as a model for the origin of undifferentiated multicellularity. PLoS Biology, 9(8), e1001122.

[2] This assumption seems realistic when undifferentiated cells aggregate due to a failure in cell separation.

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