UNIVERSITY OF COPENHAGEN

PHD SCHOOL OF SCIENCE
UNIVERSITY OF COPENHAGEN

Final PhD Plan - APPROVED

1. General information	
Document date:	24/01/2025
Name PhD student:	Jakob Hallundbæk Schauser
Department:	Niels Bohr Institute
KU ID:	pwn274
Principal Supervisor:	Ala Trusina
Co-supervisor:	

2. PhD Programme	
5+3 PhD programme:	5+3 PhD programme
Subcategory:	Please choose
Subcategory:	Please choose
Subcategory:	Please choose
Subcategory:	Please choose
Full-time/part-time:	Full-time

3. Start date and expected end date	
Start date:	01/12/2024
Expected end date:	30/11/2027

4. Title of project (working title)

Investigating spatial algorithms for morphogenetic patterning in biological and artificial systems

5. Description of the PhD project

(Working) Title:

Investigating Spatial Algorithms for Morphogenetic Patterning in Biological and Artificial Systems

Abstract (Approx. 1000 characters)

Morphogenetic patterning is a fundamental process underlying the organization of biological tissues and the emergence of complex structures in both natural and synthetic systems. My research will investigate spatial algorithms that govern such patterning, focusing on their applications in both biological and artificial contexts. I will integrate experimental data collection from 2D gastruloid systems (simplified in vitro models of early embryonic development) with computational approaches, including neural cellular automata (NCA) and theoretical modelling. The experimental observations of gastruloid pattern formation will provide a biological basis for the development and validation of our spatial algorithms. Meanwhile, NCA models will be employed to simulate self-organizing processes, hopefully revealing parallels between artificial and biological patterning mechanisms. This interdisciplinary PhD will bridge experimental insights and computational methods, offering a unified framework to study the rules and dynamics of morphogenetic processes.

Background and Hypothesis (Approx. 2000 characters)

The study of morphogenetic patterning lies at the intersection of biology, physics, and computation, drawing from a rich history of biophysics and mathematical modelling. Biophysics emerged as a field to explain the physical underpinnings of biological phenomena, from molecular interactions to tissue mechanics. Pioneering efforts, such as Alan Turing's landmark 1952 paper, introduced the concept of reaction-diffusion systems to describe how chemical substances, or morphogens, could interact and diffuse to produce spatial patterns in biological systems. These "Turing patterns" provided a mathematical foundation for understanding phenomena like animal coat patterns, leaf arrangements, and embryonic development.

In parallel, cellular automata (CA) arose as computational tools to explore self-organization and emergent behaviour in complex systems. CA consists of grid-based models where simple, local rules drive the evolution of complex, global patterns over time, much akin to how cells can be thought of. These systems can provide a conceptual framework for studying natural processes, including morphogenesis, from a computational perspective.

Building on these foundations, neural networks (NNs) and, more recently, neural cellular automata (NCA) have extended the capacity to model and simulate pattern formation. While traditional CAs rely on pre-defined rules, NCAs leverage the learning capabilities of neural networks to discover rules autonomously. This hybrid approach merges the strengths of biologically inspired computing and the adaptability of machine learning, enabling NCAs to capture dynamic and nonlinear phenomena more effectively.

The interplay between these frameworks—reaction-diffusion systems, cellular automata, and neural networks—provides a powerful toolkit for understanding and replicating morphogenetic processes. However, challenges remain in integrating insights from biological systems, where stochasticity, feedback mechanisms, and multiscale interactions play critical roles.

Hypothesis
I hypothesize that spatial algorithms inspired by biological systems, when informed by experimental data from 2D gastruloids, can be effectively implemented and enhanced using neural cellular automata. These algorithms will in some way replicate the self-organizing principles observed in biological morphogenesis, and hopefully also reveal some universal rules that govern pattern formation across both natural and artificial systems. By unifying insights from biology, physics and computer science, my research aims to bridge the gap between biological experimentation and computational modelling, uncovering novel principles with broad applicability.

Importance and Impact (Max. 1000 characters)

This research has the potential to unify principles of biology and computer science, addressing the pressing need for cross-disciplinary frameworks in understanding complex systems. With a paper already submitted for peer review in Current Biology and insights gained from discussions with a Nobel laureate during our visit to Princeton, my work is rooted in both rigorous science and transformative collaboration.

The findings promise to advance our understanding of self-organization in natural systems while informing novel strategies for artificial systems design. This work could impact diverse fields, from the underlying chemistry in developmental biology to machine learning, cellular automata and their intersection. Through the lenses of physics, my research (loftily) aspires to catalyze a new era of interdisciplinary exploration between biology and computation, fostering innovation across both scientific domains.

Work plan and Implementation (approx. 2000 characters)
This PhD project have experimental, computational, and theoretical.

The experimental component will focus on 2D gastruloids, in vitro systems that mimic aspects of early embryonic development. The imaging will be done in our local lab at NBB, once the move is finalized.

On the computational side, neural cellular automata (NCA) will be developed to simulate self-organizing processes. These models will be informed by biological insights found in the experiments and trained to replicate the observed patterns.

Theoretical modelling will unify these approaches, linking the cellular automata, and neural networks to derive generalized rules of patterning. Iterative feedback between experimentation and computation will guide refinement. Together, these components will yield a comprehensive framework for understanding and applying morphogenetic principles across biology and computation.

Year 1: Generate data on micropatterns (for 2D gastrulation) using embryonic mouse stem cells. Here we will use existing protocols for differentiation cells towards the 3 germlines, but subjected to a range of spatio-temporal alterations/perturbations to evaluate how the system encodes information in space and time.

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  - Year 2. Develop image processing and quantitative analyses of the data sampled in 1. Here we will use the state-of-the-art Machine-learning techniques to sample the data from hundreds of images and build up an array of models.
  - Year 3: Use the data from 1. and 2 to build quantitative models to predict how the spatial signalling can be modified to direct cells towards different fates/cell proportions. In addition, develop methods to use the models to suggest how to interpret the AI-generated rules from our collaborators (Sebastian Risi, ITU)

Attached is my preliminary course plan in one of the possible file formats (.png is not one of them)

6. Start-up seminar

Evaluation	Start date	End date	Progress
Startup seminar (to be planned) *	01/02/2025	01/02/2025	Planned

7. Change of scientific environment

Institution	Country	Start date	End date
Princeton University, NJ, USA	US United States	01/01/2026	01/04/2026

8. Knowledge dissemination and/or teaching activities

Activity	Contribution	Number of hours
Will be teaching DatF, Ala's course Physics of Molecular Diseases, and more to be planned	Teaching/Dissemination activity (to be planned) *	

9. PhD Course Portfolio

Title of course	Link to database	Suggested ECTS
Fundamentals of the PhD education at SCIENCE - module 4		2.5
Statistical methods for the Biosciences II - SmB II (generic course) - LPhD015		3.0
Python for SCIENCE		3.0
Advanced Genome and Cell Biology		7.5
Fundamentals of the PhD education at SCIENCE modul 1 - K6		2.5
Applied Machine Learning	https://kurser.ku.dk/course/nfyk20002u	7.5
Fundamentals of the PhD education at SCIENCE - module 2 - k6		2.5
Fundamentals of the PhD education at SCIENCE - module 3 - K6		2.5

10. Agreement on the form and extent of supervision

Weekly 1hr meetings in person, weekly group meetings and additional supervision when needed

11. Running costs

The research project:	100000
PhD Courses:	0
Change of environment:	20000

12. Agreement on intellectual property rights (*e.g.* patents)

Not relevant

13. ORCID

ORCID no.:	0009-0009-6877-2393

14. Comments

Student's comments:	12/12/24
Supervisor's comments:	resolved the missing points, 03/12/24
PhD Coordinator's comments:	19/12/2024 Looks good- Approved. best Poul Martin ---------- 12/12/2024 NOT approved. Please update your project description according to the template given on this link': https://kunet.ku.dk/faculty-and-department/science/PhD/phd-plan,-supervision-and-regular-assessments/Pages/PhD-Plan.aspx Also, make sure to add 30 ECTS of course activities. best Poul Martin
PhD administration's comments:	6 January 2025 - Final plan ok. //VICH
Chair of PhD committee's comments:	6/1-2025 All well enjoy your studies! dbc
Head of PhD School's comments:	Approved/LA