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Marseille, April 16th 2026

The PhD manuscript written by Stanisław Żukowski focuses on morphodynamics, the physical principles by which forms arise in physical and biological systems. More specifically, the thesis addresses the problem of unstable moving fronts, in which a front grows locally as a function of a physical field (concentration of chemical species, pressure, stress, etc.) and forms fingers or branches. In that context, Stanisław Żukowski uses theory and experiments to treat a diverse set of problems related to tip growth and Laplacian networks: the invariant shape of dissolution fingers, the reconstruction of growth rules from network snapshots, the reconnection between branches of the network—generally thought to be prevented by screening between branches—and finally the morphogenesis of the canal system of the jellyfish Aurelia Aurita.

In Chapter 1, Stanisław Żukowski introduces the questions and concepts that underlie his PhD work. After a short introduction on the diversity of shapes observed in nature (1.1), he gives a historical overview of the physics of morphogenesis, through hydrodynamic instabilities, reaction-diffusion, and the study of invariant forms in moving fronts (1.2). He then describes in more details the problem of the Laplacian growth of a front, an archetype for unstable front problems and branching morphogenesis. He then moves to the network scale (1.3), and presents the principles of screening between growing branches, that in general prevent looping. This identifies a knowledge gap, the mechanisms of branch reconnections. Finally, he introduces the theoretical tools and experimental systems that will be used in the following chapters (1.4): 1/ the thin finger model (an ersatz for Laplacian growth), 2/ the Hele-Shaw cell used to make viscous fingering experiments and their dissolution variant, and 3/ the canal network of the jellyfish Aurelia. Because of the diversity of content, section 1.4 is slightly more disjointed and less consistent throughout. However, taken separately, 1.4.1, 2 and 3 are very well-conceived and pedagogical. A remarkable effort has also been made to introduce in detail the jellyfish Aurelia: its position in evolution, its biology, its anatomy, and its development. Overall, the introduction is well-documented and clear, and the outstanding questions are well-defined.

Chapter 2 is a first author article published in PRL that studies dissolution fingers in Hele Shaw cells. The key question is whether such dissolution fingers admit invariant (shape-preserving) solutions, analogous to Saffman–Taylor fingers, and whether these shapes encode geo-physical conditions. Using microfluidic experiments and theory (including conformal mapping and transport analysis), Stanisław Żukowski demonstrates that individual fingers rapidly converge to a time-invariant shape that translates without deformation. An analytical expression for the finger profile away from the tip is derived, and shows good agreement with experiments. A central result is that the finger slope is directly linked to flow rate (via Péclet number). This is important because it provides a quantitative bridge between geological morphology at a given time and underlying transport parameters (groundwater flow). An interesting aspect that is not presented in the paper is how well invariance generally holds in nature. A related question is whether invariance holds when basic hypotheses are relaxed (i.e. non-linear reaction kinetics close to saturation, or heterogeneous bottom layer).

Chapter 3 is a first author article published in Sci. Rep. that studies the growth of branched networks. The central question is an inverse problem: can one infer the underlying growth rule from a snapshot of the network? Stanisław Żukowski et al. introduce a backward evolution algorithm (BEA), which reconstructs network history by evolving the structure backward in time and testing candidate growth rules. They show that this method can very nicely recover both growth laws and bifurcation criteria from synthetic data. In the river network case however, the inversion seems somewhat degenerate and sensitive to the choice of metrics—although combining different metrics allows for unique inversion. I wondered whether this degeneracy reflects limitations of the method, or if it could stem for spatial or temporal variations of the growth rule across the network? In that context, does performing the inversion on subregions improve or worsen identifiability? And more generally, would relaxing the assumed power-law form of f(J) reduce degeneracy, or would it instead make the inverse problem less well-posed?

Chapter 4 is a first author article published in PNAS that investigates the emergence of loops in Laplacian networks, challenging the common assumption that such systems remain tree-like. The key question is to ask how loops can form spontaneously in systems dominated by screening-driven growth, which typically prevents reconnections. Stanisław Żukowski shows that breakthrough events—localized increases in permeability or conductivity—can destabilize tree-like structures and trigger loop formation. Using a combination of modeling and experiments, he demonstrates that once a secondary path becomes sufficiently conductive, it can capture flux and close a loop. This is an important result because it provides a possible mechanism for reconnections in natural branched networks, in which loops can enhance transport robustness. This raises the question of whether this mechanism is limited to a one-off time window preceding breakthrough, or if the breakthrough regime can be sustained in time to allow for the generation of entire looping networks.

Chapter 5 is a second author article published in Frontiers in Physics. It investigates the patterns formed by the gastrovascular canals of the jellyfish Aurelia Aurita. The authors quantitatively show that significant variability exists in the pattern, including among clones sharing the same breeding conditions. They propose that this variability may be the signature of a physical instability. I wondered whether this argument could be made stronger. For instance, could variability have predictable statistical features—for instance in branch spacing, angles, or correlations—that would be a quantifiable signature of proposed instabilities? Finally, possible mechanisms for reconnections of new sprouts to younger canals are discussed, that notably consider the breakthrough mechanism proposed in Chapter 4, or a stiffness difference between younger and older canals.

Chapter 6 picks up on the possible mechanisms underlying canal growth in Aurelia Aurita. An elegant image analysis pipeline is presented to first segment the jellyfish body, then the canals. A systematic morphometric analysis is conducted using this segmented data (notably growth rate and density of canals along the radius). Two canal growth models starting from an initial trident configuration are then presented. The first model assumes that canal tip growth could be dictated by the local scalar stress (Von Misses). The biological relevance of this hypothesis could maybe have been discussed more. The second model assumes that tip growth could be dictated by the local gradient of the (Laplacian) pressure field. In both cases, growth pre-factors and canal sprouting frequencies from the rim are calibrated to match the average size and sprout density measured *in vivo*. Simulations show that for an adequate choice of parameters (moderate Young modulus ratio for the stress-based model, moderate viscosity ratio for the pressure-based model), both models can produce canal networks that resemble the ones observed in vivo. Given the strong formal constraints and the calibration, one could think that other models with different fields could yield similar results (including chemical signals sent by the canals, morphogen gradients, etc). In that context, it would have been interesting to discuss possible ways to experimentally rule out or validate some of these scenarios.

The manuscript has no general discussion/conclusion section. It was not an easy task given the diversity of topics, but I personally would have enjoyed seeing how the set of results presented in the thesis could be put into a broader context and perspective in the rapidly changing field of morphogenesis and biological morphogenesis.

Overall, the work presented by Stanisław Żukowski in his thesis manuscript is of outstanding quality. He brings significant contributions to the field of Laplacian growth and branching morphogenesis; and proposes a new take on the problem of looping in moving front instabilities. The diversity of problems and systems he tackled during his PhD —combining theory, simulations, and experiments—is impressive. This is not done at the expense of quality and consistency, and it is clear from his writing of papers and manuscript that he took the time and effort required to become an expert in each of the systems and methods used. Considering that they range from dissolution fronts to jellyfish morphogenesis, this is a great achievement. In addition, the PhD has been exceptionally productive, with three first author and one second author publications in high impact journals. For all these reasons, I highly recommend that Stanisław Żukowski should be allowed to defend his PhD, and that he should be considered for Summa Cum Laude during the defense.

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