An Interdisciplinary Approach to Morphogenesis

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A simple definition ?

Morphogenesis (*Oxford dictionary*)

1. *Biology* : The origin and development of morphological characteristics
2. *Geology* : The formation of landforms or other structures.

$\rightarrow$ *A well-defined notion ?*
... Or a scrambled-eggs basket ?

Research Question

[Bourgine and Lesne, 2010] : interdisciplinary workshop on morphogenesis

$\rightarrow$*To what extent the notion is indeed transdisciplinary, i.e. are there common definitions across disciplines ? What are the concepts shared or the divergence ?*

Method : Broad interdisciplinary review on its use or the use of related concepts ; extraction of fundamental concepts ; construction of a meta-framework

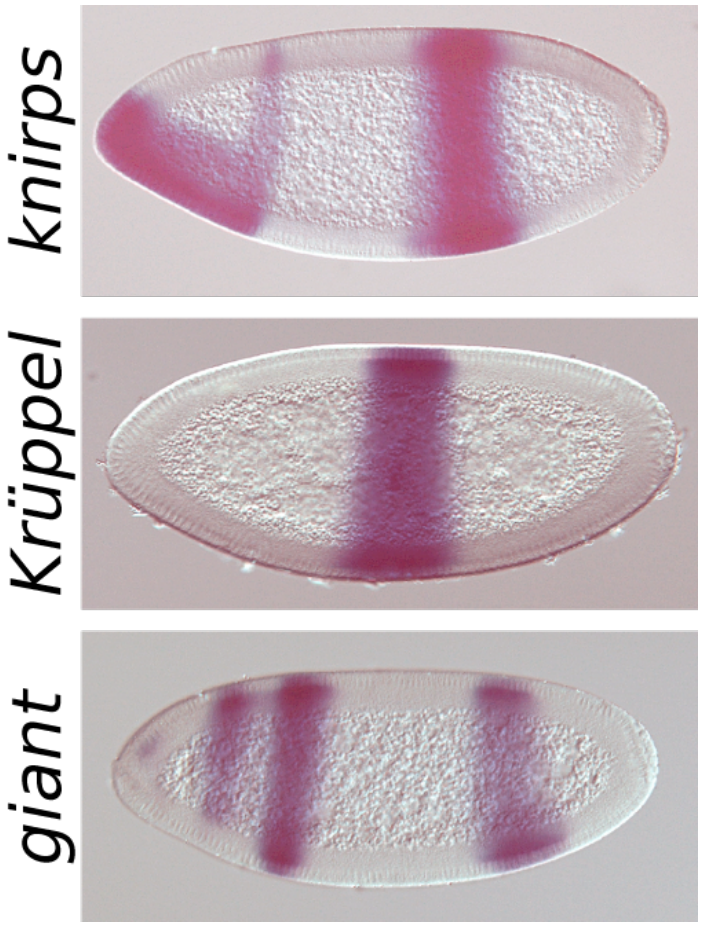
History of the notion

$\rightarrow$ Started significantly with embryology around 1930 [Abercrombie, 1977]

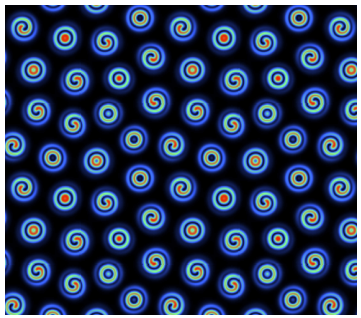
$\rightarrow$ Turing's 1952 paper [Turing, 1952], linked to the development of Cybernetics

$\rightarrow$ first use in 1871, large peak in usage between 1907-1909, increase until 1990, decrease until today. *Scientific fashion ?*

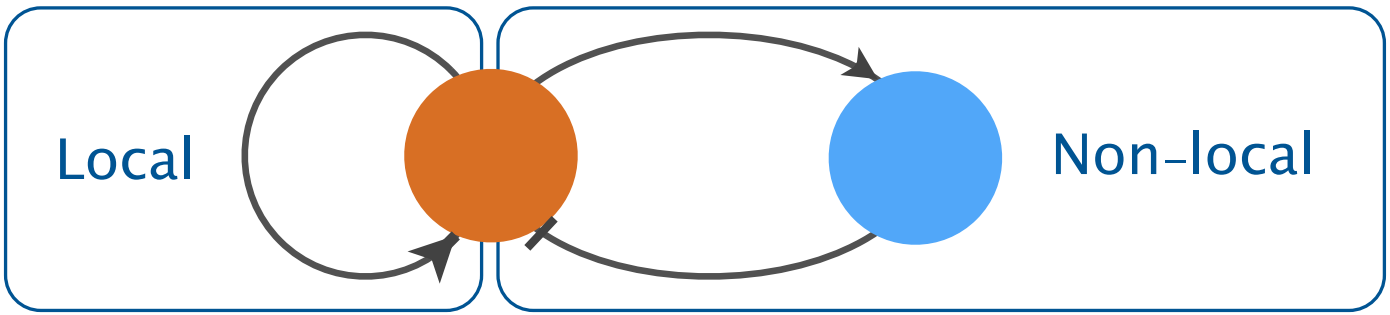
Patterns in biology



Turing mechanism explains various patterns



Alan Turing provided the theoretical starting point for pattern formation during morphogenesis in 1952.



Activation

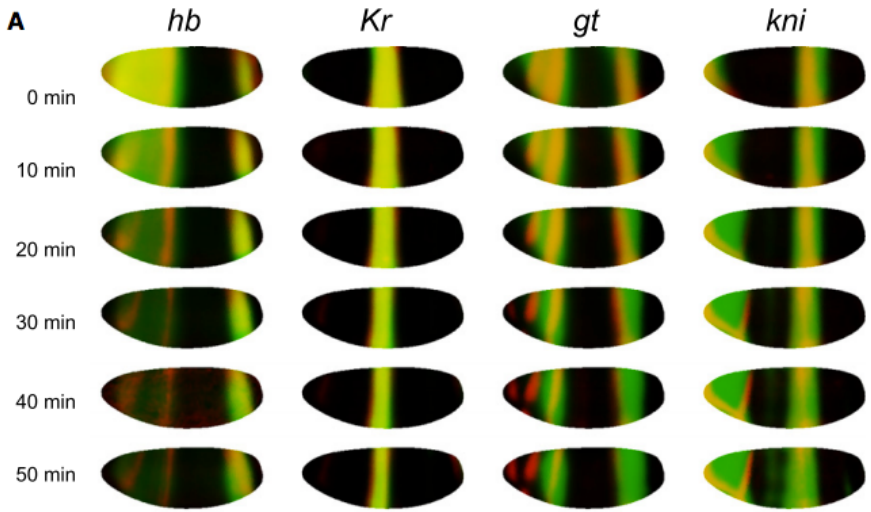
Inhibition

1. Local self-activation amplifies stochastic inhomogeneity

2. Locally produced inhibitor spreads out more quickly than the activator and therefore suppresses the activator further away from the peak.

Example: Drosophila segmentation and gap genes

Embryonic development in Drosophila



$$\frac{\partial}{\partial t} m_i(\vec{x},t) = f_i(p(\vec{x},t)) - \lambda_i^m m_i(\vec{x},t) + D_i^m \Delta_S m_i(\vec{x},t). \quad (1)$$

$$f_i(p(\vec{x},t)) = R_i^m g\left(\sum_{j=1}^{8} T^{ij} p_j(\vec{x},t) + h_i\right). \quad (2)$$

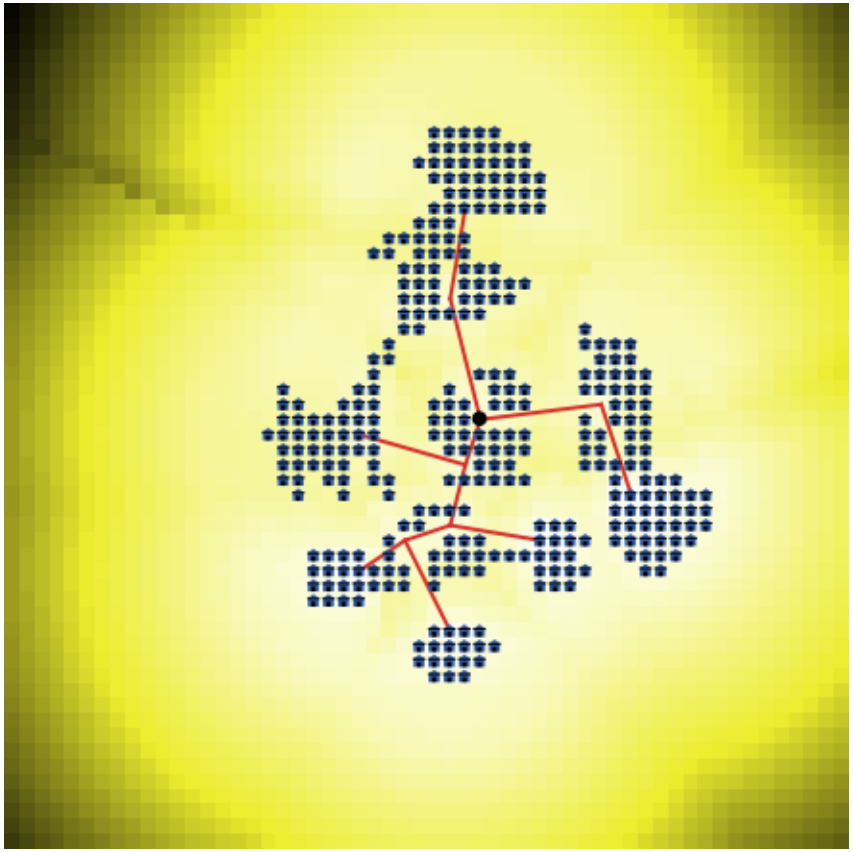
$$\frac{\partial}{\partial t} p_i(\vec{x},t) = R_i^p m_i(\vec{x},t) - \lambda_i^p p_i(\vec{x},t) + D_i^p \Delta_S p_i(\vec{x},t), \quad (3)$$

Bieler et al. (2011), Biophysical Journal

Example : urban geography

Simple model of urban morphogenesis in [Raimbault et al., 2014]

$\rightarrow$ local interactions captured by density feedback
$\rightarrow$ global position captured by network centrality feedback and accessibility to amenities

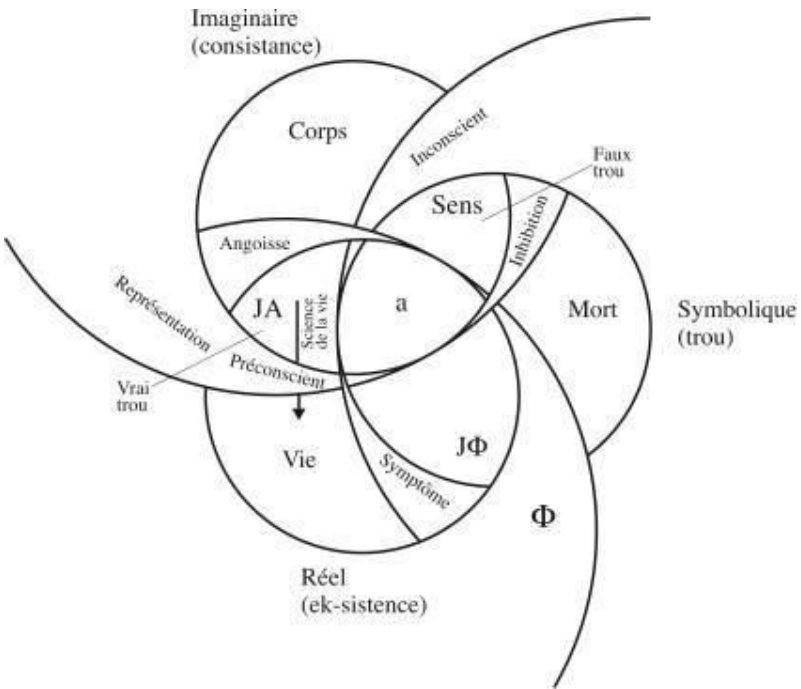


Example : psychology

→ A very powerful metaphor to conceptualize social change and the subject within it and processes like the relation to evolution of human cultural behavior and learning.
→ Useful in fields like: Neuroscience ; Evolutionary Psychology ; Social Psychology ; Clinical Psychology ; Psychopathology ; Psychoanalysis

Examples :

- Emergence of Psychical structures
- Self-organization of relational forms (the self and the other)
- Formation of the symptom
- Transference-Countertransference Matrix.



Overview

- **Biology**
  - External phenotype morphogenesis (ant colony) [Minter et al., 2012]
  - Symbiosis of species [Chapman and Margulis, 1998]
  - Botany [Lord, 1981]
- **Social Sciences** : Archeology [Renfrew, 1978]
- **Epistemology** : [Gilbert, 2003]
- **Artificial Intelligence** : From self-assembly to Morphogenetic Engineering [Doursat et al., 2013]. Synthetic Biology ?
- **Geomorphology** : dunes formation [Douady and Hersen, 2011]
- **Physics** : Arbotrons playing Tetris ?
- etc. . .

Concepts

- **Morphogenesis and Self-Organisation** : when does a system exhibit an architecture ? Insights from Morphogenetic Engineering [Doursat et al., 2013]. Architecture : the relation between the form and the function ?
- **Scales, Units and Boundaries** From local interactions to global information flow (Holland's signal and boundaries [Holland, 2012]: morphogenesis as the development of Complex Adaptive Systems ?)
- **Symmetry and Bifurcations** : on quantitative becoming qualitative. René Thom's theory of catastrophes [Thom, 1974]
- **Life and Death** : link with autopoiesis and cognition [Bourgine and Stewart, 2004] ; co-evolution of subsystems as an alternative definition ? In psychology, attractors of the mind.

Framework Proposition

Hierarchical imbrication of concepts :

Self-organization $\supsetneq$ Morphogenesis $\supsetneq$ Autopoiesis $\supsetneq$ Life

- Architecture links form and function [Doursat et al., 2013]
- Emergence strength [Bedau, 2002] diminishing with depth, whereas bifurcations increase [Thom, 1974]

Application : An ontological [Livet et al., 2010] specification yield a particular application (*inclusions and properties depends on disciplines*), but no direct equivalence of projected concepts [Bourgine and Lesne, 2010]. Different levels of falsifiability [Lakatos, 1976]

Perspectives

→ Main result for now : discrepancy of the concept across disciplines

→ Systematize the framework : iterative construction ; systematic comparison / update of concepts

→ Application to a concrete case to implement effective interdisciplinary transfer

→ Algorithmic Literature Review [Raimbault, 2016] and Text-mining complementary to the qualitative approach ; look for disciplinary proximity and level of interdisciplinarity

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