Introduction to Complex systems Science

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Introduction to Complex Systems Science

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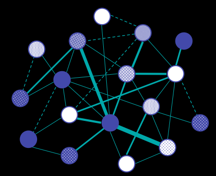
Les systèmes complexes

➢Nous sommes entourés de *systèmes complexes*



- un grand nombre d'**agents** élémentaires interagissant **localement**
- des comportements individuels locaux créant un comportement collectif **émergent**
- *une dynamique **décentralisée** sans plan/grand architecte*

✓ systèmes **physiques**, **biologiques**, **techno-sociaux**

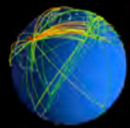
formation
de motifs
(= particule)

développement
animal
(= cellule)

cerveau
et cognition
(= neurone)

colonies
d'insectes
(= fourmi)

Internet
& Web
(= hôte/page)



réseaux
sociaux
(= individu)

Upward and Downward Causality

Everything being helped and helping, caused and causing, I consider as impossible to know the whole without knowing the parts and to know the parts without knowing the whole.

– **Pascal, *Pensées***

Multiscale Objects

- From Atoms to Condensed Matter
- From Molecules to Organisms - the «physiome» project
- From Neurotransmitter to Social Cognition
- From Individual to the Social
- From Organisms to Ecosphere
- ....

Transversal Questions

- Reconstruction of multiscale dynamics and emergent phenomena
- Robustness to perturbations
- Prevention & Resilience to «extreme» perturbations
- .....

Feuille de route – Entretiens de Cargèse 2006 et 2008

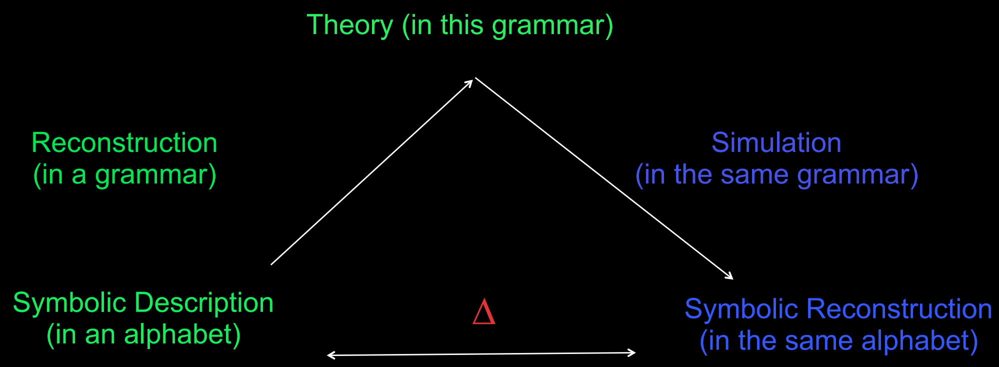
➢« Vers une science des systèmes complexes »

Grandes questions / Grands domaines	Nano/ Matière Complexe	Vivant / Ecosphère	Cognition / Web	Environnement / Climat	Homme / Société / Internet	……
Observation in vivo, in toto / Reconstruction et prédiction des dynamiques multi-échelles	Morpho-scale	E2C2, Embryomics Mechanical Induction, MORPHEX	E2C2	E2C2	E2C2, EVERGROW, DELIS, ERG 4, TiGrESS	
Grands réseaux interactifs / Comportements collectifs	STARFLAG	Plurigenes, BioEmergences, Mechanical Induction		STARFLAG	STARFLAG, ISCOM	
Robustesse, Prévention/ résilience distribuée/centralisée		PATRES, BioEmergences	PATRES	PATRES	PATRES, EVERGROW DELIS, TiGrESS, ISCOM, EVOTEST	
Conception de systèmes adaptatifs complexes		MesoBionics, SynBioTIC	MesoBionics, DEVOBOTS, CogniMorph	MesoBionics, EnergyWeb,	MesoBionics	
……						

First transversal question :

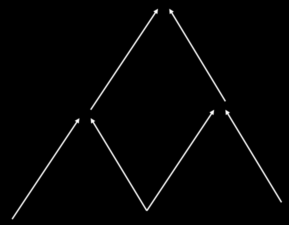
Observation & Reconstruction
of in vivo, in toto scale dynamics

Reconstruction as a Representation Principle



Reconstruction with deterministic formalisms

Turing Machine



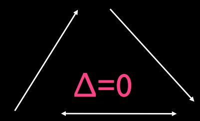
A Hierarchy of
Deterministic Grammars

Under-determination of
theories by the facts (Quine) :

Chaitin-Kolmogorov Complexity of a chain A : the length of the smallest program/theory T that reconstructs A (non constructive definition)

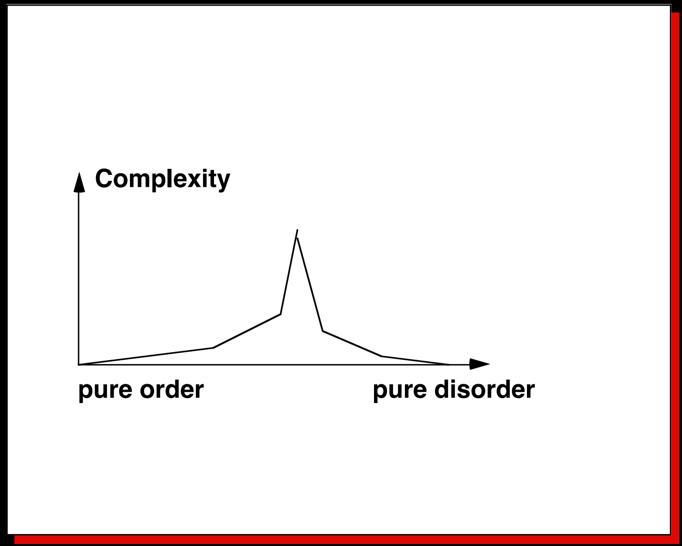
'small' theory T that reconstructs A (constructive)

Theory



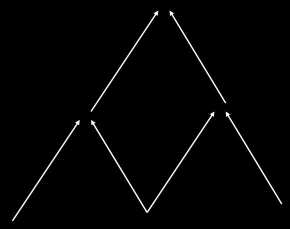
Description A Description B

A fundamental idea is that complexity arises between pure order and pure disorder



Reconstruction with stochastic formalisms

Bernouilly Machine



A Hierarchy of
Stochastic Grammars

A pure disorder : a long random series of 0/1

011001010010111....

1 b - Symbolic dynamics reconstruction

Markovian Representation Theorem

- Theorem (Knight 75) : Any (discrete) stochastic process can be represented as a Hidden Markov Model, i.e. a random function of a homogeneous markov process
- How to reconstruct the « ideal » HMM of a symbolic dynamics ?
  - = infinite chain ....AABCCBDA.................

Causal State

Crutchfield & Young, 89

- Consider the equivalence relation between past A and past B :

  A~B iff P(future|A) = P(future|B)

  - The equivalence class of A is said « a causal state » [A]
  - The « past » can be partitionned in « causal states » [A]

Optimal properties of causal states

Shalizi & Crutchfield 2001

- Theorem : the causal states are minimally sufficient and defines the minimal Hidden Markov Model
- Theorem : sufficiency for the whole future is equivalent to « next step » sufficiency AND recursivity : $s_{t+1}=F(s_t, x_{t+1})$

Mazurka 1

Mazurka 2

1 b - Phenomenological/Theoretical Multi-scale dynamics reconstruction

Principle of Exchangeability & Representation Theorems

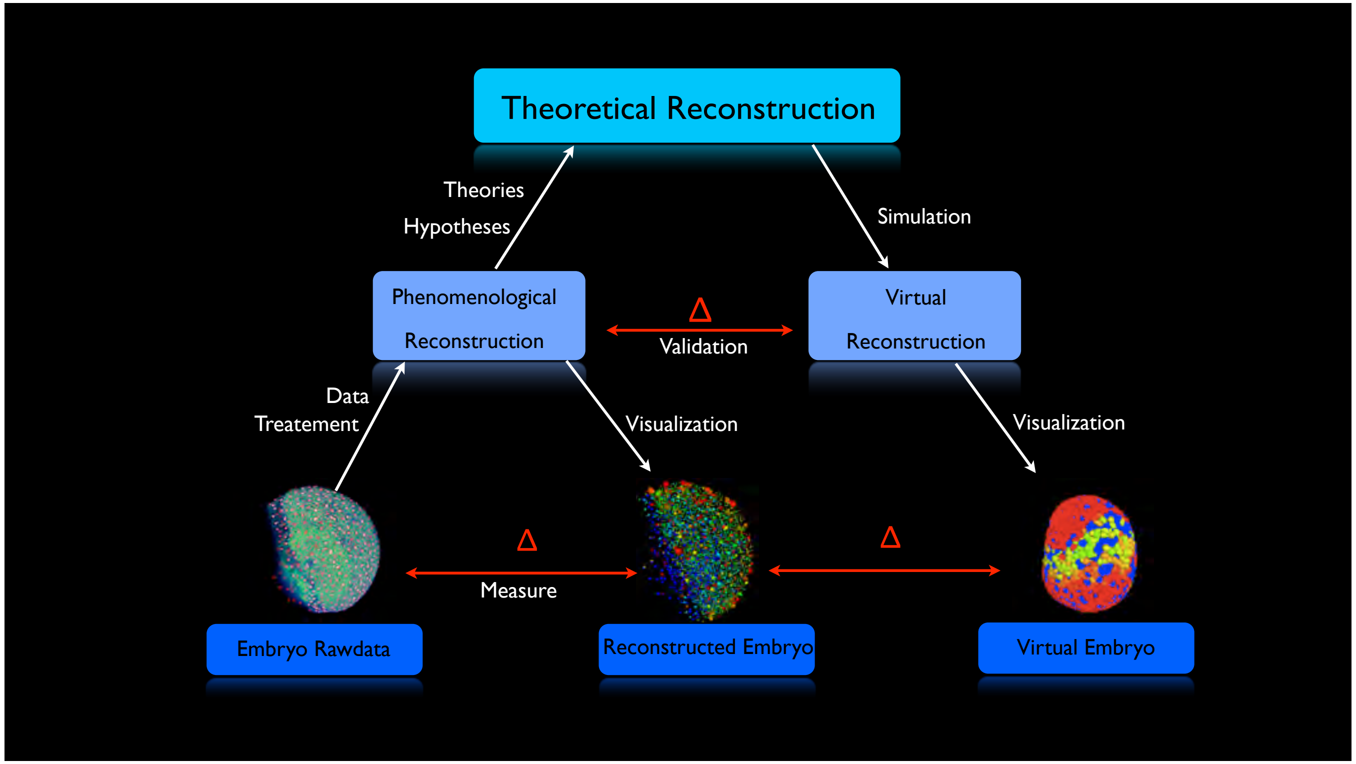
de Finetti

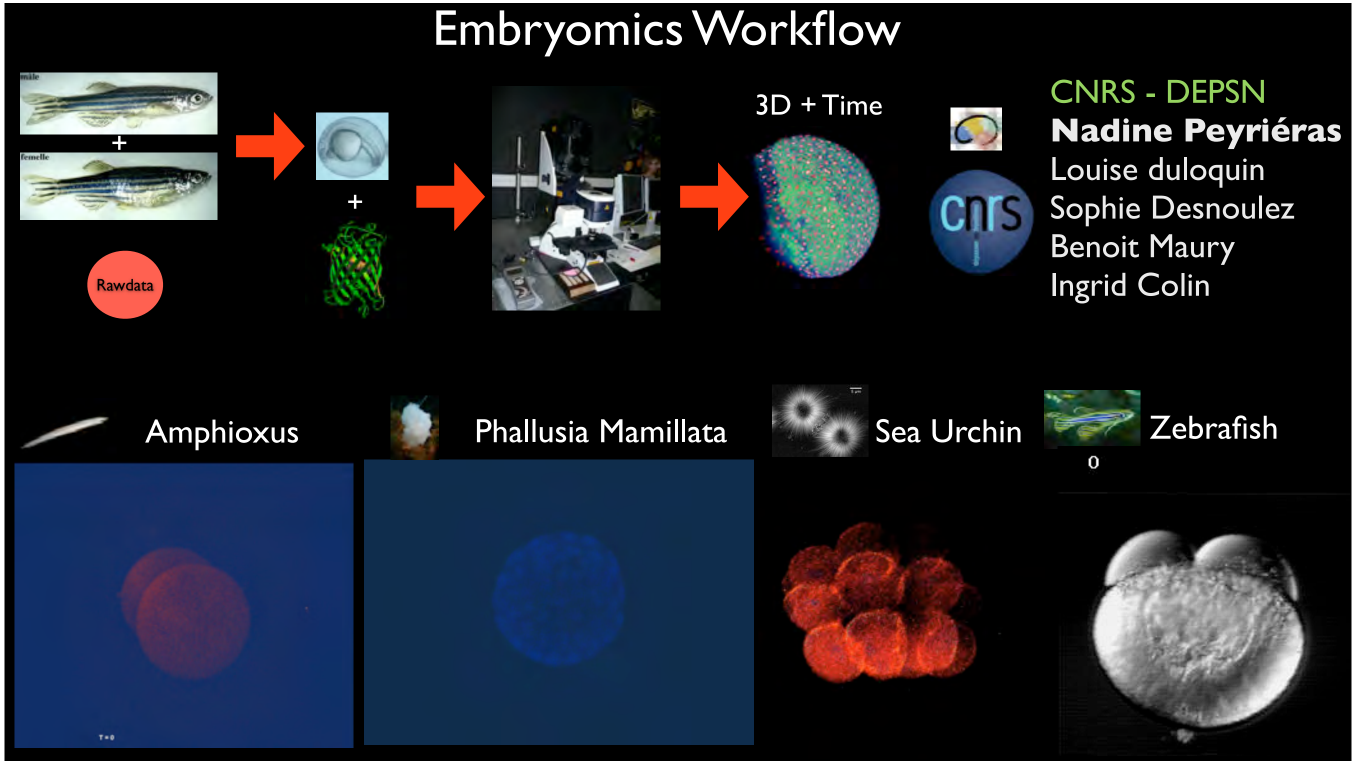
Theorem : If a series of data is exchangeable, all happen as if they are an *a priori* mixture of i.i.d variables. This *a priori* mixture converges to the empirical law

- X a Bernouilli variable {0,1} ; the mixture of i.i.d. Bernouilli laws converges to the empirical one. The minimal sufficient statistics is $(\sum x(i),n)$

- X a spherical random vector ; the mixture of i.i.d. normal law converges to the empirical one (resp. multivariate normal law if V.X spherical for all V)

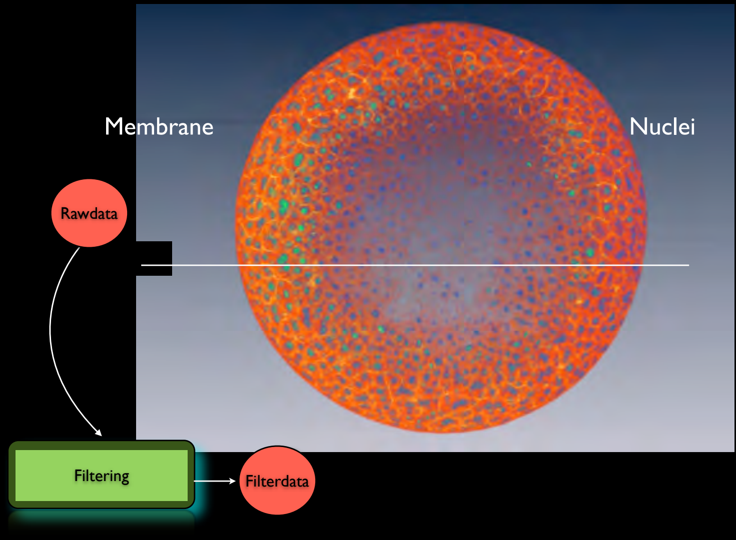
- X any random variable ; the mixture of i.i.d. law converges to the empirical law. The sufficient statistics is $(\sum \partial[x(i)],n)$


Theoretical Reconstruction
Theories
Hypotheses
Simulation
Phenomenological
Reconstruction
Δ
Validation
Virtual
Reconstruction
Data
Treatement
Visualization
Visualization
Δ
Measure
Δ
Embryo Rawdata
Reconstructed Embryo
Virtual Embryo



Four different animal models chosen for their phylogenetic position, accessibility, transparency but also their sequenced genome and availability of molecular tools

Embryomics Workflow

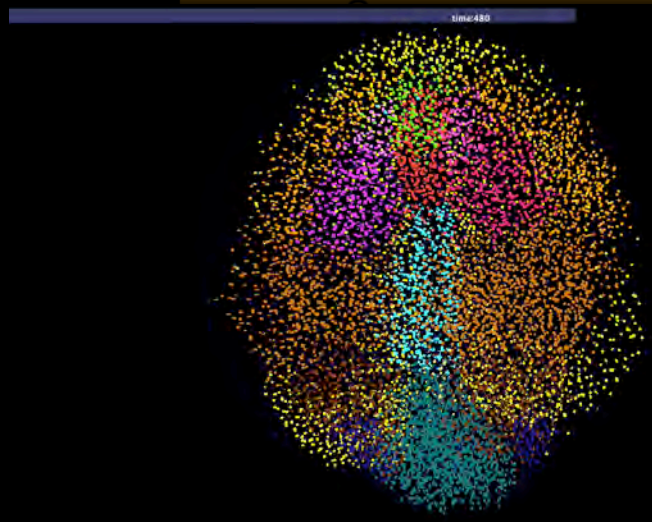


DMDG Bratislava
Karol Mikula
Robert Čunderlík
Olga Drblíková
Mariana Remešíkova

Filtering Methods :
- Perona Malik
- Mean Curvature Flow
- Geodesic Mean Curvature Flow
- Gradient Anisotropic Diffusion
- Twister Segment Filtering

Luengo-Oroz, M, **Faure, E,** Lombardot, B, & Sance, R. *Twister Segment Morphological Filtering. A New Method for Live Zebrafish Embryos.* Confocal Images. IEEE ICIP, Jan. 2007

Tracking and Visualization



Principle of Exchangeability & Macrodynamics reconstruction

Pb1 : given a new multimodal time lapse f(x,t), find the most probable v(x,t)

- Optical flow constraint : $\partial_t f - \partial_x f \, v = e1$

- Incompressibility : div (v) = e2

- Biomechanics : ∂_t rot v - nu Δ rot v =e3 and v=0 on the bundary ∂D

Pb1' : v^ = argmin P(v):=Integral(S1(x,t,x',t')e1(x,t)e1(x',t')+..)dxdtdx'dt' [under the hypothesis that e1,e2,e3 are multispherical with empirical spatiotemporal covariances S1,S2,S3 given by the exchangeable series of embryons]

Principle of Exchangeability & Microdynamics reconstruction

Pb2 : given the multimodal time lapse f(x,t) and the most probable v(x,t), find the most probable tracking and the morphogenetic fields.

- macroscopic laminar flow : vi(x,t) - v(x,t) = e4

- similarity of multimodal cell shapes : Hausdorff distance = e5

Pb2': Tracking^ = argmin ∑ ∑Si(x,t,x',t')ei(x,t)ei(x',t')) under the hypothesis that e1,e2,e3 are multispherical

Remark : given also the other macrodynamics : the division waves, the morphogenes reaction-diffusion patterns.

Theoretical Reconstruction

- Universalisation of macrodynamics. Examples :
  - Heat equation
  - Navier-Stockes Equations
- Morphogenetic (sub-)fields as resulting (up to a noise) from :
  - Biomechanics of cells
  - Reaction-Diffusion Processes of Morphogenes and molecules

Other transversal questions :

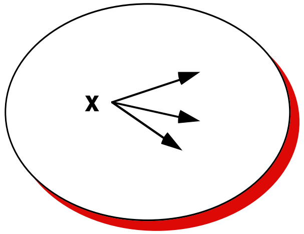
Prediction & Robustness,
Prevention & Resilience
of multi-scale dynamics

Prediction in Probability

- The question is not to predict what WILL happen but what CAN happen (Ilya Prigogine)
- Example of Stochastic Differential Equation & Fokker Planck Equation
  - SDE : $dY(t) = a(Y,t)\, dt + b(Y,t)\, dW(t)$
  - FPE : $\partial p(y,t)/\partial t = - \mathrm{div}\,(p\, a) + \mathrm{div}\,(\mathrm{div}\,(p\, d))$ with $d = b_t b$
- Stationnary state in probability (around the dynamic stationnary state)

Viability Theory

J.P. Aubin



$x'(t) \in g(x(t))$

g = differential inclusion

After discretization:

$x(t+1) \in f(x(t))$

K = viability domain

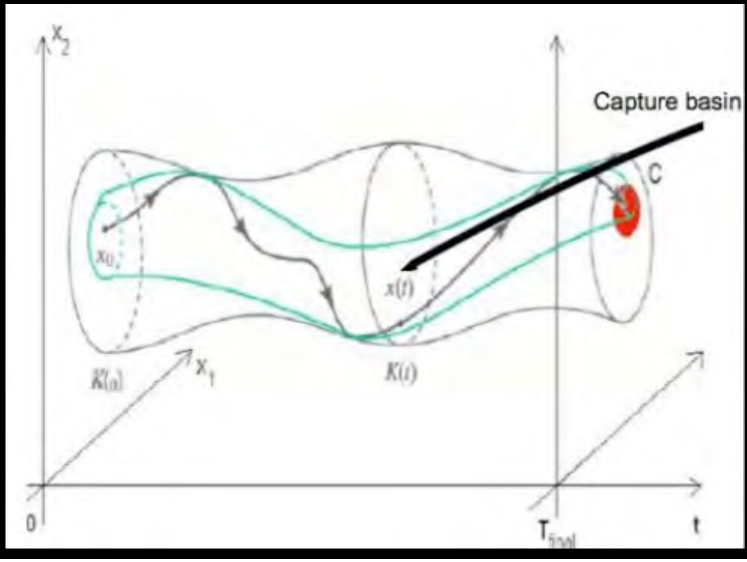
K is known :

- $\forall x \in K,\ f(x) \cap K \neq \emptyset$
- $\forall x \in K, \exists$ a viable trajectory

K is not known :

- $x \in K,\ K \supset f(x)$
- $\forall x \in K, \forall$ trajectory including x is viable

Viability tube and Capture basin



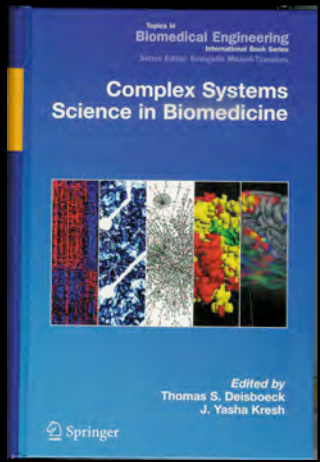
Integrated Model

- Random autonomous system (endogeneous, controlling its boundary conditions) as a random multiscale dynamical system with
  - exchangeable series of sufficient statistics at the different scales
  - each one representable as a mixture of i.i.d distribution
  - including observations of humans actions : preventive, resilient
- What is the best integrated model given all the multi-scale data & the best preventive/resilient strategies ?

Complex Systems
Digital Campus
~ CS-DC ~

Complex Systems Digital Institute
CS-DI : Toward integrated models

Complex Systems Digital University
CS-DC : Toward integrated knowledge



« The task is not so much to see what no one yet has seen,

But to think what

nobody yet has thought about that which everybody sees »

- Schopenhauer

Thanks !