A Geometry of Biological and Cognitive Time

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Francis Bailly, Giuseppe Longo, Maël Montévil. *A 2-dimensional Geometry for Biological Time*, (**Progress in Biophysics and Molecular Biology**, *to appear*).

Giuseppe Longo, Maël Montévil. *Protention and retention in biological systems,* (submitted for publication).

Methodological (and logical) premises

Physical vs. Biological Theories
in Bailly-Longo three (correlated) approaches:

Theoretical **extensions** (in the sense of Logic) of physical theories

Physical vs. Biological *Theories*

Ontological *vs.* **Theoretical** issue.

What about considering ***extensions*** of Physical Theories by *proper observables?*

- Extended criticality
- Levels of biological organization
- Various forms of irreversibility of time (+ a two dimensional time)

Reduction to the physical (sub-)theories? Why not …

In Physics:

unification (Newton vs Galileo; Thermodynamics (limit); Relativity/QM …)

Question: "**conservative" extension** (in the sense of Logic) **?**

Physical vs. Biological Theories
in Bailly-Longo three (correlated) approaches:

1 - ***extended*** **criticality** *(a physical oxymore),* **JBS**, 16, 2, 2008.

2 - **organization** (a new observable) as **anti-entropy**, **JBS**, 17, 1, 2009.

3 - **extra (irreversible) time** and **two dimensional time** *(not linear time),* ongoing, with M. **Montévil** (*this lecture*)

Common point to the approaches in 1, 2 and 3:

Strict "Consistent" **extensions**, in the sense of Logic,

compatible with current physical theories, *but not necessarely reducible:*

1: contract the extension of criticality *(from interval to point);*

2: "=" instead of "≤" in balance equations *(anti-entropy goes to 0)*;

3: collapse the extra dimension *(a time bifurcation).*

Question: are they "conservative"?

CONSERVATIVE (?) EXTENSIONS

Examples from **Logic**: $T \subset T'$ = T+NewAxiom (T' *extends* T)

Formal Arithmetic (PA)

1. **PA + König's Lemma** (any *infinite*, finitely branching tree has an infinite branch) is a ***strict***, ***conservative*** extension: it proves more on infinite trees, but no more *arithmetic* statements.

2. **PA + Axiom of infinity = Set Theory** (Set)

is a ***strict***, ***non-conservative*** extension of PA, since Gödel '31:

an axiom of **infinity** allows to prove Consistency of PA (*Coher*).

Hilbert's *wrong conjecture:*

Set is conservative over PA (thus, PA $\vdash$ *Coher*)

CONSERVATIVE (?) EXTENSIONS

In **Biology**:

1. Preparata, del Giudice (1995-7): **Water coherence domains** (in phase oscillations of molecules of water) in **cells**: derivable from enclosure of water in *organisms* (10^{14} cells) and *Quantum ED*. ***Strict, conservative extension***.

2. Biot - Pasteur: **asymmetry in chirality** of (levo-)tartaric acid.

So far, no *physical* explanation: ***non-conservative extension*** needed ?

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So far, no *physical* explanation: ***non-conservative extension*** needed ?

Our theoretical attempts: ***strict, conservative*** (?; add new observables):

1 - ***extended*** **criticality** *(a physical oxymore),* **JBS**, 16, 2, 2008.

2 - **organization** or complexity as **anti-entropy**, **JBS**, 17, 1, 2009.

3 - **extra (irreversible) time** and **two dimensional time** (this talk)

Biological and cognitive extensions of physical time

One dimension, three forms of time

Different observables

(*same dimension*; e.g. in Physics, Energy, *free* vs. *potential*)

1. **thermodynamical** time (***physical*** irreversibility)

2. time of the **constitution of biological order**
   (Evolution, embryogenesis: proper ***biological*** irreversibility)

3. **cognitive** time (retention *and* protention : ***cognitive***
   irreversibility, by an asymmetry; Part I, here)

Part II: **two dimensional time**

More on the first form of time (thermodynamics)
a debate: physics vs. biology

1. **thermodynamical** time (*physical* irreversibility): entropy as
   - **1.1** energy dispersal (*not necessarely* disorder, in ***physics***)
   - **1.2** energy dispersal *implies* disorder in ***biology***

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"*in physics, a lowered energy state is not necessarily disorder, because it simply results in the identical molecule with a lowered energy state. The fact that such a molecule might be biologically inactive may not concern the physicist, but it definitely does concern the biologist ….*" (Hayflick , 2007)

More on the second form of time
(biology)

2. time of the **constitution of biological order**

(Evolution, embryogenesis: proper *biological* irreversibility)

Mytosis, per se, *increases order,* yet*:*

- it is *never an identical reproduction* (at least non-identity of proteomes and membranes);
- it induces *an unequal diffusion of energy*.

Thus, biological reproduction, as morphogenesis, is *intrinsically joint to variability* and, *thus, it produces entropy also by lack of (perfect) symmetries.* By this, it induces *its proper irreversibility*, beyond (and in addition to) thermodynamics.

(cf. a computers' production: *reversibility* and *iteratability* …)

An ongoing project …

Part I: **retention** *and* **protention**

or

“***memory***” *and* “***expectation***”
in terms of **characteristic** time

Learning as "***memory***" (retention) and **preparing action** as "***expectation***" (protention)

Usually (and informally) analysed as *conscious activities*

Extend to *pre-conscious* activites

(e.g.: paramecium, [Mislin, 2004])

Retention and **protention**, *in humans*:

e.g.: retention of a *note,* in music, or of the beginning of a word or a sentence;

protention as expected ending, towards meaning and *action*.

Compatible with, but beyond Husserl: pre-conscious

Brain: **«un comparateur projectif»**

[Berthoz-Petit, 2006]

Example of **protention** :

« the **anticipating** deplacement of neurons' receptif fields *before* saccades » p. 70

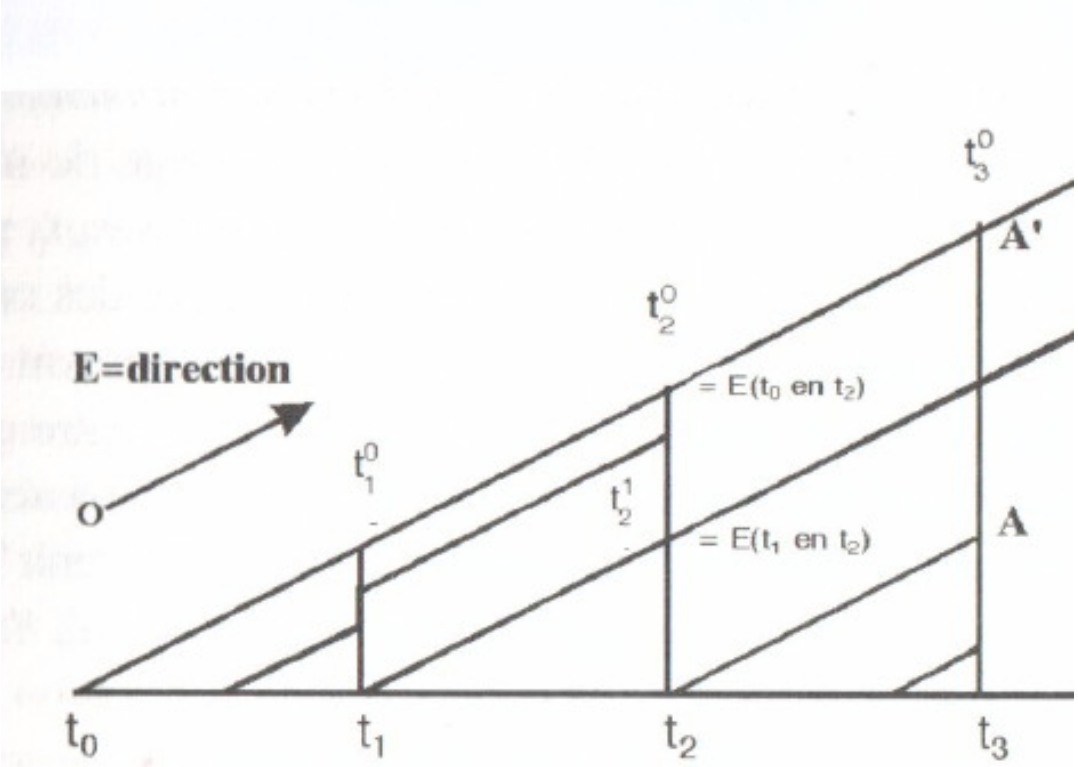
Protention as « a fundamental property of the organism equiped with a neural system » p. 78

Active *constitution* of **reality itself** as « an anticipatory constitution » p. 75

Husserl's analysis

(Phenomenology of intimate consciousness of time, 1893 - 1917)

Retention: consciousness of past events, as ***linear*** traces:



Protention: Intentionality (no mathematical representation)

Retention *and* **Protention**
in terms of **characteristic** time

Towards “biological inertia”

A conceptual frame

VERY SIMPLE MATHEMATICS,
BUT JUST MATHEMATICS

Premise: on the role of **time** in the ***structural coherence*** and ***stability*** of a living unity

I. Correlation Length and **Characteristic Time**

II. Biological Rhythms

Characteristic Times and **Correlation Lengths**

Large organisms: ***propagation*** *within an organism*

Speed: v_p

Correlation length: $L_p = v_p\tau$ (τ, characteristic time)

(e.g.: propagation from/by lungs-blood)

Small organisms: ***diffusion*** *within an organism*

$L_d = (D\tau)^{1/2}$, with D diffusion coefficient

(e.g.: diffusion by trachea in insects)

Scaling of characteristic time: $\tau \approx W^{1/4}$ (empirical evidence)

Thus: $\mathbf{L_p \approx W_f^{1/4}}$ and $\mathbf{L_d \approx W_f^{1/8}}$ *(W is a mass)*

Tools: exponential relaxation times

Relaxation functions f :

from Physics: “going back” to an equilibrium f_e

at speed: $df/dt \approx |f - f_e| / \tau$.

Where τ is a **characteristic time**

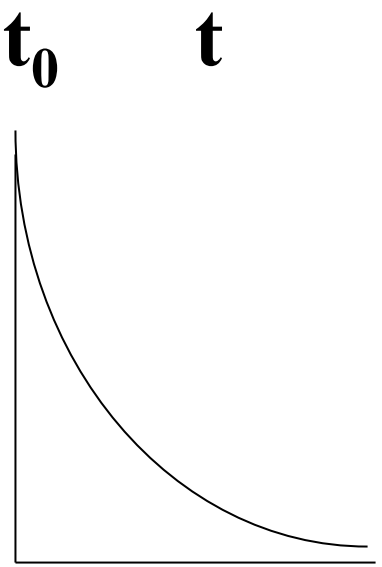
Form: $f(t) \approx \mathbf{a_c exp(t_e - t)/\tau}$

Aim of Part I:

define (mathematically) **a “biological inertia”.**

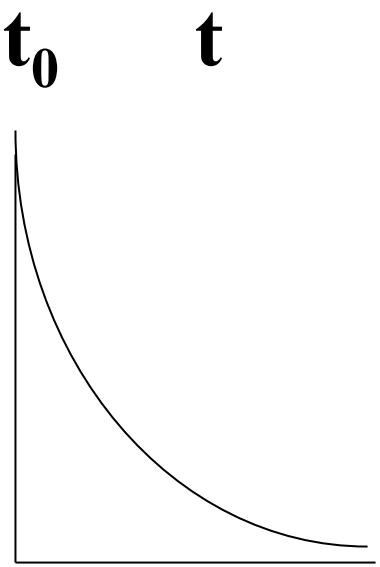
Retention *and* (Virtual) Protention :

$R(t,t_0) = \mathbf{a_R exp(t_0-t)/\tau_R}$



Retention *and* (Virtual) Protention :

$R(t,t_0) = \mathbf{a_R exp(t_0-t)/\tau_R}$ $\quad$ $P(t,t_1) =$ **?**



Retention *and* (Virtual) Protention : by ***symmetry*** (first try)

$R(t,t_0) = \mathbf{a_R exp(t_0-t)/\tau_R}$ $\quad$ $P(t,t_1) = \mathbf{a_P exp(t-t_1)/\tau_P}$

$\mathbf{t_0}$ $\quad$ $\mathbf{t}$ $\quad\quad$ $\mathbf{t}$ $\quad\quad$ $\mathbf{t_1}$

Retention / Protention
definitions

Retention:

$R_k(t,t_0)$ at *instant* $t \geq t_0$ of *event* e of *nature* k

Protention (to be split: *virtual* and protention *capacity*):

(virtual) $P_k(t,t_1)$ at *instant* $t \leq t_1$ (it will be defined by symmetry)
(capacity) $C_P(t,t_0,t_1)$ **depending on R**

Principles:

$C_P(R_k,t,t_1) = 0$, when $R_k = 0$

no protention without retention;

$\partial P_k/\partial R_k \geq 0$

protention increases w.r.to retention

Retention / Protention: specifications by *relaxation functions*

Time interval $[t_0 \le t \le t_1]$

Retention:

$$R(t,t_0) = a_R \exp(t_0 - t)/\tau_R$$

(Virtual) Protention *by symmetry* :

$$P(t,t_1) = a_P \exp(t - t_1)/\tau_P$$ *(an adjusted **symmetry** w.r.t. relaxation: sign(t) changes, decreasing* $|t - t_1|$ *)*

No protention without retention: Protention (Capacity):

$$C_P(t,t_0,t_1) = R(t,t_0)P(t,t_1)$$ (thus linear in R and P)

$$= a_P a_R \exp[(t_0 - t)/\tau_R] \exp[(t - t_1)/\tau_P]$$

Protention Capacity C_P

From

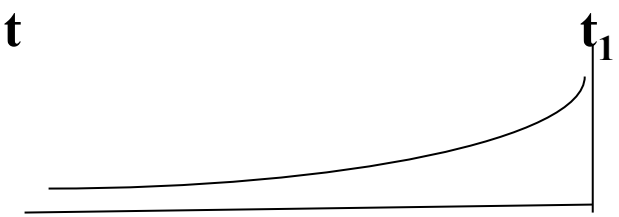
$$C_P(t,t_0,t_1) = a_P a_R \exp[(t_0-t)/\tau_R]\{\exp[(t-t_1)/\tau_P]\}$$

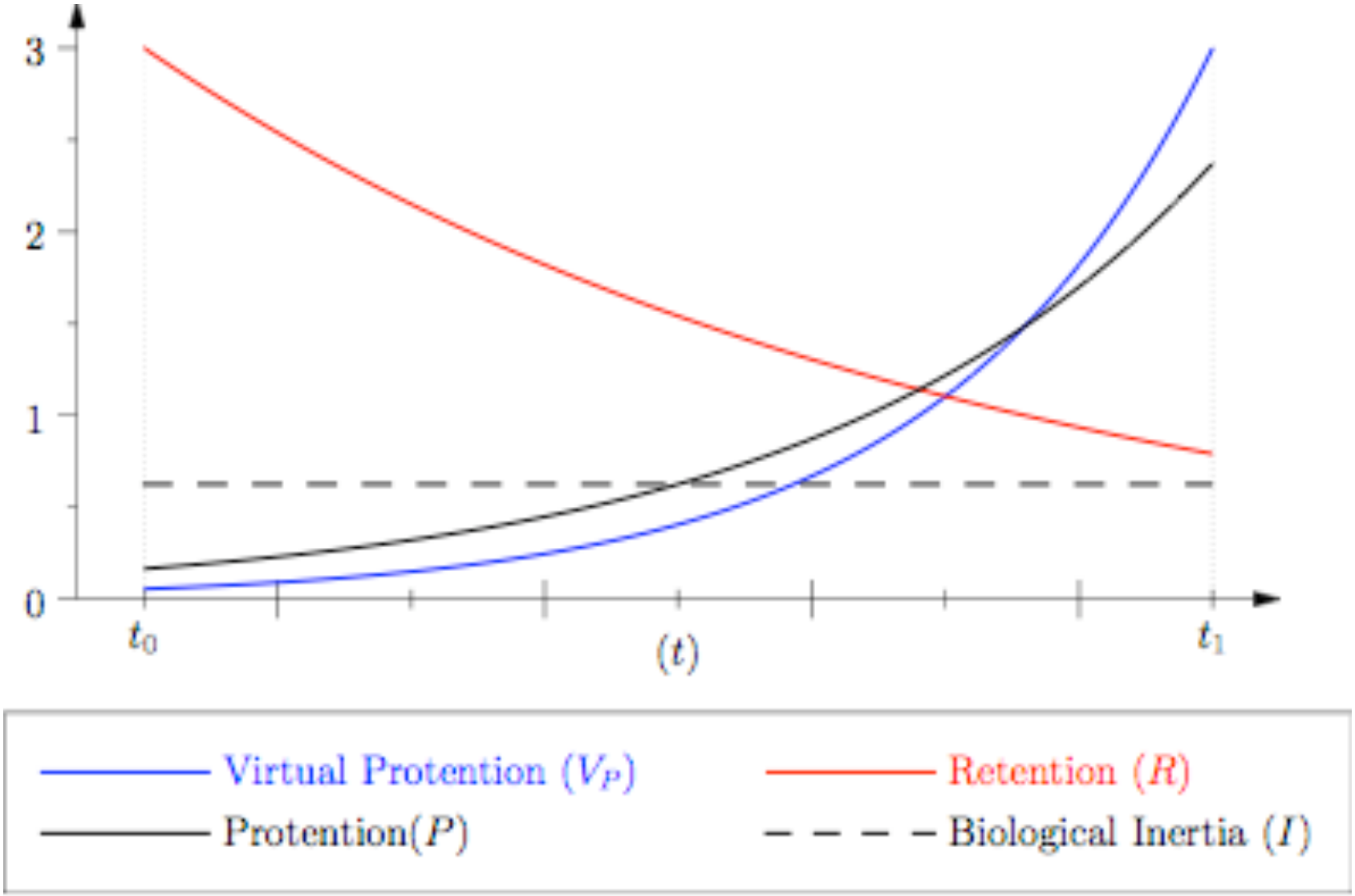
compute:

$$C_P = \{a_R a_P \exp[(t_0\tau_P - t_1\tau_R)/\tau_R\tau_P]\}\exp[t(\tau_R - \tau_P)/\tau_R\tau_P]$$

(just one factor with time t dependency)

Maths Plot: fig. 1




3
2
1
0
t_0
(t)
t_1
Virtual Protention (V_P)
Retention (R)
Protention(P)
Biological Inertia (I)

Biological Inertia

In

$$C_P = \{\mathbf{a_R a_P exp[(t_0\tau_P - t_1\tau_R)/\tau_R\tau_P]}\}\exp[t(\tau_R - \tau_P)/\ \tau_R\tau_P]$$

Extract the coefficient:

Inertia: $\mathbf{I(t_0,t_1) = a_R a_P exp[(t_0\tau_P - t_1\tau_R)/\tau_R\tau_P]}$

$\mathbf{I(t_0,t_1)}$ "contributes" to protention (a coefficient):

$$\mathbf{C_P = I(t_0,t_1)}\exp[t(\tau_R - \tau_P)/\ \tau_R\tau_P]$$

Biological meaning: *inertia as a coefficient of Protention, depending on Retention* (from Paramecium to … Man).

An analysis: $\mathbf{I(t_0,t_1) = a_R a_P \exp[(t_0\tau_P - t_1\tau_R)/\tau_R\tau_P]}$

Assume $\tau_R = \tau_P = \tau_c$:

$$C_P = a_P a_R \exp[t(\tau_R - \tau_P)/\tau_R\tau_P] \exp[(t_0\tau_P - t_1\tau_R)/\tau_R\tau_P]\}$$

$$= a_R a_P \exp[(t_0 - t_1)/\tau_c] = \mathbf{I(t_0,t_1)}$$

Thus, $C_P = I(t_0,t_1)$ *and*

C_P assumes its least value as a function of $(\tau_R - \tau_P) \geq 0$

Comment: when $\tau_R = \tau_P$, **Protention** and **Inertia** *coincide*,

as Inertia is the key component of Protention, which increases only depending on increasing $(\tau_R - \tau_P)$ (cognitive complexity)

Previous hints on biological inertia

Vaz, **Varela**, 1978: « the lymphoid system has an *inertia*, which resists attempts to induce sudden and profound deviations in the course of events ».

(a weak notion: sort of persisting structural stability)

Edelman, **Tononi**, 2000: « dynamic core »

(continualy maintained activity, independently of stimuli)

Varela, 1997: «inertia as… bringing forth of an identity »

(stronger: it concerns the entire organism, its individual variability, yet with continuity)

For us: **Inertia is the coefficient of protention** (capacity)

From the spatialisation of time
to the *time continuity* of space

From the spatialisation of time *to* the time *continuity* of space

(Physical) space-time ?

Thesis: No **continuous *pre-given*** frame

We conceptually (mathematically) reconstruct a continuous frame *from*

the continuity of trajectories (borders…)

as actions (saccades, mouvement…)

As a result of “glueing” (le “recollement”) of

retention and ***protention***

e.g.: a trajectory *is* continuous as we “glue toghether” the “memorized” part and the “expected continuation”.

Part II: Rhythms of Life
or
a two dimensional time

Spatialisation of time in Physics

- **Simple geometries:**

1. **Linear** (absolute) **time**: the Cantor real line
2. **Oriented** Line (thermodynamics): an arrow along Cantor's reals

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H. Weyl's phenomenological critique of "Cantorian" time

[Das Kontinuum, 1918]:

the extended present, no analytic treatment with "individual" points

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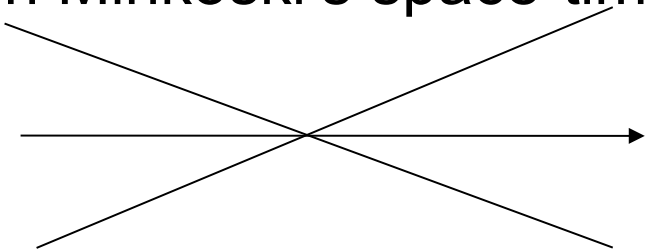
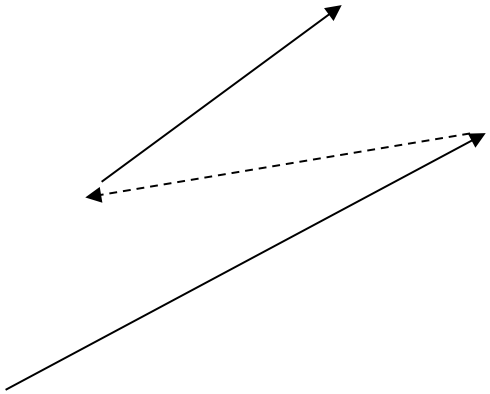
- **Relativistic** time in Minkoski's space-time:



- **Feynmann's** "zig-zag" time:



Particle anti-particle creation

Biological Time and Rhythms

(an introduction)

Physics: central role of

- ***Energy*** (from Galileo's inertia to QP energy spectrum)
- ***Invariants*** (geodesics and conservation, as *invariants* of physical determination, w.r. to ***transformations***, e.g. symmetries)
- ***Major physical constants***: G, c, h…. (dimensional!)
- ***Time:*** *an "epiphenomenon"* of movement (Aristotle, Newton…)

Biology: Conceptual priority of

- ***Organisation***
- ***Time***, as observable (an "**operator**"?):

  1. External-physical rhythms

  2. Internal rhythms (derived from non-dimensional values: major ***constant***; an orthogonal dimension w.r.to physical time)

Biological Rhythms

1. ***External-physical*** rhythms (**Ext**: periods or physical frequencies):

   dimensional: s, Hz… exp(iωt): daylight, seasons…)

2. ***Internal rhythms*** (**Int**: physiological functions):
   - *non-dimensional*: heart beats, respiration, metabolic rhythms… **b** ≈ 1.2×10^9 , **r** ≈ 0.8×10^9 in mammals;
   - *pure numbers*: they *produce* time scales as a function of the mass, e.g. LifeTime ≈ $W^{1/4}$

Geometric scheme for *two* dimensional Biological Time

0. **Thermodynamical oriented time t:** the horizontal axis -------> t

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   Internal rhythms (Int): physiological functions

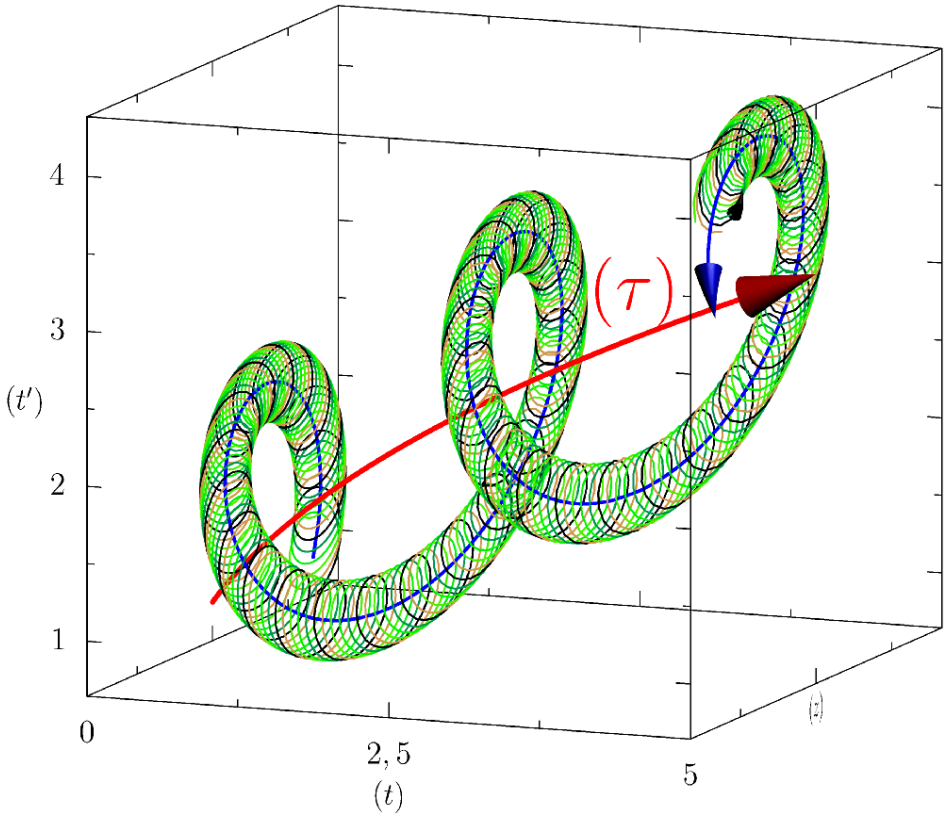
Their product:

R

Taking into account also **External** Rhythms

(Bailly, Longo, Montevil, 2010)

1. **Ext**: Day/Night…
2. **Int**: heart beats, respiratory … (+ the internal “trace” of Day/Night)



Some applications…

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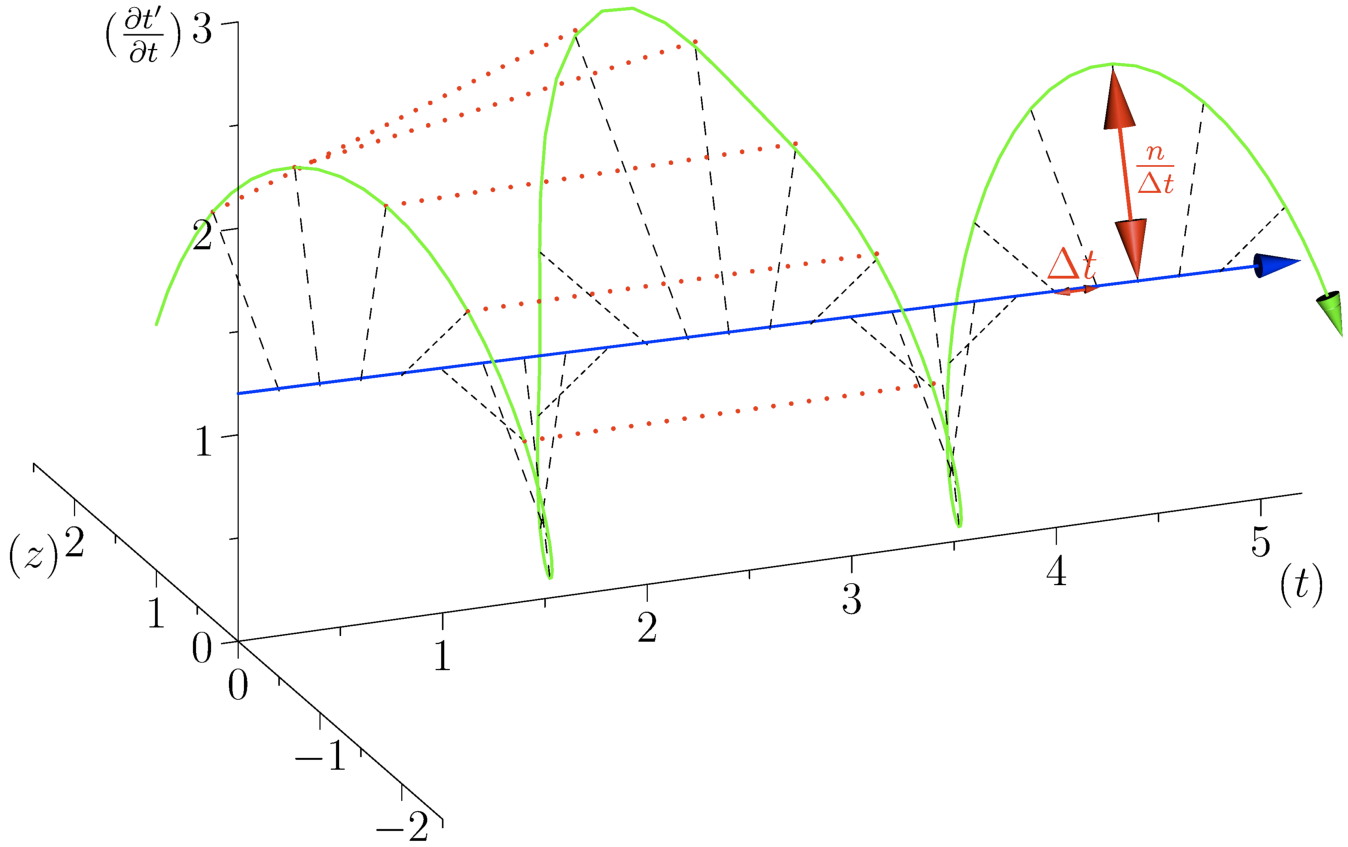
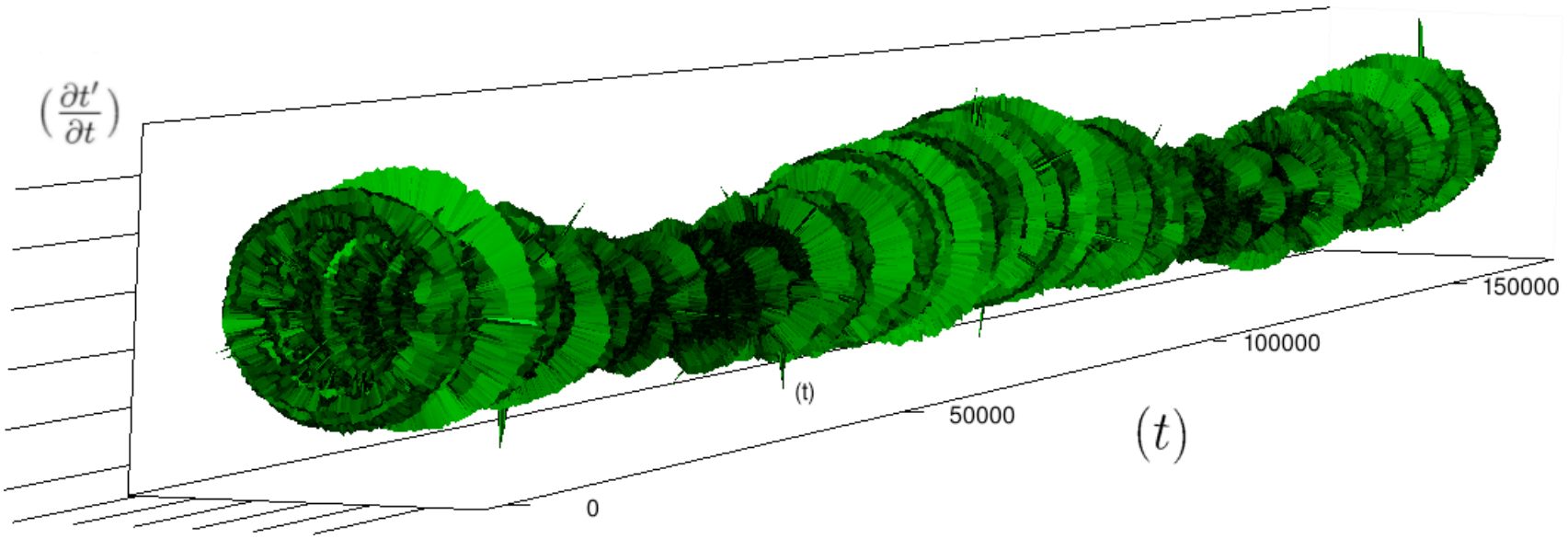
Ideas: **enlarge** at constant speed (and **renormalize**)

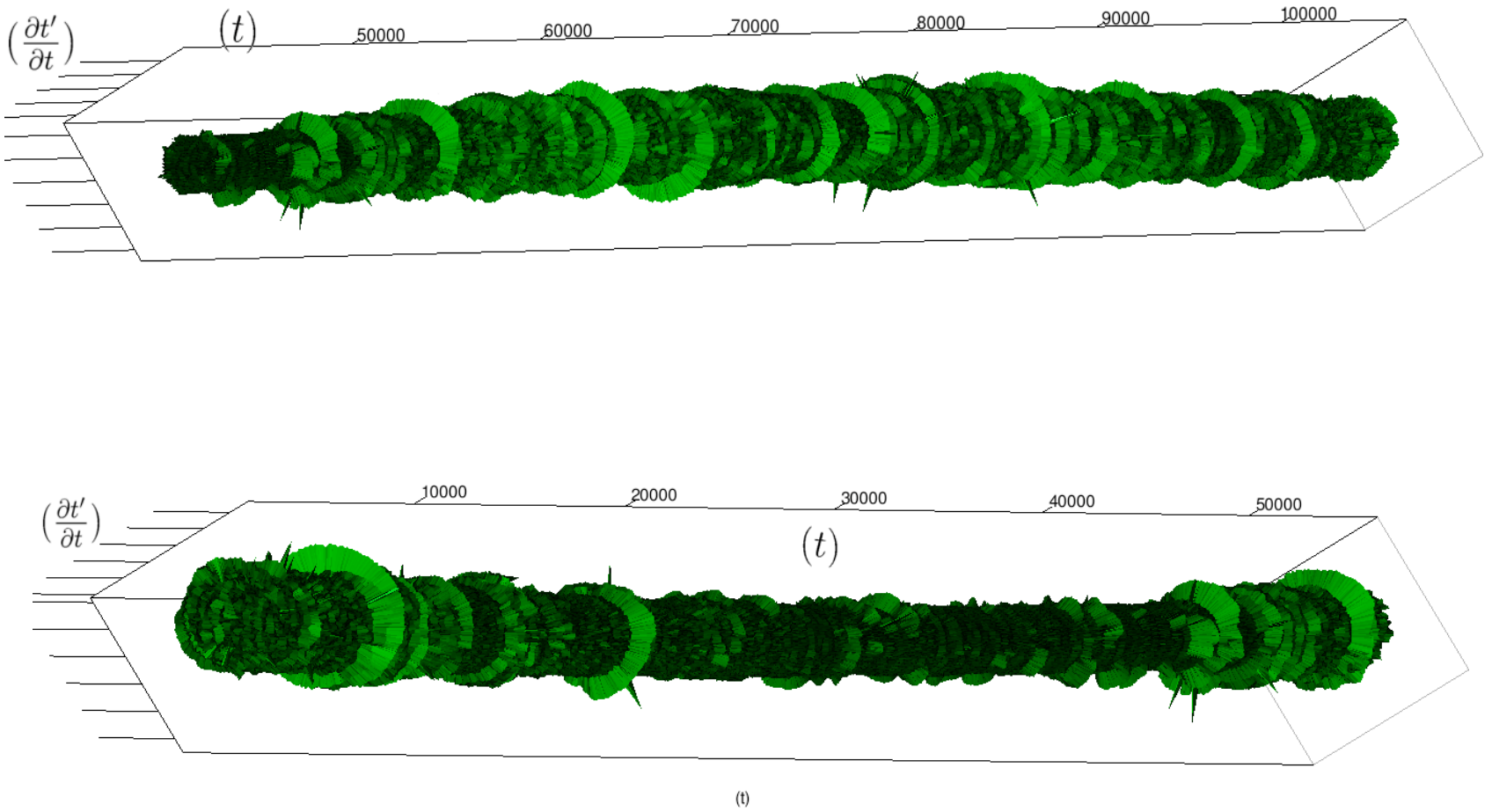


Cardiac Rhythm: **two days**

Sample s20011 from The Long-Term ST Database, [13]



Cardiac Rhythm: ***day*** vs. ***night*** (200 beats per circle)



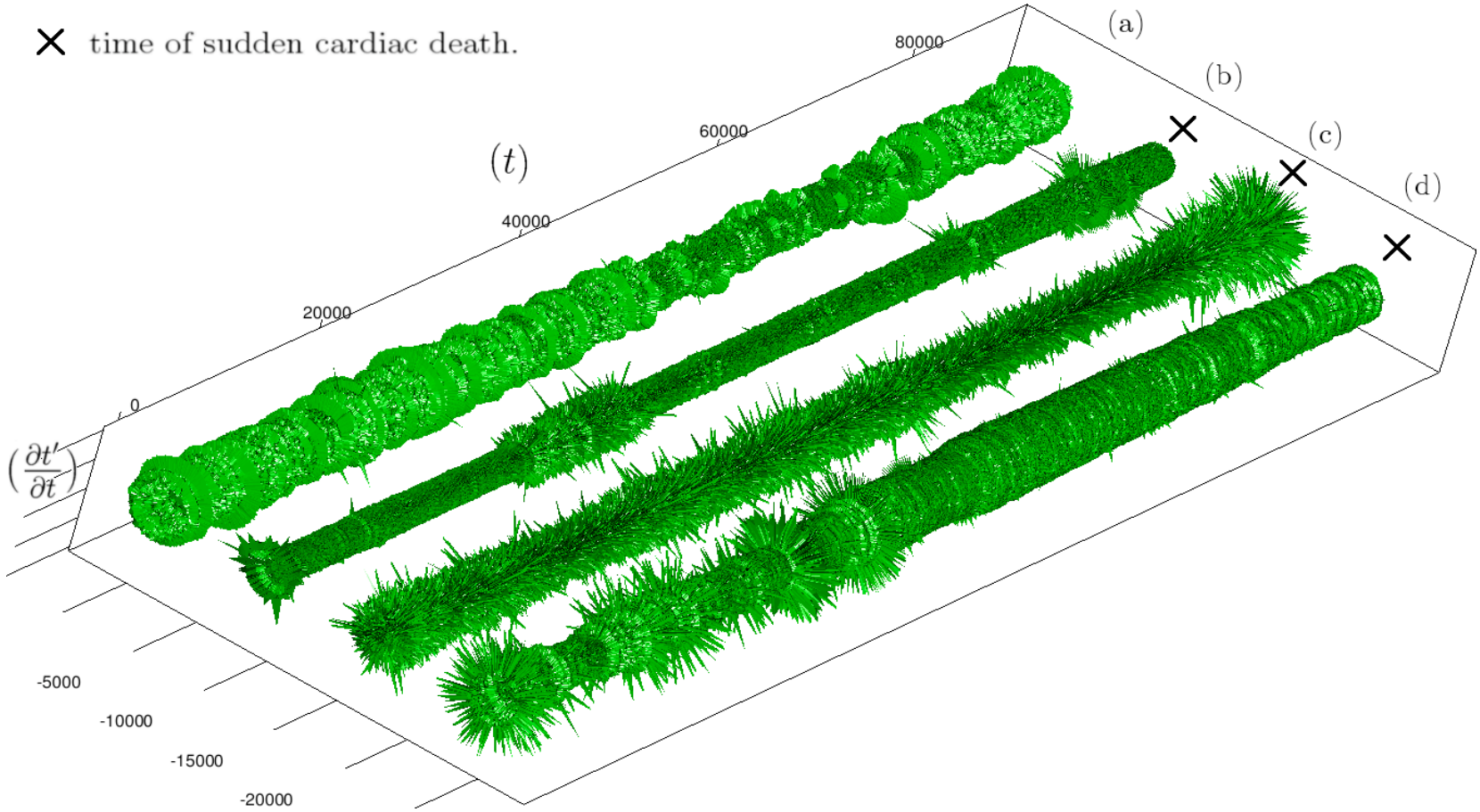
Comparison (sudden cardiac death): (a) Healthy case,

(b) Female aged 67 with sinus rhythm and intermittent pacing.

(c) Female, 72, with atrial fibrillation.

(d) Male, 43, with sinus rhythm.

Data from samples 51, 35 and 30, The Sudden Cardiac Death Holter Database, 2009 (200 beats).



Where internal rhythms come from?

- Central Rhythm Generators in the ***Brain***

See the work by **Jean Champagnat**

http://www.cnrs-gif.fr/iaf/ngi/index.html

Some references

http://www.di.ens.fr/users/longo *or* **Google: Giuseppe Longo**

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