Cybernetic Modelling. Proof-of-Concept Example

Boldur E. BĂRBAT, Florin G. FILIP
Sibiu *The Romanian Academy*
bbarbat@gmail.com *ffilip@acad.ro*

***Abstract* — Continuing the preceding paper [5], this one illustrates *Cybernetic Modelling*, applying it to biologic stability. A Lotka-Volterra model for predator-prey species is employed to (discrete-time) modelling homeostasis with hysteretic delay, simulating (macrochronic) stability of simple cybernetic (Barkhausen loop) systems. NL-capability is achieved replacing differential equations by iterative loops (with polysemantic time granularity) and employing (some) non-numeric mathematics. The modelling subspecies is evaluated from both transdisciplinary bridge legs: *software engineering* (undemanding yet flexible post-industrial apparatus) and *biology/ecology* (versatile (field or laboratory) research tool, with user-friendly interface, allowing to write "What-if" scenarios for handling (over)simplified ecologic (sub)systems in their real-world habitats).**

***Index Terms* — biologic stability (Lotka-Volterra model), cybernetic modelling (CyMo), non-algorithmic software, non-numeric mathematics, service-oriented engineering.**

Not everything that counts can be counted, and
not everything that can be counted counts
EINSTEIN [17]

I. COMMERCIAL HYPES OR NEW PARADIGMS?

"Many social science theories […] reveal the essential role of the environment […] to mediate […] cognition. […] [K]nowledge is externalized in a shared environment […]. The basic mechanism […] has been conceptualized […] in terms of stigmergy" [12]. This non-algorithmic paradigm is confirmed by thirty years of real-world applications. Thus, computer scientists have open path to (successful) research. The challenge is to discern early between promising ideas and hypes (e.g. prefixes like "*cyber*" or suffixes like "*2.0*").

The message targeting (post-industrial) engineers from countries (like ours) with scarce resources (above all for in-house academic research) and (systemic) difficulties with rationing them, is positive: if research is felt as more than a profession – even a bit more than a *Violon d'Ingres* – it is rewarding in areas like AI – where a PC and Internet access suffice for effective innovative research. The paper aims at endorsing this message, giving the example of cybernetic modelling (CyMo), employed in [5] as working model for illustrating the shift towards semiotic-oriented software in AI [3]. (Focusing on its non-algorithmic nature, CyMo "was sketched out as informal, […], conceptual background for a mathematical definition of Wienerian time […], and was employed in a "Proof-of-Concept" application focused on bounded rationality and "Just in Time" [10]" [4].)

To follow the message in spirit and the paper title in letter, here will be tackled only the factors that have been proof-of-concept validated by the appliance in [10]: the triad of (approaches to) main concepts that impair LS2 model interpretability (NL-capability, uncertainty, time).

Thus, after avoiding main pitfalls in choosing a new research direction and focusing on a modelling subspecies (Section II), its foremost points are worked out in the next three sections: homeostasis (Section III), and two cardinal approaches to achieve both efficiency and interpretability (hence, end-user acceptance, [5]): discrete-time modelling (Section IV) and non-numeric mathematics (Section V). The conclusions (Section VI), reasserting the message, are a call to collaborative academic research.

II. A NOTIONAL X-RAY OF CYBERNETIC MODELS

A token of the conceptual blurriness of the "cybernetic" word-family is its absence from the Stanford Encyclopedia (perhaps *cyber* and *cyborg* are among the first to blame). Beyond cognitive upset, there are misleading paths. Thus, the domain of cyber-physical systems known as *Internet of things* – allows very successful research but not here and now. Indeed, any *SWOT* analysis for countries like ours would show that the strength (high research abilities) is impaired by the weakness (no money); hence, the strategy. "follow the leader" is workable in rich countries (in EU mainly for avionics or automotive engineering) but in poor countries it leads (only) to parochial, incremental research.

Thus, here "*cybernetic*" regains its original Wienerian connotation. In this light, CyMo is dedicated to, grounded on, and restricted by the limitations of LS2. The cardinal restraint: the modellers lack any flexibility, because LS2 are *given*. Unlike in robotics, system behaviour can not be *emulated* (e.g. in stigmergic control [12]), it can be just *simulated*. Thus, the (intrinsic and paradigmatic) error of ordinary modelling emerges: two given, natural beings are supposed to communicate (or even to interact), through an artificial language out of place for both: unable to mirror system behaviour as well as to let the user understand it). Expressed in engineering language: two non-algorithmic "individuals" – a (Simonian, boundedly rational) model interpreter and a (Zadehian, fuzzy) modelled LS2 – interact through an (Hilbertian, precise) algorithmic language (too formalised for end-users, too limited to explain the system).

Hence, NL-capability is not an (optional) design-space dimension but – as condition for model interpretability [5] – a non-negotiable premise. "Models are ineffective (either using intractable mathematics or oversimplifying system complexity) and lack user acceptance)" [4]. Both aspects refer to tractability but the outcome is intensely contextual. *Efficiency* is harmed by complexity, no matter if models are too complex (lacking interpretability) or too simplistic (leading to irrelevance). *Acceptance* depends on the weight of user-system interaction. For LS2 both effects are strong, because humans *must communicate* (or *interact*) with their living environment via the model engineers gave them, no matter the target (in biology mainly exploring, in ecology controlling/monitoring). From a slightly different outlook, the binomial "*Efficiency* + *Acceptance*" can be regarded as *Usability* ("personalization according to needs, adaptation to […],knowledge, anticipation of the user' requests" [11]). "Because mental representations are imperfect, there will always be […] contingency uncertainty" [6] (estimated by means of functional neuroimaging, where computational models are necessary, proving that CyMo is not surrogate of conventional modelling.) Though, "future-contingency-uncertainty" was not modelled. "Bergsonian time" neither.

III. HOMEOSTASIS: STATE OR PROCESS? BOTH

"Living beings maintain steady state despite a complex of processes occurring at various scales […]. Such a property, called homeostasis, has been known since long, but a full explanation of it is still missing" [7].

Biologic stability was explored in the prehistory of cybernetics: "La fixité du milieu intérieur est la condition d'une vie libre et indépendante" [wiki/Claude_Bernard]. The penultimate from the quintet Bernard-Wiener that reshaped (much more than) the science of stability, was sceptical about modelling in biology: "[T]he best material model for a cat is another [cat], or preferably the same cat." [wiki/Arturo_Rosenblueth]. Essential too, in the mid-30s, Alexis Carrel introduced some key ideas [9], showing him as a forerunner of new paradigms: a) Comparing energy consumption in brain and biceps, he asserted that energy alone cannot explain brain activity, thus ushering in the information era. b) Emphasising the basic endocrine system role in any state of mind, he promoted systemic thinking in psychosomatic medicine (thus, he heralded *G*eneral *S*ystem *T*heory). c) Of undeniable verity (and telling for the distinct paths of robotics and AI [5]) is his warning against simple reductionist approaches (to "exact sciences"), instead of holistic approaches in biology and medicine. "Biological systems are highly complicated, non-linear, and require very high-dimensional and high-volume data analysis. In reality, we as human beings are not good at handling such data" [15]. A very recent book "highlights the qualities of inclusivity, collaboration, and holistic thinking inherent in systems research" [14]. However, the reigning paradigm is strong: "[We] propose a dynamic theory of homeostasis based on a generalized Lagrangian approach" [20]; "We [employ] the theorems of Krasnoselskii's Fixed Point and Arzela-Ascoli. [W]e provide an existence result on the discrete fractional Lotka–Volterra model" [2]; the scale ("India's population") allows "entropy maximisation" [1].

Here, the scope of outlining homeostasis (loop) and hysteretic disturbance is confined twofold: to uncertainty and time (as approached in [5]); to two major aspects of favouring semiotic-oriented software: reducing the amount of (intractable) mathematics (Section IV); employing (modern) non-numeric mathematics (Section V).

In CyMo a *microchronic approach* is inevitable because cybernetics as science was built on the concept of *negative feedback*. Indeed, at a first glance, it is puzzling to consider a process consisting in taking a system's output magnitude, processing it, and *feeding* it *back* into the system together with the initial input so that the (new?) output value should diminish. The rationale emerges not in cybernetics, where it is fundamental, but – decades before Wiener redefined the concept – in radio engineering (where it comes from), to reduce the fading effect in radio wave propagation, i.e., to counteract an external perturbation. (Apparently, infinite speed should be easier to conceive mentally than to apply in engineering practice. However, although hard to accept cognitively, in electronics – due to the great speed of signal propagation – feedback mechanisms can mostly afford to sidestep temporal dimensions. Yet such circumvention is impossible when modelling processes in LS2. Homeostasis is no exception. *A fortiori*, when hysteresis is involved.)

From a biologic perspective, homeostasis is a key way to ensure *preservation*. The *homeostatic state* results from an *adaptation process* triggered by a *perturbation*. Nature always achieves *homeostasis* via *hysteretic delay*, lagging in response to perturbation (the meaning of *hysteresis* is "*lag in response*"). Indeed, without *exogenous perturbation* (entering the system) there may be *stability* but there is *no homeostasis*. Certainly, *homeostasis* could be approximated by *equilibrium* but only *macrochronically* (even for LS2 *iff* processes are of explicit chemical nature and fast enough).

To impair redundancy with [10], below is given from a software engineering stance (*SE*), as well as from a biology/ecology one (*BE*) only the semantics of the main symbols visible in Fig. I, denoting the defining values for (macrochronic) stability of a simple cybernetic system (Barkhausen feedback loop), in an appliance enabling field researchers to write "What-if" scenarios – as shown below:

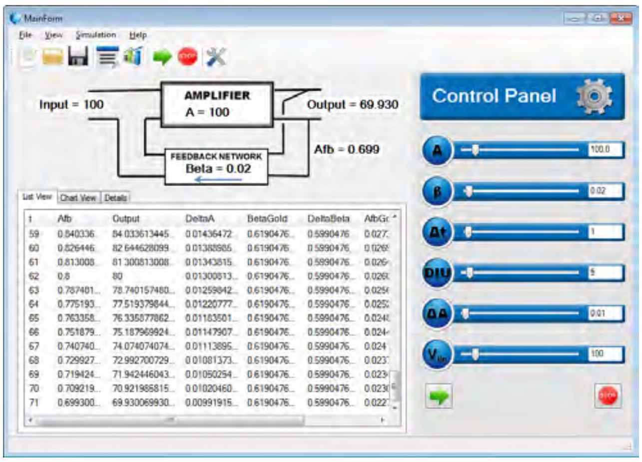

Fig. I. The user-validated interface (taken from [10]).

- **A**. *SE*: amplification factor; real number associated to a cybernetic amplifier ***CA*** (according to the theorem below). *BE:* (unrestricted) growth; gross reproduction rate.

- **β**. *SE*: transfer factor of the feedback network; real number (**|β| <1**) associated to a cybernetic amplifier ***CA***. *BE*: growth reduction rate; species adaptation rate to habitat perturbation, aiming to achieve a homeostatic state.

- $\mathbf{A_{fb}}$. *SE*: feedback amplification factor; A in dynamic context. *BE:* (sustainable) growth rate; reproduction rate in stable (homeostatic) state. Because of ecologic complexity, it depends on various factors as: fertility, mortality (caused by all causes, including pollution), biologic decline, etc.

- **Δt** and **DIU** are described in Section V.

- **ΔA**. *SE*: $|A_{fb\ i+1} - A_{fb\ i}| / A_{fb\ I}$; iterations are stopped when the feedback amplification factor, $\mathbf{A_{fb} = A/(1 + \beta * A)}$, varies with less than **1/100** from one iteration to the next one. *BE*: the homeostatic state is regarded as arrived at.

- $\mathbf{V_{iin}}$. *SE*: "big bang" input voltage value; *BE*: initial prey population (before interacting with predator species).

IV. DISCRETE TIME FOR INTERPRETABILITY

"[R]epresentation of time is […] a modeling choice […] In integrated approaches […], it may be fruitful to consider several independent time variables […]. This would […] answer [the] opposition between microscopic reversibility and macroscopic irreversibility of isolated systems" [16]. "[H]uman psychological processes unfold in irreversible time (*rule of time*). [This rule lets psychological processes share common ground with […] thermodynamics [22].

Since instantaneity is unacceptable, the problem of what kind of time should be used (i.e., setting up a model of time itself) is consequential for modelling (the stability of) LS2. Choosing Barkhausen's approach (revisited) as foundation for CyMo, the shift from atemporality to discrete time was strongly suggested. It proved to be colossally beneficial to interpretability, evading (almost) intractable mathematics: Lotka-Volterra differential equations are replaced by *IF*s and *LOOP*s in modelling. As regards time granularity:

- **Δt**. *SE*: macrochronically interval between successive discrete time moments; macrochronically, **Δt → 0**; time granule; in (deterministic) Lotka-Volterra-like models it tends towards time derivatives. *BE:* minimum time span for observable changes; usually, (prey) generation lifespan. For fine-tuning granularity, the interval between two successive moments (in discrete microchronic view), has no value limits but instead a set of magnitude units to select from. Now **Δt ϵ {*seconds*, *minutes*, *hours*, *weeks*, *months*}**.

However, hysteretic delay needs other time dimensions:

- **DIU**. *SE*: (irreversible) time span between perturbation occurrence and feedback start ("big bang"). In CyMo it is implemented by *WAIT* (with nonalgorithmic TIMEOUT, set up through the third value of the non-deterministic *IF*): *WAIT* is terminated irreversibly in both cases (system reaction *XOR* exception); *BE:* hysteretic delay (required to start adapting to perturbation – anthropogenic disturbance).

The two are very unlike: **Δt** illustrates *reversible discrete* time, while **DIU** (*D*elay, *I*rreversibility, *U*ncertainty due to future contingents) expresses *irreversible continuo*us time. (The ***U*** facet was not employed yet, neither in [10] nor in later scenarios). Thus, it is a tempting new research path.

Exploiting the semantic flexibility of the trivalent logic displayed by the non-algorithmic *IF*, the third exit was later easily adapted to answer "What-if" scenario questions.

V. NEW MATH FOR ENGINEERS IS NON-NUMERIC

"Although the application of mathematics to every aspect of science is its ultimate goal, biology is still too complex and poorly understood. Therefore, for now the goal of medical science should be to discover all the new facts possible. Qualitative analysis must always precede quantitative analysis" [wiki/Claude_Bernard] cited in [10]. The quote still holds because neither psychology nor the (former) "exact sciences" are ready to shift paradigms: "The third type of specialized brain is that of Verbal logic thinkers, characterized by word-oriented thinking and high verbal ability" [13]. "[H]igher-order thinking is the type of non-algorithm thinking which include analytical, evaluative and creative thinking" [19]. Non-numeric mathematics is not reckoned with: among the "reasons for the delay in the recognition of mathematical chemistry as a discipline [is] the little recognition of non-numerical mathematics" [18]. "The progress made in recent years […] makes us think of the many possibilities offered by the arithmetic and non-numerical mathematics of uncertainty" [8]. "Approaches to modeling management […] processes in the foresight management system […] must develop optimal areas for […] using […] non-numeric mathematics" [21]. "A school is far more than the sum of a set of numbers. [Q]uantitative data, […] is not the objective measure that it is presented to be [D]ata should not drive, but inform. The term "data-driven" should be accompanied by a critical warning" [17].

In [10], to illustrate non-numeric mathematics, a theorem (required for a (meta)mathematically sound extension of CyMo, but not necessary for the Proof-of-Concept example implementation) was formulated and proved:

Prefatory. An electronic amplifier is a quadripole having associated a real number **A**, meaning that the output value will be **A** times greater than its input value. This model suffices for linear growth. For the sake of simplicity, potentiometers, i.e., passive electric circuits composed by a resistor and a cursor, are considered amplifiers with **|A| ≤ 1**.) A cybernetic amplifier ***CA*** is an amplifier connected in (Barkhausen) loop to a feedback network (as in Fig. I).

Theorem. The set of *cybernetic* amplifiers ***CA*** together with the operation of connecting in *s*eries ***S***, forms a group. *Proof.* To prove that (***CA***, ***S***) has a group structure, i.e. **∀ x ∀ y ϵ *CA* → x*S*y ϵ CA**, it suffices to show that the four group axioms are satisfied:

- *Closure*. The result of the operation **x*S*y** gives another amplifier obtained connecting **x** and **y** in series. Thus, the compound amplification, namely the output value of **y** divided by the input value of **x** will be the product of $\mathbf{A_y}$ and $\mathbf{A_x}$. But $\mathbf{A_y * A_x \in \mathbb{R}}$. Hence, **x*S*y ϵ *CA*** (In practice that means that any amplification (or attenuation, (**|A|** < 1) needed, is attainable with at most two components.)

- *Associativity*. Connecting in series is evidently *physically* associative; hence **(x*S*y)*Sz* = x*S*(y*Sz*)**.

- *Identity*. Carrying on this plainness approach, it is obvious that the identity element, $\mathbf{1}_{CA}$, is a pair of wires or – to give it a minimal electrical embodiment – a resistor or any kind of passive circuit letting the input value unchanged (**A = 1**). For any amplifier ***x*** the output value will remain unchanged (and equal to the input value), i.e., the equality chain $\forall\, x \in CA \rightarrow 1_{CA}Sx = xS1_{CA} = x$ holds.

- *Invertibility*. For each amplifier $\boldsymbol{x}$ (amplification factor $\mathbf{A_x}$), there is an amplifier $\boldsymbol{y}$, (its *inverse element*, $\boldsymbol{x^{-1}}$), having an amplification factor of $\mathbf{A_y = 1/A_x}$. Hence, the equality chain $\forall x \forall y \in CA \rightarrow xSx^{-1} = x^{-1}Sx = 1_{CA}$ holds.

Even numeric maths can be simpler: when $\boldsymbol{\beta}$ was set at the *golden ratio* (anecdotal evidence shows that Australian rabbit reproduction *could be* related to Fibonacci series), it was rated **13/21** avoiding equations, radical signs, etc.

VI. *CONCLUSION*: CYMO, A CALL TO RESEARCH

- Dedicated to LS2 modelling, CyMo must be evaluated from both transdisciplinary bridge stances: *SE* and *BE*.
- *SE*: CyMo is an undemanding, yet multifunctional and flexible tool, for swift-modelling (over)simplified LS2.
- *SE*: Model tractability, as main attribute of *process-oriented* (software) *engineering*, is achievable only through NL-capability; hence no *probabilities*, *bivalence*, *precision*.
- *SE*: CyMo boosts NL-capability enhancing its arsenal with *discrete time* and *non-numeric mathematics*. It keeps apart *complexity* from *complicatedness* (blending bounded rationality with Occam's razor): choosing for homeostasis a Lotka-Volterra model (relevant for predator-prey species pair) it avoids intractableness (usually, awful differential equations totally overshadow model features), employing iterative loops with flexible semantics for time granularity.
- *SE*: There is no wholesale abandonment of older paradigms. Not every *IF* can emulate exceptions (at least for simulation, algorithms are necessary). Not everywhere amplifiers can replace equations (computational models are unavoidable in many application areas –, above all for [6]).
- *SE*: Perturbation evolves obviously in a time dimension $\boldsymbol{\tau}$ distinct from feedback-loop time $\boldsymbol{t}$ = Im ($\boldsymbol{w}$). However, not enough to Proof-of-Concept validate Wienerian time.
- *BE*: CyMo is a versatile (field or laboratory) research apparatus, with user-friendly interface, allowing to write simple scenarios for handling LS2 in real-world habitats.
- *SE + BE*: (Meta)conclusion: CyMo is a vivid example that (post-industrial) engineers can accomplish ambitious transdisciplinary research with modest in-house resources. Let us give it a chance in collaborative academic research.

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