Dynamical Systems Theory in Cognition: are we really gaining?

Alcibiades Malapi-Nelson (author; presenter if accepted)
Department of Philosophy, Concordia University

1226 Du Fort #102, H3H 2B3
Montréal, Québec, Canada

alci911@yahoo.com
(514) 409-4455 / (514) 848-4590 [fax]

Expected to be included in the Conference:
Philosophical Aspects of the Computational Models of Scientific Reasoning: Cognitive Theory Formation
(Keywords: Cognition, Computationalism, Connectionism, Dynamicism, Explanation)

ABSTRACT:

Dynamical Systems Theory (DST) claims to be an epistemological weapon particularly broad and rich in providing a fair explanatory account of the operations of our mind. However, the very features that this DST espouses as reasons for having an edge over Computational Theory of Mind (CTM) and Artificial Neural Networks (ANN), are the ones that are causing trouble in the philosophy of science speculation, especially regarding issues of Explanation. This paper aims to suggest some possible problems that could arise from the application of DST's characteristically abstract mathematical framework to the study of the mind. As I have not found anything that suggests something like this, my aim is to at least show the reasonability of a possibility.

INTRODUCTION.

In philosophy of mind, the search for a How-answering *explanatory mechanism*[1] was well embraced by many, and among theories, the Computational Theory of Mind (CTM) is claimed to provide with one, thanks to the arrival of Syntax, which operates over (Representations correspondent to) the old well-known Logical structures of our Thoughts.[2] Cognitive Science (CogSci) is born in the image of a Turing *Machine*,[3] which provides a *mechanism*[4] concretized in the idea of an innate 'syntactic processor' (as Chomsky[5] puts it), and in that way bringing back a *causal history* that Logic alone could not provide out of its Analytical womb.[6] Even archenemies like Andy Clark, from the lines of Artificial Neural Networks (ANN), recognizes in CTM an "*Engineering* Project", as opposed to a merely "Descriptive" one (his).[7] ANN theorists are not friendly to this heavily 'engineered' computational *mechanism*, because it overloads the head with useless (and probably false) mechanistic assumptions, which restrain a cognitive system (like an automaton, or insect), from coping in efficient ways with random environmental change.[8] If we want to understand the mind, we should be able to reproduce a model, and CTM, ANN claims, insufferably complicates the task.[9] Parallel Distributing Processes (PDP) –an ANN variance--, Massive Modularity Thesis (MMT) and the Thesis of Radical Embodied Cognition (TREC) also entered the game, trying to give answers of their own, not entirely unrelated to each other. Lately however, ANN complaints against CTM 'have been heard', but at a high price: both CTM and ANN itself are risking falling in oblivion. Faced with the new contender, they rather look like good friends with complementary ideas.[10] The new proposal for CogSci is called Dynamical Systems Theory (DST):

> A Dynamical System is a "system with numerical states that evolve over time according to some rule. …A *system* is a set of changing aspects of the world. The overall *state* of the system at a given time is just the way these aspects happen to be at that time. The *behavior* of the system is the change over time in its over all state." (vG&P 1995,p.5)

DST proposes approaching mental processes through the numerical recognition of the 'states' of a given cognitive system, states that, as long as systemic, will be interdependent among themselves and dependent to a broader 'parameter', itself less prone to change but more prone than another 'higher' parameter, according to which the first parameter would be a state, and so forth. The *summatory* of states conform the behavior of a system. The systemic properties are holistic: in order to be counted as properties, they have to affect at least a system's parameter, and therefore, the system itself.

> …For a set of aspects to qualify as a system, they must be interactive and self-contained: change in any aspect must depend on, and only on, other aspects of the set. (vG&P 1995,p.5) …Factors that affect, but are not in turn affected by, the evolution of a system are known as *parameters.* (p.6) …Changing a parameter of a dynamical system changes its total dynamics…" (Van Gelder 1995,p.357)

DST claims that: (1) It can comfortably subsume CTM and ANN if wished,[11] with or without Representations.[12] Its framework is so broad, and hence powerful,[13] that can bring under its scope every possible theory of cognition, *plus* having virtually unlimited space for richer accounts now and yet to come. (2) It brings Time back into consideration. Not far from TREC, what DST claims is that Time is the big absent in the Computational version of a *mechanism*. Cognitive processes occur in *real time*, and CTM's mechanical heurism is simply ignoring it,[14] due to the disengagement of their intellectual elucubrations[15] and the Cartesian dualisms[16] that they underpin. A mechanism that accounts for real-life processes cannot be timeless.

> The evolution of a system over time corresponds to a sequence of points, or trajectory, in its phase space. These sequences can often be described mathematically as functions of an independent variable, time. These functions are *solutions* to the differential equations which describe the behavior of a system. (vG&P 1995,p.7)[17]

As Time (its measurement, calculation and very concept) pertains to the realm of Mathematics,[18] differential equations will be the framework for giving an account of the behavior of cognitive processes. The Sciences had already recognized this: mathematics provides a conveniently general and extremely accurate framework that allows us to do away with contradictory theories. Math gives us a way to make those theories either communicate or be cast out due to an inconsistency with its own mathematical results. The accuracy and broad scope of this powerful tool could be successfully applied to cognitive systems, having the advantage of espousing points (1) & (2) stated above, and therefore providing a richness, consistency and wide theoretical frame much needed in the study of cognition.

OBSERVATIONS AND CONCERNS ON DST

One of the advantages of DST, maybe the most important claimed, is that Time is brought back into the game, as an essential descriptive feature of any explanatory mechanism of a real process (and not only cognitive process, for that matters).[19] And this is accomplished using mathematics as the main theoretical work tool.[20] With this, another advantage is claimed at the same time: math allows the scientist to subsume a large quantity of phenomena, even qualitatively different, under the same scope; and the same is applied to CogSci,[21] therefore rendering a powerful frame capable of handling the two main theories of mind –CTM and ANN-- and confidently claiming to be able to handle any other yet to appear.

However, this theoretically omnivorous tool, now brought to Cognition after the huge success in physics (and physicalized sciences) since Newton, has caused some serious concerns, regarding the path that this sort of unchallenged methodology is taking sciences to. The trouble philosophers of science are beginning to observe could well be transmitted to the operational and conceptual way in which DST is giving treatment to the cognitive fact, claiming that it is exactly this feature the ones that gives the dynamical approach an edge over the classical contenders.

Van Gelder presents DST as inspired from Maxwell's mathematical account[22] of Governors,[23] void of a Representational framework[24] and very attentive to Time states[25] (by means of mathematical equations)[26]. This is no surprise, as Maxwell occupies a pivotal place in the history of Science and in the philosophy of Scientific Explanation due to his Unification of Optics and Electromagnetism; indeed the most important scientific achievement since Newton.[27] Maxwell tried to avoid Newton's Ontology in order to make his theories mechanistically viable (although in a heuristic sense, he always reminds us) and theoretically consistent. His strategy was to use the analytical mechanics of Lagrange, characterized for providing a very broad mathematical framework, with a tremendous capacity of subsumption, and for being a convenient reducer of variables, eliminating some 'negligible' pieces of data by the end of the formulaic operations.

The description of the Governor is admired by dynamicists for the new feature of not needing Representations, thanks to this particular application of pure Mathematics: Abstract Mechanics;[28] and although Maxwell does not specifically mention the Lagrangian formulae in the Governor's article, we should be aware that DST does bare Lagrangian mathematics as a constitutive aspect of its own operational nature,[29] and that Lagrange's formulations provided the very advantageous theoretical tool[30] that not only Maxwell's Electromagnetic Unification, but other mathematized sciences have profitably advantaged from. Maxwell was the first one to use Lagrangians for experimentation in physics; others were going to follow his steps (in physics and physicalized sciences). The concept of Dynamical Systems in contemporary pure Mathematics bare at its very core the formulations of Lagrange. The relation between Mathematics and Sciences, the former providing to the latter with an accurate, theoretically wide and prediction-capable structure, furnished Sciences with an unprecedently successful capacity of unification within themselves. It is this powerfully broad frame and exactness that allowed this approach to be applied to other Sciences, such as economy, sociology, biology, statistics, and now, CogSci.

As a result of trying to get away from Newton's realistic metaphysical assumptions, which nevertheless provided the grand Unification of Galileo's terrestrial gravitational theory and Kepler's celestial mechanics, Maxwell was the first one to take advantage of those features, by means of Lagrangian mathematical procedures; so it is worth taking a look at his experience. But the upmost relevance of Lagrange's contribution will be shown as we dilucidate how fundamental it was for the development of the current notion of Mechanism.

MAXWELLIAN UNIFICATION AND LAGRANGIAN FORMULATIONS

Maxwell**'**s theoretical inconsistencies regarding phenomenal behavior (of electricity and magnetism) were due to the Newtonian ontological presuppositions of the time. Following the example of other contemporary scientists, and witnessing their success, he gave it a try with Lagrangian formulae. The interesting feature about this mathematical methodology is that it not only requires little data input into the equation, but that some variables vanish as the operations go on:

> The aim of Lagrange was to bring dynamics under the power of calculus. He began by expressing the elementary dynamical relations in terms of the corresponding relations of pure algebraical quantities, and from the equations thus obtained he deduced his final equations by a purely algebraical process. Certain quantities… appear in the equations of motion of the component parts of the system, and Lagrange's investigation, as seen from a mathematical point of view, is a method of eliminating these quantities from the final equations. (Maxwell 1873,§2)

The advantages are obvious. If minimal data is required and the operation becomes simplified after some steps, then the amount of phenomena about which it can give account is seriously widened, and therefore apparently antinomical theories may be unified, or put it simply, those that are seemingly distinct, under such a large scope do not look that different any more. But Maxwell was very aware of the price that was being payed, as the richness of the details was being lost. Those details could be the very things that could give us an *explanatory* account in terms of answering How-type of questions, and he therefore advices to somehow keep them, at least as a heuristic device:

> In following the steps of this elimination the mind is exercised in calculation, and should therefore be kept free from the intrusion of dynamical ideas. Our aim, on the other hand, is to cultivate our dynamical ideas. We therefore avail ourselves of the labours of the mathematicians, and retranslate their results from the language of the calculus into the language of dynamics, so that our words may call up the mental image, not of some algebraical processes, but of some property of moving bodies. (Maxwell 1873,§2)

At this point answers to How-questions and explanatory Mechanisms take each its own route: although the first one could well accomplish a descriptive and elucidatory task, the second one would actually *model* the process itself, rendering predictive capacities and experimentally fruitful results. That is why the concept of Mechanism is inherently linked to Lagrangian equations, after known as Lagrangian Mechanics or Lagrangian Formalism (or just Lagrangian).

> …We may conceive the system connected by means of suitable mechanism with a number of movable pieces, each capable of motion along a straight line, and no other kind of motion. The imaginary mechanism which connects each of these pieces with the system must be conceived to be free from friction, destitute of inertia, and incapable of being strained by the action of the applied forces… When the values of all the variables (q) are given, the position of each of the movable pieces is known, and, in virtue of the imaginary mechanism, the configuration of the entire system is determined. (Maxwell 1873,§3)

Lagrange's work, suggestively called *Mechanique Analitique* (1788), became a powerful theoretical tool widely accepted and fundamentally shaping Physics, through the Electromagnetic-Optics Unified Theory, Classical

Analytical Mechanics and Quantum Mechanics,[31] to the extent that its simplifying methodology was regarded as the "demechanization"[32] or "mathematization"[33] of Physics, both highly analytical interpretations of what occurred in the Physical sciences.

Abstract generalizations, even if they operate as unifying explanatory mechanisms, are generally conceived and used with a price to pay; we want understanding and we get it (probably by means of a simplified, reduced or unified explanatory theory), but sacrificing some neglected aspects of the phenomena, either out of not being considered for subsumption (this at the same time depending on the framework from which we judge) or out of loosing those details as they vanish in the new theoretical structure. In this case what was provided was 1) an extremely useful *wide theoretical framework* capable of handling a large amount of not only phenomena but of theories about those phenomena as well; 2) a Mechanism, consistent and not data demanding, very general and self simplifier, that through the power of Algebra rendered surprisingly simple and exact results. Simplicity is almost an axiomatic criterion in scientific research, and why this is so is a topic of its own. But the simplification and even theory reduction that Lagrangian Formalism provided was paramount in scientific unification; the new capacity for giving a simultaneous account for an immense range of phenomena was regarded as an achievement to be cherished in Science.

What was lost were phenomenal details that philosophers of science (and at his time Maxwell himself, although as a scientist) are beginning to regard as the very explanatory items that a theory would need to take into account in order to understand the studied occurrence beyond the numeric results provided by mathematical operations. Philosophical worries regarding a virtual gap existing between a consistent logico-mathematical unified structure and a set of phenomena reducible only theoretically, lead philosophy of scientific explanation literature to be wary of any ontological assertion that those mathematized systems conclude regarding reality; the metaphysical jump is not well regarded. Recall Van Fraassen's critique to the unwarranted metaphysical commitments in doing science and Morrison's advise against an excessive cheerfulness regarding the simplified outcome that Science is providing by means of the extended usage of abstract mathematizations, thus loosing the explanatory capacity that was probably the original aim at a certain moment.

POSSIBLE CONSEQUENCES FOR DST APPLICATION ON COGSCI

As we see, the advantages of theory mathematization come at a price: we could end up loosing features that could give us fundamental clues about the nature of the studied object, or at least about the model we are using to intellectually reproduce the process. Nevertheless, DST has been taken as a powerful theoretical weapon well beyond the realm of Physics. Later research advancement in Mathematics have enriched Dynamical Systems (DST is properly a branch of pure and applied math[34]) considerably since Maxwell's employment of it,[35] thereafter triggering even further applications in other fields of knowledge,[36] furnishing the correspondent researches with the scientific-community-approved features mentioned above (large unifying framework and a mechanism). If mathematization has entered into biology, economy, sociology, decision theory, etc., it does not come as a surprise that the extremely attractive features that DST provides would open "new" possibilities of understanding, describing and eventually somehow reproducing to a certain extent the operations of our mind.

Expectably, as systemic states are what count as to what to subsume under dynamic parameters, the distinction between mind and body is the first one with which we get away; actually the relegation is a bit more subtle: it does not matter much whether or not that dualistic distinction is valid. What matters are the identifiable states, in virtue of the recognition of Time as the main feature to take into account in systemic processes. Representations, computations, connections… all of that becomes unessential, useless or even trivial;[37] and it is not that DST denies their plausibility, in fact it mercifully welcomes them, but very aware that its own account is the one that furnishes research in CogSci with the strength of mathematical results, and therefore, with an exactitude and broad scope that seemingly surpasses the naturally limited frameworks of any other theory of cognition.

Van Gelder's justifying appraisal of Maxwell's explanation of Governors' behavior, mathematically structured and hence, void of Representations (among all the other advantages pertaining to theory mathematization);[38] as well as extensive usage of Lagrangian 'formal mechanics' in the posterior (and current) development of DST in Mathematics; suggests that the edge provided by such a powerful epistemological model could have underlying drawbacks not reckoned so far,[39] but to be shown in the near future *if* the philosophical speculation regarding Explanation extends to the study of theory application in CogSci, and engages into the questioning of how DST is performing on CogSci and therefore what sort of hidden features are being spread in the study of cognition (under DST).

So, as DST asserts that "cognitive processes are ultimately physical processes taking place in real biological hardware",[40] the abstract, general and formal nature of its explanation gets somewhat unveiled, if it is true that:

> The Lagrangian method (or method of the dynamical analogy) by far transcends the scope of mechanics; it is, essentially, a mathematical framework (a formalism) having an enormous generality: as such, it potentially embraces an unlimited number of concrete contents. (Bunge 1959,p.218)

CONCLUSIONS

The reasons that are claimed for validating and promoting the application of DST on CogSci (and for choosing DST over other theories of the cognitive mind and other systems), are the very ones that other sciences espoused when they had to opt for the employment of DST as a theoretical framework for consistency/exactitude/widely-subsuming-results research purposes. No wonder why Van Gelder is fast in reminding us that DST's wild successes have been demonstrated in the Sciences for quite a while already. All the features that had been mentioned as clear advantages over other possible approaches to the understanding of cognitive processes are acknowledged, considered and respected. But there is another story that not only philosophers of science and scientific explanation, but scientists themselves have recognized since the beginning, a story that is 1) reason for discomfort for those very intellectuals that pioneered and proposed the usage of abstract mathematical formalisms in their field of research; and 2) reason for philosophical concerns regarding the nature of the explanation we are currently getting from contemporary scientific research:

> [The] mathematical framework provides little or no insight into specific physical details, leaving the problem of how to interpret the mathematical model and whether or not that physical interpretation should be construed realistically.[41] …The generality and lack of detail of those [mathematical] structures enhance our ability to provide a unified account of diverse physical systems.[42] But without any substantial explanation of how that took place the reduction offer[s] little in the way of true understanding.[43]

DST has this other side of the story at its core. Still it is so appealing, conveniently abstract, and therefore general[44] (seemingly of a 'higher order' –which, for *empirical adequacy* could be fairly valid), that the strength of the results DST renders is extremely attractive for several fields**,** and wanted to be adopted as a characterizing aspect of their own. This is gradually happening and, expectably, the very constitution of those fields of research are being reshaped by this omni-subsuming theoretical weapon, gaining new consistent structure and getting closer to the possibility of being considered an accurate (if not exact) science. Which suggests that the package of theoretical concerns (coming from philosophy and science itself) could very well be spreading among all the branches of knowledge that DST now pervades. These concerns, that intuit a widening gap between the highly ordered mathematical structures accounting for phenomenic understanding, and the ontological assumptions it could be suggesting (or at least unconcerned about making specific), begs for, in general, a revision of our current hopes in matters of theory unification (and its counterpart in reality). Specifically for CogSci, they advise at least prudence regarding our appreciation of the results DST is rendering in the understanding of cognition. What seems to matter here is 1) the validity-status of the semantic question of what those numerical values really mean regarding the way I think, and 2) the possibility of falling into the enchantment of the tempting, normative and curently fashionable notion that "certain questions do not need to be even asked"[45] or that "we do not have to problematize ourselves unnecessarily",[46] both approaches pertaining to a *kind* about which it could not be said without doubt that enjoys at least the feature of being theoretical or even epistemic, in which case I would not know why I am writing this. It seems that if the sciences are telling us about the unmitigated success of DST applied to themselves, they can as well warn us about the dangers of using it, especially in certain fields in which the objects of study are not naturally that close to mathematical framing. However, because this latter view renders in the best of cases an *empirically adequate* position towards scientific explanation, aiming to *save the phenomena*, and neutral to any ontological/metaphysical commitment, it is very widely regarded as Instrumental, and even cynical, and therefore, less accepted. The Hope that abstract mathematical structures (with all the wanted features that come with them) *have something to do with reality*, is taken as Truth ---probably for reasons that may fall well beyond the realm of philosophical speculation.[47] For whatever reasons DST enter into CogSci, besides those suggested here, CogSci could be inheriting the goodies as well as the to-be-unveiled misfortunes of DST. It is probable that the cons are eventually to be recognized as the very reasons which made it possible for DST to enter right footed into cognitive research, awareness whose consequences are to be felt well beyond the science of cognition, as it could cause the whole theoretical scientific edifice to tremble.

REFERENCES

Bunge, Mario (1957) "Lagrangian Formulation and Mechanical Interpretation" in *American Journal of Physics*, vol. 25, No.4, pp. 211-218

Birkhoff, George David (1966) *Dynamical systems.* Providence, R.I.: American Mathematical Society.

Chomsky, Noam (1959) "A Review of B. F. Skinner's *Verbal Behavior*" in *Language*, 35, No. 1, 26-58

Clark, Andy (1988a) "Thoughts, Sentences and Cognitive Science" in *Philosophical Psychology*, vol.1, No.3, pp.263-278

(1988b) "Critical Notice. Psychosemantics: The problem of meaning in the philosophy of mind" in *Mind*, vol.xcvii, 39, pp. 605-617

(1998) *Being there : putting brain, body, and world together again*. Cambridge, MA: MIT Press.

Fodor, Jerry (1987) *Psychosemantics. The problem of meaning in the philosophy of mind.* Cambridge, MA: MIT Press.

(2000) *The mind doesn't work that way: the scope and limits of computational psychology.* Cambridge, MA: MIT Press.

Hacking, Ian (1996) "The Disunities of Science" *in The Disunity of science : boundaries, contexts, and power* (edited by Peter Galison and David J. Stump). Stanford, CA: Stanford University Press.

Kant, Immanuel (1770) *Kant's inaugural Dissertation and early writings on space*. Translated by John Handyside. Chicago: The Open Court Publishing Co., 1928

(1781/1787) *Critique of Pure Reason*. Unified edition, Translated by Werner S. Pluhar. Indiana: Hackett Publishing Company Inc., 1996.

Maxwell, James Clerk (1868) "On Governors" in *Proceedings of the Royal Society*, XVI, No.100, pp. 270-283

(1873) *Treatise on Electricity and Magnetism*. Unabridged 3d ed. New York: Dover Publications [Reprinted 1954].

Morrison, Margaret (2000) *Unifying Scientific Theories. Physical Concepts and Mathematical Structures.* Cambridge University Press.

Percival, I. and Richards, D. (1982) *Introduction to Dynamics*. Cambridge; NY: Cambridge University Press.

Thirring, Walter (1997) *Classical mathematical physics: dynamical systems and field theories*. 3rd ed. Translated by Evans M. Harrell II. NY: Springer.

Van Gelder, Timothy (1995) "What might cognition be, if not computation?" in *Journal of Philosophy*, 91, 345-381.

Van Gelder, T. and Port, R. (1995) [vG&P] "It's about time: an overview of the Dynamical Approach to Cognition." in *Mind as motion: explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.

Walker, John Andrew (1980) *Dynamical systems and evolution equations : theory and applications*. New York: Plenum Press.

---

[1] "Explanation by derivation from quantitative laws very often doesn't provide what Richard Feynman calls the "machinery" of a particular system. The machinery is what gives us the mechanism that explains why, but more importantly, *how*, a certain processes takes place". Morrison 2000, p. 3. Italics original.
[2] Articulated by Fodor in *The Language of Thought* (1975), and defended ever since with some modifications added.
[3] Turing,A., "Computing Machinery and Intelligence" in *Mind*, vol. LIX, No. 236 (1950), 433-460
[4] Fodor 2000,p.17; Fodor 1987,pp.143-147
[5] "It is at least possible, …that such a notion as *semantic generalization*, to which such heavy appeal is made in all approaches to language in use, conceals complexities and specific structure of inference not far different from those that can be studied and exhibited in the case of **syntax**, and that consequently the general character of the results of syntactic investigations may be a corrective to oversimplified approaches to the theory of meaning." (Chomsky 1959,XI,§3.Bold mine) "…It may be possible to study the problem of determining what the built-in structure of an information-**processing** (hypothesis-forming) system must be to enable it to arrive at the grammar of the language from the available data in the available time." (Chomsky 1959,XI,§6. Bold mine).
[6] Fodor 2000,pp.15-19
[7] Clark 1988a; Clark 1988b,pp.608-609,613-616
[8] Clark 1998,pp.141-142
[9] vG&P 1995,p.24
[10] vG&P 1995,p.3
[11] Van Gelder 1995,p.374
[12] vG&P 1995,p.12
[13] vG&P 1995,p.23
[14] Van Gelder 1995,p.379
[15] Van Gelder 1995,p.373; vG&P 1995,p.12
[16] Van Gelder 1995,p.380
[17] "…Since the phase spaces or their systems are numerical, natural notions of *distance* apply. Thus, dynamicists conceptualize cognitive processes in *geometric* terms." (vG&P 1995,p.15) Kant already clarified the nature of geometrical counterpart of Time: "…Precisely because this inner intuition [of time] gives us no shape, do we try to make up for this deficiency by means of analogies. We present time sequence by a line progressing *ad infinitum*, a line in which the manifold constitutes a series of only one dimension. And from the properties of that line we infer all the properties of time, except for the one difference that the parts of the line are simultaneous whereas the parts of time all always sequential." (Kant 1781,B50)
[18] In addition to vG&P (1995,p.19) brief justification of this fundamental statement, Kant's insight regarding the relation between Time and Number may come handy: "Pure mathematics considers space in geometry and time in pure mechanics… To these there is to be added a certain concept which, though itself indeed intellectual, yet demands for its actualization in the concrete the auxiliary notions of time and space (in the successive addition and simultaneous juxtaposition of a plurality), namely, the concept of number, treated of by arithmetic." Kant 1770, Paragraph 12
[19] vG&P 1995,p.10
[20] vG&P 1995,p.3
[21] vG&P 1995,p.10
[22] "I propose at present, without entering into any details of mechanism, to direct the attention of engineers and mathematicians to the dynamical theory of such governors." (Maxwell 1868,p.271)
[23] "A Governor is a part of a machine by means of which the velocity of the machine is kept nearly uniform, notwithstanding variations in the driving-power resistance." (Maxwell 1868,p.270)
[24] Van Gelder 1995,p.352

---

[25] Van Gelder 1995,p.355
[26] Van Gelder 1995,p.353
[27] "In 1931, on the 100th anniversary of Maxwell's birth, Einstein described the change in the conception of reality in physics that resulted from Maxwell's work as 'the most profound and the most fruitful that physics has experienced since the time of Newton.'". Encyclopedia Britannica.
[28] "Maxwell's analytic treatment of speed governors is generally regarded as the founding paper on cybernetics." Encyclopedia Britannica
[29] "In most of the dynamical applications, Lagrangian systems can be regarded as dealing with a system of particles subject to certain forces and geometrical concerns." (Birkhoff 1966,p.23)
[30] "The advantage of the Lagrangian over the Newtonian formulation is that the form of the equation of motion is invariant under changes in the generalized coordinate q…" (Percival and Richards 1982,p.71)
[31] Bunge 1959,pp.212-214
[32] Bunge 1959,p.217
[33] Morrison 2000,p.93
[34] vG&P 1995,p.14
[35] vG&P 1995,p.39
[36] vG&P 1995,p.14
[37] In parallel fashion, DST applied to Physics renders similar results: "Elementary mechanics gets extended to a more flexible scheme. The various infinitely small quantities like "infinitesimal variations" and "virtual displacements" disappear and are replaced more precisely with mappings of the tangent spaces. The tangent spaces and their associated bundles are the real stage for dynamics… At first it may seem only as an exercise in the abstract style of writing. But the reward is that this abstract notation succeeds in reducing the general assertions of classical mechanics to trivialities." (Thirring 1997,pp.6-7)
[38] Van Gelder 1995,p.356
[39] "When a physical system is modeled by a formal equation…, often assumptions are made for the convenience of the modeler; that is, they are made so that the formal equations "makes sense"… One approach taken to the modeling problem has been to ignore it; by this approach one simply postulates an abstract mathematical object called a dynamical system…" (Walker 1980,p.85)
[40] vG&P 1995,p.19
[41] Morrison 2000,p.105
[42] Morrison 2000,p.105
[43] Morrison 2000,p.107
[44] Van Gelder 1995,p.364
[45] "The dynamical approach handles the embeddedness problem by refusing to create it." vG&P 1995,p.29
[46] Consider Rodney Brook's motto regarding the foundational premises for the conception of his Mobots: "The world is its best representation." Cited in Clark 1998, ch.1. Check: www.ai.mit.edu/people/brooks
[47] For an anthopological approach, see Ian Hacking's "The Disunities of Science" (1996), in which he contributes with a «human touch» to the discussion regarding theoretical unity.