Reconsidering the Notion of Dynamical Systems Theory Resources as a Conceptual Framework

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Abstract

Taking DST (dynamical systems theory) resources as a conceptual framework for thinking about dynamical systems transforms numerical complexities into conceptual deliberations, and consequently greatly facilitates embodied cognitive science (Clark 1997, 1999, 2001). In fact, some dynamicists, such as Thelen & Smith (1994), Thelen (1995) and van Gelder (1998), worked at this conceptual level. However, the management of those conceptual resources may risk floating away from the anchor of the DST-based equation-governed modeling. This may, at least, incur three mis-implications, as this paper aims to uncover. Firstly, conceiving of cognitive systems on the grounds of DST resources, surprisingly, does not warrant a DST-based underlying mechanism. Secondly, inference across the DST resources may be a mistake. Lastly, the entitlement of a 'dynamical system' on grounds of DST resources may direct our attention to various troubling ambiguities of that term. Therefore, before all those risks are avoided, DST resources would not be safely useful as tools.

Introduction

Dynamical systems theory (DST) is seen by Clark (1997, 1999, 2001) as a useful tool for understanding embodied mind; more strongly, it is taken by van Gelder (1998) as a dominant tool for describing the behavior of dynamical systems [1] and in turn for understanding cognition, even at its highest level. Clark takes this useful tool to support a *dynamic approach in action* for understanding adaptive behavior in the environment; more thoroughly, based on this dominant tool does van Gelder entrench a *dynamical hypothesis*: To wit, cognition *is* a dynamical system and cognitive science can and should take dynamical form. The requirement of taking dynamical form is not simply a technological concern as to dynamical modeling. Rather, it fundamentally raises a normative dimension of understanding: Understanding of cognition should be grounded on resources of DST, such as 'geometric landscape' and 'coupling relationship' etc. Although this normative dimension is not seen as an exclusive way to understand cognition,[2] van Gelder takes it as a must for understanding dynamical *modeling*.[3] This is plausible, but what he later announces, concerning the status of DST resources, tends to be groundless.

Van Gelder (1998) treats the DST resources as still useful for understanding cognition even when the equation-governed modeling is in complete absence. When there is no dynamical modeling available, we can still think cognition in terms of such DST resources. He overtly proposes as follows.

> These resources *can be* brought to bear even in the absence of an actual equation-governed model. If done rigorously, this can buy a qualitative or preliminary understanding of the phenomenon, which may be the best available and forms a solid foundation for further exploration. This approach is useful in situations where, for whatever reason, providing a model is not currently feasible (e.g. Thelen 1995) (van Gelder (1998), p. 621).

This passage recognizes the DST resources as an independent conceptual framework for understanding cognition, independent of its relating mathematical characterization (viz., equation-governed modeling). As is worth noting, such an attitude would perhaps not also be admitted by some dynamicalists who attempt to transpose the DST into cognitive science. Before they apply the DST resources to an envisaged target domain, they may see equation-governed modeling as a pre-condition.

In addition, Clark (1997, 1999, 2001) sees DST as 'a useful tool', and has not made overt distinction between dynamical modeling and DST resources. Still, readers

[1] The two terms 'dynamic systems' and 'dynamical systems' used by Clark and van Gelder respectively seem to mean the same.

[2] Van Gelder (1998) states that modern dynamics 'is a highly general framework that must be adapted, supplemented, fine-tuned, and so forth, to apply to any particular cognitive phenomenon' and that '[t]his typically involves merging dynamics with other constructs (e.g. the schema, …) or theoretical frameworks (e.g. ecological psychology, …)' (p. 621). In addition, Clark (1999, 2001) argues effortfully for a combination of dynamical systems and representations. Such attitudes clearly see the role of dynamical systems in the understanding of cognition as non-exclusive.

[3] Van Gelder (1998) asserts that '[t]he distinctive complexities of cognition yield to scientific understanding only when dynamical modeling is enriched by the perspective and resources of DST (p. 621)'.

should bear this distinction in mind, when they see dynamicalist characterization of cognition unsupported with mathematical modeling, e.g. Oyama (1985), Thelen & Smith (1994), and Thelen (1995).

The warning, as this paper contends, is that the full-scale application of the DST resources to cognition, even simply limited to embodied cognition, remains lacking in evidence but it really needs evidence (of equation-governed modeling). Without the approval of DST's equation-governed modeling, the conception of cognitive nature on grounds of DST resources is likely to be fragile in its empirical validity. The dynamicalist attempt of an overall understanding of cognition in terms of the DST resources, as a consequence, would be premature. A dynamicalist account on the grounds of DST resources should be supplemented with the equation-governed modeling as its price for being convincing (e.g. Thelen *et. al.* 2001); otherwise, it will remain in a position of a not-yet-confirmed hypothesis. Worse, considering a non-DST based phenomenon in terms of the DST resources may risk misleading us with regard to what its nature is.

Basically, the DST is a mathematical theory that characterizes its target domain on the grounds of a set of differential equations. When such mathematical characterization is fortunately available, seeing a target system as a dynamical system is qualified; under such a circumstance, the DST resources would serve to *understand* that domain. However, when that characterization is not available, conceptions with the DST resources would not warrant a dynamical system.

This paper plans to argue these three points. Firstly, understanding of a cognitive system on grounds of DST resources, if not further supported with equation-governed modeling, may still indicate very different kinds of systems; hence is so incomplete that it has no indication of its underlying mechanism. Secondly, a judgment of a system's being a dynamical system grounded on *some* DST resources, would likely be misleading when it readily implicates *other* theoretical properties among the DST resources. For example, an inference from a coupling system to the fact that it is driven by in interdependence of certain low-dimensional factors, would be wrong. Thirdly, the DST resources altogether, which entitle a target system to be a 'dynamical system', do not seem useful as tools in practice, because separate features (such as (b) the notion of coupling relationship) would be less confusing (in understanding a system's being a coupling system).

These three considerations would convince us that conceiving of cognitive systems purely on the grounds of DST resources/metaphors, as Thelen & Smith (1994) and Thelen (1995) did and van Gelder (1998) suggested, would be misleading, unless it is further supported with equation-governed modeling.

2. The DST resources

Perhaps, the equation-governed modeling manifested in DST is generally inessential for the dynamical hypothesis,[4] and in particular nor is it intrinsic for the dynamical approach in action. What matters for understanding the embodied mind is the DST resources as a *conceptual* framework. Such an understanding, yet, is not plausible, as this section will argue.

2.1 Explicating DST resources

The DST, as Clark (2001) describes, includes the following key features:

1. the discovery of powerful but low-dimensional descriptions of systemic unfolding,
2. the provision of intuitive, geometric images of the state space of the system,
3. the (closely related) practice of isolating control parameters and defining collective variables (…), and
4. the use of the technical notion of coupling (…) to model and track processes involving continuous circular causal influence among multiple sub-systems (p. 121) .

When they are transposed into the cognitive science domain, these features can be taken at a technical level and/or at a conceptual level. The former is manifested in the equation-governed modeling such as Beer (1995) in robotic navigation and Grossberg (1995) in the psychology of motion perception, to mention only two. Dynamical systems, therein, are understood in a literal sense—the sense included in the term 'dynamical systems theory (DST)'. The latter (conceptual level) is generally manifested in the attempt to understand dynamical systems without recourse to mathematical modeling, but instead by relying directly on DST resources. The dynamical systems so understood are construed in a looser sense (including a metaphorical sense):[5] systems whose behaviors are *like* the dynamical systems' (in literal sense) behaviors, no matter whether they are observable or purely existent in a mathematical space. The likeliness, according to the general understanding of DST together with Clark's characterization (aforementioned 1-4 points), is characterised in the following four key theoretical notions, which would constitute the aforementioned DST resources:

(a) an unfolding system controlled by **a limited number of interdependent factors**, whose values are **depicted in control parameters and collective variables** of a set of numerically-characterised equations (as manifested in DST);

[4] This seems to be the perspective of van Gelder (1998). See the cited passage in the above text.

[5] The term 'metaphor' is used by Thelen (1995) to describe ideas drawn from the DST, which are the DST resources discussed here.

(b) understanding the change of cognitive states with the **metaphor of geometric landscape**, which according to DST may be further specified in the **metaphors of attractors and bifurcation**. Furthermore, time unfolds along with **trajectory** of the landscape;

(c) **multiple sub-systems:** A system unfolds in accordance with a number of interdependent factors; a system is but one of a few sub-systems, among which are continuous circular causal influence, and these sub-systems constitute **a higher-level system** that in turn can be seen as a sub-system of a further higher-level system. Thus, **within a system there is a continuous circular causal influence (i.e. the coupling relationship) taking place among its sub-systems**, and the role of a 'system' turn up multiply with different levels;

(d) **self-organization:** A **novel pattern** of cognitive order and stable cognitive states may **emerge** although it previously has never been existent. This notion answers the question how cognitive mechanisms and processes arise and are sustained; this requires (a) and (c) as pre-conditions.[6]

Dynamicalists have general understanding of all four points (e.g., as manifested in Thelen & Smith (1994)), but Clark and van Gelder hold different emphasises. Clark emphasizes (c)—the coupling relationship between agent and its environment—and van Gelder (and Thelen (1995)) focuses on (b)—the geometric images of such systems' state space. Common to all of them is an attitude that they can entitle a system 'a dynamical system' without requiring an equation-governed modeling. Surrounding to this attitude can we find certain topics as follows.

2.2 Positive consideration: Resources and tool

The above discussion explicates DST resources point by point; still, the term 'resources' needs clarification as to its role in van Gelder's notion of 'DST resources as a conceptual framework'. This role may relate to Clark's (1997, 1999, 2001) notion of seeing DST as a useful tool, specifically regarding the questions of what tool it is, and what tool it is *for*.

To begin with, the concept of 'DST resources' refers to what DST specifically can illuminate, as opposed to other scientific theories or philosophical theses. A mechanical perspective, as Bechel (1998) points out, can offer analysis into parts and wholes, while DST's main way of relating systems is by means of coupling. The former (mechanical perspective) can decompose the system into various constitutes, while the latter (DST) focuses attention on the reciprocal relationship between its part-systems ((c)).[7] The former can vertically manifest phenomena at different levels and horizontally show how one system affects the control parameters of another; yet, the latter does not present such distinctions. Here, like a mechanical perspective, the notion of coupling serves as a philosophical (metaphysical, specifically) resource of analysis. Following this line of consideration, we can find more resources inherent in the DST or its relating conceptual framework.

Apart from the abovementioned conception of coupling, DST resources are manifested in various conceptions as previously marked in boldface. These conceptions form solid resources of metaphysical analysis. Such an analysis has a two-fold significance. On the one hand, a number of metaphysic conceptions serve to *describe* how equations of DST unfold; on the other hand, those conceptions also have the *explanatory* power for metaphysic understanding as to the way a 'literal' dynamical system unfolds.

Thus, we can deliberate about why ultimately such DST resources subserve our scientific understanding as a tool. The DST, basically, is a mathematical theory, with its scientific details beyond human comprehension. So is the equation-governed modeling on the basis of DST. The behavior of dynamical systems may be hard to understand unless we seek support from a conceptual tool—those conceptions seen as DST resources.

Above is a positive part of the understanding with recourse to DST resources. Below are negative considerations.

2.3 Negative consideration: Is the equation-governed modeling inessential?

Is the equation-governed modeling really inessential? Yes and no. Yes, because it is the DST resources—the above four points—that constitute theoretical understanding of the dynamical systems themselves and the dynamicalism. Mathematical modeling itself does not speak at all. The mathematical characterization, in fact, usually goes beyond human comprehension. No, because a system whose behavior being conceived of as manifesting (a)(b)(c) and (d) may risk having completely no equation-governed modeling on its ground, or even worse, may be simply stored in the theorist's inner sense but indeed never been cashed out. In short, the risk is that a system *looks like*, or *conceived of as*, a dynamical system (in literal sense) may turn out not to *be* that.

The problem is that what *looks like* a dynamical system (in literal sense of DST) does not warrant its being grounded on a DST-based mathematical

[6] The (a) (b) (c) entries are summarized from the aforementioned four key features of dynamical systems that Clark proposed. The (d) entry is advocated by van Gelder as a reason (among others) to support the dynamical hypothesis.

[7] In the parenthesis is the entry this notion corresponds in the aforementioned four DST resources.

modeling. The role of DST resources, in consequence, risks having a principal move from the conceptual foundation of the DST to a metaphorical use of the term 'dynamical systems'. The theoretical thrust may therein become very loose. A metaphorical description of dynamical systems would have no constraint on what the underlying mechanism really are.

An overt problem of the above move is a theoretical understanding heading toward a wrong direction and consequently losing sight of a target phenomenon. This is similar to a medical mistake of offering a wrong prescription, despite the similar clinical symptoms.

3. Underlying Mechanisms

This section discusses the possible mis-implications arising out of using DST resources without grounding on DST-based modeling. To begin with, consider the first main point of this paper:

> Conceiving of a system on the basis of the DST resources does not warrant a DST-based underlying mechanism.

To understand this, let's consider the assumption of using DST resources: DST-based modeling at the highest level would always be feasible.

3.1 Presuming the existence of DST-based laws

A dynamicalist may contend that the underlying mechanism of the target domain may *in reality* be equation-governed on the basis of DST, while the corresponding mathematical characterization is simply *not yet* detected. This is tantamount to saying that the conceptual framework of DST resources implicate the feasibility of DST-based equation-governed modeling at the highest level. The differential equations are *really* out there as the underlying mechanism although not yet epistemologically present. It is in the metaphysical sense that we understand the underlying mechanism of a cognitive domain on the grounds of the DST resources. We can understand that a newly detected star must be governed by certain physical laws, although they are not yet detected. Analogously, the target cognitive phenomenon must be understood in terms of the DST resources, although they are not yet detected.

The previous argument on the basis of analogy, about the existence of a mechanism in accordance with DST modeling, is not successful. It is grounded on an assumption that every physical phenomenon is law-governed. In the celestial bodies this principle is largely plausible; however, when it is argued that it is equally tenable in applying dynamical systems theory to cognitive phenomena, the argument begs the question. To wit, whether the DST-based equation-governed modeling is generally applicable to a target cognitive domain at its highest level remains an open question.

3.2 Mis-implication

A dynamicalist conception of cognitive complexities grounded on *some* (but not all) DST resources may lead to something wrong. When a novel pattern turns up, people would be inclined to think it in terms of emergence, hence categorize it as a self-organizing pattern. If the theoretical deliberation is put in the context of dynamicalism, then it is easy to quickly recognize the aforementioned feature (d) and consequently see the detected pattern as arising out of a dynamical system in the DST sense. It is straightforward, with the DST resources as a conceptual framework, to take other three features (a)-(c) as its theoretical properties. If the feature (c) is further confirmed in observation, a theorist will be further convinced of its being a dynamical system in DST sense. Consider the feature (a) as a feature of the underlying mechanism. The envisaged pattern would thus be regarded as arising out of interactions between low-dimensional factors (such as the control parameters and collective variables in the equation-governed modeling). However, there is no warrant that a DST-based equation-governed modeling at the target system's highest level would necessarily be in position. The question of what the underlying mechanism is should remain open. It may well be a connectionist neural network, where the system is controlled by a *large number* of units; alternatively, it may be a system with Brookian subsumption architecture, where no overt low-dimensionality is required. Worse, the underlying mechanism may be somehow controlled by certain action-oriented representations, as evident in Clark & Grush (1999). There is basically nowhere to position representation within the framework of DST resources, especially considering feature (a); yet, (a) is part-and–parcel to DST resources. All above rebuttals can be cleared away when the DST-based equation-governed modeling is required in the first place for recognizing a dynamical system.

Crudely speaking, the features (b)-(d) are not features exclusively pertaining to a DST-based dynamical approach. If the requirement of low-dimensionality is loosened, even (a)—the interdependence between some factors—is not an exclusive character of DST. The feature (b) can be seen in Waddington's landscape (Waddington 1975). The feature (c) and (d) are both prominent in various non-DST-based complex adaptive systems, such as animate vision (Ballard 1991). Hence, (a)-(d) amounts to the negation of the computational approach to cognitive science; the coverage of this is very broad and has gone greatly away from the DST itself, be it DST modeling or DST resources. The most distinctive characteristics of DST resources are two: interdependence between low-dimensional factors and the geometric landscape controlled by attractors and bifurcation. They must be specifically supported by

DST modeling, rather than simply the property remaining in (b)-(d).

The above argument is a criticism on the conception of cognitive complexities grounded on *some* (but not all) DST resources but without DST-based modeling. How is it if the word 'some' is replaced by 'all': viz., a conception is grounded on *all* (a)–(d) features but remains lack of DST-based modeling?

This replacement would not lead to any change in conclusion. Given that it is controlled by a *limited* number of factors, the underlying mechanism would not be a neural network. However, other possibilities remain at stake. Before the conclusion is drawn, the current argument can still reach the same point that the envisaged system is a DST-based dynamical system. In fact, the argument leading to this point is more straightforward, as all four features are at hand. The conclusion would remain the same: What the underlying mechanism is remains an open question. Seeing an envisaged system as necessarily being a DST-based dynamical system would still be misleading.

3.3 All dynamical systems can and should have a DST-based modeling?

Van Gelder (1998) seems to believe that all quantitative systems will have a dynamical modeling, when he summarizes his thesis of dynamical hypothesis as follows:

> For every kind of cognitive performance exhibited by a natural cognitive agent, there is some quantitative system …; in addition, causal organization *can and should be* understood by producing dynamical models using the theoretical resources of dynamics, and adopting a broadly dynamical perspective (italics added, van Gelder 1998, p. 622) .

If it is further granted that understanding the causal organization can be grounded on DST resources, the aforementioned mis-implication would be in position. As previously discussed, van Gelder's belief, that '[t]hese resources *can be* brought to bear even in the absence of an actual equation-governed model', would lead up to this undesirable point. That is, when DST resources are deemed as universally applicable to any cognitive system, the easily-made implication of a DST-based underlying mechanism would be misleading. However, a mis-implication as to the system's understanding mechanism would easily be in the way.

The above arguments entrenches the aforementioned first main point of this paper.

3.4. Implication across the features of DST resources

Consider the second main point:

> Implication across the four features of DST resources is likely to be misleading.

The above section gives a warning as to the implication from some features (out of (a)-(d)) to the underlying mechanism of the entire system. The point at issue gives another warning regarding the application of DST resources: the implication from some features to another would also be misleading. Giving such a warning would not be very startling, as this is implicit in a previous argument. Implication across the four features of DST resources is most likely when the target system is regarded as a DST-based dynamical system. If the notion of DST resources mistakes a feature of them as a *criterion* of a DST-based dynamical system, then another feature pops out as this notion's implication. Thus, for example, we can infer from a coupling relationship between brain, body and the environment (feature (c)) to predicting a self-organizing novel pattern ((feature (d))), or to the fact that the envisaged system is controlled by a low-dimensionality of interdependent factors (feature (a)). Such an implication is misleading, basically because (as previously argued) there is no warrant that the underlying mechanism of that sort of system is DST-based at the system's highest level. Therefore, we present this second warning.

4. What is meant by a 'dynamical system'?

Consider the third main point:

> The DST resources altogether would not be as useful as any single resource.

The DST resources altogether, allow us to consider a target system in terms of 'dynamical system'. This would not necessarily direct our attention to some treasure, but may lead to confusion. The name 'dynamical system' is highly ambiguous, as appears in the peer review of van Gelder (1998). It may refer, as van Gelder himself suggests, to a quantitative system; yet, it may otherwise be considered to be a state-dependent system, as Michael Wheeler (1998) suggests; or, it may simply mean a system with any single feature among the aforementioned four features of DST resources—a system with a coupling relationship or a system whose trajectory is manifested in a geometric landscape. Of course, it may also strictly refer to a system with DST-based equation-governed modeling. All these systems are different; hence the name 'dynamical systems' would bring about confusion, as to what it is. If DST resources are to be taken altogether as a tool, hence, that tool would likely be very blunt.

Why not, as this paper suggests, reserve it (the name 'dynamical systems') strictly to those systems with DST-based equation-governed modeling? Then, those systems with coupling relationships can be specifically named to be 'coupling systems'. This, at least, avoids confusing such systems with the strictly DST-based dynamical systems.

Consider van Gelder's (1998) original concern—quantitative systems at the highest level. Defining a 'dynamical system' in terms of a quantitative system would likely lead to the undesired contravention, as it takes place between van Gelder (1998) and Beer (1998), that a digital computer is a dynamical system. A better way to managing that term, as this paper suggests, would be leaving the so-far-confusing title 'dynamical system' specifically exclusively to those systems with DST-based modeling, and call the target systems in van Gelder's mind with its direct name 'quantitative systems at the (system's) highest level'. This will save much time for clearing up similar confusions.

The gist of this section is as follows: DST resources are useful tools when they turn up separately; however, when they turn up altogether as features of a special sort of systems—dynamical systems—they bring about much confusion.

5. Concluding Remarks

Dynamical systems theory (DST) is indeed attractive, as it presents an alternative to the orthodox computational approach to cognitive science, indeed a new approach appropriate for illuminating various dynamical features of cognition. Yet, it is hard to conceive because it's basically a mathematical theory with numerical subtleties; consequently, it needs to rise to an upper level in the light of *conceptual* explanations. DST resources, thus, arise for this need, and serve as useful tool for understanding the embodied mind. However, the management of that conceptual illumination may incur certain illusory implications. Certain as-yet-unnoticed risks are lurking, basically because those conceptual resources float away from the anchor of the DST-based equation-governed modeling. However, managing DST resources in this way have been approached in some dynamicists' works, such as Thelen & Smith (1994), Thelen (1995) and van Gelder (1998), and also appeared in reconsideration of dynamical systems analysis, such as Clark (1997). This paper aims to uncover such risks by elucidating the notions of DST resources in the beginning and then expounding their nature as a useful tool. On these grounds, the discussion went on to examine various possible mis-implications. Firstly, conceiving of a system on the basis of the DST resources has no bearing on a specific understanding mechanism. Secondly, when any one among the four features of DST resources turns up and is taken as a criterion of DST-based dynamical system, an inference of that system's also having another feature may be a mistake. Lastly, discussion criticized the entitlement of a 'dynamical system' on the grounds of those DST resources, because may it direct our attention to ambiguities of that term. The DST resources would not be safely useful tools unless all those risks are avoided.

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