The dynamical system approach
Dynamic systems theory has been introduced in physical science. The main goal of this paradigm has been to explain the changes over time (and change in rate of change over time, etc.) of a system. (Clark 2001, p. 121)

More recently, some authors maintain that dynamic systems theory is the most appropriate framework for understanding cognition. Cognitive systems are taken to be dynamical systems as van Gelder suggests: “cognitive agents are dynamical systems and can be scientifically understood as such”. (van Gelder 1999) The new metaphor discusses the core notions of the preceding paradigms—notions such as computation and representation. Within this new metaphor, there are already some tendencies for various classifications of the dynamicists: representationalists, non-representationalists, or meta-representationalists, computationalists and non-computationalists, connectionists and dynamic connectionists, and so on.

A dynamical system is characterized by a set of state variables and a dynamical law that governs how the values of those state variables change with time. The set of all possible values of the state variables constitutes the system’s state space. The parameters of the system determine the dimensions of space. A state of the system is a point in its state space. The sequence of the states represents the trajectory of the system. The behavior of a system (that changes over time) is represented by a sequence of points in its phase space (a numerical space described by differential equations). (van Gelder and Port 1995, p. 5) Usually, geometric images are used to grasp this trajectory: “behaviors are thought of in terms of locations, paths, and landscapes in the phase space of the system.” (van Gelder and Port 1995, p. 14) The common notions are control parameters (factors that affect the evolution of a system) and collective variables. A common example of a dynamical system is the solar system in which the position and the momentum of one planet differ from that of other planets and mathematical laws relate the changes over time. (van Gelder 1995, p. 363 or van Gelder and Port 1995) In fact, scientists try to explain such a real system by means of a mathematical dynamical model. The rates of change are represented by differential equations.
Space state is a set of possible trajectories; to describe the laws that are giving the shape of possible trajectories (the flow) are used for either the conceptual tools of discrete mathematics or of continuous mathematics. The main concepts taken into account to describe state space are the following: (1) an *attractor* is a point or a region with the property that any trajectory which is passing near to a point or a region is attracted in that point or region; the surface of such influence is called the basin of attraction (2) the *repellor* is a point or a region which has the contrary property of attractor: rejects all trajectories which are passing near to that point or region (3) a *bifurcation* is a point in which a small change in the values of the parameters can change the direction of the state space’s flow and can shape a new space of attractors and repellors.

In the framework offered by dynamical systems theory cognition is viewed “in motion”. The Cartesian distinction between mind and body is abandoned. Mind, body and the environment are dynamical-coupled systems, which interact continuously, exchanging information and influencing each other. The processes happen in real continuous time. In connectionism, van Gelder claims, a change in system is a transformation from one representation to another, these being “static” entities which exist only at an instant of time: “they result from freezing the behavior of the system”. (van Gelder 1995) In a dynamical system we do not have discrete identifiable steps in which one representation gets transformed into another. From this perspective there are two points of view regarding the problem of representation. The radical one considers that the brain does not compute representations. (van Gelder 1991, 1995; Kelso 1995; Thelen & Smith 1994; Skarda & Freeman 1988) The moderates suggest that we need only to replace the vehicle of representations or to take the notion of representation in a weaker sense. (Bechtel 1998; Clark 1997a, b; Wheeler & Clark 1997)

The radicals among the dynamicists pretend merely that terms such as “representation”, “computation”, “symbols”, and “structures” are useless in any explanation of human cognition. (van Gelder, Thelen & Smith, Skarda & Freeman, Wheeler)
Explanation in terms of structure in the head-beliefs, rules, concepts, and schemata-are not acceptable. … Our theory had new concepts of the center-nonlinearity, reentrance, coupling heterochronicity, attractors, momentum, state spaces, intrinsic dynamics, forces. These concepts are not reductible to the old ones. (Thelen and Smith, 1994, p. 338; my emphasis) (Clark 2001, p. 129)

We posit that development happens because to the time-locked pattern of activity across heterogeneous components. We are not building representations of the world by connecting temporally contingent ideas. We are not building representations at all! Mind is activity in time… the real time of real physical causes. (Thelen and Smith, 1994, p. 338; my emphasis) (Clark 2001, p. 129)

The notions that dominate dynamical theory are those of pattern and self-organization, and they are strongly related to coupling and circular causation. (Clark 1997b; Kelso 1995; Varela et al. 1991) They are used especially to describe and analyze the patterns that emerge from interactions between organism and environment (where “organism” means the totality of neural and bodily elements). Important is to grasp the processes through which “regular structure in space and time are produced … without either a specific plan or an independent builder …but simply organize themselves. (van Gelder and Port 1995, p. 26-7) The organism and the environment could be considered as a single coupled system (composed of two subsystems), the evolution of which is specified by a set of differential equations. The coupled system unfolds by a kind of special causation, called circular causation: each subsystem is continuously influenced by the other and at the same time influences the evolution of the other subsystem. This kind of causation is known as continuously reciprocal causation. (Clark 1997a, Chapter 8) Evidently, there is a kind of circular causation between the brain, body and environment.

Dynamic system theory rejects the existence of representations and introduces an essential parameter: time. (Port and van Gelder 1995) Usually, dynamicists give examples of bodily actions such as a child’s walking (Thelen and Smith 1998) or the movement of fingers (Kelso 1995), and they extrapolate the conclusions from procedural to declarative knowledge or from perception and sensoriomotor processes to high-level cognitive processes. The proponents of DST do not take into account concrete declarative tasks. Thelen and Smith, van Gelder and other dynamicists replace static and discrete representations with attractors that are in continuous movement and, at the conceptual level these attractors seem static and discrete. An
essential difference between computational and DST is time. “The heart of the problem is time. Cognitive processes and their context unfold continuously and simultaneously in real time.” (van Gelder and Port 1995, p. 2) And time involves changes of a system.

There are some dynamicists in cognitive science (Globus 1992, 1995; Kelso 1995) who reject not only the representations but also the process of brain computations. Globus replaces the process of computation with constraints that take place between elements and levels of the system, and Kelso mentions that “[r]ather than computes, our brain dwells (at least for short times) in metastable states”. (Kelso 1995, p. 62)

When the interactions between the human organism and the environment are very complex, certain bodily and outer aspects take over the tasks usually associated with some pure innate computational resources, which leads to the increase of behavioral fluency and flexibility. In such situations, the participating processes and states cannot be completely specified and the adaptive hookup does not follow from a set of instructions generated by a general control, but from self-organization processes that underlie the brain, the body and the environment. (Wheeler and Clark 1999) Clark takes into consideration “hungry representations problems” (decision making, counterfactual reasoning, etc.). These involve a potential decoupling between the representational system and the environment that is a kind of off-line cognition rather than on-line as the dynamicists suggest. He considers that in such cases the cognitive system has to create a certain kind of item, pattern or inner process that stands for a certain state of affairs, in short, a representation. (Clark 1997a)

The theory of dynamical systems best captures the complexity of change. This is why it has been used to explain:

(a) the constitutive interactions between neurons and between ensembles of neurons and

(b) the constitutive relations between primitives of the conceptual level (representations and concepts) through child development using mathematical apparatus (especially differential equations).

Although these approaches cannot predict the course of events, as in classical physics, they can explain them. (Fisher and Bidell 1998; van Geert 1994)
Van Gelder rejects mental representation and computation. He makes an analogy between mind and a particular mechanism—Watt’s governor—that is in motion. (van Gelder 1995)

The computational approach is nothing less than a research paradigm in Kuhn's classic sense. … Natural cognitive system, such as people, aren’t computers… It is not the brain, inner and encapsulated; rather, it is the whole system comprised of nervous system, body, and environment. The cognitive system is not a discrete sequential manipulation of static representational structures; rather, it is a structure of mutually and simultaneously influencing change. The cognitive system does not interact with other aspects of the world by passing messages or commands; rather, it continuously coevolves with them. . . . [T]o see that there is a dynamical approach is to see a new way of conceptually reorganizing cognitive science as it is currently practiced (Van Gelder & Port, 1995, pp. 2-4).

And

dynamical and computational systems are fundamentally different kinds of systems, and hence the dynamical and computational approaches to cognition are fundamentally different in their deepest foundations" (Van Gelder & Port, 1995, p. 10). (Bechtel 1998, p. 296)

The computational governor vs. the Watt centrifugal governor

Van Gelder compares two kinds of governors (and their “conceptual frameworks”, van Gelder 1995, part III): computational and centrifugal governors. On one side, the computational governor follows an algorithm with a few steps and it has three characteristics: (1) operating internal representations and symbols, (2) the use of computational operations over the representations (3) discrete, sequential and cyclic operations (4) “homuncular in construction”: homuncularity is the decomposition of a system in parts/components, each realizing a subtask and communicating with the others. (van Gelder 1995, p. 347-8 and 350-1; comments Clark 2001, p. 126 or Bechtel & Abrahamsen 2001, p. 266) On the other side, the centrifugal governor is norepresentational and noncomputational. The relationship between the two quantities (arm angle and engine speed) that are coupled in a “continuously reciprocal causation” can be explained only within a mathematical framework of dynamics. (van Gelder 1995, p. 353)
The Watt centrifugal governor for controlling the speed of a steam engine:

![Figure 1](image)

The governor was designed by Watt to solve the problem of maintaining constant speed for the flywheel of a steam engine. Watt solved this problem by a technology already employed in windmills. It involved attaching a vertical spindle to the flywheel which would rotate at a speed proportionate to the speed of the flywheel. He attached two arms with metal balls on their ends to the spindle; these arms were free to rise and fall and, due to centrifugal force, would do so in proportion to the speed of the governor. Through a mechanical linkage, the angle of the arms would change the opening of a valve, thereby controlling the amount of steam driving the flywheel. This provided a system in which, if the flywheel was turning too fast, the arms would rise, causing the valve to partly close. This would reduce the amount of steam available to turn the flywheel, thereby slowing it down. On the other hand, if the flywheel was turning too slowly, the arms would drop and this would cause the valve to open, resulting in more steam and hence an increase in the speed of the flywheel (Figure 2a). (Bechtel 1998, p. 303)

Such mechanisms are “control systems” that are noncomputational and non-representational: in this system we cannot find any kind of representations and any discrete operations (so no steps in an algorithm). The only way to explain them is the
dynamic analysis. The idea is that the relationship between the arm angle and the engine speed cannot be explained by computational explanation. These two quantities continuously influence each other and this process involves the dynamic notion of coupling. (Clark 2001, p. 127) (Leibniz’s two clocks on a wall…) Through analogy, this process is available for the relationship between brain, body and environment. In Clark interpretation, the dynamical system approach reflects the continuous reciprocal causation between brain, body and environment. (Clark, p. 128)

Usually, the examples offered by the proponents of DST are taken from physical system (the Watt governor, van Gelder 1995) or sensoriomotor control systems – learning to walk (Thelen and Smith 1994) or rhythmic finger motion (Kelso 1995). For radical dynamicists, high cognitive processes are just the result of the evolution of perception and sensoriomotor control systems. Thus, if the last phenomena are the result of continuous reciprocal causation between brain, body and environment (“ongoing coupling”, Clark’s notion), then the cognition is in the same situation. For instance, Pollack (1994) considers that for “unifying nature cognition with nature” we should look not at “software law” but at physical law. (Pollack 1994, p. 119 in Clark 2001, p. 130)

Rejecting the use of representations in explaining cognition, the proponents of DST consider that the representations can be replaced by certain dynamical processes.

while dynamical models are not based on transformations of representational structures, they allow plenty of room for representation. A wide variety of aspects of dynamical models can be regarded as having a representational status: these include states, attractors, trajectories, bifurcations, and parameter settings. So dynamical systems can store knowledge and have this stored knowledge influence their behavior. The crucial difference between computational models and dynamical models is that in the former, the rules that govern how the system behaves are defined over the entities that have representational status, whereas in dynamical models, the rules are defined over numerical states. That is, dynamical systems can be representational without having their rules of evolution defined over representations. (van Gelder & Port, 1995, p.12) (Bechtel 1998, p. 304)

In DST the rules are define over numerical states = dynamical systems are representational “without having their rules of evolution defined over representations.” (van Gelder and Port 1995, p. 12) More then this, the DST can
manages discrete state transitions (a) using discrete states (catastrophe model that leads to a bifurcation) or (b) imposing discreteness in describing “how a continuous system can undergo changes that look discrete for a distance”. (van Gelder and Port 1995, p. 23) If cognition (an intelligent system interacting with the world) is a particular structure in space and time, the mission for researchers is to discover how the structure “turn out to be a stable state of the brain in the context of the body and environment”. (van Gelder and Port 1995, p. 27)

Clark introduces the distinction between on-line and off-line processes. “Off-line cognition are decision making and counterfactual reasoning where the subject has to think about representations in their immediate absence.” (Clark 1997b) Clark (and others) notices that there is a problem regarding the extension of continuous reciprocal causation from on-line to off-line processes. He believes that we cannot follow DST in rejecting the computation of the brain. And computation involves representations.

talking about “hungry representation problems”, Clark underlies the necessity of representation for off-line cognition, which suppose a potential decopulation of the subject from his continuously interaction with environment.

In “Open Peer Commentary” from BBS (1998) at van Gelder’s article, many people argue that DST can explain only perception and sensoriomotor control systems not higher level cognitive processes.

Essential it would be the difference between knowledge-based and physical-causal systems. (Clark 2001, p. 134) that reflects the relationship between perception/action and high-level cognitive processes (“embodied cognition” or “cognitive incrementalism”, Clark p. 135) For grasping this relationship from an evolutionary neural perspective, Clark introduces Milners and Goodale’s “two visual systems” hypothesis (p. 136): dorsal stream supporting on-line visuomotor action and ventral steam for off-line visual reasoning, visually based categorization and verbal report.
For van Gelder, if everything is in motion, then we do not have any static and discrete representations. Thus he tries to prove that everything is in motion and “everything is simultaneously affecting everything else.” (van Gelder and Port 1995, p. 23)

dynamicists conceptualize cognitive processes in geometric terms. The distinctive character of some cognitive process as it unfolds over time is a matter of how the total states the system passes through are spatially located with respect to one another and the dynamical landscape of the system. (van Gelder and Port 1995, p. 15) and

cognitive processes always unfold in real time; that their behaviors are pervaded by both continuities and discretenesses; that they are composed of multiple subsystems which are simultaneously active and interacting; that their distinctive kinds of structure and complexity are not present from the very first moment, but emerge over time; that cognitive processes operate over many times scales, and events at different times scales interact; and that they are embedded in a real body and environment. (van Gelder and Port 1995, p. 18)

In their view, the embeddedness of cognition within neural system is the framework for idea that a system can be simultaneously described at two levels: dynamical and computational levels. In fact, the dynamics of central cognitive processes and dynamics of neural processes are two-levels (high and low) of description. “Dynamical systems theory provides a framework for understanding these level relationships and the emergence of macroscopic order and complexity from microscopic behavior.” (Van Gelder and Port 1995, p. 29)

Let me analyze Watt’s example from a different perspective. Depending on the subject’s conditions of observation, in our ecological niche we can represent things continuously or discontinuously, in motion or as static. I think van Gelder is wrong in introducing this analogy in order to reject the existence of mental representations. Let us imagine that we can spatially extend the wheel on which the driving belt moves this, being, in Ptolemaic epicycles, a blow-up from the macroscopic “level” to the level of macromolecules. The wheel would not be even anymore, but like that of a clock. And if we have a cog system instead of a driving belt, the transmission would be discrete, involving certain steps of movement. In this case we have a different organizational “level”. (Vacariu et al, 2001)
According to Skarda and Freeman’s experiment, a rabbit has a certain pattern of activity of neurons while smelling something. (Skarda and Freeman 1988, 1990) After the mouse smells something else, it returns to smell the first thing again. In the latter case, the pattern of activity is no longer identical with the first pattern even though it is similar. In this way they consider that there are no representations.

There is nothing intrinsically representational about this dynamic process until the observer intrudes. It is the experimenter who infers what the observed activity patterns represents to or in a subject, in order to explain his results to himself (Werner, 1988a, 1988b). (Freeman and Skarda, 1990, p. 376) (Bechtel and Abrahamsen 2001, p. 271)

DST- the introduction of time and continuous brain-body-environment interactions motivates the rejection of representations. Van Gelder and Port claim that dynamical system theory catches both the continuity and discreteness aspects of cognition (van Gelder and Port 1995). We can grasp both continuity and discreteness taking into account Fischer and Bidell or van Geert’s directions that are interested in the dynamical combinations of representations. (Fischer and Bidell 1998; van Geert 1993). However, can we reject the existence of representations? Fisher and Bidell speak about a dynamical structuralism where variations appear within stability. (Fischer and Bidell 1998) They claim that structure is in motion. Then what is stable? From an organizational viewpoint, we can think that a structure is in motion only if we consider that that structure is given by the relations among the entities (in our case, the neurons). According to Merzenich and deCharms, relations are more important than entities. (Merzenich and deCharms 1996) Thus we can say that the relational structure of entities that is constant in a brain-body that belongs to macro-world corresponds to a particular mental representation from the mind. In the dynamic of structure, the organizational structure of a system is maintained through the relations between neurons, not through the neurons themselves. The structure is stable but it can appear to be in motion when regarded in the light of the interactions of a system with the environment.
