consciousness, on the other, was completely severed" (Thompson, 2007a, p. 5). Consequently – as Thompson claims – cognitivism works with inadequate notion of cognition. This statement is at odds with practical achievements within cognitive science and its contributing disciplines. Since its very beginning cognitive science offered numerous explanations – in terms of cognitive psychology, cognitive neuroscience or cognitive models. Solutions provided by cognitive science changed and evolved. This evolution can be seen in two aspects. First, the scope of phenomena addressed by means of representations and computations changed in time. Cognitive scientists embrace new phenomena in their research: emotions, motivations, individual differences, cognitive development. Recently, cognitive scientists attempt to address the problem of consciousness as well. Second, purely symbolic systems were replaced by robotic, embodied agents interacting with their environment. It seems that Thompson's objection is partially addressed.

The above presentation of cognitivism is not complete. I will return to the methods of standard cognitive science in Chapter 8. I argue there that cognitive (computational) modeling can be applied in studies on meaning-making activities. Specifically, I present and discuss one example (out of many available) of a computational model of meaning-making processes and I outline my cognitive model of semiosis.

5.8 Departure from cognitivism: dynamical systems

In the closing section on cognitivism I present the basic notion of the third approach to cognition, "embodied dynamicism," as Thompson calls it (2007a, p. 10). Embodied dynamicism stresses the role of cognition as an embodied activity, it focuses on self-organization and treats cognition as something emerging from sensorimotor interactions between a cognitive system and its environment. It is based on van Gelder's dynamical systems theory. Standard cognitive science – as stressed number of times – is based on the assumption that cognitive systems represent information in some form and perform operations on these representations. As Rowlands (2010, p. 114) states: "Invocation of mental representations has been a staple of cognitive-scientific theorizing." The dynamical approach is seen as an alternative promising explanations of cognition without reference to representations.

Dynamical approach assumes that we can explain how organisms respond to environmental stimuli and how agents can navigate in their environments without assuming the internal machinery of representations and computations, described in previous sections. Instead, the dynamical approach to cognition invokes three key notions: a *state space*, *trajectory* through that space, and *laws* determining the shape of the trajectories. A state space is a geometric way of presenting possible states in which a dynamical system can exist. The state space has an arbitrary number of dimensions

– depending on the parameters taken into account. We can unambiguously identify any state of a system as a set of coordinates in its state space. The addition of a new dimension in the state space – the one representing time – allows for the representation of the sequence of states of the system (its evolution) in the form of a trajectory through state space. In other words, behavior is described in terms of a point changing location in such space. The successive states are determined by *dynamical laws* (e.g. in the form of differential equations). The ultimate goal of the dynamical approach is to *provide equations* describing trajectories that the system may take through the state space. Such equations govern the evolution of the system (given certain initial conditions of the system). One more crucial notion needs to be mentioned, namely the notion of an "attractor." An attractor is characterized as a point in space (or a region in this space) which attracts trajectories passing in the vicinity of this point.

In sum, a dynamical approach sees certain systems (including human beings) as systems evolving over time according to dynamical laws. A typical example of a dynamical system is an idealized swinging pendulum (cf. e.g. Bermúdez, 2010, pp. 417–421 for a detailed description). As numerous elaborations of the dynamic system theory note, the Watt governor can be also described in terms of the dynamical approach. Van Gelder (1995, pp. 356ff) highlights the four features of Watt's governor:

- it can be described by means of differential equations specifying how the angle changes as a result of engine speed;
- it is time-sensitive: the relation between flywheel speed and arm angle changes with time;
- as a whole it is a so-called coupled system, namely there is an interdependence between the arm angle, the throttle value and the speed of the flywheel. The arm angle fixes the speed of the flywheel and simultaneously the speed of the flywheel fixes the arm angle;
- it can be described in terms of attractors: points in the system's state space on which different trajectories converge.

To sum up the example, the Watt's governor is an example of a system which can be characterized without reference to representations, computations or subsystems. Instead, it is characterized as a coupled system, working in real time and displaying a version of attractor dynamics.

In contraposition to representational cognitive science, which – according to van Gelder – is committed to the so-called reverse engineering, a dynamical approach uses an alternative theoretical framework to answer the question: *how the mind works*. Van Gelder (and his followers) suggest that we can apply the same set of tools – dynamical theory systems – to explain cognitive activities or, in other words, workings of the mind. The justification of the claim is that dynamical systems theory highlights the basic principles of mind. Mind, according to the approach, is a coupled system interacting with its environment. This coupling (between the mind and the environment) evolves in time as a function of a small number of variables.

So far we have only an analogy between the mind and a governor (or a pendulum). What makes this approach relevant for discussions on cognition and meaning-making? Let us first have a look at two applications of dynamic systems in explanations of cognitive activities.

5.8.1 Dynamical systems – applications

Esther Thelen (1995) suggests an explanation of an infant learning to walk without reference to high-level cognitive capacities like planning or decision making. This activity, as the author argues, emerges as a result of complex causal interactions between limbs, muscles and various features of the environment. The peculiar feature of learning to walk is the U-shaped developmental pattern: there are three stages in the process of learning to walk. First, children are capable of making stepping movements. Then the stepping movements disappear for some time. Finally, the child makes stepping movements again and starts to walk. The conclusion of Thelen's study is that one cannot take into account just the brain and nervous system and grant them a privileged position. The possibility of inducing stepping movements during a "non-stepping" period by, e.g. suspending an infant in a warm water, suggests that the non-stepping period is not the result of an insufficiently maturated cortex. Instead, the author argues, the walking behavior can be explained by means of dynamical equations taking into account a small number of variables.

The second area where the dynamic approach has been applied is the so-called phenomenon of *A-not-B error*. This example shows that alternative (representationalist and non-representationalist) explanations of the same phenomenon are possible. Jean Piaget (1954) in his studies on object permanence (i.e. children's understanding that objects exist even when children cannot perceive them) noticed that in a hiding-searching task children make a striking error: they have difficulties in finding an object even if they see where it was hidden. Piaget himself explains the phenomenon with reference to mental representations. According to his approach, children are not able to form abstract mental representations of objects by the age of 12 months. Instead, their "knowledge" takes a form of a sensori-motor routine. In the experimental situation, the child is presented with an object (a toy) which is hidden a number of times in a box A. The procedure is repeated until the child starts to reach towards the box A. Next, after a short delay in time, the toy is hidden in box B (and the child can see where the toy was hidden). Researchers observed that the child reaches toward box A. Thelen and collaborators (2001) reject the Piagetian representational explanation and suggest an alternative account based on the dynamical systems theory. In a similar way as in the case of learning to walk, the author identifies various factors influencing infant A-not-B behavior. Namely, the results of the experiment change when we draw an infant's attention to one side of the table. Tapping the "right" side of the table significantly improves children's performance. Second, infant behavior depends on the number of trials during the first stage of the experiment. The performance – which may be surprising – depends also on the infant's posture (sitting during the first stage and supported-standing posture during the second stage improves performance). The conclusion drawn by the authors is that phenomenon cannot be cognitive (in a traditional, cognitivist sense): the results of manipulations suggest that infants' capacities do not depend on cortex activity alone. The explanation provided by Thelen and collaborators is based on a dynamical systems modeling: namely, it involves the notion of the dynamic field, which is supposed to represent the visual and reaching space in front of the infant. Higher activations (cf. tapping) in a particular area of the field result in infant's reaching activity toward that area. The dynamical field – in line with general assumptions of dynamical systems theory – is time-sensitive, so it evolves in time. The activation levels of preceding states influence in a continuous way the activation levels of successive states. The evolution of an activation level is a function of three factors: environmental input (constraining: e.g. infant's possible actions – a sitting or standing position is relevant here), task-specific input (e.g. drawing attention to one of boxes) and memory input (as a result of previous experiences). The three factors influence the activation level for a particular location (either box A or B).

To sum up the section, dynamical systems theory proved its applicability to selected (mainly developmental) aspects of cognition. Can the dynamical approach be seen as a real alternative to the standard cognitive scientific view? Some researchers (Thompson, 2007a) claim that this approach replaces (successfully) the computational theory of cognition. Van Gelder himself hoped that the dynamical system model will finally completely replace the computational model (cf. Bermúdez, 2010, p. 429). One can formulate two objections to such optimism. First, the number of experiments and models based on dynamical systems is relatively small. The notion of representation, in turn, proved to be useful and fruitful in a huge number of psychological experiments and models developed within cognitive psychology. Similarly, the relatively small number of attempts to apply dynamical systems theory in robotics (see Chapter 6) is confronted with a huge body of research within representationalist and computational Artificial Intelligence. One can say that the difference in results is an effect of the novelty of the dynamic approach. Regardless of validity of this claim (van Gelder proposed dynamical system theory in the mid 1990s; Thelen and collaborators presented their approach in 1993 and 2001), there is a more important reason why the dynamic system approach will not gain popularity as an exclusive tool for cognitive science. Namely, dynamic system theory undeniably provides a uniform description of certain world processes. It can be applied equally to Watt's governor, traffic jams and sensorimotor development of children. This is possible because the dynamical approach is formulated – as José Bermúdez (2010, p. 420) writes – at a high level of abstraction. As such, the approach ignores a number of specific phenomena. In the case of traffic jams we can predict the concentration of traffic and, accordingly, plan our trip. But we cannot say anything about the types of cars, their engines, drivers, etc. Similarly – Bermúdez continues – we can predict that after the infant's initial trials to walk at around 11th months, an infant will enter non-stepping period. But we will not know how this phenomenon is related to other cognitive and sensorimotor capacities. In addition, we will not be able to relate it to neurobiological, developmental, social dimensions.

The dynamical systems theory is presented in the chapter on cognitivism, since it is considered as the third stage in development of cognitive science (Thompson, 2007a) and should be assessed in connection with symbolic and connectionist approaches. The dynamic approach promises studies on cognition without representations and computations. Some aspects of van Gelder's approach (e.g. sensitivity to temporal factors, dynamic coupling of brain, body and environment, self-organization present in dynamic systems) clearly highlight weaknesses of standard cognitive science. These features, together with its anti-representationalist attitude, made the dynamic systems theory the first step to non-standard and non-Cartesian approaches to cognition. These approaches are discussed in the next chapter.