Chapter 6

Sensorimotor agency

To trace the development of mind from the earliest forms of life that we can determine, through primitive acts which may have vague psychical moments, to more certain mental acts and finally the human level of "mind," requires a more fertile concept than "individual", "self" or even "organism"; not a categorial concept, but a functional one, whereby entities of various categories may be defined and related. The most promising operational principle for this purpose is the principle of individuation. It is exemplified everywhere in animate nature, in processes that eventuate in the existence of self-identical organisms; it may work in different directions, and to different degrees; that is, an organism, proto-organism, or pseudo-organism may be individuated to a low or high degree, in some respects but not in others, and anomalies of individuality—double-headed monsters, parabiotic twins, as well as properly semi-individual plants and animals—may arise by imperfect or by normally only partial individuation. Under widely various conditions, this ubiquitous process may give rise to equally various kinds of individuality, from the physical self-identity of a metabolizing cell to the intangible but impressive individuality of an exceptional human being, a Beethoven or a Churchill, who consequently seems "more of an individual" than the common run of mankind.

Individuation is a process consisting of acts; every act is motivated by a vital situation, a moment in the frontal advance of antecedent acts composed of more and more closely linked elements, ultimately a texture of activities. The situation, uniquely given for each act (and therefore not amenable to specific description), is a phase of the total life, the matrix from which motivation constantly arises.

—Susanne K. Langer (1967, pp. 310–11)

6.1 The plot thickens

Bandit cannot metabolize rubber. Yet he spends a good part of the day chasing and chewing rubber balls. He swallows small fragments of hard rubber when he succeeds in splitting them apart at a rate of about one new ball every couple of days.

Bella has no interest in seafood and she hates it when her owner wants to give her a bath. Yet twice a day she runs after the receding waves on the beach and stays there, paws sinking in the wet sand, expecting the moment she will get soaked in the cold salty water.

Why would these dogs be committed to activities with no apparent consequence for their biological survival? And committed they are. Try to take away Bandit's ball and you will get a growl. Call Bella to come out of the water and she will not even look in your direction. Why do they behave like this? "She's always been that way," Bella's owner might say, “loves getting wet and rolling over in the sand. No matter how much I try to clean her afterwards I always end up walking home with a schnitzel on a leash.”

In referring to who they are, we often describe the way an animal or a person typically behaves. And in trying to explain what they ordinarily do, we often find no better reason than to say “that’s just who they are.” Perhaps this is what Susanne Langer intends when she says that individuation consists of acts?

In Chapter 5, we built a concept of agency upon the bedrock of the concept of biochemical self-individuation in living systems. In a way, we have proceeded as expected from an ontology that demands that entities must exist first and only after can they relate to other entities. This ontology started to break down a bit when we saw that behavior (what agents do) and self-individuation (what they are) can intermingle in intricate manners, along a historical dimension of co-definition.

But even these bold forays have so far kept us relatively safe within known territory. A bit of nonlinearity here, a bit of self-organization there, nothing that will shake any ontological edifices. In this chapter we are going to suggest that self-individuation, and even agency, can occur at the sensorimotor level. The processes that individuate a sensorimotor agent are *acts themselves*. It is acts—the acts of an agent—that constitute and reassert a new kind of agency, one that is enabled and constrained, but ultimately underdetermined, by biology. It is literally a case of explaining who you are by referring to what you do, and explaining what you do by referring to who you are.

If there is a sensorimotor level of agency different from basic biological agency, it will have to fit our definition of the term. We will already find important clues in how certain sensorimotor schemes become self-sustaining, as in the case of habits. But we will also need to look at the structure of everyday action. In everyday activities, sensorimotor schemes relate to each other in complex, adaptive ways, forming webs of mutually supporting relations. These networks of acts develop and change as processes of differentiation and integration between schemes (including the disappearance of schemes or the emergence of novel ones). Ultimately, these sensorimotor networks can achieve operational closure, in other words, their own individuation. The norms that guide action at this level are not only those given by biological self-individuation; some of them are also sensorimotor norms.

The processes that make up a sensorimotor life are the very acts that it performs (as well as the embodied and environmental structures that enable and constitute these acts). This may cause a few cases of ontological dizziness, but the idea is to follow closely the operational method of the enactive approach, while relating our findings to other theories and supporting evidence as well as phenomenological insights, to make certain at each step that the path we are laying down is firm.

6.2 **Habits**

In Chapter 5 we used the living cell as a concrete example of the emergence of individuation and normativity out of physicochemical processes. The three conditions for agency are clearly manifested in the cell’s material embodiment and behavior. But we can envision the emergence of autonomous agency also at levels far removed from the specific processes of the biological substrate. Much of the behavior we observe in animals and persons, while remaining biologically viable, is clearly underdetermined by the conditions for biological autonomy. Many actions acquire value "on top of" their organic functionality, sometimes even in tension with it. Movements can be dexterous; postures awkward; a gait elegant; and so on. Some actions are as effective as others are in terms of their biological purpose, but they are preferred because they are habitual and comfortable. Also, complex agents may sometimes pursue goals that have the tendency to undermine long-term biological viability, such as the rewards gained from risky situations (extreme sports), or as in the case of substance abuse. Bandit's taste for chewing rubber cannot be said to contribute to the maintenance of his metabolism and eventually may even put him at some risk of poisoning. But we still intuit in his activity the hallmarks of an agent in action: a motivation, a commitment, and compensatory acts when something deviates him from his goal. Similarly, a person suffering from Parkinson's disease might not be concerned mainly with physiological consequences if she fails to grasp the glass of water. The very same frustration would arise if the glass were full of wine. In a sense that is yet to be properly spelled out, what is challenged in the patient is a sensorimotor identity, the capacity to assert herself as an agent through everyday safe and effective action.

Any theory of agency beyond the biological level has to provide an account of how autonomy and adaptivity arise in the domain of interest. For the case of sensorimotor agency, this is the behavioral domain.[1] But before considering the question of whether we can conceive of an autonomous organization at the behavioral level, it is helpful to introduce the concept of "habit" as a kind of minimal self-maintaining sensorimotor entity.

The received view about habits is an impoverished version of what the idea once represented (Barandiaran and Di Paolo 2014; Carlisle 2014). Reduced to reinforcement-modulated stimulus-response pairings by behaviorism, the concept all but disappeared from scientific discourse with the advent of cognitivism. Alternative, more organic

---

[1] The definition of agency may be applied to other domains too. In the current context, a form of agency that is relevant to mention is social agency. We will only discuss some elements of this in Chapter 8 but not in sufficient detail. The reason is that it would make the exposition of the core ideas of this book too difficult if we kept another kind of agency in mind while simultaneously attempting to establish whether sensorimotor agency is even a coherent idea. In reality, we can expect social factors of different kinds to play important roles in the development of sensorimotor agency. Processes of interpersonal equilibration can scaffold sensorimotor capabilities in the developing infant and new kind of norms emerges during social interaction processes (Di Paolo 2016a; De Jaegher and Di Paolo 2007). Without ever becoming disembodied, forms of social agency take more complex forms beyond the regulation of face-to-face interaction, regulating also other kinds of social encounters, events, and activities, and eventually institutionalizing community-wide norms that enable new kinds of embodied capabilities and sensitivities, what Cuffari, Di Paolo, and De Jaegher (2015) call *linguistic bodies*. These skills are social, some of them are linguistic, but they always also involve sensorimotor elements and biological ones as well. The picture of human agency, in particular, will not be complete until the interaction between all these kinds of agency, corresponding to the three dimensions of embodiment, is properly understood, which is beyond the scope of this book.

conceptions of habit can be traced back to Aristotle, German idealism, pragmatism, and phenomenology. For these traditions, habits are complex and plastic patterns that integrate body and environment. According to a recent proposal, habits constitute self-sustaining behavioral life forms (Egbert and Barandiaran 2014). Following this idea, it will be useful to think of habits as *self-sustaining precarious sensorimotor schemes*.

To be more precise, we propose that a sensorimotor scheme as we have defined it in Chapter 4 is self-sustaining, or habitual, when the elements that support it (muscular dispositions, neural connectivity patterns, spatial arrangement of objects and tools, etc.) depend for their structural stability on the exercise of the scheme (Barandiaran 2008). Habits, thus understood, extend the concept of sensorimotor schemes by adding the notion of precarious self-maintenance: if the habitual scheme is not enacted with sufficient frequency, the structures supporting it start to lose the properties that enable it. Eventually, the capability to enact the scheme degrades and disappears.

Notice that with this definition the concept of habit is different from what we could more generally call "drill." A repeated enactment of a given behavior can transform the agent's support structures so as to predispose future repetitions of the same behavior. But if the support structures remain unchanged after having been established, then the predisposition toward the scheme also remains unchanged, even if repetitions cease. We demand a stricter condition to call a scheme a habit, which is that the support becomes structurally unstable in the absence of frequent enough exercise of the scheme. This is what we mean when we say that a habit is precarious.

This approach captures the idea that repeated enactments of a given scheme can induce plastic changes in the processes that structurally support it—both in the agent and in the environment—and keep these processes from degrading. This is analogous to the situation when people repeatedly walk across a lawn in a park, which leads, after some time, to the formation of paths where the grass is prevented from growing. This in turn encourages further walking along the paths, which continues to "sediment" the path network. Similarly, a habit "calls" for its exercise and its exercise in turn reinforces its durability. In Piagetian terminology the sensorimotor scheme $A \times A' \rightarrow B \times B' \rightarrow \ldots$ is a habit when the stability of the coordination support structures and processes $A, B, \ldots A', B', \ldots$ depends on sufficiently frequent enactment of the whole scheme $A \times A' \rightarrow B \times B' \rightarrow \ldots$ (Figure 6.1). The mutual stabilization of a scheme and its support structures may involve neural mechanisms such as Hebbian-type synaptic strengthening during task performance. But our definition also allows for plasticity to occur in the rest of the body (e.g., through adjustment of muscle tone or posture) and the environment (e.g., ordering of habitual workspaces).

The individual habit already provides a first approximation of a sensorimotor conception of identity and normativity (Barandiaran 2008; Di Paolo 2005; Egbert and Barandiaran 2014). A habit can take on a "life of its own": it is both condition and consequence of its own enactment. This form of recursion (a kind of closure) individuates the habit. The dependence of habitual behavior on the precarious brain-body-environment structures supporting it defines a set of viability conditions, and with it, certain normative

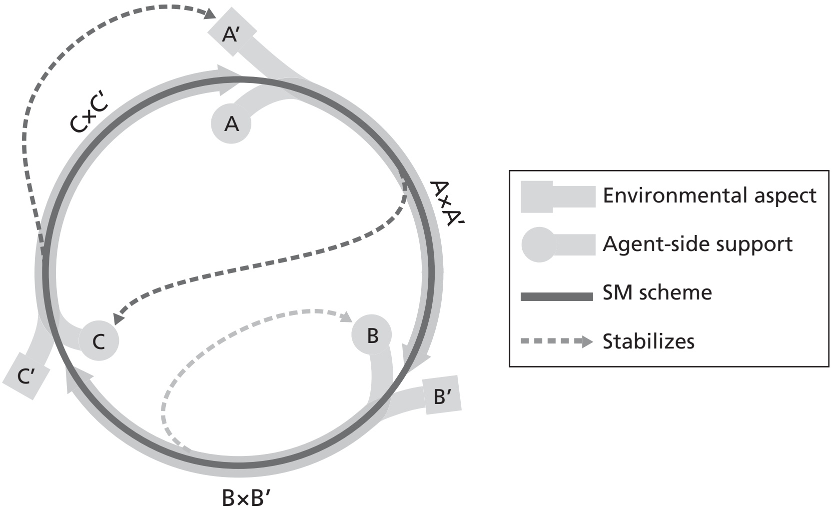

Figure 6.1 Habitual sensorimotor scheme. The circular organization (compare with Figure 4.1) of the three sensorimotor coordination events A × A′, B × B′, and C × C′ (light gray) forms a single sensorimotor scheme (dark gray). The supporting structures A, B, C and A′, B′, C′ in each coordination can be stabilized by the enactment of the scheme as a whole or a particular sensorimotor coordination. The process of stabilization is symbolized by dashed arrows. Only some possibilities are drawn here: for example, a sensorimotor coordination may stabilize its own support structures as illustrated by the light arrow leading from B × B′ back to B. Also, the enactment of the whole scheme may stabilize a support structure in the agent, as indicated by the dark arrow leading to C, or in the environment (arrow leading to A′).

constraints: the environmental conditions within which it can be enacted, the required frequency of repetition at which the habit self-reinforces without vanishing, and so on. One can picture those viability boundaries for specific cases, for instance, the period required between cups of coffee to keep a coffee-drinking habit alive. A coffee every morning may be more than sufficient, but an abstinence of a few months may extinguish it (see Box 6.1 for an example of how habit formation can be modeled).

Various conditions should be in place to sustain a habit. But these conditions may change over time, particularly as a consequence of a history of enactments. It is conceivable (indeed, it happens often) that habits become “hardened,” that is, they lose their precariousness (or the timescales of required re-enactments grow too long). We remain predisposed toward such “habits” even if we stop enacting them. This need not be the case with all habits; it is a possibility, not a certainty that habits become strict automatisms. The loss of precariousness (and metastability) in such cases is problematic for our proposal because there is no intrinsic need for the self-sustaining pattern to remain dynamic and adaptive. This relates to the so-called double law of habit (Ravaisson 1838/2008), which links increased ease of performance with progressive loss of sensitivity. Habits that move in this direction involve less effort, but also a receding awareness (loss of precariousness

Box 6.1 Modeling habits

In a model relevant to some ideas in this chapter, Egbert and Barandiaran (2014) study the formation of habits using a "deforming sensorimotor medium." In a simulated robot, sensorimotor trajectories induce plastic changes such that similar trajectories become more probable. The idea relates to the paths formed on a lawn by people's repeatedly walking on them. The process can be visualized as a vector field in sensorimotor space where vectors are rearranged and reoriented in the direction of state trajectories passing by. As the robot is coupled with an environment, self-maintaining metastable patterns ("habits") appear. Habits depend on the agent's body and environment and seem to vary in stability, depending on how the structures that appear in the deformable medium "resonate" with the behavior in the environment. For instance, patterns seem to be most stable if they form a regular interaction with environmental features. Owing to its metastability, the system can also exhibit switching between habits, and between periods of exploration (of new sensorimotor patterns) and exploitation (performance of existing patterns). Higher level organizations also seem to occur at times, e.g. the "super-habit" of switching between two "subhabits" at more or less regular intervals.

The model is congruent with our theory of sensorimotor agency, since it treats closed-loop sensorimotor coordination patterns as the fundamental units of development. An interesting aspect of the model is that the existence of stable sensorimotor patterns is precarious. The deformable medium is constructed so as to gradually relax to its default state, such that existing patterns intrinsically fade away if the states constituting it are not revisited frequently enough. Because of this (simulated) precariousness, only through regular enaction can a habit maintain itself.

implies that adaptive regulation, and, as a consequence, sense-making, are no longer necessary). When this occurs, the habit becomes an automatism and stops being a habit in the technical sense we give to the word, although they are still called habits in other contexts.

6.3 From habits to activities

Habits provide us with some powerful elements to address the issue of agency (e.g., precarious self-individuation; a notion of norms at the level of the habit itself). But we do not find ourselves all the time enacting a single habit or another. Normally, we are involved in more complex activities that necessitate sophisticated and fluid relations between several sensorimotor schemes, for instance, the activity of cooking a meal or the activity of shopping for groceries. Moreover, the normativity associated with individual schemes often originates not in their own precariousness but in the way they relate to each other. The efficacy of chopping skills is "evaluated" in the context of related activities, for instance, in terms of avoiding uneven cooking times. We therefore need to examine the origins of the relations between schemes that make up such activities and what distinguishes one activity from another.

In analogy with autocatalytic networks (see Section 5.2.1), we can move beyond a single self-reinforcing habit (comparable to a single autocatalytic reaction) to identify closure and adaptivity at the level of many schemes in mutually self-sustaining interactions (*reflexively* autocatalytic in Stuart Kauffman's terms). This was already suggested by William James (1890), who conceived of animals as "bundles" or "ecologies" of habits. Habits do not stand in isolation as egotistically self-sustaining behavioral patterns. On the contrary, habits (or schemes) are nested in hierarchical, sequential, and ultimately networked relations in a kind of ecosystem, whereby a given scheme calls for, reinforces, inhibits, or subsumes others. Despite the possible loss of precariousness when a habit gets hardened, interdependence makes schemes more metastable (richer in potentialities) and adaptive than the traditional picture that associates habits with automatisms. John Dewey recognized this point:

> Strict repetition and recurrence decrease relatively to the novel. Apart from communication, habit forming wears grooves; behavior is confined to channels established by previous behavior. In so far the tendency is toward monotonous regularity. The very operation of learning sets a limit to itself, and makes subsequent learning more difficult. But this holds only of a habit, a habit in isolation, a non-communicating habit. Communication not only increases the number and variety of habits, but tends to link them subtly together, and eventually to subject habit-forming in a particular case to the habit of recognizing that new modes of association will exact a new use of it. Thus habit is formed in view of possible future changes and does not harden so readily" (1929, pp. 280–1)

This "communication" between habitual schemes, as Dewey calls it, is easy to see if we focus on *activities* and *behavioral genres* (cooking, eating, cleaning, riding a bicycle, commuting in the city, working at the construction site, playing sports, etc.). In these settings or *microworlds* (Varela 1992), the linkage between schemes is inherently meaningful. This is because schemes relate among themselves (e.g., as a sequence of preparatory and central actions) or because adaptive changes in one scheme are necessary to effectively perform another. In his study on dexterity and development written in the 1940s, Nikolai Bernstein (1996) provides several examples of such relations. One is the case of a smoker lighting up a cigarette:

> A smoker takes a cigarette pack out of his pocket, opens it, selects a cigarette, kneads it, and puts it between the lips; then he opens a matchbox; takes out a match; glances at it to check if its head is intact; turns the matchbox; strikes the match once or several times, as necessary, until it ignites; turns it so that the flame flares up; if necessary, protects it from the wind; moves it closer to the cigarette; sucks the match's flame into the cigarette; extinguishes the match; throws it away; and eventually puts all the things back where they belong.
>
> (Bernstein 1996, p. 147)

This series of twenty or so schemes forms a micro-network. Some schemes must be enacted before others are even possible. Others (e.g., taking a pause from walking in order to light up the cigarette) may facilitate other schemes that are otherwise possible but hard to perform. But the activity is not a strict rule-based sequence. If we observe this process many times, we will notice that the whole activity shows adaptive variability, as Bernstein remarks. Protecting the flame from the wind may or may not be required, if a match breaks while being struck, the process must go back a few steps, although if it breaks having also been ignited maybe it can still be used, but if it falls to the ground it must be put out, and so on. Someone could use a lighter instead of a match, and the activity would change a bit, but there is a sense in which similar functional relations obtain and both cases would be related as instances of a same genre. What determines these relations between schemes is a normativity proper to the activity itself (lighting up a cigarette cannot be said to be done as a way of improving organic viability).

In this example, the structural relations among the component schemes are very explicit and easy to see. But this is not always the case. Many complex activities are composed of webs of sensorimotor schemes whose deep structure does not reveal itself until disrupted. Such is the case, for example, in Kohler's (1964) experiments on adaptation to visual inversion goggles discussed in Chapter 4. Recall that recovery of normal vision in this case proceeds in a fragmented fashion. Some "perceptual habits," such as the ability to avoid obstacles, are restored before others (the recognition of numbers on license plates). Only when these individual skills are brought back into alignment is vision as a whole restored. For Kohler, through rehabituation experiments like these one can "penetrate more deeply into the structure and mutual interweaving of habits than would be possible in any direct way" (1964, p. 139). In view of this, we should aim at a concept of sensorimotor agency not so much based on an aggregation of individually self-sustaining habits, but on a network of "mutually interweaving" schemes.

In agreement with this idea, psychologists and biologists interested in behavioral development have long realized that behaviors not only become increasingly differentiated during ontogeny, but that they also integrate into more complex coordinated sequences or, more generally, into hierarchical organizations. John Fentress stresses that the neuroethologist seeks to understand behavior by analyzing how "each act fits into the context of others," and that she must "both find ways to separate behavior into its basic parts and define the rules by which these parts are joined together" (1983, p. 939). Fentress sees behaviors as organized in nested webs of rich interconnections at several levels such that "tugs on any one strand will have ramifications elsewhere, while preserving the web's overall structure" (1983, p. 941). Equally, Kurt Fischer refers to the "complex interconnections among skill components and domains" in a networked "developmental web" (Fischer, Yan, and Stewart 2003); Kenneth Kaye (1979) describes the hierarchical embedding of Piagetian schemes; and Michael Arbib and colleagues speak of complex networks of interdependent schemes where "each finds meaning only in relation to others" (1998, p. 44).

Like Bernstein and Kohler, these authors highlight that actions are linked into functionally coherent ensembles. Because of these links, some actions increase or decrease together in frequency or intensity; some actions compensate for the unwanted effects of others; other actions compete with each other as behavioral options; and so on.

As an example, consider the grooming behavior of rodents, which Fentress analyzes in great detail. The structure of grooming is hierarchical. At the top level, it consists of a cluster or set of related activities that can be clearly distinguished from other clusters, such as locomotion or feeding. At the next level, it can be divided into regions of bodily contact, e.g. the grooming of face, belly, and back, usually in that sequence. Facial grooming itself can be further divided into different stroke types, which themselves exhibit different kinds of groupings and sequential structures. This organization of behavior into hierarchical clusters of schemes makes it possible also to describe how the transitions between activity clusters develop. For example, the switching between activities is more regular than the switching between individual acts within a given activity; and one can describe in some detail the changes in the sensitivity of the animal to external stimuli when immersed in different activities (Fentress 1983, p. 948; also Fentress and Gadbois 2001). Similarly detailed analyses of the networked organization of behavior have been conducted, for example, for food caching and ritualized fighting in canids (Phillips et al. 1990; Moran et al. 1981), the compositional complexity of transition relationships between phrases in bird song (Marler 1981; Berwick et al. 2011; Sasahara et al. 2012; Weiss et al. 2014), and the development of infant locomotion (Muchisky et al. 1996).

Related to this networked view of activity clusters, Piaget's theory of equilibration, as we saw in Chapter 4, suggests that accommodation proceeds not only by creating new schemes when the current repertoire cannot assimilate a new situation, but also by *integrating* these schemes into the already existing network, through mutual equilibration between schemes. Depending on history and context, the changes undergone by different sensorimotor schemes and coordination patterns can give rise to a novel behavior. For example, in a longitudinal study of the development of reaching in infants Thelen, Corbetta, and Spencer (1996) demonstrate that reaching emerges from interactions and modifications of other non-reaching patterns such as bringing the hand to the face or moving arms rhythmically. Depending on the infant's preferred movement speed (which in turn depends on individual factors such as body size), successful reaching may require learning to control fast movements to improve accuracy or learning to expand and accelerate short, slow movements so that the hand can reach the goal. The developmental integration of previous schemes and coordination patterns depends strongly on individual history and preferences, so certain schemes may emerge from others with considerable developmental variability.

These examples show that sensorimotor schemes do not exist or develop in isolation, but always in mutual co-dependence on other schemes (not unlike new species evolving as part of an ecological community). While the concept of a habit indicates the existence of precarious self-sustaining organizations at the behavioral level, an account of sensorimotor agency needs also to consider the networked organization of sensorimotor schemes, their grouping into activity clusters, and their co-dependent development.

6.4 Sensorimotor networks

Our main proposal in this chapter is that the interconnectivity between schemes we have just described may serve as a substrate in which a new form of operational closure can develop. We now examine whether a network of interrelated sensorimotor schemes can satisfy the conditions of individuation, asymmetry, and normativity required for agency.

6.4.1 Sensorimotor individuation

Let us first consider the question of whether a network of sensorimotor schemes can individuate itself. In the case of the living cell, two elements contribute to active self-individuation: the operational closure of molecular transformations and the construction of a semipermeable membrane. We suggest that a sensorimotor network of mutually enabling schemes may also exhibit closure. In Figure 6.2 we illustrate the kind of relations that may hold between sensorimotor schemes, as well as between schemes and their support structures in the agent and the environment. Comparison with autocatalytic sets (see Figure 5.1) suggests a similarity in these relations. Remember that closure in the latter case involves mutual interdependence between two levels: reactions and molecules. In the autocatalytic network, each molecule is the product of a reaction, and each reaction is

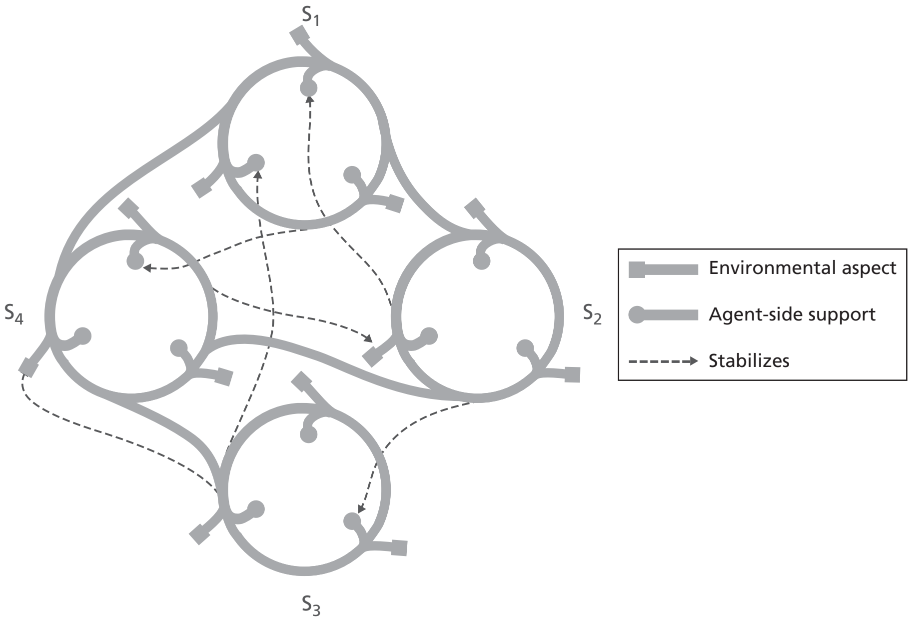

Figure 6.2 **A network of four sensorimotor schemes**. The schemes are labeled S_1 to S_4 (see Figure 6.1 for details regarding individual schemes). Sensorimotor schemes are interconnected in two ways. On the one hand, predispositions exist that link schemes "horizontally," such that they usually are, or can be, performed in a particular sequential, hierarchical or parallel fashion. This is indicated by the thick gray lines connecting the circular schemes. On the other hand, the support structures in one scheme may depend for their structural stability on the frequent enough exercise of other schemes, indicated by thin, dashed arrows. In this way, the sensorimotor schemes are interconnected also via structural ("vertical") dependencies. Note that we have drawn the support structures of the agent and the environmental aspects as each contributing to a single sensorimotor scheme, but in reality support structures in the agent and the environment may contribute to several different schemes.

catalyzed by molecules produced by other reactions in the network. Analogously, in the kind of sensorimotor network we propose, each scheme depends on at least one support structure in the network, and each support structure, in turn, is stabilized by at least one sensorimotor scheme.

These dependencies may happen as reinforcement of support structures at the level of body and brain (muscle strength, increased cohesion in a neuronal cell assembly, dendritic growth, etc.) or at the level of the environment (the progressive shaping of a shoe, the organization of folders in a computer, or the arrangement of utensils in a kitchen). In the example of the schemes involved in opening a door, the neuromuscular synergies used for reaching for door-handles act as agent-side support structures. We can imagine that the continued stability of these synergies may depend on the repeated exercise of opening doors and/or other activities that involve reaching (say, reordering books in bookshelves). In this sense, precarious supporting synergies can be stabilized by several sensorimotor schemes in the network. At the same time, of course, the schemes for door-opening, book-holding, etc., depend on the presence of appropriate neuromuscular synergies. In this way, schemes and support structures can become mutually dependent on each other at the network level (and not just the level of individual schemes and their *own* support structures, as in the case of habits). This is what we mean by closure at the sensorimotor level.

Figure 6.2 also suggests that closure at the sensorimotor level may go further than the mutual, networked dependence between support structures and schemes, since sensorimotor schemes also relate to each other in various ways. For example, some schemes act as preconditions for the exercise of others, and some situations require the joint, parallel exercise of several schemes for the desired outcome. In other words, complex behaviors often depend on a particular linkage of several sensorimotor schemes. Moreover, this dependence between schemes may be malleable: the usual enactment of scheme S_1 followed by scheme S_2, in a Hebbian-like manner, can make future exercise of the same sequence more likely. Experience may thus shape predispositions that orient some schemes toward the "anticipation" of others. We therefore propose that closure at the sensorimotor level involves a network of mutually enabling conditions both "horizontally" among sensorimotor schemes, as well as "vertically" between schemes and their support structures.[2]

---

[2] The network view of interrelated sensorimotor schemes may still sound abstract, and one may wonder if and how one could identify such a network in real systems. In this regard modeling studies may be one way forward. For example, Randall Beer and colleagues have extracted "functional networks" of stable sensorimotor states, or more specifically, state machines mapping the transitions between different stable states, from the dynamics of a simulated learning agent (Phattanasri et al. 2007; Izquierdo et al. 2008). From an empirical perspective, Paul Cisek and John Kalaska review neurophysiological evidence for a view of the brain as having evolved primarily to support interactive sensorimotor behaviours. In this view, closed sensorimotor loops relate to each other by competing in parallel for their enactment (Cisek and Kalaska 2010).

We may ask where exactly this network of schemes resides. Can we identify a physical boundary that confines it, like the membrane in the case of the cell? Is it located in the brain or perhaps in the biological body? The short answer must be negative. While we may be inclined to point to an organism's body as the locus of sensorimotor agency, it is important to stress that sensorimotor schemes, and networks of these, constitutively involve both the organic body and its environment. Of course, a lot of the support structures, potential for plasticity, and a capacity for selective enactment and equilibration rest within the organism (and in particular within its nervous system). But a network of schemes equally depends on its environmental support. Scheme selection may in some cases rely on resonance of the network with specific aspects of the environmental situation, and equilibration may involve plastic changes in structures of the environment (as we mentioned in Chapter 4, see Agre 1997; Kirsh 1995, 1996). Sensorimotor schemes are by definition modes in which structures in the agent and structures in the environment meet and mutually stabilize. As such, it makes no sense to try to identify their physical boundaries. We may inspect the anatomical and physiological properties of a human body and at best, we will be able to risk a very general guess as to what kind of sensorimotor agency it contributes to instantiate.

It should therefore be clear in particular that we do not propose individuation of a sensorimotor organization as equivalent to closure at the level of neuronal activity, as Maturana and Varela have proposed in their early work (Maturana and Varela 1980; Varela 1979; see Barandiaran 2016 for a critical discussion). Rather, the kind of closure we envision involves both the biological organism, in the form of enabling neurodynamic patterns and bodily configurations, as well as the environment, through its contribution to the closing of each sensorimotor scheme's loop.[3]

But if we are going to propose that the sensorimotor agent is constituted at the relational level of sensorimotor schemes, which in turn involves the environment, how can it be truly individuated (i.e., distinct from the environment)? While this may seem logically impossible, it is only because we have not been very precise in the use of the word "environment." It is important to realize that the environment for the biological organism is different from the environment for the sensorimotor agent. Strictly speaking, in dynamical systems terms an environment is always defined relative to a system. Just like

---

[3] The agent-side support structures for sensorimotor schemes are the most familiar to contemporary researchers in behavioral and cognitive sciences. Our emphasis on the relational nature of schemes does not imply that we should not study their neuronal dimension. In fact, it is reasonable to assume that some of the complexity of the network activity relates to the brain. Functional and structural dynamics in the brain enable sensorimotor schemes and are in turn shaped by their enactment. We should highlight, however, that sensorimotor schemes and the networks they form will rarely depend on specific brain regions, but most probably involve forms of large-scale brain coordination, and that these patterns depend on sensorimotor events, that is, they could not appear in the absence of the right agent-environment coupling (Aguilera et al. 2013; Barandiaran 2016). Some relevant properties of sensorimotor networks might well be pictured as transition networks between large-scale brain patterns (see Aguilera [2015] for an exploration of this idea with robotic models).

biological agents, a self-sustaining network of interdependent schemes brings forth its own domain of interactions. For example, we could argue that a virus is part of the environment of the biological organism, in so far as it triggers in the organism immune reactions and other defense processes. But the same virus, as such, cannot automatically be said to be a part of the sensorimotor agent's environment; we do not perceive the virus floating in the air, we cannot smell it or touch it, nor does it typically affect the relations between sensorimotor schemes. In fact, if the immune response is successful we do not even notice any effects related to the presence of the virus. It is only when the immune response is not quickly successful, as it often happens in the case of the common cold, that the support structures of several schemes are affected and the effects are noticeable at the sensorimotor level too (symptoms such as dizziness, fatigue, etc.). But the same effects could be provoked by other causes (e.g., overwork). However caused, the changes in the support structures themselves (bodily or external) constitute the immediate environment of the sensorimotor network.

The sensorimotor agent's environment, in other words, is constituted by all those aspects that can influence the web of sensorimotor schemes. Conversely, any external factors that in principle cannot influence the dynamics of the sensorimotor network are not part of its environment. The closed network of sensorimotor schemes thus specifies a new domain of what is or is not relevant, and it is in this sense that it distinguishes itself from its own environment.

We can relate the issue of individuation further to the creation of interactional "boundaries." In the first instance, as just described, the particular constitution of a sensorimotor network specifies what are the possible, relevant interactions for the agent. But as the cell produces a membrane for increased adaptive control over its material and energetic exchanges, so a sensorimotor agent may assemble functional boundaries to protect its particular way of life. Now, it might be tempting again to identify such boundaries in physical space. For example, we could point to the notion of territory and note that many animals exhibit a tendency to protect their immediate habitat. This indeed constitutes an easily identifiable boundary. But even a territory is not just a map. It is not simply an objective spatial enclosure, but involves a network of actions such as marking, sheltering, nesting, giving alarm calls, and so on. In the same way, boundaries of individuation are often actively and selectively created through specific actions or inhibition of actions (e.g., not calling a person that systematically challenges my suggestions, arranging my surroundings to be able to exercise a particular activity without disturbance, preparatory actions done for safety reasons, and so on). These are functional boundaries, manifested at the level of relations between sensorimotor schemes.

Last but not least, we want to emphasize the active nature of sensorimotor individuation. A sensorimotor agent—when it emerges as such, not all agents reach this kind of closure, as we discuss later—is not only self-distinguish*ed* but also self-distinguish*ing*. The closure of the sensorimotor network and its boundaries are not just established once and for all, but need to be actively sustained. It is, ultimately, through regulation of the network's coherence[4] (i.e., the degree to which schemes are mutually equilibrated as we saw in Chapter 4) that the sensorimotor agent becomes distinct. The particular way in which a sensorimotor network realizes itself, that is, its own way of life as a sensorimotor agent, is specific to the system's developmental history. Sensorimotor self-individuation is hence a recursive process in which an organization of schemes reinforces and shapes itself through the actions it generates. The system's doing and being are intimately intertwined.

6.4.2 Sensorimotor normativity and interactional asymmetry

The self-individuation of a network of sensorimotor schemes is related with the network of biochemical processes that constitutes the organism, but it is in fact a different kind of system. We already mentioned that these two operationally closed entities have different environments, as well as different ways of self-producing and self-distinguishing. It should then come as no surprise that the norms that emerge in each case will be also related, but different. In general, as we have already hinted at, we can postulate a relation of dependence between the closed sensorimotor network and the organismic body. Processes in the organism (metabolic, physiological, neuromuscular, etc.) enable and constrain all of the sensorimotor schemes in a network individually and in terms of how they relate to each other. However, there remains certain indeterminacy in this enabling relation, which is to be expected if the sensorimotor network can truly achieve its own autonomy.

We have already seen a hint of this indeterminacy at the end of Chapter 5 when we mentioned that the sensorimotor mechanisms in simple organisms such as *E. coli* can become "partially decoupled" from the logic of ongoing metabolism. This decoupling is never complete, as the sensorimotor processes still need to be sustained metabolically. Indeed, in many cases it is shown that taxis is performed contextually on metabolic states in *E. coli* and other bacteria (see Alexandre [2010] for a review on so-called "energy taxis"). Still, the functioning of the sensorimotor pathways that regulate chemotaxis is not entirely determined by current metabolic needs. This metabolism-independence assumption has dominated the studies of bacterial behavior for decades, since it was shown that in *E. coli* the capability to metabolize a reactant is neither necessary nor sufficient for taxis (Adler 1966). From our perspective, independence is an incorrect way to describe this relation. It is more accurate to speak of under-determination.

Despite the possibility of "partial decoupling," many sensorimotor schemes (most if we consider non-human animals) are nevertheless linked to the satisfaction of some vital norm (see, e.g., Barandiaran and Moreno 2008). This is in general explainable in

---

[4] By *coherence* we here refer to the use of the term in dynamical systems theory, especially as applied in theories of development (Smith and Thelen 2003; Lewis 2000). It signifies the emergence of stable (coherent) forms, or patterns of coordination, in complex systems of many interacting processes. In particular, a network of sensorimotor schemes is coherent to the extent that its schemes are stable patterns given the system's current environmental context. The network is incoherent to the extent that any of its schemes, or the organization as a whole, becomes unstable; that is, when in Piagetian terms the system is facing disequilibrium and requires accommodation to a new situation.

evolutionary terms. Even if the function of sensorimotor processes is not entirely regulated by metabolism here and now, evolutionary processes still play a role in fine-tuning this wider space of sensorimotor functions so as to satisfy both the norms of self-individuation and the norms of effective reproduction. For the purpose of the current discussion, we may refer to these two sources of norms (organic and evolutionary) using the single label *biological normativity* (despite the well-known fact that many biological conflicts originate precisely in the clash between individual survival and the success of a lineage).

In the human case, at least, but also possibly in other species, not every detail of a successfully enacted scheme matters from this wide biological perspective. I need to hydrate in order to survive, but whether I drink water or ice tea, whether I use my favorite cup, or whether I enjoy doing it with my friends is underspecified by biological norms. These options are regulated by other sources of normativity; we are not indifferent to them or we would not notice them as options. Some of these norms are social, but we will not focus on them at the moment. Apart from these, we propose that specific norms emerge at the sensorimotor level and that they are related to what is needed to sustain a viable organization of behaviors, dispositions, attitudes, etc.

If we keep in mind the linkages between schemes in Figure 6.2, we notice that a particular sensorimotor engagement brings forth a normative dimension over and above biological normativity because of how the implications of its enactment can ripple through the network. We know from Chapter 4 that circular schemes in the Piagetian framework are assumed normative in themselves in that the closure of the cycle of sensorimotor coordination is the measure of successful enactment and the basis on which equilibration works. When schemes are linked via enabling relations, as in Figure 6.2, normative implications spread through these links. Not only can a scheme be a precondition for a subsequent scheme—a “good” or successful reach for the door handle is, among other things, one that allows me to subsequently turn the handle and open the door—but its successful or unsuccessful enactment also bears vertical consequences for its own support structures and those of other schemes. Every action we perform sends waves through a network of structural and functional relations. When these relations become operationally closed, every enacted scheme in the network can have positive or negative consequences for the viability of the whole. The set of structural and functional dependencies between schemes defines the viability conditions for the ongoing maintenance of the sensorimotor network, very much like molecular self-individuation defines how food concentration, pressure, or temperature affect the viability of cellular life.

We should note that it now is possible to relax the condition of circularity of sensorimotor schemes that we introduced in Chapter 4 following Piaget and return to our broader definition in Chapter 3 of a scheme as an organization of sensorimotor coordination subject to normative constraints. Schemes may involve “open,” non-circular chains of coordination patterns, which are not required to lead back to the initial coordination. What is required of a scheme within a closed sensorimotor network is that it leads to an appropriate transition to another sensorimotor scheme according to the conditions of viability of the network. What identifies schemes as behavioral units is often resolved at the level of activities, in which sets of sensorimotor coordination patterns form larger units that may be adaptively exchanged or recombined.

Normative relations between schemes become apparent in the cases of activity clusters, as in Fentress' studies of grooming in rodents or Bernstein's vignette of lighting up a cigarette. The relations between schemes within a cluster are adaptive. This is seen in another example provided by Bernstein (1996, p.111). A boy is running and while running he jumps and picks up an apple from a tree. Picking the apple demands various complex coordination patterns (eye, arm, and hand movements; a firm enough grip; a sharp pulling movement to yank the apple from the branch; etc.). But if the branch is too high, the success of the activity depends on the running and jumping schemes, themselves not normally part of the picking-an-apple scheme. In general, the primary "goal" of an activity demands the enactment of some particular schemes but it also necessitates the availability of background corrections to other supporting schemes in "cooperative and harmonious interaction" (Bernstein 1996, p.111). The idea of cooperation or harmony is precisely the kind of normative notion that emerges at the sensorimotor level. Other sensorimotor normative dimensions include efficiency, robustness, adequacy, dexterity, elegance, and coherence.

The felt enjoyment of movement and the flow of action are also indicative of a normative dimension in sensorimotor engagements beyond their biological functionality. The kinesthetic experiences that accompany all movement are clearest in physical play, dance, and exercise. What is felt in these cases is not the potential benefit of these activities, but the embodied dynamics of the activities themselves. "Pleasure or fun in running, chasing, laughing, jumping, beating, and so on, is quite literally pleasure or fun in the flesh. It is not an accessory to a main event, but the main event itself" (Sheets-Johnstone 2003, p. 415). The affective aspects of these "forms of vitality" (Stern 2010) sustain the senses of flow and immersion (Csikszentmihályi 1990), which, in our terminology, could be explained in terms of coherent, long-range relations between integrated sensorimotor schemes.

Conversely, sensorimotor normativity is also clearly manifested in cases of breakdowns. For instance, if we injure our dominant hand so that it cannot be used at all, most of us will still be capable of many everyday activities, such as brushing our teeth, getting dressed, preparing breakfast, or taking money out of the wallet. But we will be painfully aware of an overall clumsiness, lack of familiarity, and frustration that accompanies these activities simply because of the fact we must perform them in a different, less comfortable (or less enjoyable) and less efficient way. The same can happen if we are suddenly placed in an unfamiliar environment or we suffer from some illness affecting sensorimotor schemes.

Let us now consider the requirement of interactional asymmetry and whether an operationally closed sensorimotor network can meet it. How should we understand a network of sensorimotor schemes asymmetrically and adaptively regulating the coupling with its environment? This environment, as we have said, consists of all those aspects outside the network of schemes that may influence the enabling relations between sensorimotor schemes. In particular, this environment includes events or situations that may destabilize or perturb the coherence of the sensorimotor network. Adaptive regulation, therefore, is the network's ability to be sensitive to and to counteract such perturbations and seek opportunities that help reassert the agent's sensorimotor individuation.

We have seen in previous examples that during specific activities, schemes relate to each other adaptively with respect to the norms proper to the activity itself and the network as a whole. Thus, there are "correct" and "incorrect" orderings of some schemes in time or transitions between schemes that occur too fast or too slow with respect to the activity's goals. There is, for instance, a "correct" period in which to move the ignited match toward the cigarette in order to light it up. These acts relate in an adaptive manner in the sense that they depend on factors that may disrupt how schemes link to each other. They are regulated according to these factors (e.g., the presence of wind or an injured dominant hand affect how a person lights up a cigarette). A sensorimotor agent may also regulate her coupling with the environment by adaptively shaping the environmental factors involved in the whole activity. Adaptive regulations of this sort include actions taken to rearrange one's environment in order to facilitate certain engagements. Consider, for example, expert workers such as carpenters or kitchen chefs. In order to ensure successful and efficient execution of their work, they become accustomed to a specific arrangement of tools and utensils, arrangements that they themselves have developed over time. They often prepare themselves for the task at hand, by wearing the right shoes, goggles, aprons, etc., not just for safety reasons but also to work better. Ensuring that everything is in its proper place and other acts *aimed at further acts*, are asymmetric regulations of the primary activity that is precision woodwork or preparation of a sophisticated dish.

Asymmetric regulations of the conditions affecting the network of schemes may also involve the kind of internal adaptations we have mentioned in Chapter 4 as examples of equilibration. For example, a child whose experience with animals is limited to interactions with dogs may have developed certain schemes and skills to engage in with four-legged, furry animals. When this child first encounters cats, which fit the same description but do not participate in the fetching game, assimilation by some schemes fails. This may lead to a process of accommodation in which new schemes for cats are developed (possibly also affecting the child's behavior in the presence of dogs). The child has modified the way she interacts with four-legged furry animals by reorganizing her sensorimotor schemes. This change in the organization of the sensorimotor network induces asymmetrical changes in the agent-environment relation, in this case, by splitting an assimilated sensorimotor category (furry four-legged animals) into subsets of interlinked schemes associated with two new categories (dogs and cats).

We then conclude that it is possible for operational closure to obtain at the level of networked relations between precarious sensorimotor schemes. The self-individuation of this network entails its own normative space: the conditions that affect its viability and could potentially destroy its closure. It is conceivable that this sensorimotor network is able to change adaptively with sensitivity to how it currently stands with respect to its viability and that regulations are enacted according to these conditions—in other words, the network may also exhibit interactional asymmetry. Since the three requirements for agency in principle can be met by a network of interdependent precarious sensorimotor schemes, we conclude that sensorimotor agency is a viable concept. Several examples support this idea, which would help us explain a variety of phenomena that would otherwise remain obscure if we stuck to a single form of agency. We now turn to exploring this concept of sensorimotor agency by looking at some developmental considerations and further evidence.

6.5 Becoming a sensorimotor agent: networked micro-identities

In arriving at the idea of sensorimotor agency as a precarious self-sustaining network of schemes, we have followed the implications of the theory of agency, allowed them to roll, and found that they point to a possible solution to a conundrum posed by the theory itself: is sensorimotor life (and with it action, emotion, and perception) reducible to the operational logic of the self-individuating organism? In other words, is psychology reducible to biology? Since evidence seems to point to a negative response, the theory would be in trouble if we were compelled to answer in the affirmative. But we are not.

The proposal is out in the open and we need to see whether it can fly. This is going to be the concern of this and the next sections, and largely also of the next chapters. Our first stop is to look at the idea of a closed network of sensorimotor schemes in more detail and over longer timescales—developmental ones.

6.5.1 Weaving a developmental web

In Chapters 3 through 5, we have heavily relied on a dynamical systems perspective, in which phenomena are understood as emerging from interacting processes involving brain, body, and environment. It seems natural to employ a similar approach to examine the developmental processes that underlie the formation and maturation of a network of sensorimotor schemes. Luckily, we do not have to reinvent the wheel. A long tradition of research, drawing on ideas from nonlinear dynamical systems theory (Waddington 1977; Kugler, Kelso, and Turvey 1982; Thom 1983; van der Maas and Molenaar 1992), motor skills and synergies (Bernstein 1967; 1996; Kelso 2009, Latash 2008; Sporns and Edelman 1993; Turvey and Carello 1996), and dynamical interpretations of the work of Piaget and others (e.g., Fischer 1980; van Geert 1998) has converged on a view of behavioral ontogeny not as the deterministic unfolding of a prescriptive developmental plan, but as the emergence of stable patterns in a complex system of multiple interacting levels, from the genetic to the cultural (Kuo 1967; 1970; Gottlieb 1992; Oyama 1985; Fischer and Bidell 2006; Thelen and Smith 1994). We cannot here review this field as a whole, but we shall make use of some its key ideas to sketch how a sensorimotor network may arise from a history of agent-environment co-determinations.

A recurring metaphor for developmental change is Waddington's epigenetic landscape (Waddington 1977). The underlying assumption of this metaphor is that processes at the level of genes, cells, and the organism as a whole, including its behavior, interact in complex ways such as to produce more or less coherent and coordinated patterns that change in stability over time. Development, in this view, consists in a "series of evolving and dissolving patterns of varying dynamic stability, rather than an inevitable march towards maturity" (Smith and Thelen 2003, p. 344). In Figure 6.3 we visualize a particular interpretation of Waddington's metaphor: an ontogenetic landscape of changing behavioral patterns and stability, as proposed by Michael Muchisky, Esther Thelen and colleagues. Time, here, proceeds from the top to the bottom of the figure, and each horizontal curved

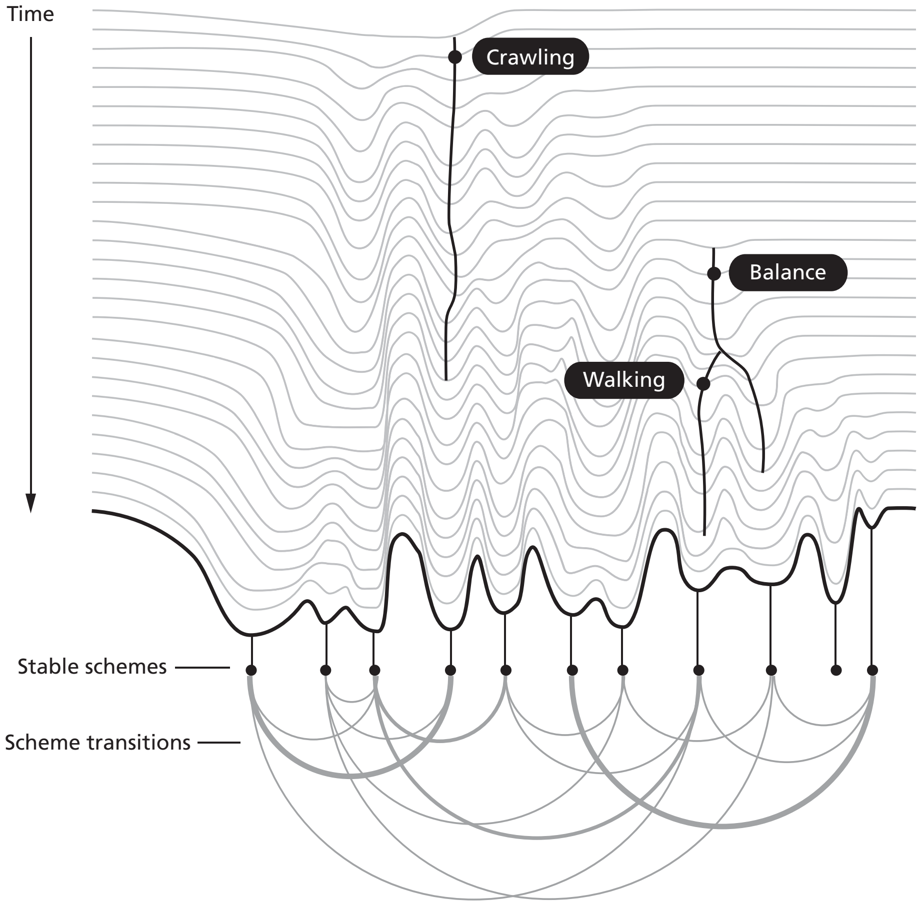

Figure 6.3 Ontogenetic landscape for a set of sensorimotor schemes. The diagram shows the development of sensorimotor schemes as a process of differentiating patterns in a (hypothetical) ontogenetic landscape. Developmental time flows downward. Each curved horizontal line corresponds to a snapshot of the stable schemes at a particular point in time. Valleys correspond to stable sensorimotor schemes. From an initially almost uniform state (top), the landscape becomes increasingly differentiated. As an example, crawling may be the only stable locomotion pattern in the early stages of infant development. When the infant learns to balance in an upright posture, walking emerges as another. At the bottom an arc diagram indicates possible relations between schemes (behavioral transitions).

Copyright © 2017 Ezequiel A. Di Paolo, Thomas Buhrmann and Xabier E. Barandiaran, with permission.

line represents a one-dimensional snapshot of stable patterns at a particular time. These patterns could correspond to behavioral capacities, traits, or, more specifically, sensorimotor schemes. The depth of a valley in the landscape indicates the stability of the corresponding pattern. Accordingly, development starts from an initially undifferentiated, highly synergistic attractor and proceeds by creating and dissolving stable states, with the changes in the shape of the landscape (over time, i.e., down the figure) indicating rates of developmental change. In dynamical systems terms, development is the succession of bifurcations that create and destroy attractors with varying degrees of stability. This is a useful way of describing processes such as the one depicted in Chapter 4 (Figure 4.2), in which equilibration results in one scheme differentiating into two new ones.

Consider the development of infant locomotion (Thelen and Smith 1994; also, see Muchisky et al. [1996], for a detailed ontogenetic landscape in this case). At a certain stage, when infants have developed sufficient strength to support themselves in a quadruped posture (which itself depends on the prior exercise of stepping and kicking behaviors that are already present), crawling is a coherent and stable pattern of locomotion (see top of Figure 6.3). In other words, the infants' specific muscle strength, skeletal configuration, and neural circuits, at this stage and in the context of an appropriate supporting surface, all contribute to a particular dynamic movement pattern, which remains stable for several months. Once infants develop the balance and strength required for an upright posture, however, they will learn to walk. In addition to crawling, patterns for bipedal standing and walking now become stabilized. In Figure 6.3 this corresponds to the emergence of a stable attractor for upright balance and its subsequent differentiation into walking.

The ontogenetic landscape metaphor captures some important aspects of development quite intuitively (e.g., the emergence, dissolution, and stability of coherent patterns), but it fails to capture others (Newell, Liu, and Mayer-Kress 2003). For our current purpose its main limitation is that snapshots at given points in time only show which behavioral patterns are potentially present. But it does not show how the patterns relate to each other nor to how their stability changes at behavioral timescales so that the system may move from enacting one scheme to enacting another.[5]

At the bottom of Figure 6.3, we have included hypothetically existing behavioral transitions between the different stable patterns. For these to occur, if we wished to keep the landscape metaphor, certain currently stable patterns would have to disappear temporarily, along with the boundaries separating them, such that the system may transition horizontally toward a different stable state. We would thus have to imagine the landscape

---

[5] In part the limitations of the ontogenetic landscape metaphor are a result of a reinterpretation of Waddington's original landscape. The original idea was meant to capture the developmental path of, for example, different tissue types in the embryo. The development of each type of tissue corresponds to taking a single path through the epigenetic landscape (illustrated by a metaphorical ball rolling down through it). The result corresponds to the selection of one of the various final stable states. In the reinterpreted form of the landscape, in contrast, the stable states are meant to exist all at the same time as potentially available behaviors. Clearly, the one-dimensional layout cannot do justice to how the stable schemes are functionally related to each other.

changing also at faster timescales, such that patterns may become transiently unstable, disappear, and reappear. In other words, we have to distinguish between the schemes that are *structurally* available in general, and the schemes and transitions between them that are *functionally* accessible right now.

We suggest that a better model for these ontogenetic aspects is to view sensorimotor development as the growth of a network of stable patterns and the relations between them, very much like John Fentress's "behavioural network" (1983) or Kurt Fischer's "developmental web" (Fischer and Bidell 2006) previously mentioned. Figure 6.4 is an attempt to visualize this idea. Each network should be interpreted here as corresponding to a particular point in developmental time of the ontogenetic landscape in Figure 6.3, but we now expand the arc diagram at the bottom of this figure into two dimensions to make its network structure explicit. Note that the dynamic nature of the picture does not change. Each node in the network here corresponds to a stable sensorimotor scheme, which itself is the result of various support processes in the organism and its environment interacting and mutually stabilizing each other. In other words, each node corresponds to schemes such as those shown in Figure 6.2, but we have now "zoomed out" further and in the process abstracted some details regarding the schemes' shared support structures. The connections drawn in the network figure represent both the "vertical" links (stability dependencies between schemes and their support structures), as well as the "horizontal" connections among schemes themselves (transitions, preconditions, etc.).

The network view makes explicit that behavioral ontogeny involves processes of differentiation and integration. Differentiation is the creation of new stable sensorimotor schemes and sometimes their dissolution. The formation of new attractors in the ontogenetic landscape metaphor corresponds here to the appearance of new nodes in the network and the loss of an attractor corresponds to the removal of a node. Integration, in turn, is the connection of new schemes to the existing repertoire (the establishment of enabling relations, disposition, transitions, and so on). In the network this corresponds to the changing pattern of connectivity between nodes. Such connections may usually be created between related schemes, for instance, between those that usually follow one another (in a Hebbian-like manner) or between those that play similar roles in a given context (i.e., generally between nodes of the same color in the figure). Links may also be established between remote schemes (nodes of different color). Note that transitions between schemes, as represented by the links, may sometimes occur spontaneously as in the case when the termination of one activity leads naturally to the initiation of the next, and in other cases, it may involve environmental triggers, such as the ringing of the phone while one is immersed in preparing a meal. Our pictorial representation of the network does not distinguish these differences.

Over developmental time the processes of differentiation and integration (the latter driven by preferential connectivity between schemes involved in similar situations) lead to the formation and change of highly integrated "behavioral clusters." These clusters (nodes of the same color) should be interpreted as regional activities, for example, those related with locomotion, with feeding, with interacting with others, and so on. Initially,

Figure 6.4 **Networked sensorimotor schemes.** A (hypothetical) sensorimotor network is depicted at three different stages of development. Initially (top), the network is relatively small, but different sensorimotor schemes already appear connected, forming clusters that correspond to types of activities. Individual clusters may themselves be organized differently, e.g., mostly hierarchically (pink) or sequentially (turquoise). Some pairs of clusters are more strongly connected than others. Over time (middle and bottom) clusters get progressively interconnected and differentiated as the network develops. A wider range of transitions (links) is available, activity bundles are split into smaller subunits, and so on. (See color plate.)

Copyright © 2017 Ezequiel A. Di Paolo, Thomas Buhrmann and Xabier E. Barandiaran, with permission.

the connectivity between and within clusters may not be well differentiated. But over time, the functional grouping of actions becomes more precise. Fentress (1983) has observed, for example, that young mice often switch between unrelated activities when the component acts are similar. If during locomotion a paw passes along the face, for example, the mouse may suddenly switch to a short grooming sequence. In the network model, this may be represented as a case of strong connectivity between schemes in different clusters that share similar conditions for their enactment. During development, as activity clusters become more clearly separated, such "motor traps" tend to disappear.

As the figure illustrates, some nodes have connections to more than one cluster. These nodes can be interpreted as schemes that support more than one activity. For example, the scheme for grasping cups may be involved both in having breakfast and in organizing the kitchen's cupboard. Also within each activity, some schemes may be more central in the sense that they are involved more often in that context. In the network figure, this corresponds to the size of nodes, which more specifically indicates the amount of connectivity between a scheme and others.

The network perspective could shed new light on certain phenomena in (human) ontogeny. For example, it is known that both micro-level and macro-level processes contribute to developmental change, the former consisting in the construction of new skills to be exercised in specific situations, and the latter in their consolidation, generalization, and integration (Fischer and Bidell 2006). In the network view, this distinction may correspond to small and local changes in the structural connectivity on the one hand, and large macroscopic changes on the other, such as the emergence of clusters and connections between large components. The same observation may provide a means for better understanding the presence of developmental "levels," in other words, the synchronized co-occurrence of many discontinuities in developmental change, or "spurts" of growth (see e.g., Fischer 1980; van der Maas and Molenaar 1992; van Geert 1998). "The clustering of discontinuities in macrodevelopment arises not from a mysterious underlying stage structure but from the dynamics by which people build skills through the integration of earlier components in a gradual process with constraints" (Fischer and Bidell 2006, p. 364). An intuitive explanation for how such discontinuities arise from otherwise small and gradual changes may lie in the dynamics of network growth and the resulting transitions in network connectivity patterns. Phenomena such as the consolidation of previously weakly connected schemes into a strongly connected cluster, the establishment of long-range connections between remote clusters given a novel context, and, generally, phase transitions that result in the sudden emergence of new network properties (small-worldness, hierarchies, etc.; Dorogovtsev, Goltsev, and Mendes 2008) may underlie the occurrence of sudden developmental spurts.[6]

---

[6] Neuroscientists will wonder at this point how the network structures and phenomena that occur at the sensorimotor level relate to similar structures observed in the brain. The analysis of structural, functional, and effective networks in the brain is a growing field (see, e.g., Bullmore and Sporns 2009), and it would be a natural next step to investigate the links between these two levels. It would also

Compared with the landscape model, not only does the network description (see Figure 6.4) better capture the development of the complex structure linking individual acts, it also allows us to describe how the interconnections between schemes may become operationally closed, and therefore autonomous. In this view, development starts with the early emergence of simple sensorimotor support structures that enable the organism to engage in basic sensorimotor couplings with the environment. The formation of these structures may originate, for example, in anatomical and functional constraints (e.g., retinotopic wiring; Kirkby et al. 2013), the fixation of self-organized patterns (e.g., spinal circuits driven by spontaneous firing; Marques et al. 2013) or the chaotic exploration of bodily constraints and their sensorimotor regularities (Kuniyoshi and Sangawa 2006). For example, basic kicking, stepping, or arm flailing patterns are present at birth, and constitute part of an initial repertoire that allows the infant to start exploring more complex sensorimotor capabilities and regularities (Thelen and Fisher 1983). During the early stages of development, the differentiation and organization of sensorimotor schemes may be directed primarily by biologically adaptive signals and anatomical constraints together with social and environmental scaffolding. For example, the development of balance and an upright walking pattern depends on the infant having sufficient muscle strength, motivation (e.g., the desire to reach a toy on the table or to follow her mother), and parental support.

Over time, in some species and given typical developmental conditions, a nested web of sensorimotor schemes appears that becomes progressively more independent from biologically adaptive signals and more dependent on the coherence and stability of the organization of sensorimotor schemes themselves. This is inevitable when under internal tensions individual sensorimotor schemes can no longer be accommodated in isolation. For instance, basic patterns of locomotion become important parts of many other activities, including games, dancing, etc., and their relevance in these contexts is no longer determined by the kind of original needs that motivated their creation. The network as a whole becomes increasingly reliant on higher order stability dependencies between individual schemes, and the interactions that they sustain with the environment. The stability and coherence of the organization as a whole depends on the kind of higher level forms of equilibration mentioned in Chapter 4. Eventually, the adaptive regulation of behavior to preserve the consistency and stability of the network of schemes becomes a central organizational principle. It is at this point, we propose, when a sensorimotor network

---

not be a great conceptual leap to identify neuronal cell assemblies (see e.g., Buzsáki 2010; Huyck and Passmore 2013) and processes of rhythmic coordination and synchronization (Varela et al. 2001; Engel, Fries, and Singer 2001) as supporting parts of sensorimotor schemes and their relations. One may also attempt to find correlated phenomena in behavioral and neural development (Fischer and van Geert 2014). But, at this stage, we refrain from hypothesizing about specific mechanisms at the neural level and how they contribute to the sensorimotor network (although they are no doubt integral to its functioning), and limit ourselves instead to a description of the cognitive organization necessary for sensorimotor agency at a mesoscopic level.

achieves autonomy from its underlying organismic self-maintenance, that one may speak of *sensorimotor life*.[7]

6.5.2 **Sensorimotor networks in action**

When seen over developmental timescales, we tend to emphasize changes in the sensorimotor network depicting structural relations (e.g., emergence or disappearance of nodes and links). But we have already suggested with some of the above examples that the network metaphor is also useful to understand how behavior is enacted in concrete situations and how schemes relate functionally, as well as structurally, to each other, as we have seen in Bernstein's example of the activity of lighting a cigarette.

The functional relations between schemes involve the context-dependent ways in which the structural enabling relations, so to speak, are "navigated" at the timescales of behavior.[8] Thus as one or more schemes become active, linkages between schemes may become potentiated or inhibited. This effect may be path-dependent, that is, regulated according to the history of how the agent engages in a particular activity. One could imagine a single node in a cluster lighting up as symbolizing a current enactment of the corresponding scheme. This is illustrated in Figure 6.5, the red node indicating the currently active scheme. As a consequence, several of the links in the cluster and in the network in general get momentarily strengthened while others are momentarily weakened (depicted in the figure as a change in the thickness of links).[9] In the example of lighting up a cigarette, we can imagine all the actions depicted by Bernstein as belonging together in a functional cluster. However, the transitions between schemes in this cluster are not arbitrary; they follow a set of constraints. Some transitions, such as striking the match before taking it out of the matchbox, are impossible. Other transitions are possible but "incorrect,"

---

[7] Some of us have previously used this very characterization for the more general or abstract notions of *cognitive autonomy or mental life* (Barandiaran and Moreno 2006; Barandiaran 2007, 2008, Barandiaran and Di Paolo 2008).

[8] We use the terms *functional* and *structural* in the neuroscientific sense in analogy with the way in which brain connectivity constraints but not fully determines (functional) interactions at short time scales, with the latter in turn modulating structural connectivity over longer timescales (see e.g. Sporns 2013; Byrge, Sporns, and Smith 2014). This usage should not be misunderstood in terms of schemes necessarily fulfilling a functional role in a given architecture. In specific conditions, it may be possible to interpret the enactment of some schemes in this way, of course (scheme A achieves certain results that facilitate scheme B). But, more generally, such interaction links between schemes are not necessarily defined in terms of functions as such, but in terms of dispositions, inhibitions, pre-activations, etc., some of which may not play any functional role (e.g., certain quirks and mannerisms induced by recently enacted schemes).

[9] Fentress (1984) already emphasized that at "each moment the animal or person performs within the context of actions that *have* occurred, *will* occur, and *might* occur" (p. 120, original emphasis), and compares the dynamic balance of different actions using a center-surround model to account for their relations. Similarly, Cisek (2007) argues that the brain structures involved in several currently available actions can be activated in parallel while competing for enactment by mutually inhibiting each other.

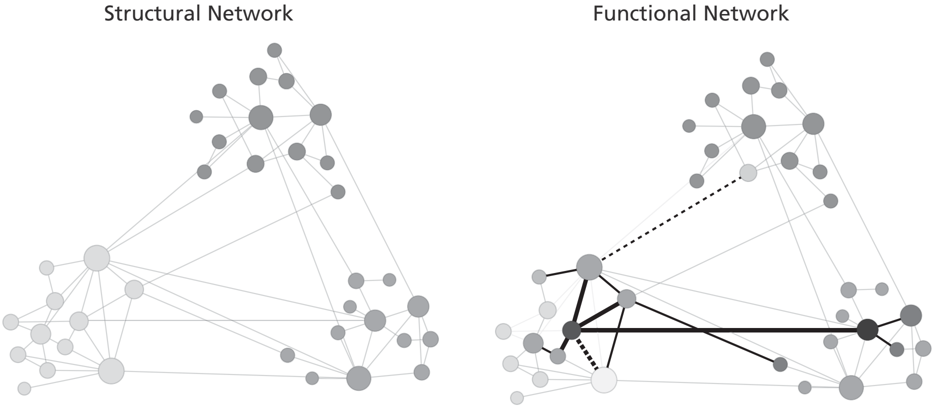

Figure 6.5 **Structural and functional sensorimotor networks.** Depicted is a small part of a network of sensorimotor schemes, consisting of three clusters of activities. On the left, the structural connectivity is shown. It consists of all vertical and horizontal links between the included schemes. On the right, the functional connectivity at a particular instance in time is shown. The currently active scheme is highlighted in red. Its activation makes transitions to some other schemes more likely (thicker solid lines) or less likely (thicker dashed lines). Through the transitional links, some neighboring schemes may already become pre-activated ("primed") or inhibited (shown here as a change in the intensity of the node's color), which in turn may lead to modulation of their own transitional links. Note that this is a simplified picture. In reality there can be more than one hotspot of concurrently active schemes at the same time, and their activation not only involves the influence of neighbors (which in addition may be path dependent), but also the world. (See color plate.)

for instance, lighting the match and blowing it out before lighting the cigarette. This defeats the purpose of the activity. Other transitions have equivalence (e.g., blowing out the match or putting it out by shaking it). Others have some flexibility (e.g., using the same ignited match to light up more than one cigarette). And others simply co-occur or are facilitated without any particular function or meaning for the activity itself, although they may fit the overall style (e.g., adopting a Humphrey Bogart or Lauren Bacall attitude). In addition, some schemes in a cluster tend to act as entry and exit points, due to their functional connections to schemes outside the cluster (e.g., putting away the matchbox to resume walking). Thus one does not enter the activity of lighting up a cigarette, so to speak in the middle of it, nor is the activity typically abandoned halfway.

That these functional relations follow certain normativity suggests that activities are microworlds, to use the apt term proposed by Varela (1992). They are frames of significance inhabited by a micro-identity formed by tightly connected structural and functional relations between schemes. Phenomenologically, once an agent inhabits a microworld, there is a certain readiness-to-act and a certain set of sensitivities implied by the possibilities and demands inherent in this activity. In other words, activities are to a greater or lesser extent *absorbing*. This does not mean that the agent is insensitive to possibilities and demands outside the current activity. Hearing someone urgently calling for help can freeze a person between picking a match from the matchbox and striking it. But even these possibilities show some structure. It may be easier to break the flow of an activity between some schemes but not between others, it may even be harder to break the flow within schemes. Even if I am expecting an important telephone call while I am also repairing a chair, I am not likely to freeze my activity if the phone rings, say, the instant I have begun a strike of the hammer. In other words, there is a degree of commitment that is manifested differentially as the agent is drawn into the different stages of enacting a microworld.

Microworlds are realms of significance, where whatever happens is either readily interpreted within the frame they provide or else it induces a kind of breakdown that can bring the agent outside the frame. If events allow an interpretation within a microworld, they are assimilated into it. Thus, if I am repairing a chair, small breakdowns in my activity are dealt with by the adaptive variability already in place within the cluster of schemes. I may pick up a nail but realize when I start hammering that it is too thin or too short, and so I must stop hammering, remove it if it is partly driven into the wood, go back to the box of nails, and select a different one. There is a concrete focus of my sense-making, and even a sort of style in my actions, which is given by the kind of relations that have developed historically between schemes clustered together. In the absence of major breakdowns, the activity will flow naturally toward its "exit nodes."

In contrast, if an event leads to a major breakdown, the activity is interrupted. This could be an irrecoverable breakdown within the activity (I hurt my thumb while hammering) or it may be something external to the activity: an alarm bell or the sudden recollection I had promised to be somewhere else at this time. These induced breaks in the activity demonstrate that absorption is not absolute and that sensitivity and readiness of a larger scope remain present even while I am quite committed to actions in a microworld. Again the network metaphor is useful here. We can see the analogy between activities and densely connected clusters of schemes, which nevertheless may still connect to schemes in other clusters. There may even be some loose sense of hierarchies (clusters of clusters) or *genres* ("a texture of activities" in Susanne Langer's happy phrasing in the opening quote of this chapter). Take the various activities involved in making repairs around the house; they can themselves form a wider microworld with its own realm of significance, sensitivities, and readiness. So for instance, realizing I should repair the electrical light installation before it gets dark, can make me abandon temporarily my actions on the chair, while I remain involved within a home improvement genre.

Still, what happens if a breakdown is so severe that the agent is not, so to speak, "caught" within any particular activity or genre? There is likely at this stage a hiatus of deep disorientation, of simultaneous partial abandonment and retention of the old frame of significance. We may find ourselves still involved in some of the previous schemes, only that they do not seem to make much sense now. In fact, until the situation is resolved and a new microworld emerges, we are *world-less*. This is a time between moments where *enaction happens*: "at the hinge between one behavioral moment and the next" (Varela 1992, p. 443). At these junctures, the frame of sense-making is reconstituted, brought forth, possibly as a transition to some different existing frame or even as the start of a totally novel one. To begin to enact a microworld is to bring ourselves into the adequate genre and the adequate activity such that we can re-establish the coordinates of significance that were lost during the breakdown.

Microworlds—dynamic clusters in the sensorimotor network—resonate with theories in psychology that characterize regions of interconnected behaviors according to environmental or social settings. One important affinity is with activity theory, the Soviet school of psychology built on the work of Lev S. Vygotsky, Alexei Leont'ev (1978), and others. Activity is the category used to describe a set of interrelated actions that confront a subject with a situated, culturally mediated, often social series of objects, tools, and goals. The daily running of a bakery, the writing of a joint report, and the care of a sick person are examples of activities. The concept is introduced in an attempt to move from an exclusive focus on the "inner" categories of psychology (motives, beliefs, etc.) and explain them as embedded in networks of actions that do not assume a hard distinction between psychological and socio-technical processes. The actions that make up an activity are not unitary in the sense that each of them must satisfy a specific goal to fulfill a specific need. Their conditions of satisfaction are oriented toward the goals of the whole activity. Activities thus involve patterns of coordination between actions, normative orientation toward the environment from which tools and objects are selected and used, and coordination with other actors. Activities are highly dynamic and context-dependent; new motives and goals can emerge in the course of an activity, which is then reoriented accordingly. These properties fit well with our clustered sensorimotor network model; with the difference that activity theory is also oriented to describing the sociocultural and technical organizations. Our network, in contrast, can be interpreted as a projection of these larger macrostructures onto the sensorimotor organization of a single agent. From our perspective, we follow the agent over time, who may transit between activities.

Another useful projection of the concept of activity, this time not onto the organization of the agent but onto the structure of the environment is the notion of behavior settings. The idea, developed by Roger Barker in the 1940s is deeply influenced by Gestalt psychologists like Kurt Lewin and Fritz Heider, with whom Barker worked closely. Behavior setting theory (Barker 1968; Schoggen 1989) associates recurrent behavioral patterns with structures in the environment that constrain and guide these behaviors. An example of a behavior setting is a waiting room. The arrangement of sitting places, the general entrance and the entrance to some inner space, the temporality of events such as the time to admittance, and so on, all are environmental factors that massively influence the flow of activities, including the enactment of sensorimotor schemes that accord to the setting. In this way, behavior setting theory studies activities in terms of the objective environmental processes that enable behavior and how these processes are sustained, partly by the very enactments they enable.

The idea of sensorimotor agency as a dynamic self-sustaining network of schemes is in general compatible with activity theory and behavior setting theory (about the potential links between enactivism and the latter, see McGann [2014]; see also the discussion of affordances as relative to the situated normativity of a form of life in Rietveld and Kiverstein [2014]), although as we note, their emphases are complementary. Activity theory's emphasis is on the sociocultural embedding of activity and its influence on psychological processes. Behavior setting theory highlights environmental structures and spatiotemporal relations in the milieu as strong determinants of behavior.

We notice that since we are dealing with a network of sensorimotor *schemes*, nothing of what goes on is this network is entirely determined either by the support structures in the agent or in the environment on their own. Environmental settings can funnel activities into a few constrained behavioral options, but they do not wholly remove the possibility of an agent breaking away from those activities. In fact, it may be necessary to introduce a further distinction between the general environment of a sensorimotor agent, and the more specific environment as part of a microworld (activity theory and behavior setting theory could provide useful tools for developing this distinction). The same general environment, a street, becomes radically different in its significance depending on the microworld we are currently enacting (e.g., whether I am strolling aimlessly or returning home from shopping with heavy bags). Thus, we provide only partial information when we describe what the general environment affords an agent if at the same time we do not also describe the activity that frames her current microworld within that environment.

6.6 **Kinds of agency, sensorimotor bodies**

The definition of agency is sufficiently explicit to be operational. We have demonstrated this by using examples of simple life forms, showing that even single cells exhibit agency in the minimal sense. We should equally be able to determine which sort of system exhibits *sensorimotor* agency. For example, can we say whether non-human mammals, like cats or dolphins, are sensorimotor agents? What about "simpler" animals? Do fish have the required sensorimotor organization? Do ants or flies? How about a bee colony or a tree?

To answer these questions, we must test whether the three requirements are satisfied in each case. In other words, does the system in question form a network of sensorimotor schemes with stability dependencies among schemes as well as between schemes and their substrates? Is the system organized such that its activity regulates the coupling with its environment so as to normatively preserve its particular sensorimotor organization? In what sense does the sensorimotor network establish a functional "boundary" that separates and protects its mode of being?

These questions are tricky because agents in the minimal sense tend to engage in overt behaviors, often displaying the frequent use of lawful sensorimotor regularities (coordination patterns, schemes, and even series of related schemes). In short, we may find creatures able to enact sensorimotor schemes of various degrees of complexity, but in itself, this is not yet a sign that all of the requirements for *sensorimotor* agency are fulfilled in this kind of agent.

We can propose a rough progression in complexity from minimal to open sensorimotor agency.

1. *Minimal agency*. The fulfillment of the three requirements in the minimal sense, without specifying any restrictions on the sensorimotor domain. All living organisms are minimal agents.
2. *Minimal sensorimotor engagement.* The minimal agency of many organisms involves what we describe as sensorimotor dynamics with specialization into sensory and effector processes. Many of these organisms can enact a variety of sensorimotor schemes. These schemes are coupled to metabolism, grounding their normativity in the organism's survival. Yet the schemes themselves are more or less fixed, showing only limited scope for adaptive change in their organization.
3. *Minimal sensorimotor learning.* Of the creatures capable of minimal sensorimotor engagements, some can exhibit learning and flexibility in individual sensorimotor schemes. Each scheme can equilibrate, but not necessarily in relation to others. Schemes relate to each other via organismic agency (i.e., coupled through metabolism).
4. *Minimal sensorimotor agency.* In some organisms, precarious sensorimotor schemes are organized into a network of enabling relations. At this stage, the sensorimotor network becomes operationally closed in itself and not only through the organismic closure; it becomes individuated in the sensorimotor domain.
5. *Open sensorimotor agency.* Some sensorimotor agents have the adaptive capacity to learn new sensorimotor schemes in an open manner and integrate them in the overall network.

According to our definition, only creatures at or above level 4 of this progression are proper sensorimotor agents. As we move up through the lower categories, we find examples that are not yet sensorimotor agents, but which gradually move toward increasingly complex forms of biological agency. For example, even the bacterium *E. coli* exhibits sensory-guided behaviors and is able to adaptively switch between different behaviors in response to metabolic demands. But for exactly that reason, the operation of the bacterium remains firmly rooted in its organismic agency, and it is not able to flexibly adjust its schemes according to norms at the sensorimotor level. We would thus place *E. coli* in category 2 (i.e., as an agent capable of minimal sensorimotor engagements).

Next, consider the nematode worm *C. elegans*. It has a nervous system, exhibits a whole range of different behaviors, such as chemotaxis, thermotaxis, and avoidance of noxious stimuli, and is able to adapt behaviors to new circumstances. For example, it will learn to associate the presence of food with a certain environmental temperature if the food is reliably found at this temperature along a thermal gradient. And it will unlearn this association when starving and food is no longer found at the learned temperature. *C. elegans* could be said to have a set of sensorimotor schemes and the ability for some of these schemes to adapt. But while there are some linkages between the different schemes (as demonstrated by their associative flexibility), these relations do not yet necessarily form an operationally closed network.[10] Moreover, the driving force behind the adaptations within or between individual schemes remains the metabolic requirements. We suggest that *C. elegans* is an example of category 3, an agent capable of minimal sensorimotor learning.

Sensorimotor agents in the full sense (category 4) also have a flexible organization of sensorimotor schemes, but in addition, this organization forms a closed self-sustaining network of relations between precarious schemes. This means that we would expect to find in sensorimotor agents that some aspects of their behavior make sense according to sensorimotor norms apart from strictly metabolic needs. Many animals fall in this category in more or less obvious ways. For instance, all species capable of exhibiting play behavior are clear cases of sensorimotor agents because they can show behavior that is not directly linked to biological norms and yet are capable of normatively regulating their schemes within the play-activity frame. The same is true for species susceptible of showing maladaptive and compulsive behaviors in the absence of a sufficiently engaging physical and social environment (e.g., rats; Alexander, Coambs, and Hadaway 1978).

Since we considered the question of open-endedness in Chapter 4, we may also distinguish basic forms of sensorimotor agency from open ones (category 5). The behavioral repertoire of open sensorimotor agents is able to change in unpredictable, historically and culturally influenced manners. This is not only the case with humans and primates, or songbirds with very flexible song repertoires, but also with what we could very broadly describe as "trainable" animals (e.g., domestic pets, crows solving problems using tools).

The five categories above are merely indicative. It is likely that they share many gray areas and that suggesting that an organism is an agent of one kind and not of another will be highly dependent on current knowledge about it. The categories are also not perfect in that they move simultaneously along different dimensions: flexibility, plasticity, organization of a sensorimotor repertoire, and whether norms are strictly biological or both biological and sensorimotor. We could attempt to separate these dimensions or even to add other ones such as, for example, the degree to which an agent engages in active niche construction, or the forms of spatiality implied in the agent's movements (animals move differently from plants), bodily reflexivity, or the degree of sociality involved in enabling a sensorimotor repertoire. We also have not said much about the

---

[10] The relative independence of sensorimotor schemes in *C. elegans* is revealed by ablation studies (Rose and Rankin 2001) and specific mutations (Zhang, Lu, and Bargmann 2005) that induce selective inhibition of behaviors while maintaining the rest of the behavioral repertoire comparatively unmodified. Also high degrees of modularity and decomposability in *C. elegans* (Reigl, Alon, and Chklovskii 2004) may considerably reduce the role of self-organization at a large scale and thus the precarious interdependence between scheme support structures. Nevertheless, we are still far from understanding the full complexity of *C. elegans'* sensorimotor dynamics (Izquierdo and Beer 2013), and the kind of agency it embodies is something that deserves a further empirical study. The virtue of our approach to sensorimotor agency is precisely to make possible the generation of hypothesis to be tested regarding levels and kinds of agency.

developmental aspects that could inform these distinctions either: a particular organism may not fall within one of these categories at a given developmental stage but do so at another. And to make matters more complicated, there is no reason why we should not also look at some collectives, such as ant colonies, as potential sensorimotor agents, if we could suitably define what we mean by sensorimotor closure, asymmetry, and normativity in such cases.

These problems could be addressed and we could come up with better ways of categorizing kinds of agency. Our point is simply to indicate some broad differences along some dimensions that tend to be of general interest.

Related to these issues, the question as to whether a robot can become an agent finds a straightforward answer within our proposal: insofar as the robot is capable of supporting the emergence, maintenance, and adaptive regulation of a network of *precarious* sensorimotor schemes it is a sensorimotor agent. Note, however, that current examples from autonomous robotics are not agents of any kind in this classification since they do not self-individuate. Still they can "behave" in functionally more or less complex ways. These behaviors, however, do not quite go beyond being analogous to level 2 of agency. Most often, behavioral layers are independently defined and later connected. Few (if any) of the mechanisms involved can be said to be precarious. The challenge for robotics is to create agency directly at the sensorimotor level. It is an open issue whether this is possible or not. It would require the design of "architectures" that can instantiate a plastic web of precarious "sensorimotor" processes, with the additional capacity to organize themselves into finely tuned hierarchical and horizontal dependencies to achieve global coherence. If such an operationally closed dynamic architecture could be instantiated, it would probably suffice to bootstrap the normative requirements to anchor the activity of sense-making (processes at that point would become properly sensorimotor, without scare quotes).

In order to achieve artificial sensorimotor agency in real environments self-organized processes of accommodation and assimilation within and between schemes need to be in place, and we are yet to find a general-purpose approach capable of producing this (although see discussion on open-ended equilibration in Section 4.6). A promising avenue for engineering artificial sensorimotor life could be to explore the evolution of developmental processes whose deployment in a specific bodily and environmental setup leads to the emergence of a sensorimotor scheme network with regulatory capacities. Some connected ideas have been modeled (Di Paolo 2000b; Egbert and Barandiaran 2014; Iizuka and Di Paolo 2007), but the principles for open-ended sensorimotor agency have yet to be implemented artificially. While strict material self-production may possibly be sidestepped, open-ended attunement will nevertheless demand that the body also be subject to material evolution and self-organization, otherwise it cannot be open-ended. The environment will need to be sufficiently complex too, and open enough to afford selective and self-organized support of the sensorimotor scheme network. An example of this kind of material and environmental openness are the cases of evolvable hardware and growth of artificial sensors mentioned in Chapter 5.

The flipside of the question of artificial sensorimotor life without material self-production is the question of how biological and sensorimotor agency relate in a same organism. We may sketch some of the expected relations between the two forms of agency, especially since in many cases we see an overlap of self-asserting organizations in a given organism, which could potentially aspire to agency status. This is a complex area that deserves more elaboration so we cannot go further than some very broad considerations.

The first thing to note is that there are not simply just two forms of self-individuation: organismic and sensorimotor. What we have broadly described as organismic or minimal agency, based mainly on the adaptive, self-sustaining identity of metabolic processes, is in itself in many cases constituted by more than one level of autonomy. This has long been recognized by proponents of the organizational approach to the study of living processes. Varela (1979) proposes apart from autopoietic closure, the autonomy of the immune system, as well as other self-sustaining loops, such as the relation between cellular activity and the extracellular matrix (Varela and Frenk 1987), as genuinely autonomous systems. These many levels of autonomy do not immediately translate into forms of agency, of course. In some cases, only one of the three requirements would seem to be warranted, that of individuation. But other cases could potentially be shown to fulfill the other requirements too (we could speculate for instance that self-affirming immune networks may be a possible candidate; see e.g., Varela et al. 1988; Stewart and Varela 1991).

Similarly, as we have seen, sensorimotor agency involves self-sustaining sensorimotor schemes that are themselves equilibrated in higher order organizations. Even within an operationally closed sensorimotor repertoire, we can find other kinds of closure. Micro-identities may emerge as subnetworks of tightly bound schemes within the broad sensorimotor repertoire, like the clusters in our network description. It may well be the case that we enact different forms of sensorimotor agency, for instance, in different social situations, and that at the psychological level, these are seen as different, sometimes conflicting aspects of a personality.

Given these complications what can we say about the relation between biological and sensorimotor agency? The general answer is that there is no general answer, and that the relation between these types of agency depends on the specific relations between the processes involved (and sometimes on the particular history and circumstances of the organism in question).

We can make a few observations, though. It would seem that in some sense, metabolic/organismic identity is more fundamental that sensorimotor identity, at least as presented to us empirically by every example of agency known to us. Thus, organic norms play the role of constraints on sensorimotor norms because organic self-individuation reliably enables the existence of the sensorimotor agent. But enabling is not the same as fully determining. There are many ways in which organic constraints can be met, but only some of them seem to be preferred, a fact already noted by neurophysiologist Kurt Goldstein (1934/1995). There are therefore some degrees of freedom within which sensorimotor agency establishes its own normativity. Sensorimotor norms can even be in tension with organic norms as we have noted. This tension may be sustained in time. What cannot happen is that sensorimotor agency in living systems sustains itself beyond the ultimate barrier of organism's viability. At that point both forms of agency cease to exist.

The above describes one "arc" of the relation between biological and sensorimotor agency. But the description would not be complete if we left it at that. In many ways, once sensorimotor agency is at work, it can offer the organic body many possibilities to sustain its viability that may not have been available to it before. Sensorimotor agents explore their environments and modify them, changing in so doing the conditions that affect their organic selves. And in turn this can lead to the organic identity also changing in accordance to new possibilities afforded by sensorimotor agency. At some point in this history of mutual changes, however, the organic level may not only be "helped" by the sensorimotor level, but actually become *organizationally* dependent on it. Such is the case with practically all animal life. The energy budgeting of animals (different from that of plant life) allows the development of nervous systems that control rapid movement and permit mobile forms of agency where the whole body is able to uproot itself in controlled manners. This in turn affords a variety of possible sources of nutrition. But this "gain" in opportunity is at the "cost" of organismic dependence on sensorimotor success because the energy levels required to sustain mobile agency cannot be achieved in any other way (see Moreno and Lasa 2003; Barandiaran 2008). We see then that while it is clear that organismic agency *reliably* enables sensorimotor agency, the historical/evolutionary development between the two forms can *sometimes* reach situations where sensorimotor agency in turn also enables specific ways in which biological agency is organized. These ways may eventually be such that it could become impossible for the organism to constitute itself materially, to produce its body, other than as a sensorimotor agent.

In this sense sensorimotor life can be reabsorbed into the material constitution of the organism. Sensorimotor agency becomes anchored in the body. It is no longer a case of a purely organic body, which later, in addition, enters into the relations from which sensorimotor agency emerges. It becomes a *constitutively sensorimotor body*, a second nature.

As we have said, the schemes forming a closed and precarious network are relational in nature, and therefore cannot be conceptually confined within any particular physical boundaries. Yet in everyday life, it is of course the most natural thing to identify the "sensorimotor ecologies" surrounding organisms with their physical bodies. How do we justify this association, if schemes constitutively involve both agent and environment structures? One answer may lie in the way that agent and environment support structures relate among themselves. For while environmental aspects involved in different behaviors do not generally need to be connected in any specific way, the agent-side support structures depend for their existence not only on the exercise of certain sensorimotor schemes (as per our definition of closure at this level), but of course also on a common physiological basis or substrate that is itself maintained at the level of organismic autonomy. It is through this kind of scaffolding of the different levels of autonomy that each higher level can become anchored in the levels below it. And it is this anchoring, in turn, which justifies our intuitive association of the sensorimotor agent with its living body.

This anchoring in the body is the dialectical resolution of the tension between the two kinds of agency. The double normativity of sensorimotor engagements (they are the regulatory engagements of a biological agent, but they are also the way in which a sensorimotor agent reasserts its identity) results in tensions that can only be overcome actively and sometimes partially by the ongoing (re)integration between the two kinds of agency and their historical co-dependencies. Thus, we are justified in associating sensorimotor agency with a body, only this body is not just the organic body it is anchored to. There is also a sensorimotor living and lived body. This body allows for non-organic elements (prosthesis, glasses, hearing aids, and tools) to become part of it, to be *incorporated* into it whenever they participate in sustaining the closure of the sensorimotor network. The sensorimotor body can also be extended beyond direct contact with the organic body, while remaining functionally anchored in it. It extends into the nest, the territory, the vehicle of the expert driver, etc. This occurs, again, whenever the (structural or functional) stability of extra-organic elements also faces precarious circumstances, and by becoming involved in the closed network of precarious sensorimotor processes these external elements become stabilized.[11]

These briefly sketched mutual constraining and enabling relations do not exhaust the interdependence between organic and sensorimotor agency. In their call for a radically embodied approach to the neuroscience of consciousness, Thompson and Varela (2001) highlight the fact that the brain is not only the mediator of an agent's sensorimotor embodiment, but also the point where behavior is organically regulated. The organic body and the sensorimotor body in fact engage in direct and mutual interactions at various levels, mediated by links between the autonomic nervous system and the limbic system via the hypothalamus, as well as through contributions of the endocrine and immune system. Emotional states and homeodynamic metabolic processes thus regulate not only specific functions such as sleep, wakefulness, or arousal. As Panksepp (1998) notes, the interaction between the neurodynamics of basic emotional circuits and neural schemas related to bodily action plans might also be the origin of affective feelings of pleasure, anger, desire, etc. Disruptions to sensorimotor agency can be emotionally distressing (see Box 6.2). Adaptive regulation through interaction of the organismic and sensorimotor levels

---

[11] Some cases of active niche construction fall within the category of extended sensorimotor bodies, but not all. Many of them have the added complication of involving collective and intergenerational effects. Examples of more or less obvious sensorimotor extensions or incorporations include spider webs, the building of amplifying singing burrows by mole crickets, and the trapping of air bubbles for underwater respiration in insects (see Turner 2000). A nice example is that of the Weddell seal in Antarctica. She maintains a breathing hole in the ice so she can access the water below where there is food and protection from blizzards. The breathing hole is constantly shrinking as ice builds up; hence, it can be said to be a precarious structure. The seal invests a lot of energy and time trimming the ice around the hole with her teeth. This prevents the hole from freezing over (Castellini, Davis, and Kooyman 1992). There is, in this case, a relation of co-dependence between biological individuation and sensorimotor agency, and between sensorimotor agency and the structuring of the environment, all of them precarious networks of processes that stabilize each other.

Box 6.2 Sensory deprivation and sensation seeking

Sensorimotor agency is precarious; a systematic prevention from sustaining the networked relations between schemes and support structures can, over time, result in minor, traumatic, or even fatal damage to sensorimotor autonomy.

Such is the explicitly stated purpose of techniques described by the 1983 *Human Resources Exploitation Manual* used by the CIA to train (para)military personnel in Latin America. These techniques include manipulation of the environment to disrupt familiar sensorimotor patterns and induce disorientation, physical weakness, and dread. Ultimately, the goal is to provoke a "psychological regression in the subject by bringing a superior outside force to bear on his will to resist. Regression is basically a *loss of autonomy*, a reversion to an earlier behavioral level" (Schutz 2007, p. 155, our emphasis).

Studies in sensory deprivation in the 1950s—covertly funded by the CIA (McCoy 2006)—revealed that apart from the need for "the sensory stimulation of the normal complex environment" during growth, "the *integrity* of the mind at maturity continues to depend on that stimulation" (Hebb 1980, p. 96, our emphasis). Sustained isolation from patterned stimulation (often inseparable from limitations to action possibilities) leads to visual disturbances, anxiety, mood swings, apathy, and cognitive impairments.

Attempts to explain these effects on autonomy and integrity often involve the notion of stimulus hunger: a need for an optimal level of sensory stimulation (e.g., Hebb 1955), although this does not clarify why deprivation leads to some effects in particular and not others, nor does it make explicit what need is served by satisfying this "hunger." Given the chance to voluntarily trigger a stimulus even if it is meaningless (e.g., pushing a button to show some colored stripes), sensory-deprived subjects will seek these sensory sources (Zuckerman and Haber 1965). This sensation-seeking behavior is explained as originating in an inherent personality *trait*, which is determined by the neurochemistry of reward systems in the brain and modulated by social and occupational factors (Zuckerman 1979).

We can formulate an explanation that moves beyond considering stimulus seeking as a trait by exploring its underlying logic as a disruption to sensorimotor subjectivity, i.e., as threats to the integrity and autonomy of sensorimotor networks. The need for stimulation is literally a *hunger*; not so much a trait that just happens to be modulated by neurochemical and social factors, but a well-defined, contextual sensorimotor demand that fits the logic of self-maintenance of sensorimotor networks (as hunger for food fits the logic of metabolic self-individuation). The clue is that, if sought after, stimulations are not meaningless. On the contrary, they afford (or fail to afford) the enactment of certain sensorimotor coordination patterns and even whole schemes (e.g., following the direction of the colored stripes with the eyes, or crossing them over repeatedly; even patterned color flashes can pre-activate schemes), so they are meaningful according to sensorimotor norms. "Sensation" seeking is a longing for the action/perception *enactments* needed to stabilize precarious relations between schemes and their support structures.

of agency may even underlie a “basic self-affection or a core consciousness of one’s bodily self-hood. Thus, processes of life and processes of mind are inseparably linked. Every conscious state is rooted in the homeodynamic regulation between brain and body, and, in a sense, integrates the present state of the organism as a whole” (Fuchs 2009, p. 5). Similar points are elaborated by Giovanna Colombetti in her book *The Feeling Body*, where she proposes an enactive, dynamical theory of affectivity and emotions. What she calls primordial affectivity is a property of the whole organism as a sense-maker. This affectivity belongs to living organisms, even those that are not themselves sensorimotor agents. For the latter, primordial affectivity takes the shape of moods and emotional episodes, which she describes as “self-organizing configurations of the organism” (Colombetti 2014, p. 82). Emotions act as emergent high order constraints to the dynamics of muscular, neural, and autonomic processes that integrate the affective experience of the whole body engaged with the world.[12]

6.7 **Sensorimotor subjectivity and mastery, again**

If we take the definition of agency in Chapter 5 seriously, then evidence of actions that follow “non-biological” norms also counts as evidence of some other kind of self-individuation happening at a level that corresponds to these norms. But exactly *what* is being self-individuated? To answer this question, we have explored whether individuation and agency at the sensorimotor level are coherent ideas.

Self-sustaining precarious patterns of sensorimotor activity do occur; we call them habits. They are metastable relations between organic and environmental processes poised between blind automatism and unpredictable spontaneity. Habits confirm that the indeterminacy of sensorimotor processes with respect to metabolism allow the possibility of self-individuation in a different space from that of biochemical processes. The circularity between the enactment of a habit and the stabilization of its support structures is extended as an oblique relation between several schemes and their support structures. In this case we are dealing with a self-individuating network of sensorimotor schemes.

Sensorimotor networks of this kind can meet the requirements of self-individuation, normativity, and interactional asymmetry. As we explore this idea in detail, we profit from the network metaphor and find that through regional developmental differentiation and integration of schemes, integrated subnetworks can be formed that correspond well to notions such as activities, microworlds, and sensorimotor genres. The structure of the

---

[12] Here we should remind ourselves of Hans Jonas’s reflections on the passage from basic forms of affectivity in metabolizing life to the co-emergence of action, perception, and emotion with the mobility typical of animal life (1966). For Jonas, not only are action and perception possibilities afforded by movement that arise as developments of basic forms of sense making (in our terms), they are also inextricably linked with a complexification of primordial affectivity as novel emotional dimensions are afforded by animal mobility. Thus, fear is an emotion that integrates temporal and spatial elements (e.g., sensing now the approaching predator in contrast to sensing now the pain of an injury).

sensorimotor network reflects the history of the agent. In humans the possibilities are open-ended and path-dependent, as we would expect, leading to a way of characterizing otherwise vague concepts such as sensorimotor styles (an idea that merits further exploration).

Sensorimotor agency, a non-homogeneous network of interrelated micro-identities, fends off the frequent criticism of enactive cognitive science reducing mind to biology. This is a clear example of the emergence of autonomous domains, in this case a sensorimotor domain, which does not contradict life–mind continuity, but on the contrary is only understandable through it, as a dialectical development of the relations between organism and environment. In this case, in particular, it is thanks to the operational concept of agency that developed at one level that we may find a different kind of agency at another. The distinction between biological and sensorimotor levels corresponds to the ontological leap afforded by distinguishing between manifestations of autonomous entities at different domains. There is a sensorimotor body that extends beyond the organic body, but at the same time, it is anchored in it. The organic body in turn becomes dependent on the sensorimotor body, not only in the direct sense that behavior is required for survival in sensorimotor creatures, but also in the sense that organic self-individuation is organized in ways that are enabled by the sensorimotor body.

We will continue to explore some of the implications of sensorimotor agency in Chapters 7 and 8. Before we do, we briefly return to Thompson's (2005) critique of the sensorimotor approach to perceptual experience. According to him, sensorimotor contingencies theory does not provide a sufficient account of perceptual experience as it obviates reference to the subjective aspects of this experience. Could the concept of sensorimotor agency help in addressing these concerns? We think so.

Myin and O'Regan (2002) argue that the sensorimotor approach can account for fundamental properties of perceptual experience, viz., forcible presence (sensory experience imposes itself on us), "ongoingness" (this experience happens in the here and now), ineffability (experience is always richer than what may be described in words), subjectivity (sensory experience is an experience for me, the subject). The latter property would obtain simply by the fact that there is a subject whose resources are put into constituting her conscious experience. According to Thompson, to repeat what we said in Chapter 2, the sensorimotor account of these properties is enriching but incomplete, as it requires a more compelling account of selfhood and agency as well as an account of pre-reflective bodily self-consciousness (Thompson 2005, p. 417).

Thompson reminds us of the difference between simple agents like bacteria that meet our definition of agency and systems that do not, like O'Regan and Noë's example of the missile guidance system (2001, p. 943), which they claim has some kind of mastery of sensorimotor regularities that allows it to operate adequately. Perhaps it can be argued that this system is able to alter its coupling with its environment in an asymmetric manner (for instance, by activating new sources of information contingently on its current state). But the system is individuated only by convenience of design and use, not as a consequence of its own activity. Moreover, while its operation is subject to norms, these norms are strictly external to the individuation of the system—see a similar argument by Jonas (1966) about goal-seeking control in the guidance system of a torpedo. This is not an agent. Guiding a missile to the right target or missing it with the concomitant tragedy of so-called "collateral damage" is not something the guidance system cares about. There is no risk and no opportunity, in fact, nothing to "perceive" by this system that is of any interest to the system itself. Its "individuation" does not put the system into that kind of Jonasian relation of needful freedom with its surroundings.

In a sense, a fundamental property of perceptual experience that has so far been missed by the sensorimotor approach is that perception is inherently meaningful for an agent—even when we perceive something nonsensical, this character is precisely a locus along dimensions of meaningfulness (see e.g., Froese and Cappuccio 2014). There must be an agent that does the perceiving, and there must be a meaningful relation between agent and world in order to speak of action or perception at all. What sensorimotor agency adds to this is that this meaningful relation is not only established between the biological body and its environment, but involves also the new forms of self-individuation that obtain in the sensorimotor spaces opened by basic kinds of agency; it involves the sensorimotor body.

We should keep in mind that for the enactive approach to have a meaningful relation to the world is to enter into the activity of sense-making. What is meaningful is that which the agent is sensitive to and adaptively capable of regulating. In the case of the sensorimotor agent, the world consists of those factors that the agent is able to identify as relevant to the ongoing individuation of its closed sensorimotor network of schemes, or more concretely, as relevant to its effective action in the world. These include factors relevant for the normal enactment of schemes, which are needed to reaffirm the agent's identity and factors perturbing this enactment, potentially impeding it.

Some confusion may arise from the fact that by definition a sensorimotor scheme is constituted by the interaction of agent-side and external support structures (the A, B, C, … and A′, B′, C′, …). If we think of the schemes involved in picking an apple from a branch and taking a bite of it, it is obviously the case that the apple in this situation is meaningful. It is meaningful for the biological agent but it is also meaningful for the sensorimotor agent. Although related, these meanings are not identical. What matters from the sensorimotor perspective is not the nutritional value of the apple, per se, but the effectiveness at performing a series of actions, the relations between the schemes involved (stretching the arm and body long enough to reach the apple, gripping it firmly enough so it does not slip, pulling it with sufficient force, etc.) and also the relation to other schemes. The apple provides several properties that enable these schemes, e.g., its solidity and its graspable size. These are the A′, B′, C′ … elements that co-constitute the different acts, while the neuromuscular activity, the body posture, the pressure put on the grip, etc. are the A, B, C, … agent-side support structures. What is meaningful to the sensorimotor agent are not these elements in themselves but the apple's potential for providing these sensorimotor supports, of affording certain schemes, as well as the body's own capacities and skills involved in performing them. The sensorimotor agent will be sensitive to the apple's affordances and to the bodily possibilities and this includes factors that disrupt or alter the successful enactment of the scheme and therefore impede its role in asserting the sensorimotor network that makes up the agent. Thus, it will be meaningful for the sensorimotor agent if the apple is too high and out of reach. If the agent is a small child, the apple may be too big to grasp with one hand or too firmly attached to pull off the branch. But these sensorimotor breakdowns (obstacles and lacunae) may be adaptively equilibrated; after a few failed attempts, the child may jump, grab the apple with both hands, and pull it with her whole body. Equilibration in this case shows the presence of sensorimotor norms at play, that is, the regulation of relations between schemes so as to overcome sensorimotor barriers and restore the agent's effectiveness in the world.

Thinking of a sensorimotor network as closely connected schemes appropriate to certain activities and behavior settings—clustered into what Varela refers to as micro-identities—brings a new angle to the notion of mastery. In Chapter 4 we have linked mastery to the equilibration of sensorimotor schemes. The way that sensorimotor agency is organized—as a non-homogeneous network of enabling and functional relations between schemes—allows us to see mastery more concretely. Not only do we master a given sensorimotor scheme as we undergo progressive equilibration such that it better fits a given situation, we also master the regional relations between schemes and their adaptive variability in the concrete context of an activity (the effects shown in Figure 6.5). Our picture of development shows that new clusters may emerge through processes of differentiation and integration between schemes. Achieving cluster-level mastery is equivalent to saying that the elements of the cluster become progressively integrated and adapted to each other. Enacting a single scheme in a cluster involves the influence of several other non-enacted schemes (cf. the quotation by Mead on this point in Chapter 2).

This is why some of the examples of perceptual know-how given in the sensorimotor literature make intuitive sense. An object like a tomato is seen as voluminous because I may change my angle of vision or grasp it or turn it, and these schemes—which are not necessarily enacted—inform my visual perception. But why do they? And why these schemes and not others? My visual perception of the voluminous tomato does not appear to be that much informed by many other things I could potentially do, such as smashing it with a hammer, touching it with my forehead, or covering it with a newspaper. This is because what we master is strongly colored by the clustered schemes that correspond to concrete activities, in other words, the subnetworks of schemes in Figure 6.4. Thus seeing a tomato, grasping it, and moving it so that I now see it from a different angle are all schemes that belong together as part of activities such as cooking or shopping for groceries. And this is the reason why these closely networked schemes affect the enactment of a single one of them, such as looking at the tomato. The structural and functional links that connect schemes in a cluster mean that I rarely just look at a tomato in the abstract (an issue we will come back to in Chapter 8), but instead I look at it in order to start preparing the salad, for example. If the looking scheme belongs to clustered activities, looking is always already *looking-in-order-to* as well as *looking-because-of*. In other words, mastery of sensorimotor contingencies is *regional*, something that is only implicit in the sensorimotor approach to perception.

There is operational closure at the whole network level as well. Thus, we speak of a single sensorimotor level. However, the high integration of regional, closed or quasi-closed sensorimotor clusters is phenomenological relevant in questioning the extent to which there is a unified self at this sensorimotor level. As Varela (1992) has noted, we transit through microworlds of significance (walking aimlessly in the park or hurriedly to catch the train) in which we literally act as micro-identities. Enaction is the transit between microworlds, the time between moments.

If this is so, there could be, apparently, not a single *sensorimotor* subject, but many, which are nevertheless interlinked, and also integrated by the same sensorimotor body and same sociohistorical-narrative embeddedness. Varela (1991) has spoken of the various forms of self-individuation that make up an organism as "a meshwork of selfless selves." By this he means to picture an organism somehow as the ongoing integration of many kinds of autonomy (metabolic, immune, neural, sensorimotor, cognitive, social, personal, etc.) with no single substantial locus where one could find a unifying "self." The subnetworks of schemes that make up a sensorimotor agent add to this picture, as they make even one level of selfhood (sensorimotor) into a potential multiplicity of micro-identities.

It would be tempting—but incorrect—to conclude from this insubstantiality and multiplicity that the notion of selfhood should be discarded, that such a thing does not exist. We have done nothing so far but show that concepts of this kind can be perfectly grounded in natural science. A self that like many other concepts (energy, force, dynamics, etc.) is not an intrinsic property of matter but a relational one, does not for this reason have any less reality or efficacy. The enactive approach is not skeptic about the self, in any of its manifestations; it has precisely reinvigorated the idea of selfhood while at the same time demonstrating that it is a multiple, dynamical, relational, historical, and situated concept.

So, to come back to the sensorimotor approach, sensorimotor agency, as we have proposed it, not only places the agent at the center of the engagements that constitute a perceptual act, it also provides us with a deeper understanding of context-dependent mastery and activity-dependent selfhood. This helps us address only the first of Thompson's worries.

> Adding an enactive account of selfhood to the dynamic sensorimotor approach goes only part way toward addressing the body-body problem [the problem of the relation between the subjectively lived body and the living body of the organism]. In addition we need to include subjectivity in the sense of a phenomenal feeling of bodily selfhood linked to a correlative feeling of otherness.
>
> (Thompson 2005, p. 419)

In Chapter 7 we intend to move into this direction by exploring whether our account of sensorimotor agency can help us elucidate at least one aspect of the phenomenal feeling of bodily selfhood: the sense that we are the agents of our actions.

Sensorimotor Life

An Enactive Proposal

Ezequiel A. Di Paolo
Thomas Buhrmann
Xabier E. Barandiaran

OXFORD
UNIVERSITY PRESS

OXFORD
UNIVERSITY PRESS

Great Clarendon Street, Oxford, OX2 6DP,
United Kingdom

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship,
and education by publishing worldwide. Oxford is a registered trade mark of
Oxford University Press in the UK and in certain other countries

© Oxford University Press 2017

The moral rights of the authors have been asserted

First Edition published in 2017

Impression: 1

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, without the prior permission in writing of Oxford University Press, or as expressly permitted by law, by licence or under terms agreed with the appropriate reprographics rights organization. Enquiries concerning reproduction outside the scope of the above should be sent to the Rights Department, Oxford University Press, at the address above

You must not circulate this work in any other form
and you must impose this same condition on any acquirer

Published in the United States of America by Oxford University Press
198 Madison Avenue, New York, NY 10016, United States of America

British Library Cataloguing in Publication Data
Data available

Library of Congress Control Number: 2017932492

ISBN 978–0–19–878684–9

Printed and bound by CPI Group (UK) Ltd, Croydon, CR0 4YY

Oxford University Press makes no representation, express or implied, that the drug dosages in this book are correct. Readers must therefore always check the product information and clinical procedures with the most up-to-date published product information and data sheets provided by the manufacturers and the most recent codes of conduct and safety regulations. The authors and the publishers do not accept responsibility or legal liability for any errors in the text or for the misuse or misapplication of material in this work. Except where otherwise stated, drug dosages and recommendations are for the non-pregnant adult who is not breast-feeding

Links to third party websites are provided by Oxford in good faith and for information only. Oxford disclaims any responsibility for the materials contained in any third party website referenced in this work.