The Semiotic Nature of Power in Social-Ecological Systems

by

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ABSTRACT

Anderies (2015); Anderies et al. (2016), informed by Ostrom (2005), aim to employ robust feedback control models of social-ecological systems (SESs), to inform policy and the design of institutions guiding resilient resource use. Cote and Nightingale (2012) note that the main assumptions of resilience research downplay culture and social power. Addressing the epistemic gap between positivism and interpretation (Rosenberg 2016), this dissertation argues that power and culture indeed are of primary interest in SES research.

Human use of symbols is seen as an evolved semiotic capacity. First, representation is argued to arise as matter achieves *semiotic closure* (Pattee 1969; Rocha 2001) at the onset of natural selection. Guided by models by Kauffman (1993), the evolution of a symbolic code in genes is examined, and thereon the origin of representations other than genetic in evolutionary transitions (Maynard Smith and Szathmáry 1995; Beach 2003). Human symbolic interaction is proposed as one that can support its own evolutionary dynamics.

The model offered for wider dynamics in society are “flywheels,” mutually reinforcing networks of relations. They arise as interactions in a domain of social activity intensify, e.g. due to interplay of infrastructures, mediating built, social, and ecological affordances (Anderies et al. 2016). Flywheels manifest as entities facilitated by the simplified interactions (e.g. organizations) and as cycles maintaining the infrastructures (e.g. supply chains). They manifest internal specialization as well as distributed intention, and so can favor certain groups’ interests, and reinforce cultural blind spots to social exclusion (Mills 2007).

The perspective is applied to research of resilience in SESs, considering flywheels a semiotic extension of feedback control. Closer attention to representations of potentially excluded groups is justified on epistemic in addition to ethical grounds, as patterns in cultural text and social relations reflect the functioning of wider social processes. Participatory methods are suggested to aid in building capacity for institutional learning.

to my sister Ana, whose presence was irreplaceable

our parents V. & V.

my former co-traveler A.

and a few select people whose name starts with S.

such as spinosaurus

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CHAPTER 1 INTRODUCTION

The main motivation for this study is the existing conceptual and practical gap in interdisciplinary research usually characterized as running between quantitative and qualitative methods, specifically in the understanding of resilience in social-ecological systems (SESs). While there is considerable interplay between perspectives on this topic, a division still runs between institutional approaches that rely on modeling and economic experiments (Ostrom 2005; Anderies et al. 2016; Anderies 2015), and case studies that examine social differences and justice (too many to list) or analyze complex relational and textual data from the field (e.g. reviewed in Bodin and Crona 2009).

Of possible pitfalls, Cote and Nightingale (2012) note that institutional and quantitative approaches risk a lack of attention to how social power imbalances shape SESs, and concerns of underrepresented groups in them. The potential blind spot is especially problematic as the results of this research can have direct practical effect through the guidance they offer to international and national agencies. Indeed, providing policy advice is one of the main stated aims of Anderies (2015); Anderies et al. (2016). While these studies mention the necessity to address power inequalities as well as employ participative methods, little is offered by the way of specifics.

The present essay offers one avenue to address this gap by taking up the issue of empirical legitimation of critical and interpretive research. While there is no lack of practical advice and experience in meaningfully treating quantitative and qualitative data side by side (Small 2011), there is a gap in what kinds of data and methods are accepted as trustworthy that is quite real. As Rosenberg (2016, ch. 1) presents it, one extreme seeks replicable and quantifiable relationships that can neutrally inform policy and consider qualitative study too subjective to be useful; the other is happy to relay and interpret study participants' own points of view, often eschewing systematic comparison altogether. The tack taken here is to argue that textual and perspectival data, while subjective, closely bear on a materially efficacious phenomenon, social power; and to offer a framework consilient with natural sciences to investigate it.

It makes sense to consider social power, seen generally as the ability to shape and control how other people act through one's own social actions, as a natural phenomenon. In addition to the fact that we are material beings and everything we do is consistent with findings of natural sciences, social influences decisively shape biological features and prospects of human populations. War deaths, for example, can be attributed to battle, hunger, and disease, each of which can be traced to a different assortment of specific biophysical and social causes, from bacteria to bayonets. Whatever caused the war indirectly shapes basic material characteristics of populations, in this case by influencing death rates. While connections have been indeed been made, for example, between demography and population ecology, primary social dynamics the data reflect, such as war, while intelligible, remain hard to analyze rigorously. There are many noticeable patterns in human action and they interact in complex ways, and there is so far no agreement in social research on how to systematize them or compare different perspectives. This poses the question, how, if at all, can one characterize social power in general as a material phenomenon consilient with natural sciences?

Addressing this question leads far afield. Since most human activity involves symbolic representations, accounting for power requires addressing what kind of a natural phenomenon symbols are, what is their material nature and efficacy, the topic investigated in biosemiotics (e.g. Pattee 2007; Rocha 2001). Building on this work, it can be argued that social power arises from self-reinforcing networks of interactions that can span many kinds of social activity ("flywheels"), to which we can attribute emergent collective intention, if rudimentary. These networks comprise human symbolic interactions, which, it is argued, mediate a process of sociocultural change with evolutionary characteristics.

Information involved in social reproduction is multilayered and still incompletely characterized. We can tell it resides in *persons*, enculturated humans, and *activities*, kinds of interactions we initiate in our surroundings. This means especially that any large scale social processes materially shaping persons and activities (our surroundings and how we interpret them), and group interests in position to influence these processes (explicitly or diffusely), are implicated in power, shaping social relations and cultural representations. A number of perspectives in social sciences are compatible with this view, for example dialectical materialism as articulated in Harvey (1996); Cox and Nilsen (2014).

If the flywheel picture of social power is correct, patterns in individual and group relations and narratives are likely to reflect the regularities in self-reinforcing interactions that shape it. In particular, differential access to infrastructure is likely to be a primary means of shaping social activities. Anderies et al. (2016) address the importance of coupling between different infrastructures; it is the coupling of differences in access, if it can be detected, that might reflect features of robust control-like self-maintenance in SESs (Anderies 2015). For the framework in Anderies et al. (2016) this points to two empirical directions, as well as two general suggestions for interdisciplinary research.

First, differences in access to infrastructure are likely to drive social-ecological dynamics and can in some cases be investigated directly. Second, information on social relationships and a diversity of narrative accounts needs to be gathered, as they together indicate wider dynamics (Mohr and White 2008; White 2008). Moreover, modern environments change quickly, so attempts at practical advice in institutional design to communities as suggested by Anderies (2015, pp. 277–278) need to attend to local capacity for redesign and change. This points in favor of methods that are accessible to and potentially replicable by the study participants as citizen science, such as, indeed, mapping the networks of social relations and beliefs.

Finally, for research traditions whose coexistence is mutually epistemically uneasy the broad advice is simple. Find observables both claim to voice on, and focus on differences in respective answers to Tinbergen's (1963) four questions: how does it manifest in social activities, how is it learned, what is its history, what else it shapes and what shapes it.

Chapter Overview The treatment proceeds in three strides covering the span from natural to social sciences from a semiotic perspective. Given the breadth, the steps are speculative and differ in depth. In some preliminary analysis is offered, others summarize the argument and discuss related literature. First, it is argued that representational phenomena arise with natural selection, with genetic code one that can be considered symbolic. Second, material manifestations of signs are traced through evolutionary history to human symbolic interaction, which, it is claimed, is versatile enough to underlie sociocultural dynamics with evolutionary characteristics. Finally, possible nature of patterns in human activity that thereon arise is discussed, along with implications for decreasing the epistemic gap in interdisciplinary studies of SESs. Each of the steps takes up a cluster of chapters in the document, with introductory two setting the stage, as follows.

Chapters 2 and 3 address underlying conceptual concerns and preliminary assumptions. A natural science of human society is best, it is argued, that assumes the least about the society and itself as a social activity. In general, occurrences in the world are taken to be events that interact, and with which we can interact and describe them. The way to sort out our accounts, it is argued, is to recognize that each is contingent on context, and to initiate conversations interlinking them with natural sciences, possibly difficult to reconcile.

Chapter 2 asks how a natural science of society can proceed by making the fewest assumptions on the nature of society, and about itself as a social activity. Qualitative and perspectival statements, it is argued, cannot be excluded without assumptions on existing social relationships. The result is a multitude of accounts, expressed in vocabularies tied to specific contexts. They can engage by constructing more encompassing contexts of interlinked conversations, committed to eventual, if often indirect and incomplete, engagement with physical sciences. The suggestion is guided by Longino's (2002) sociopragmatism and by Feynman's (1965) analysis of research in theoretical physics.

Chapter 3 outlines the basic assumptions: phenomena in the world can be seen flexibly as occurrences or actions that interact, their interaction another action (a given); we can interact with and describe them (to be explained). A formal representation of a statement about such occurrences is introduced, later used as pseudo syntax to clarify arguments about the link between semiotics and material processes. Then, the choice of natural sciences as the starting set of statements is substantiated with reference to our social actions. Both a justification and a responsibility for sciences is claimed to ground results in terms that ultimately lead to widely shared, if not quite culturally independent concepts and activities, such as counting, measuring, and so on.

Chapters 4 to 6 argue that representation of information arose as a natural phenomenon at the origin of life, with genes the earliest attested code that can be deemed symbolic. This is done by casting the explanation of physical origins of intentional, "about," relationships by Deacon (2012) in partly formalized, semiotic terms, representing potential interactions among non-living natural processes. Representation originates, it is argued, as autocatalytic sets such as those modeled by Kauffman (1993) achieve semiotic closure (Rocha 2001) (section 6.1 to 6.3). The account follows Deacon's from basic physics to the first living beings, representing material processes as proto-semiotic information transmission channels.

Chapter 4 introduces a way to represent physical relationships as information channels, and demonstrates how doing so naturally connects with semiotics. There is no intrinsic content in physical relationships other than change over time, but opportunities of interaction a process affords to another can be shown to exhibit some properties of signs. On two examples, physical processes are associated with Shannon transmission channels: a cannon shot with a continuous one, and combustion with a discrete channel. Proto-semiotic relationships are identified formally on the discrete example.

Chapter 5 applies the proto-semiotic representation of physical relationships to aggregate and emergent material processes, such as those in Deacon (2012, ch. 6–8). Implications of viewing material processes as information channels are discussed, such as assumptions on time scopes and the social nature of symbols used in our descriptions. This lays grounds for the argument in the next chapter on the origin of semiosis (sign making) and intentionality, by extending the framework to processes just preceding living beings.

Chapter 6 traces how interacting matter first organized itself into what we can recognize as a symbolic representation or a message. Research in biosemiotics (Pattee 1969, 1982; Rocha 2001) posits that representations are parts of *semiotically closed* processes. Symbols are recognized and used to initiate other interactions, including but not limited to reproducing the message and molecules that interpret it; the example is the genome.

An account for the material origin of representation is given, guided by Tinbergen's (1963) four questions and Kauffman's (1993, ch. 7) models of the origin of life. Kauffman argues natural selection sets in as autocatalytic (self-reinforcing) reaction sets become supracritical, able to interact with almost arbitrary chemicals, due to increase in possibilities for interaction. Such sets satisfy criteria for semiotic closure, thus they are (somehow) representational. The origin of representation is traced on an example autocatalytic set from Kauffman, cast in semiotic terms from the previous two chapters.

The representation within the living process evolves along with it. Organs and metabolic pathways can be seen as distinct information contexts, operating on scopes appropriate to the affordances they address, integrated into the bounded organism. Metabolic relationships can approximate robust control (Csete and Doyle 2002). Further, information needs to pass through the bottleneck of reproduction, which favors evolution of symbols, in this case genetic code (Pattee 1969). The three aspects of evolution of symbols in semiotic closure: self-reinforcement, specialization, symbolic encoding, are proposed as the general framework for appearance of representation.

Chapters 7 and 8 follow material manifestations of semiotics from genes to human symbols. In the previous chapter, semiotically closed representations were argued to evolve symbols in three aspects: while in an *autocatalytic* set one can not locate representation precisely other than tied to the living process, semiotics *specialize* as the population evolves, and are eventually encoded *symbolically*. The three provide a framework to consider evolution of semiotics other than genetic, such as evo-devo regulatory switches, cognitive concepts, and human symbols. Human social interaction is argued to support evolutionary dynamics.

Chapter 7 discusses how further representational and evolving processes may originate, now involving living beings and their actions. This helps understand what kinds of affordances an organism addresses and how, specifically what kinds of semiotic processes other than genetic it can recognize and initiate. When and if new representations appear, it is argued, they follow to differing degrees the three aspects of the evolution of symbols. This assumes the least about the information carrying substrate, and suggests specific indicators of the three aspects. The chapter ends with a heuristic argument why it is reasonable to expect a sociocultural evolutionary process, and about the likely nature of social reproduction.

Chapter 8 analyzes evolutionary transitions (Maynard Smith and Szathmáry 1995) for semiotic closure, looking at proposed indicators: self-reinforcement giving rise to selective dynamics; differentiation reflected in individuation and teleonomy; symbols appearing at information bottlenecks. Human culture is argued to be the first appearance of an evolutionary process on a new channel, persons in social activities, or symbolic interaction. Semiotic closure in human symbolizing has evolved as primate social learning intensified within a diversity of ever faster interactions. The channel of reproduction is outward, with symbols both spoken and present in the interaction, in people in their surroundings (*activity*). Enculturated humans (*persons*) carry the representation between activities, with its material realization not fully known. Current sociocultural evolutionary approaches (Boyd and Richerson 2005; Henrich and Henrich 2007) model only a small part of the channel; Garfinkel (2008) presents an attempt to characterize it more fully.

Chapters 9 to 11 finally bring the account to human society. A simple model for wider dynamic entities on top of social interactions is offered, "flywheel," a semiotically closed self-reinforcing networks of activities, exhibiting a degree of distributed intentionality. Flywheels are hypothesized as the material and dynamic basis for social power. Observable proxies of their patterned effects are identified in relational and cultural sociology (White 2008; Patterson 2014). Finally, implications for research of resilience of SESs are discussed.

Chapter 9 begins with considering the semiotics of human symbolic interactions and relations. It then argues that wider dynamics that take shape in cultures and societies have the nature of semiotically closed self-reinforcing sets of social interactions, "flywheels," and that these are the likely immediate material manifestation of social power. Their persistence over longer periods can with care be ascribed to collective intention of social groups, ranging from emergent and diffuse to explicitly stated. Infrastructure systems, regularities shaping action situations (Anderies et al. 2016) do indeed convey social power, from (any) persons and groups with preferential access to the infrastructure. The dynamics structure social relations and cultural representations over wider scopes, and so viable methods to study them include structural similarity in social networks (Kadushin 2012), and cultural content analysis (e.g. Mohr and Neely 2009; Mohr and Guerra-Pearson 2010). Specific sociological and critical formulations of social power are examined (Wolf 1999; Mann 1986; Ortner 2006; Kondo 1990; Freire 1970; Mills 2007), establishing common points with the semiotic perspective. Finally, the criticisms of sociocultural evolution by Fracchia and Lewontin (1999); Ingold (2007) are addressed, with the current perspective offered as a response to their main objections.

Chapter 10 turns to consider ways to pay greater attention to power imbalances and participation in research of SESs. Investigation of such differential access, it is suggested, needs to be primary, treated on part with institutional design principles. The differentiation into social groups is likely to shape sustained relations and narratives in any SES; also, specific attention to gathering accounts of underrepresented concerns helps reduce possible ignorance effects (e.g. Mills 2007). Potential directions for research are considered, starting with the logistic barriers to coordinating disparate efforts in general. Then, a study of knowledge creation by alternative food initiatives in an area is proposed and evaluated. Finally, the need to support local institutional learning through participatory methods is briefly noted: enabling communities to experiment with semiotic closure.

Chapter 11, finally, charts the next needed steps to advance the argument, and offers the final suggestions for transdisciplinary research: broaden infrastructural affordances, and ask the four questions (Tinbergen 1963).

CHAPTER 2 BABYLON

This essay outlines a case for accounts of human society and culture that focus on symbolic interaction, social relations, and power, as consistent and consilient with empirical positivist natural sciences. Although a detailed philosophical treatment is beyond my competence, articulating the foundations briefly is necessary, as the theoretical link between natural and social sciences is established via evolution.

Currently, while they offer many valuable ideas, evolutionary approaches to social sciences retain barriers to engagement with much of the rest. Arguing that some of the gaps are bridgeable will necessitate a fresh look at the informational characteristics of evolutionary processes as semiosis or sign making. Semiotics is usually seen on the opposite side of the division between sciences and humanities; however, it would be hard to give an empirical account of science itself if we do not somehow explain sign making, in form of symbol use. I now briefly turn to the vexed philosophical issues, most importantly how we can characterize human society as a natural phenomenon while acknowledging that the study of natural phenomena, as a social activity, is a part of what we are trying to account for, so that we need to make its social assumptions transparent at start. To navigate this, I rely closely on the pragmatic characterization of physical sciences by Feynman (1965), and on insights about the relation between the social and the rational by Longino (2002); Anderson (2017).

2.1 The Material with Which We Work

What statements we make about the world make sense in light of natural science? To address this, we need to get some sense of what we mean by natural science. This is far from decided, a matter of heated debates among philosophers of science as well as between them and sociologists. I will bring up some insights from these arguments when relevant, but will not delve into them very deeply now. Instead, I start with advice arising out of one scientist's understanding of his own work:

> What is necessary 'for the very existence of science', and what the characteristics of nature are, are not to be determined by pompous preconditions, they are determined always by the material with which we work, by nature herself. We look, and we see what we find, and we cannot say ahead of time successfully what it is going to look like. The most reasonable possibilities often turn out not to be the situation. (Feynman 1965, pp. 147–148)

Following this advice, to get a sense of what we mean by natural science, we need to look at "the material with which we work" when we talk about it. This can be one of many things. By natural science we may mean, for example, what a person or a team of people is doing at a given moment, a course one takes in school or university, written matter that is considered part of this subject, or the works of many people through history that manage these written texts and formal representations.

The last meaning is the most comprehensive one. As an observable empirical phenomenon, natural science is an ongoing human social activity that produces, changes, and maintains symbolic representations tied to observation ("we look, we see what we find"). This sense can be taken to comprise the others: the doing and learning of natural science are its parts, particular written expressions its products.

Here we run into a few snags.

Epistemic Circle First, because natural science is a social activity, understanding what we mean by it in its own terms already requires a social science consilient with natural science, which is what we are trying to work toward. (For simplicity, we can call natural science together with such consilient social study simply "science.")

The way out is to aim for epistemic closure. Grant that the account is necessarily circular, so that our understanding of science needs to be responsive to the scientific study of science as a social activity (Longino 2002), then provide a starting point for such a natural scientific understanding of culture and society. In the remainder of this chapter, I outline a few characteristics of science as a social activity that aim to assume as little as possible. Heeding the warning against imposing preconditions, I err on the side of inclusion, of assuming broad, observably evident features of a wider range social activities, that can plausibly be argued to include both natural sciences and studies of society that could participate in work on a consilient account. The rest of this essay approaches the issue from the other side, aiming to demonstrate how it is possible, beginning with known findings of natural sciences, to account for human sociality in general, and as a part of it for those social activities that satisfy the starting assumptions. Fine tuning of what precisely counts as science is left aside.

In doing this, I am placing the bet that the disputes between sociologists and philosophers of science are eventually to be carried by sociologists. Claims anyone makes about science are either factual, thus empirically observable and can be checked against the actual practices that produce knowledge we deem as science, or normative, thus an attempt to legislate what science is, which also observably holds or not, as any scientist in practice follows or disregards any specific norm. So, Feynman (1965) above caricatures the normative requirement that "the same conditions always produce the same results," parrying that in quantum mechanics they do not (p. 147). Admittedly, social studies of science still have a way to go before they can take on the task of evaluating arbitrary empirical claims about scientific practice; before then, their debates both with philosophers and with practitioners such as Sokal and Bricmont (2003) have ways to go to clear the thickets.

What is Informative? Second, in social study of science along with the rest of social science, but unlike in much natural science, experiments are in general not available. Feynman (1965) continues from the above:

> If science is to progress, *what we need is the ability to experiment*, honesty in reporting results – the results must be reported without somebody saying what they would like the results to have been – ... (p. 148, emphasis added)

The way out is, in parallel to giving up strict prediction, to relax too the condition on experiment in favor of a more general empiricism. While experimental social sciences are thriving, there is also no shortage of other kinds of data or ways to interpret them. While few seek predictive laws, they offer a trove of empirical observations and analyses informed by them, claims that any natural science of society would seek to evaluate. In Feynman's (1965) words, we need to "make statements about the regions [of experience] that we have not seen, or the whole business is no use" (p. 76).

We thus admit any kind of reporting on interaction with "the material with which we work" as long it is *informative*, able or at least aiming to shed light onto other contexts. The scope of this ambition can be modest: for example, an ethnographic thick description may only aim to impart to the reader some of what they may experience should they participate in situations very similar to those described, to provide context for evaluating other accounts from and about the same cultural group, or the like; some such potential needs to be present.

Voices and Values Third, in science as in any other social activity, almost everything we say says something about society: practically every word we speak and every gesture we make we have encountered before, learned it from someone else and adapted it for our purposes, and many of them carry quite a history. Also, almost everything we say does something in society: it is told to someone with the expectation of having an effect on what they will do later, even if we are just speaking to ourselves. This simple observation in its extreme implications spelled out by poststructuralists such as Foucault and Derrida has sowed a rift between interpretive and experimental approaches to social sciences, which many (e.g. Rosenberg 2016, pp. 28–32) consider unbridgeable.

When studying abstract concepts or non-living subjects, one can set oneself apart from the matter of study and bestow on one's terms meanings that are clear and distinct. In social sciences, such a tactic has proved elusive. There are many reasons for this but one is immediately easy to see: at least some areas of social science the subject matter of study needs to include one's own social activities, including that of study, lest one deems oneself exempt from study or study exempt from itself. As Anderson (2017, sec. 7) points out,

> When the objects of inquiry are knowers themselves, these assumptions [of subject/object dichotomy] rule out the possibility that knowers' self-understandings help constitute the ways knowers are. It therefore rules out the possibility that some of our characteristics, such as our gender, are socially constructed. Ironically, these assumptions may lead people to make the very projective errors the objectivity package is supposed to avoid: attributing to the essential natures of the objects of study what are actually products of people's contingent beliefs and attitudes about those objects (citing Haslanger 1995).

This is a general point and it works in several ways. The first is the one primarily meant by Anderson (2017): that one's "findings" may be an artifact of the wider social dynamics that make certain kinds of observation possible in the first place. In this case, the power male observers had to dictate what women do lead them to conclude that women were intrinsically passive (2017, sec. 7). Another is that familiarity with a theory about humans can change the understandings and actions both of the researchers and of the public at large. Learning rational actor theory can make students more selfish (Frank et al. 1993; Hargreaves Heap and Varoufakis 2004, box 5.2, p. 182), and small talk about one's repressed urges was likely rare before Freud became well known. The final possibility, more abstractly, if what we study are the terms that help articulate the study, what we find out can change these terms and thus change the study. In short, society is dense with changing information on many levels and time scopes, and the act of research or the one who performs it are not innocent of or easily isolated from this.

For all his celebration of science as a way to not fool himself, Feynman (1998) fell into the first trap head on, expounding on the supposed virtues of rational skepticism on the example of arguing against a fictional woman's suspicions that "her husband is trying to make trouble for her" (p. 103–105). This a few years after he confessed to "Extreme Cruelty," "physical and mental," in the dissolution of his messy second marriage (Gleick 1992, p. 294). Feynman was not alone in this: at the time, published papers in psychiatry argued domestic violence gave wives "apparent masochistic gratification" (Snell et al. 1964, quoted by Time 1964).

History of science is replete with examples of the use of the mantle of scientific reasoning to wholly or partially deny the legitimacy or existence of someone's viewpoint, usually of those belonging to a social group underrepresented among the reasoners, too often to the point of advocating actions that jeopardize another's livelihood or life. In some cases, e.g. in relations between the colonizers and the colonized, this was so pervasive that major aspects and aims of positivist science are seen as intrinsically Eurocentric (de Sousa Santos et al. 2007; Tuhiwai Smith 2012).

It does not suffice simply to call these historical cases bad science. Such judgment is passed in retrospect; at the time it mattered, abuse had the imprint of science and commanded the prestige and authority accorded to it, and was typically not limited to isolated incidents but systematic and predictable. The fact that it is now recognized as bad science may curtail similar excesses, but does not foreclose the question which scientific practices today will be seen as abusive a generation down the line.

The way out is to extend Feynman's warning against preconditions to idealized notions of objectivity. These are always set and maintained by specific communities of practitioners, too easily replicate their blind spots, and can be used to forward their interests. As Mills (2007) points out, an idealized picture of social practices in the face of blatantly observable inequality is too often a mask for self-serving willful ignorance. In the interest, then, of not fooling ourselves, we need to include self-consciously *perspectival* and *value-laden* accounts in our conception (a) of natural science as a social phenomenon in particular, as these views contribute to understanding the social role played by activities recognized as natural science in the past and today, and (b) of a science of society in general, as they are an informative way at getting at explanations not just of what we do or why, but what what we do does (Dreyfus and Rabinow 1983, p. 187, citing Foucault).

Symbolic representations, scientific or not, can be implicated in social power dynamics, and if we are to grasp how this takes place we need to consider front line reports from many sides; it is only to be expected they will be personal and passionate. This does not mean, however, that all value-laden and perspectival accounts are scientific or indeed insightful. Many are informative, and many are not; biases can be both generative and limiting (Anderson 2017, sec. 5). One salient and largely accepted point is that value-laden inquiry can only be epistemically fruitful if it avoids narrow circularity:

> It is now generally agreed that the theory-laden character of observations does not threaten their status as evidence for a theory, provided that the theories presupposed in those observations do not immediately include the very theory being tested by those observations. Circularity, at least of a narrow sort, should be avoided. Similarly, the chief danger of value-laden inquiry is a kind

> of circularity of wishful thinking or dogmatism (Anderson 2004). The value-laden character of the background assumptions linking evidence to theories should not foreclose the possibility of discovering that one's values are mistaken, because (for example) they are based on erroneous beliefs about human potentialities and the consequences of putting certain values into practice. ...
>
> As long as the different research programs are producing empirical successes not produced by the others, and avoiding clear error and viciously circular or dogmatic reasoning, there is good reason to treat the value-biases animating them as epistemic resources, helping us discover and understand new aspects of the world and see them in new perspectives, rather than as obstacles to the search for truth. (Anderson 2017, sec. 6)

Remarkably, Feynman (1965) anticipates and fully endorses this view in physics:

> ... and finally – an important thing – the intelligence to interpret the results. An important point about this intelligence [to interpret results] is that it should not be sure ahead of time what must be. It can be prejudiced, and say 'That is very unlikely; I don't like that'. Prejudice is different from absolute certainty. I do not mean absolute prejudice – just bias. As long as you are only biased it does not make any difference, because if your bias is wrong a perpetual accumulation of experiments will perpetually annoy you until they cannot be disregarded any longer. They can only be disregarded if you are absolutely sure ahead of time of some precondition that science has to have. (p. 148)

So, prejudice is in, dogma is out.

2.2 All Talk

Babylon in Babel Now, while these relaxations address one set of problems, they introduce others. Simply, everyone possessed of senses and language can observe and communicate one's perspective, one's experience of own situation and of other social activities, in ways that can in principle be informative. We are open to the entirety of phenomenal world disclosure, subject to the condition that it is not circularly dogmatic. And given the proliferation of perspectives, it is clear that even this condition cannot hold up in the form outlined above.

One, it is badly defined, as what is a circular dogma for one person may be a fundamental starting assumption for another, and there is no fixed point of view from which we can judge this. Two, lines of reasoning based on assumptions we would consider impervious to being proven wrong can still yield informative insights. The case in point is Cartesian dualism. The present essay agrees with Deacon (2012, pp. 39, 544) and Dennett (2017, pp. 13–22) that considering mind and body as made of separate stuff is nowadays both untenable and unproductive. Yet little would remain of science if we ignored insights that assumed the Cartesian division or excluded speakers whose reasoning was rooted in it.

The way out is to specify more explicitly what the proliferating accounts can be taken to refer to, and how they can engage with one another. Thus: all we say refers to some practical context, limited in scope (when, where, for whom) and manner (how) it comes about. What we can say is unlimited, but contexts we can talk about are limited, as they arise when we interact with the world and so are limited by our physical capacities. Through conversation, a context in its own right, we can link up different statements about a(n other) context, and statements about different contexts intersecting in scope.

Such an approach follows Longino (2002, pp. 93–95) in recognizing that statements are attached to contexts, and that there are subtle and not-so-subtle ways whereby different accounts of what is naively seen as the same phenomenon end up not easily reconcilable. In such cases, though, the approach *recommends* “constructing a further or more encompassing context” in which different ways of making statements may establish dialogue, if not be entirely reconciled. The resulting structure of conversations can be seen as a loosening of the positivist framework by Nagel (1979): instead of boundary conditions on the validity of physical law, specify situated contexts with the added condition “for whom”; instead of lawlike statements, just informative ones; instead of bridge principles, conversations between contexts. This adopts what Feynman (1965, pp. 46–50) dubs the Babylonian attitude, writ large: rather than fixing first principles from which to deduce the rest, we start from the many things we know or think we know and look to expand connections between them.

This is not much; it grants much ground to poststructuralists, and resembles the Tower of Babel characterized by Rorty (1989), for whom knowledge is conversational, tied to practical contexts, and expressed in vocabularies that may do nothing with each other. However, it assumes that it is possible to link conversations up by reference to some stubbornly observable features, albeit with criteria up for discussion. The bet is, there can be conversations that purposely aim to make visible in present practice whatever background assumptions and historical sediments lie in the terms being used, and clear up or at least anticipate possible misunderstandings. So, a degree of dogmatism is tolerable when practiced by some, as long as there are others engaging with the same context building bridges. The mandate against dogmas is enacted through their distributed deconstruction.

Manifest Science Finally, note that, in including statements relevant to understanding society in general and natural science in particular, we have given up strict experiment and allowed in value-laden and perspectival accounts. With these relaxations, what remains is to reestablish what it still means, if anything, that the conversations are consilient with natural sciences.

We cannot rely on the division between the manifest and scientific images of the world, introduced by Sellars (1963) and taken further by Dennett (2017, pp. 61–63). Both of these concepts are idealizations of ontologies that are shared by many people to differing extent, and are deeply contingent on culture (manifest image, the "common core of ontology that is shared by all normal human beings" as early as age six, p. 61) or institutions that create and purvey it (scientific image, "something you have to learn about in school," p. 62). As we are trying to assume the least about how society shapes knowledge, just stamping the seal of science on institutional knowledge will not do: it only passes the buck to explaining how one set of social institutions, in comparison to whatever else we do, is good at producing scientific accounts.

The way out is to *invert* the relationship between the manifest and scientific images, and make the scientific image rely on the transparency of the manifest image, to the extent parts of it indeed are common to different cultures. Thus we root physical sciences in the study of those objects and relationships we can agree are manifestly material, if and when we can do so, and in addition afford a detailed analysis and a thorough account, to some negotiated standards. This removes the methodological requirements for something to be considered physical science, and recasts it instead as a practical social achievement.

So, some contexts and relationships that we consider we can agree are physical, and some of these are separable from us, in ways that we can replicate in practice, and as such demonstrate and teach. Physical contexts are such that one can, with effort, eventually replace the delineation "for whom" with instructions about when, where, and how, and so reenact situations in them quite widely, with minimum or no background knowledge about people who first produced them: "Don't trust me; check it out for yourself" (Cartmill 2002). This turns out usually to be the case with processes that are informationally much simpler than us, so they can be accounted for precisely and quite completely, to the point where for many practical purposes and wide ranges of conditions, “we do not know where to look for trouble, we think everything is all right” (Feynman 1965, p. 158).

In this essay the trouble is seen to start with the study of life. While we can describe in detail the many of its physical aspects, living matter is packed with information to the smallest scales and its gross features and behavior cannot be predicted nearly as easily or to the same precision (Schrödinger 1956, p. 16–17). Also, aspects of living creatures can be described as intentional, apparently acting on purposes, which poses a range of conceptual conundrums about causation (Dennett 1995, ch. 1; Deacon 2012, ch. 0), along with the question “is there anyone in there?” These require evolutionary arguments to address in terms of physical causes (chapters 6 and 7).

Evolution is one of the *cranes* (Dennett 1995, pp. 74–77) used to link up different accounts to physical sciences. This means that, if we view the study of a context as a social activity, at least some people who take part in it are committed to connecting their world descriptions with physics on the basis of observation, directly or indirectly. There are no *skyhooks*, no entities or processes that we can invoke to obtain arbitrarily complex information. We cannot postulate a God or a separate realm for mind or culture, though in the latter cases there can be disagreement on how tight or tenuous connections to simpler accounts can be. Otherwise, the simplicity and clarity of context vocabularies are up to the speaker; there can be as many “moos and goos” and they can be as vague as one wants as long as one takes a rain check on eventually being able to prove them useless. Feynman (1965) makes some fun of ambiguity in psychology to make a point that “you cannot prove a vague theory wrong,” but immediately backtracks and allows room for guesswork, with care, at the beginning of every science (pp. 158–160, 164).

2.3 Sociopragmatism

Summing up what we have got so far. Observably, science is a social activity. As a social activity, science is a part of interlinked conversations that create and manage symbolically represented statements about various practical contexts of human activity. Its goal is to be informative: what it finds out about one context, it claims, can be used in others. Alternative accounts are judged by reference to what can be observed. Slanted accounts are fine as long as they use the bias as a resource to come up with informative claims, and are open to negotiating and carrying the burden of attempting to obviate it. In each conversation there is at least a notional understanding that we are talking about the physical world, and a commitment to connect to physical accounts via a possibly large number of other conversations.

This picture ends up close to Longino's (2002, pp. 207–208) "critical contextual empiricism" or "sociopragmatism," of knowledge as partial, plural, and provisional, with plural*ity* as a recognition of empirical realities of inquiry rather than an *a priori* theoretical commitment to plural*ism* (p. 95). This should not be controversial: in physics too there is a plurality of lines of inquiry, and we do not yet know how to connect some of them very well. In addition, in recognition that all phenomena we are considering are ultimately physical, the present essay replaces the monist stance frequent among proponents of naturalism with the openness to establishing conversational links with natural sciences, possibly quite indirect.

Feynman (1965), in fact, anticipated a similar picture, as the work of "all the efforts of intellectual kinds, ... to see the connections of the hierarchies, to connect beauty to history, to connect history to man's psychology, man's psychology to the working of the brain, the brain to the neural impulse, the neural impulse to the chemistry, and so forth, up and down, both ways" (p. 125). While many will disagree that this cloud of conversing inquiries is science, most conceptions of science should be contained as subsets of it. Better to err on the side of inclusion, as “it is necessary for the very existence of science that minds exist which do not allow that nature must satisfy some preconceived conditions” (Feynman 1965, p. 148).

Here, then, are what seem to be minimal conditions on “nature” necessary for science to exist as a social activity. Any science assumes something of the sort, and any comprehensive social science can only achieve epistemic closure by accounting for them:

1. We (human beings) can perceive, interact with, reason, and issue symbolic statements about the world.

2. Our statements about the world usually, self-consciously or not, make sense in particular contexts. Contexts are practical, associated with some social activities, and also with vocabularies from which our statements draw their terms. Each context possesses scopes in time, space, and society, which we may be able to discern and delineate to differing degrees of accuracy.

   These first two points are restated and partly formalized at the beginning of chapter 3.

3. With each other, we can enter into relationships that exhibit persistent features.

   This includes assumptions on the institutional arrangements of science as a social activity, as well as roles such activity plays in the larger society for good or ill. Any value-orientation of inquiry makes reference to features of relationships. Conversely, any orientation to inquiry that makes reference to specific relational arrangements can, in absence of further analysis, be taken to be value-laden by default.

4. We can engage in conversations, and change our minds as a result of them. We can agree or agree to disagree on the terms of engagement, reenact or translate between vocabularies of existing conversational contexts, or create new ones.

To this are added the normative commitments to consilience in general and with naturalism in particular:

(a) In each context, we can conduct a study: an ongoing stream of conversations about our statements about the context.

(b) We can attempt to address disagreement between statements whose context scopes overlap by studying the overlap. If such statements drawn from different contexts, we can attempt translation between context vocabularies by studying a more encompassing context, possibly created for the purpose.

(c) We can agree that some contexts are physical or material and we can study them. The extent and degree of this agreement is a social achievement.

(d) We can in principle connect the study of other contexts to physical study through conversations as in (b) above, though the ways to do so may be too indirect for us to be able to accomplish in practice; call them *bridging conversations*.

Moving on, I use a simple syntax to express the fact that we make statements about what goes on in the world. Then I rehearse how we can justify math and physical sciences on practical grounds, as social activities traceable to the above assumptions (chapter 3). Having justified the needed tools, I use information theoretic concepts to elaborate a rudimentary semiotics describing the insights of physical sciences (chapters 4 and 5).

CHAPTER 3 ACTION

In keeping with a number of attempts to reconcile explanations of emergent phenomena with natural sciences such as Juarrero (2002); Bickhard (2003); Deacon (2012), I am adopting the ontological orientation of process or *action*. This means, I take that the phenomena under study have the nature of an event, whether change or abidance, and afford description by a verb, in its basic grammatical sense of an act, an occurrence, or a mode of being (Merriam-Webster 2017, Croatian: radnja, zbivanje, stanje). The only thing I am assuming about actions is that some can influence each other and so give rise to interactions, which too are actions. By implication, some actions are interactions that come into being through mutual influence of other actions.

3.1 Describing

As an observed fact that lets me proceed but that eventually needs to be explained, I take that we can describe interaction at the most general level by sentences of form $A \circlearrowleft_C B$. Here A and B are symbolic representations, and C some practical context of action they refer to. The sentences may be read as "B accompanies or follows A (in time, not necessarily causally) in context or under conditions C," or "A in interaction with (aspects of) C is accompanied or followed by B," or the like. More precisely,

(a) A and B each describe one or more interactions somehow associated with C (part of, implied in, or necessary for it);

(b) if A and B tell about different times, A comes before B.

In essence, the least we need to be able to say anything is an action c from the context C, and an interaction with it, a, affording different descriptions A and B; or in a typical case, two interactions a and b separated in time, a occurring first. We inherit the notions of context, vocabulary, and description from the above argument (chapter 2), but take a rain check on how any of them can be understood and accounted for in terms of action.

The sentence $A \circlearrowleft_C B$ can be understood in information theoretic terms: A and B can be seen as the source and received messages, and C as the information channel. I will expand this intuition in more detail below. Also, the arrow $\circlearrowleft$ is used to denote an action mostly because it is unusual, but specific ways to read it will crop up in time.

As discussed above, the sentences can be anything; in particular, they can be any phenomenological account. For example, a thick ethnographic description D such as that propounded by Geertz (1973) can be seen as part of the sentence "I took part in context C and observed D." This can be parsed in several ways:

$$\begin{aligned}
\text{I participate and observe} &\circlearrowleft_C \text{ I write } D \\
\text{I participate and observe } C &\circlearrowleft_{\text{I write}} D \\
\text{I take part in } C &\circlearrowleft_{\text{I observe and write}} D \\
C &\circlearrowleft_{\text{I participate, observe, and write}} D \\
C &\circlearrowleft_{\text{social science}} D
\end{aligned}$$

The first rendition focuses on the context C as the information shaping channel, presumably affecting various participants differently. The rest do so with the research process at varying levels of generality.

As another example, take the simple statement of linear uniform motion, $x(t) = x_0 + vt$.

Again depending on focus it can be rendered as

$$x_0, v, t \circlearrowleft_{\text{linear uniform motion}} x_0 + vt$$

$$x_0, t \circlearrowleft_{\text{linear uniform motion at velocity } v} x_0 + vt$$

$$x_0 \circlearrowleft_{\text{linear uniform motion at velocity } v \text{ in time } t} x_0 + vt$$

$$v, t \circlearrowleft_{\text{linear uniform motion starting at } x_0} x_0 + vt$$

$$x_0 \circlearrowleft_{\text{linear uniform motion in time } t} x(t), v = \left(x(t) - x_0\right)/t$$

and so on.

In this case, the sentences can notionally be seen as describing *action* in the physical sense. Action in physics has a specific use in expressing laws of motion via path integrals, which is intrinsically interesting but does not play much of a role in this essay. It happens to be the closest quantity to depicting what occurs in the physical world when one describes a phenomenon with a verb or a clause. It combines duration or extent (time or distance) with influence or change (energy or momentum), so it includes aspects of state (mass), occurrence (distance or time), and activity (velocity or energy).

The naturalist stance taken in chapter 2 can be reformulated as an assumption that all statements about the world ultimately refer to action in the physical sense, albeit possibly very abbreviated statements about very intricate arrangements of action. What such arrangements may be is the topic of much of this essay. First, though, I establish how statements in physical sciences can be reconstructed from the above assumptions about society, and represented in information theoretic terms with help of the pseudo-syntax just introduced.

3.2 Numbering and Measuring

Almost every person, presumably everyone who has made it this far, and almost every human language recognizes the actions of repeating and counting, and has words for at least the first few natural numbers and some simple shapes. We can extend the notion of number in familiar ways to words and later symbols for different kinds of numbers, their relationships, and other mathematical concepts.

Elementary mathematical concepts systematize manipulations with objects and some common tools that produce reliable results. For example, we can establish the first few hundred numbers just by counting tokens or repetitions of an action, then define the operations of addition and multiplication, and so extend the natural numbers as far as we wish. Subtraction and division, associated with notions such as debt and partition, can get us to zero, negative numbers, and fractions. If we augment counting with use of a straight edge and a compass we get to geometry along with some irrational numbers, algebraic such as square roots and transcendental such as π.

We move from such manipulations to operations with symbols as we are confident the two are equivalent, and in simple cases we can switch between them. Once comfortable with symbols and abstract statements, we can work with them exclusively, and introduce formalisms of real and complex numbers, calculus, non-Euclidean geometries, axiomatic systems, and so on. What we find out in abstract we can still translate back into concrete contexts that involve analogous operations.

One first makes the transition from mathematics to physical sciences via measurement. We pick unit lengths, periods, weights, and so on, and using arithmetic and geometric operations assign them to particular real world quantities. In their introductory lecture on time and distance, in fact, Feynman et al. (1963) dispense entirely with trying to define these properties and *equate* them with the corresponding acts of measurement:

> All we can say is that we find that a regularity of one kind fits together with a regularity of another kind. We can just say that we base our *definition* of time on the repetition of some apparently periodic event. (p. 5-2, emphasis in original)

> It would be difficult to measure the horizontal distance between two mountain tops using only a meter stick. We have found by experience that distance can be measured in another fashion: by triangulation. Although this means we are really using a different definition of distance, when they can both be used they agree with each other. Space is more or less what Euclid thought it to be, so the two types of definitions of distance agree. (p. 5-6)

On this account, physics fundamentally involves *translation*, in its linguistic sense, among actions we undertake to examine reliable relationships in the world. It translates between different ways of identifying and measuring physical concepts, and between them and the colloquial meanings and experiences of distance, time, and the like. Starting, then, with these basic experiences of the physical world, such as movement, light, heat, and others, we can devise ways of measuring them and new concepts that help us make sense of them, then formulate hypotheses and design experiments to test them. We often get findings that go deeply against everyday intuitions, but we justify and defend them as ultimately accessible. In principle, if one is ready and able to shed the sweat to follow the train of an argument, one can check it for oneself, or at least reliably fail to falsify it.

At the same time, scientific research is a complex social process. It takes time and effort for any putative conclusion to get accepted and established, and most theories are eventually superseded by new ones. At any moment, then, what we say we know is not set in stone but holds FAPP, for all practical purposes and under the conditions tested and those reasonably similar. This is quite a lot, though.

Moving forward, I assume that the findings of mathematics and empirical sciences of the non-living world, such as physics, chemistry, planetary sciences, and the like, can if necessary be bootstrapped in the above ways. The specific examples I will work with are not controversial, and in any event, a skeptic should always be able to ask for demonstration. It is to be expected if such demonstrations are to be at all accessible that they would freely cross between the manifest and scientific images to the point where it would make little sense to pry the two apart.

CHAPTER 4 CHANNELS

The previous chapter has sketched out how one can view mathematics and physical sciences as connected conversations about contexts of action, according to the assumptions outlined at the end of chapter 2. In this chapter, in preparation for discussing the origin of intentionality, I bring together a mathematical conversation, information theory, with a phenomenological one, semiotics.

Semiotics and information theory complement each other both in their methods and in their subject matters. Semiotics is a qualitative study of signs, phenomena that are understood or experienced as representing others, and has found application in fields such as cultural criticism and art theory. Its main focus is the nature and the meaning of signs. The ways signs are produced and the channels they follow are considered, but take a back seat. Information theory, on the other hand, is quantitative, used in engineering. It analyzes statistical relationships between codes or variables at either end of communication channels. This is the sense of information we use when we talk about it in terms of bits, bytes, and terabytes; we also call it "Shannon information" after the author who first articulated it (Shannon and Weaver 1949, pp. 31–125). The meaning of the signs is irrelevant to the theory, so they are represented as numbers or abstract tokens.

Making sense of the Babel of possible statements requires both semiotics and information theory. Recall that the sentence form $A \circlearrowleft_C B$ can be understood with A and B as symbolically encoded source and target messages, and C the channel. (Departing from information theory, I use "target" instead of "receiver" as the channels I am considering are not engineered nor necessarily involve living beings.) Semiotics helps account for what the messages A and B are, and what vocabularies of signs are used to express them. What the signs mean and how they came to be requires understanding how they are interpreted in the context of action C, which is a task for information theory and natural sciences.

In the ensuing chapters I will argue that meaningful signs as a physical phenomenon originate along with life, with the ability of organisms to discern and react to aspects of their environments (Dennett 2017, p. 40). Semantic information, information expressed by the signs (p. 107) can be seen as embodied, an evolved property of non-living interactions that comprise living beings. Signs require a point of view to interpret them, which life provides.

In this chapter, I aim to establish how the prerequisites for semiosis can be found in the context of fundamental physics. Reliable change effected by a physical or chemical process can be represented as a Shannon information channel between the underlying quantities. Particular values and ranges of these properties that can be influenced by or can affect another process in interaction can be seen as precursors to signs. In other words, the notion of the sign can be founded in opportunities for interaction one physical process provides another, and formally expressed in information theoretic terms.

4.1 Interfaces

Information theory defines various measures of information with respect to two random variables, source X and target Y. It recognizes two basic cases, the discrete and the continuous. In the discrete case X and Y are sets of symbols and we are given their individual and joint probabilities, while in the continuous case they are real-valued variables and we work with their probability distributions (Reza 1961, ch. 3, 8). In principle, any situation where we can express relationships among variables and measurements as probabilities can be treated as an information channel. In particular, we can state quantitative regularities in physical sciences in this way directly.

For illustration, here are two examples, one continuous, the other discrete. In both cases I give the conditional probabilities of target values given the sources. I start with the continuous case as it does not assume any preexisting vocabularies other than real numbers.

Continuous: Horizontal Shot For the continuous case, take a cannon firing a horizontal shot at a given initial speed $u = u_0$ in Earth's gravitational field with acceleration $g = 9.8\,\mathrm{m/s^2}$ [figure]. After time t, the shot will move at the velocity that combines the horizontal component u_0 with the vertical speed gt it gained by falling in this period of time. The total speed of the shot $v(t)$, i.e. the absolute value of its velocity, is given by

$$v(t) = \sqrt{u_0^2 + (gt)^2} \tag{4.1}$$

Let us say we measure the speed after $t = 1\,\mathrm{s}$, and we do so with accuracy σ_v. The probability distribution of measurements v after one second, given starting speeds u, is

$$\rho(v|u) = \frac{1}{\sqrt{2\pi}\,\sigma_v}\, e^{\left(v - \sqrt{u^2 + (9.8\,\mathrm{m/s})^2}\right)^2 / 2\sigma_v^2} \tag{4.2}$$

for $u \geqslant 0, v > 0$.

Qualitatively, this expression gives the speed after one second $v(1\text{ s}) = \sqrt{u^2 + (g \cdot 1\text{ s})^2}$ for varying initial speeds u with measurement error added on top [graph]. More formally, for a given starting speed u, this is a normal distribution in v with the mean $\bar{v} = v(1\,\mathrm{s})$ and standard deviation σ_v. In information theoretic terms, the gravitational field is reformulated as though it communicates the speed of the horizontal shot at time $t = 0$ by converting it to the speed at time $t = 1$ s, with measurement error treated as noise.

Discrete: Combustion In the discrete case there are known vocabularies for both source and target. As an example take combustion: the sources are several possible compounds that could be burning, the targets are the products. Let the starting substances be, say, molecular hydrogen (H_2), methane (CH_4), methanol (CH_3OH), glucose ($C_6H_{12}O_6$), methylamine (CH_3NH_2), and hydrogen sulfide (H_2S). If they burn completely, they can produce water (H_2O), carbon dioxide (CO_2), a nitrogen oxide (NO_x, either NO or NO_2), and sulfur dioxide (SO_2). In short,

$$X = \{\mathrm{H_2}, \mathrm{CH_4}, \mathrm{CH_3OH}, \mathrm{C_6H_{12}O_6}, \mathrm{CH_3NH_2}, \mathrm{H_2S}\} \tag{4.3}$$

$$Y = \{\mathrm{H_2O}, \mathrm{CO_2}, \mathrm{NO_x}, \mathrm{SO_2}\} \tag{4.4}$$

As a somewhat contrived outcome, let the target symbol be a random molecule of the combustion product we detect afterwards. For simplicity, assume that the starting mixture of gasses that sustains the burn, such as air, has enough oxygen to complete combustion, and optimistically that there is no prior amount of CO_2. We could make the example more realistic by specifying detected quantities, such as concentrations, rather than probabilities of discrete events. This would represent the interaction as a multidimensional continuous channel instead.

The conditional probabilities of the targets are:

$$P\{Y|X\} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 2/3 & 1/3 & 0 & 0 \\ 2/3 & 1/3 & 0 & 0 \\ 1/2 & 1/2 & 0 & 0 \\ 5/9 & 2/9 & 2/9 & 0 \\ 1/2 & 0 & 0 & 1/2 \end{bmatrix} \tag{4.5}$$

Similarly we can express situations that enact physical relationships in general as information channels. If needed, we can proceed to determine information theoretic quantities such as the maximum channel capacity etc.

Interfaces over Directives This exercise hopefully upsets to the popular mindset toward physical relationships as laws encoded in disembodied equations. There is no question that equations predict outcomes with very high accuracy, and are certainly less clunky than probabilities to represent these relationships. Everything physics ever learns from or hopes to apply to, however, are informative relationships between and within interactions such as those sketched out above. Except when we write them down, natural "laws" are not ever realized as equations: science describes *interfaces* rather than *directives*.

While this makes no difference in how the world behaves, it does in how we conceptualize it: as orchestrated by an implacable, all knowing, quasi-legal clockwork; or proceeding, possibly implacably, on limited information present. Physics is no stranger to the latter perspective: for instance, fields and field potentials are seen as local properties of space that interact with object attributes, such as position, momentum etc., to specify how they change from one moment to the next.

The terms "interfaces" and "directives" come from an analogous distinction in computing, between object-oriented and procedural programming languages. Procedural languages represent their flow as execution of successive directives ("have A done to X") on data of simple types (numbers, strings) that afford relatively few basic operations; at best data can be combined into buckets (structures). Object-oriented flow comprises interaction among objects of complex types (classes) which encapsulate the nitty-gritty of the data along with ways (methods) they can behave, bundling them into interfaces ("Y can do B with Z"). The programs written in the two paradigms can behave exactly the same, allowing for a few clock cycles either way, but their formal representations and the ways of thinking that go into implementing them can be quite different.

Note that this and a few other analogies with computing in this chapter are not meant to argue, as e.g. Wolfram (2002) does, that the universe is a big computer program or a computer. Computers are systems of many interacting layers of informational relationships that we have engineered and largely understand, so they can serve as a toy case to help clarify informational aspects of complex processes that arise on their own.

4.2 Semiosis

While the predictions of physical relationships are extremely accurate, they often do not hold all that much information. The above examples take nary a few lines to describe, are not hard to approximately enact in practice, and if we are careful doing so will not present many surprises. If a process, while following the same physics at the micro level, can represent and act on information about these relationships ahead of time, it can have more information about how the action will proceed than there is in the action itself up to the moment it is initiated. We, in fact, do this all the time. If we can account for how this happens, how a physical process can represent and express information, we can demystify our own intentional acts and get a sense of who or what else can perform them too.

To start putting some substance on this intuition, revisit for the moment the case of combustion. We can represent the entire process as a matrix multiplication:

$$[X] \qquad \circlearrowleft_{\text{combust}} \qquad P\{Y|X\} \qquad [Y] \tag{4.6}$$

$$\begin{bmatrix} \mathrm{H_2} \\ \mathrm{CH_4} \\ \mathrm{CH_3OH} \\ \mathrm{C_6H_{12}O_6} \\ \mathrm{CH_3NH_2} \\ \mathrm{H_2S} \end{bmatrix} \circlearrowleft_{\text{combust}} \begin{bmatrix} 1 & 0 & 0 & 0 \\ {}^{2}\!/_{3} & {}^{1}\!/_{3} & 0 & 0 \\ {}^{2}\!/_{3} & {}^{1}\!/_{3} & 0 & 0 \\ {}^{1}\!/_{2} & {}^{1}\!/_{2} & 0 & 0 \\ {}^{5}\!/_{9} & {}^{2}\!/_{9} & {}^{2}\!/_{9} & 0 \\ {}^{1}\!/_{2} & 0 & 0 & {}^{1}\!/_{2} \end{bmatrix} \begin{bmatrix} \mathrm{H_2O} \\ \mathrm{CO_2} \\ \mathrm{NO_x} \\ \mathrm{SO_2} \end{bmatrix} \tag{4.7}$$

This simply says that a process that isolates one of the source compounds $[X]$ and brings them to burn or otherwise oxidize results in the ratio of products $[Y]$ as given by the corresponding row of $P\{Y|X\}$. For each chemical the result is reliable: if we know what the substance is and what is done to it, we know what we will get. Once the reaction happens, we can sometimes say what the original compound was, but only by comparing the differences between results. For example, we cannot tell methane from methanol at all from these ratios. If we are limited to detecting the products one random molecule at a time, we will have difficulty telling glucose from either methane or methanol before we sample the vapors several times, and methylamine will look very similar too until we perform many trials or come across a nitrogen oxide.

These relationships exhibit an elementary semiotic quality. While we are far away indeed from arbitrary signs, the initial substance $x_i \in X$ can be seen as a signifier and its result row of ratios $P\{Y|x_i\}$ as its referent. Physical relationships that produce the referents thus constitute the "meaning system" instead of the abstract signifieds. Formally, for each source character $x_i \in X$, call the single-member subset $X_i = \{x_i\}$ the *channel-signifier* or *c-signifier* corresponding to x_i, and the corresponding row $P\{Y|X_i\} = P\{Y|x_i\}$ the *channel-referent* or *c-referent* of X_i. Take this to mean that $P\{Y|X_i\}$ is the precursor to a referent that can be ascribed to X_i as a signifier with respect to the given action context serving as the information channel.

Anticipating e.g. de Saussure (1959, pp. 117–122), we can distinguish signifiers only by relating and comparing their referents, i.e. we can tell the original substances apart only if they burn into different ratios of products. This, incidentally, is one heuristic way to read the symbol $\circlearrowleft$: whatever is on the left side gives rise to what is on the right, but whatever shade of meaning the source can communicate can only be reconstructed from the target. Formally, if we have a channel with discrete source and target vocabularies X and Y, let X' be a subset of X be such that all the rows of $P\{Y|X'\}$ are the same, so $P\{Y|x_i\} = P\{Y\}$ for all $x_i \in X'$. This means that X' and Y are independent, with mutual information $I(X';Y) = H(Y) - H(Y|X') = 0$. For all we know, the information we detect is introduced at the receiving end. If no $x_i \in X'$ at the source makes any difference to which $y_j \in Y$ we receive, given y_j we cannot tell what x_i we started with. Given vocabularies and a channel, Shannon information too is a distinction that makes a difference.

The reference relationship can be established in the opposite direction as well. If we were to enact the experiment and probe the smoke, we could use $P\{Y|X\}$ to help us guess what burned. In this direction, the combustion products can be called *c-symptoms* and the possible original compounds they denote *c-states* (Sebeok 2001, p. 4). The exact relationships depend on the details of what we are detecting and how, and on what we know beforehand about what might be burning, so I leave the formalization aside.

The letter “c” in front of “c-referent” etc. stands for **C**hannel/context/conditions, or if one wishes “cituation.” As a mnemonic, the letter will move forward through the alphabet to indicate increasingly explicit ways the reference relationship is represented. (The first two letters are taken by **A**ction and **B**abel/Babylon/babble.)

Channel-reference is a descriptive category, portraying a reliable relationship in physical sciences. It is not represented or used in any part of the information channel, not even potentially, as the processes that comprise the reference relationship have no capacity to do so. In general, it can be represented externally, exposed as potentially available to other processes, and used by them. In these examples we have represented the source and target vocabularies ourselves.

The link between interaction opportunities and semiosis can be more easily illustrated on the continuous example. We can represent the horizontal shot as

$$u \ \circlearrowleft_{\text{horiz. shot after } t=1\,\text{s}} \ \rho(v|u) = \frac{1}{\sqrt{2\pi}\,\sigma_v}\, e^{\left(v-\sqrt{u^2+(9.8\,\text{m/s})^2}\right)^2/2\sigma_v^2} \tag{4.8}$$

a distribution of values $v > 0$ for each $u \geqslant 0$.

The reference relationships can be established analogously in both directions, intuitively for focal intervals of initial and final speeds. For initial speeds in range $U = (u_1, u_2)$ as c-signifiers, the c-referent are the final speeds they can give rise to; conversely, the final speeds in range $V = (v_1, v_2)$ are a c-symptom for the initial speeds as c-states that can lead to them. Because of the probabilistic nature of the relationship, in both cases the counterpart of the focal interval (the c-referent of U and the c-state for V) can be represented by a fuzzy set: some values are almost definitely its members, most are quite certainly outside it, with blurry boundary regions in between. In general, the reference relationships obtain between fuzzy subsets on both ends.

Channel-reference provides a way to talk about the opportunities afforded and conditions required for interaction with other physical processes, one abstraction step removed from specifying focal fuzzy intervals. Suppose the cannon is a part of a Rube Goldberg contraption we are designing. On one end, we can vary the cannonball c supplied by the previous task, and the mass of the explosive charge m residing in the cannon, resulting in different possible ranges of initial speeds $U_c(m)$. On the other end, the shot is supposed to hit a dolly on the floor 4.9 m below (so it reaches it in 1 s) at the speed within a given range V_d to impart just the right push to send it off to perform the next task [figure].

By itself the horizontal shot is just that, but as part of the device, a cannon charged with the explosive of mass m provides the opportunity to the task supplying the cannonball c to have it fired at a given speed, and to the dolly to receive the impetus to accomplish what it needs to. The contraption works if c and m are chosen so that, from the point of view of the cannon, the c-referents of speeds in $U_c(m)$ are included within V_d, or from the perspective of the dolly, the speeds in V_d are c-symptoms of initial speeds that include $U_c(m)$.

I am rehearsing the steps to suggest there is an explicit information theoretic basis for moving from the exact quantitative ways we express physical processes to the qualitative language of the intentional stance we use to talk about and understand living creatures. The point is not to argue we can easily measure semantic information; this is of limited use and difficult or impossible to do, and probably will be for quite some time (Dennett 2017, pp. 122–128). Rather, I aim to make explicit the physical rather than metaphysical nature of the epistemic cut between natural scientific descriptions by us and the semantic information embodied in organisms. In basic physics there is no text, but an interaction of two processes provides two different points of view from which to articulate their interface in semiotic terms. This is still done by us; for a sign to exist, a process that can interpret it needs to as well.

Over the next several chapters I will consider increasingly complex dynamics of interaction, and outline how we can represent semantic information associated with living processes as physically transmitted Shannon information if we keep track of what kind of a process the communication channel is, what the source and target vocabularies or measures are, and what or who can determine and represent them.

4.3 Process and Emergence

A few conceptual notes.

First, this information theoretic restatement of physical relationships does not claim that all that exists is information. (I am aware that there are conceptions of physics claiming so, and will consult them for more detail in near future.) Instead, it may simply be a way of saying that there is such a thing as (change in) time, and information a way we have of talking about and making sense of it. In other words, if a piece of information is characterized as a difference (in something) that makes a difference (in something else), then, on the one hand, the concept of information depends on and requires the existence of change; and on the other, any change can be said to be informative because it makes a detectable difference. Even no change over a period is informative as what changes is the time. Physics is not information, but information requires physical change.

Second, the fact that we can think of physical relationships as information-bearing and need physical interactions to gain information about the universe signals a flaw in naive arguments for determinism based on the mathematical determinism of physical equations. Here I offer a few heuristic observations that should be helpful to keep in mind in what follows; I am sure have already been brought up and evaluated, likely turned out either as obvious or obviously wrong. Feynman (1965, pp. 57–58, 166–167) anticipates some of it, and Wolpert (2008) makes a related case formally.

If we really are pawns in a majestic Laplacian clockwork with physical laws unfolding as real-numbered functions with values at every point in continuous space, as they are often imagined to do, it is not at all certain where such values might reside. Any detectable information in the universe comes from interactions in spacetime. With quantum uncertainty, we cannot approach every point in space indefinitely closely or precisely. Even if we could, we cannot even logically obtain an uncountably infinite continuum of values, at least not using particulate matter for interactions. Therefore, if real-valued physical laws acting on continuous spacetime corresponded to reality in detail, the information they work with would need to be represented and the calculations carried out *independently of the known universe*. A Laplace's demon is a physically impossible analog computer pulling the strings from nowhere: a candidate for Occam's razor if there ever was one.

It makes as much sense to conceptualize spacetime as simply very dense with an unknown topology at very small scales, and "real" numbers a formalism with, as far as we can tell, no realizable physical equivalent, invented to represent our intuitions of continuity and to do away with Zeno's paradoxes. Ongoing experiments (Chou et al. 2016) should be able to tell if spacetime is granular, but whatever it is, our successful use of real and complex numbers in calculation should not fool us into forgetting that actual spacetime can most likely hold no more than finite amounts of information in finite volumes, depending on interactions a volume can realize.

In effect, the overall picture here adopted amounts to a version of the process ontology by Whitehead (1929), but more reductionist. The assumption of panpsychism, intrinsic anticipated mentality, is given up in favor of what is already unmysteriously known from physics. Instead, mechanical determinism is avoided by viewing physical change as informational rather than law-like. Physical relationships may be seen neither as set by an absent watchmaker, or more modernly as infinitely precise impersonal algorithms, but as immanent to tiny but finite pieces of energy and spacetime, always in motion, acting on limited information available. This is just another way of saying that their actions are reliable, simple, and reliably uncertain (Deacon 2012, pp. 167–168). Contrary to Whitehead and recent panpsychists (e.g. Mørch 2017), there is no room for mind in basic physics, and neither there is for representation. Quantitative regularities are intrinsic to action at these scopes and not expressed in any terms; Rorty (1998, ch. 4) would say they exist only causally, not representationally. Each opportunity for interaction, however, provides a perspective with respect to which we can say a physical process makes rudimentary signs. Interacting processes give rise to new dynamics on wider scopes which we can express using such signs; eventually, the novel behaviors themselves represent opportunities of interaction, giving rise to symbols and minds using the symbols. All is action all the way up and down, and every new level of phenomena, including representation, arises from a different process organization (Deacon 2012, p. 168).

Viewing all the interactions as interfaces flattens emergence events into transitions between physically realized dynamics in information and time. If, instead of an infinitely precise continuous clockwork packed with data to the last uncountable point, we see the physics of our world as consisting of fuzzy blips moving on limited information over small but definite extents in space and time, it is much easier to allow elbow room to conceptualize different levels of phenomena, such as that of chemistry and particle physics, as existing and unfolding side by side rather than one governed by the other. Rules of chemistry can be *reduced to* particle physics, expressed in its terms, but they cannot *fit into* spacetime extents relevant to the elementary particles, as they represent genuinely different semiotic dynamics realized only in relationships among conglomerations of particles we call atoms. Indeed, while a potential for it certainly existed, chemistry only came into being when heavier atoms formed and matter cooled down to allow nuclei to keep electrons: at one point atoms, molecules, and the ways they behave together were quite new. The "extra something" to chemistry over and above particle physics, then, is the way many interacting atoms handle information; chemistry is not so much *determined by* physics as it *arises from*, or, if we wish to sound computational, is *implemented in* it.

In the next chapter, I apply the informational lens to discuss how various non-living phenomena interact and constitute each other, connecting up and down spatial and temporal scopes. Later on (chapter 6) I work through Kauffman's (1993) analysis of the origin of life, and demonstrate that ways living processes handle information, including the time reversal associated with intentionality, should be as unmysterious as relationships among non-living processes comprising each other. This then forms a basis for tracing semiotic changes through evolutionary transitions (chapter 8, tables 8.1, 8.2).

CHAPTER 5 AFFORDANCES, TIMES, GRADIENTS, CYCLES

Symbols as a natural phenomenon have not been around forever. We take our history to begin when we started writing things down, and we know that before then we were producing symbols all the time, speaking, although we inscribed them only indirectly. Further back, we were capable of actively producing signs only only to a limited extent (Maynard Smith and Harper 2003). The cells in our bodies depend on the representation in genes that has a number of properties of a formal symbolic language (Pattee 1982, p. 171). Genetic code has been around for much longer than human languages, but there was a time when it did not exist either. At some point the first natural phenomena we can identify as signs needed to appear.

Signs do not exist independently but are made and read, produced and interpreted by natural processes capable of doing so; call them semiotic processes. To show that a phenomenon is semiotic, we need to be able to demonstrate that some of its features are salient to and informative about its occurrence in ways we can claim amount to signs. Pattee (1969, 2007); Rocha (2001) offer a suggestion of what it would mean for a material to be symbolic, and one of the criteria they offer is that it inform processes that in turn reproduce it (more detail in section 6.1).

To discuss incipient semiotic phenomena before symbols, this criterion is considered on its own. Some portion of a physical process, a material, a state, or an event, is informative to interactions that (may) in turn reproduce it. As discussed in section 4.2, opportunities for interaction between processes exhibit features of signs. Thus, a process is a candidate to be seen as semiotic when it unfolds depending on whether and how some opportunities for interaction are realized, while the process itself regularly produces such opportunities. Once a natural occurrence reliably depends on and reproduces a (proto-semiotic) assortment of potential interactions, we can say that it functions as an information channel, in which the source and target vocabularies consist of sign(s) that represent these ways to interact.

This is easiest to exhibit on a natural phenomenon that cycles, a few examples of which will be presented below. The exercise, however, amounts to little more than assigning symbolic labels to stages within a repetitive process, which is a long way from claiming moving matter is capable of arbitrary symbolizing. General purpose representation originates with life, with repeating processes that are versatile, able to interact with many features of their environments, and reproduce, and thus eventually compete for materials. Matter first forms signs when natural selection, in effect, *condenses* information from lives of many individuals over evolutionary history into a single organism over a lifetime, as discussed in the next chapter.

This chapter, in preparation, considers the incipient semiotics of interaction vocabularies in the non-living world. The discussion draws on and parallels Deacon's (2012, ch. 5–8) proposed dynamics of constraints, the basis for his argument for material efficiency of intentionality. The following section reviews this topic. Section 5.2 introduces some examples, while the concluding section addresses underlying assumptions and epistemological concerns of representing physical processes as information channels.

5.1 Affordances of Constraints

Deacon (2012, ch. 6) begins his discussion of intentionality as a natural phenomenon with the notion of *constraint*. Per Deacon, constraints, limitations on what can be realized in a given situation, are lacunae that possess causal efficacy. They interact and propagate, generating new restrictions on what can happen when one goes up in dimension, and we recognize the result as emergent dynamics. Equipped with this, Deacon charts a sequence of emergent dynamics with respect to how constraints change and interact, culminating in intention (chs. 7–10). This essay instead locates causal efficacy conventionally, in matter and energy, and argues that the novelty brought forth by emergent phenomena is indeed where it seems to be on its face, in the organization of processes (Deacon 2012, pp. 167–181; Kitcher 2011, p. 108). Deacon's dynamics of constraints provides very valuable insights, however, so it behooves us to attend to it and consider some of its advantages and shortcomings.

Bound to Be Throwable Deacon (2012, p. 183) invokes C. S. Peirce's ontological starting point of *tychism*, complete spontaneity, in which constraints correspond to *habits* that, for Peirce, underlie all regularity. A completely spontaneous universe, however, is impossible to realize and not easy to characterize. For example, it is not at all certain what length or duration would be in a tychist world, as our notions of these properties depend on non-spontaneous acts of repetition and comparison (section 3.2). Tychism is and remains a metaphor, its value in what it helps clarify.

The actual instances of constraints Deacon (2012, e.g. p. 198) offers are restrictions on specific interactions, which are in turn contingent on additional conditions. For example, a cylinder restricts a gas explosion to apply pressure in only one direction, but the for gas to ignite we need the right amount of oxygen and fuel in the air, the pressure of the mixture, the temperature of the spark, and so on. It seems thus that the physics of constraints is first and foremost a way to reformulate concrete interactions available in given circumstances. Even the physical phenomenon most akin to and arguably anticipated by tychism, quantum uncertainty, itself amounts to a restriction on what can happen in a given context rather than to an unrestricted possibility.

If, however, constraints are just a way to reframe what actually goes on, it is not certain at all that Deacon's dynamics avoid reductionism, which is one of the main gains he claims from the approach. The reasoning goes approximately as follows. What is present at any moment in matter and energy can be decomposed and accounted for in terms of physical laws without residue. Suppressed possibilities, what could be but is being hindered from taking place, are not a part of this material account. Thus, constraints are "not ... reducible, because there are no components to what is absent" Deacon (2012, p. 204).

On the other hand, Deacon (2012, pp. 194–195) also notes that constraints apply to natural processes so they can be expressed explicitly in terms of physical properties. This means, though, that constraints and their interactions *are* reducible to physics: simple ones can just be written down, while their combinations can in principle be analyzed and decomposed.

Here is how Deacon envisages causality arising from interacting constraints:

> To illustrate, consider this list of negative attributes of two distinct objects: neither fits through the hole in a doughnut; neither floats on water; neither dissolves in water; neither moves itself spontaneously; neither lets light pass through it; neither melts ice when placed in contact with it; neither can be penetrated by a toothpick; and neither makes an impression when placed on a wet clay surface. Now, ask yourself, could a child throw both? Most likely. They don't have to exhibit these causal incapacities for the same reasons, but because of what they don't do, there are also things that both can likely do or can have done to them. (p. 190)

We can immediately see that characterizing these properties in negative terms is partly contrived. Instead of saying what neither of the objects can do, we can say that both of them, for example, are at least as big as a golf ball, sink in water, remain whole in water, stay still when undisturbed, and so on. Whether we talk about these conditions as enabling or limiting does not make a difference to the objects or to the child throwing them; neither should it make a difference to us. Thus there is no necessary causal link from the fact that these properties can be seen as restrictive to what we can do with the objects: in the final sentence, “because” denotes correlation rather than causation.

These attributes can be thought of as fuzzy ranges of physical quantities, and indeed they mostly involve uncomplicatedly material features: size, density, composition, speed, and so on. The physical requirements for the composite quality they enable, throwable by a child, could be specified in similar detail, for example by a blueprint for a robotic arm; but the intentional description is simpler and more informative about what else we can do with the object in a social context. This, indeed, points to what needs to be explained: how complex intentional properties (throwable) arise from the simpler ones they entail or are entailed by (size, density, etc.), and what they tell us in addition to them.

Thus no matter how we represent the attributes, what we communicate by them are relationships, conditional or mutual information, between different ways of interacting with an object. We say that for a child to be able to throw something, it helps if the object sinks in water and stays still when undisturbed. Instead of constraints, then, the conditions can be seen as precursors to *affordances*.

Properly the term affordance applies to the perspective of a living being, and in this example the focal action does involve one, a child throwing an object. In general, we can extend the notion to the perspective of a process: what can events in an action context C interact with and how? Take, say, the above example of a horizontal shot as part of the Rube Goldberg device (section 4.2). A certain range of masses of the cannonball and the explosive charge will result in the shot traveling at just the right speed to hit the dolly waiting for it. From the perspective of the dolly there are three kinds of horizontal shots: those that hit at the desired speed, those that hit at other speeds, and those that miss. These three possibilities thus represent what is salient about the cannon shot at the level of the device.

Whether conceptualized as constraints, affordances, or ranges of physical quantities, these attributes correspond to opportunities for interaction. They are not causal in their own right but serve as building blocks, mediating and organizing the interplay of material causality to give rise to broader phenomena. As argued in section 4.2, opportunities for interaction also have semiotic characteristics, so they figure in defining and moving between vocabularies in different contexts. In this example, the contexts are those of physical measurements on the one hand, and of the contraption on the other.

Layers of Efficacy In studying relationships between parts and wholes, Deacon (2012, p. 166) adopts the guideline that there should be no double counting of causal influences. This leads him to address the arguments, notably by Kim (1993), that because we can reduce emergent phenomena to underlying physics, higher level concepts such as intention are redundant heuristics, colloquial shortcuts for what really goes on: "merely a *description* of some relationships between components ... inevitably a simplification and an abstraction ... a comparative assessment or idealization ... physically epiphenomenal" (p. 179). Thus, for Deacon, simply establishing domains of interaction and devising appropriate languages for them is insufficient, because they do not guarantee that what we describe is causally efficacious. On the other hand, Deacon claims (pp. 203–204), constraints ensure that the account is causal, as they are absent from reductionist explanations yet supposedly actively shape what goes on.

As just argued, it is an open question what substantively new is added to an account of a phenomenon by casting it explicitly in terms of restrictions, and whether doing so avoids reductionism. By questioning the special role of constraints we also give them up as possible carriers of causation. Deacon invokes causality without defining it and we cannot treat it here at length. Typically, a causal relationship implies an asymmetric dependency between two events, the effect somehow contingent on the cause (e.g. Rosenberg 2016, pp. 13–14, 59–61); causal explanations are seen as preferable to "mere" descriptions to the extent they are more likely to refer to what reliably takes place regardless of us. In this essay, the notion is interpreted in light of the assumption that all that is knowable is material action. A causal account can thus be seen as a plausible explanation, an answer to the question "why?", that describes material efficacy, ways the world is affected by physical interaction. (Also, causation is easily misunderstood and best invoked sparingly; "efficacy" is here preferred.)

Causal explanations are taken to be accounts of physical efficacy in some domain of interest. This accords with the response Kim (1993, ch. 14) offers to the criticism that coarser descriptions are merely epiphenomenal. The targets of Kim's discussion are several articulations of nonreductive materialism, the claim that, while the mental is supervenient (fully dependent) on the physical, it is not nomologically reducible. Nonreductivism holds, in other words, that even though the mind is fully physical, there are mental properties and entities that cannot be reduced to the physical realm in terms of strict bridging laws and definitions such as in Nagel (1979, ch. 11). Against this, Kim argues convincingly that either the mental is not fully dependent on the physical, or that mental processes can in fact be reduced to physical ones. As an alternative, he offers the possibility of "supervenient causal relations": that macroscopic processes are causal *in virtue of* being supervenient on microscopic physical causes. The sentence "[h]eating the water [in a kettle] caused it to boil" is just as causal as the respective statement about movements of H_2O molecules, as they both describe physical efficacy (Kim 1993, pp. 282–283), one in terms more informative for the kitchen and the other for the lab. We do have the benefit of understanding quite closely how "heat," "water," and "boil" are physically realized, but this not crucial for the present argument. Kim adds that such an answer is not likely to satisfy nonreductivists because it logically implies that macroscopic terms are nomologically reducible (ch. 4).

However, Kim (1993, pp. 68–78) also demonstrates that nomological reduction, while logically entailed by supervenience, is not easy to achieve, as bridging laws and definitions may involve an infinite number of statements. This agrees with the empirical observation by Longino (2002, pp. 93–94) that although there is one world under study, each scientific theory defines its own conditions of truth and falsity that are always different and often incompatible, even while leading to useful and informative findings. Kitcher (2011, p. 108) argues on the example of meiotic division that mapping explanatory levels one to another is anything but straightforward. While one can account for every atom, one cannot easily express the principles of classical genetics from molecular biology, as the language of molecules has no easy way to discern which entities are genes or what events count as meiosis, let alone *derive* the fact that genes on different chromosomes assort independently during division.

Given these limitations, it is prudent to give up the quest for a description somehow more real than others past what we can demonstrate empirically, and accept that multiple informative causal explanations may be given for the same phenomenon. A slip of the pen by Deacon (2012, p. 165, emphasis added) suggests this is quite alright: "[i]t's all just quarks and gluons—*or pick your favorite ultimate smallest unit*—and everything else is just descriptive simplification." This in effect suggests that what counts as causal and what as a mere description may well be in the eye of the beholder.

Science offers many fundamental accounts. At various points in history different theories counted as basic, and at any one time there are always many equivalent or closely related explanations. In fact, physical relationships *lend themselves* to multiple conceptually disparate mathematical interpretations, and practicing physicists keep track of them because each is informative in its own way (Feynman 1965, pp. 50–55, 168). The requirement that instead one set of relationships be taken as ultimate and smallest runs counter to our experience of how scientific descriptions actually relate to the material world, and thus needs to be treated with skepticism. As Rorty (1998, p. 57) pointed out, philosophy is cultural politics, a set of suggestions of what perspectives we should try. In this case the recommendation is to privilege one explanation, "pick your favorite" as long as it can be argued to be fundamental and is only one. One should feel free to refuse this advice as unrealistic.

Bringing in multiple informative accounts naturally includes perspectives away from physics, as discussed in section 4.3. Once explanations are taken to describe events or processes, "framing emergence in dynamical terms does *not* necessarily favor either bottom-up or top-down priority of causal influence" (Deacon 2012, p. 180). Wider phenomena, while compatible with and arising from more basic dynamics, are expressed in their own terms, so events at different levels can be seen to proceed in parallel without contradiction, their descriptions causal in virtue of describing material interactions in their own context. Put simply, more is different; at wider scopes there are qualitatively new properties and dynamics, requiring new theoretical languages over and above the ones we consider fundamental.

An analogy from computing is here apt: computers are organized as multiple levels of virtual machines, one implemented in another, each operating with concepts suited to its task, whether it is basic digital logic, or the operating system, or applications programming (Tanenbaum and Austin 2013, pp. 2–7). Unlike in computing, science constructs theoretical vocabularies by, in effect, reverse engineering reliable naturally occurring relationships. Guided by our own decisions of what is interesting to study, the languages we come up with are often inconsistent with each other, transitions between them tenuous (Longino 2002, pp. 93–95). In physics our job is easier because the relationships lend themselves to mathematical representation, and because different kinds of phenomena are segregated by large differences in dimension (Anderson 1972; Deacon 2012, pp. 200–201). In general, the connections between levels are more complex.

As Deacon (2012, p. 166) accepts that there should be no double counting of causal influences, he finds it necessary to posit constraints as an entirely new avenue of causality so as to argue that emergent dynamics are both novel and causally efficacious. This essay instead accepts the suggestion by Kim (1993, pp. 282–283) that more complex phenomena be seen as causally efficacious in virtue of being reducible to and dependent on physics. New domains of interaction give rise to new explanatory levels, yielding information about what matter can do that it cannot under other circumstances. Explicit nomological reduction between different domains of interaction is usually difficult to accomplish so it is not generally available in practice, but what we can realize instead are bridging conversations suggested by Longino (2002, p. 94).

Put another way, the difference between which explanation is causal and which one "merely" a description is not decided by establishing one or the other account as fundamental. What is at issue instead is that an account is consilient: that we can plausibly claim that statements formed in a given vocabulary are informative about a realm of material interactions, and establish bridging conversations with other relevant domains of study.

Thus, accounting for intentionality in the next chapter will involve demonstrating a basis for it in ways moving matter can organize. This is done, to paraphrase Kant, by keeping track of natural phenomena as *communication among materials* (Deacon 2012, p. 302). For now the phrase is just a metaphor, although it suggests we may fruitfully employ concepts from information theory in the explanation as begun in chapter 4. The next section extends the approach and applies it to several examples, while the last one considers in more detail the implications of doing so.

5.2 Before Signs

Chapter 3 introduced the sentence form for describing action in context, $A \circlearrowleft_C B$, and the previous chapter showed on two examples that interpreting such sentences as about information channels reveals semiotic features, in form of opportunities for interaction on both ends. To put the two together, knowable natural phenomena can be represented as events of information transmission that can be described by sentences of form $A \circlearrowleft_C B$. C, the action context, reflects *conditions* that circumscribe events. Interactions within the context are represented by *vocabularies* of terms that express messages A and B. Contexts C are thought of as information channels, configurations of material action seen (by us) as communicating by “sending” a source message A describing one interaction in C, and “receiving” the target message B describing the same or another interaction, occurring at the same time or later. As argued in section 4.2, reciprocal relationships between ranges of outcomes that mediate interactions have proto-semiotic properties. We can treat these ranges as signs and use them as terms in vocabularies that express A and B.

We now briefly turn to characterize transitions between domains of material efficacy before the origin of life. If we take the above model and the discussion in the previous chapter as a basis, we assume we can represent known physical relationships as proto-semiotic information channels, representing interactions available under given conditions. We will briefly characterize the nature of the conditions, when the relationships hold; and of the vocabulary, what kinds of interactions are available and how diverse they are.

Starting with the very small, we can say from what we know at present that a basic vocabulary can comprise the standard model of particles and their interactions. Some *particles combine*, which opens up new possibilities for interaction and new contexts. There are 17 elementary particles we know of; only three of those form most matter at moderate energies and temperatures (neutrons and protons are composed of up and down quarks, plus electrons); but they in turn form 90+ elements; a few of which can in principle form arbitrarily complex structures. In case of molecules, the number of possible composites grows too large to ever be realized, requiring the right conditions: temperature, materials, energy sources, and so on. As shown in the example of combustion (section 4.1), vocabularies in contexts involving chemicals and particles are to an extent discrete, as they represent localized, distinct bundles of affordances.

On the other hand, moving to *aggregate states* of matter e.g. in solid state physics or thermodynamics, the difference in dimension is so large that all information about individual particles is lost (Anderson 1972; Deacon 2012, ch. 5–7). Overall statistical properties are reflected in the opportunities for interaction on wider scopes. The relationships between micro- and macro- processes can be stable or animated through energy input. As they aggregate over many interactions, they are usually continuous.

Deacon (2012, ch. 7) discusses how, as a fluid in a compartment is heated on one side, the energy is first conducted uniformly; the entropy (variation) of molecules on the micro level is reduced reflecting a macroscopic influence. Deacon examines the relationship as interacting constraints across scales, introducing new terms to distinguish processes that unfold spontaneously and those that require energy expenditure elsewhere. For our purposes, the salient fact is that, despite many orders of magnitude of particles in the heated compartment, the informational relationship between the micro and the macro is very simple.

It does not stay so if we turn up the heat. Not all the energy can be absorbed into the movement of molecules, and it gets expended as large swaths of the substance start moving. The liquid starts convecting, forming macroscopic cells of circulation. Bénard cells, weather patterns, stars, formations such as stone circles (Dennett 2017, pp. 44–45) and snowflakes, dubbed by (Deacon 2012, ch. 8) morphodynamic, are *dissipative structures*, requiring a steady expenditure of energy to sustain, or at some point during their formation. Dissipative processes require energy gradients, which form in environments subject to regular change, such as due to planetary cycles.

From the present perspective we consider dissipative and *cycling processes* together as one step toward semiosis. Repeating processes such as day and night structure time scopes, and drive energy fluctuations that helps interactions diversify over multiple extents, from climate patterns to chemical reactions. Put another way, if we know enough, states within cycles are informational about their own reappearance. Eclipses can be predicted with a finite number of calculations, and geysers can be modeled (O'Hara and Esawi 2013). What such disparate processes share is bringing about a specific set of opportunities for interaction at (semi-)regular intervals, and they do so over multiple scopes.

A repeating opportunity for interaction in a cycling process means we know *that* it will appear next time. If it has several possible outcomes, this does not necessarily mean we know *how* it will appear. In other words, if the interaction is P_i and the way it is realized is $x(P_i)$, discrete or continuous, the value of $x(P_1)$ at one appearance may not be related to $x(P_2)$ next time. The notional text $x(P_1)$ that describes how an interaction took place is not informational about similar future content $x(P_2)$, and so the content cannot be considered a repeating phenomenon of the same kind as is the physical cycle. In general, in other words, these processes lack memory. The Old Faithful geyser "remembers" insofar that short eruptions are followed by short heating periods, but the pattern is not reported to persist.

Cycling processes on planetary scales do, however, help create environments where potential interactions are diverse enough so that processes reproducing their choice of pathways are possible (Dennett 2017, pp. 44–48). (King 1982) argues that in a network of chemical reactions sustained by an energy inflow, that recycle their materials, reproducing *autocatalytic reaction networks* can originate spontaneously. These are seen as the first kind of reaction that undergoes natural selection, and so the first (section 6.2).

5.3 Communication among Materials

Representing physical interactions as proto-semiotic information events presented above adds only a thin layer of abstraction on top of natural sciences: information channels for action contexts where we expect certain kinds of phenomena, signs and syntax for opportunities for interaction. The constraint-centered account by Deacon is rearranged but still holds up well. Deacon (2012, p. 318) notes that "information is ultimately constituted by preserved constraints;" here we invert the order, viewing informational relationships as fundamental and constraint as one way to express them. To do their explanatory work in propagating restrictions constraints need to interact; we view this directly as processes reacting and combining to give rise to collective dynamics with new kinds of interactions, requiring new vocabularies. Constraints still play a central role, as the boundary conditions for when a vocabulary is relevant, as well as the ranges of physical quantities that mediate interaction, now assigned to proto-signs.

Times Calling a set of circumstances an action context and treating it as an information channel makes several assumptions about the time dynamics in what is being described. (Time periods come up often from now on and are marked by the hourglass ⧖.)

If the substance of what we say about events in an action context C is to be of any consequence, some aspect of the conditions that bring the occurrences about, even if tangentially related, needs to recur in whole or in part. For the sentence $A \circlearrowleft_C B$ to be informative, on the one hand, we need to have grounds for understanding it, which means we have encountered some of its aspects already; on the other hand, if what we learn is to make any difference, we anticipate facing some of its features again. In particular, repeating events are assumed in the mathematical formulation of Shannon information. Channels are specified by mutual probabilities of random variables, which represent or are drawn from a stream of repeated or related interactions.

In general, $A \circlearrowleft_C B$ can refer to any correlation or pattern in physical properties of spacetime, with C detailing when, where, and how it obtains. Any statistically significant relationship reflects mutual information, established through repeated measurements. For example, two random variables with Pearson correlation ρ, $|\rho| \neq 1$ carry at least

$I = -{}^1\!/\!_2 \ln(1 - \rho^2)$ bits of mutual information (Reza 1961, p. 283). Reliable relationships in physical sciences can be represented as channels, representing interfaces between measurements (chapter 4).

The sentence $A \circlearrowleft_C B$ is a statement about differentiation in time scales: whatever the conditions for C, we can say that they obtain as long and usually longer than the flow of interactions we are observing, which in turn lasts as long or longer than any particular incidence. Formally, the least we need to occur to say $A \circlearrowleft_C B$ is one action, c from context C, and one interaction with it, a described by both A and B, though typically there are two interactions at different times, a before b (chapter 3). Actions are taken to be of finite extent in time and space, possibly very small but not non-dimensional or infinitesimal. Thus the sentence implies three time scales: of ⧖ durations of a and b described by A and B, of ⧖ a and b together with times between them, and of ⧖ conditions giving rise to C.

For example, the firing and the impact of the horizontal shot (chapter 4) are nearly instantaneous, its flight takes time, and the cannon can presumably fire again afterwards in clement conditions: in Earth's gravity field, if the neighbors do not complain, and so on. Longer phenomena may be treated as actions in another situation: the cannonball flight is a component of the Rube Goldberg contraption.

The durations of action, of time between interactions, and of channel conditions reflect whatever relationships we choose to represent in the channel. I will argue later on that living beings can be seen as naturally enacting complex information channels. In organisms, the three time scales are reflected in three explanatory stances: physical causation, development, and evolutionary history (section 6.3 below, Tinbergen 1963).

Setting the boundaries for the circumstances we want to examine, or for any phenomenon we wish to describe, is often an inexact exercise. Our knowledge is limited, and conditions can change or be affected by external events. With respect to **C**ircumstances' recurrence or comparability in time, and continuing the alphabet game, we can distinguish

Disturbances, occasions that affect the context quite significantly or put an end to it, transforming or voiding the applicable vocabulary; and **E**vents, all occasions that somehow register in the action context, some of which we choose to represent by vocabularies. Both can be thought of as probability distributions of occurrences in space and time, possibly unknown.

Words We take that action in the world can in general be described by sentences of form $A \circlearrowleft_C B$ (chapter 3), which can be seen as akin to information transmissions in channel C. If so, signs that comprise the messages A and B need to be some from somewhere. As discussed in section 4.2 and again above, opportunities for interaction between physical processes have semiotic features, so we can represent them with (continuous variables or) vocabularies of terms. As $A \circlearrowleft_C B$ can, in principle, be any sentence, this leads us to ask whether any concept we use can be tied to some, possibly complex, range of opportunities for material interaction. According to this view, messages A and B would reflect potential interactions inside the focal context C, and between C and other contexts, at some semiotic level: of the entire sentence, words and syntax, or individual letters.

The present argument expands on Deacon's (2012) reasoning to suggest that this can, in part, be done, if we recognize that one reliable physical manifestation of our concepts are the social activities we learn and use them. Messages A and B can indeed refer to any concepts we use, as long as C is a moving target, a range of social activities in which or about which, to our knowledge, the terms that comprise A and B make sense. Consequently, our terms remain fuzzy: they need to be learned and mean different things to different people, and any settled meanings are achieved in ongoing interactions through education, negotiation, and use. There are social practices we have initiated, such as sciences, which construct and use concepts that articulate more explicitly their relationship to the world. However, ultimately, no matter if it is a word in everyday language or has a technical definition, any term is tied socially and historically to communities of practice within which it has meaning.

I now lay out in more detail why tracing arbitrary concepts to opportunities for material interactions leads to society and culture. Consider first the cannon shot example. When stringing up components into a larger contraption, one action context provides a proto-affordance to another; the cannonball imparts a given momentum to a dolly. Opportunities for interaction can be represented, in simpler cases, by overlapping intervals of (i.e. constraints upon) physical variables that mediate the relationship. In this case the terms are not intrinsic to the processes but imposed externally, by a human with designs on what the entire device should accomplish. These ranges can be seen as precursors to *referents*, signs in the target vocabulary for one channel (the cannon), or proto-*symptoms* in the source vocabulary for the other context (the dolly). Each such lump term, represented at simplest as an interval, probability function, or a fuzzy set, can be treated as a category, and depends on the properties of the two processes.

This poses the question whether and how any category or concept we use could in principle be traced to some material interactions, potential or actual. Deacon (2012, ch. 6), responding to the metaphysical debate between nominalism and realism, indicates that it can. Ontological realism, dating back to Plato, holds that all concepts we come up with are actual entities, although they may exist in a physically inaccessible realm. Nominalism on the other hand claims that words are just sounds fallible people make up, referring to anything out there partly or wholly by chance. For Deacon (p. 189) responds to the dilemma by recognizing that the mental is also material. A property needs to exist as some kind of patterning in the brain, a Peircean habit of mind, for one to assess whether another pattern in the phenomenal world fits the description. The concepts we use exist, at least, as a relationship between our neural firings and patterns in the rest of the world (p. 202).

Any realized interface between our neurons and the world is bound to be sociocultural;

Deacon (1997) elsewhere discusses at length the social underpinnings of our terms, but does not pursue this fact in his ontology. However our concepts may be stored in our synapses, the only way the mental can make any difference to the materially observable is by influencing what we do, and what what we do does. Our concepts are performed in our actions, which in most cases involve other people immediately, and if not typically include some expectation of what others will do. Also, each of our terms passes through a sociocultural filter in which it is dissolved and rebuilt. What we understand a word to mean is largely learned from others; it can change, if a little, any time it informs our and others' actions and experiences.

Take the example by Dennett (2017, pp. 122–123): Daniel walks into a room and yells "Put on the kettle!" One person infers he wants tea, the other that he probably lives in the house, the third is Hungarian and only understands an English-sounding phrase has been shouted, the last one knows the speaker has a nefarious purpose. Linguists distinguish among propositions expressed ("put on the kettle"), justified ("the speaker speaks English"), and implicated (all others; pp. 123–124).

If the words we use are viewed as information transmissions, the channels that carry them contain all characteristics of the context that may affect how the messages are understood. Many of these are social and cultural. People abridge, interpret, and creatively improvise on what they hear; there is no such thing as simple one-way transmission and no firm line between senders and receivers, though the social occasion may be managed so as to approximate it. The linguistic categories of propositions thus refer to the properties of the activity as the channel wherein the message is interpreted: expressed meanings rely on a listener understanding the literal meanings in the language, implicated ones on what she knows or guesses about the social context, and so on. We need social information to surmise the meaning an utterance has for each person in the room.

Perhaps anticlimactically, all this tells us is that the meaning of any word relates to, though does not necessarily amount to, a regularity in what some people may do. The observation does not seem to say much and appears prone to infinite regress, explaining a concept with more terms about the social occasion, which need more terms to explain them, and so on. What it does is pass some off the load off an ontological inquiry into concepts to an empirical one about society. We can flesh out, to the extent possible, how we understand a term with observations of how it is learned and used. When Deacon (2012, pp. 187–189) asks, for instance, what we mean by a spiral, what it is that galaxies, hurricanes, and vortices have in common, we can answer that at the very least they together provide affordances to mathematicians to model them as spirals. We can ask next, what do exactly the mathematicians do when they model spirals?

Conversations Describing who mathematicians are, what they do when they study spirals, what kinds of patterns they look for, and so on, involves adopting new vocabularies, presumably ones relevant to the topic and shared with desired interlocutors. This appears to pass the load yet further, the infinite regress of concepts turning into one of conversations. However, for every concept, the buck stops at some store of shared notions and practices. While the folk ontology of the manifest image by Sellars (1963) is culturally naive, the point taken is that any conversation requires common concepts, which have to come from somewhere. Rather than from what is manifest, however, terms can more modestly be drawn from social activities where they make sense. The basic implications, as I discuss next, are that our concepts are fuzzy and negotiated; we can maintain conversations relating them to what we argue is material and observable, but assigning terms to anything real may be a fool's errand.

Shared meanings within a culture (can be seen to) express messy clusters of opportunities for interaction, imperfectly negotiated common affordances: they imply answers to questions such as what we can or cannot do with *X*, or what we think *X* does or not regardless of us. We differ in our answers to these questions; mapping opportunities for interaction onto words and vice versa is uncertain, and it is neither usual, possible, nor always desirable that the correspondence be clear and distinct. The example Dennett often invokes are day and night: usually we can tell when it is one or the other, but there are times when different people would disagree or be unsure. Setting a sharp boundary is never completely satisfactory and always partly arbitrary. It is also potentially political, as it typically prefers someone's views and leaves another's out.

Clarifying our concepts, if desired, is thus inevitably a social and cultural enterprise, and the Babel of perspectives and politics cannot be avoided. Presently, we seek to navigate the accounts with respect to how informative they are about observable phenomena, and so we employ Feynman's Babylonian approach (see chapter 2). Whatever agendas statements may advance, we can at least be sure they overlap to the extent they recognize and refer to related physical phenomena. We start from the many points we have and attempt to reconcile the accounts insofar as they (claim and aim to) talk about the material world. We can initiate conversations with the aim to translate, reinterpret, and interlink vocabularies with respect to what we observe about the overlap, agree or not. In physical sciences this tactic has held up quite well, although translating the terms between fields of study is by no means easy (section 5.1).

The overall picture of accounts produced by interlinking conversations parallels in many ways the dialectics articulated by Harvey (1996, ch. 2). A detailed comparison is beyond present scope, but a common orientation is quite apparent. As in Harvey, processes and relations (actions and interactions) are here taken as fundamental; things or permanences are physical processes offering stable assortments of affordances (opportunities for interaction), parts and wholes constitute each other, and space and time are considered relational even if they are represented and modeled quantitatively.

Of the differences, the broadest is that, while Harvey does not commit to presenting his dialectics as the nature of reality (ontology) or of knowledge (epistemology), here we note specific domains of observables that can be fruitfully understood as dialectical, both bearing on how we represent what we know. One, every term we use is dialectical to the extent it is learned and used in conversation, i.e. uttered in interaction. Two, our accounts of the world are in a dialectical relationship to the extent they can shape one with another, agree or not. Topic three, what we can know about the relationships of entities "out there" in the world, depends on choosing who and how can produce claims about reality (that we trust), which requires addressing dialectics both one and two.

Without making claims about reality, we can say that our terms are dialectical insofar they are continually renewed in social activity, and that much of their meaning manifests in (socially negotiated) relationships with other terms. This distinction can, for example, help clarify the claim that there is "no basement" (Harvey 1996, pp. 51–53), that all "things" and putative basic units are heterogeneous and decomposable all the way down (also Levins and Lewontin 1982, p. 278). Here an attempt is made to relate the statement to observables as appropriate. Whether there is a conceptual basement in reality boils down to whom and how we can trust to check and report; while we can never be sure, for example, physics may well have already landed upon a few fundamental phenomena. About inquiry, it is a trivial observation: of course we can keep asking questions, indeed the only way to remain reasonably certain of anything is to keep unsuccessfully undermining it. The universe may or may not have a basement, but our representations of it and efforts to dig beneath them remain dialectical.

The assumption taken on trust in chapter 3, that we can describe action in the world, can now be separated into questions in three domains. The question of origin, how come anything symbolic ever appears, is addressed in biosemiotics and is taken up in the next chapter. Next, why we humans are beings that can produce signs nearly at will, is approached from evolutionary biology in the following chapters. The final one, how come some of our practices result in trusted symbolic claims about reality, is largely out of scope. A few previous points about the relationship between scientific accounts and "nature," however, bear reviewing with it in mind.

One way science and mathematics secure trust for their claims is by formalizing notions such as movement and number that are widely shared across cultures, by relating them to actions and symbolic manipulations that can be described and repeated in desired detail. As discussed in chapters 2 and 3, this is why, rather than as a privileged conversation, the present paper chooses natural science as a starting point about whose claims we may have an easier time agreeing, subject to this actually being true. Moreover, while the practice of physics privileges mathematics as enormously useful in describing natural phenomena, it rarely produces unique accounts. More typically, it lands on multiple compatible articulations that are conceptually quite distinct. Faced with empirically equivalent accounts we cannot meaningfully distinguish which is "real" and in practice do not attempt to; we do try to pursue their different implications further afield (Feynman 1965, pp. 53–54, 168). Which description is reliable and which of the concepts it employs is real are separate issues.

We thus do not expect or aim to seek any simple relationship of correspondence between representations and reality. Instead we turn to the natural origin of intentionality and representation along with life, and consider the evolution of semiosis to the symbolic representation in genes.

CHAPTER 6 ORIGINS

The word *intention* conjures many meanings, such as active conscious expectation and legal responsibility. This essay uses the term in a broader formal sense, common in philosophy and linguistics, of *aboutness*. Intention is a quality that can be ascribed to someone or something of having a topic or an aim, of being about something.

Deacon (2012, p. 27) thought the potential for confusion with everyday meanings great enough to use his own coinage *entention* for the formal sense. I tend to find unfamiliar words more perplexing and stick with the accepted technical meaning. To avoid ambiguity, I call *teleonomic* the non-cognitive intentional properties of living beings (Mayr 1974), and prefix intention with "conscious" or "collective" in cognitive and sociocultural realms. In addition, I use *intentionality* for the capacity of anything to exhibit intention.

The examples of intention Deacon (2012, pp. 1–2) gives are the meaning of a sentence, the function of a shovel, the reference of waving in greeting, and the purpose of writing a book. In all these senses, intention holds causal information about future states of the world related to their topic. It can be seen as representing complex but partly predictable physical consequences, and it does so even if the referent physical states are absent or never come about. This is in reversal to physical laws, which act with respect to the present state and move reliably forward from it with no notion of the future. Since intentionality is in addition usually attributed to living beings, it is often overlooked in scientific research as hopelessly inexact and subjective. Deacon (ch. 0) argues that this is an omission, that it is exactly because it appears so unusual that intention calls for scientific explanation.

I aim to demonstrate that intention can be associated with physical processes that can represent and transmit information in their own right, such as living beings, their artifacts, and wider dynamics involving either or both. In this chapter, I argue that intentionality and symbolic representation originate together, along with life.

6.1 Life and Semiotic Closure

To tease out the nature of intentionality I start at the origin of life, then follow the gradual elaboration of intentional dynamics through transitions in evolutionary history (Maynard Smith and Szathmáry 1995). The discussion of the origins parallels the accounts of Dennett (2017) and Deacon (2012). Like Dennett, I argue that intentional properties appear along with life at the very onset of natural selection; Deacon (pp. 136–137) holds that such features are refined through evolution but precede it. With Deacon (pp. 114) I argue that intentionality of living beings and designed artifacts of comparable complexity can not be easily analogized, as the former is integrally incorporated into bodies managing the physical resources for their growth and upkeep. Dennett affirms the distinction but is more concerned with the results arising from different methods used by the "designer," mindless evolution or a thinking engineer.

As mentioned, the origin of intention will be argued to parallel that of representation. Pattee (1969, 2007); Rocha (2001), responding to von Neumann (1966), suggest that matter becomes text as a part of a process that achieves *semiotic closure*. (Pattee originally called the property "semantic closure" but later adopted Rocha's wording.) Recapitulating the several definitions, we can say that a string of molecules is symbolic when (1) it is not in direct interaction with the environment, forming an inert part of an encompassing network of processes; (2) it is transcribed and translated, directly recognized by other molecules that manipulate the string and execute some specific though in principle arbitrary actions; and (3) these actions include the synthesis of the transcription and translation molecules as well as the reproduction of the code itself in the wider environment.

Requirements (1) and (2) boil down to saying that there is in an information channel mediated by the transcription and translation processes, in which the putative symbolic string is the source message, and ultimate actions the targets. Condition (3) can be seen as ensuring the information channel where the molecule string is a message occurs again: it asks that the source encode the channel which can in turn both interpret and reproduce the message. These three conditions are taken to mark the appearance of representation where before there was none: (1) and (2) together define the syntax, (2) also provides semantics, while (3) amounts to pragmatics (Rocha 2001).

Pattee (2007, pp. 275, 283) does not account for the origin of semiotic closure, indeed assuming that the symbols are irreducible to physical laws. I proceed to present a heuristic argument of how representation does indeed originate in a consilient manner, as chemical processes that begin to undergo natural selection become representational as soon as the four explanatory stances given by Tinbergen (1963) become applicable, and before they evolve explicitly symbolic means of encoding. Following the account through to the appearance of genetic code, three aspects of informational dynamics at the origin of life are discussed, following the analyses by Kauffman (1993, ch. 7–10).

1. *Versatile self-reinforcement (e.g. autocatalysis).* A set of mutually reinforcing interactions appears that can, given the needed inputs, keep going indefinitely, multiply, and incorporate a large variety of new interactions. In chemical terms, the reaction is collectively autocatalytic and its graph is near-critical or supracritical. Natural selection sets in and gives rise to intentional properties.

2. *Stabilization and differentiation (autopoiesis).* Subsets of interactions evolve to differentiate and specialize for separate tasks, notably the management of energy flows. In biology, we can say the process now has organs and a metabolism; in system theoretic terms, it is self-maintaining or *autopoietic*. If the substrate allows for establishing boundaries, the process forms individual entities, with respect to which we should be able to point out periods of reproduction and growth.

3. *Coding.* A part of the process specializes to represent information about how organs (specialized subsets) and competences are formed. While many actual developments during growth are particular to parts of the process in interaction with the environment, the bulk of information, of differences that make a difference in growing a new being, is passed on during reproduction. Over time, the representation evolves to be more discrete and general.

These three elements are idealized, and in realistic situations they are apt to manifest concurrently; various models of the origin of life accord them different priority. The order follows logically from more diffuse semiosis to more specific, focusing on the ability of living processes to respond and specialize in light of diverse affordances in their environments. *Versatile self-reinforcement*, such as autocatalysis with a supracritical reaction graph (Kauffman 1993, pp. 312–318) allows the evolving process to interact with virtually any new affordance it is presented with. As autocatalytic sets multiply, spread, and compete, they also grow to incorporate new chemical reactions, and the combinatorial explosion of possibilities is balanced by the capacity of the living process to sort them out and refine them. *Specialized organs* evolve to deal with matter and energy flows, to interact with the environment, and to store and reproduce information. *Symbolic codes* and syntax are then favored to evolve, as they can represent the information most generically.

These dynamics are generic; Kauffman (1993, ch. 7, 8) frames his models in terms of peptides or RNA sequences, but the argument is combinatoric, and can apply in any context with sufficiently diverse and frequent interactions. New processes that come into being with life, such as specific behaviors or entire lives, can in principle interact and manifest these dynamics in part or in entirety. Also, the genetic code is a *symbolic* representation, using four discrete chemical letters to encode proteins comprising cells of all living beings we know. The three aspects of semiotic closure dynamics are thus a potential blueprint for evolution of symbolic representation in any context.

I now turn to these dynamics in detail.

6.2 Autocatalysis

A process coming alive needs to be both responsive and variable enough that its behavior can make a difference to its success under a wide range of environmental conditions it encounters. This happens only if there are multiple alternative pathways the reaction can incorporate, so that it needs to be versatile; perhaps not supracritical, able to react with nearly arbitrary new compounds, but nearly so (Kauffman 1993, pp. 312–318, 330).

Explore and Remember The argument for the origin of intentionality and representation (section 6.3) is demonstrated most clearly on autocatalytic sets, which belong to the wider category of metabolism-first models of the origin of life. Such models have known problems; for example Vasas et al. (2010) suggest that just compositional information (*composome*), i.e. the organization of the process, does not preserve information faithfully enough from one generation to another for evolution to start. Nonetheless, for life to start there needs to be a certain self-reinforcing set of interacting compounds, no matter their nature. Some are perhaps already good at preserving information in ways such as template replication, while others may be better at garnering materials and catalyzing reactions needed to replicate information. Autocatalytic sets assume the least about such internal structure so they are suitable for discussing information dynamics in any hypothetical case of a self-reinforcing set of reactions leading to the origin of life.

An autocatalytic process cycles, so within the context a state "refers" to itself by way of a series of symptoms from one reaction to the next, ultimately bringing itself about again (section 5.2). Semiosis in autocatalysis differs from simple cycling in several ways:

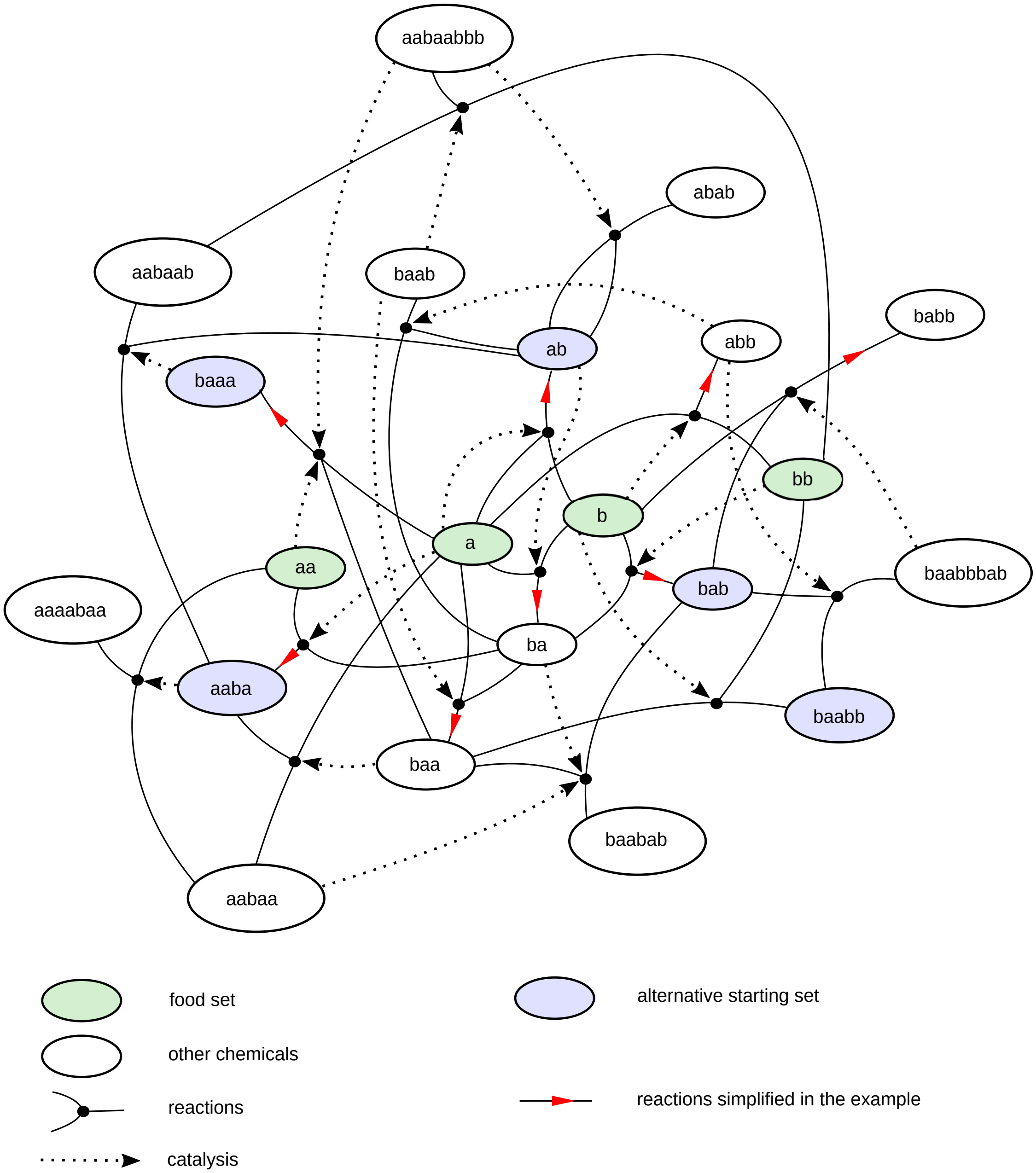


Figure 6.1: An example of a small autocatalytic set. Each ellipse encloses a chemical inside the set, a polymer of two monomers, a and b. Reactions are indicated by black dots and can unfold in two directions, toward a longer polymer (ligation) or toward two shorter ones (cleavage). Catalysis is represented by dotted arrows pointing from the catalyst to the reaction. Red arrows indicate some of the reactions involving the food set (green ellipses) that are, for the purpose of the example, taken to run only toward longer polymers. An alternative starting set is marked in blue from which the whole autocatalytic set can regenerate, given the food supply. Adapted from Kauffman (1993, p. 323).

$$\begin{aligned}
\mathsf{a} &\circlearrowleft_{\text{catalyze}} (\mathsf{a}, \mathsf{b} \circlearrowleft_{\text{react}} \mathsf{ab})^* \\
\mathsf{b} &\circlearrowleft_{\text{catalyze}} (\mathsf{a}, \mathsf{bb} \circlearrowleft_{\text{react}} \mathsf{abb})^* \\
\mathsf{ab} &\circlearrowleft_{\text{catalyze}} (\mathsf{a}, \mathsf{bb} \circlearrowleft_{\text{react}} \mathsf{abb})^* \\
\mathsf{ab} &\circlearrowleft_{\text{catalyze}} (\mathsf{b}, \mathsf{a} \circlearrowleft_{\text{react}} \mathsf{ba})^* \\
\mathsf{a} &\circlearrowleft_{\text{catalyze}} (\mathsf{aa}, \mathsf{ba} \circlearrowleft_{\text{react}} \mathsf{aaba})^* \\
\mathsf{bb} &\circlearrowleft_{\text{catalyze}} (\mathsf{ba}, \mathsf{b} \circlearrowleft_{\text{react}} \mathsf{bab})^* \\
\mathsf{abb} &\circlearrowleft_{\text{catalyze}} (\mathsf{ba}, \mathsf{ab} \circlearrowleft_{\text{react}} \mathsf{baab}) \\
\mathsf{abb} &\circlearrowleft_{\text{catalyze}} (\mathsf{baab} \circlearrowleft_{\text{react}} \mathsf{ba}, \mathsf{ab}) \\
\mathsf{baab} &\circlearrowleft_{\text{catalyze}} (\mathsf{ba}, \mathsf{a} \circlearrowleft_{\text{react}} \mathsf{baa})^* \\
\mathsf{b} &\circlearrowleft_{\text{catalyze}} (\mathsf{baa}, \mathsf{bb} \circlearrowleft_{\text{react}} \mathsf{baabb}) \\
\mathsf{b} &\circlearrowleft_{\text{catalyze}} (\mathsf{baabb} \circlearrowleft_{\text{react}} \mathsf{baa}, \mathsf{bb}) \\
\mathsf{aa} &\circlearrowleft_{\text{catalyze}} (\mathsf{baa}, \mathsf{a} \circlearrowleft_{\text{react}} \mathsf{baaa})^* \\
\mathsf{baa} &\circlearrowleft_{\text{catalyze}} (\mathsf{aaba}, \mathsf{a} \circlearrowleft_{\text{react}} \mathsf{aabaa}) \\
\mathsf{baa} &\circlearrowleft_{\text{catalyze}} (\mathsf{aabaa} \circlearrowleft_{\text{react}} \mathsf{aaba}, \mathsf{a}) \\
\mathsf{aaba} &\circlearrowleft_{\text{catalyze}} (\mathsf{aa}, \mathsf{aabaa} \circlearrowleft_{\text{react}} \mathsf{aaaabaa}) \\
\mathsf{aaba} &\circlearrowleft_{\text{catalyze}} (\mathsf{aaaabaa} \circlearrowleft_{\text{react}} \mathsf{aa}, \mathsf{aabaa}) \\
\mathsf{ba} &\circlearrowleft_{\text{catalyze}} (\mathsf{baa}, \mathsf{bab} \circlearrowleft_{\text{react}} \mathsf{baabab}) \\
\mathsf{ba} &\circlearrowleft_{\text{catalyze}} (\mathsf{baabab} \circlearrowleft_{\text{react}} \mathsf{baa}, \mathsf{bab}) \\
\mathsf{aabaa} &\circlearrowleft_{\text{catalyze}} (\mathsf{baa}, \mathsf{bab} \circlearrowleft_{\text{react}} \mathsf{baabab}) \\
\mathsf{aabaa} &\circlearrowleft_{\text{catalyze}} (\mathsf{baabab} \circlearrowleft_{\text{react}} \mathsf{baa}, \mathsf{bab}) \\
\mathsf{baaa} &\circlearrowleft_{\text{catalyze}} (\mathsf{aaba}, \mathsf{ab} \circlearrowleft_{\text{react}} \mathsf{aabaab}) \\
\mathsf{baaa} &\circlearrowleft_{\text{catalyze}} (\mathsf{aabaab} \circlearrowleft_{\text{react}} \mathsf{aaba}, \mathsf{ab}) \\
\mathsf{baab} &\circlearrowleft_{\text{catalyze}} (\mathsf{aabaab}, \mathsf{bb} \circlearrowleft_{\text{react}} \mathsf{aabaabbb}) \\
\mathsf{baab} &\circlearrowleft_{\text{catalyze}} (\mathsf{aabaabbb} \circlearrowleft_{\text{react}} \mathsf{aabaab}, \mathsf{bb}) \\
\mathsf{aabaabbb} &\circlearrowleft_{\text{catalyze}} (\mathsf{ab}, \mathsf{ab} \circlearrowleft_{\text{react}} \mathsf{abab}) \\
\mathsf{aabaabbb} &\circlearrowleft_{\text{catalyze}} (\mathsf{abab} \circlearrowleft_{\text{react}} \mathsf{ab}, \mathsf{ab}) \\
\mathsf{aabaabbb} &\circlearrowleft_{\text{catalyze}} (\mathsf{baa}, \mathsf{a} \circlearrowleft_{\text{react}} \mathsf{baaa})^* \\
\mathsf{abb} &\circlearrowleft_{\text{catalyze}} (\mathsf{baabb}, \mathsf{bab} \circlearrowleft_{\text{react}} \mathsf{baabbbab}) \\
\mathsf{abb} &\circlearrowleft_{\text{catalyze}} (\mathsf{baabbbab} \circlearrowleft_{\text{react}} \mathsf{baabb}, \mathsf{bab}) \\
\mathsf{baabbbab} &\circlearrowleft_{\text{catalyze}} (\mathsf{bab}, \mathsf{b} \circlearrowleft_{\text{react}} \mathsf{babb})^*
\end{aligned}$$

Table 6.1: The autocatalytic set from figure 6.1 as an information channel. Asterisks * mark the reactions that are reversible in the original example, and here taken to run only toward longer polymers; in the figure, they are shown as red arrows.

(a) *Reproduction.* The component contexts are discrete and separable (like in a geyser); and the process can sustain itself and spread given the right conditions (like convection). Hence, it spreads by each discrete component facilitating the production of more than one copy of itself. Seen semiotically, each component signals via intermediates more than one occurrence of itself later on. The process as a whole also refers to more than one copy of itself.

(b) *Variation.* Components are not set in stone, and the structure of the process can change. New polymers or sets of polymers can be brought in and impact what is already going on, so an autocatalytic set can reach many stable behavior patterns (Kauffman 1993, pp. 331–332). The semiotic representation changes along with the process.

(c) *Competition.* As the process both reproduces and can vary, its copies can differ in how quickly or successfully they obtain necessary materials and multiply in turn. The semiotic representation is of consequence to (is informational about) how successful the process is.

These are the preconditions for evolution by natural selection. Kauffman (1993, p. 330) argues that the threshold to evolution is crossed as a phase shift when the reaction is supracritical, when it can interact with and incorporate almost any new chemical. However, Kauffman's models are idealized, for example they assume an unlimited food set, which an autocatalytic reaction in reality may not have available. It may be more realistic to assume that a reaction set leading to life is just near-critical or versatile. If such a set of reactions can reproduce and sustain itself, say in balance with another Deacon (2012, pp. 302–323), then near-critical evolving lineages can cross the same threshold.

Internal Logic The phase shift to life becomes possible with reaction sets of some minimal complexity (Kauffman 1993, pp. 340–341). Going back to Kant's expression, to have competition among reaction sets, there needs to be sufficient communication among their materials for each to sustain itself, multiply, and adopt varied possibilities. In living beings, Kant's turn of phrase is no longer metaphoric. Although there is no specific part of the process tasked with the representation, by treating the reaction as a semiotic information channel one can express the signaling among reacting polymers quite explicitly. The matter can be seen as performing over and over a simple task in rump implicational logic.

To see how this takes place, consider more closely the internal structure of an autocatalytic set. Take the example from Kauffman (1993) reproduced in figure 6.1, and treat the entire set an information channel. There are two natural ways to do it. In one, $\circlearrowleft_{\text{catalyze}}$, the channel is catalysis, the sources are the catalysts, and the targets are the reactions they catalyze. In the other, $\circlearrowleft_{\text{react}}$, the channel are the reactions, and the sources and targets are the polymers on each side of a reaction. The entire autocatalytic set is represented in this pseudo-code in table 6.1. (For simplicity, I take some of the reactions involving the food set to run only toward longer polymers. This does not affect the argument at this point and is realistic if the food is abundantly resupplied. More below.)

Recall from chapter 3 that $\circlearrowleft_C$ in general just means "accompanies or is followed by in time in context C." We adopt the strict time direction, "followed by," for both catalysis and reaction channels. Let p denote one of: a polymer a, a reaction $a \circlearrowleft_{\text{react}} b$, catalysis $a \circlearrowleft_{\text{catalyze}} r$, or any complex furtherance $p \circlearrowleft_F q$ combining these components. Let the logical proposition p be true when the empirical statement "p can recur" (or alternatively "p can reproduce") holds. We can then replace both channel symbols with horseshoes $\supset$ denoting logical entailment and get true propositions about the autocatalytic set. The chemical reaction that comes alive behaves like a logical circuit with reactions implementing the operation "implies." (The similarity between the two symbols was the other reason to choose $\circlearrowleft$ to denote action moving forward.)

The resulting partial implicational propositional calculus resembles the early statement of mathematical logic by Russell (1903), which predates symbolic logic and the better known *Principia* (Whitehead and Russell 1927). Russell takes implication as primitive, and distinguishes formal and material implication, the former between propositional functions, rendered as "if-then"; the latter between propositions, "implies," here $\supset$ (Russell 1903, p. 14). If we give $\supset$ the physical interpretation of one component or reaction eventually furthering the recurrence (reproduction) of another through one or any combination of the two pathways $\circlearrowleft_{\text{catalyze}}$ and $\circlearrowleft_{\text{react}}$, most axioms and definitions can be checked to hold (pp. 16–18). Not all; discrepancies occur because we can readily move from statements representing physical relationships to logical ones but not vice versa without relaxing the physical interpretation of $\supset$ under some circumstances. The parallel points in favor of Russell's original realist interpretation of logical relations, that they are not purely mental constructs, which he later abandoned in favor of a more nominalist view (Feibleman 1944).

If one takes any model, whether metabolism-first or replicator-first, of a self-reinforcing set at the origin of life, one should be able to find a way to carve it into components ("propositions") and relations of furtherance ("implications"), treat it as an information channel, and proceed to draw analogous analogies. The idealization is, of course, only approximate; for example, the relations of furtherance are not nearly as certain as logical entailments. It may not be immediately apparent, however, what is gained by the exercise. It has no immediate explanatory power; the reason we can draw a parallel between chemistry and logic is because catalyses and reactions are reliable relationships we understand very well. The experimental method we use to study chemistry assumes that underlying relationships have the structure of logically connected isolable causes, and so there is no surprise some chemical reactions can be compared to logic.

The analogy helps clarify semiotic relationships present at the origin of life. If we take any component of the autocatalytic set, we can trace a path from it through consecutive other components all the way back to itself. If *H* is a component (compound or process) that participates in autocatalysis as above, then if we take "*H* is true" to correspond to "*H* can recur (reproduce)" in the context of an autocatalytic set (if the necessary minimum concentrations are present), every component of the set is "true." Every component of the set thus partly satisfies criteria for semiotic closure, as it successfully gets "interpreted" and reproduces with help of others; the one condition not directly represented is memory. If, in addition, we expand the perspective to include environmental interactions, they can be distinguished with respect to whether they aid, hinder, or have no effect on the recurrence (reproduction) of a semiotically closed reaction set.

In considering the semiotics of an autocatalytic set in its environment, we need to distinguish occurrences with respect to how they react with it. Continuing the alphabet game, events with which the set can interact are possible a**F**fordances or food. Products of reactions with and within the set not incorporated back into it are results of its **G**rowth. Interactions within the set that immediately feed back into it are **H**ome.

Events in these categories can be semiotic not just in relation to us (we describe them symbolically) but with respect to the reproducing autocatalytic sets. Let F, G, H are respectively a potential affordance, a product, and a component reaction. Events *H* are signs with respect to the set because they are partly semiotically closed, both produced and interpreted by the set. Informally this can be seen to mean, for example, that if an autocatalytic set fails to realize a component reaction *H*, it both produces and receives a "sign" that it may have trouble reproducing later on. Similarly, interactions *F* can be signs received by the set if they are actually affordances, if they make a difference to its reproduction. Meanwhile, products *G* can be signs produced by the set if there is another semiotically closed process whose reproduction they help or hinder.

The interaction between an autocatalytic set and an affordance *F* is semiotic and information about it persists, so we can meaningfully say that *F* actually functions as a sign every time the set interacts with it (this is consistent with Sebeok 2001). In addition, supra-critical autocatalytic sets can initiate and incorporate a wide range of interactions, and information about (variations in) interacting with any of them can be favored to persist, as long as it can be represented. Living beings thus populate the environment with affordances, their *Umwelt*, events seen by whether and how they help or hinder reproduction (Lewontin 2000, pp. 52–57; Dennett 2017, pp. 78–80). On this view, a semiotically closed process defines a perspective with no need to assume panpsychism, that every piece of matter has a rudimentary sense of awareness. Particles by themselves can no more than change and affect change, while a point of view is an emergent phenomenon associated with a particular way changing matter can organize.

The semiotic representation of the autocatalytic set thus helps clarify the transition between chemistry and biology. It maps how self-reinforcement, with it semiotic closure, is implemented in simpler interactions, by delineating relationships among them forming a larger entity. It functions as an extension of the semiotics of cycles from the previous chapter (section 5.2). The most important difference from the simpler cycles is that autocatalytic sets, and living beings in general, are able to enter into, vary in, and reproduce a wide range of interactions, only a tiny fraction of which can ever get realized. Since reproducing organisms also compete, they are bound by pragmatic constraints of their environments. At every later point, thus, surviving beings carry the evidence of what practical approaches worked in the past. While this is true by the simple fact of their survival, an internal representation that remembers and reproduces successful traits is a favored asset.

Organisms become representational slowly, at the pace of individual selection events. At the same time they become intentional, anticipating future environmental interactions. I turn next to outline how this takes place on a scenario of a single evolutionary event.

6.3 Why Write?

Four Questions The appearance of intentionality is the moment when the question “why?” about some natural process becomes equivocal. Before, it means only *how come?*, and after, it can also mean *what for?* (Dennett 2017, pp. 40–52). With help of the above syntax, going through the account step by step, I aim to demonstrate that the appearance of living beings involves a differentiation of phenomenal and (thus too) explanatory time scopes, and that they involve not just one, but three new senses of “why” we can start asking. This gives the total of four questions outlined by Tinbergen (1963): immediate causation, development, evolutionary history, and survival value.

For visual clarity, in the rest of the text the four questions are tagged with a capital letter in angle brackets, ⟨A⟩⟨L⟩⟨H⟩⟨D⟩, in the above order. The tags anticipate the meaning of the questions applied to society. The more usual ways to refer to them are given at the end of each item before the example.

1. If we look at the autocatalytic set at any moment or over a short period, we see just chemistry. In the ⧖ short term of physical ⟨A⟩ction within the autocatalytic set, the salient answer to “why?” is that to *how come?* referring to what we take as immediate causation (mechanism):

   “Why aabaabbb?” “But of course, baab $\circlearrowleft_{\text{catalyze}}$ (aabaab, bb $\circlearrowleft_{\text{react}}$ aabaabbb)!”

2. In Kauffman’s model of autocatalysis, after catalytic closure there is always a certain nonzero concentration of every polymer. We can treat the whole set, call it ℓ_A, as an action context providing catalysis, and focus only on the reactions, taking catalyst action as a part of the channel conditions. Let $\circlearrowleft_{\ell\text{-react}}$ denote this context.

   Suppose now that for an autocatalytic set there is a subset that can, given the food set and itself as a starting supply of both catalysts and raw materials, gradually synthesize the whole set. In the example in figure 6.1, the entire set ℓ_A can be bootstrapped from the food set $\ell_0 = \{\mathsf{a}, \mathsf{b}, \mathsf{aa}, \mathsf{bb}\}$ or, say, from $\ell_0' = \{\mathsf{ab}, \mathsf{bab}, \mathsf{aaba}, \mathsf{baaa}, \mathsf{baabb}\}$ (see figure 6.1). With a smaller starting set of catalysts only a few reactions are available, but the products in turn expand the set. With $\ell = \ell_0$ only the first two reactions can occur, then after the first reaction increases the density of ab, the first four open up. We can write this as

$$\begin{array}{rlrl}
\mathsf{a}, \mathsf{b}; \ell_0 \circlearrowleft_{\ell\text{-react}} & \mathsf{ab}; \ell_1 = \ell_0 \cup \{\mathsf{ab}\} & \mathsf{a}, \mathsf{b}; \ell_1 \circlearrowleft_{\ell\text{-react}} & \mathsf{ab}; \ell_1 \\
\mathsf{a}, \mathsf{bb}; \ell_0 \circlearrowleft_{\ell\text{-react}} & \mathsf{abb}; \ell_2 = \ell_0 \cup \{\mathsf{abb}\} & \mathsf{a}, \mathsf{bb}; \ell_1 \circlearrowleft_{\ell\text{-react}} & \mathsf{abb}; \ell_3 = \ell_1 \cup \{\mathsf{abb}\} \\
 & & \mathsf{b}, \mathsf{a}; \ell_1 \circlearrowleft_{\ell\text{-react}} & \mathsf{ba}; \ell_4 = \ell_1 \cup \{\mathsf{ba}\}
\end{array}$$

and so on. (The middle reaction in the right column represents two possible reactions going from $\mathsf{a}, \mathsf{bb}; \ell_1$ to $\mathsf{abb}; \ell_3$ using different catalysts.) Writing everything out would quickly get complicated, as we would need to specify all reactions for every intermediate realizable subset between ℓ_0 and ℓ_A.

This exercise yields one or more sequences $\boldsymbol{\ell}_{i,A}$ that trace all the way from ℓ_0 to the whole set ℓ_A, say $\boldsymbol{\ell}_{1,A} = (\ell_0, \ell_1, \ell_3, ..., \ell_A)$. Call them *life paths*. On the scope of ⧖ a $\langle\mathsf{L}\rangle$ifetime of an autocatalytic set, we can ask *how come?* and expect a life path as the answer, recounting the steps of development (ontogeny) from a supposed beginning:

"Why ba?" "Well you know, (ℓ_0, ℓ_1, ℓ_4)."

3. Self-reinforcing sets of reactions modeled by Kauffman (1993) exist in simulated chemical universes where they can, once versatile enough, evolve to flexibly track different food sets (p. 330) or settle on a choice of stable behavior patterns (dynamical attractors) producing different autocatalytic sets (pp. 331–332). Kauffman notes

the open questions about how a diversity of autocatalytic sets can come into being and track their environments (pp. 332–333), and recent research is skeptical of how faithfully metabolism-first models can preserve information. For present aims, assume the universe, simulated or real, is such that self-reinforcing reaction sets can both diversify and remember the new configurations well enough to fulfill the criteria for natural selection.

Say that in environment E_0 there is a population of self-reinforcing reproducing sets of reactions proceeding from similar starting points, so all are variants of some set ℓ_A. Over time, two new stable patterns appear, ℓ_B and ℓ_C, and there is a change in the environment to E_1. The new variants do about equally well in E_1 but better than ℓ_A. Eventually, after variants of ℓ_A die out as they can not compete and, say, those of ℓ_C dwindle due to bad luck, the whole population ends up consisting only of variants of ℓ_B.

Over the time of ⧖ many life cycles of the reproducing sets we can look at the entire population, ask "why?", and expect as a reply a part of this $\langle\mathsf{H}\rangle$istory, a *how so?* over a longer chunk of time. The answer comes in form of a sequential narrative about change through evolution (phylogeny), both selective and random:

"Why ℓ_B?" "Once upon a time, in environment E_0, there was a population of self-reinforcing reproducing sets [...] the whole population ended up consisting only of variants of ℓ_B. Just so."

4. The above history can but need not need to refer to any reasons, e.g. "ℓ_B got selected *for* the environment E_1." There was no forethought in the process, and concentrating on selection events leaves out the brief but hopeful tenure of ℓ_C.

   However, if we know or can surmise enough about this history, we can look again at the scope of ⧖ a life time or shorter, and offer an answer to *what for?*, what

$\langle\mathsf{D}\rangle$ifference ℓ_B or some feature of its makes to survival value (function):

"Why such part of ℓ_B?" "We think, for such feature of E_1."

Time Slip When we can say a living organism is capable of representing what it does to a large extent depends on what we decide constitutes representation. Dennett (2017, pp. 84–94) argues that representation means comprehension: an animal can represent when it understands its options and actions and uses its cognitive competences to articulate and manipulate a model of them. Dennett argues that we can claim this capacity with any confidence only for humans. Other animals may be imagining and running through practical scenarios, but do not have anything that corresponds to actual terms (pp. 94–101).

Generalizing on Pattee (1969), the present essay adopts a considerably more inclusive notion of representation, Simply, wherever there is intention, there is representation. In other words, whenever there is information in one part or at one stage in a (living) process that in some way anticipates its features at a future time, there is or has been some kind of representation. This perspective will help clarify the origin of symbol use in humans by letting us consider simpler cases first.

To argue there is intention, we need to establish the physical basis for the claim that information about future interactions is a part of a present living being. To do this, we revisit the four questions (see figure 6.2). Recall that, in the question about ontology or growth over $\langle\mathsf{L}\rangle$ifetime (item 2 above), the initial sets $\ell_0 = \ell_{0,A}$ and ℓ'_0 suffice to generate the entire set ℓ_A. They can be seen as "codes" for the set: they contain all the information needed to rebuild it given the materials and the known chemistry of the simulated universe. Measured in bits, they do not contain as much information as the entire set; this is reconstructed, *enrolled* from the environment in shape of food and chemical relationships. The initial set $\ell_{0,A}$ suffices to decode the entire autocatalytic set ℓ_A from the environment, and by itself does not contain any additional information.

Now consider the set ℓ_B from the question about function or ⟨D⟩ifference in survival value (item 4) and let $\ell_{0,B}$ be an analogous initial set for it. Taken on its own, it functions quite similarly to $\ell_{0,A}$, just generating the set ℓ_B instead of ℓ_A. However, if we consider the entire population at some point after ℓ_B became predominant, by knowing or surmising the ⟨H⟩istory of how this transpired we can claim that $\ell_{0,B}$ also contains information about what makes ℓ_B do better than ℓ_A in environment E_1.

Here is why. Seen individually, $\ell_{0,A}$ and $\ell_{0,B}$ decipher their respective sets ℓ_A and ℓ_B from the environment. After the change in the environment, individuals resembling ℓ_A and ℓ_B exhibit differing degrees of success. The population thereby *becomes informational*: the reproducing population in the environment holds information about some aspect of how to ⟨A⟩ct in E_1 that resides in whatever difference in the sets' interactions with E_1 makes a difference to their respective success. Then, the environment and the population together forward this information to the future over evolutionary ⟨H⟩istory by stochastic search, reducing the proportion of those members of the population that do not know the beneficent trick. There is no mystery about this: with tools of population genetics, we can estimate how well and how quickly this information is stored, inscribed in the population.

Any initial set $\ell_{0,B}$ in the new population still generates ℓ_B from environment and chemistry. However, what was before just a chance difference in success in E_1 became a part of every individual; through evolution, what was optional became obligatory (Dennett 2017, p. 178). From the point of view of any single set's ⟨L⟩ifetime, the information about how to interact with the environment *slipped back in time*. Of course, these are entirely new sets, each starting anew without the benefit of knowing the history. However, as long as the environment changes more slowly than it takes for a trait to come to fixation, whatever distinction between ℓ_A and ℓ_B made the difference in their success in E_1 ends up in the descendants of ℓ_B and in any initial set from which they may spring. This means that a set such as $\ell_{0,B}$ now *anticipates* those aspects of the environment E_1 that have made a difference in the past. Just as $\ell_{0,A}$ above, it can decode the entire set ℓ_B from the surrounding materials and chemistry, and in doing so it will also decode whatever feature made the difference for ℓ_B in its relative success over history.

The additional information in ℓ_B that made a difference for its predecessors and anticipates features of E_1 can be considered (defined as) its *intention*. Note that we can only know what kind of intention ℓ_B manifests by investigating beyond the life path of any single set. We may know the history, or have fossil remnants of ℓ_A, or maybe ℓ_A is a common mutant that does not persist any more and we can study why. Perhaps there is another set ℓ_D which does as well as ℓ_B in environment E_1 but in a completely different way, and we guess that there had to be a less well adapted common ancestor from which both diverged. Maybe the adaptive fit, the look of design, between the features of ℓ_B and the environment is highly suggestive, or maybe it has appeared in other lineages. Or we may know that the organisms we are studying have a specialized way of storing information about their development, such as the genetic code, which itself is evidence for evolutionary favoring of memory embodied within living processes.

The apparent time slip appears because the population records information faster than the environment changes. After a selection event, nearly every organism, unbeknownst to oneself but ready to be decoded, has information about what interactions with the environment it can expect in the future. However, every life also starts from scratch, and there is no guarantee the environments will be the same. Intention is inexact precisely because it depends on physical causation to manifest. It is causal in the sense discussed in section 5.1 because it (literally) represents information about future interaction in ways unavailable to basic physics alone, by spelling out a far from certain bet that a future may unfold in some particular way.

Text in Matter Pattee (2001) discusses the epistemic cut between text and matter, offer-

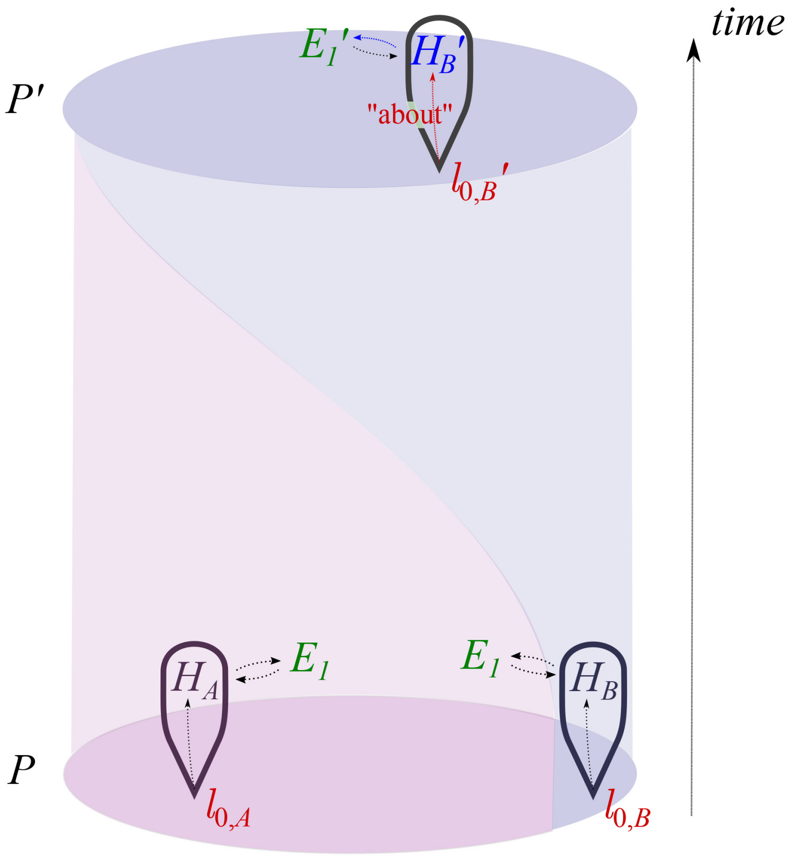


Figure 6.2: The origin of representation in a selection event.

A population P of autocatalytic sets are reproducing in an environment, which at start (bottom) has just changed to E_1. A minority of sets formed from the initial set $\ell_{0,B}$, via some subset of reactions H_B, interact better in the new conditions than the more prevalent H_A starting from $\ell_{0,A}$. The population P holds information about which of the two growth paths works better, in form of the difference in the practical effect interactions $H_{A,B}; E_1$ have on the respective sets' proliferation.

At a later time (top), reaction sets descended from $\ell_{0,B}$ have come to predominate. The population is no longer informative, as all sets interact similarly with their possibly changed surroundings E'_1. With the benefit of additional information, however, such as the history of selection or the purposeful appearance of interaction, we can infer that the starting set $\ell'_{0,B}$ is informational about a better way for H'_B to interact with some feature or event in the environment that has persisted in the past.

Relationships salient to all four explanatory stances by Tinbergen (1963) are represented. These are: immediate causal inter$\langle\mathsf{A}\rangle$ction in the environment $(H_x; E_1)$; ontogenetic $\langle\mathsf{L}\rangle$ife paths forming H_x from $\ell_{0,x}$; $\langle\mathsf{H}\rangle$istory of a selection event unfolding from bottom to top; the teleonomy (function) in $(H'_B; E'_1)$ and the representational role of $\ell'_{0,B}$ corroborated by the $\langle\mathsf{D}\rangle$ifferential past pragmatic consequences of $(H_B; E_1)$ that favored the spread of $\ell_{0,B}$.

ing the criterion of semiotic closure for when a molecule becomes a message (Pattee 1969). As argued above (section 6.1), the first two of the three requirements, that a molecule string is symbolic when it is transcribed and translated into some specific arbitrary actions, boils down to requiring that there is a physically realized communication channel where the string is the source message. The abbreviated criterion just employed, that representation requires intention, i.e. information at one stage of the process anticipating future features, says effectively the same thing.

Indeed, it is easy to see that the initial sets such as $\ell_{0,A}$ and $\ell_{0,B}$ satisfy both the requirement of intentionality and for semiotic closure: by interacting with the environment, they decode (and thus anticipate) a larger set of reactions which includes their own decoding and replication. Therefore $\langle \mathsf{L} \rangle$ifetime development of an organism can be seen as a channel with a native source vocabulary inferred but not imposed by us. The epistemic cut in explanation between matter and symbols is thus accounted for by more of an epistemic outflank in reality, switching focus along two dimensions: between momentary action and change over time, and between one organism and the population [diagram]. The focus moves from $\langle \mathsf{A} \rangle$ction of one organism over short times; to $\langle \mathsf{L} \rangle$ifetime of one organism, changing over time; to $\langle \mathsf{H} \rangle$istory of population in the environment, changing over time; to $\langle \mathsf{D} \rangle$ifference a trait in population makes in the environment, over shorter times.

Interpreting phenomena as information channels can be seen as establishing different levels of explanation (section 5.3). Informational relationships are probabilistic, they model repetition or require repetition to establish. If we are saying we have established the existence of a kind of an information channel, we are in effect saying that we have found a new way we can expect phenomena to recur, in whole or in some aspect. To complete the argument why the answers to the four questions yield explanations, we now attend to what kinds of repeated phenomena each question accounts for.

To begin, causal $\langle \mathsf{A} \rangle$ction relationships in physics and chemistry (item 1) are *lawlike*, reliably repeat given starting conditions. They can be seen as unproblematically informational as discussed in the previous two chapters, with vocabularies worked out in the lab.

As just discussed, $\langle\mathsf{L}\rangle$ifetime development, precursor to organism growth, is also a channel, and comes into being at the origin of life. Any one organism from a population undergoing natural selection is a repeated information channel. Of the requirements for natural selection, heredity entails semiotic closure, so we can say that growth is informed by (some kind of) representation, while variation and differential reproduction ensure that the representation makes a difference. The developmental channel in effect *bootstraps* itself from an initial core of messages and processes, successively opening up new interactions in the environment (item 2).

Explaining how this self-reproducing core comes to be and persist requires further extending the perspective in time and ecology. Evolutionary $\langle\mathsf{H}\rangle$istory at base views the population of self-reinforcing sets as a genetic search algorithm (initially without recombination), looking at what it takes to store a bit of information in the proto-organisms (item 3). How informational a population can be depends on its genetics: population sizes, accuracy of replication, mutation rates, fitness differences, and so on. Information capacity can be estimated on models of population biology by representing them as channels, in a manner similar to examples in chapter 4. In this way we can account for one or a few evolutionary flips, selective or random. Sequences of such events over longer periods, phylogenies, are conveyed as *narratives*, recounting the changes along with contingencies that have led to them. What reliably recurs are evolving populations, for each of which we can meaningfully describe the history in this way: by population genetics over shorter times, by sequential narratives over longer periods.

These three channels closely correspond to the three different time scopes implied in representing the living being as an information channel (section 5.3): specific interactions, time between them, and context conditions. In addition, environmental interactions that percolate through the selective events manifest as teleonomic or adaptive. They are useful intel, anticipating aspects of the environment relevant to the organism (affordances), such as how to find a meal or avoid becoming one. Whenever an organism uses such information, it ⟨D⟩istinguishes parts of the environment with respect to itself (item 4). A living being inherits useful intel. Answers to the question “what is it for?” comprise a qualitatively new account, an additional layer of explanation of causal and developmental events. What repeats between specific cases are the *intentional* semiotics of these explanations, in which an organism action is *about* an event in the environment.

These explanations are all applicable at the same time and ultimately refer to physical processes. Every one gives qualitatively different information about organism behavior: ⟨A⟩ its physical manifestation, ⟨L⟩ife path that brings it about in a single body, ⟨H⟩ one or many information fixation events in a population that led to it, and ⟨D⟩ what it is for. In addition, I submit that the argument in this section functions as a bridging conversation among them. As discussed in section 5.1, this is sufficient to establish the four questions as accounts of material efficacy consilient with natural sciences.

This reveals the gap between matter and text as less categorical than in Pattee (1982); Rocha (2001) and ultimately bridgeable. Rocha (2001, sec. 4.2) claims that “biological organisms, subjected to natural selection, gained control of precisely those aspects of the environment which can be molded and which physical law does not describe.” The present claim is quite the contrary: populations of organisms maintain memory of successful physical interactions, evaluated and recorded through stochastic search. In a manner of speaking, populations do simple science with symbolic and practical resources at their disposal, using themselves as hypothesis, experiment, and publication.

6.4 Autopoiesis

As Dennett (2017, p. 31) noted, the first living organisms may well have been akin to Rube Goldberg contraptions, surviving and reproducing successfully but none too elegantly. Kauffman (1993, p. 330) argues that autocatalytic sets start evolving when they become supracritical, when they can interact with almost any chemical presented to them. In his models, supracriticality is a phase transition beyond which evolution becomes well nigh inevitable. While such a state may not easily appear in nature, the models suggest that self-reinforcing reaction sets at the outset of evolution are likely to make up for their lack of elegance through versatility, by being able to get over evolutionary humps through exploring a wide range of alternatives. And humps are there; to begin with, a living being needs to keep going past the point where a simply dissipative process would run out of fuel.

Once a population of self-reinforcing reaction sets comes to sustain natural selection, it becomes less important to explore all the possibilities than that already used biochemical pathways do their job well (Deacon 2012, pp. 268–271). The stakes, opportunities, and problems facing an organism, as we may now start calling it, differ in time, space, and topic, and so similarly differentiated responses are favored to evolve in new generations. The communication among materials becomes more conservative, with discernible parts, organs, integrated into the growing organism. Between lineages, we can talk of quasi-species, populations that follow similar environmental strategies; species require sexual reproduction. Each quasi-species is subcritical, while the biosphere itself remains supracritical (Kauffman 1993, pp. 336, 390–393).

In particular, an organism differentiates as it evolves *enclosure*. A membrane separates the reactions inside from the outside; unwanted materials are kept out and the metabolites kept in proximity, making it possible to regulate reaction rates. Also, information-bearing chemicals (eventually genes) are kept together, and are then favored to evolve to cooperate

(Maynard Smith and Szathmáry 1995, p. 99). Criteria for life and the related concept of autopoiesis, dynamic self-maintenance and reproduction, often include boundaries as an explicit requirement (Koshland 2002; Maturana and Varela 1972, p. 81). If physically realizable in the medium, enclosure is an affordance favored to evolve: it is easier to know what is **H**ome.

We can speak of organs rather than parts, relevant to specific circumstances while integrated into the self-maintaining growing process. For example, let us say that a lineage has evolved enclosure, and that it makes a difference to the reactions inside an organism whether a particular chemical m is kept in or out based on its concentration inside the membrane. Another compound that can be built into the membrane reacts to the gradient in concentration of m by tightening or loosening the enclosure. The compound is favored to become part of the membrane, and comes to perform the function of a rudimentary valve.

As a population evolves to differentiate, from a semiotic perspective, different contexts and concepts by which we may represent the operation of each organ evolve as well. For example, a membrane divides the outside world from the inside of a proto-cell, and different kinds of chemical reactions tend to occur on each side. Each side of the enclosure is its own information context with a separate vocabulary, its own frequencies of events, umwelts of affordances, and so on. Moreover, if we zoom in closer, we can represent specialized features as information channels with their own vocabularies etc. For example, the membrane valve communicates the concentration of the molecule m to the state of the valve, open or closed.

Differentiation, specialization of parts and of organisms, introduce new kinds of choice. Every choice between chemical pathways, growth timings, or behaviors during an organism's lifetime can be seen as an information channel with its own vocabulary of affordances. The organism, of course, cannot represent what it does in nearly as much detail as we can when we analyze it, but in the above sense of embodied implication it can be said to contain lumped terms for its basic components and capacities. With specialization, we can now say that various parts of a body handle information differently. There are different vocabularies, corresponding to the different tasks the organism undertakes, stakes that organs handle, that differ physically and are spatiotemporally segregated.

In general, as Csete and Doyle (2002) report, an organism's metabolism behaves in very similar ways to robust control systems invented by human engineers, accomplishing self-regulation in a range of tasks. As elaborates:

> 1. Organisms depend on and utilize energetic and material gradients in their environment in order to perform work to sustain the constraints of their persistent, far-from-equilibrium dynamics, and to maintain constraints that are critical for countering the tendency toward thermodynamic decay.
> 2. Organisms actively reorganize their internal dynamics and relationships to the environment in ways that specifically counter or compensate for any depletion of the gradients that is necessary to maintain their dynamical integrity and their capacity to so respond.
> 3. Many organisms have evolved means of gradient assessment and spatial mobility that enable them to anticipate and avoid conditions of depleted gradients and to seek out more optimal gradients.
> 4. Organisms and ecosystems evolve toward forms of organization that increase the indirectness of the "dissipation-path length" of energy and material throughput in order to extract more work from the available gradients. (p. 269)

6.5 Encoding

I turn to the origins of genetic code briefly, in light of the previous discussions.

One way to look at the origin of coding is as differentiation of organs tasked with storing and interpreting evolutionary information. Organs differ by how much energy and matter they command, over what periods of time, and for what purposes. If we look at different time slices and bodily parts over an organism's lifetime, different regions and time periods are more consequential in bringing about subsequent states; some are relatively peripheral, while others are central in building much of the organism. Although organs are interdependent, we can talk about their relative *power* over time in summoning matter and energy to move the living process forward. While the relationship is likely to be anything but exact, parts that are more powerful in this material sense can be seen to hold more information about the subsequent states.

Those organisms that can better coordinate the interplay of their organs over space and time, along with where consequential information resides, are likely to be more successful. The special role in this is played by the moment of replication, when matter that gives rise to each new being is at a bottleneck. As, in comparison to other periods over lifetime, the newly reproduced organism enrolls the most matter and energy, the materials that replicate are the most likely to be the specialized for information storage. Over time, such storage is favored to become more efficient, both by becoming concentrated in one physical spot, and by evolving to more generic, symbolic forms of representation. As atoms and molecules are discrete units, they provide a natural medium that for forming symbols. Ultimately, on the organism level, genes have the basic information that can encode the requirements for almost every living process. The rest of the body gets to decide on a "need to know" basis (Dennett 2017, pp. 49–50).

This argument, in effect, extends the concept of gene power by Dawkins (1999, 224–

225) to putative reproducing organisms prior to the origin of specialized information storage. As Vasas et al. (2010) note, some kind of specialized information storage may be necessary for the origin of natural selection; as argued here, it would be favored to evolve anyway.

With the advent of generic symbolic representation in genes, we can distinguish between two different kinds of intentional, or teleonomic processes. One are those informed by genes; in them, intention is expressed over time scopes of ⧖ organism growth through enrolling matter and energy to build bodily features which enable certain competences: "grow cilia." We can talk about *i-reference* (**I** as myself, symbolically in-formed). The other kind is the embodied implication discussed above, and amounts to exercise of teleonomic competences, delegated to body part and times of its ⧖ use, and reacting to information from the environment: "run away from chemical *Z*." This can be termed *h-reference* (**H** for home, as above).

Semiocycles What is remembered in living beings and acted upon in evolution may be called (new word) *semiocycles*. They are physically realized as networks of interactions, collectively autocatalytic, informed by some representational medium, such as nucleic acids, translated into a cascade of reactions downstream. At the same time, while we can read the information encoded in molecules letter by letter, what is recorded in it is evaluated in the interactions it affects in the environment. Natural selection in a population can, with luck, discern affordances at any level or at any part of the reaction network.

> Typically the semiotics of the genetic system is construed as follows: all processes taking place before translation (from transcription to RNA editing) define the set of syntactic operations; the relation between mRNA (signifier) and folded amino acid chains (signified), through the genetic code, implements a semantic relation; and finally, the selective pressures on the obtained proteins

> and their developed products as the pragmatic evaluation of the genetic sign system (Rocha 2001, sec. 4.2).

In the example of the simple autocatalytic set, the representation is expressed dynamically, distributed over the entire process in a way resembling the (aptly named) material implication of symbolic logic (section 6.2). While this is just a restatement of the fact that the underlying chemistry unfolds reliably, it also anticipates the claim by Varela et al. (1991) that cognition is enacted and embodied.

For Dennett (2017, p. 122, emphasis removed), *pragmatic implication* describes the way animals represent "semantic information about how best to fit in ... mindlessly gleaned from the cycle of generations," at least when it does not need much cognitive work (likely per Grant 1958). This is true in that teleonomic properties of living beings manifest practically, their intentional nature to us "conveyed by circumstances" of a particular environmental context, in general as a competence without comprehension (Dennett 2017, pp. 56–57). However, the information, the potential and proclivity for interaction, resides at all times in the relationships of bodily processes, able to recognize the context and ready to be used if needed. By the manner of its representation in the context of immediate use, we can talk of *embodied implication*. While we supply the words to explain it and describe it, the living process itself materializes the implication "when close to F, eat it and grow" for some range of substances F in its environment.

These practical purpose-like features and behaviors of living beings depend on specialized symbolic representation in genes in several ways. First, the variation in fitness needs to have a genetic basis and be salient enough over enough many lifetimes for a population to be selected for a trait. Second, genes hold relatively little information but allow for arbitrary representation ("unlimited heredity"). The translation apparatus interprets the message to bootstrap the living process from the environment by anticipating features it can react with, affordances. Third, there is a continuity of material interactions between the genes and the phenotype. Despite the phenomenal distance the number of steps is finite, and selection can act at any one.

Absences The dynamics of representation in semiotic closure, from autocatalysis to autopoiesis to coding, also close out the wider account of the three emergent dynamics by Deacon (2012), from homeodynamics to morphodynamics to teleodynamics, articulated in terms of semiosis rather than constraints.

The contexts corresponding to homeodynamics are those in which there is only physical change with no intrinsic semiosis, and any representation of what is going on is gained from outside through study. Morphodynamics can be associated with the contexts where interaction between two or more physical influences produces behavior that repeats in space or cycles over time, resulting in maintenance of opportunities for interaction and thus notionally in simple forms of reference, but without capacity for versatile representation. Finally, teleodynamic processes can be understood as those where a generic internal representation plays a major role in influencing how matter interacts with its environment.

Deacon (2012, p. 0) sets off at the task of explaining intentionality with the paradox of constitutive absence. A shovel is for ("about") digging but exists quite independently of it, and any single shovel may never be used for digging at all. This in part motivates Deacon's choice of constraints as efficacious absences upon which intentionality is based. This essay instead puts forward two claims about the nature of intentionality. First, intention is representation in some information channel, so to explain it we need to identify the channel. Second, representation arises with living beings, and intention is a reply to one of the four questions that apply to any feature of life, what is it for? To find the channel, we can ask the other three questions: how its manifest physically, how it develops individually, how it came to be over history.

In the present account, constraints are not a constituting absence but a resource, affordances and necessary preconditions for realizable patterns of interaction. Absences do come into play when intention appears, at the origin of life. First, as per Deacon, precise details of the future life of an organism are absent from the information needed to build the body. Second, symbolic representation brings forth a range of possibilities too wide to ever be realized except for a tiny bit. The design space described by Dennett (1995, pp. 75–76, rendered as “Design Space” in the original) comes into being, too big to ever be explored fully, and there are beings that inhabit and wander around it. Absent are potential life paths unrealized, parts of the design space not yet or ever reached by evolving histories.

CHAPTER 7 SEMIOTICS IN EVOLUTION

This chapter establishes the requirements for discussing the semiotics of human symbolic interaction, addressing three related issues. First, if we take that living processes are symbolically informed by the genome, what constitutes the referent of a message? What can the genes be about? Second, what is the semiotic nature of organism processes? Specifically, what would it take to evolve a response to a set of affordances that uses symbolic representation in addition to the genome, and what would it take for these symbols to underlie separate evolutionary dynamics? Finally, what are the potential prerequisites for and implications of humans evolving symbolic interactions on a channel separate from genes, in effect starting a sociocultural evolutionary process?

7.1 Explanations

The previous chapter has argued that with natural selection living beings become informational about environmental interactions, and that this representation evolves to a symbolic form due to the bottleneck at reproduction. With representation originates, the four explanatory stances by Tinbergen (1963) become salient to understanding how a population evolves to embody information about interaction fitness. We now turn to consider the semiotics of the four stances as they now apply to a living process informed by a known symbolic code, and discuss the implications in light of the debate between gene-centered and interactionist views of organic evolution (e.g. Dawkins 1999; Lewontin 2000, respectively).

Each of the four explanatory stances offers information about specific material interactions the evolving organism or population enters into (section 6.3). Viewing these phenomena as information channels requires establishing circumstances (ecological and temporal scopes) when a channel applies, and source and target vocabularies (section 5.3). In organisms informed by the genome this raises the question as to what interactions are symbolically guided, in other words, what vocabularies can contain parts of the genetic text. We now consider the semiotics of the four explanatory stances while incorporating the genome. For each we review the question it answers and the kind of explanation it offers, note the relevant ecological and temporal scopes, and suggest semiotics.

In the formalism, upright letters a denote parts of the genetic message along with apparatus necessary to transcribe and translate it. Capital letters refer to different kinds of processes: environmental events E in general, affordances F with which the organism can interact for good or ill (e.g. food), processes H comprising the organism (home), their products and effects G (e.g. garbage). Pairings of organism and environmental processes $H; E$ stand for some combination of interactions $H \circlearrowleft E$ and $E \circlearrowleft H$ at scopes relevant to the explanatory stance considered. The four questions and associated information channels appear in angle brackets: $\langle\mathsf{A}\rangle$, $\langle\mathsf{L}\rangle$, $\langle\mathsf{H}\rangle$ and $\langle\mathsf{D}\rangle$; while additional time scopes are presented in parentheses: (M)olecular interactions (G)rowth processes, (E)cological processes.

1. $\langle\mathsf{A}\rangle$ction (mechanism). *How come* H is doing this right now?

   Reply: Chemical reactions and other *lawlike* processes.

   Scope: one organism in its environment, ⧖ immediate causes at (M)olecular scopes.

   $$\text{Semiotics: } H_1; E_1 \circlearrowleft_{\langle\mathsf{A}\rangle} H_2; E_2, \text{ with } E_1 \in \{F_i, H_i\}, E_2 \in \{G_i, H_i\} \tag{7.1}$$

   The interactions comprise occurrences in the non-living world such as those discussed in chapters 4 and 5. No material realizations of symbols enter into them.

2. $\langle\mathsf{L}\rangle$ifetime (ontogeny). *How come* H grew this or came to be able to do this?

Reply: Developmental life paths *bootstrapping* themselves from core sets of symbols and interactions.

Scope: one organism in its environment, ⧖ range of durations of (G)rowth processes from immediate to the full life span.

$$\text{Semiotics: } \mathsf{a}; E \circlearrowleft_{\langle \mathsf{L} \rangle} H; G, \text{ or in short } \mathsf{a} \circlearrowleft_{\langle \mathsf{L} \rangle} H \tag{7.2}$$

The symbolic genetic message informs a range of possible life paths in indirect ways, resulting in different phenotypic expressions. Developmental outcomes aggregated over possible environments comprise the ecological reaction norm of the genotype.

3. $\langle \mathsf{H} \rangle$istory (phylogeny). How come H evolved this? *Just so.*

   Reply: Accidents and selective influences stringing into sequences related as *narratives* in evolutionary time.

   Scope: population environmental interactions ⧖ over the number of lifetimes, durations differ for any specific evolutionary $\langle \mathsf{H} \rangle$istory event depending on how and how quickly distributions of genetic information change.

$$\text{Semiotics: } \rho_s \left(H; F \circlearrowleft_{(\mathsf{G})} \mathsf{a}'\right) \circlearrowleft_{(\mathsf{E})} \left[\rho_{t=1} \left(\mathsf{a} \circlearrowleft_{\langle \mathsf{L} \rangle} H\right) \circlearrowleft_{\langle \mathsf{H} \rangle} \rho_{t=2} \left(\mathsf{a} \circlearrowleft_{\langle \mathsf{L} \rangle} H\right)\right] \tag{7.3}$$

Selective and random influences ρ_s of $H; F$ on reproducing the allele a' affect the population probability distribution ρ_t of alleles a informing the growth of H. $H; F$ affect reproduction over periods shorter than lifetime (G), and influence the population over (E)cological times. The uneven pace of changes in ρ_t comprises evolutionary $\langle \mathsf{H} \rangle$istory.

Consider the semiotic closure of a single organism, $\mathsf{a} \circlearrowleft_{\langle \mathsf{L} \rangle} H;F \circlearrowleft_{(\mathsf{G})} \mathsf{a}'$. At start, information about the effect of interaction $H;F$ on reproduction is in the second part of the expression, $H;F \circlearrowleft_{(\mathsf{G})} \mathsf{a}'$, distributed over the population in form of differences in reproduction chances ρ_s. In a selective event, the information moves to the initial part, $\mathsf{a} \circlearrowleft_{\langle \mathsf{L} \rangle} H;F$, now residing in every organism (assuming directed selective influence ρ_s drives an allele a in the distribution ρ_t to fixation) in proclivities to grow H. As discussed in section 6.3, allele a informs ontogeny of H in anticipation of $H;F$ aiding reproduction of a'.

4. $\langle \mathsf{D} \rangle$ifference (function). *What for* is H's action or organ?

   Reply: Claims of teleonomy or *intention* in an organism's recognition and responses to environmental affordances.

   Scope: individual environmental interactions ⧖ at periods from immediate to lifetime, resulting from past selection,.

$$\text{Semiotics: } \mathsf{a};E \circlearrowleft_{\langle \mathsf{D} \rangle,\langle \mathsf{L} \rangle} (H;F \circlearrowleft_{\langle \mathsf{D} \rangle,(\mathsf{G})} \mathsf{a}'), \text{ or in short } \mathsf{a} \circlearrowleft_{\langle \mathsf{D} \rangle} H;F \tag{7.4}$$

   Allele a informs growth of an organism in environment E, in expectation of a future teleonomic interaction $H;F$. In it, a bodily process H meets an environmental affordance F, promoting allele reproduction a'.

Dawkins (1999) and Dennett (2017) discuss the nature of teleonomic properties of living beings, suggesting that adaptive explanations are contextual and provided by us. For example, for Dawkins, to call an allele a one "for" reading, a needs to make a difference whether and how a person reads; the argument may have been made as easily, say, for criminality or obesity. Dennett calls these inferred relationships "floating rationales," intentional hypotheses about observations we can invent by informed guess. This, however, glosses over two assumptions. First, how come we humans can infer the rationales and expect the guesses to be serviceable; and second, how do the phenomena the explanations refer to, such as reading and obesity, come to populate the environment? Dennett's (2017) proposed replies rely on the duality between the manifest and the scientific images, which as argued in chapter 2 bring in assumptions about society.

Rather than assuming too much about the context to which teleonomic organism processes respond to, we consider more closely the nature of semiosis in occasions of use. The simplest example of a functional process discussed by Pattee (1973) is enzyme recognition and binding. An enzyme interacts with a substance and changes its shape to bind to it, continuing to the next interaction. For enzymes, $H;F$ can be unpacked as

$$\left.\begin{matrix} H \\ F \end{matrix}\right\} \circlearrowleft_{\mathsf{(M)}} HF \circlearrowleft_{\mathsf{(M)}} E \tag{7.5}$$

$$\text{or } F \circlearrowleft_{\mathsf{(M)}} H \circlearrowleft_{\mathsf{(M)}} HF \circlearrowleft_{\mathsf{(M)}} E \tag{7.6}$$

The enzyme H recognizes a substance F and binds with it, producing HF and further interactions E, such as effects in the body, a functional response, or byproducts.

While Pattee (1973) discusses the statistical (informational) properties of the fit between the binding site and the compound, by itself $H;F$ is just a chemical reaction. However, it is not independent: it affects and acts constrained by a larger process it is a part of. Per Pattee, $H;F$ takes place within

> a collection of element types that may combine or interact with each other individually in many ways, but that nevertheless persist as the same collection when looked at in detail over a long period of time. (p. 103)

Pattee, pp. 107–108 recalls that sets of such interactions come to persist through population dynamics, which select specific "internal, detailed dynamics," and rely on internal arbitrary representations. The enzyme interaction, in other words, is semiotic because it aids reproduction of "time-dependent, rate-control processes in populations of elements," by providing a microscopic degree of freedom.

To illustrate the relationship between the competence and the genome, extend the expression (7.4) into the life of the child organism (see figure 7.1):

$$\mathsf{a}; E \circlearrowleft_{\langle \mathsf{D} \rangle \langle \mathsf{L} \rangle} \left(H; F \circlearrowleft_{\langle \mathsf{D} \rangle (\mathsf{G})} \left(\mathsf{a}'; E' \circlearrowleft_{\langle \mathsf{D} \rangle \langle \mathsf{L} \rangle} \left(H'; F' \circlearrowleft_{\langle \mathsf{D} \rangle (\mathsf{G})} \ldots\right)\right)\right). \tag{7.7}$$

There are two semiotic cycles in this expression, two loci that are informative about each other by way of affecting each other's reproduction. A symbolic, semiotically closed cycle goes from allele a to a' and reproduces with the organism, informing the ontogeny of competence H every time. The other is semiotic as well (at least a simple sign), runs from competence H to H', mediated by the effect of its pragmatic use in environmental circumstances F on reproduction of a'.

Competence H is grown in anticipation of future interaction of a complex process with an environmental event F. It is semiotic because it is informative, if in a rudimentary way, about a specific interaction and its own future reproduction at the same time. We argued at some length in section 6.3 that the information about meeting the affordance is embodied, materially represented by the component providing the degree of freedom.

The intentional response to the affordance portrayed in expressions (7.5), (7.6) is straightforward, but there is no reason outright why an embodied representation would not be more elaborate. Symbols can be costly to represent in matter, but as reviewed in the previous chapter, sometimes they are favored to evolve. Genes, for example, are symbolic; can complex representations arise as a somatic or behavioral competences, and how?

Beach (2003) argues that indeed, more efficient somatic representations evolve during

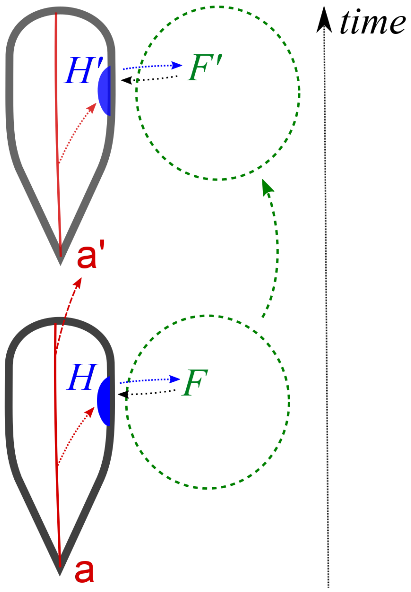


Figure 7.1: Semiotic relationships for a generic competence of an organism. Allele a informs competence H in anticipation of affordance F, aiding reproduction of a′ and future reappearance of interactions H'; F'. Discussion in the text along with expression (7.7).

evolutionary transitions in partial competition with genes. Also, a variety of animal behaviors have semiotic content (Maynard Smith and Harper 2003; Mayr 1974). The next section considers circumstances under which a versatile structured representation, employing syntax and symbols, can arise somatically and in their ecological and social interactions.

7.2 Matter and Text

Throughout the history of life, living beings have evolved a wide range of ways to represent and produce signs other than in their genes, as well as to combine their informational facilities by forming larger entities. Maynard Smith and Szathmáry (1995) analyze a number of such evolutionary transitions, and Beach (2003) argues that they take place as representational structures available to a population of organisms compete. The present account agrees; however, such representations usually need genes to reproduce and vice versa, so their relationship is not only competitive. Semiotic structures differ in what they can represent, and new ones take over as they can gather relevant information more efficiently, which points in favor of division of labor; Beach argues similarly.

This section proposes some features of representations other than genetic during evolutionary transitions, arising through semiotic closure of interactions with the environment in addition to the semiotic closure of the genome. The previous section has argued that somatic competences already are representational, anticipating a future interaction of a semiotically closed process they are a part of, and cyclical, as they indirectly affect their own recurrence. However, their semiotic structure as well as their physical realization can be very modest. For example, a stimulus-response mechanism such as the example of a membrane valve (section 6.4) works as a simple pre-semiotic state switch (section 5.2).

Organism competences, though, can become representational in more than this simple sense, evolving counterparts to syntax and symbols. While Beach (2003) analyzes fitness and metabolic considerations in major evolutionary transitions (Maynard Smith and Szathmáry 1995), the present focus is on how the representation manifests materially and over time, and what kind of syntax and symbols it may have evolved.

As with representation in autocatalytic sets discussed previously, the evolution of phenotypic semiotic structures requires semiotic closure. Any competence affecting reproduction also influences its recurrence, and so satisfies one criterion for closure. The other criteria, such as that the representation can inform a (nearly) arbitrary set of interactions, are not in general satisfied. What kind of a representational structure evolves that meets them, in whole or part, depends on the nature of affordances being met and the properties of the substrate.

To approach the transitions, recall from the previous chapter the three aspects of evolution of representation in semiotic closure: self-reinforcement, specialization, symbolic encoding. The latter are logically dependent on the prior, but all may be manifesting at any time. The dynamics are substrate neutral: originally considered for interactions of organic molecules, but applicable to interactions of any kind that achieve semiotic closure. Deacon (1997, pp. 84–88), for example, discusses similar representational changes in the studies of primates learning symbol use, moving from simple signs, one per referent; to symbolic terms, their relationships reflecting real-world relationships among referents.

Each of the three aspects also suggest broad observables as to whether and what kind of a representation is indeed evolving; more detail in chapter 6.

1. Versatile self-reinforcement. Processes such as autocatalysis that abet initiation of multiple instances of themselves, can incorporate a wide range of new interactions, as well as vary and reproduce the variation, initiate natural selection. To the extent they can reproduce faithfully, a population can over time become representational about past environmental interactions.

   Semiosis is favored to originate when self-reinforcing networks of interactions are also versatile, meeting a wide range of possible interactions within their context. Living beings already are self-reinforcing, so the ingredient more significant in the evolution of secondary semiotic structures is the *diversity and acceleration of possible interactions* in some relevant domain not readily selected for genetically.

2. Specialization, stabilization, autopoiesis. Living processes evolve specialized components, such as teleonomic (uncomprehendingly competent) features, regulatory feedbacks, and metabolism. Component processes can be seen as representational of their competences, and of how they communicate to maintain the whole. The living process forms individuals, if it can.

   Autopoiesis can manifest in two ways. First, to the outside the process forms boundaries, and we can discern *individuals*. Second, on the inside it differentiates, and we can at least in part infer the *function of specialized component processes*.

3. Symbolic encoding. A part of the living process evolves to specialize for representing and decoding information. Methods of representation are favored that are partly or entirely discrete, exhibit syntax, or employ symbols, which can in principle represent an arbitrary range of (capacities for) interaction.

   At this point we can identify parts of the process that function as symbols: discrete or partly separable entities that can, transcribed and translated by other interactions, represent and inform a wide range of the process's features and actions. We can expect to find *symbols at material bottlenecks in reproduction*, where they are favored to evolve.

There are many options where a phenotypic representation could reside. Recall the semiotics of adaptations (section 7.1) extended to the growth of the child organism, here shorn of parentheses:

$$\mathsf{a}; E \circlearrowleft_{\langle \mathsf{D} \rangle \langle \mathsf{L} \rangle} H; F \circlearrowleft_{\langle \mathsf{D} \rangle (\mathsf{G})} \mathsf{a}'; E' \circlearrowleft_{\langle \mathsf{D} \rangle \langle \mathsf{L} \rangle} H'; F' \circlearrowleft_{\langle \mathsf{D} \rangle (\mathsf{G})} \ldots \tag{7.8}$$

The statement is a shortcut for a long string of interactions, from genes to tissues and behaviors and back and again. It describes a semiocycle (section 6.5), a materially continuous cyclical process involving the genome and an environmental interaction, integrated into the wider living process. The two legs of semiotic closure are shown: genetic, from a to a', mediated through reproduction; and phenotypic (pragmatic), from H to H', mediated by the development of the child organism.

Secondary representation may appear at any point in this cycle, manifesting the above three aspects to differing degrees. It can appear at different distances from genes: developmental switches are in the genome, cognitive structures in the brain, letters patterns on the screen. In particular, a phenotypic semiotic structure not tied to genes would comprise a potential reproduction channel for additional evolutionary dynamics.

Most of the representations in evolutionary transitions are somatic, residing in the body *H*, and so still materially tied to genes, as the signs or a proclivity to form them needs to be rebuilt every time during organism life time. The parts of the cycle most remote from genes are outside the body, the environment *E* where the organism develops and affordances *F* it addresses. Living beings indeed pass information to others through the environment, by active signaling (Maynard Smith and Harper 2003) or by modifying their environments (Odling-Smee et al. 2003).

In the next chapter, the three aspects are considered for major evolutionary transitions (Maynard Smith and Szathmáry 1995). For each new semiotic structure, or mode, we discuss the variety of affordances it meets, whether it forms components and entities, whether and how it is encoded. We also look at the materials and events that represent the signs, and the periods over which they are interpreted and have effect. Finally, we evaluate whether and how the semiotic structure can support evolutionary dynamics in addition to genetic.

The following section anticipates the conclusion of this discussion, that there is likely an additional, sociocultural evolutionary process, communicating via both active signals and environments, mediated through persons and activities. A heuristic argument follows as to why it is reasonable to expect this is so, and implications are discussed for the gap between "standard" and evolutionary social research.

7.3 Persons in Activities

The expression "socially constructed" is a root of much anguish, often wielded as a bludgeon by its proponents and a target of gratuitous dismissals by its critics. I will argue, broadly in this section and in more detail later on, that the term expresses the fact that culture underlies a semiotically closed evolutionary process, symbolically reproduced by humans in social activities, that writes its text both in our bodies and in our living environments.

It is not necessary to know precisely how information is represented and reproduced to infer that evolution may be taking place in a domain of interest. By analyzing patterns in observable differences over time, we can say that information of some kind persists between occasions and infer much about it. Indeed, Darwin and Wallace both first characterized organic evolution almost a century before the discovery of DNA as the information carrier. They did so by reasoning from observed similarities in gross morphology between parents and offspring, both in the wild and in the experience of animal breeders.

Suppose we did not know much about human societies, and wanted to start formulating possible theories on the basis of what we can observe directly, with some advice from evolutionary biology and the preceding discussions. We would likely note the immense diversity in what people do; no single species on Earth engages in such a wide range of behaviors. This is the first hint that evolutionary explanation may be applicable, as it is the most general natural scientific framework we have to explain the origin of variety in some phenomenal realm. The second hint is that we use symbols, which, as argued in the previous chapter, are closely associated with evolving processes.

If we were then to tally the *prima facie* patterns in human action, we would notice two main regularities. First, by person: any one person engages in a range of actions she or he is likely to reenact, if never exactly; a randomly selected other person would likely reproduce a different range of actions. Second, by activity: similar people do similar things in similar places at similar times. We would find out considerably subtler patterns once we delved deeper, but these two are the most apparent.

Moreover, extending the time frame, we would recognize two circumstantial pieces of evidence for evolutionary processes, paralleling ontogeny and evolutionary history in Tinbergen (1963). First, history: if we track similar cultural behaviors over many people and longer time periods, we can see that they change in complex ways, which we convey in narratives. Second, ontogeny: what humans do is learned, how a person acts today is related to and took shape over activities one took part in earlier, possibly over a long time. This also identifies the activities as a channel of reproduction.

From this, we would be justified in making the educated guess that evolutionary explanation is a candidate approach to making sense of human societies. We do not know much of the details of the process, seeing that they depend on the details of reproduction (Cavalli-Sforza and Feldman 1981, pp. 346–357). We do know that social interaction is a reproduction channel, and that the four explanatory stances by Tinbergen (1963) would be salient to explaining any evolving phenomena so they can be a fruitful initial approach.

On this basis, we can take *socially constructed* to denote any phenomenon about which we can ask the four questions and expect an informative answer in terms of human social activity. In particular,

1. ⟨A⟩ctivity: one person, immediate social and biological causes. How come X is doing this right now? What does X experience and mean to do? How does S, a social phenomenon we are trying to account for, manifest?
2. ⟨L⟩earning: one person, learning over lifetime. How come X came to learn this? How is S learned and by whom?
3. ⟨H⟩istory: interaction over a number of lifetimes. How did X's social context come to include this? How did S come to be?
4. ⟨D⟩ialectics: interaction and influence in a social activity, times from immediate to lifetime; social power. What is X responding to and what does s/he aim to accomplish? What social or cultural reason are people doing S for? What shapes S at any moment?

These questions, of course, are nothing new, in fact they pervade the so-called standard model of social sciences. The questions are often explicitly anticipated, for example by Mills (2000, pp. 6–7) at the very beginning of his well known discussion of sociological imagination poses three questions we can ask about societies and their features. The first of Mills' questions is $\langle \mathsf{D} \rangle$, the second is $\langle \mathsf{H} \rangle$, and the third combines $\langle \mathsf{A} \rangle$ and $\langle \mathsf{L} \rangle$. The questions may be obvious, which may also make them important. By the present argument, much work in "standard" social sciences is already pursuing, qualitatively, explanations corresponding to Tinbergen (1963).

If this picture of sociocultural evolution is true, it offers an alternative framework to the current work on the topic (e.g. Smith 2013), a point of comparison and evaluation. For instance, models such as biased transmission in dual inheritance theory (Boyd and Richerson 1985), while based on population genetics, crucially differ in how closely they can approximate the dynamics. The biases due to success, prestige, majority influence, and so on, are not direct quantitative skews on our learning of new cultural traits, but mediated by attributes of human activities. The dynamics suggested by the models apply to the extent these influences are reflected in the details of the sociocultural reproduction channel, symbolic interaction. Population genetics models very closely reflect details of information transmission such as ploidy and zygosity; in society we generally know far less. Although this essay does not offer an alternative formal model of sociocultural evolution, it does discuss general features such a model may have and how they reflect current research (chapter 9).

Next, I offer a more detailed argument as to why human symbolic interaction is a plausible basis for an evolution-like process. This requires tracing the origin of representations other than genetic through the history of life, informed by Maynard Smith and Szathmáry (1995); Beach (2003).

> the first fact to be established for the study of history is the corporeal organization of human beings and their consequent relation to the rest of nature. (Marx and Engels 1975, as quoted in Fracchia 2017)

Maynard Smith and Szathmáry (1995) analyze a sequence of transitions in evolutionary history, from the origin of life to that of complex societies. The changes they track involve an elaboration of ways living beings handle information (p. 6). Indeed, the idea for their book came when the two realized they were researching similar issues in widely different areas of biology, both concerning information.

This section briefly reviews evolutionary transitions, tracking in more detail the dynamics of intentional representation in each. The aim is to show there is a continuity of semiotic processes from the first living beings to human societies and cultures, and establish intermediates between DNA-informed ontogeny, where a symbolic representation is contained deeply within an organism and expressed in physical form over a life, to human symbolic interaction, where symbols are performed, in principle available to all participants, and often refer to their own use.

The resulting picture portrays a sequence of changes, each building on the previous and exhibiting several overall trends, such as shortening of time of symbolic production and expression. However, no one transition happens necessarily; each is contingent on the existing material conditions and affordances, and has likely evolved only after many false starts. At any point in history all intentional dynamics that have evolved up to that point exist alongside each other. Thus the language of progression through stages associated with orthogenetic evolutionary theories is misleading. I will call the kinds of semiotics that appear with each transition *intentional* or *semiotic modes*.

Transition	**Info Elaboration**	**Environment**	**`Syntax` and Text**	**Sources**
Physics and Chemistry	Reliable interactions, channels described by us. Small: uncertainty. Many: thermodynamics. Chapter 4	Basic physics. Time: interactions and entropy.	Proto-discrete: quantum states, particles, elements, molecules	Deacon (2012, ch. 7).
Cycling	Recycling, periodic, self-reinforcing dynamics. Choice of paths, memory. Chapter 5	Natural cycles, e.g. planetary and weather. Energy gradients. Geysers, nuclear reactors, stars.	Self-reference to future recurrence. Clocks, hysteresis.	Deacon (2012, ch. 8); Dennett (2017); Lewontin (2000); King (1982).
Organic Life	Natural selection. Semiotic closure, intention, symbols. Autopoiesis, reproduction. ⧖ Selective choice, lifetime, molecular. Memory. Chapter 6	Quasi-species, bundles of similar life strategies, collectively supracritical. Biochemistry, metabolism.	Genetic code. Channel: DNA, RNA replication, delegation to enzymes.	Maynard Smith and Szathmáry (1995, ch. 2–7), also Kauffman (1993) and Eigen (1992), teleonomy Mayr (1974), design and intentional stance Dennett (1989), representation Pattee (1969).
Eukaryotes	Symbiosis by predation or self-reinforcement of byproducts. Info spec. between symbionts evolving to cell parts.	Morphological variation.	Linear chromosomes. Channel: nuclear DNA replication	Maynard Smith and Szathmáry (1995, ch. 8); Lane (2015, ch. 5)
Sexual Species	Population genetics. DNA refers to alleles in a pool of beings with similar ⧖ lives, and to how to ⧖ act to exchange them. ⧖ Evol choice: speciation, greater info capacity.	Species: populations of life strategies variable over common themes. ⧖ Behavior: mate, intention to DNA exchange with other.	Recombination. Channel: e.g. diploid DNA, fertilization of haploid gametes of two organisms.	Maynard Smith and Szathmáry (1995, ch. 9).

Table 8.1: Transitions in matter and text, part 1: From Physics to Sex and Species.

Transition	**Info Elaboration**	**Environment**	**`Syntax` and Text**	**Sources**
Multicellular Bodies	Germ and soma, tissues, body plans. Intention in one part of DNA to affect specialized cell function of another. Evo-devo.	⧖ Multiple. Seasons and weather, feeding and breeding, growth, perception, movement.	Developmental switches. Channel: germ line DNA	Maynard Smith and Szathmáry (1995, ch. 12–15).
Ecological Interactions, Cognition	⧖ Ecol. cycles: young or fodder. Niche constru. ⧖ Repeated behaviors: predation, mutualism. ⧖ Action choices: situational awareness	Material exchanges. ⧖ Seasonal patches, subgroups, communities. ⧖ Situation: diverse intentional affordances.	Representation in situations, cognition; of development, DNA; in ecology, via various cues.	Ecology: Drury (1998); Allhoff et al. (2015). Cognition: Multiple drafts, how's it like to be a bat, Popperian creatures, "best avenue of escape" (Dennett 1991, 2017).
Animal Social Groups	Intention to repeated interactions, self in relationships with conspecifics. Social learning. Mirroring.	Kin selection, social hierarchies. Theory of mind, empathy. Self and fellows as choice.	Proto-channel: social learning. Baldwin effect, signals, animal traditions.	Maynard Smith and Szathmáry (1995, ch. 16); Maynard Smith and Harper (2003); Galef (2009)
Culture	Shared intention. Symbolic interaction, sociocultural evolution. Hardware: crooked timber. Chapter 9	Social activity. Speech. Cultural group. Relations: family, forage, trade. Ethnoecology, technology. Built environment. Skills, values, norms.	Language, other signs. Channel: social learning; person and activity. Text in roles, crafts, norms, stories.	Shared intentions Tomasello et al. (2005); Moll and Tomasello (2007), cumul. culture Boyd and Richerson (1996), social nets Hill et al. (2011) distributed cog. Hutchins (2004), norms Hill (2009)
Society	Intention to action informed by shared text. Network-domains, inscription, subject making. Specialization for symbolic production.	Self-reinforcing cycles of relations. Work, power, flows, infrastructure. Learned shared action. Communities of practice.	Channel: sociocultural evolution; constructed media and codes.	Dennett (1991) multiple drafts extended to societies. Semiotics, identity and control, actor networks, social fields, biopower, institutions, human ecology.

Table 8.2: Transitions in matter and text, part 2: From Soma to Societies.

After each evolutionary transition, there are living beings and processes that exhibit the newest intentional mode. Further intentional modes evolve as organisms adapt to this environment, and their own internal representations come to inform interactions with similarly shaped living processes. In this way, phenomena in the newest mode become affordances to be referred to. If mutual intentional affordances are beneficial, originally independent living beings become a part of larger entities such as multicellular organisms, or of broader sets of relationships such as animal societies (Maynard Smith and Szathmáry 1995, p. 9).

Maynard Smith and Szathmáry (1995, p. 10–14) discuss the kinds of evolutionary changes that lead to the major transitions: increases in genetic complexity, division of labor, emergence of new languages. From the semiotic perspective, we can pare down the major mechanisms of intentional elaboration in each transition to two:

- *Mutual reinforcement*: intention to interact in partly cooperative ways with intentional processes shaped by different representations.
- *Self-reference*: intention to interact with the same or a similar representation directly.

The transitions associated with eukaryotes and sexual reproduction, respectively, can serve as paradigmatic examples of these two mechanisms (figure 8.1). In many cases, such as the origin of multicellular organisms, the two mechanisms operate at the same time.

The major transitions are listed in Maynard Smith and Szathmáry (1995, table 1.2, p. 6); for brevity, only those from genetic code onward are here considered. The main ones, along with the preceding semiotic modes associated with physics and simple cycles (chapter 5), are outlined in tables 8.1 and 8.2, and their semiotic features illustrated in the figures accompanying this chapter. The information in these tables and the ensuing discussion are partly speculative.

The transitions are reviewed with respect to the following main points:

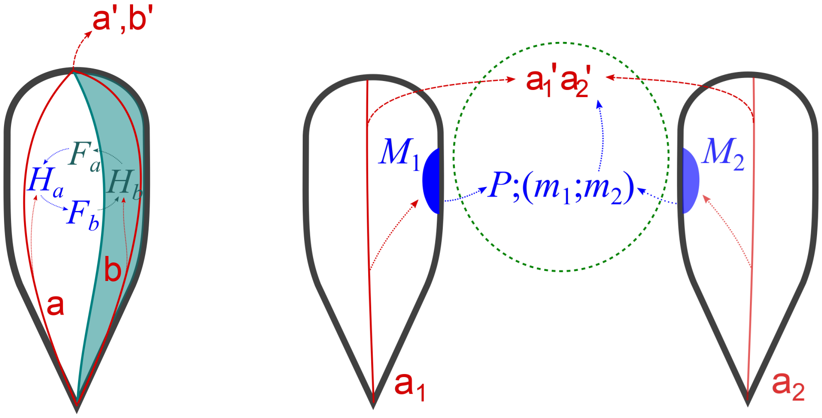


Figure 8.1: Semiotic relationships in eukaryotes and sexual reproduction.

In eukaryotes (left), two formerly independent living beings, one marked in teal, have evolved to form one by providing mutual affordances. Their genomes a and b reproduce together, though still partly independent.

In sexual reproduction (right), alleles $\mathsf{a}_{1,2}$ inform capacities for mating $M_{1,2}$, which refer to the breeding population P and the interaction $(m_1;m_2)$, mating, performed with another organism. The common action anticipates and precipitates recombination of genes a_1 and a_2 and reproduction. Indirectly, an organism's genes refer to a population of similar ones. Exchange of information through gene flow creates and maintains wider formations, breeding populations and species.

- *Mechanism.* Which of the above two mechanisms of elaboration likely underlies the evolutionary transition.
- *Syntax and code.* The new ways of representation, if any, that evolve.
- *Channel.* How the new representations are reproduced.
- *Expression.* The nature of the processes the representations refer to: how long they take, how they manifest, e.g. in the organism, in behavior, in symbol production.

We consider the semiotics of some of the modes in more detail. The starting point are teleonomic (evolved adaptive) relationships from the previous chapter (figures 7.1; 8.2, left):

$$\mathsf{a}; E \circlearrowleft_{\langle \mathsf{D} \rangle \langle \mathsf{L} \rangle\,\mathrm{grow}} H; F \circlearrowleft_{\langle \mathsf{D} \rangle (\mathsf{G})\,\mathrm{use}} \mathsf{a}'; E' \ldots \tag{8.1}$$

$$\text{or just} \qquad \mathsf{a}; E \circlearrowleft_{\langle \mathsf{L} \rangle\,\mathrm{grow}} H; F$$

Genetic message (allele) a informs ontogeny of competence H addressing the environmental affordance F so as to help reproduction a', and so on (more detail in section 7.1).

In the notation, tags $\langle \mathsf{L} \rangle$ife time, (G)rowth (lifetime or shorter), and $\langle \mathsf{A} \rangle$ction indicate ⧖ time periods of the relationships. To simplify, we can drop the reference to the next generation as well as $\langle \mathsf{D} \rangle$ indicating teleonomy, which can be assumed.

Living Cells As discussed in chapter 6, living beings come into being through persistent mutual reinforcement of chemical processes. The code is genetic, represented in the DNA, and it reproduces as DNA replicates. It is expressed over the cell's lifetime, in building the cell and its specialized capacities. Enzyme action is a basic example of short term intentional action (section 7.1).

Prokaryotes, bacteria and archaea, have thoroughly explored the biochemical and metabolic pathways available to single cells. Compared to them, eukaryotes are chemically less versatile, while they vary greatly in their form (Lane 2015, ch. 5).

Eukaryotes Eukaryotic cells arose via mutualism (figure 8.1, left), with endosymbiosis (one organism becoming a part of another) of two or more prokaryotes, likely a bacterium and an archaeon. Symbionts have evolved into organelles, mitochondria and chloroplasts, that have mostly relinquished genetic information to the nucleus, although they keep limited DNA sequences (Maynard Smith and Szathmáry 1995, ch. 8). Nuclear DNA consists of multiple linear chromosomes, which can divide in parallel and hold more information; most prokaryotes are limited by a single circular chromosome, copied sequentially. Nuclear and organelle genomes are reproduced in cell division, and expressed over the cell's lifetime, as above.

Sexual Species Sexual reproduction involves a direct shuffling of similar messages (figure 8.1, right). There are no new codes, and to the extent there is new syntax, it is in the mechanisms for recombination. Once recombined, the code is reproduced as above, in division of the fertilized cell, and expressed in growing the organism and its capacities. One of the capacities is mating, intentional behavior toward organisms assumed to hold similar DNA messages. As a result, in addition to the interactions of a single organism, the DNA indirectly refers to its instances in the entire interbreeding population.

Multicellular Bodies The origin of multicellularity can be seen as combining the two above mechanisms, of versatile specialized capacities of tissues achieved in part because the same genetic message gets copied to all somatic cells (figure 8.2, right). Nuclear DNA reproduces in all tissues of the body, where different parts of it turn on or off depending on local conditions in the organism and its surroundings. There is a new code, developmental switches, which still resides and is reproduced in cellular DNA. According to Maynard Smith and Szathmáry (1995), epigenetic inheritance of tissue cells allows for unlimited heredity, or arbitrary representation. Regulatory switches are expressed over developmental and shorter times, reacting to environmental changes as well as current interactions, by affecting the portions of nuclear DNA that are active in each cell. There are limited cases in which environmental changes affect DNA transcription directly, such as gene editing in cephalopods (Liscovitch-Brauer et al. 2017).

Developmental switches are a secondary representation that is reproduced in genes, but acts over shorter periods, affecting organism growth. The start of a life cycle may be tied to the change of daylight or weather, for example. A simple way to represent this is

$$\mathsf{a}; E \circlearrowleft_{\langle \mathsf{L} \rangle\,\text{copy}} \mathsf{d}; F_d \circlearrowleft_{(\mathsf{G})\,\text{grow}} H; F_h \tag{8.2}$$

Genetic message a informs organism growth and passes the developmental switch d into all cells. At some later point, the switch is activated in response to the environmental affordance F_d, informing growth of tissues H, in expectation of further specific interactions F_h. As Beach (2003) argued, there are two kinds of encodings, each more efficient for a domain of phenomena.

The secondary encoding d is partially in semiotic closure: it is translated into in principle arbitrary actions, informing the growth of tissues and organs, which ultimately help its reproduction. However, developmental switches do not code for their immediate translation and reproduction. While an informationally distinct from other parts of the genome, they depend on the same molecular machinery and reproduction channels.

Ecological communities, especially ones that comprise living beings with multicellular bodies, include a wide range of potential points of view (figure 8.3). Environments are interactive, with living beings reacting to an assortment of both living and non-living affordances over a diversity of spatial and temporal scopes. As Stephens et al. (2007, p. 31) put it,

> A rufous hummingbird perches on a prominent branch and surveys a flower-covered slope. Most of the time, it waits and watches. Occasionally, it flies off its perch to probe the hanging flowers of scarlet gilia within its territory. Scarlet gilia is a classic hummingbird flower. An inflorescence consists of six to twenty flowers, each of which is a long scarlet tube with a pool of nectar at the base.

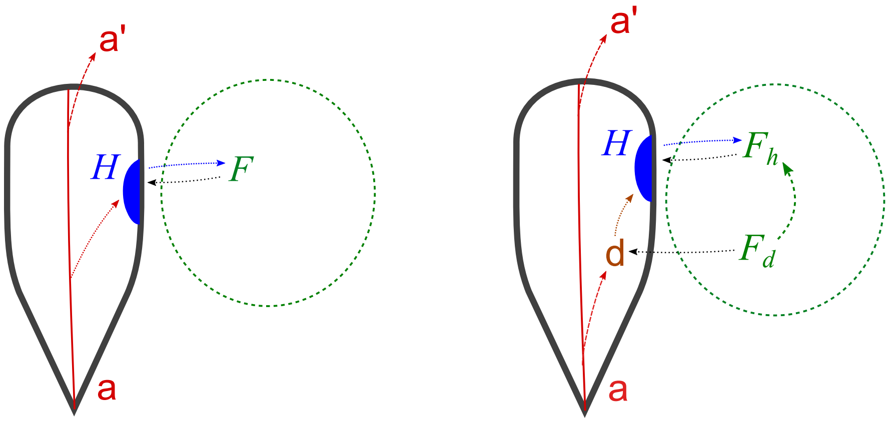


Figure 8.2: Semiotic relationships in simple teleonomy and multicellular development compared. See discussion accompanying expressions (8.1) and (8.2).

In the general case (left), allele a informs a teleonomic competence H anticipating affordance F. The information about how H is formed is in the details of the growth process.

In multicellular development (right), developmental switches d are copied into all cells. They anticipate bodily growth stages and environmental affordances F_d, such as chemical and temperature gradients, to time the growth of H anticipating F_h later in a similar environment.

> Each inflorescence makes up a clearly defined patch in the sense of classic foraging theory—even more so than most patches because it consists of discrete, visitable entities; i.e., flowers. ... Inflorescences vary: some consist of mostly empty flowers, while others have mostly full flowers. Our hummingbird's own behavior partially creates this pattern, but some other actors are involved as well. Robber bees move methodically from one flower to the next, making neat incisions in the corolla that allow their short tongues access to the nectar. (p. 31)

Approximately by the length of time over which an affordance is available, we can distinguish between ecological interactions, involving continuous exchanges of materials or sequences of similar behaviors over longer times, and behavioral ones, necessitating short-term choices.

Ecological Interspecies Interactions There are multiple opportunities for interaction between species, such as feeding, predation, parasitism, and mutualism, combining into complex and often stable webs of relationships (Allhoff et al. 2015). The bulk of information about how to engage in these interactions is still encoded and reproduces with DNA. However, there is a possibility for rudimentary information storage in the environment, via niche construction (Odling-Smee et al. 2003). The stability of food webs and the ubiquity of ecological patches with similar combinations of species may be evidence of mutual reinforcement among regular material interchanges between species, and of incipient semiosis in a medium that cannot easily establish boundaries (section 7.2).

Complex Behavior Choices Given a complex environment, a single organism, especially a heterotroph with motor skills (i.e. an animal) may need to evaluate any of a multitude of momentary options. Any syntactic structure within our cognitive processes would evolve to aid in sorting out these options, interpreting rich sensory information and responding with complex bodily movements. Cognitive representations affect behavior in particular situations over short time scales. Information about what to in an environment can be learned by the organism during its lifetime.

Individual animal cognition as a teleonomic competence could be stylized as:

$$\mathsf{a}; E \circlearrowleft_{\langle \mathsf{L} \rangle\,\mathrm{grow}} K; A \circlearrowleft_{(\mathsf{G})\,\mathrm{expect}} \left(\mathsf{k}; F_k \circlearrowleft_{\langle \mathsf{A} \rangle\,\mathrm{act}} A; a_k\right) \tag{8.3}$$

Genetic text a informs the development of cognitive capacity K for use in situations (activities) A. Environmental events F_k are anticipated by the internal representation k, which guides the response action a_k with respect to the current activity. The representation k can be of any complexity as long as it possesses some recollection of previous interactions. On Dennett's (2017) account these can be both Skinnerian creatures, remembering trial and

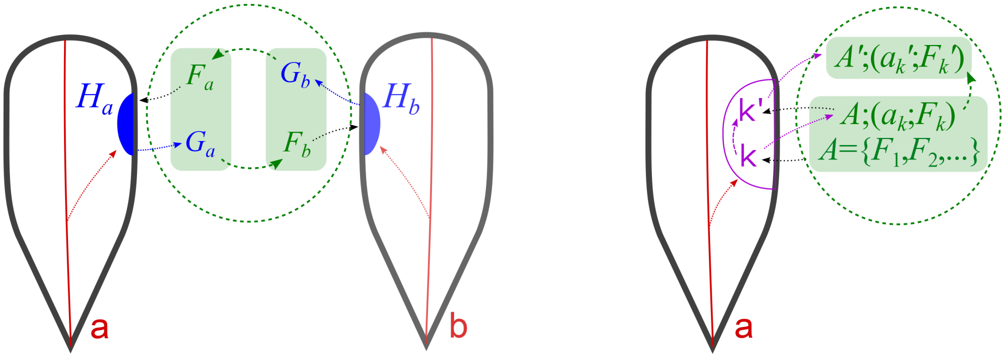


Figure 8.3: Semiotic relationships in interspecies interactions and cognition.

In ecological interactions between organisms (left), both between and within species, byproducts of one G_a influence the affordances of the other F_b and vice versa. The interaction shown is the most indirect possible, of mutual shaping of niches in an ecological community. It suggests, however, that the environment can potentially carry information between organisms (Odling-Smee et al. 2003).

With cognition (right), an organism represents a multitude of potential affordances in the immediate environment (activity) A, meets affordance F_k with action a_k, and adjusts its internal representation. In this way, organisms carry information between environments. See expressions (8.3), (8.4), and accompanying discussion.

error outcomes; and Popperian ones, modeling scenarios.

Individual learning in a single interaction can be shown thus:

$$H;\mathtt{k} \circlearrowleft_{\langle \mathsf{A} \rangle\,\text{act}} A;(a_k;F_k) \circlearrowleft_{\langle \mathsf{A} \rangle\,\text{learn}} H';\mathtt{k}' \tag{8.4}$$

The living being represents previous interactions from its lifetime, and learns through new ones. Cognitive content $\mathtt{k}$ is a representation that has a chance to get updated every time it is used; unlike genes, it does not need to wait for population dynamics. The ⧖ time period of both expressing the content and of updating it can be as short as a single $\langle \mathsf{A} \rangle$ behavior. However, the representation is tied to an individual organism, and cannot outlast it.

Social Groups Animals evolve to live in groups, spending their lives in each other's company (figure 8.4, left). Genes of social animals in effect refer to sharing one's lifetime with lifetimes informed by similar sets of genes. While sexually reproducing organisms anticipate an interaction with similar beings, mating, that can occur relatively rarely, social animals anticipate many diverse interactions with conspecifics. New cognitive capacities evolve relating to social cognition, such as theory of mind. Social learning is a new channel of information exchange within the group that facilitates adopting others' behaviors, and can give rise to animal traditions.

$$\mathsf{a}_1; E \circlearrowleft_{\langle \mathsf{L} \rangle\,\text{grow}} S_1; A \circlearrowleft_{(\mathsf{G})\,\text{expect}} \big[(H_1, \mathsf{s}_1); (H_2; \mathsf{s}_2) \circlearrowleft_{\langle \mathsf{A} \rangle\,\text{act}} A; (H_1; a_1); (H_2; a_2)\big] \tag{8.5}$$

Social cognitive capacity S_1 in the organism H_1 maintains the representation s_1 in anticipation of interaction with H_2 in the activity A. The content represented can include both organisms, potentially as well the other participants' representations s_2, inferred through theory of mind.

$$\left.\begin{array}{l} H_1; \mathsf{s}_1 \circlearrowleft_{\text{act}\,1} \\ H_2; \mathsf{s}_2 \circlearrowleft_{\text{act}\,2} \end{array}\right\} A; (H_1; a_1); (H_2; a_2) \left\{\begin{array}{l} \circlearrowleft_{\text{learn}\,1} H_1'; \mathsf{s}_1' \\ \circlearrowleft_{\text{learn}\,2} H_2'; \mathsf{s}_2' \end{array}\right. \tag{8.6}$$

A single interaction demonstrates that content can be learned from conspecifics. The social cognitive representations s_1 and s_2, whichever form they take, influence one another. They can reproduce from one organism to the other, although in non-human animals they cannot refer to arbitrary interactions, and what is learned does not persist faithfully enough (Boyd and Richerson 1996).

Cultures and Societies A fundamental ability humans use to interact is that to form shared intentions (figure 8.4, right): two or more people can direct their attention and actions toward arbitrary commonly recognized objects or goals (Tomasello et al. 2005; Moll and Tomasello 2007). This capacity is symbolic, as the association between actions and goals can in principle be any.

Common characteristics of the evolution of such abilities (section 7.2) direct us to look for an increase in number and speed of interactions in a domain that cannot easily affect the genome. Great apes can already learn many behaviors socially, forming group traditions (Whiten 2000), which represents the domain. On top of this, recent research suggests several ways these interactions could have intensified and diversified: a rapidly changing climate in the Pleistocene (Richerson and Boyd 2000), wide ranging exchange networks (Hill et al. 2011), or, more speculatively, cooking (Wrangham 2009). The reproduction bottleneck is the interaction itself, which is where we expect symbols may evolve; and language did.

This is an innovation. Human culture is not the first time an arbitrary representation evolved after the the genetic code: as noted, developmental switches that regulate the growth of multicellular bodies allow for it. Switches, however, reside in the DNA and depend on the genetic channel to reproduce. On the other hand, the crucial part of sociocultural reproduction, human symbolic interaction, takes place in public. This is the first case a new self-reinforcing process has become supracritical, giving rise to an arbitrary symbolic representation, on a channel of reproduction other than genetic.

With both a symbolic capacity and another reproduction channel other than genetic, a new, sociocultural evolutionary process comes into being. Its structure is very unlike organic evolution: cultural information is expressed, reproduced, and shaped at the same time, in symbolic interaction in social activities. In fact, our symbolic acts often represent and anticipate themselves.

$$\left.\begin{array}{r} H_1; \mathsf{s}_1 \circlearrowleft_{\text{enact 1}} \\ H_2; \mathsf{s}_2 \circlearrowleft_{\text{enact 2}} \end{array}\right\} (A; \mathsf{P}); (H_1; a_1; \mathsf{p}_1); (H_2; a_2; \mathsf{p}_2) \left\{\begin{array}{l} \circlearrowleft_{\text{interpret 1}} H_1'; \mathsf{s}_1' \\ \circlearrowleft_{\text{interpret 2}} H_2'; \mathsf{s}_2' \end{array}\right. \tag{8.7}$$

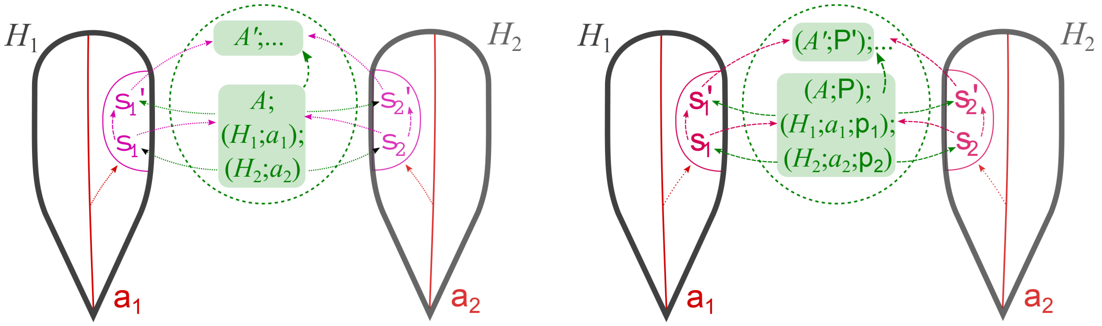


Figure 8.4: Semiotic relationships in social animals and humans (8.5, 8.6, 8.7).

In animal social interactions (left), conspecifics $H_{1,2}$ engage in a common activity A and perform actions $a_{1,2}$. The participants represent each other and their actions as intentional. Their cognitive representations $\mathsf{s}_{1,2}$ change based on common activity, and organisms can later reproduce learned actions with others, giving rise to animal traditions. In most social animals interactions are simpler than in the diagram, and learning takes place gradually, extending over many interactions.

In human symbolic interaction (right), social learning takes place within activities, inscribed with cultural text P relatively to their participants. Their actions are informed by internal (partly) symbolic representations $\mathsf{s}_{1,2}$ and publicly perform symbolic messages $\mathsf{p}_{1,2}$. Persons and activities together carry the information reproduced during interactions.

The core difference from animal social interactions is that human are at least partly symbolic in all of their components. Our embodied representations $\mathsf{s}_{1,2}$ employ symbols (marked by the slight change in font), our actions $a_{1,2}$ perform symbols $\mathsf{p}_{1,2}$, our activities A contain inscribed symbols P for people to interpret.

Overall, during evolutionary transitions semiosis in living beings speeds up and becomes more elaborate in several respects:

- The period one living being or the population needs to encode a preferred choice of response to an affordance shortens. At the very start of life this took place in populations over evolutionary time, relying on stochastic search. Baldwin effect, thanks to which the chance of a group of organisms to learn a new behavior increases if one of them learns it, the effect still requires a population but the learning is done by individuals over shorter periods (Dennett 1995, pp. 77–80). Other animals such as primates and dolphins learn over shorter periods, maintaining group traditions (Galef 2009).

- The actions the new representations refer to shorten. Genes are expressed over lifetimes, developmental switches over growth periods, cognitive representations in behaviors.
- The semiotic content used to represent actions becomes more elaborate. In section 7.1 we noted that teleonomic behaviors are semiotic in virtue of contributing to the reproduction of the whole, but that their informational structure is in general as simple as a stimulus-response mechanism. With cognition, our actions are represented in some structured way; while our cultural practices are both represented by and manifest symbols.

These sequences meet in human interaction and our capacity for arbitrary symbolizing, and possible sociocultural evolutionary dynamics. In the next section we turn to discus what kinds of phenomena arise on this basis.

CHAPTER 9 CROOKED TIMBER

The origin of culture can be tentatively explained as the first complete realization of the three aspects of semiotic closure (self-reinforcement, specialization, symbolic encoding) in a new phenomenal domain, human social practices, on a reproduction channel dependent on but separate from genetic, social learning combined with niche construction. The previous chapter has suggested one way this could have happened: primate social learning became faster and more versatile, so that symbolic representation was favored to evolve, in our capacity to establish and act on arbitrary shared intentions (Moll and Tomasello 2007) and eventually in language (Deacon 1997).

Theories of sociocultural evolution are a third rail in social sciences for some good reasons, one of which includes their use in political projects that suggest certain social outcomes are inexorable and predetermined, such as domination of a "less evolved" social group by another. In the present essay, stating that evolutionary reasoning can be applied to society amounts to claiming (a) there is a process of sociocultural reproduction through symbolic interaction that (b) gives rise to a very wide variety of representations, practices, and phenomena, which (c) are socially learned and enacted, (d) at least partly rely on symbolic representation to persist, and (e) exhibit possibly diffuse wider intentional properties. This is in line with "standard" social science claims, and indeed anticipates critiques of sociocultural evolution such as by Fracchia and Lewontin (1999); Ingold (2007), as will be discussed toward the end of this chapter.

To approach explanation on this basis, section 7.3 suggested to ask the four questions, and now expect answers that involve human symbolic interaction. This then amount to the study of, in order, social activities; learning; history; and dialectics, understood as mutual shaping of our symbolic actions.

9.1 Closures

Asking Tinbergen's (1963) four questions about a social phenomenon requires that we select one of interest. In this we face a task that is particularly difficult in society, that of drawing explanatory boundaries and choosing categories. What is a city, a town, a village? As discussed in section 5.3, categories typically cannot be expected to be exact and are based on some range of shared affordances, such as what one can usually do in a city. Yet this says little; social science terms central to public discourse have no settled meaning precisely because disagreement on the common attributes they reflect. What is fascism? Are fascists people who adhere to certain shared attitudes (Eco 1995), members of a definite range of movements in interwar Europe, or is it "a rather imprecise but nonetheless justifiable term of abuse" (Mann 2004, p. x), pending elaboration?

A closely related issue is articulated by Rosenberg (2016, p. 22), that of choosing natural kinds. For example, if by "fish" we mean just any aquatic animal, we will be including many species with incongruous attributes and inquiries into fish will be impeded. If, instead, we choose scaly aquatic vertebrates, we are closer to carving the subject at the joints. Rosenberg continues to restrict natural kinds to those about which "there are laws," contrasting for instance fake gold with gold, whose properties we can examine and describe with much more precision. The present essay does not assign a special role to lawlike relationships (section 5.1 and elsewhere), but the criterion can be relaxed along the lines suggested in section 2.1: the categories we need to seek are those more informative, about which we can meaningfully ask more questions. The question is, then, what do the analyses earlier in this essay propose about common characteristics of wider dynamics and entities in society and culture?

Rosenberg's (2016, p. 22) example with fish is salient, as it points to why we can tell more about one category than another when studying living creatures. Fish have common characteristics not because they are aquatic vertebrates with scales, but ones that can be traced to a common progenitor and have no land dwelling ancestors. The category chosen is both materially and informationally connected; the excluded vertebrate species are those that (had) significantly modified the fish body plan to meet the exigencies of life on land. Informational and material continuity discerns smaller biological entities too, if trivially. In a work arguing that phenotype stretches far beyond a body, Dawkins (1999, p. 258–259) points out that "[a]n organism is a physical unit associated with one single life cycle," "the unit which is initiated by a new act of reproduction via a single-celled developmental 'bottleneck'."

Seeking entities would thus involve identifying an "act of reproduction" at an informational bottleneck, standing at the beginning of a physical expression. The tactic does not transfer easily from biology to society and culture, as the primary phenomena we are trying to categorize are sociocultural performances: disjointed, interspersed in space and time, accessible only when in progress. The reproduction channel are social activities which are physical media, but the information is not encoded and copied materially. Instead, it is performed, carried between people, interpreted, and reinscribed, to be performed again.

Because of this, the meaning of reproduction is ambiguous. It may refer to one person repeating a practice they knew before, or to another person learning, or to someone performing a new practice for the first time. For embodied sociocultural information, reproduction strictly speaking takes place in the act of learning, while repeating a performance can be referred to as reenactment. A performance, however, is typically necessary for learning to take place, and constitutes reproduction of outward symbolic content. Thus the accepted meaning of reproduction in social sciences can be adopted, subsuming all three senses (e.g. as in Bourdieu 1977).

Recall, now, that we take an arrangement of matter to be symbolic when it achieves semiotic closure (Pattee 1969; Rocha 2001). In addition, as discussed in section 6.4, semiotic closure can favor evolution of entities or dynamics approaching them, as mutually reinforcing interaction sets evolve to become more individualized. Dawkins's (1999, p. 258–259 and above) characterization of organisms as life processes starting from the informational bottleneck of reproduction, in fact, amounts to defining them as semiotically closed. Thus, while underlying processes in society and culture are vastly different, looking for semiotic closure of sociocultural information can point to dynamics approaching entities. This is, on the view presented in this essay, the closest analogue in society to the criterion that a category be materially and informationally connected.

Reviewing from section 6.1, a piece of matter is considered semiotically closed when: it is specialized, meaning that its interactions are limited; these can be seen as semiotic, such as transcription and translation, because they manipulate the message to initiate further actions; these in turn include the semiotic actions themselves as well as the capacity to reproduce the message (section 6.1). The criteria do not apply easily to embodied sociocultural text. We cannot say how the messages are represented materially, so we cannot easily tell whether their immediate interactions are limited and semiotic. However, if we do assume that the text indeed is (partly) symbolic, we can take as given that there are corporeal processes that represent, interpret, and enact it. To demonstrate semiotic closure, it remains to identify the outward practices that reproduce the message.

To repeat the reasoning in brief: embodied messages are symbolic, symbols are in semiotic closure, semiotic closure includes (capacity for) the symbols' reproduction, semiotic closure can point to entities, thus realized sustained reproduction of symbols can point to entities. As symbols reproduce in interaction, semiotic closure is achieved through (sets of) social interactions reproducing and reinforcing cultural representations. We now consider a single interaction in more detail to suggest a semiotically closed building block for wider dynamics, social relation.

Interactions Sociocultural reproduction takes place in human activities, whose semiotics are hard to disentangle, as they appear in streams of overlapping symbolic events. We also do not, as of now, understand the full range of ways information can be inscribed on and in physical persons, actions, and surroundings. We do know that our cognitive capacities play a major role, but our bodies also represent information in complex ways. Despite this, we can assume that embodied representations are to a significant extent symbolic. One, many of the actions humans perform manifest symbols, and two, people are capable of learning and performing an enormous range of sociocultural practices, suggesting use of a generic and thus likely symbolic underlying representation.

Simplifying slightly from (8.7), a single symbolic interaction can be stylized as:

$$\left.\begin{matrix} H_1; \mathsf{s}_1 \circlearrowleft_{\text{enact}\,1} \\ H_2; \mathsf{s}_2 \circlearrowleft_{\text{enact}\,2} \end{matrix}\right\} (A;\mathsf{P}); (a_1;\mathsf{p}_1); (a_2;\mathsf{p}_2) \left\{\begin{matrix} \circlearrowleft_{\text{interpret}\,1} H'_1; \mathsf{s}'_1 \circlearrowleft_{\text{enact}\,1} \\ \circlearrowleft_{\text{interpret}\,2} H'_2; \mathsf{s}'_2 \circlearrowleft_{\text{enact}\,2} \end{matrix}\right\} (A';\mathsf{P}'); \ldots \tag{9.1}$$

Two people $H_{1,2}$ with embodied text $\mathsf{s}_{1,2}$ are engaging in a common activity A holding a store of inscribed cultural information P. Within $A;\mathsf{P}$ each person performs actions $a_{1,2}$ with outward symbolic content $\mathsf{p}_{1,2}$ (parole), changing the activity. Every person then interprets the interaction, updates their embodied representation to $\mathsf{s}'_{1,2}$, and can be affected in non-symbolic ways, hence $H'_{1,2}$.

As discussed, we can only infer the embodied cultural representations $\mathsf{s}_{1,2}$ by how they inform actions $a_{1,2}$. Consequently, we can tell that H_2 learns s_1 from H_1, or that information s_1 gets reproduced in s'_2, only by a change in H'_2's proclivities to perform symbolic acts in ways typically associated with s_1. Some of the texts represented in the actions $\mathsf{p}_{1,2}$ and inscribed in the activity P are outwardly discernible as symbolic, while many others are not. External inscriptions exist only for someone who can read them; here, $\mathsf{P}, \mathsf{p}_{1,2}$ are considered as relative to everyone taking part and likely to take part in the activity.

There are two paths to semiotic closure illustrated above, for $\mathsf{s}_{1,2}$ from person to person, and for $\mathsf{P}, \mathsf{p}_{1,2}$ from activity to activity. While the latter are more readily accessible, we concentrate on the presumed embodied messages $\mathsf{s}_{1,2}$ because they are attached to living beings and thus more readily activated. The two sets of representations are interdependent: s_1 can reproduce only when H_1 performs $a_1; \mathsf{p}_1$ in a context where it is understood, so semiotic closure requires that participants possess the cultural background needed to interpret the performed text p_1 in the context $A; \mathsf{P}$. Focusing on reproduction of s_1 thus assumes further social reproduction is continuing apace, both of the activity and of the understandings participants bring to it.

In the above interaction, s_1 can be seen as semiotically closed with s'_1 any time it informs an action $a_1; \mathsf{p}_1$, indeed any time it is invoked in any way. We can say this for two reasons. First, the representation changes materially insofar the interaction reinforces or otherwise affects any neural connections involved in it. Second, as s_1 is socially learned, every enrollment of s_1 in action amounts to a (partial, imperfect) production of “a physical unit associated with one single life cycle,” and typically a chance for others to learn it as well. The cycle of actions implied in semiotic closure: decode, perform, reproduce, is achieved: future chances of reenactment are likely to be affected, and anyone else present has an opportunity to learn. In other words, the semiotic closure of the act of social learning, s_1 to s'_2, is the reason why s_1 to s'_1 can be seen as semiotically closed.

Social learning, however, only accounts for reproduction of cultural traits from person to person, meme-like, allowing for individual level changes such as misunderstanding and creativity. It does not allow for the general case, in which texts $\mathsf{s}_{1,2}$ are performed with reference to a common activity, one in which both play part and can change if slightly. In such an interaction, two semiotic closures through social learning are effected: s_1 to s'_2, and s_2 to s'_1, so we can say that $\mathsf{s}_{1,2}$ are semiotically closed with $\mathsf{s}'_{1,2}$ through mutual influence in a given context. Repeated, such occasions amount to what we call a social *relation*.

Social relations can be associated with the symbolic content, distributed between their participants, that shapes and is reproduced by the repeated interactions. In this example, formally, we can tell that the text combines messages s_1 and s_2. The symbolic content of relations can, however, impact whether they need to be performed at all. To have a grocer I need to shop with him on occasion, but I can have an aunt without ever meeting her. Relations, seen as symbolically marked kinds of (potential) interactions, are the smallest semiotically closed "wider dynamic" in society and culture.

Human cultural capacities indeed are set apart from similar abilities of other primates by being relational. Moll and Tomasello (2007) report that, unlike other great apes, human children 12-18 months old can: establish joint attention, such as through pointing; recognize the perspective of another; commit to shared goals; and take and reverse roles in reaching them. Similarly, Hill (2009, pp. 275–280) argues that human culture differs from animal traditions in shaping social relations. Hunter-gatherer societies establish and keep norms and rules in areas of human activity that affect biological fitness, such as mating, food production and redistribution, and political power, then signal their adherence through symbolic markers and rituals. These comprise the outward expression of the ethnic group, and function thanks to regular shaping of social activities.

Persistent wider dynamics in societies and cultures require repeated symbolic interactions and thus lasting relations. Interactions, and by extension social relations, are a primary material manifestation of our evolved capacities for somatic representation (chapters 7 and 8). Relations established and maintained through symbolic social learning, as well as wider processes into which they combine, are proposed as the closest to a "natural kind" (Rosenberg 2016, p. 22 and above) in explanation of any social phenomena.

The next section turns to consider regular structuring of our activities, and to the overall properties of social processes that may result.

9.2 Infrastructures

Social activities are a reproduction channel for sociocultural information, the way it manifests, and the environment that shapes it. Analogues to phenotypic expression, reproduction, and selection take place in the same context at the same time. Understanding what comprises and shapes social activities is thus necessary to explain the nature of any wider dynamics in society and culture. Cavalli-Sforza and Feldman (1981, pp. 346–357) support this, evaluating a range of models based on epidemiology and population genetics and concluding that the mode of cultural transmission, i.e. the structure of the reproduction channel, is of central importance to predicting the changes traits undergo.

In general, social activities are too complex for us to identify such detail as to allow for the explanatory power of population genetics. Exceptions to this are the situations that can inherently be formally modeled or those that we design that way. What we can say is that *any* persistent aspect of social activities is likely to (a) affect other aspects of the same activities, (b) be reflected in regularities in what is learned, which means it will in turn (c) have recurring consequences further afield. When these regularities can be anticipated, a persistent aspect of social activities becomes a potential affordance for other practices. One persistent affordance we avail ourselves of is language, integral to symbolic interaction.

Others we introduce. Informed by Frischmann (2012), Anderies et al. (2016, p. 8–9) suggest a focus on infrastructure in the study of social-ecological systems (SESs). Infrastructure is taken to be "a coherent structure of any kind"; meaning, a clearly discernible structure that is geographically, socially, or otherwise bounded, that in tandem with other such structures shapes action situations, providing affordances for production of "a variety of mass and information flows we value" (emphasis removed). The authors proceed to name five types of infrastructure: hard, such as roads and canals; accepted arrangements and instructions, such as institutions, for handling other kinds of infrastructure; environmental, ecological and geological assets; available knowledge; and social relationships. The examples are heterogeneous, and the lines between some types of infrastructure are blurry, but all comprise sets of lasting shared affordances in given domains.

Anderies et al. (2016, p. 9) point out *configural* properties of infrastructure, which they depict in two ways. Infrastructure acts as an input for downstream activities, and it interacts with other infrastructures to produce “interesting higher-level organizational patterns.” Interactions among infrastructures can be messy or misdirected, such as in the examples of representing resource use as Prisoner’s Dilemma and commodification of ecosystem services (pp. 15–16). Baggio et al. (2016), moreover, analyze multiple observed relationships between Ostrom’s (2005) design principles and properties of resources.

To characterize configural influences from the present perspective, first note one salient feature of any infrastructure, direct human engagements with it that form the pragmatic interface to its affordances, in the broadest sense. These are, for example, learning the use, daily uses, development, maintenance, innovation, and so on. Anderies et al. (2016) consider some of these practices downstream activities, while others are infrastructural, as accepted arrangements and instructions for use. However, immediate uses are obviously present for each infrastructure, representing the front from which its influence spreads.

The practices of use of any infrastructure and the affordances they meet are social constructs. A wetland presents one set of opportunities to the sewer treatment utility, another to a bird watcher, and so on: infrastructural affordances are tied both to the ecology and to human activities, which change. Meanwhile, one particular set of our practices, sewage treatment, reproduces (its representations and performances are semiotically closed) with respect to one affordance of the wetland, its filtering capacities.

If we were to trace the material connection from the wetland to the first point of contact with human activities, we would grab a multitude of disparate social and cultural practices. Interaction with sewage over a day reflects individual, cultural, and organizational rhythms of work and hygiene. City sewers then aggregate such information with respect to what the wetland filters, establishing an information channel between the ecosystem and our daily lives. By effecting a simple interface between hard (sewage treatment plant) and environmental (wetland) infrastructure, some ways to interact with the ecosystem are closed off, while our daily activities benefit from convenient access to the water cycle as need arises.

Infrastructure thus shapes human activities: while mediating influences from away, it flattens itself into specific situations. It becomes inscribed in $A;\mathsf{P}$, sometimes to the point participants are unaware of it. The configural nature of infrastructure amounts to a *regular simplification in information* at one or more points between human activities and opportunities tied to the infrastructure. Streamlining activities encourages their reproduction and opens opportunities for other pursuits, which speeds up sociocultural evolutionary processes, whatever they may be.

In the previous section we argued that persistences in societies and cultures are likely to be semiotically closed, reproducing symbolic representations: individually, as when one learns a word; and relationally, realized in repeated interaction. Just now, we discussed regular shaping of human activities by coupled infrastructures that mediate access to coherent sets of affordances, which simplifies and accelerates interactions further away. We now turn to characterize semiotically closed dynamics that can arise on top of multiple mutually reinforcing symbolic interactions.

9.3 Flywheels

Social relations, regular opportunities for symbolic interactions of a given kind, are semiotically closed, as their representations reinforce each other transparently every time people engage (section 9.1). Relations are also a building block for wider phenomena. As just discussed, infrastructure is configural: it clarifies particular social activities, which simplifies existing interactions, and makes room for further relations for people to enter into.

Accelerating interactions can become mutually reinforcing, leading to semiotic closure in an autocatalytic fashion. This, it was argued, took place earlier in the history of life, at its origin and in the evolution of somatic and cultural representations (section 7.2, chapter 8). The question arises whether and how it can occur *among our relations*. The reply is inevitably equivocal, as boundaries between visible relations and persistent emergent dynamics are blurry. In fact, common social entities such as organizations reproduce through a continuum of explicit and tacit means (Nelson and Winter 1982, ch. 5).

On present view, human cultures and societies are engines for overlapping semiotically closed networks of interactions of multiple kinds and sizes. Every infrastructure and every common practice simplifies different aspects of activities and encourages further interactions in some way. The shape of wider dynamics depends on how the original interactions are simplified and on how they relate to others. Thus, we cannot say much in general about overall contours of SESs, although we are acquainted well with specific cases.

Some purchase on general features of wider semiotically closed sociocultural dynamics can be gained from the view of evolution of representation presented in section 7.2. Semiotically closed, autocatalytic-like sets of interactions tend to exhibit to varied extents the trio of self-reinforcement, self-maintenance through differentiation, and symbolic marking, along with aspects of distributed intentionality. Rather than a ratchet, a better mechanical metaphor for complex phenomena arising in sociocultural evolution are *flywheels* (as a shorthand, although a non-mechanical metaphor would be preferred, say flydances).

Flywheels are ways human activities can feed into each other and back over any social, physical, and temporal scope. An elementary example from archaeology are *chaînes opératoires*, networks of interdependent activities involved in the production of stone tools. Such dynamics, it is suggested, are a candidate causal explanation for social and cultural persistences, and can be said to manifest social power. Depending on the context, any of the three aspects of evolution of representation can be manifested to any degree. Models of random grammars, strings of letters operating on each other in a virtual chemistry, indicate the range of forms flywheels may take (Kauffman 1993, pp. 372–374). Just to list the names of different geometries: Jet, Lightning Ball, Mushroom, Egg, Fixed, Traveling, Wobbly Ergodic and Hairy Egg, Filigreed Fog, Pea Soup (Kauffman 1990, p. 10).

Human examples are likely to be more down to earth. Dreyfus and Rabinow (1983) characterization of Foucault's biopower bears quoting in full, as they may be describing a human Filigreed Fog:

> This is not a new form of functionalism. The system is not in any way in equilibrium; nor is it, except in the most extended of senses, a system. There is no inherent logic of stability. Rather, at the level of the practices there is a directionality produced from petty calculations, clashes of wills, meshing of minor interests. These are shaped and given a direction by the political technologies of power. This directionality has nothing inherent about it and hence it cannot be deduced. It is not a suitable object for a theory. It can, however, be analyzed ... (pp. 187–188)

Flywheels are complex, internally connected material processes. They consist of seemingly disjoint interactions, but every encounter between people is a physical medium exchanging sociocultural information. They take up and move matter and energy, appearing for example as persistent supply networks in economies.

The three aspects of evolution of representation in societies and cultures (section 7.2) are broad, and so can offer at best circumstantial clues; some bear a brief mention. The classification by Ostrom (2005) of common expectations of others' institutional behaviors into shared strategies, norms, and rules parallels closely the triad of self-reinforcement, self-maintenance, and coding. The invention of writing usually starts with pictorial representations and grows more stylized, syntactic, and abstracted. Overall, symbolic systems we use such as scripts, currencies, legal codes and so on, can be seen both as evolving in concert with, and as facilitating accelerating interactions in their domains.

Boyd and Richerson (2008) discuss one kind of infrastructure, social institutions, in light of population models of human cultural change. The article lists six stylized facts about institutions (pp. 307–309), which can be qualitatively accounted for if we view institutions as (parts of, partly) flywheels. The first three are basic properties of self-reinforcing interaction sets: persistence over time in a population, lack of conscious design, and internal complexity and heterogeneity of interaction. The next two, that institutions may or may not favor any specific social group, can be read as a statement on their uncertain intentionality. The last, that they are often symbolically marked, such as by a flag, reflects the fact that flywheels are a semiotically closed process, continually producing and reproducing texts. Flywheels are not deterministic, but mediated by the agency of people who partake in them. People may, for example, decide to make an institution more official by producing symbols that apply to it in entirety, such as emblems and codes.

Intentions Flywheels often exhibit intentionality: there is a meaningful (usually uncertain, occasionally unpleasant) reply to the question "for what?" or "for whom?" This does not require a complex set of events, any mutually reinforcing set of interactions can be intentional: indeed, any repeated interaction, or a social relation, and it does not have to be effected in person.

One example are the live-and-let-live agreements that developed between Entente (French or British) and German soldiers across no man's land in World War I (Axelrod 1984, ch. 4). Without any contact, the soldiers of the two sides would time and direct their artillery rounds in such a way to minimize or avoid casualties, effecting an undeclared cease fire. In the literature on cooperation dilemmas, this is usually cited as an example of coordination.

In light of the earlier discussions, it is also a distributed act with intention.

When the soldiers on the two sides realized they could coordinate, they likely also became cognizant of it as a good idea, and continued acting on it on purpose. Similarly, the visiting officer who "made up [his] mind to do away with that sort of thing when we took over; such things should not be allowed" (Axelrod 1984, p. 73, quoting Dugdale 1932) clearly found the tacit agreement in violation of army discipline. Plausibly deniable but glaringly apparent, it is an intentional act to be countered by another: "These people evidently did not know there was a war on. Both sides apparently believed in the policy of 'live and let live' " (p. 74).

Intention implies representation (chapter 6), and in this case, the tacit truce is represented in two ways. First, the soldiers on each side are quite aware of it and intend to follow it through. Second, soldiers on *both* sides are quite aware of it and intend to follow through: the two aims are in concert and are confirmed by any successful joint action. If this ceased to be the case, for example if a visiting officer enforced discipline on either side, the awareness and good intention of the opposing soldiers would be in vain. The truce intent is represented both by the content intended by each side, realized in specific actions, and by the relationship between the contents.

The nature of intentionality in larger self-reinforcing sets of interactions (flywheels) is proposed to be similar. Individual conscious aims and actions partake in wider intentional dynamics, never entirely independent but rarely fully overridden by them. Thus, paralleling poststructuralist notions, a person is at the same time being made by the different (textual and disciplining) flywheels she or he takes part in, while too shaping them (Foucault 1984). It is not necessary for people to be aware of their participation: "[p]eople know what they do; they frequently know why they do what they do; but what they don't know is what what they do does" (Dreyfus and Rabinow 1983, p. 187, quoting Foucault).

Dimensions The semiotic perspective allows for more internally structured dynamics than Dreyfus and Rabinow (1983) paint Foucault's biopower. With evolving representation, we can expect that certain flywheels exhibit partly functional internal structure, and that for others people develop symbolic codes specific to the dynamic.

Consider mutually reinforcing networks of symbolic interactions that are not just diffuse, but to some extent manifest autopoiesis. We would expect such flywheels to be differentiated, to link up interacting heterogeneous components in a self-maintaining fashion, possibly exhibiting attributes of function. Because they are distributed social processes, we do not in general know much about their contours. A flywheel can be clearly marked, but we cannot rely on one to have boundaries, and it does not "die" or necessarily leave a tangible trace if the people who partake in it stop doing so.

The foundation for such dynamics, it was proposed in section 9.2, is the configural nature of infrastructure. Communication with some coherent structure in society or on the landscape is streamlined, providing affordances for material and information exchanges, and structuring our activities. This creates and provides a *social field*, allowing for diversification and acceleration of other interactions.

The simplifications provided by infrastructures in action situations can be related to the notion of social dimensions in organizational ecology. McPherson (2004, pp. 264–269) does not say how to observe flywheel dynamics, but provides valuable intuitions about what actually takes place on top of infrastructural affordances. McPherson considers social dimensions, relational affordances, "quantities that locate social positions in relationship to one another." In early humans, on his view, these have been status and material accumulation; one could add gender, ethnicity, and geography – and later came to include education, occupation, income, race, and many others. Dimensions, in turn, facilitate organization of entities: "firms, groups, associations, events, cultural artifacts, markets, social circles" and so on. As noted by Ostrom (2005, pp. 269–270), interactions within a (discernible) coupled infrastructure system (CIS) encourage creation of nested enterprises.

Recall that flywheels are semiotically closed: whatever else they do, they reproduce symbolic representations. This does not require people to intentionally inscribe a social dynamic as an entity, such as by a flag or laws. Texts exist within processes that interpret them, so steady interactions with infrastructure tend to stabilize such cultural understandings of them as are particular to persons and groups taking part.

Methods that may indicate this patterning can be found in cultural domain and cultural content research. For example, Mohr and Neely (2009); Mohr and Guerra-Pearson (2010) categorize self-published descriptions of work by charities, asylums, and social service agencies in New York at the turn of the 20th century. The studies map structural similarities among the texts across several dimensions, such as a person's status, the social problem they experience, and potential technology to address it. Mohr and Guerra-Pearson (2010) point out partially intentional historical patterns, specifically the competition between settlement houses and scientific charities.

Finally, while infrastructures persist, their footprint on societies and cultures, the ways they direct the "flows we value," is both diverse and uneven. No infrastructure reaches everywhere, or everywhere equally, or in the same way. According to McPherson (2004, pp. 267, 276–277), these differences represent dimensions along which interaction with CISs sorts people into positions. Similar profiles of access to amenities result in similar life histories, which makes it more likely people meet. The interplay between available infrastructural affordances thus gets reflected in social relations. The consequence are domain dependent networks of relationships on multiple scopes, among people, communities, research disciplines, organizations, industry sectors, and so on (White 2008, ch. 2). Wider relationships between network positions occupied by social groups are reflected as structural similarity, tendency to form similar links, studied by methods such as blockmodeling (Burt 1983).

Social network positions, however, can be involuntary, relationships among them unequal or coerced. We now compare the semiotic perspective with articulations of social power by Wolf (1999); Mann (1986); Ortner (2006); Kondo (1990). In the next section, we continue to consider possible parallels and differences with critical studies.

Powers Wolf (1999, p. 5) distinguishes “four modalities in how power is ... woven into social relations”: individual, interactive, contextual, and structural. In part anticipated by Wolf’s (pp. 6–7) attention to the importance of communication and symbolic codes, the four modalities all have semiotic interpretations, associated with the different loci of sociocultural inscription.

The first, the “capability that is seen to inhere in an individual,” characterized as “Nietzschean” (Wolf 1999, p. 5), perhaps modestly parallels embodied symbolic representations, $\mathsf{s}_{1,2}$ in expression (9.1), along with a person’s ability to enact them. The second, “the ability of an *ego* to impose its will in social action upon an *alter* (the Weberian view),” expresses the public interaction of performed representations $\mathsf{p}_{1,2}$, the differences in their immediate public visibility, along with the embodied and contextual representations thereby learned and inscribed. The third, the “power that controls the contexts in which people exhibit their capabilities,” is the ability to affect inscriptions P in activities. Finally, the power that “organizes and orchestrates the settings themselves, and that specifies the direction and distribution of energy flows,” is represented in sustained relationships between different realms of interaction, whether between regiments in opposing trenches (relation), or among infrastructures in social-ecological systems (flywheel).

These four loci of sociocultural inscription are mutually materially constituted paralleling the explanatory stances by Tinbergen (1963). Successful en$\langle\mathsf{A}\rangle$ctments of s produce p, prevailing performances p inscribe activity contexts P and shape what is $\langle\mathsf{L}\rangle$earned, and structures arise over $\langle\mathsf{H}\rangle$istory through sustained mutual reinforcement of activities.

The analysis of sources of social power by Mann (1986, and later volumes) focuses on the interplay between the most encompassing of these dynamics, the contextual and the structural. Mann characterizes primary social dynamics as “overlapping and intersecting ... networks of social interaction,” which provide “institutional means of attaining human goals” (p. 2, emphasis removed), in accord with the view of flywheels as heterogeneous sustained relations across coupled infrastructures. Mann (pp. 11–14) criticizes the view of societies as functional systemic wholes formed in symmetrical levels or dimensions, as per Marx or Parsons, offering instead the view of networks of intensified interactions with blurry boundaries. As discussed above, dimensions such as they exist arise along these boundaries, as differences in infrastructural uses and effects sort people into groups (McPherson 2004). Much of this structure is outside Mann’s purview, as it is reflected in communities’ cultural representations.

Mann’s (1986) approach has been fruitfully employed in analyzing social change in historical times and the archaeological record, such as to compare conditions favoring the rise of chiefdoms in Denmark, Hawaii, and Peru (Earle 1997). In every historical era, Mann contends, there are power networks using one or more of four main sources of social power, both dominant and interstitial, in coexistence or opposition. The four sources of organization can in the terms of section 9.2 be seen as the main interfaces of human activities with infrastructural affordances that shape societies on the widest level. These are, per Mann (pp. 22–30): ideological (transcendent and everyday beliefs), military (concentrated coercion), economic (circuits of production and exchange), and political (negotiated territorial control).

The reach of any exercise of power is shaped by the logistics of its material spread, which Mann (1986, pp. 6–10) analyzes with aid of heuristic dichotomies. Power can be collective (enhanced by joint action) or distributive (power over, zero sum), extensive (wide reaching and minimally stable) or intensive (tightly committed and organized), authoritative (consciously willed) or diffused (spontaneous and decentered). These oppositions afford semiotic interpretation, respectively: relations can be maintained through mutual reinforcement of cultural texts versus their exclusion by one side; there is a trade-off between the complexity of shared symbolic representation and the reach of interactions it can inform; intentionality can be expressed explicitly by persons and groups or distributed across relationships comprising flywheels. Semiotically similar power dynamics reinforce each other; for example, diffuse religious practices are helped by the spread of universalizing means of symbolic exchange such as literacy and currency (p. 23).

On the opposite end from Mann's (1986) focus are the expressions of power Foucault (1976, pp. 96–97) termed capillary, those tied to persons and interactions. One source of social power likely on par with others is thus overlooked, family and gender dynamics, owing their influence to their central role in social and cultural reproduction. The examination of gender identity allows Ortner (2006); Kondo (1990) a more nuanced look at the symbolic formation of persons in intersection with other power relationships.

Ortner (2006, pp. 129–153) associates power with the capacity to express one's own representations. On the one hand, this amounts to people's ability to formulate and enact their cultural projects, pursuing "desires that grow out of their own structures of life" (p. 147). On the other, it manifests as the power to impose one's own cultural aims, including by denying others the right to view themselves in an active role entirely; as well as in ways such impositions are neutralized and resisted from below. Serious games, sustained heterogeneous sets of practices constituting and performed by cultural actors (pp. 129–130), inhabit the continuum of power dynamics between mutual coordination and suppression of participants' represented projects.

In her partly autoethnographic field study of work in a family owned confectionery in Japan, Kondo (1990) charts the connection between the daily performance of serious games and structural (infrastructurally mediated) power dynamics. Kondo (pp. 304–308) notes that wider influences, such as family, community, and workplace, all intersect on the ground of personal identity, shaping contexts in which different "selves" can be asserted. Every action has multiple meanings, partaking in and reproducing multiple broader configurations of relationships. Ultimately, theorizing cannot fully be separated from experience, as Kondo's own identity as a third-generation Japanese American is challenged by her self-perception as an employee in a Tokyo neighborhood factory.

In the next section, we examine more closely the ways social exclusion can itself work as infrastructure, and discuss epistemic and ethical implications raised by critical studies.

9.4 Front and Back

The continuum of power expression Ortner (2006, pp. 129–153) foregrounds in serious games, between (positive) enactment of projects and (negative) suppression, aims to counter dualistic notions of false consciousness in Marxian materialism. These, Ortner contends, tend to obscure both reasons why people in subordinate positions follow along, as well as ways they transform and challenge the impositions in the space they are afforded.

Dual oppositions with normative implications do appear frequently in critical and Marxian work, such as between false and true consciousness, or common and good sense (Gramsci, cited by Cox and Nilsen 2014, pp. 8–9). They refer to attitudes of a person respectively conforming to and challenging wider power relationships she or he partakes in, in thought and in deed. However, the question of how one gets from one to the other is rarely clarified. In Freire (1970), for example, this manifests in the figure of the revolutionary leader, who is assumed to originate in the elite or the middle class, has seen through the obfuscations of power, and is committed to enter into an equitable dialogue with the poor about revolting against their condition. There is little discussion, however, on how these individuals gain their awareness and commitments, save for the account of Freire's own experiences with hunger (Macedo 2000, pp. 12–13).

These dichotomies are here associated with the relationship between two sets of activities tied to infrastructures. They can be seen as the generalization of Ortner's (2006) dichotomy, between power as performance of projects and power as relative repression, to social dynamics wider than serious games. As discussed in the previous section, recurrent structuring of activities can *facilitate* movement on narrower scopes by providing a reliable social affordance. It can also be inferred to *partake in* such wider semiotically closed dynamics that sustain it. The distinction between these two kinds of dynamics, those sustaining recurrences in social activities and those facilitated by them, can be illustrated, for example, by comparing the entirety of operations of a store with only the front end of interaction with customers.

The person shopping, the store clerk, one shunting boxes in a warehouse, assembling the product, and so on, form a network of interactions, the supply chain. While the interactions in the store are a part of the chain, they are also divided from the rest by a configural interface which, by obscuring much of the complexity, simplifies and so can help intensify further interactions. In other words, the store provides an infrastructural interface of activities that (presumably) facilitates convenience in shoppers' lives, as well as partakes in the wider dynamics of the market. The rest of the supply chain, while integral to the shop, is largely out of view.

In the study of institutions, the distinction between "front end" and "whole store" is reflected in the recognition that infrastructures both provide affordances and have costs (Anderies et al. 2016). The "front end" dynamics of these affordances can be (although are by no means always) quite apparent: groups and organizations supported by certain institutional arrangements, tools and artifacts produced thanks to a given technology, beliefs and worldviews arising from specific meaning systems, and so on.

The "whole store" dynamics, or "costs" in the terms used in institutional studies, can be harder to discern for two reasons. One, they operate farther out and can involve many interacting and interdependent pieces. Two, sustained flywheels can be inferred to involve social differentiation. While the relations between different people and groups can simply amount to consensual specialization, they could also be wholly or partly involuntary, so there can be both hidden and overt power barriers to teasing them out.

We can infer existence of (some kind of) "whole store" dynamics by the very fact that social affordances persist, then try getting a better sense of them by asking the four questions and employing the methods of textual and relational analysis discussed above. As mentioned, a foundational example from archaeology are the networks of activities involved in tool production or *chaînes opératiores*. A number of examples in complex societies are given by Whatmore (2002), e.g. tracing the networks that took "leopardus" (big cats from Africa and Asia) into Roman arenas for battles of beasts and executions. A salient present day example is the ongoing civil war in Congo fueled by the demand for rare metals for the manufacture of advanced electronics.

A major reason social exclusion can maintain itself is willful denial. Mills (2007) details five ways white people's ignorance of others' experiences manifests in "processes of cognition, individual and social," which almost precisely align with the four questions by Tinbergen (1963). These are perception (immediate activity), conception (learning), memory (history), testimony and group interest (dialectics). The white ignorance frame is generally applicable to many kinds of exclusion through coercion for a simple reason: decisive violence is one way to interact without ever having to engage with other's symbolic representations.

This can be represented in a very stylized way by modifying the expression (9.1):

$$\left.\begin{matrix} H_1;\mathsf{s}_1 \circlearrowleft_{\text{coerce}} \\ H_2;\mathsf{s}_2 \circlearrowleft_{\text{enact}} \end{matrix}\right\} (A;\mathsf{P});(a_1;\mathsf{p}_1);(a_2;a_2|\mathsf{s}_1) \left\{\begin{matrix} \circlearrowleft_{\text{interpret}} H_1';\mathsf{s}_1' \\ \circlearrowleft_{\text{adhere}} H_2';\mathsf{s}_2' \end{matrix}\right. \tag{9.2}$$

The public symbolic meaning H_2 enacts is completely repressed, substituted by the interpretation $a_2|\mathsf{s}_1$ of the non-symbolic component of the other's action in H_1's symbolic terms.

To bring this back to institutions, one way to characterize them is that they aim to fulfill a perceived common intention at the "front end," providing infrastructural affordances or services, as discussed above. These, however, may or may not be compatible with intentional aspects of the "whole store" dynamics, conceptualized by Anderies et al. (2016) as institutional costs. This discussion suggests, significantly, that some part of the web of interactions may easily involve relations we would consider as asymmetric through coercion, and that if so, there are likely to be difficulties in identifying and examining them. Asking what these difficulties are, and indeed what we mean by asymmetric coercive relations, is outside the scope of this essay, and the focus of critical studies.

Symbolic Performances and Evolution The previous chapters undertook a formalized excursion across the transitions in domains of interaction in the physical and biological worlds. This chapter has instead shifted focus to a more qualitative characterization of persistent processes in society. One could quip that the semiotic viewpoint thus loses its meaning, that it is easily employed with various social scientific perspectives because it adds little to them. Saying that sustained processes in society rely on repeated interactions can indeed be tautological, expressing no more than that there are regularities in what takes place. In addition, evolutionary frameworks have historically been used to justify oppression of groups across multiple lines of social difference. It is not certain thus what is comparatively gained by employing evolution to restate the findings reached by other means. In particular, the relationship between teleonomic traits informed by genes and intentional social action is not clarified, in light of the sociobiological preference to attribute our proclivities to past genetic selection.

The main reason evolution is herein employed is to clarify the nature of symbolic processes. Any symbolic encoding is seen to be connected to the action of living beings, and the evolutionary perspective offers common notions to compare and distinguish different kinds of symbolic inscription and performances. Genes as symbols inform material interactions in cells, tissues, and organism behaviors. On the other hand, our cultural symbols are performed in activities, which their participants inscribe and symbolically represent ahead of time. The two processes differ greatly in what interactions they can represent, and what kinds of dynamics of change each can support.

Representational systems are tied to scopes of action that can be affected by the interactions that interpret the messages. While these can be very diverse, including for example interactions with other intentional agents, the limited reach of resulting (phenotypic) effects delineates a range of uncertainty, of possibilities an encoding cannot enact. Organic representations that evolved after the genetic code referred to interactions in those domains that could not be efficiently selected for in genetic reproduction, for example unfolding over periods much shorter than single life times (Beach 2003). New codes evolved relatively rarely in part because representational structures are costly (Boyd and Richerson 1996; Dawkins 1999, ch. 2). However, human sociocultural interaction relaxes this barrier, opening a separate channel of reproduction and allowing for creation and maintenance of a diversity of symbolic texts, codes, and languages.

The kinds of change evolving interactions undergo depend on details of the reproduction channel. In biology, we can make statistical idealizations because we know the accounting of genetic recombination (section 7.3). Population genetics describes overall trends, not unbending laws; changes reflect patterns in what organisms actually do, not built-in natural certainties. The effects of selection can indeed be quite decisive and measurable over short periods, such as the preferred selection of deep beaks in Galapagos finches that survived a yearlong drought (Weiner 1994). However, the pressures can be fleeting: the same drought favored larger chicks, which were at a disadvantage the next year because they were too immature to eat enough to sustain their size. Still, non-human animals can do little to affect the overall statistical success of their strategies.

As argued in section 9.2, any such statistical accounting of sociocultural reproduction is in general not available. Instead, we offered a general model for sustained dynamics comprising mutually reinforcing social relations, or flywheels. These are partly intentional overlapping networks of sustained interactions that connect social fields, human activities configured through infrastructural influences. Flywheels are internally heterogeneous and maintain cultural texts, ranging in scope from Ortner's (2006) interpersonal serious games, to Mann's (1986) interstate political networks, to Mills's (2007) perpetuations of white ignorance.

Fracchia and Lewontin (1999, pp. 67–78) criticize dual inheritance approaches to sociocultural evolution, objecting to the answers current evolutionary theories offer to the three requirements for natural selection. These are: the source and locus of variation; the avenues of heredity; and the influences shaping differential reproduction. The criticisms are here addressed as follows.

Random variation is seen primarily to reside in symbolic representations, embodied (existence inferred), performed, and inscribed, always interpreted in interaction. While internal representations are assumed to be partly symbolic, no presumption is made as to the nature of actual cultural units, such as memes. Patterson (2014) proposes that culture is structured in a similar way as language, exhibiting both performed regularities (*parole*) and more lasting abstract structures (*langue*). On this account, our cognitive representations may well avail themselves of cultural analogues to units such as morphemes. If units exist, though, they are never enacted individually.

On heredity, the current analysis together with Fracchia and Lewontin (1999) is advised by the results by Cavalli-Sforza and Feldman (1981), that cultural change in evolutionary models is shaped by the details of the reproduction channels. Instead of searching for a proper accounting of meme transmission in a population, a common framework is proposed for sustained dynamics shaping the reproduction channels, such as "family, social class, institutions, communication media, the workplace, the streets" (Fracchia and Lewontin 1999, p. 73). Relational and critical approaches are put forward as salient to explaining these influences. Finally, on differential reproduction, we agree with these authors that Darwinian individualism of variants is of limited use in explaining sociocultural change. Cultural texts reproduced in flywheels are complex and coordinated through social relations, far from the aggregate "state of the 'memes' " Fracchia and Lewontin (p. 71) criticize.

Similarly, the present argument effectively concurs with the critique of evolutionary anthropology by Ingold (2007) on all points except that the baby needs to go out with the bathwater. Ingold's characterization of the blind spots in Mesoudi et al. (2006) is affirmed, along with the defense of cultural anthropology as productive, interdisciplinary, and informative about its topics, against conventional hard scientific criticisms by these authors. Allowing that some sociocultural change may be fruitfully analyzed by models of population genetics, here the view is that such efforts will always have limited reach. For social scientific topics of daily concern, the focus on agency, power, and social relations Ingold finds lacking in dual inheritance accounts indeed offers a more relevant explanatory angle.

Ingold (2007) outlines four specific shortcomings of the evolutionary view by Mesoudi et al. (2006), all of which are here preliminarily addressed. One, historical agency is accounted for by different degrees of intentionality of sustained sociocultural processes, and by the contestation of personal and group interests over infrastructural avenues of social influence, logistics of power (Mann 1986, pp. 9–10). Two, what evolves is recognized as fully contingent on context. The present account notes the symbolic nature of our performances and activities, and assumes partly symbolic embodied representations, but these inscriptions can be animated only in interactions.

Three, while faithful copying indeed plays a significant role in sociocultural reproduction, there are no *a priori* assumptions on how people learn in any single context. Indeed, a variety of learning theories are expected to be relevant, from conditioning to Vygotskian activity theory favored by Ingold (e.g. Lave and Wenger 1991; Wenger 1998). Four, the apparent circularity of explanation reflects the fact that sustained sociocultural dynamics are semiotically closed, that the reproduction of (inferred) embodied texts depends on their repeated enactment and performance through public messages. The present approach, finally, has no fundamental differences with the alternatives to sociocultural evolution outlined by Ingold (2007), such as Oyama's developmental systems theory and Bateson's ecological framework. Detailed comparisons are beyond our scope.

If "standard" social scientific explanations are recast in terms of the present semiotic perspective on sociocultural evolution, they can present a challenge to established evolutionary accounts on their own terms. Human activities as a reproduction channel underlie a domain of symbolically informed material efficacy, with its own orientations toward explanation (interaction, learning, history, dialectics). Embodied and enacted representations, as noted in section 7.2, tend to evolve in each other's blind spots. One cannot ahead of time tell the extent a human practice is influenced by genetic variation, or shaped by sociocultural exchanges in regions with no certain effects on biological reproduction. A hypothesis from the established evolutionary standpoint can be countered from the perspective of evolving semiotically closed power dynamics on top of symbolic interactions.

In an early attempt to adjudicate the sociobiology controversy, Kitcher (1985, pp. 208–211) juxtaposes possible sociobiological with sociological explanations of gender differences, noting that evolutionary biology has no good ways to decide between them. This justifies skepticism about reductionist evolutionary theories, as they themselves are ambiguous as to sociocultural mechanisms mediating supposed evolved proclivities, and do not address at all the gender roles' social construction. With the benefit of the present view, we can raise the burden of proof of such and similar accounts, to convince us of the extent the phenomena they seek to explain are biologically influenced rather than culturally constructed. We can also separately ask "*cui bono?*" with respect to the researchers' own embeddedness in political developments of their day. Sociobiological arguments such as those about which Kitcher expresses concerns were largely expressed by men, coincided with debates of second wave feminism, and were roundly criticized by its authors.

The aim of the present document has been to offer a common language whereby many of these conceptual gaps may be mapped, as a potential boundary object among research traditions. I next turn to how the framework may be employed in practice in interdisciplinary research in social-ecological systems.

CHAPTER 10 ROBUSTNESS AND POWER

The research on dynamics of sustainable social-ecological systems (SESs; Anderies 2015; Anderies et al. 2016) combines the institutional analysis framework by Ostrom (2005) with formal modeling techniques from biology, economics, and engineering. The quantitative methods are employed to examine in abstract the dynamics of SESs, to suggest attributes of institutional arrangements that can help make them sustainable. One of the stated aims of the research is to advise policy makers and other stakeholders in deliberately shaping institutional rules to reach sustainable outcomes.

These studies open up two perspectives on SESs relevant to the present discussion. First, sustainable social-ecological processes are conceptualized as dependent on feedbacks that regulate interactions, and so amenable to modeling as robust control. The approach has been evaluated favorably on the Gordon-Schaefer fishery equations (Anderies et al. 2007) and the Pumpa rice irrigation system in Nepal (Cifdaloz et al. 2010). Anderies (2015) further abstracts the fishery model to a stylized mathematical representation of any SES. Second, Anderies et al. (2016) propose that SES can be thought of as coupled infrastructure systems (CIS), in the sense discussed in section 9.2. These are coherent structures, such as roads, institutions, and ecosystems, which when combined provide affordances for social and material exchanges (some) people value.

Resilience studies, the broader collection of social-ecological research efforts which includes the study of robust institutions, gets praise from Cote and Nightingale (2012) for adopting a holistic perspective toward their topic, and for viewing complex systems as adapting to change rather than controlling it. On the latter point, the robustness research is somewhat ambivalent: while control is a guiding concept, results reveal the importance of institutional learning (Anderies et al. 2007), and of ability to cope with directed changes and unknown shocks (Cifdaloz et al. 2010).

Cote and Nightingale (2012, pp. 478–479) proceed to point out two sets of issues in understanding SESs which the study of resilience has left largely unexplored. These are first, power, the role of differential access to infrastructure in driving social change; and second, competing value systems, as different people's and groups' ideas of the (proverbial) flows we value can be in sharp contrast. These are significant, Cote and Nightingale point out, because resilience research aims to both describe and prescribe; yet despite offering advice, it lacks attention to the influence of social power and cultural values in SESs adaptive dynamics. As a result, while there is ample recognition that some resilient social outcomes are undesirable, such as dictatorships and colonial extraction projects, there are few explicit attempts to bring normative concerns into the analysis or policy advice.

This chapter considers ways to account for the significance of social power and culture in shaping CISs in light of earlier discussions in this document.

10.1 Mind the Gap

The picture of social and cultural processes presented in the previous chapter affirms attention to feedback in CISs, clarifying its nature as a social-ecological phenomenon. Regulatory dynamics, on this view, can appear as parts of "flywheels," semiotically closed networks of mutually reinforcing symbolic interactions, within processes of sociocultural change exhibiting evolutionary characteristics. CISs constrain and simplify certain ranges of activities, which can accelerate actions dependent on them.

This, first, shapes and facilitates some of our daily activities; second, offers common paradigms of interaction for forming possible smaller entities such as organizations (section 9.2; Anderies et al. 2016; McPherson 2004); and third, leads to longer term regulation among infrastructural uses, such as through supply chains. The narrower entities, such as organizations; and the cyclical exchanges maintaining infrastructural uses, such as supply chains, tend to become heterogeneous and specialize. Incipient regulatory networks emerge via acceleration of more diffuse dynamics (section 6.4; Deacon 2012, p. 269).

Viewed as flywheels, sustained interactions among uses of infrastructure can be expected to manifest two other properties. First, all interactions are symbolic; sustained networks of activities are informed by and maintain cultural texts. Flywheels reproduce symbolic representations tied to people's practices comprising them. Second, the dynamics exhibit intentional characteristics, explicit or vague, potentially working in favor of some groups' interests and against others'. Sustained wider relations cannot be assumed to be equitable, and in fact, a degree of such skew may be involved in maintaining many of them (section 9.4). At least in theory, the present perspective adds the two missing ingredients, culture and power.

The flywheel picture extends the robust control framework with the notion of materially realized semiotic closure. Possible directions for the robustness approach so extended could be indicated by asking how the view would apply to itself. The original framework is general, so just as one can ask what it would take for a set of resource institutions in a SES to be sustainable and robust so as to offer proper advice to the stakeholders, one can examine what it would take for the work of the institutions offering institutional advice to be sustainable and robust. One can ask if institutional analysis and design can understand themselves as institutional activities, then offer and follow their own advice.

If we apply the stylized picture of a semiotically closed feedback loop in an SES or in a complex "real world" network of exchanges (Anderies 2015, fig. 1b,d, p. 263) to institutional design, we can notice two openings. One is in singling out policy as an audience to advise, and the other are the informational bottlenecks to providing advice resulting from the chosen epistemic framework.

The first gap is significant insofar, as Anderies et al. (2016, p. 16) point out too, gatekeepers of infrastructure such as policy makers and experts may not serve the best interests of all stakeholders. If either the interests of the gatekeepers or the complex spillovers of infrastructure can adversely affect excluded populations, policy makers may not be the most desirable audience to seek to inform. Prudently, the advice is to stay away if unsure (Anderies 2015, p. 261). The research can best have impact "where political and social structures exist that increase the will and capacity for actors to engage in collective action (e.g. at local, regional, and national scales)."

This in effect means that political will, a component that is in the general case recognized as required for institutional design, is external to the model. The present focus on power views political will as an intentional phenomenon whose nature, duration, and social scope are subject to study, and can be considered with the rest of intentional phenomena in an SES. The problem, however, is how, both conceptually, and keeping in mind that formal models need to be simple enough to provide advice (Anderies 2015, p. 261).

In the robustness framework, the component that can be seen as intentional is the controller K, which corrects the plant P when its aim is off. In the extension of the fishery model to the general case (Anderies 2015, pp. 270–272), the set of allowable controls (i.e. power) for the controller is denoted by U, and the social choices as to how it is used by J. On the present account, we can expect U to take a different form for every sustained set of social interactions. In addition, Anderies et al. (2007); Anderies (2015, pp. 273–274) point out that the choice of $J(U)$ is not just fixed, but needs to keep track of changing conditions.

The range of SESs simple enough to allow for an informative model whose parameters can be continuously relearned, in a place where people want to try it out, is likely to be very restricted. The insight from the robust control framework is that discrepancies may be addressed by a focus on institutional learning. This, however, raises another question, given the real difference between a hypothetical benevolent policy maker and actual constraints of existing institutions, and the importance of articulating one's own cultural projects to equitable relations of power (Ortner 2006). What are the capacities of communities to design their own arrangements?

The broader issue here is the interplay between social scientific knowledge and power in general, the question what any particular view of social power can suggest as to how the policy to research cycle can be neutral. Theorizing, study, and design of robust institutions are typically conducted by members of relatively advantaged social groups, and could fall prey to the blind spots that reinforce the social differences (Mills 2007) unless explicitly guarding against them (section 9.4). The significance of this concern is borne out by past experience of community-based participatory research (CBPR). In a primer on the topic, Stoecker (2013, pp. 141–148) discusses policy prescriptions from the perspective of meeting communities' needs to research and advocate alternatives to policies actively harming them; the example given is redlining in Chicago neighborhoods. Anderies (2015, p. 264) does open an avenue to address this, citing Scott (1998), an analysis of failed state-centered projects for human betterment. The opportunity is not pursued, even while Scott's work offers convincing grounds to do so. The approach, in effect, assumes a benevolent policy maker.

There are many glib replies to the evolutionary and potentially sensitive political question: *cui bono?*, who benefits in an SES? We now argue for treating social differentiation as a potential (undesired) principle of institutional design.

Designs Ostrom (2005, p. 259) lists eight design principles, common characteristics of institutions over a range of case studies, that were found to be best practices in successful resource management institutions. Anderies et al. (2016) reinterpret these principles as ways institutions process information, with which the present argument is in accord. The design principles play three broad roles with respect to semiotic closure in their domains: tools and tactics; instances of semiotic closure; and structural properties arising from flywheel sociocultural dynamics. We consider each in order briefly; the numbering of principles by Ostrom is given in parentheses.

The *tools* are: monitoring; sanctioning; and conflict resolution. Monitoring (4) works better within relations that promote semiotic closure, for example if the monitors are users (Ostrom 2005, pp. 265–266). Graduated sanctions (5) work similarly on somewhat longer time scales, where closure is achieved to the extent officiators are accountable. Conflict resolution mechanisms (6) help achieve semiotic closure between different views and values with respect to their uses of infrastructure.

Desirable *instances of semiotic closure* are: congruence between conditions and institutions; collective choice arrangements; and rights to organize. Congruence between local conditions and institutional arrangements (2, proportional equivalence between benefits and costs) is closed in pragmatic interaction with ecology and the maintenance of infrastructure. Collective choice arrangements (3) are closed via equity and participation in crafting the rules. Rights to organize (7) open up local innovation in institutional work; this compensates for informational inefficiencies of wider institutional hierarchies, and reduces the need for conflict resolution.

Third, *structural properties* are: boundaries; and nested enterprises. Clearly defined boundaries (1) encourage specialized semiotic closure within them on all scales, from decision making to use rights, by encouraging coordination of repeated material and symbolic exchanges. Nested enterprises (8) reflect the tendency to form smaller structures in partial closure, such as organizations, upon support from lasting infrastructural affordances.

The present argument indicates broad merits of considering *social differentiation* an additional structural design property, one which if manifested as specialization is a principle of good design, while if realized as exclusion can play a design role that is rarely desired.

The first is *prima facie*: human complex societies are usually unequal, in contrast to smaller groups which can move between hierarchical and egalitarian arrangements (Leach 1954; Boehm 1999). Differences in power and influence are a first order variation in characterizing how humans live. Sustained practices that reproduce social differences can thus be expected to play a major role in shaping wider regularities in interactions, including all infrastructure uses outlined in Anderies et al. (2016).

Second, per discussions in 7.2, we would expect any self-maintaining social dynamic to exhibit internal differentiation (section 6.4). In organisms, these manifest as metabolic regulatory relationships (Csete and Doyle 2002). Self-maintaining sociocultural dynamics in CISs are in general much more diffuse, although there is no shortage of visible interdependent specializations in human activity. As has been argued above, differences between social groups can be consensual or coerced, and in either case be functional *for someone*. We can expect social power barriers against giving weight to the representations of excluded groups (section 9.4; Mills 2007), and understanding how this takes place is an explicit need in examining sustained processes in CISs.

Finally, persistent differential uses and effects of infrastructure are avenues of social influence, which makes them candidate vectors for conveying any system-wide influences in implementing institutional advice. The nature of practices maintaining differential uses of infrastructure will affect the feasibility, advisability, pace, and possible extent of any institutional changes.

Identifying social differences and their role in sustaining interactions in CISs in empirical work is likely to present a considerable challenge. The previous chapter suggested that the semiotic perspective can serve as a bridge among research perspectives, and the remainder of this chapter turns it toward this aim. The guiding concept of semiotic closure is enrolled to motivate the discussion of transdisciplinary collaboration as closure within research, research of knowledge work as efforts toward closure in the field, and participatory methods to achieve closure between the two.

10.2 Praxis

In the last chapter, several perspectives from across social sciences were suggested to intersect with the current semiotic view. The plurality can be seen as promising, but also a cause for concern. Any gain derived from the approach depends on how well it can be used to compare different perspectives, and the proliferation of possibilities brings up the question where to start, as well as whether the possibilities are so divergent that comparisons are likely to be superficial.

To make sense of the possibilities, we again enroll the notion of semiotic closure. In chapter 2 we noted that perspectival approaches need to be included as plausible social scientific explanations, as long as they are not dogmatically circular (Anderson 2017). We can now rephrase this that, to be credible, theories and methods need to be semiotically closed with the subject of their study rather than, or in addition to, with other requirements of their existence.

First, as relevant viewpoints in transdisciplinary research of sociocultural processes are uncertain, infrastructural options that allow for experimentation with and juxtaposition of various approaches are discussed on the ideal level. Next, a potential study of knowledge work in the food movement in an area is outlined and its possible extensions examined. Finally, potential benefits of participatory research are noted.

Reaches The previous chapter mentioned a number of avenues to the study of mutually reinforcing interaction networks in societies and cultures. Detecting empirical proxies of such sustained dynamics is likely to involve coordination of many methods, such as analyses of cultural content, social networks, institutional arrangements, and power relationships. Given the overhead of a transdisciplinary study and the diversity of potential CISs to examine, the first issue of research design is thus infrastructural: what the options are for organized coordination among diverse studies, along with the realistic limits on doing so within existing institutional affordances. To chart the ground coordinated research efforts can occupy, consider for a moment hypothetical extremes in the dichotomies of logistics of social influence Mann (1986, pp. 6–10): collective/distributive, intensive/extensive, authoritative/diffuse.

A distributive, "power over" research approach would attempt to anticipate as many shared protocols in advance, defining a narrow focus to future study and allowing only gradual adjustments. On the other hand, a collective, "power with" approach would encourage complementary, partly independent projects. Both offer advantages in the study of sustained relationships on CISs. The first is fairly common in academic research, and while it encourages disciplinary fragmentation, studies following shared conventions are more easily comparable. On the other hand, a collective approach allows researchers to choose methods appropriate to the study and to their own predispositions. Each discipline makes its own simplifications, and as we aim to combine perspectives that would compensate for each other's blind spots, we do not know ahead of time which are relevant. Repeating the same combinations risks repeating the same domains of ignorance, and a collective orientation provides room to experiment with alternatives.

Similarly, most research undertakings are intensive, requiring concentrated commitment and organization. To the extent extensive organization truly is "minimally stable" (Mann 1986, pp. 7–8), we do not expect it to play a large role in study. This, however, points to an intrinsic barrier both to data available to an research discipline, requiring intensive organization for each gathering effort; and to the lack of reach of its methods and findings across contexts where they can be of use, the full extent of which is barely known. An extensive research effort would need to reach outside institutional boundaries, for example by encouraging and collaborating with citizen science initiatives.

Finally, social studies are authoritative in that they are "willed by groups and institutions" (Mann 1986, p. 8). The advantages of diffuse organization over wider scopes are, however, suggested by the requirements for the onset of a flywheel. Once diffuse interactions become frequent and versatile enough, they can reach the point of mutual reinforcement and eventually become self-sustaining.

A possible horizon for coordination of transdisciplinary study can thus be proposed: large scale semiotic closure in research, mutual comparison between different perspectives and research efforts, lay and academic, intensifying to the point where it starts producing well rounded accounts of sociocultural dynamics, and counteract pressures to fragmentation. Such synergy is, admittedly, hard to imagine under present guiding assumptions, requiring ways for widely different viewpoints to communicate on comparable terms. The present essay has examined one potential set of shared concepts, subject to practical appraisal and revision.

We now briefly discuss a study design that brings together several approaches considered in the previous chapter, in examining the diversity of the alternative food movement in an area.

Knowledges Cote and Nightingale (2012) suggest that resilience studies pay more attention to the practices of knowledge creation and use: in other words, to conscious efforts by participants to achieve semiotic closure among their own representations, practices, and aims. Foregrounding local knowledge work also anticipates the need for future institutional learning, as well as for guarding against blind spots to social differences. We turn now to consider an attempt to formulate such a study of alternative food initiatives (AFIs) in an area (Božičević 2015), and its discuss possible insights and limitations. (Short excerpts of a working paper handed out during the presentation of Božičević (2015) have been carried below verbatim.)

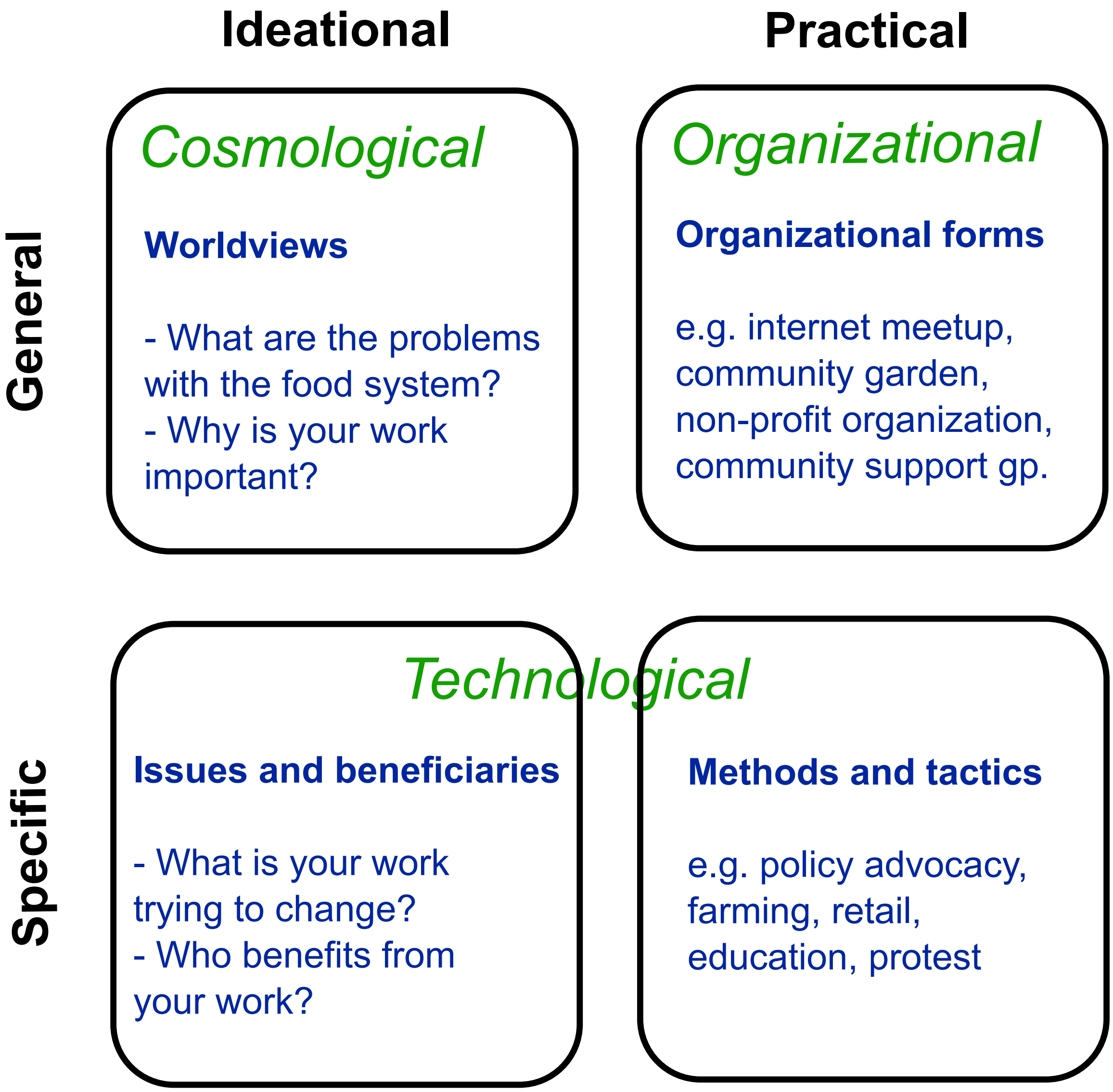
The main motivation of the proposed study has been to analyze the diversity of concerns and initiatives in alternative food activism (Gottlieb and Joshi 2010; Hinrichs 2014), with the aim to discern wider patterns in social movement practices in the heterogeneous environment of a major United States metropolitan area. The research design draws on two prior qualitative studies: of beliefs and practices of AFIs across California by Allen et al. (2003), and of knowledge work in intensive rotational grazing in Wisconsin by Hassanein and Kloppenburg (1995). While the former inquiry overlaps in the subject matter and the study area, the latter informs the conceptual approach.

Hassanein and Kloppenburg (1995) studied dairy farmers who, against the prevailing trends, had chosen to graze their cows rather than raise them in feedlots. This reduced the graziers' dependence on inputs, but made it necessary to monitor the pasture and manage the cattle more closely. After realizing that land grant universities and corporations had little useful advice to give them, the farmers took to creating and curating their own knowledge, forming organizations for horizontal exchange of information. Hassanein and Kloppenburg (1995) apply the perspective by Eyerman and Jamison (1991), who see social movements as tied to knowledge work, or cognitive praxis. Dairy farmers' knowledge practices are analyzed from the point of view of three dimensions of cognitive praxis proposed by Eyerman and Jamison: cosmological (self-understanding), technological (ecological knowledge and cattle raising skills), and organizational (knowledge exchange meetings).

Božičević (2015) argues that the dimensions of cognitive praxis can be mapped onto cultural content coordinates parallel to ones employed by Mohr and Neely (2009) to analyze aspects of power in the work of New York carceral organizations in 1888. Four categories of knowledge work of social movements are proposed: worldviews, issues, organizational forms, and methods (figure 10.1). In case of alternative food, the growing range of disparate *issues* initiatives address include concerns about farming, technology, trade, nutrition, health, the environment, and other areas (Hinrichs 2014; Hinrichs and Eshelman 2014). Cohen (2014) notes the variety of innovative *organizational forms* in local food production and distribution, and compares their interactions to those of "species in a healthy ecosystem." Initiatives' *methods* also vary, challenging prevailing practices directly and indirectly, acting both within and outside established institutions (Allen 2004; Hinrichs and Eshelman 2014). Finally, issues, organizational forms, and methods are informed by AFIs members' *worldviews*: systemic problems their work aims to address, and the ultimate goals they envision for the food system (Allen et al. 2003; Mares and Alkon 2011; Holt-Giménez and Shattuck 2011).

These domains of movement knowledge inform, in turn, cultural content analysis, which along with the social network study of relations among AFIs, it is claimed, would help indicate the exclusionary effects of infrastructure, as well as any differences arising from emergent specialization. It is likely, though, that such an inquiry would fall short of conclusively delineating relationships comprising a flywheel, although it can indicate some of them. For example, blockmodeling analysis by Ernstson et al. (2008) of networks of environmental organizations in Stockholm has revealed a core-periphery structure facilitating collective cognitive praxis. A few organizations with legal and political expertise relied on a diffuse network of local associations, which could quickly inform them of developments on the ground, such as illegal construction, allowing for timely intervention with city authorities. While based only on one network survey, the structure of interactions suggests specialization by knowledge work sustained through repeated interactions toward a common aim, proclaiming green areas of Stockholm a National Urban Park.

These and most other analyses of content and networks (e.g. Bodin and Crona 2009) represent only momentary snapshots of effects of infrastructural influences. They tell us little about the direction of social change, which means we cannot discern the shape of any driving dynamic in CISs. The most direct way to address this issue is to conduct a longitudinal study, to revisit the same study area later in time and chart any changes. Such efforts, however, require decade long commitments. Employing Mann's (1986) terms,



	Ideational	Practical
General	*Cosmological* **Worldviews** - What are the problems with the food system? - Why is your work important?	*Organizational* **Organizational forms** e.g. internet meetup, community garden, non-profit organization, community support gp.
Specific	*Technological* **Issues and beneficiaries** - What is your work trying to change? - Who benefits from your work?	*Technological* **Methods and tactics** e.g. policy advocacy, farming, retail, education, protest

Figure 10.1: The articulation table for social movement cognitive praxis (knowledge work), based on Mohr and Neely (2009) is shown in blue. The dimensions of cognitive praxis originally proposed by Eyerman and Jamison (1991) are shown in green. Adapted from Božičević (2015).

longitudinal studies cannot be extensive: we cannot expect many of them will soon be conducted and bear general results.

We note, though, that the range of possibilities is so wide that any study will have lacunae, and that at this point we do not know which such blind spots are salient. The question then becomes how an inquiry can compensate for its shortcomings, by anticipating (potentially extensive) comparison with related research. For example, the above proposal revisits a part of the same region Allen et al. (2003) examined with different methods, and uses similar methods as Levkoe (2014) in a geographically distant area.

An intermediate approach between a longitudinal study and serendipitous comparison would be to analyze two areas in tandem, as Baldassari and Diani (2007); Diani (2015) did analyzing movement networks in Bristol and Glasgow. These studies have found, for example, that network structure reflects varying levels of political polarization resulting from different movement histories of the two cities. While the approach is insufficient to track changes over time, it can reveal the topology of dominant power configurations. Such patterns may be easier to detect than actual mechanisms of change, and can have analogies in evolutionary ecology. For example, mating behaviors within species as well as some trophic relationships stabilize into a trio of strategies in a rock-paper-scissors fashion. The broadest networks of influence in a society could fall into similar patters.

Participations The final semiotic closure to be considered runs between research and the field: a possible role for participatory research in building capacities for institutional learning. The topic is extensive and would be best treated with a particular study in mind; I will keep to a few basic observations.

The necessity of institutional learning, of adaptive change in institutions in a SES with respect to the surrounding biophysical, political, and community conditions, points to the need for SES stakeholders to develop capacities to scrutinize their arrangements and modify them. As discussed briefly above, the studies of robust feedback are very far at best from being able to provide such advice on a widespread basis. On the other hand, stakeholders such as grass dairy farmers have, in a period of time appropriate to meeting their need, organized to develop knowledge about how to combine different uses of infrastructure.

This points to seeking ways for research interests to facilitate such organization through direct involvement with the community or a close intermediate. An example from resilience studies are community workshops alongside agent-based modeling of land use in Vietnam (Castella et al. 2005). Of the methods discussed above, maps of cultural content and network relationships can easily be presented to non-experts. In addition to providing empirical insight into wider sociocultural dynamics, the results of such research would be well suited to informing organizations and public forums that mediate between municipal agencies and communities, such as food policy councils.

Participatory research is also no panacea: Cote and Nightingale (2012) note instances in which putatively inclusive management efforts have been co-opted by local elites and state authorities. Thus, any effort that combines research and practice will require coordination of plural ways of gaining insight and ensuring the advice ends up in the right hands, indeed a collaborative assessment of what the right hands may be.

At this point, the following elaborations to the research directions outlined in Anderies (2015) can be proposed:

1. Case studies informing the typology of common SESs in a complex society would need to keep track of how differential uses of infrastructure affect SES dynamics, and of how such differences manifest in relations among and cultural understandings of the social groups affected.

   Cote and Nightingale (2012, p. 483) suggest that, “[i]f knowledge is multidimensional and processional, culture, world-views and axes of social differentiation such as gender, class and race are crucial starting points to understand the positions from which actors become enrolled in decision-making processes." The present essay agrees, and has suggested a combination of mixed-method relational and critical approaches to charting these positions.

2. There is a need to devise techniques of formal modeling of SESs that keep track of emergent differentiation and cultural text. A starting point discussed in chapters 6 and 9 are autocatalysis and random grammars (Kauffman 1993, chs. 7, 10).

3. Perhaps most significantly, the design methodology can best be assumed to be neutral if it explicitly incorporates a level of analysis inquiring into its own semiotic closures.

   There is a level between robust control and implementation that is intrinsically cultural and political, and it needs to be considered both in research and practice. In research, as differences in access to, use of, and effects of infrastructure mediate social power and decisively shape human lives. They are also the first source of information about harmful effects often hidden in plain view. In practice, institutional learning can not, and indeed has not historically, depended on robust control. Thus a salient interest is not just how to design institutions, but how research can best aid and build on any institutional design skills and practices already present.

CHAPTER 11 FUTURE DIRECTIONS

This essay has argued that social power manifests as self-reinforcing networks of symbolic interactions, “flywheels,” unfolding over different scopes in time and society, exhibiting a degree of distributed intentionality. It is suggested that this picture is consilient with natural sciences, with self-reinforcing networks appearing as wider sociocultural evolutionary dynamics, in which information is reproduced in social interaction and inscribed in persons and activities. This view of social power is applied to research in institutions and robustness in social-ecological systems (SESs) (Ostrom 2005; Anderies et al. 2016; Anderies 2015).

To argue that human symbolic interactions serve as a reproduction channel for an evolutionary process has required establishing more firmly the link between semiotic (representational) and physical processes. In chapters 6 to 8, a semiotic framework is applied to trace the nature of representation from its origins at the onset of natural selection, to the evolution of a symbolic code in genes, to other codes such as developmental switches and cognition (Sebeok 2001; Deacon 2012; Kauffman 1993; Dennett 1991, 2017; Maynard Smith and Szathmáry 1995). Human symbols are argued to be the one representation apart from genes that supports an open-ended evolutionary process, with flywheels, based on autocatalysis, a general model for wider dynamics.

The picture offered is broader though less formally developed than the dual inheritance view by Boyd and Richerson (1985, 2005); Henrich and Henrich (2007), which is here seen to apply to special cases. All the main objections against this and other recent sociocultural evolutionary approaches raised by Fracchia and Lewontin (1999); Ingold (2007) are, however, met in the present account (section 9.4). In particular, there is a firm recognition of the role of complex social relationships and textual structures in shaping human activities. Symbolic sociocultural reproduction is seen as fully dependent on contexts of interaction, and a range of learning theories is expected to be relevant to understanding it. Humans and groups can exercise agency on wider scopes through the means of social power they have access to, implementing their culturally informed projects and potentially leaving intentional marks on history.

There are many directions in which the account of semiotics of emergent and living processes in chapters 5 through 8 can be extended. Of the most immediate, the analysis of parallels with Deacon's (2012) account of intentionality and can be deepened by considering further specific examples and models. Informational characteristics of evolutionary events can be estimated both analytically and computationally, contributing a formally justified model of the evolutionary origin of semiosis from chapter 6 to biosemiotic analyses (Pattee 1982; Rocha 2001). Finally, the analysis of semiotics of evolutionary transitions in chapter 8 can be elaborated through further comparison to Beach (2003), models of information capacity of somatic representations (e.g. Tkačik et al. 2008), and empirical results (e.g. on cephalopod gene editing, Liscovitch-Brauer et al. 2017). Finally, if we were to formally model flywheel dynamics in society, a model of autocatalysis or random grammar would be one possible start (Kauffman 1993, chs. 7, 10).

Social activity, the channel of reproduction of sociocultural information on the present account, corresponds to the action situation in Ostrom (2005). Anderies et al. (2016) rightly note the importance of known regular influences of such situations, infrastructures, as well as the informational nature of design principles. Since robust-control like relationships are associated with specialization and differentiation of a self-reinforcing process, it is differential access to infrastructure, it is argued, that drives these feedbacks. Precisely for this reason, different social groups in a SES are likely to have divergent aims toward and cultural narratives about the infrastructures, and their and others' uses of it.

It is significant to gather these narratives to prevent ignorance effects, such as those outlined by Mills (2007), which play a feedback-like role in social differentiation by maintaining exclusion. Also, entities relying on longer lasting infrastructures, such as organizations, are expected to form patterns in cultural narratives and mutual relationships that reflect the overall differentiation as well as any shorter term emergent dynamics; such patterns may be fruitfully studied. Finally, self-reinforcing dynamics are in semiotic closure, able to partly represent and reproduce themselves. Any practical attempt at design of robust institutions needs to consider how its own activity, institutional learning, can be semiotically closed in a SES. Any widely applied approach to institutional design needs to be participatory, as Anderies (2015) points out, and so needs to favor methods that aid the participants in advising their own institutional choices. Chapter 10 proposes a hypothetical study that incorporates some of these suggestions in researching alternative food organizations in a locality, and considers its shortcomings. Longitudinal and tandem comparison study designs are suggested as possible improvements, and the need for coordination among disparate research approaches is noted.

Every research tradition has its own idea why its work is justified in its context; human social and cultural phenomena are multifaceted and can be fruitfully understood from many angles, difficult to tally, let alone reconcile. For social research in general, the implication from chapter 9 is that an account produced in a study needs to be in some meaningful way semiotically closed with the empirical phenomena it examines, on top of other assumptions; as Anderson (2017, sec. 6) pointed out, we can be prejudiced but not dogmatic. In starting the more encompassing contexts of conversations among these efforts, the question becomes what common points can link studies across a diversity of perspectives.

If, as is argued, sociocultural dynamics are in some part evolutionary, explanation starts with the four questions (Tinbergen 1963): how does it manifest in our actions, how is it learned or reproduced, what is the history, what does it shape and what shapes it. It would benefit any research tradition, thus, to choose whom to trust on those of the stances it does not address, and to pursue common study interests. For competing accounts of the same phenomenon, one can compare and contrast all four explanations and methods that justify them, then ask the evolutionary and potentially difficult question: *cui bono?* To whom are they informative and what good or ill can they do?

Chapter 10 briefly discusses the logistical challenges of coordinating many disparate perspectives. Such exchanges, it is argued, would need to overcome academic institutional limitations against extensive (widely publicly available) and diffuse (versatile but interacting) ways to coordinate. An eventual prize goal is a network of conversations, potentially self-reinforcing and supracritical with respect to the breadth of societies and cultures, in balance with the fragmentation still needed to explore novel insights.

Science fiction? Perhaps.

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