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Mind outside Brain:

a radically non-dualist foundation for distributed cognition

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Abstract: We approach the problem of the extended mind from a radically non-dualist perspective. The separation between mind and matter is an artefact of the outdated mechanistic worldview, which leaves no room for mental phenomena such as agency, intentionality, or experience. We propose to replace it by an action ontology, which conceives mind and matter as aspects of the same network of processes. By adopting the intentional stance, we interpret the catalysts of elementary reactions as agents exhibiting desires, intentions, and sensations. Autopoietic networks of reactions constitute more complex super-agents, which moreover exhibit memory, deliberation and sense-making. In the specific case of social networks, individual agents coordinate their actions via the propagation of challenges. The distributed cognition that emerges from this interaction cannot be situated in any individual brain. This non-dualist, holistic view extends and operationalizes process metaphysics and Eastern philosophies. It is supported by both mindfulness experiences and mathematical models of action, self-organization, and cognition.

Introduction

Socially extended knowledge is an aspect of the more general thesis of the *extended mind* (Clark & Chalmers, 1998; Palermos & Pritchard, 2013; Pritchard, 2010), which states that mental phenomena, such as memory, knowledge and sensation, extend outside the individual human brain, and into the material and social environment. In other words, the skull can no longer be seen as a clear physical boundary between (inside) mind and (outside) world.

While the extended mind hypothesis originates in philosophy, a number of closely related conceptions have been formulated in cognitive science under headers such as *situated*, *embodied*, *enactive* and *embedded cognition* (Anderson, 2003; Clark, 1998; Stewart, Gapenne, & Paolo, 2014; Susi & Ziemke, 2001). The general idea is that human cognition is not confined to information processing within the brain, but actively dependent on external phenomena. These include the body, cognitive tools such as notebooks and computers, the situation, the interactions between agent and environment, communications with other agents, and social systems. We will summarize this broad scale of "extensions" under the header of *distributed cognition* (Hutchins, 2000), as they all imply that cognitive content and processes are distributed across a variety of agents, objects and actions. Only some of those are located inside the human brain; yet all of them contribute to human decisions by providing part of the information necessary to make these decisions.

While the distributed nature of information processing is difficult to deny, the extended mind thesis remains controversial. The reason seems to be that most philosophers investigating this idea feel that there is a fundamental difference between truly "mental" phenomena, such as belief, desire or intention, and the merely "mechanical" phenomena of information transmission, storage and processing. Thus, the Alzheimer patient Otto, who relies on his notebook as an external memory in the original "extended mind" thought experiment (Clark & Chalmers, 1998), does not really seem to outsource his desires, intentions or beliefs to his notebook. He merely believes (internally) that this notebook is a dependable tool for storing information (externally) that his own brain cannot reliably store. These and other intuitions about how the mind works fuel an on-going discussion about whether and in how far mental phenomena truly can extend outside of the brain.

The aim of the present paper is to propose a radical resolution to this controversy: we assume that *mind* is a ubiquitous property of all minimally active matter (Heylighen, 2011). It is in no way restricted to the human brain—although that is the place where we know it in its most advanced, complex form. Therefore, the extended mind hypothesis is in fact misguided, because it assumes that the mind originates in the brain, and merely "extends" itself a little bit outside in order to increase its reach, the way one's arm extends itself by grasping a stick. While ancient mystical traditions and idealist philosophies have formulated similar panpsychist ideas about the ubiquity of mind (Seager & Allen-Hermanson, 2015), the approach we propose is rooted in contemporary science—in particular cybernetics, cognitive science, and complex systems theory. As such, it strives to formulate its assumptions as precisely and concretely as possible, if possible in a mathematical or computational form (Heylighen, Busseniers, Veitas, Vidal, & Weinbaum, 2012), so that they can be tested and applied in real-world situations—and not just in the thought experiments beloved by philosophers.

But before we can elaborate our thesis of a ubiquitously distributed mind, we need to explain why this idea appears so radical, and why the comparatively modest hypothesis of extended mind or extended knowledge remains so controversial. For this we need to go back to what we see as the root of the problem: Cartesian dualism and Newtonian mechanics.

From dualism to action ontology

Descartes formulated his philosophy of the fundamental duality of mind and matter in the context of the mechanistic worldview that was emerging at the time. In Descartes's view, the body was merely a complicated mechanical system, an automaton essentially equivalent to a clockwork in which one gear passes on its movement to another gear. This understanding was later elaborated scientifically by Newton, Laplace and their successors as the foundation for the mechanistic worldview (Toulmin, 1993), which became dominant in the 19^{th} century. We will from now on refer to this mechanistic vision of the world as the *Newtonian worldview* (Heylighen, Cilliers, & Gershenson, 2007). By investigating its assumptions, we will try to clarify why Descartes and many thinkers after him felt they had to introduce mind as a realm separate from the realm of matter.

The Newtonian worldview reduces the world to a collection of material objects that move through space along fixed trajectories. The laws of mechanics specify how one material body exerts a force on another material body, thus affecting its movement—in the same way that a gear transmits movement to another gear. These laws completely determine the trajectories of all material bodies—just like the movement of a clockwork is rigidly fixed by the configuration of its gears. To clarify the implications of this theory, in a famous thought experiment Laplace imagined a demon that would be able to precisely observe all the positions and velocities of all the pieces of matter in the universe. Using this information together with the laws of mechanics, this demon would be able to predict all movements at any point in space or time, and thus anything that would ever happen. Such deterministic picture implies that there is no freedom to intervene, to choose between different courses of action, or to act intentionally.

To Descartes it was obvious that the mind has such freedom. Therefore, the mind cannot be subjected to mechanical laws. But since all matter obeys such laws, the mind cannot be material. Therefore, the mind must be independent, belonging to a realm separate from the realm of matter. This in principle allows the mind to leave its material body—the way the soul is supposed to do in the religious conception of dying.

However, this assumption immediately creates a paradox: if mind and matter are independent, then how can the one affect the other? The seemingly unsolvable mind-body problem (McGinn, 1989) is in essence a series of variations on the following two questions:

1) how can the immaterial mind sense, feel or become conscious of the material world, i.e. be affected by matter?;
2) how can this mind in turn affect the matter of the body and through it the material world, given that the behavior of this matter is already rigidly determined by mechanical laws?

In part because of these problems, the strict Cartesian separation between mind and matter has been abandoned by all but a few contemporary scientists and philosophers. Most scholars nowadays agree that the mind supervenes on the matter of the brain, i.e. it cannot exist without the presence of this material infrastructure. Thus, few academics still believe in the existence of an immaterial soul. However, in practice most of them still stick to what Dennett has called "Cartesian materialism" (Dennett & Kinsbourne, 1992). This is the implicit assumption that while the mind is somehow constituted out of the matter in the brain, it still has some kind of autonomous agency that separates it from the rest of the world. This intuition is based on the same apparent inconsistency observed by Descartes between the mechanistic view of the world and our experience of free will—however without offering any resolution to the paradox.

This intuitive separation between mind and world is reinforced by what Chalmers has called the "hard problem of consciousness" (Chalmers, 1995). The mind does not only freely decide and act, it also subjectively experiences the world; it "feels" the phenomena it encounters. If the mind were merely a mechanical system, then it seems that there would be no room for such subjective experience or phenomenal consciousness. The only way to affect a mechanical system is to affect the movement of it material components; the matter itself, however, remains inert, unresponsive, insensitive. Chalmers illustrates this problem with the zombie thought experiment—where a zombie can be seen as a robot-like creature in which incoming stimuli are transmitted and processed through the forces inside the mechanism, eventually producing outgoing actions. Thus, a zombie is merely a more sophisticated, intelligent version of the automaton conceived by Descartes as a model of the body. Assuming that we could build a zombie that is not distinguishable in its behavior from a real human person, then—the argument goes—that zombie would still be lacking something essential, namely phenomenal consciousness. Though it may move, act and react like a person, it cannot feel like a person. Thus, the mind somehow still has this mysterious property of experience that is absent in matter.

Thus, we see that modern conceptions of mind are still implicitly dualist, even though few would deny its materialist basis. Our position is that this continuing separation is an artefact of the Newtonian worldview. Mind seems incompatible with the material world merely because we have a much too simple, outdated view of what that world really consists of.

Modern physics, chemistry and biology have long abandoned the reductionist and deterministic Newtonian worldview. Instead, they see the world as a network of processes. The "matter" that constitutes it is completely unlike the inert "billiard-ball"-like particles following predetermined trajectories as envisaged by Newtonian mechanics. Instead, quantum field theories see particles as merely temporary, local "condensations" of fields representing potential interactions. Particles are constantly being created and destroyed by elementary particle reactions, and this in a fundamentally indeterministic manner. For example, it is intrinsically impossible to predict when a radioactive atom will decay into smaller particles: two identical atoms in identical states will in general decay at different times. Particles constantly emerge out of nothing and then disappear again in the form of virtual particle-antiparticle pairs produced by quantum fluctuations of the vacuum (Milonni, 2013). Such a virtual particle can even become real (i.e. stable) when its partner is absorbed e.g. by a black hole (Hawking, 1975).

At a higher level, the molecules that constitute living organisms are similarly ephemeral, constantly being produced and consumed by the chemical reactions that constitute the organism's metabolism. Here again, whether a particular molecule will be formed or not is fundamentally unpredictable. Cells and organelles in the body too are in a constant flux, being broken down by processes such as apoptosis and autophagy, while new ones are grown through cell division and from stem cells. The same processes can again be found at the level of ecosystems, where relations of predation, symbiosis and reproduction between organisms and species join with meteorological and geological forces to produce a constantly changing landscape of resources and constraints, opportunities and dangers.

All these processes are indeterministic because of the underlying Heisenberg uncertainty principle, which entails that some properties of quantum systems can never be determined, and that their behavior is only statistically predictable. But this indeterminism is not limited to the microscopic quantum world, as is often thought. First, there are plenty of physics experiments that illustrate how quantum systems can produce macroscopically observable effects. More generally, non-linear dynamics and chaos theory have shown that most non-trivial systems, such as the weather, the brain or society, exhibit a variety of "butterfly effects" (Heylighen et al., 2007; Hilborn, 2004; Smith, 1990): the non-linear amplification of microscopically small fluctuations into major, macroscopic changes—such as the emergence of a hurricane triggered by the fluttering of the wings of a butterfly. Therefore, most real-world processes are fundamentally unpredictable, at either microscopic or macroscopic scales.

However, these processes are not random, but *evolutionary*: they have a preferred direction towards survival, adaptation and growth (fitness), engendering increasingly complex and intelligent forms of organization (Heylighen, 1999). Thus, they lead to the emergence of ever more sophisticated, meaningful and adaptive forms. This evolutionary worldview (Heylighen, 2011; Heylighen et al., 2007) is very different from the lifeless, static picture of the clockwork universe, where inert pieces of matter follow predetermined trajectories. As we will argue further, in such an evolving, interconnected world, mind no longer appears like an alien entity that cannot be explained by scientific principles, but rather as a natural emanation of the way processes and networks self-organize into goal-directed, adaptive agents.

This is not really a novel idea. It has been formulated by philosophers such as Whitehead, Bergson and Teilhard de Chardin under the label of *process metaphysics* (Rescher, 1996; Teilhard de Chardin, 1959; Whitehead, 1978). But analytically trained philosophers are understandably not very keen on these rather mystical and obscure theories, preferring the clear distinctions of logic and mathematics to these poetic and grandiloquent writings. Therefore, analytic philosophy has tended to stay firmly rooted in the reductionist approach of Newtonian science. The problem is that this leads it straight back into an implicit dualism, and its apparently unsolvable mind-body problem.

The thesis of this paper is that you can have your cake and eat it: it is possible to develop an understanding of the mind that is both non-dual *and* analytic—in the sense of based on clearly defined, formal distinctions. To achieve that, we need to replace the vagueness of process metaphysics by the concreteness of what may be called *action ontology*

(Heylighen, 2011; Turchin, 1993). That will allow us to "extend" the mind not just across notebooks and social systems, but across the whole of nature and society.

Agents and the intentional stance

Taking its cue from quantum field theories (Bickhard, 2011; Cahill, 2005; Turchin, 1993), the action ontology is not based on static substances, particles or pieces of matter, but on dynamic actions or reactions. These are elementary processes that lead from some initial condition X to a subsequent condition Y:

$$X \rightarrow Y$$

These conditions can in general be decomposed into conjunctions of more elementary conditions. Adopting the notation used for reactions in physics and chemistry, we will denote conjunctions by the "+" operator:

$$a + b + \ldots \rightarrow e + f + \ldots$$

A reaction can be interpreted in several, approximately equivalent manners: as a transition from the state X to the next state Y; as a causation producing the effect Y out of the cause X; as a production rule, to be read as "if X, then Y", which specifies under which condition X the action (change of condition) Y is produced. Note that reactions are in general not deterministic: the probability that Y would follow X is not necessarily 1. This indeterminism becomes clearer when more than one condition can follow a given condition: $X \rightarrow Y$, $X \rightarrow Z$ means that in the condition X, the conditions Y and/or Z can be produced.

Conditions merely specify that some distinguishable category of phenomena is present at the beginning or end of the reaction. Therefore, reactions can represent processes in any domain or discipline. This is best illustrated by a few examples, as listed in Table 1.

Elementary particle reaction
$n \rightarrow p + e^- + \nu e$ (Beta decay of neutron)
Chemical reaction
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (burning of methane)
Ecological process
plants + sunlight + carbon dioxide + minerals → more plants + oxygen
Causal rule
Glass falls + hard floor → Glass breaks
Action of thermostat
Temperature < 21° → switch on heating
Animal action
dog + meat → dog + meat eaten
Human action
See friend → greet friend

Table 1: examples of reactions in different domains

In all these examples, the reaction starts from a distinguishable initial state, which is then transformed into a new state. While this may seem to make reactions dependent on states, in fact states can be defined in terms of the reactions that are possible in that state (Heylighen, 2011; Turchin, 1993). (This is similar to how quantum mechanics defines properties in terms of the observation processes that can be used to establish the presence of such properties.) Thus, (re)actions or processes are truly the building blocks of the action ontology, while states are secondary.

Agents (A) can be defined in this framework as necessary conditions for the occurrence of a reaction, which however are not themselves affected by the reaction;

$$A + X \rightarrow A + Y$$

In chemistry, the function of A is the one of a catalyst: it enables the reaction that converts X into Y. Since A remains invariant during the reaction, but needs to be present in order for the reaction to take place, it can be seen as the agent of the conversion. The *reaction* between A, X and Y can therefore be reinterpreted as an *action* performed by the *agent* A on condition X in order to produce condition Y:

$$A: X \rightarrow Y$$

Agents will in general participate in different reactions. This means that they are able to perform different actions, reacting to different conditions by different actions producing different new conditions. For example:

A: X → Y, Y → Z, U → Z, V → W, E → F, F → G, W→ G, …

We are now ready to ascribe rudimentary mental properties to an agent. First, agents have "sensations": they are able to sense the conditions to which they react, acting differently under different conditions (X, Y, U, …). Inert pieces of matter do not react to specific conditions with specific actions: they are "insensitive" to their situation.

Second, agents have "desires" or "goals". One way to understand this is by noting that the list of actions that an agent can perform defines a *dynamical system* (Beer, 1995, 2000). This is a mathematical model of a process that describes possible trajectories in a state space, leading from some initial state (say X), to the next state (Y), and the next (Z), and so on. Dynamical systems typically have one or more *attractors*. These are states or subsets of states that are in a sense end points of the process: different trajectories lead into the attractor, but no trajectory leads out of it. In the example of agent A above, Z and G are attractors (see Fig. 1). Starting from X or Y, the system will end up in Z; starting from V, E, F, or W, the system will end up in G.

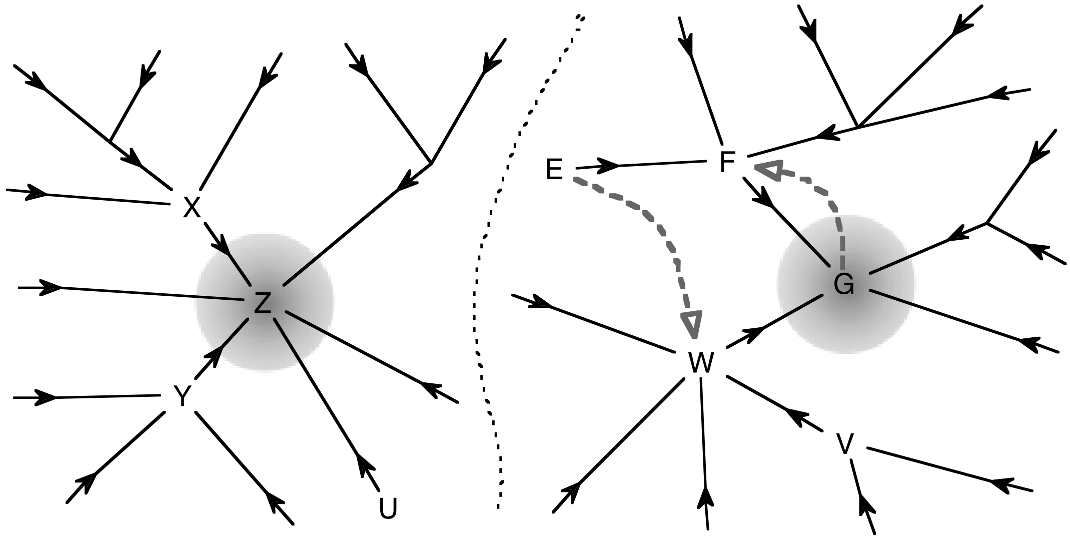

Figure 1: a phase portrait of the dynamical system defined by the agent A. Arrows represent the agent's actions leading from one state (e.g. X) to the next (e.g. Z). The shaded areas Z and G are attractors, each surrounded by their basin, from which all courses of action lead into the respective attractor. Curvy broken arrows represent external disturbances, which make the state deviate from its normal course of action

The states that lead into an attractor define the attractor's *basin*. For example, V, W, E, and F are part of the basin of the attractor G. That means that it does not matter from which state in that basin the process starts: the end result will always be G. This property is called *equifinality*: different initial states produce the same final state (Von Bertalanffy, 1973). Let us assume that the state of the system is disturbed by some outside intervention, for example pushing it out of the attractor state G into basin state F, or diverting its trajectory from E to W instead of F (see Fig. 1). As long as the deviation remains within the basin, the end result will anyway be G: the disturbance is neutralized by the system. It is as if the agent is actively intervening in order to secure the reaching of the attractor, e.g. by pulling the perturbed state back from E into G. Therefore, we can interpret G as a "goal" of the agent, i.e. a state that it desires to reach, and that it will defend against any perturbation that might push it away from this preferred state.

The trajectory that the system would follow without disturbances can be interpreted as the agent's *course of action* (Heylighen, 2012): the sequence of steps that it needs to perform in order to reach its goal starting from the present state. Each action in that sequence can be seen as intentional, directed at reaching the goal. The disturbances, which make the agent deviate from its course, on the other hand, are unintentional. They are the *challenges*, originating in the outside world, which the agent does not control, but which it may be able to tackle by appropriately changing its course of action.

This reinterpretation of a dynamical system as a goal-directed agent is an application of what Dennett has called the *intentional stance* (Dennett, 1989). It assumes that the behavior of systems can be seen as if it were intentional, i.e. directed towards some future goal state. In contrast, the more traditional causal or mechanistic stance (which Dennett calls "physical") assumes that that behavior is better seen as a sequence of causations, in which the present state produces the next state, which produces a subsequent state, and so on. As we have shown with our example, the two stances are equivalent, in the sense that the one can in principle be translated into the other one.

This can be proven mathematically: each "causal law" in physics (where subsequent states are derived from previous states) has an equivalent formulation as a "variation principle" or "optimization principle" (Bordley, 1983). These include the principle of least action (Feynman, Leighton, & Sands, 1964; Kaila & Annila, 2008), the second law of thermodynamics (viewed as the maximization of entropy), and the minimization of potential energy. In the optimization formulation, trajectories are calculated so that some variable would reach an "optimal" (minimal or maximal, as the case may be) value. Optimizing some value (such as "utility") is precisely the behavior that is expected from a rational agent, whose desire is to achieve the "best possible" outcome. This mathematical equivalence between causation and optimization is not limited to physics, but can be proven for dynamical systems in general (Mesarović & Takahara, 1975).

In practice, the equivalence means that causation (physical stance) and optimization (intentional stance) are equally useful perspectives for describing simple, deterministic systems. For example, you can describe the falling of a stone as the effect of the gravitational force causing the stone to accelerate downwards to the floor (physical stance), or as a process in which the stone tries to minimize its potential energy by moving to the lowest position available (intentional stance). Since force in physics is defined as the derivative of potential energy, the mathematical descriptions are equivalent. In more complex, difficult to predict systems such as organisms or social systems, however, it is easier to reason by specifying the optimal values, attractors or desires that direct the overall movement of the system, because the actual trajectory will be diverted by so many unforeseeable perturbations that causal reasoning becomes essentially unreliable (Heylighen, 2012). That is why we normally use the intentional stance to describe intelligent—typically human—agents.

Panpsychism and the Theory of Mind

Let us delve a little deeper into what the intentional stance says about the mind, and how it relates to panpsychism and our proposed radical non-dualism. Dennett (1989) introduced the intentional stance as a level of abstraction in which the behavior of some putative agent is described in terms of mental properties, and in particular the properties of *belief* and *desire*. The "sensations" we introduced previously can be seen as rudimentary "beliefs" that an agent has about the conditions it is experiencing. Dennett considers the intentional stance to be justified when it allows us to adequately predict the behavior of such an agent. The prediction is that the agent will perform those actions that are most likely to realize its desires given its beliefs about the situation it is in. In Dennett's view nothing more is needed in order to ascribe beliefs and desires to the agent: "all there is to being a true believer is being a system whose behavior is reliably predictable via the intentional strategy, and hence all there is to really and truly believing that p (for any proposition p) is being an intentional system for which p occurs as a belief in the best (most predictive) interpretation" (Dennett, 1989, p. 29). The only thing we want to add is that Dennett assumes that physical systems can be predicted more accurately using the physical stance, while we have just argued that the intentional stance can predict them at least as well.

However, while Dennett asserts that we do not need more than such predictive abilities to ascribe mindlike properties to a system, most other philosophers will want to reserve the category of mind to systems that have some kind of subjective experience and/or "free will" (or at least some autonomy in choosing actions without being fully determined by their physical state). That is why Chalmers (2015) has proposed panpsychism as a possible solution to the "hard problem" of consciousness and the unsatisfactoriness of dualism to resolve it. If even the simplest physical particles would already have some form of rudimentary experience, then we would not need to postulate mind as a category separate from matter, because then matter would already be endowed with an essential aspect of mind. However, as Seager (1995) notes, if we do the effort to ascribe such additional mental properties to matter, then we would expect these properties to somehow manifest themselves beyond the ordinary mechanistic properties of matter. Otherwise that ascription would make little sense. Finally, as both Chalmers and Seager note, a remaining problem with panpsychism is that it is not sufficient to attribute aspects of mind to particles unless we can explain how the composition of many such rudimentary minds can give rise to the much more complex mind that is inherent in the human brain—but not in a stone, even when it contains at least as many particles as a brain.

Our approach provides a solution to all these problems. First, conceiving particles (or any other agents) as capable of sensation is equivalent to saying that they "experience" their situation: they are "sensitive" to what happens in their surroundings, just like a stone "feels" the force of gravity. Second, as we noted when discussing quantum mechanics, the mechanistic or causal description is fundamentally incomplete: it does not fully determine the behavior of a particle. If you consider independence from physical causation to be an essential aspect of mind, then you could see radioactive particles "deciding" when to decay as exerting some rudimentary form of "free will". None of this is in contradiction with present theories of physics. It merely appears paradoxical when seen from a traditional, Newtonian perspective. What ascribing mindlike properties adds to the mechanistic picture is the apparently goal-directed or "intentional" behavior of physical systems, which allows you to predict that certain outcomes of a complex process are much more probable than others, in circumstances where a mechanistic description would conclude that either there is not enough information or the outcome is too complex to compute. Finally, the problem of composition is solved by the systems-theoretical understanding of *emergence* (Checkland, 1999; Corning, 2002; Heylighen et al., 2007), which sees emergent properties not as mysterious phenomena appearing out of nowhere but as the result of organizing agents into a coordinated system that is capable of reactions that none of the component agents is capable of. As we will explain further, organizing simple agents into coherent networks does enable more complex mental phenomena. Thus, our radically non-dual approach is compatible with Chalmers's and Seager's requirements for panpsychism. In practice, though, it is closer in spirit to Dennett's more pragmatic approach, since it is interested not so much in whether particles or stones actually *have* mental properties, but in how far conceiving them as such helps us to better understand and predict the material, biological and social systems that they constitute.

Since there is no formal criterion to demarcate situations in which the intentional stance is appropriate from situations in which it is not, the action ontology simply generalizes it to all systems and processes. In practice, this means that any agent defined as above in the action ontology can be characterized as having desires, beliefs and intentions (and if you like, "experience" and "free will"). This brings us to the *Beliefs-Desires-Intentions* (BDI) framework, which is a standard way of conceptualizing mind and agency (Bratman, 1999; Georgeff, Pell, Pollack, Tambe, & Wooldridge, 1999).

Psychologists have observed that people have an inborn *Theory of Mind* (ToM), based on the BDI components, which they use to predict the behavior of other people (Astington & Baird, 2005; Whiten, 1991). For example, if you know that John *desires* to see that football match, and that he *believes* that taking the bus is the best way to get from his home to the football stadium, then you can predict that he will first form the *intention* of taking that bus, and then, if no unforeseen disturbances prevent him from carrying out his intention, that he will effectively get on the bus. You can make that prediction even when you know that the road ahead is closed so that the bus will not actually reach the stadium, and therefore that John will fail to realize his desire in this way. Such ToM reasoning is an easy, efficient and natural way of predicting agents' behaviors, even though it reduces the complex interplay of thoughts, feelings, memories and perceptions in the human mind to the simple BDI elements.

The action ontology extends this ToM/BDI conceptualization to the simplest physical agents, such as particles, molecules or bacteria. For example, you could try to predict the outcome of a ball rolling down a hill by assuming that the ball *desires* to be at the bottom of the hill (where its potential energy would be minimal), that it *believes* or *senses* that it is on a a sloping surface, and that it *intends* to go down in the direction where the slope is steepest. That rudimentary model would probably give you a pretty good idea of where the ball is likely to end up, even when the hill surface is cut through by weeds, stones, gullies and trees that constantly disturb the movement and make the actual trajectory of the ball impossible to predict. Thus, in this case the intentional stance gives you a better prediction than the physical stance, where you would need to extremely accurately measure and calculate the precise angles of impact, distribution of forces and degrees of deformation and friction for the ball and all the obstacles it would encounter, as well as the possible deviations by gusts of wind that may arise while the ball is rolling down—a task that is simply impossible to perform.

This approach of treating physical systems as if they were intentional agents is nothing new. It is in a sense equivalent to *animism*, i.e. the belief—typical of "primitive" cultures of hunter-gatherers—that all phenomena, such as trees, animals, or rocks, are sentient beings. One advantage of an animist worldview is that it avoids alienation (Charlton, 2002; 2007), i.e. the feeling that we do not really belong to the world that surrounds us. For a person raised in an industrial, mechanistic culture, the environment consists of impersonal, alien objects and mechanisms. For an animist, these phenomena are agents to interact with on an equal footing—as potential allies, rivals or enemies, but never as cold, inert "matter".

Animism has been nearly universally rejected as naïve, because it anthropomorphizes simple phenomena into human-like intelligences. But the intentional stance or action ontology does not presuppose any near-human level of intelligence: it merely attributes to all agents in-built desires, the ability to sense certain conditions, the belief that sensed conditions actually hold true, and the tendency to react to these conditions by actions appropriate for realizing their desires. These minimal assumptions apply equally well to elementary particles and to intelligent human beings. As such, they restore a continuity and interactivity to the world that prevent us from feeling alienated from nature. Moreover, they allow us to get rid of the mind-matter duality and its problems at the most fundamental level.

Of course, these "intentional" agents differ radically in their level of complexity or organization. As agents become more complex and intelligent, they start to exhibit more advanced mental qualities, such as memory, emotion, reasoning or consciousness. But our underlying philosophy sees this evolution as continuous. It does not presuppose any strict boundaries between systems that exhibit these qualities (e.g. humans and higher animals) and systems that do not (e.g. insects, plants or rocks). At most, it distinguishes approximate levels of intelligence in the organization of systems (such as reactive, state-determined, learning, and thinking). These levels are the outcomes of subsequent "metasystem transitions" (Heylighen, 1995; Turchin, 1977), i.e. major steps within the overall evolutionary process of complexification (Heylighen, 1999; Maynard Smith & Szathmáry, 1997). But such transitions—which include the emergence of life from chemical cycles, of multicellular organisms from single-celled ones, and of humans from animals—only look like "quantum jumps" when seen at a sufficiently coarse time scale. In reality, each transition took millions of years during which innumerable intermediate forms appeared and transformed into other forms. Such an evolutionary perspective makes it much easier to understand the origin of complex and mysterious phenomena, such as human consciousness and intelligence, by retracing their emergence from much simpler phenomena.

While we cannot review this evolutionary journey from simple to complex minds in the space of the present article, it is worth examining one fundamental mechanism of complexification that is readily expressed within the action ontology: the emergence of an "organization", i.e. a system of coordinated actions.

Organizations

An emergent level can be modelled in the action ontology as a coherent network of coupled reactions. Reactions are coupled when the output or final condition of the one forms the input or initial condition of the other, like in $X \rightarrow Y$, $Y \rightarrow Z$. These couplings become more complex when input and output conditions overlap without being identical, like in:

$$a + b \rightarrow c + d$$
$$c \rightarrow e + f$$
$$d + f \rightarrow g$$

This is typical for chemical reactions that consume and produce combinations of molecules. The metabolism of a living cell is a huge network of such coupled chemical reactions, which produce and consume a wide variety of molecules in order to provide the cell with all the energy and building blocks it needs to survive and grow.

A living organism is a typical example of a complex agent. What distinguishes such an "agent-like" network of reactions from the uncoordinated reactions that may take place e.g. in a test tube is *autopoiesis* (Maturana & Varela, 1980; Mingers, 1994; Razeto-Barry, 2012): the network produces its own components, thus maintaining an invariant organization in spite of a continuously changing state. This state is characterized by changing concentrations of molecules and a barrage of external perturbations that need to be counteracted. Autopoiesis or self-production provides the network with a stable identity in spite of the fact that it is in a situation of permanent flux. This makes it autonomous, i.e. to a significant degree independent of what happens in the environment. Still, the autopoietic network A interacts with the environment, by producing the actions Y appropriate to deal with the external challenges X. This defines the autopoietic organism as a higher-order agent:

$$A + X \rightarrow A + Y$$

At the abstract level of this overall reaction, there is no difference between a complex agent, such as an animal or a human, and an elementary agent, such as a particle. The difference becomes clear when we zoom in and investigate the changing state of the network of reactions inside the agent.

A very promising way to do this is the formalism of *Chemical Organization Theory* (COT) (Dittrich & Fenizio, 2007; Heylighen, Beigi, & Veloz, 2015). COT starts from reactions similar to the ones of the action ontology, but adds a generalized notion of autopoiesis, which it defines as the combination of closure and self-maintenance. A network characterized by closure and self-maintenance is called an *organization*. (Note that, unlike the original definition of autopoiesis, this does not include the formation of a topological boundary separating the network from its surroundings). *Closure* means that the network of reactions functions so that no qualitatively new conditions are produced: in spite of all the change implied by the ongoing reactions, eventually the situation always comes back to some of the conditions that existed before. *Self-maintenance* means that not just some but all of the conditions that existed before are eventually produced again, possibly to a larger extent. Closure means that nothing new is added; self-maintenance that nothing old is lost. Together they imply that all the essential parts are eventually recycled. In spite of this higher-level invariance, the system is in a constant flux, as conditions are relentlessly transformed into different conditions, while the magnitude or intensity of the conditions varies.

Note that an organization is an attractor for the system formed by the network of reactions: through self-organization, the system sooner or later settles into a configuration that is closed and self-maintaining (Heylighen et al., 2015). Thus, according to the intentional stance autopoiesis (which is equivalent to survival and growth of the organization) is the implicit goal for such a system.

Perhaps the simplest example of such a self-producing organization is a cycle: $X \rightarrow Y$, $Y \rightarrow Z$, $Z \rightarrow X$. But when couplings are complex, the organization is subtler. For example, here is a highly simplified model of the ecosystem of the Earth:

plants + CO_2 + minerals → plants + O_2	(plants grow while producing oxygen)
plants + animals + O_2 → animals + CO_2 + waste	(animals consume plants and oxygen)
plants → waste	(plants die)
animals → waste	(animals die)
bacteria → waste	(bacteria die)

waste + bacteria → bacteria + minerals + CO_2 (bacteria grow while converting waste to minerals)

All the components or conditions in this system are both consumed by some reaction and produced by some other reaction. As a result they are fully recycled: the network is closed and self-maintaining. None of the components will ever disappear from the system, although their concentrations are constantly varying.

How does such COT model help us to understand complex agents, and in particular their cognitive or mental capabilities? COT extends the basic action ontology by modeling the internal processes and changing internal state of an agent. When the agent is simple, like a particle or a rock, its "belief" or "sensation" is trivial: an incoming causal signal that is directly transformed into an outgoing effect. Such agents without internal state are called *reactive* (Beer, 1995; Heylighen, 2014b): they react directly to their sensed conditions.

With a complex agent, incoming signals (sensations) each in turn affect the internal state. The internal state thus keeps a (partial) memory determined by the sequence of sensations that the agent has undergone. This memory together with present sensations constitutes the agent's system of "belief". This state is further processed by the network of internal reactions, which depends on the agent's autopoietic organization. The resulting state may or may not result in a particular outgoing signal (i.e. an action affecting the outside world). This can be seen as a process of "deliberation" or "sense-making" (Stewart et al., 2014): the incoming sensation needs to be processed or interpreted, taking into account the agent's memory of previous sensations and its implicit desire for continuing autopoiesis. This in general triggers an action to deal with the sensed condition.

If the action turns out to be appropriate in bringing the agent closer to its desired situation, then the beliefs leading up to this action have been "justified" and thus can be assumed to be "true". Thus, the beliefs (i.e. the internal state of the agent leading up to its action) can be said to constitute "knowledge". This is equivalent to the original argument that autopoiesis necessarily entails cognition (Maturana & Varela, 1980), since the autopoietic agent must "know" how to act on a potentially perturbing situation in order to safeguard its autopoiesis. Note also that this conception of knowledge also fits in with the epistemological position of "virtue reliabilism", which asserts that beliefs can be seen as knowledge when their reliability is evidenced by the cognitive capabilities ("virtues") they confer to the agent (Palermos, 2015; Pritchard, 2010).

Nevertheless, it may well be that it turns out that the sensed situation does not affect autopoiesis and that therefore no action is needed. This points at an essential difference between a complex, autopoietic agent and a simple, reactive agent. The reactive agent necessarily reacts to the particular conditions it is sensitive to (although it may randomly choose precisely how or when to react, like in the case of a radioactive atom "choosing" when to decay). The autopoietic agent may decide to ignore the condition, however, after having become "aware" of it and having evaluated it through its internal dynamics.

One of the arguments used by Chalmers (1995) to justify why consciousness is such a "hard" problem that cannot be tackled by the traditional methods of science is that conscious experience does not seem to have a function. Indeed, we can sense, feel or experience phenomena without this affecting our actions. However, that does not mean that experience is useless: conscious experience (as contrasted with elementary sensation) is the outcome of the process of sense-making, in which incoming sensations are combined with existing memories and interpreted in terms of their implications, meaning, and valence (positive or negative) relative to our value system. Experience prepares or *primes* the mind for further deliberation and action that potentially needs to be performed, but that may never actually happen (Heylighen, 2014b). The zombie thought experiment views the zombie's mind as a mechanical system in which causes (stimuli) directly lead to effects (actions), while leaving no room for this complex process of sense-making that an agent needs to undergo in order to deliberate which, if any, action may be needed.

Note also that this process of deliberation, in which different alternative interpretations and possible courses of action are explored, but whose outcome is essentially unpredictable, captures our intuitive notion of "free will" much better than the simple indeterminism of quantum phenomena: many potential actions can be conceived and examined, but eventually only one (or none) is actually performed. Thus, an "organization", or autopoietic network of reactions, provides us with a potentially much richer picture of mental attributes such as experience, memory or volition than a simple agent. But that does not mean that these attributes a priori have no place in the description of such agents. After all, organizations are still agents, and even simple agents can in principle be conceptualized as autopoietic networks of reactions.

For example, an atom is usually seen as an inert piece of matter that reacts in a predictable manner to outside forces. But a more detailed, quantum electrodynamic model (Cohen-Tannoudji, Dupont-Roc, & Grynberg, 1997; Milonni, 2013) would depict an atom as a "cloud" of electrons that electromagnetically interact via virtual photons with protons in the nucleus, other electrons and even the surrounding vacuum, and this in such a manner that this network of virtual processes is closed and self-maintaining. But this apparent stability is not absolute, as illustrated by the potential absorption or emission of photons by atoms, chemical reactions in which atoms bond with other atoms by exchanging electrons, and even more by nuclear reactions, in which the atomic nucleus itself can disintegrate or merge with another nucleus. Yet, the point of the intentional—and a fortiori autopoietic—stance is that is worth applying only if it provides simpler predictions or explanations than the physical stance. In the case of a typical, non-reacting atom the physical stance seems adequate enough, and therefore in most cases we do not need to worry whether the atom will "decide" to emit a photon or to take part in a chemical reaction with another atom that it "senses", so as to satisfy its "desire" for a state of minimal potential energy…

Socially distributed cognition

The COT model of self-sustaining networks of processes is so general that it can describe a wide variety of complex, organized systems (Heylighen et al., 2015). These include chemical reaction networks, single cells, multicellular organisms, ecosystems, planetary atmospheres (Centler & Dittrich, 2007), markets, brains, and social systems (Dittrich & Winter, 2005). Using the intentional stance, each of these can be described as having sensations, beliefs, desires, intentions, memories, and experiences.

Note that this list is broader than just living systems. The original definition of autopoiesis (Maturana & Varela, 1980; Varela, Maturana, & Uribe, 1974) included a requirement for the production of a physical boundary that separates the system from its surroundings. This requirement was inspired by the membrane surrounding the metabolic network that characterizes a living cell, and was intended to limit autopoiesis to living organisms. By leaving out this requirement, COT can also describe self-producing networks that are distributed in space, such as markets or ecological networks. This allows it in particular to apply a generalized notion of autopoiesis to social systems—a move made by several authors (e.g. Luhmann, 1986; Mingers, 1994) wanting to extend autopoiesis beyond biology.

Let us then focus on socially extended knowledge and examine in how far a social system can be characterized as having some form of knowledge that is not merely the knowledge inside the brains of its human components. To clarify the matter, we first need to explain the relation between component agents and the social "super-agent" that they constitute.

COT defines a super-agent as a closed, self-maintaining network of reactions, some of which are catalyzed by simpler component agents (Heylighen et al., 2015). The network forms an "organization" when the actions of its agents are coordinated to such a degree that the whole becomes autopoietic, i.e. closed and self-maintaining, in the sense that whatever processes it undergoes, it reliably reconstitutes its own "essential" components. That leaves us quite some leeway in deciding which are the essential components that need to be reconstituted. Normally, these components are chosen such that they define a stable *identity* for the organization, meaning that subsequent states or configurations of the system can all be recognized as aspects of the same organization. In Luhmann's theory of autopoietic social systems (Luhmann, 1986, 1995), these components are distinctions or symbols that are transmitted and processed via communications from agent to agent within the system, but such that the overall process leaves the essential organization invariant. Note that this notoriously difficult theory can actually be formalized—at least in part—rather easily by means of COT (Dittrich & Winter, 2005).

In our own approach to social systems, we conceive such processes as a *propagation of challenges* (Heylighen, 2014a). This can be seen as a generalization of Hutchins's analysis of socially distributed cognition taking place through the propagation of "state" (Hutchins, 1995, 2000): the state of some agent determines that agent's action or communication, which in turn affects the state of the next agent receiving that communication or undergoing that action. Since a state is a selection out of a variety of potential states, it carries information. Therefore, the propagation of state from agent to agent is equivalent to the transmission and processing of information. This is an adequate model of distributed cognition if cognition is conceived as merely complex information processing. But if we want to analyze cognition as the functioning of a mind or agency, then we need to also include that agent's desires, or more broadly its system of values and preferences. What counts for an agent is not so much the objective state of some phenomenon, but the degree to which that state affects the agent's values: in how far does it either help or hinder the agent in realizing its desires? This shifts our view of information from the traditional syntactic perspective of information theory (information as selection among possibilities (Shannon & Weaver, 1963)) to a pragmatic perspective (information as trigger for goal-directed action (Gernert, 2006)).

We make this change of perspective more concrete by replacing the terms "information" or "state" by "challenge". A *challenge* is defined as a situation (i.e. a conjunction of conditions sensed by some agent) that stimulates the agent to act, because acting on that challenge would bring benefit to the agent relative to not acting (Heylighen, 2012). Challenges can be positive (acting brings the agent closer to realizing its desires) or negative (not acting pushes the agent farther from realizing its desires). Positive challenges can be seen as resources to be exploited or as opportunities for advancing towards the goal, negative challenges as dangers to be evaded or as problems to be resolved. For example, a tasty treat is a positive challenge that will elicit the action "eat". A poisonous snake is a negative challenge that will elicit the action "run away".

By acting on a challenge, the agent will change the situation. If the challenge is fully "relaxed" (opportunity exploited or problem solved) (Heylighen, 2014a), then the new situation will no longer be a challenge. However, for complex challenges—such as building a house—a single agent can in general not fully resolve it. For example, an architect may make a plan for the house, but cannot build the house without help from others. In this case, the new situation (available plan) constitutes a challenge for one or more agents (e.g. contractor, builders, carpenter, plumber…) to perform the implied next actions. After each action, the situation moves closer to a full resolution of the initial challenge. Yet, so long as that end has not been reached the resulting situation defines a new challenge. Thus, challenges propagate from agent to agent until full relaxation.

This propagation typically follows the links within an organization or social network, as people pass on challenges to contractors, collaborators or friends. In formally structured organizations, such as an administration, a company or a factory, such propagation follows predefined paths, called *workflows* (Van der Aalst & Van Hee, 2004), in which a complex task is decomposed into a number of more specific tasks to be executed in a particular sequence by agents performing specialized roles. Each individual contributes his or her specific skills or expertise to tackling some part of the challenge. Thus, knowledge about how to solve the problem is divided across a variety of agents, some of which (e.g. computer programs, robots, measuring apparatuses, rulebooks, …) may not be human. But knowledge and processing is distributed across more than individual agents: it is distributed across the network of actions that connects them.

This can be understood by going back to the elements of the action ontology: actions represented as production rules of the form X → Y. Each agent can be characterized by a collection of production rules representing the actions that this agent is able to perform. This includes both actions that change the external situation and internal, "mental" actions that constitute the process of sense-making, in which the agent interprets the incoming information and eventually formulates a course of (external) action. These cognitive actions can be seen as *inferences* in which some condition Y is inferred from some previously established condition X. Here is an example of a three-step inference, starting from the perception of a snake, and ending with the intention to flee:

snake → poisonous
poison → mortal danger
mortal danger → flee

Seen from the outside, the agent behaves as if it follows the single rule: snake → flee. The intermediate inferences are not directly observable. They implement a (very simple) process of deliberation, in which the perception is assessed against pre-existing beliefs (that snakes can be poisonous, and that a bite from a poisonous snake can kill) and desires (for survival) in order to decide about a course of action (that it is best to flee).

Each agent in a workflow will use a variety of such internal inference rules to process the incoming challenge and form a plan of action. It will then execute the plan while monitoring the provisional results, and if necessary, use this feedback to correct the course of action until it achieves the intended goal. Assuming that these inference rules are correct and justified, they can be seen as the agent's *knowledge* about how to tackle this kind of challenges. The question now is whether a social system possesses knowledge that is not located in the brain of its human components.

The case is most obvious for rules that are implemented in material supports, such as computer programs or documents listing rules too numerous or complicated for anyone to remember. For example, if tackling the challenge at some stage requires the calculation of the logarithm of a number, a human agent will not calculate that logarithm inside its skull, but rather enter the number into a calculator and register the result. Before computing technology, that same person would have searched for the number in a big book with logarithm tables, and similarly noted down the corresponding result. In neither case would we have found any person in the organization who knows the logarithms for all relevant numbers, i.e. whose brains would have contained the production rules of the form log (x) → y, for any substantial series of numbers x. However, the organization as a whole does know how to calculate a logarithm. The same applies for other operations that an organization regularly performs. These tend to be written down in the form of manuals, guidelines, regulations, or procedures. These documents may have to be consulted in order to ascertain that a specific condition X is a special case of condition Y, which requires the performance of action Z, while checking for the presence of condition W, and so on.

But the case for distributed knowledge can be made even in a purely social system, where all information processing is done through individual reasoning and communication between individuals. The situation is perhaps most obvious for procedural knowledge. A complex item, such as a car or a computer, is never manufactured by a single person. No person knows how to perform all the operations that are necessary to assemble all the components of a car. But together, all the employees of a car factory can build a car, because each one will apply his or her specific skill by adding, adjusting or assembling these particular components. Nevertheless, it is not sufficient to gather a group of individuals having each of those skills in one big room for them to start building a car. The workflow or process itself is crucial, because these specialized skills can only be applied at the precise moment when all the preparatory actions have been performed. Thus, person B needs to know that some person A has performed the action $X \to Y$, before B can perform the subsequent action $Y \to Z$. The procedural knowledge of how to build a car is more than the aggregate of the procedures that the different employees have in their brain: the workflow connecting these individuals and their procedural knowledge to each other is itself part of the overall procedure.

This argument can be extended to declarative or semantic knowledge. Suppose that John receives a phone call telling him about condition U (say a specific client request). He knows that this is a special case of condition V, but otherwise does not know anything about V. Therefore, he passes on the challenge to his colleague Ann, whom he assumes to be more knowledgeable about this domain. Ann knows that a crucial part of V is W, and that her colleague Barbara is an expert in W-related matters. Barbara immediately sees that W entails X, a type of problem dealt with by the people of the X-matters department, including Tom. Tom recommends tackling X by action Y, which is finally executed by Jane, thus satisfying the client. In this way, the organization to which John, Ann, Barbara, Tom and Jane belong has performed a process of inference of which different steps are distributed across different agents:

John: $U \to V$
Ann: $V \to W$
Barbara: $W \to X$
Tom: $X \to Y$

The process can be summarized by saying that the organization knows that U entails X and is to be dealt with by action Y. But no single individual in the organization knows that $U \to X$. It is not sufficient that each of the rules leading to that conclusion is known by some individual in the organization for that conclusion to be effectively drawn. The agents must moreover be organized in such a way that the next step in the process is propagated to an agent who knows how to perform this step. For example, assume that Barbara is not reachable at her usual phone number because she is working in a different office. In that case, Ann will not be able to pass the challenge on to her, and therefore the chain of inference is broken. As a result, the organization cannot answer the client's request, even though all the people with all their knowledge are present within the organization. Thus, the network of connections within the organization is an essential part of that organization's knowledge of how to deal with challenges. Therefore, the knowledge must be conceived as socially distributed.

While we have here focused on objective knowledge (U entails X), the same reasoning can be made about more subjective mental phenomena such as perception, meaning, experience or desire. In a typical process of challenge propagation in an organization, decisions are made based on the feelings, values and desires of the different agents along the propagation chain. These include the implicit "sensations" and "desires" of non-human agents mediating between the human ones. For example, if Barbara's telephone is broken, it will not be able to "sense" Ann's call. Therefore, it will fail to alert her to the incoming challenge, thus interrupting the propagation chain. On the other hand, the central coffee room in the building may function as an attractive destination for employees, thus embodying the organization's implicit "desire" that its employees would meet there informally. This may be enough for Ann and Barbara to run into each other and thus find out about the phone problem.

This example illustrates an emerging perspective on how social and physical environments can be organized so as to elicit or stimulate certain perceptions, decisions and actions (Borghini, 2017; Heylighen, Kostov, & Kiemen, 2013; Thaler & Sunstein, 2008). Thus, the environment can support not only distributed cognition but even a distributed desire or "extended will" (Heath & Anderson, 2010) that complements individual human desires.

Together, the "mental" properties of all these human and non-human agents will determine the overall course of action of the organization. This course of action moves towards a certain "attractor", which defines the collective desire or system of values of the organization. While moving in this direction, the organization continues to collect information about its situation through a variety of sensory and communicative channels involving different agents, while trying to make sense of that information, and deliberating whether this awareness of the situation requires some change in its course of action.

Experiencing non-duality

Through an extended application of the intentional stance, we have argued that both simple physical agents and (self-)organized networks of processes can be conceptualized as mind-like agencies. Thus, mind does not just reside inside the brain; it is distributed across the whole of nature and society. This implies a radical negation of the mind-matter duality: not only is it impossible to have a mind independent of matter, it is impossible to find matter that does not exhibit some mind-like properties.

Although the above argument may appear logically coherent, it is unlikely to be convincing on a more intuitive level. After all, we all feel that our mind is sitting somewhere inside our skull, looking out at the external world, experiencing its sensations, and pondering what to do next—don't we? Apart from other human beings such as us (and perhaps some of the smarter animals) that outside world lacks knowledge, intelligence, feeling, or desire—doesn't it? That world is merely a collection of inert, material objects and mechanisms, ready to be manipulated through the actions conceived by our independent mind—isn't it?

While these intuitions may be common in our materialistic and reductionistic, Western society, they are in no way universal. We already noted that prehistoric thought was fundamentally animistic (Charlton, 2007). Before the mechanistic worldview became dominant, panpsychism was a very common philosophical position (Seager & Allen-Hermanson, 2015). Moreover, Eastern civilizations have produced a number of holistic philosophies, such as Taoism, Buddhism and to some extent Hinduism and Sufism, that advise people to give up the illusion of the individual mind or "self" as an independent agent, and to seek reconnection with the world. Some schools of Hinduism and Buddhism define *non-duality* as the emptiness of the distinction between subject and object or between cognizer and cognized (Dunne, 2011). This is not precisely the same as our "radical non-dualism", but it makes a similar point of blurring the boundary between (human) mind and (physical) world. Taoism conceives this world as an immense process or flow, a "Becoming" or "Tao". Individuals should not try to control this flow, the way Western science and technology try to control nature, but go along with it, by becoming aware that the self is fluid and that it does not have any clear boundaries with the surrounding flow of existence.

Although Taoism's picture of the inseparability between mind and world may appear alien when seen through the lens of analytic philosophy, it provides a cue for reconceptualizing how science can tackle the complex challenges of our time. Take for instance the grand challenge of urbanization and the need for developing sustainable and resilient communities. Formulating the connection between our actions, our mental models and the surrounding world through non-dual philosophies can help us to develop engaging narratives and models for change. *Mindfulness Engineering* (Beigi, 2014), for example, is an approach that integrates holistic approaches to the mind-body connection with the engineering of sustainable and resilient cities. In this view, cities are not just aggregates of buildings, roads and other material infrastructures, but organized networks of people and objects that together constitute a "super-agent". Only through understanding the nature of the human mind and its connection with other minds, including the implicit "mind" of the physical environment, can we design a truly "smart" city (Chourabi et al., 2012), which is able to deal with complex challenges such as pollution, traffic jams or earthquakes. Part of the solution is to engineer the environment in such a way that it stimulates or "nudges" people to act in a more sustainable manner (Heylighen et al., 2013; Thaler & Sunstein, 2008), thus fostering a "distributed desire" for a self-maintaining system at the level of the city or the planet (Heylighen, 2014a). This illustrates how pragmatic engineering and technical solutions inspired by distributed cognition and action ontology can revitalize old and unsustainable ways of doing things.

The complex, dynamic and interconnected nature of the social, technological and ecological systems that surround us is now well recognized by scientists (e.g. Ball, 2012; Helbing, 2012; Walker, Holling, Carpenter, & Kinzig, 2004). However, it is still too often ignored by the actual decision-makers—the politicians, managers or employees—who need to develop a sustainable course of action that takes into account the interdependency of our world. Scientific theories, such as systems dynamics, complex adaptive systems and distributed cognition, especially when supported by more a general philosophical framework, such as process metaphysics or action ontology, should help people to better understand and deal with these complexities.

Still, our decision-making is ideally supported not only by theoretical understanding, but by the concrete experience of connectedness, non-duality and flow. This is what the practices of Buddhism and Taoism try to achieve (Dunne, 2011), through techniques such as meditation, yoga and qigong (Schure, Christopher, & Christopher, 2008). For example, intense meditation can result in a so-called "oceanic feeling" in which the subject no longer feels like a separate individual, but as merging with the larger whole. Different spiritual practices aim at achieving a more enduring state of "enlightenment" (Harris, 2014), in which people no longer sense the need to control their situation by cautiously planning all their actions, but instead are able to act spontaneously, without worry or rumination, while being in "flow" (Nakamura & Csikszentmihalyi, 2002) with the process, and "mindful" (Bishop et al., 2004; Dunne, 2011) of their environment. Such an altered state of consciousness could be seen as a form of recovered animism, in which the individual again feels part of an encompassing network of interactions (Charlton, 2007).

Western observers who attempt these practices typically emphasize the great effort, discipline and time needed to achieve any form of non-dual consciousness (Harris, 2014). For most people, it seems very difficult to get rid of the impression that there is some individual self sitting inside the Cartesian theater, talking to itself, and looking out at the world. However, from our perspective, this difficulty appears largely like an artefact of our upbringing. Infants cannot yet distinguish between self and world (Rochat, 2001), and need to learn that some movement they perceive is the result of their own action rather than an outside event. Older children's more elaborate concept of self is to an important degree a product of the social system, which teaches them that they are individuals with a particular identity, role and duties towards the rest of society. These duties are interiorized in the form of what Freud has called the "super-ego". For many people, this appears like a little voice inside their head that is constantly reminding them of the rules they should be heeding, and deliberating verbally which is the best action to take. Most people find it very difficult to shut off that relentless inner monologue (Harris, 2014), which is constantly monitoring and commenting on the situation instead of spontaneously interacting with it.

Therefore, they find it difficult to experience the world as it originally appears to the senses, i.e. as a continuous, non-verbal flow of interactions that is not controlled by some Cartesian homunculus that constitutes their "mind central" or "seat of consciousness". Researchers in cognitive psychology and neuroscience have found evidence that there effectively is some mechanism or network, called the "central executive" (Jurado & Rosselli, 2007) or "global workspace" (Baars, 2005) and located in the prefrontal region of the brain, that performs this function of conscious monitoring and control. However, at the same time they agree that this is merely one cognitive mechanism among many that our brain and body use to perceive, decide and act, that it is not essential for most everyday functioning, and that its boundaries are fuzzy and fluid. That means that it is possible to develop a non-dual, mindful awareness as a default state, where the "executive" self merely functions as a specific tool that is switched on whenever the situation requires explicit reflection rather than an intuitive going with the flow. We have recently started to investigate this state under the label of "meta-awareness". It illustrates that non-dualism it not just a philosophical theory, but a concrete attitude and experience that can help us to cope with a complex and dynamic world.

Conclusion

We have approached the problem of the extended mind, and in particular of socially extended knowledge, from a radically non-dualist perspective. Mind-matter dualism is an artefact of the outdated Newtonian worldview, which reduces all phenomena to the mechanical motion of material bodies, governed by deterministic laws. In this picture, there is no room for free will, agency, desire, sensation or experience. Therefore, both philosophers and laypeople are inclined to situate these phenomena in the distinct, non-material realm of mind, even when they believe that this mind still somehow supervenes on matter. This artificial and inconsistent separation between mind and matter creates a host of apparently unanswerable questions, paradoxes and other "hard problems". For us, the only way out is to get rid of dualism at the most fundamental level.

We have proposed to do that by introducing an ontology of action, which can be seen as a concrete, scientifically underpinned implementation of the process philosophy implicit in the quantum field theories that have replaced Newtonian mechanics as the fundamental layer of physics (Bickhard, 2011). The elements of this ontology are actions or reactions. These have the form X → Y, representing an elementary process that leads from some condition X to a new condition Y. Agents are defined as catalysts of such reactions, i.e. conditions necessary for the reaction to take place, but that are not themselves affected by the reaction. The different reactions triggered by an agent A constitute the actions that A is capable of executing. We then applied the intentional stance by interpreting an agent's actions as goal-directed. This makes sense because these actions are characterized by equifinality: they lead from a variety of initial conditions (the basin) to the same final condition (the attractor), and thus resist disturbances that make them deviate from this trajectory.

That allowed us to characterize an agent as having sensations or *beliefs* (the conditions to which the agent reacts), *desires* (the attractors the agent tries to reach), and *intentions* (its expected course of action leading towards an attractor). This BDI conceptualization fits in with the "theory of mind" that people intuitively use to predict and explain the behavior of others. Its extension to the simplest kind of agents explains why in pre-scientific cultures mind and agency are so easily ascribed to non-human phenomena—a way of thinking known as animism. Animism has been abandoned as a description of purely physical phenomena because modern science can describe these more precisely through complex causal models. However, a description in terms of cause and effect can in principle always be translated into an intentional description, without loss of accuracy. Such an intentional description is actually more general and more robust, because it allows predictions and explanations even in situations where intrinsic indeterminism, chaotic dynamics, insufficient information or sheer complexity preclude causal modelling. Thus, even the most primitive agents, such as particles, can be conceived as having a rudimentary mind—a position known as panpsychism.

More complex minds can be modelled as networks of reactions. Such networks tend to self-organize to a configuration where they become self-maintaining or autopoietic. That means that they develop an invariant identity within a flux of endless change by continuously rebuilding their essential components. This property can be elegantly expressed in the action ontology with the help of the formalism of Chemical Organization Theory (Dittrich & Fenizio, 2007; Heylighen et al., 2015). Autopoiesis turns the network into a higher-order autonomous system: a *super-agent*. In contrast to an elementary, "reactive" agent, such a complex agent has an internal state that is affected by both present and previous input or "sensations", thus keeping some sort of memory of these interactions. This state in turn affects the agent's output of "actions". The intermediate process, where a host of sensations, memories, and internal, goal-directed dynamics interact to produce a continuously changing state, can be seen as the agent's process of "sense-making" and "deliberation", in which it interprets the situation and decides about a potential course of action.

This general, abstract model of a complex agent can be applied to social systems. Here the components agents are people and their material supports, such as books or computers. The process of deliberation can here be seen as a form of *distributed cognition*: the different human and technological agents interpret the situation, make inferences, solve problems, and plan actions by propagating information, or more precisely *challenges*, from the one to the other, along the links in the social or organizational network. Each agent in such a workflow will typically contribute its own specialized knowledge to tackling the challenge. However, in general the outcome is emergent: no individual agent has the knowledge to deduce the final solution from the initial problem. That knowledge is distributed, not only across human individuals and their external memories, but across the links in the organizational network: the same agents linked in a different way may not be able to collectively solve the problem.

We have concluded our review of the action ontology perspective on mind by examining why such a philosophy, in spite of its simplicity and coherence, is unlikely to be easily accepted. The Cartesian split between mind and matter is a basic tenet of our Western culture, with its attitude of materialism and mechanicism, on the one hand, and of individual freedom and autonomy, on the other hand. The more holistic and collectivistic Eastern cultures are more prone to see the world as a single, indivisible process, in which the separation between self and world is an illusion. They even propose concrete techniques, such as meditation, to help people free themselves from this illusion. But the fact that these disciplines are typically experienced as very demanding shows that this "illusion" has a rather strong psychological basis.

Yet, there is evidence that the self–world distinction is not as pervasive as generally assumed, and that people can spontaneously experience themselves as part of an encompassing flow rather than as an independent mind in its Cartesian theater. Such non-dual awareness is worth promoting, because it not only seems to prevent alienation and other sources of psychological suffering (Charlton, 2007; Harris, 2014), but helps people to better understand how they fit in with the complex processes and systems in which they participate.

The action ontology may support this general enterprise of raising awareness of the inseparability of mind and world by integrating the broad, but vague, outlook of process metaphysics and Eastern philosophy with the clarity and precision of more analytic, formal models of actions and networks.

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