

Why Dreyfus' Frame Problem Argument Cannot Justify Anti-Representational AI

Nancy Salay (salay@queensu.ca)
Department of Philosophy, Watson Hall 309
Queen's University, Kingston, ON
K7L 3N6

Abstract

Hubert Dreyfus has argued recently that the frame problem, discussion of which has fallen out of favour in the AI community, is still a deal breaker for the majority of AI projects, despite the fact that the logical version of it has been solved. (Shanahan 1997, Thielscher 1998). Dreyfus thinks that the frame problem will disappear *only* once we abandon the Cartesian foundations from which it stems and adopt, instead, a thoroughly Heideggerian model of cognition, in particular one that does not appeal to representations. I argue that Dreyfus is too hasty in his condemnation of all representational views; the argument he provides licenses only a rejection of disembodied models of cognition. In casting his net too broadly, Dreyfus circumscribes the cognitive playing field so closely that one is left wondering how his Heideggerian alternative could ever provide a foundation explanatorily robust enough for a theory of *cognition*. As a consequence, he dilutes the force of his legitimate conclusion, that disembodied cognitive models will not work, and this conclusion needs to be heard. By disentangling the ideas of embodiment and representation, at least with respect to Dreyfus' frame problem argument, the real locus of the general polemic between traditional computational/representational cognitive science and the more recent embodied approaches is revealed. From this, I hope that productive debate will ensue.

Keywords: representation; cognition, embodiment; embodied; enactive; Dreyfus; Heidegger; frame problem

Introduction

Hubert Dreyfus has argued recently that the frame problem, discussion of which has fallen out of favour in the AI community, is still a deal breaker for the majority of AI projects, despite the fact that the logical version of it has been solved. (Shanahan, 1997; Thielscher, 1998). Dreyfus thinks that the frame problem will disappear *only* once we abandon the Cartesian foundations from which it stems and adopt, instead, a thoroughly Heideggerian model of cognition, in particular one that does not appeal to representations. But, as I shall argue, Dreyfus is too hasty in his condemnation of all representational views; the argument he provides licenses only a rejection of disembodied models of cognition. In casting his net too broadly, Dreyfus circumscribes the cognitive playing field so closely that one is left wondering how his Heideggerian alternative could ever provide a foundation explanatorily robust enough for a theory of *cognition*. As a consequence, he dilutes the force of his legitimate conclusion, that

disembodied cognitive models will not work, and this conclusion needs to be heard. By disentangling the ideas of embodiment and representation, at least with respect to Dreyfus' frame problem argument, the real locus of the general polemic between traditional computational-representational cognitive science and the more recent embodied approaches is revealed. From this, I hope that productive debate will ensue.

The paper proceeds in the following way: in section I, I describe and distinguish the logical version of the frame problem and the philosophical one that remains unsolved; in section II, I rehearse Dreyfus' negative argument, what I'll be calling his frame problem argument; in section III, I highlight some key points from Dreyfus' positive account of a Heideggerian alternative; in section IV, I make my case against the anti-representational conclusions Dreyfus wants to draw from his frame problem argument; and, in section V, I speculate on the nature of an embodiment-directed AI not hampered by the frame problem.

I: The Frame Problem

The first version of the frame problem (McCarthy & Hayes, 1969), the *logical* frame problem, refers to a technical difficulty that emerged out of the logicist framework within which early models of AI were conceived. One necessary feature of any AI system is the ability to handle change. For a logicist AI system, 'to handle change' means to make correct inferences about which features in its world model to update and which to ignore when something in the environment changes. For example, if a ball is moved from one box to another, the system will need to update the ball's location and the empty/full status of the respective boxes, but it ought to leave its representations of the other items in the room alone, e.g. the fridge will remain white, the stove will remain off, and so on. A logicist system, however, will not infer anything unless it has a rule telling it to do so; thus, the system will need explicit rules, frame axioms, which dictate both what will change and what will stay the same for a given action. But not only is creating a comprehensive set of frame axioms impossible in a world-scale system – more on this in a moment – even were it doable, the resulting knowledge base would be prohibitively large, from an inferential perspective; for M possible actions and N attributes, M x N frame axioms would be needed. The

intuitive solution, that the system should just *assume* that properties remain unchanged unless explicitly stated otherwise – this is known as the commonsense law of inertia – turned out to be extremely difficult to formalise for technical reasons that we will not go into here. Recently, Murray Shanahan’s circumscriptive event calculus has been accepted as providing a workable solution. (Shanahan, 1997)

Now while this solves the logical frame problem, the challenge of logically representing the commonsense law of inertia, it doesn’t solve the related problem I alluded to above: How does a system engineer produce the correct set of axioms, the list of properties that *do* change given an action, in a way that can scale to real life? In other words, how will the engineer anticipate which objects and attributes are relevant to which actions *before* the situations in which those actions take place have occurred? As Zenon Pylyshyn (1987) puts it,

Another way to put this problem is to say that Artificial Intelligence must face the problem of determining the *relevance* of facts it knows to some problem at hand. This, the *problem of relevance*, is what many believe lies at the heart of the frame problem, and which will continue to be a serious problem long after all the minor technical problems (e.g., concerning the need for "frame axioms") have been dealt with. (p. x)

The axiom approach for solving this deeper relevance problem won’t work for two general reasons; first, because anything at all *might* be affected by an action, it is not possible to write a closed and comprehensive set of such axioms – call this the holism problem (Fodor, 2000); and, second, even were there a way around the holism issue, no amount of frame axioms could ever help such a system decide *which* of the axioms is relevant to the current situation – call this the infinite regress problem. Dreyfus (2008) focuses on this second aspect of the problem:

But a system of frames isn’t *in* a situation, so in order to select the possibly relevant facts in the current situation one would need frames for recognizing situations like birthday parties, and for telling them from other situations such as ordering in a restaurant. But how, I wondered, could the computer select from the supposed millions of frames in its memory the relevant frame for selecting the birthday party frame as the relevant frame, so as to see the current relevance of an exchange of gifts? (p.1138)

The holism problem and the infinite regress problem taken together constitute the philosophical version of the frame problem that has yet to be solved. The very fact that this problem exists for most contemporary AI approaches is a sign, Dreyfus thinks, that something very fundamental has been overlooked.

II: The Problem with Cartesian-Based AI

Dreyfus argues that the frame problem will arise for any approach that is founded on a Cartesian ontology,

specifically one in which cognitive agents impose meaning on the brute meaningless facts of the world. Following Heidegger, Dreyfus argues that meaning, which is always situated, arises out of holistic, dynamic, inter-relations between agents and their environment. Meaning *arises*, as a whole, out of activity, and never individually, as a result of assignments:

To say a hammer has the function of being for hammering leaves out the defining relation of hammers to nails and other equipment, to the point of building things, and to our skills – all of which Heidegger called readiness-to-hand – and so attributing functions to brute facts couldn’t capture the meaningful organization of the everyday world. (Dreyfus, 2008, p.1138)

For Heidegger, we (mostly) don’t experience objects as things to which we need to assign a meaning, rather we experience things in situations as ‘ready-to-hand’, as *some things*, embedded within meaningful situations. Thus the question "what feature of this object is relevant here?" cannot even be formulated on a Heideggerian view, since that would require seeing the object *as* something, rather than just seeing it.

On the Cartesian view, in contrast, relevance problems arise because there is always an extra step, that of deciding how to apply meanings in actual situations. Since meanings vary, sometimes dramatically, from context to context, not every context-free meaning attribution will apply in a particular situation. There are countless examples of this; indeed, the failure of computational linguistics to handle lexical knowledge in any general way is a testament to the intractability of this relevance problem, but here is one for discussion. The colour of traffic lights, one might think, has a highly circumscribed meaning in the contexts within which they are found, namely traffic systems; *red* means stop and *green* means go to all individuals using the system. There are times, however, when the authority of the traffic light is overridden, for example when there has been an accident in the middle of an intersection, and drivers must respond to the traffic officer’s signals instead of and possibly in contradiction to the traffic light signals. In such situations one must *decide* that the colour of the traffic light is no longer relevant, or that its relevance has been over-ridden by something that has greater relevance. On the Heideggerian view, in contrast, there are no analogous relevance decision problems because on that view one doesn’t first assign meanings to the constituents of a situation and then reason about what to do next; rather, one simply responds¹ to the situation at hand.

¹ Of course how we characterise this *response* will make an enormous difference in what sort of view we end up with. If we think that the response is made up of a bunch of lower level ‘decisions’ of some sort, we *might* have the relevance problem all over again – see footnote 2. I say “might” because there are different ways in which this story might go. Dreyfus thinks that Freeman is on to one such story.

Thus, on the Cartesian view of meaning, even once the meaning of an object is assigned or established in some way, one must still always ask, what is the meaning here, in this context, for this individual, with this purpose? And this is just to ask “what is it about this object or this action that is relevant here?”² An appeal to the overall body of meanings, whether stored in a conceptual hierarchy or in a system of inter-connected concept relations, cannot help for the same reason that appealing to meta-frames does not help on the logicist approach; an infinite regress of meta-meanings will be needed in order to determine what is currently relevant.

Dreyfus concludes that the Cartesian view, and all approaches that are essentially founded upon it, cognitivist AI, for example, must be abandoned. More positively, he suggests that AI projects in general still have a future: if they are founded on a Heideggerian ontology, the frame problem will not arise.

III: Heideggerian AI According to Dreyfus

To evade the frame problem, then, instead of viewing cognitive agents as founts of intentionality, we need to see intentionality as arising out of tightly connected dynamic couplings, that is, embodied relations between agents and their environments. On a Heideggerian view, embodiment takes the form of being-in-the-world, what Dreyfus describes as ‘background coping’. This relation he emphasises “...is not representational at all and does not involve any problem solving.” (Dreyfus, 2008, p. 1150) Thus, even though we do engage in inferencing over representations in high-level linguistic thinking, for example when we are solving a mathematical equation, or sometimes when situations break down, for example when the bulb in a flashlight burns out and we suddenly become aware of the flashlight *as* a flashlight, we are misguided if we think that it's that kind of process all the way down; Heidegger and Dreyfus think that the high-level, off-line, thinking that we take to be paradigmatic of cognition, e.g. planning a vacation, is derivative of background coping. If we want to find out how we think, we first need to investigate how we manage to do anything at all.

... the Heideggerian claim is that action-oriented coping, as long as it is involved (online, Wheeler would say) is not representational at all and does not involve any problem solving, and that all representational problem solving takes place offline and presupposes involved background coping. Showing in detail how the representational un-ready-to-hand in all its forms depends upon a background of holistic, nonrepresentational coping is exactly the Heideggerian project.... Indeed, a Heideggerian Cognitive Science would require working

out an ontology, phenomenology, and brain model, that denies a basic role to any sort of representation — even action oriented ones — and defends a dynamical model like Merleau-Ponty's and van Gelder's that gives a primordial place to equilibrium and in general to rich coupling. (Dreyfus, 2008, p. 1150)

Dreyfus eschews all disembodied approaches, then, because they all fall prey to the frame problem. But he goes on to reject all representational accounts because, on the Heideggerian view, embodiment is characterised by background coping, and *this* is a non-representational relation.

A non-representational view that Dreyfus singles out favourably is Walter Freeman's neuro-dynamical account of cognition. (Freeman, 2000) The central point he makes relevant to our discussion is that the cognitivist interpretation of brain neurology, as representational and computational, is inconsistent with the evidence; a non-representational dynamic systems interpretation does a better job of explaining the raw data.

Freeman takes two complementary observations to be instructive with respect to this debate. On the one hand, the neuronal patterns that cognitivists want to identify as the vehicles of representation, amplitude modulation (AM) patterns, change over time sometimes subtly and sometimes dramatically: "... even with fixed experimental conditions and invariant stimuli, the constancy of the pattern for each class of odorant holds for only a few days." (Freeman, 2000, pp. 76-77) On the other hand, evidence shows that these same AM patterns are invariant with respect to widely divergent stimuli: "in the cognitivist view, each AM pattern represents an odorant. ... [but] they cannot be representations of odorants, because it is impossible to match them either with stimuli or with pulse patterns from receptor activation that convey stimuli to the cortex." (Freeman, 2000, p. 89) AM patterns, Freeman thinks, are more a product of the unique neuronal properties of an individual brain, which change over time and as a consequence of experience, than of external stimuli. Thus, instead of thinking about AM patterns as representations of objects in an animal's world, say of *carrot* or *celery* for a rabbit, Freeman urges that we should use the language of dynamic systems theory to think of the patterns as attractor basins that stand for ‘significances’ and the clusters of neurons that promote movement to such basins as attractors for those basins. For Dreyfus, this difference in pattern interpretation is central because it provides empirical support for Heidegger's insistence that background coping does not involve any representations at all.

Thus Freeman contends that each new attractor does not *represent*, say, a carrot, or the smell of carrot, or even what to do with a carrot. Rather, the brain's current state is the result of the sum of the animal's past experiences with carrots. What in the physical input is directly picked up and resonated to when the rabbit sniffs, then, is the

² Note that these ‘decisions’ are not necessarily made consciously. There needs to be some mechanism, on the Cartesian account, agential and/or sub-agential, according to which the choice is made to treat this or that feature as relevant in the current situation.

affords-eating,⁷³ and the brain state is directly coupled with (or in Gibson's terms resonates to) the affordance offered by the current carrot. (Dreyfus, 2008, p. 1153)

By using dynamic systems theory, rather than a computational or information theoretic approach to interpreting these patterns, we not only do a better job of explaining the data, Dreyfus argues, we also gain a tool for explaining how experiences *draw* us towards other experiences, something that static cognitivist theories cannot do. Thus, on Freeman's account, we get a neurological explanation of the phenomenological resolution to the frame problem; a consequence of the tightly inter-connected relation between experience, perception, and meaning is that agents don't 'pick out' the relevant features of a situation, rather, those features 'solicit' the agent: "In coping in a particular context, say a classroom, we learn to ignore most of what is in the room, but, if it gets too warm, the windows solicit us to open them." (Dreyfus, 2008, p. 1158)

If we accept Freeman's interpretations of the neurological data, it looks like Dreyfus might have some empirical support for moving beyond embodiment to a general anti-representationalism. But, as I shall argue in the next section, although they are both right in pointing out the limitations of the cognitivist view, Dreyfus is hasty in concluding that all representational models of cognition will suffer the same fate.

IV: Dreyfus Concludes Too Much

As I've noted, Dreyfus' observation that the frame problem stems not from any particular model of cognition per se, but from a prior ontological commitment to a disembodied view of meaning provides us with a deep and important insight. But instead of concluding that we ought to be focusing on embodied AI approaches, he wants more; Dreyfus thinks that the new basis for cognitive science ought to be fully Heideggerian, not just embodied. And this, he argues, entails that our cognitive science will be fundamentally non-representational.

But the fact that a Heideggerian embodiment relation – background coping – is fundamentally non-representational is not in itself an argument that *we* must see it that way as well. The frame problem argument licenses only the move to views on which meanings arise for systems out of their on-going inter-relations with their environment; it is silent about the specific nature of those on-going inter-relations. We need an independent argument for the claim that the non-representational feature of background coping is essential to it being an embodied relation. In other words, Dreyfus needs to show us that being a representational relation and an embodied relation are at base incompatible. He does not provide this support anywhere.

To be charitable, we might read Dreyfus' use of the term 'representation' as 'cognitivist representation'. Since the frame problem argument does show us that the cognitivist representational relation is incompatible with the embodied

one, he'd be justified in his insistence that embodiment is essentially non-representational. But if we don't agree that all accounts of representation are, or must be, cognitivist, the frame problem argument will not justify a blanket dismissal of them. Nor would a Heideggerian appeal, even were we to move with Dreyfus beyond embodied AI to Heideggerian AI, since the term 'representation' as it is used today is far more nuanced and complex than it was in Heidegger's day, when it *did* mean roughly what the cognitivist conception does. Fred Keijzer (1996), for example, suggests that the internal states of a cognitive system responsible for guiding long-term behaviour should be seen as representations, though since they do not have the conceptual and computational baggage of cognitivist representations, we might want to use some new terminology to refer to them: "However, at the same time, these internal states are so different from the cognitive science's traditional notion of representation that it is perfectly reasonable to hold that they are not representations." (p.283) Evan Thompson (2007) suggests that representations *emerge* out of 'brain-body-world' interactions:

Representational 'vehicles' (the structures or processes that embody meaning) are temporally extended patterns of activity that can crisscross the brain-body-world boundaries, and the meanings or contents they embody are brought forth or enacted in the context of the system's structural coupling with its environment. (p.59)

And Rolf Pfeifer (1995) thinks of embodied representations as the "weight configurations of a neural network" (p.59) in conjunction with the physical make-up of the system and how it interacts with its environment. And there are many more variations besides. The point is that not all appeals to representation are commitments to internal content kernels that, in virtue of their content, play a role in an inferential network. To suppose that they are is to have just missed the shift in thought that has been occurring over the past decade or so. Of course, Dreyfus must be aware of the fact that not all accounts of representation are cognitivist ones. Michael Wheeler, in developing a quasi-scientific fleshing out of Heideggerian 'thrownness', takes great pains to distinguish his 'action-oriented representations' from the traditional variety. Instead of evaluating whether Wheeler's representationalism slips in a commitment to a disembodied view, however, Dreyfus (2008) rejects it out of hand:

Merely by supposing that Heidegger is concerned with *problem solving* and action oriented *representations*, Wheeler's project reflects not a step beyond Agre but a regression to aspects of pre-Brooks GOFAI. Heidegger, indeed, claims that skilful coping is basic, but he is also clear that all coping takes place on the background coping he calls being-in-the-world that doesn't involve any form of representation at all. (p. 1145)

But Dreyfus isn't *just* claiming that, in everyday coping, we don't use representations; Dreyfus ultimately wants to

conclude that cognition itself ought to be understood as a non-representational activity.

The post-Cartesian agent manages to cope with the world without necessarily representing it. A dynamical approach suggests how this might be possible by showing how the internal operation of a system interacting with an external world can be so subtle and complex as to *defy* description in representational terms—how, in other words, cognition can *transcend* representation. (Dreyfus, 2008, p. 1147)

Given what he's argued successfully thus far, however, this is just implausible. It doesn't follow from the fact that one relation or process is derivative of another that they will share all of their properties. Dancing is derivative of movement, but dancing can have all sorts of structural properties, for example, being organised according to a piece of music, without movement also having those properties. Even if we accept that cognition as a process develops out of a more fundamental embodied relation with the environment in which representations do not figure, we cannot assume, as he does, that representations will play no role in our account of the derived cognitive process.

Finally, the empirical support that Freeman's neuro-dynamical position seems to offer Dreyfus' anti-representationalism is illusory. Freeman's position is in opposition to cognitivist interpretations of neurological data – Freeman is clear about this. Thus, his account, if accepted, could serve as empirical reinforcement for Dreyfus' dismissal of cognitivist approaches, in short for his frame problem argument, but not as support for a rejection of non-cognitivist models on anti-representational grounds.

Dreyfus is hasty, then, in moving beyond the conclusion of his argument to a rejection of all representational accounts. If he pleaded a cognitivist reading of 'representation', we'd have a rationalisation for his over-reaching, but the fact that the term has been evolving rather publicly undermines that plea and places his wholesale rejection on very shaky grounds.

V. Conclusions and Speculations

Even if we cannot accept all of Dreyfus' conclusions, we can still act on the viable one and replace our disembodied cognitive models with those that are embodied. What we still need is a working definition of embodiment, one that is general enough to apply to non-human and possibly even non-organic systems, but specific enough to provide direction and cohesion to embodied approaches. As we've seen, we can't accept Dreyfus' Heideggerian suggestion, since it is entangled with the idea of anti-representationalism, and the frame problem argument does not warrant such a strong reading of embodiment.

There are many suggestions for how we might develop an embodied cognitive science – see Tom Ziemke's (2003) lucid and comprehensive overview for an up-to-date list – but not all of these will meet the minimum criterion set by the frame problem. For example, the idea of embodiment as

'having a physical instantiation' is insufficient because it's entirely possible for a system to be physically grounded through its body but at the same time gain knowledge about its environment in another way, perhaps through an externally created knowledge base, rather than through experience, over time, and via its own body parts.

As mentioned earlier, on an embodied view the frame problem really can't be formulated since, as a dynamic approach, situations aren't seen as discrete units of experience in the context of which decisions (about relevance or about anything at all) have to be made. Rather, situations are the backdrop for the continually evolving dynamic coupling of systems. Thus, in an important sense, embodied systems are never *in* situations; they are constantly moving and reacting in response to the pushes and pulls in their environment. Perhaps the litmus test for minimal embodiment, then, is whether it is possible to formulate the frame problem on a given view; if it is, then the view is not minimally embodied in the sense required to defeat the frame problem argument. But how do we know if our theory of embodiment has gone too far, as I've argued Dreyfus' Heideggerian version does? And what precisely does 'going too far' mean? An objective measure of this is unlikely. Nevertheless, a balance is required between the intuitions motivating traditional disembodiment and the new insights that have arisen in response to its shortcomings. While we are shifting paradigms and striving for new ways of thinking about the phenomena, we need to do so within the context of a theory that is explanatorily perspicuous with respect to cognition, since this is the process we ultimately want to understand. The minimal sense of embodiment that I think is best suited for this task is the concept of autopoietic embodiment that Humberto Maturana and Francisco Varela (1980) and more recently Evan Thompson (2007) have developed. But I'll have to leave to another paper the task of determining whether that view is stronger than it needs to be in order to underwrite a theory of cognition.

References

- Barsalou, L. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577–660.
- Brooks, R. A. (1991). Intelligence without reason. *Proceedings of the International Joint Conference on Artificial Intelligence*. (pp. 569–595). San Mateo, CA: Morgan-Kaufman.
- Clark, A. (1997). *Being there: putting brain, body, and world together again*. Cambridge: MIT Press.
- Clark, A. & Toribio, J. (1994). Doing without representing? *Synthese*, 101, 401–431.
- Dreyfus, H. (2002). Intelligence without representation – Merleau-Ponty's critique of mental representation. *Phenomenology and the Cognitive Sciences*, 1, 367–383.

- Dreyfus, H. (2007). Response to McDowell. *Inquiry*, 50 (4), 371-377.
- Dreyfus, H. (2008). Why Heideggerian AI failed and how fixing it would require making it more Heideggerian. *Artificial Intelligence*, 171(18), 1137-1160.
- Fodor, J.A. (1987). Modules, frames, fridgeons, sleeping dogs, and the music of the spheres. In Z. Pylyshyn (Ed.), *The robot's dilemma: the frame problem in artificial intelligence*. Norwood, NJ: Ablex.
- Fodor, J.A. (2000). *The mind doesn't work that way*. Cambridge: MIT Press.
- Freeman, W. (2000). *How brains make up their minds*. New York: Columbia University Press.
- Keijzer, F. (1998). Doing without representations which specify what to do. *Philosophical Psychology*, 11(3), 269-302.
- Keijzer, F. (2002). Representation in dynamical and embodied cognition. *Cognitive Systems Research*, 3, 275-288.
- Kelso, J. A. S. (1995). *Dynamic patterns: the self-organization of brain and behaviour*. Cambridge: MIT Press.
- Kirsh, D. (1990). When is information explicitly represented? In P. Hanson (Ed.), *Information, language, and cognition*. Vancouver: University of British Columbia Press.
- Maturana, H. & Varela, F. (1980). *Autopoiesis and cognition*. Dordrecht, The Netherlands: Reidel.
- McCarthy, J. & Hayes, P.J. (1969). Some philosophical problems from the standpoint of artificial intelligence. In D. Michie and B. Meltzer (Eds.), *Machine intelligence*, 4. Edinburgh: Edinburgh University Press.
- McDowell, J. (2007). Response to Dreyfus. *Inquiry*, 50 (4), 366-370.
- Pfeifer, R. (1995). Cognition – perspectives from autonomous agents. *Robotics and Autonomous Systems*, 15, 47-70.
- Preston, B. (1993). Heidegger and artificial intelligence. *Philosophy and Phenomenological Research*, 53 (1), 43-69.
- Pylyshyn, Z.W. (Ed.) (1987). *The robot's dilemma: the frame problem in artificial intelligence*. Norwood, NJ: Ablex.
- Shanahan, M. (1997). *Solving the frame problem: a mathematical investigation of the common sense law of inertia*. Cambridge: MIT Press.
- Shanahan, M. (2008). The frame problem. *The Stanford Encyclopedia of Philosophy (Fall 2008 Edition)*, Edward N. Zalta (Ed.), URL = <<http://plato.stanford.edu/archives/fall2008/entries/frame-problem/>>.
- Thelen, E., and Smith, L. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge: MIT Press.
- Thielscher, M. (1998). Introduction to the fluent calculus. *Electronic Transactions on Artificial Intelligence*, 2(3-4), 179-192.
- Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of the mind*. Cambridge: Harvard University Press.
- Van Gelder, T. (1995). What might cognition be, if not computation? *Journal of Philosophy*, XCII(7), 345-381.
- Varela, F., Thompson, E., and Rosch, E. (1991). *The embodied mind*. Cambridge: MIT Press.
- Wheeler, M. (2008). Cognition in context: phenomenology, situated robotics and the frame problem. *International Journal of Philosophical Studies*, 16 (3), 323-349.
- Ziemke, T. (2003). What's that thing called embodiment? In Alterman & Kirsh (Eds.), *Proceedings of the 25th Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Lawrence Erlbaum.