Activities and Interactions in the Concept of a Mechanism

Stuart Glennan, and the team of Peter Machamer, Lindley Darden and Carl Craver have recently provided two accounts of the concept of a mechanism. The main difference between these two versions rests on how the behavior of the parts of the mechanism is conceptualized. Glennan considers mechanisms to be an interaction of parts, where the interactions are occasions on which a change in a property of one part brings about a change in a property of another part. Machamer, Darden, and Craver criticize traditional conceptualizations of mechanisms which are based on parts interacting because the interaction is reduced to mere properties of the entities. In response, they introduce a new concept—activity. For them, mechanisms are entities and activities producing regular changes. I will claim in this essay that while some of Machamer, Darden, and Craver's criticisms of the traditional concept of interaction are legitimate, these problems do not justify the complete replacement of interactions with activities. Instead, both concepts are necessary for an understanding of mechanisms.

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1. Introduction. The search for and discovery of mechanisms in the sciences abounds. Whether it is geology or molecular biology, biochemistry or cosmology, what is taken to be a causal explanation often consists of the description of a mechanism. Philosophical analysis of the concept of a mechanism can obviously be traced back to the seventeenth century (and even further back to Archimedes), but the seventeenth century analysis of mechanisms, based on the actions and interactions of corpuscles, was problematic. For instance, causation resulting from corpuscular interactions was based on physical collisions, whereby one corpuscle acted on another by physically pushing it. Even forces such as gravity and magnetism were believed to be reducible to this very basic concept of a mechanical

interaction. In reality, though, gravitation and electromagnetism have resisted such a formulation. Furthermore, the conceptual frameworks that were constructed to overcome the limits of the mechanical philosophy became extremely complex. As a result, it was difficult to observe the purported corpuscular interactions or test the mechanical hypotheses (Glennan 1996, 51).[1]

The last two decades have seen a return to the philosophical analysis of the concept of a mechanism, but these efforts have predominantly evaluated the use of mechanical explanations in specific sciences. For instance, Wesley Salmon (1984, 1989, and 1998) turns to the concept of a mechanism to explain processes in physics. William Bechtel and Robert Richardson (1993) evaluate the discovery of mechanisms in the neurosciences. And Kenneth Schaffner (1993) studies the application of mechanical explanations in biology and medicine. Recently, Stuart Glennan and the team of Peter Machamer, Lindley Darden, and Carl Craver have attempted to assess the concept of a mechanism more generally (Glennan 1992, 1996, 2000 and 2002, Machamer, Darden, and Craver 2000, see also Craver and Darden 2001, and Darden and Craver 2002). With a more sophisticated understanding of how parts of mechanisms causally act on one another, these newer accounts overcome many of the problems associated with the 17th c. mechanical philosophy. Glennan's, and Machamer, Darden, and Craver's versions of mechanism share many similarities; however, they also diverge at one important point: Glennan considers mechanisms to be an interaction of parts,

[1] There is a wealth of information on the virtues and vices of 17th c. mechanical philosophy. See, for example, Dijksterhuis 1961 (section 4), Glennan 1992 (chapter 2), Gillispie 1960 (chapter 3), Hall 1952, Westfall 1971, and Wilson 1999.

where the interactions are occasions on which a change in a property of one part brings about a change in a property of another part and which can be characterized by direct, invariant, change-relating generalizations (Glennan 2000, 7). Machamer, Darden, and Craver criticize traditional conceptualizations of mechanism which are based on parts interacting because the interaction is reduced to mere properties of the entities. In response, they introduce a new concept—activity. For them, mechanisms are entities and activities producing regular changes. Machamer, Darden, and Craver are unabashed "dualists", requiring both entities and activities in a proper understanding of mechanisms (Machamer et al., 2000, 3).

Glennan claims the current accounts of the concept of mechanism (Machamer et al., 2000 included, but also Culp 2000, Darden 2000 and Thagard 1999) do have variations, but that "the basic view of the nature of mechanisms is similar to the one [he] propose[s] in Glennan 1996." (Glennan 2002, 126, fn.5) The dualists see this relationship in quite a different light. They not only take their turn to entities and activities to be different, they also take it to be more scientifically accurate and philosophically useful. In fact, they devote several paragraphs of "Thinking About Mechanisms" towards differentiating and raising their account over versions which neglect activities.

> We think state transitions have to be more completely described in terms of the activities of the entities and how those activities produce changes that constitute the next stage. The same is true of talk of interactions, which emphasizes spatio-temporal intersections and changes in properties without

> characterizing the productivity by which those changes are effected at those intersections (Machamer et al., 2000, 5).

The dualists identify a number of problems with conceptualizing mechanisms in terms of parts interacting. In response, they justify a turn to activities based on ontological, descriptive, and epistemological arguments. While I agree with many of their descriptive and epistemological points, the ontological status of the activity is problematic. I will claim below that when their ontological arguments against parts interacting and for activities are properly analyzed, the two versions of mechanism, far from being in conflict, can be seen to complement each other.

In section 2 I will introduce the two versions of the concept of mechanism provided by Glennan and Machamer, Darden, and Craver, identifying some of their similarities and differences. Section 3 is devoted specifically to the analysis of the two concepts of interaction and activity. I will examine the dualists' criticisms of the interaction concept in this section and claim that the ontological issues they identify do not justify the rejection of conceptualizing mechanisms as parts interacting but, instead, point only to requiring both concepts of activities *and* interactions. With the virtues of both positions at our disposal, I will show how the two concepts can be used to complement each other in section 4.

2. Two Definitions of a Mechanism. The account of the concept of a mechanism provided by Glennan has evolved slightly over time (Glennan 1996, 2000, and 2002). Some important points have been refined and rephrased since Glennan 1996, but the basic motivation behind

and presentation of his version have remained intact. Glennan 1996 attempts to provide a theory of causation derived from an account of mechanism, claiming that two events are causally connected when and only when there is a mechanism connecting them (Glennan 1996, 64). He defines mechanism (M) as follows:

> A mechanism underlying a behavior is a complex system which produces that behavior by the interaction of a number of parts according to direct causal laws (Glennan 1996, 52).

Glennan 1996 provides no direct definition for his concept of interaction but does associate the term with "direct, causal laws". The *direct* attempts to capture the fact that one part in the mechanism must be the immediate actor on the next part. If there are three cogs interacting in a machine: the first cog turns the second, the second turns the third; then the first cog is directly interacting with the second but *not* directly interacting with the third because it is not immediately bringing about the change. As Glennan says, "what we are trying to capture by this stipulation is the sense that a mechanism is a collection of parts, in which the behavior of the aggregate stems from a series of local interactions between parts." (Glennan 1996, 56) The very general term "causal" is then in place simply to distinguish an actual cause from simple correlations (Glennan 1996, 55). To take a classic example, while a drop in barometric pressure accompanies impending storms, we would not want to say that the falling mercury in the barometer caused the storm. The causal arrow points in the opposite direction. Interestingly, at this point, Glennan 1996 offers his reader no discussion for the choice

of the term "laws" to complete the definition. We will return to this point momentarily.

His 1996 provides the majority of Glennan's version of the concept of a mechanism; however, there are some important differences that emerge in Glennan 2000.[2] First and foremost, Glennan has altered his definition of mechanism (M) to:

> A mechanism for a behavior is a complex system that produces that behavior by the interaction of a number of parts, where the interactions between parts can be characterized by direct, invariant, change-relating generalizations (Glennan 2000, 6).

We see immediately that, while interactions used to be explained as "direct, causal laws", they are now characterized as "direct, invariant, change-relating generalizations". Glennan now avoids using the term "law" to evade the many debates revolving around the philosophically loaded concept. In his words, "in earlier papers (1992, 1996) I have in fact called such generalizations 'laws' with the caveat that these laws must be understood in a more homely way than philosophers typically understand them. Woodward and others have persuaded me to bow to prevailing philosophical usage." (Glennan 2000, 9, fn.1) Woodward has done more for Glennan than just direct him away from the problematic term; he has also provided Glennan with the substitute. "Invariant, change-relating generalizations" is borrowed directly

[2] It is important to mention here that Glennan 2000 was presented at the 2000 PSA conference after the publication of Machamer, Darden, and Craver's "Thinking About Mechanisms". The goal of this essay is to assess a difference between the two versions, so there will be no effort to label who is responsible for the *similarities* between them.

from Woodward 2000. Woodward's ambitious "Explanation and Invariance in the Special Sciences" is devoted to providing an understanding of explanation in the special sciences which is not based upon laws (see Woodward 2001 for a more recent examination of this issue). The story is a familiar one: the traditional nomothetic conception of explanation takes successful explanations to rely on laws, conceiving of laws to be universal generalizations. Fields such as biology or sociology often provide us with apparently successful explanations without basing these explanations on the strict philosophical sense of laws, so how are these explanations to be evaluated and explained? Woodward's answer comes from the concept of *invariance*, which is based upon two other closely related concepts: interventions and a change-relating capability. An intervention is an idealized manipulation employed to determine whether changes in X are causally related to changes in another variable Y. Specifically,

> an intervention on some variable X with respect to some second variable Y is a causal process that changes X in an appropriately exogenous way, so that if a change in Y occurs, it occurs only in virtue of the change in X and not as a result of some other set of causal factors (Woodward 2000, 199-200).

The change-relating capability obviously emerges in the change imposed on X and experienced by Y (Woodward 2000, 203). The concept of invariance is then based upon this idealized sense of an intervention. A generalization identified between two variables is invariant if it would continue to hold as various other conditions change (Woodward 2000,

205).[3] Glennan uses these concepts of invariance and a change-relating ability in his new definition of a mechanism. He defines an interaction as, "an occasion on which a property change in one part brings about a property change in another part." (Glennan 2000, 7) The interaction, then, is the event whereby one part induces a property change on another part by virtue of its own change-relating capability. And the relationship between interacting parts is captured by the concept of invariance. In Woodward-speak, an interaction between two parts is invariant if it would continue to hold as other conditions change. This switch from "causal laws" to "invariant, change-relating generalizations" will be important to remember when taking the dualists' first criticism of the interaction-concept into consideration.

Machamer, Darden, and Craver draw their case studies of mechanisms from scientific research in molecular biology and neurobiology and provide the following definition:

> Mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions (Machamer et al., 2000, 3).

Just as I highlighted certain elements of Glennan's definitions, it is important to identify the essential components of this characterization of the concept of a mechanism. The first place to begin is certainly at the point of divergence from Glennan: entities *and* activities. Activities, we are told, are the producers of change, while the entities are the things that engage in these activities (Machamer et al., 2000, 3). According to Machamer, Darden, and Craver, accounts

[3] Some criticisms of Woodward's account of explanation in the special sciences can be found in Mitchell 2000 and Longworth 2001.

of mechanisms have traditionally fallen into two different camps: substantivalists, like Glennan, focus on the interactions of entities and properties with capacities and dispositions.[4] Machamer, Darden, and Craver argue that this account of mechanism is incomplete because, for example, the understanding of an entity's capacity or property is first derived from grasping the activity in which that entity is engaged (Machamer et al., 2000, 4). In contrast to the substantivalists, process ontologists (see, for example, Rescher 1969, 1996, and 2000) instead base conceptions of mechanism on the understanding of the process itself and criticize the isolated focus on entities. Nicholas Rescher has claimed that there is a "revolt against process" in philosophy (Rescher 1969). The dualists seem to appreciate this move towards considering the *doings* of entities, but activities alone will not get the job done. As they admit, there are no activities which cannot be associated with a particular entity. The dualists seek to embrace the intuitions of both these positions by demanding an understanding of mechanism to incorporate both entities and activities (Machamer et al., 2000, 8).

The dualists' entities and activities are "productive of regular changes". The elements of a mechanism must generate a predictable, relatively stable behavior. The regularity, for the dualists, comes from continuity between the various stages of the mechanism from beginning to end (Machamer et al., 2000, 3). By employing the notion of "regular changes", the dualists intentionally avoid the use of the term "law" in their definition. In fact, they criticize the use of the word found in Glennan 1996, claiming, "We find Glennan's reliance on the concept of

[4] For an analysis of mechanism in terms of parts interacting besides Glennan see Wimsatt 1976 and Bechtel and Richardson 1993. Conceptualizing the interactions of parts in mechanisms in terms of the parts' properties or capacities can be found in Cartwright 1989.

a ‘law’ problematic because, in our examples, there are rarely ‘direct causal laws’ to characterize how activities operate.” (Machamer et al., 2000, 4) As I mentioned earlier (see fn. 3), the dualists’ “Thinking About Mechanisms” was published prior to Glennan’s presentation of “Rethinking Mechanistic Explanations”, so Machamer, Darden, and Craver’s concern is valid. However, as we saw from Glennan’s alterations of his definition in Glennan 2000, this critique is no longer applicable. Glennan utilizes Woodward’s notion of invariant, change-relating generalizations to avoid the very same problem the dualists have identified. Whatever the advantages of activities over interactions, it is not simply that interactions are reliant on the concept of a law while activities are not.

Machamer, Darden, and Craver provide much more than a definition of mechanism; they also show how this definition can be used to understand the scientific investigation of mechanisms. For example, they point out that mechanisms are generally idealized into start and finish conditions with intermediate activities in between. The start (or “set-up”) conditions are taken as static time slices. The important entities and their properties such as structural properties and spatial relationships between entities, along with enabling conditions such as electrical charge are identified here. The finish (or “termination”) conditions are also idealized into static time slices and considered to be the end of a particular stage of a mechanism, while the mechanism itself most often continues beyond this point (Machamer et al., 2000, 11). Mechanisms, argue the dualists, are more than these static beginning and end-points. The stages are dynamically connected via the intermediate activities. It is the ability of activities to produce the subsequent changes in the mechanism that keeps the process going.

So if we are to understand mechanisms as active things, then the concept of activity is necessary to move beyond static descriptions of them (Machamer et al., 2000, 12). This point will be important to remember in section 3 when the dualists criticize the notion of a mechanism as parts interacting because it overlooks these intermediate activities. Machamer, Darden, and Craver also point out that mechanisms are arranged in nested hierarchies such that the entities, properties, and activities of the lower levels are components of mechanisms producing higher level phenomena (see also Craver 1998, and Craver and Darden 2001). When investigating mechanisms, a "bottoming out" point is the lowest level of the mechanism that is taken to be fundamental. So while all the entities of a neural mechanism are ultimately composed of sub-atomic particles subject to the rules of quantum physics, this does not necessarily mean that a neurobiologist must explain every neural mechanism in terms of quantum mechanics. Bottoming out is thus an epistemological point about the investigation of mechanisms; it is relative to the fields studying the mechanisms (Machamer et al., 2000, 13).

3. Activities *versus* Interactions. It should be mentioned here that an evaluation of the concepts of activity and interaction is motivated by more than the mere fact that Glennan and the dualists' diverge on this point. The various accounts of the concept of a mechanism discussed so far (those of Glennan and the dualists specifically, but also those of Salmon, Schaffner, Bechtel and Richardson) all turn to an examination of this concept because of what it offers to discussions about causality and explanation. The explanatory power comes from identifying the mechanical causes, and it is the very notion of causality that the concepts of

activity and interaction hope to encapsulate. Machamer, Darden, and Craver devote an entire sub-section (§3.1) of their article to "Activities and Causing". They introduce the concept of an activity partly to demand a specification of what the term "cause" is suppose to signify (Machamer et al., 2000, 6). Similarly, Glennan uses the interaction-concept to capture causality, first explaining it as being governed by "direct, causal laws" and then embedding causality in Woodward's concept of invariance. Thus, the investigation of activities and interactions is more than the search for what lies at the bottom of a dispute about the definition of a mechanism. The investigation is about what lies at the heart of mechanical causation.

An interaction, for Glennan, is an occasion on which a change in a property of one part brings about a change in a property of another part (Glennan 2000, 7). This notion of transferring a change in property is borrowed from Wesley Salmon's concept of transmitting a mark or a conserved quantity[5], with the important switch to an invariant, change-relating capacity from Woodward (Salmon 1984, 1998, and Woodward 2000). Salmon's causal-mechanical account of explanation rests on the notion of a causal nexus as a network of interacting processes. Much of Salmon 1984 is an attempt at identifying what counts as valid causal processes and causal interactions. It is important to point out that the motivation for Salmon's analysis stems from problems he is addressing in physics, such as how processes

[5] The turn to transmitting a conserved quantity from a transmitting a mark was first suggested by Phil Dowe to avoid some of the criticisms leveled against Salmon's earlier concept of an interaction (Dowe 1992, 1995, and 2000). I will not discuss the difference between a transmitted mark and a conserved quantity or the switch by Salmon from the former to the latter, as Glennan uses neither concept.

maintain a structure through space-time. Salmon's version of a mechanism would be ideal for explaining the interaction between a pitcher and a baseball during the process of throwing a strike. The pitcher interacts with the baseball by transmitting momentum to the ball as it is released from his hand. A mechanism such as protein synthesis, though, would be more difficult to explain on Salmon's version since much of the process cannot be conceptualized in terms of conserved quantities (Glennan 2000, 25). Glennan's alteration of what an interaction is in a mechanism is partly an attempt to move beyond the world of microphysics addressed by Salmon.

Similarly, Machamer, Darden, and Craver also compare activities to Salmon's talk of interactions, and also worry that Salmon's version is incapable of moving beyond the level of fundamental physics. "Mere talk of transmission of a mark or exchange of a conserved quantity does not exhaust what these scientists know about productive activities and about how activities effect regular changes in mechanisms." (Machamer et al., 2000, 7) The dualists, in contrast to Glennan, attempt to overcome this problem with the rejection of the concept of interaction and the introduction of their concept of activity. The dualists take activities to be the producers of change, and complain that talk of interactions overlooks this productivity. The concept of productivity, along with several other notions that will be discussed below, lies at the heart of the ontological justification for the dualists' turn to

activities.[6] Their criticisms against conceptualizing mechanisms in terms of parts interacting can be summarized by the following three claims:

1. Talk of entities with capacities is misleading because the activity in which that entity engages must be known before one can establish the capacity of an entity (Machamer et al., 2000, 4).
2. Mechanisms themselves are active. This feature demands that they should be understood in terms of entities and activities rather than just as entities with property changes (Machamer et al., 2000, 5).
3. Finally, talk of interactions, though it may consider property-changes, overlooks the *productivity* by which these changes are brought about in mechanisms (Machamer et al., 2000, 5).

I will discuss each of these claims in a separate sub-section.

3.1. Activities Are Known Before Interactions. The substantivalists, according to Machamer, Darden, and Craver, characterize mechanisms as parts and properties with dispositions or capacities, but claim, "in order to identify a capacity of an entity, one must first identify the

[6] One might argue, as Machamer has, that it is difficult to separate the ontological and the epistemological realms of concepts such as activity or interaction. The idea is that ontology is derived by first asking, "What do we need to understand the structure of the world?" Ontology is then a product of epistemological need. There are certainly other ways to evaluate the ontic-epistemic relationship, but this paper is not about this discussion, so I will avoid it. It is enough to point out that the dualists divide their justifications for the turn to activities into three sections: "Ontic Status of Mechanisms (Ontic Adequacy)" §3, "Example of a Mechanism (Descriptive Adequacy) §4, and "Activities, Intelligibility, and Explanation (Epistemic Adequacy)" §7. I will address the claims found in §3 on ontic adequacy.

activities in which that entity engages." (Machamer et al., 2000, 4) Their example is aspirin. The capacity of aspirin to relieve headaches is not known unless it is known that aspirin produces headache relief. True, but the identification of this activity has little to do with the study of any mechanism. There are two questions here: What does aspirin do? And what makes aspirin do it? The answer to the first question is, in this case, the dualists' activity: it produces headache relief. But the analysis of mechanism only emerges when we turn to the question of what makes aspirin produce headache relief. The history of aspirin research reveals this fact. Even in the *Hippocratic Corpus* we find the utilization of willow tree bark to relieve pain. Various physicians throughout the ages employed such natural sources of pain relief. The cause of this phenomenon was ultimately attributed to salicylic acid in the 19th century, and the chemical took on its modern form—acetylsalicylic acid or aspirin—in 1897 when Felix Hoffman, of the German Bayer corporation, developed a manufacturable version of the chemical. However, even though this chemical compound has been utilized for over 2 millennia, all that was known about the drug up until 30 years ago was *that* the substance (or, in the case of pre-19th c. medicine, *that* some natural objects which happened to contain the substance) produced pain relief. There was no explanation for what makes aspirin produce pain relief until the Nobel-prize winning research of John Vane in the 1970s. It is only at this point that an analysis of the mechanism finally emerges. Vane found aspirin to bind to and inhibit substances in the body called prostaglandins, which naturally protect the body against damage by producing swelling and fever and increasing the body's sensitivity to pain (for a history of aspirin research, see Mann and Plummer 1991).

The mechanism of pain relief is based on an interaction—the binding interaction between acetylsalicylic acid and prostaglandin. Binding is, by definition, an interaction because it is an action requiring two entities: the binded and the binder. Reflecting on this history, it is clear that the dualists' criticism is not an ontological point, but rather an epistemic one. Basic activities must be known before investigations into underlying mechanisms can be performed to find the crucial interactions. But this identification does not ontologically base interactions upon activities; it only tells a story about the epistemological process of discovery.

3.2. Mechanisms Are Active. The dualists also claim that activities are necessary in an account of mechanism for the very basic reason that mechanisms are active. "[Mechanisms] are active and so ought to be described in terms of the activities of their entities, not merely in terms of changes in their properties." (Machamer et al., 2000, 5) This claim goes back to their conceptualization of mechanisms in terms of start-up and finish conditions with the necessary requirement of intermediate activities in between. The dualists argue that the start-up and finish stages idealize the mechanism into time slices. In reality, though, the mechanism is a dynamic system, and so the intermediate activities provide the active component between these static states.

It is true that the dualists have identified a need for the concept of an activity, but does this need imply the entire replacement of the concept of interactions? Certainly not. The dualists themselves pointed out the very fundamental need for the set-up and finish stages of

any activity. In their own words, "The start conditions include the relevant entities and their properties. Structural properties, spatial relations, and orientations are often crucial for showing how the entities will be able to carry out the activities comprising the first stage of the mechanism." (Machamer et al., 2000, 11) This interest in entities and their properties is exactly what we find in the substantivalist conception of interactions. Activities, it would seem, are far from being a replacement for any notion of interactions. Rather, the two concepts are both necessary to capture the behavior of a mechanism. We will return to this relationship in section 4.

3.3. Activities and Productivity. The dualists' third, and most repeated, critique of interactions concerns the interaction-concept's lack of an ability to capture the "productivity" of changes in mechanisms (5—7). Machamer, Darden, and Craver provide no definition of their concept of productivity, but it can be thought of as a type of cause which makes things up (i.e. produces things) from other things.[7] There are many activities, but only some are productive; and it is this productive capability, claim the dualists, which is so important in mechanisms because much of the phenomena found in mechanisms results from new entities with new activities being made up from old entities and old activities. I would argue that the dualists' requirement of productivity, rather than demanding an ontological switch from interactions to activities, only reveals the need for interactions. This is because, while there are many activities, *there are no productive activities that are not interactions*. This arises out of the

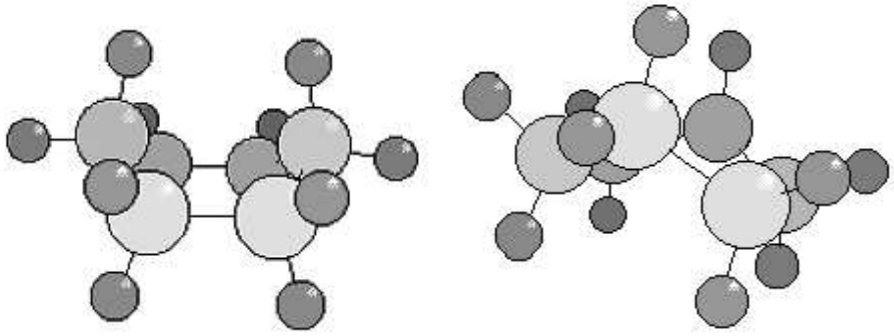
[7] Thanks here to Peter Machamer for discussing the notion of productivity with.

very concept of productivity: making something up from other things. This creative process necessitates a variety of entities to interact with each other in order to construct a new product. Machamer has challenged this claim, citing the example of a free-floating amino acid that was produced but now interacts with no other entity. It is true that the free-floating amino acid is not interacting with any other entity,[8] but we should be careful about where the productivity of this case lies. The productive activity took place during the construction of the amino acid, when it was being made up of other things. And this certainly was a series of interactions between a variety of other entities. The construction itself was a productive activity and a series of interactions, but both of these qualities disappear when the amino acid then begins floating aimlessly. We would only identify a productive activity of the amino acid if it began a process of making something new from something old, such as a protein. But again, this activity will involve interactions between the amino acid and other entities: tRNA, a ribosome, and other amino acids. A better example of an apparently *un*interactive activity might come from a behavior such as the conformation shift in cyclohexane from its "boat" form to its "chair" form (see Figure 1).[9] Unlike the amino acid, the cyclohexane molecule is actively performing an action (as oppose to passively floating in cytoplasm), but the problem again arises as to how this activity is productive. One could say that the boat form produced the chair form, and this is certainly true. But the cyclohexane molecule is not contributing

[8] At least not interacting in any interesting way. One might point out that the amino acid is interacting with the cellular cytoplasm it floats in, but this has nothing to do with a mechanism.

[9] Thanks to Megan Delehanty for suggesting this example.

anything to a mechanism at this point with the isolated, self-activated behavior. The cyclohexane molecule itself could be analyzed as a mechanism. However, now the change in conformation will be described in terms of interactions at the atomic level. In the case of cyclohexane, the shift from the boat form to the chair form results from the hydrogen atoms at the top of Fig. 1a repelling each other due to a common positive charge. The interaction between the two hydrogen atoms forces the entire structure to take on the more stable chair form. We have now identified productivity in the cyclohexane molecule's behavior, but only after it was itself conceptualized as a mechanism and understood as a repelling interaction between hydrogen atoms.



a. boat conformation b. chair conformation

Figure 1: Boat (a.) and chair (b.) conformations of cyclohexane molecule. The larger spheres represent carbon atoms, while the smaller spheres represent hydrogen atoms. From P. Sengbusch (2002), available on-line at http://www.biologie.uni-hamburg.de/b-online/e16/sessel.htm

In conclusion, while there are many activities of entities, as the dualists point out, only some are productive, and it is these productive activities which are important in mechanisms. Machamer, Darden, and Craver argue that explaining mechanisms in terms of parts

interacting overlooks this productivity, but it would rather seem that the concept of productivity only reveals how the important activities of entities in mechanisms must be understood with some notion of an interaction if they are to be productive.

I have tried to show above that the attempt to pick *either* interactions or activities in an ontological conception of mechanisms is misguided. Interactions without a dynamical component are, like the dualists claim, idle. But activities without interactions are (to borrow the dualists' own concept) *un*productive. Demanding a choice between one of the two concepts will only produce an impoverished ontological understanding of mechanisms. A different option would be to determine what exactly it is that each concept offers to a picture of mechanisms and then decide how each of those contributions can be used together to provide a more complete picture of the concept of a mechanism. The remainder of this essay will attempt such a synthesis.

4. Activities *and* Interactions. A complete account of mechanisms requires both interactions and activities, rather than a choice between the two. This interdependent relationship will be displayed easiest by first showing how each concept is incomplete without the other. After this initial step, the relationship itself will be examined. I will begin with a justification for including activities. I have argued above that the dualists' claims did not justify the rejection of interactions in ontologically conceptualizing mechanisms. The first claim was actually an epistemological point, and the third claim only showed that productive activities are, in fact, interactions. Their second claim, though, that mechanisms themselves are active, which

demands that they should be described in terms of entities and activities rather than just as entities with property changes, did point out the need for recognizing intermediate activities to move beyond the time slices that emerge from conceptualizing mechanisms as interacting parts. This is a justifiable claim, and, while it does not imply the elimination of interactions in mechanisms, it does suggest the need for including the concept of activities. The reason is this: Glennan's concept of an interaction is based on changes in properties of the entities; it identifies a change in property of one entity and then a change in property of a subsequent entity. Once the change is induced, the cause is accounted for, so the philosopher's job is essentially finished. But this conceptualization, as the dualists point out, only captures the start-up and finish conditions of this property changing event. The dynamic process of changing must be recognized too. It is the concept of activity that captures the dynamic aspect of property changes.

The second half of the relationship between interactions and activities rests on showing that activities cannot capture the behavior of mechanisms by themselves. Activities, claim the dualists, are the producers of change (Machamer et al., 2000, 3). But this very general definition of activity overlooks some important aspects of the ontological process of change in mechanisms. For example, we must identify what is changed, and more importantly what makes the producer productive. There are many activities: binding, breaking, transporting, pushing, etc. The concept of an activity captures these various verbs in this basic form, but the minute one starts to examine in what sense these activities are to be productive in a mechanism, then some notion of an interaction as an occasion whereby property changes

in one entity bring about property changes in another entity is required in addition to the concept of an activity. Take, for example, the dualists' description of chemical transmission at a neural synapse. The dualists use this example as their descriptive justification for the turn to activities, but it will also be helpful in examining the ontological status of their concept, as it is one of the only detailed examples they provide to explain what activities are in a mechanism. As is often the case, mechanisms are represented with visual diagrams. Machamer, Darden, and Craver take an example from Gordon Shepherd's classic *Neurobiology* textbook (Shepherd 1988). Diagrams of mechanisms usually involve pictorial representations of the parts of the mechanisms along with arrows demonstrating what these parts are doing in the mechanism. According to the dualists, the entities are just the visually represented objects in the picture. In the case of chemical transmission at a synapse we have, to name a few: membranes vesicles, chemical neurotransmitters, and receptors. The arrows, claim the dualists, represent the activities of chemical transmission: storage, diffusion, transport, and release (Machamer et al., 2000, 8). The aim of this section is to examine the relationship between interactions and activities, so the question is whether or not the concept of activity captures this process by itself. I do not believe so. Arrows never point to nowhere. They have a direction, and that direction inevitably points to another entity of the mechanism, implying that the action is taking place between two parts of the mechanism. Take, for example, the process of storing chemical neurotransmitters in a membrane vesicle and then releasing them into the synapse (a sub-mechanism of the mechanism Machamer, Darden, and Craver utilize). The membrane vesicle packages neurotransmitters in a vesicle and then

transports them to the pre-synaptic membrane wall to release them into the synapse. A number of activities were mentioned: packaging, storing, transporting, and releasing. But notice that all these verbs necessarily involve two (groups of) entities. One cannot just say, "entity X releases"; we must say *what* entity X releases and say what is productive about releasing X. The "what" will, of course, be another entity (neurotransmitters in this case), but the productivity demands further explication. Neurotransmitter release at a presynaptic membrane is, itself, a mechanism with stages of its own. Mobilization, docking, priming, fusion/exocytosis, and endocytosis are all activities identifiable below (see Figure 2).

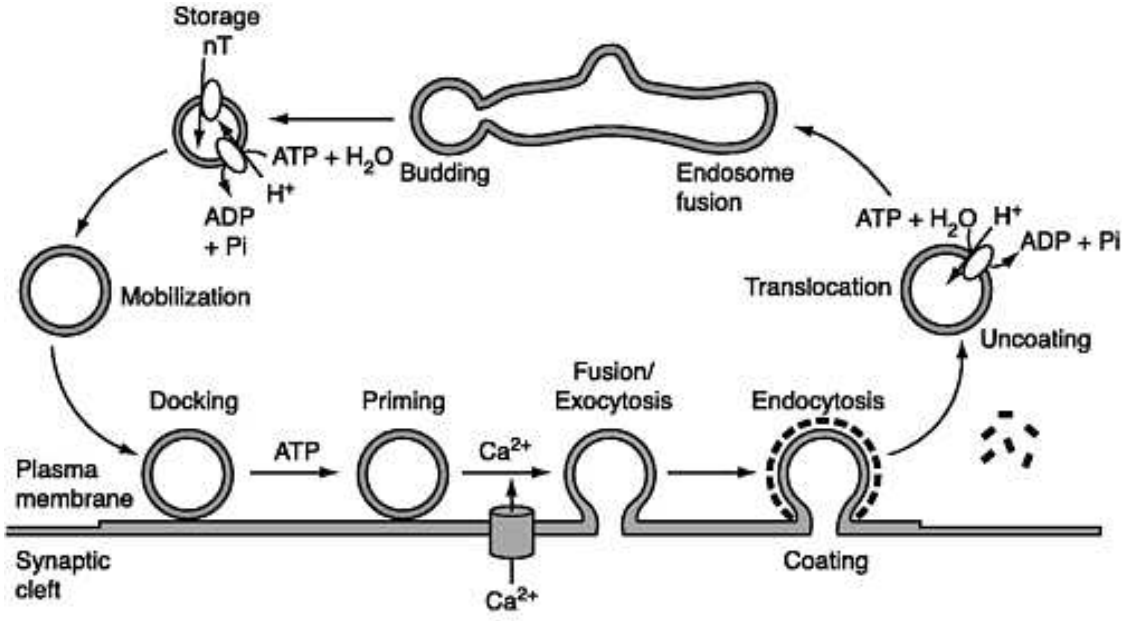


Figure 2: Diagram of vesicle cycle at presynaptic terminal. From C. Hammond (2002), *Cellular and Molecular Neurobiology,* Second Edition. San Diego: Academic Press.

To focus the discussion of the mechanism, I will speak specifically to the docking activity. Vesicles dock onto the presynaptic plasma membrane at morphologically defined sites. These sites are determined based upon proteins on both the synaptic vesicles (v-SNAREs, synaptobrevin) and the plasma membrane (t-SNAREs, syntaxin).[10] Both of these proteins are integral membrane proteins (meaning that they are embedded in the vesicle membrane and presynaptic plasma membrane) with a short extracellular region protruding from the membrane into the extracellular matrix.[11] The vesicle and presynaptic membrane SNAREs form what are called "coiled-coil structures", consisting of several α-helices wrapped about one another (Hammond 2002, 180—185). A variety of property changes such as spatial orientation, structural conformation, and charge distribution all take place as a result of chemical interactions between the SNARE proteins, leading to an incredibly strong bond between the vesicle and the presynaptic membrane (Sutton, et al. 1998).[12]

Several comments must now be made about the above example. First, the fact that the above mechanism is still under investigation should in no way undermine the fact that it is necessary to cite interactions. While a new mechanism may be proposed with new interactions governing the neurotransmitter-releasing activity, the mechanism would be

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[10] SNAREs = Soluble NSF-Attachment protein REceptors. For a brief introduction to SNARE research, see Gerst 1999 and Pfeffer 1999.

[11] Interestingly, these proteins are also the targets of toxins such as botulinum and tetanus, which attack the nervous system by disrupting this mechanism, causing paralysis and, potentially, death (Hammond 185).

[12] Thanks here to Robert Poage for a helpful discussion about the biochemical and molecular details of the vesicle cycle.

impossible to conceptualize without a similar appeal to interactions of some sort.[13] The second point concerns the pictorial representation of the synaptic vesicle cycle found in Figure 2. In the diagram utilized by Machamer, Darden, and Craver, activities are identified by the arrows in diagrams of mechanisms. But notice that in Figure 2, arrows now only represent changes in position. The activities like docking and priming are actually associated with stages where entities are interacting with one another. Finally, the dualists could certainly respond to the detailed description above by pointing out that most neurobiologists never examine or even take into consideration the docking mechanism at this molecular level; neurobiologists generally "bottom-out" above the detailed description given above. This is true, but remember that bottoming-out is a relative, epistemological point, not an ontological one. The fact remains that an activity such as docking does involve an interaction between two entities (SNARE proteins) due to a property-change (The proteins change in physical shape in response to ionic, hydrogen, and hydrophobic interactions, creating a tight connection between the vesicle and the presynaptic membrane).

I have discussed above the impoverished view of the concept of a mechanism that emerges when only interactions or activities are taken individually. But the question remains: What is the actual relationship between the two concepts? I take the relationship to look like this: Activities are dynamic causes, such as binding, releasing, and repelling. But these causes remain undefined unless they are put in some mechanical context. The concept of an

[13] See Weis and Scheller 1998 for an example of various theories of this mechanism, which are all based on similar protein interactions.

interaction provides that context. It embeds an activity into a series of two or more entities. Rather than just "repelling", now there is a hydrogen atom repelling another hydrogen atom (and vice versa). Rather than just "releasing", now there is a synaptic vesicle releasing neurotransmitters. Furthermore, embedding activities into a mechanical context makes them productive. The creation of new entities and activities from old ones is impossible without the concept of an interaction bringing the variety of entities together. In this way, the concept of an activity and the concept of an interaction become interdependent upon one another. Interactions need activities. Changes in property-states are a necessary feature of any mechanism, but the dynamic manner of changing itself must be included in this process too. And activities need interactions. Dynamic causation is essential to a mechanical process, but the activities must be productive, and this requires interacting.

5. Conclusion. The concepts of an interaction and an activity are both necessary in the ontological conceptualization of mechanisms. In contrast to Glennan's claim concerning the relationship between his version of the concept of mechanism and subsequent accounts, there is a very important difference found in Machamer, Darden, and Craver's conceptualization: interactions are not activities. But also, in contrast to the dualists' claims, (i.) the concept of an interaction is not reliant on the notion of a law, and (ii.) the concept of an activity cannot capture the ontological reality of mechanisms by itself. Both concepts contribute unique components to a mechanism. Activities make mechanisms dynamic. Interactions make activities productive. The two concepts are interdependent.

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