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On the Theorem of Correspondence

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Abstract

In a recent paper, Mammen (2016a) brought novel arguments into the discussion concerning the importance of being able to single out and track objects through space and time. Mammen offered a formal account of two basic, yet distinct, ways in which we as human beings encounter objects in the real world, that is, sense and choice categories. In this paper I discuss aspects of his theory and in particular the Theorem of Correspondence. I shall attempt to argue that Mammen's formal account is indeed a novel and powerful analytical generic tool allowing us to see the important relevance in different domains of being able to establish choice categories. Meanwhile, I will attempt to show that evidence from the so-called multiple object tracking studies -- even though these use highly artificial stimuli -- provide compelling evidence in *support* of Mammen's formal account.

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On the Theorem of Correspondence

1. Introduction

As human beings we are surrounded with numerous objects like pens, cups, chairs, cars, and books. For some of these daily encountered objects it may not make a difference whether, for instance, a given pen is exactly the same pen as the one I used yesterday (numerical identity), or just another pen sharing the same features (qualitative identity). However, when it comes to heirlooms, pieces of art, pets, close friends, loved ones, and relatives, this difference is no longer trivial; it becomes crucial.

Mammen and Mironenko (2015) recently argued that although this awareness of objects' history is a central aspect in the lives of human beings, it has actually been neglected in much of contemporary psychology. In a very recent and genuinely thought provoking paper Mammen (2016a) brought new arguments into the discussion concerning the importance of being able to single out and track specific objects through space and time. Mammen (2016a) offered a *formal description* of two basic, yet distinct, ways in which we as human beings encounter objects in the real world. By means of the objects' physical properties (e.g., size, shape, color, and texture) we compare and differentiate physical entities allowing us to establish so-called *sense categories* of objects (e.g., black pens on my office desk). Meanwhile, by means of choosing, or selecting (often physically), we also single out distinct, unique objects, or group of objects, whereby we establish what Mammen has coined *choice categories* (e.g., my favorite black pen that I eagerly attempt to keep track of). At least two claims are central in Mammen's (2016a) theory: First, as human beings we constantly relate to objects in the world by means of establishing *both* sense categories *and* choice categories. Second, much of contemporary psychology seems to have overlooked or

maybe at times even forgotten the extent to which everyday life depends on the ability to establish choice categories (Mammen, 2016a).

Mammen's (2016a) formal description is based on axioms and theorems. The 11 axioms are independent and non-contradicting statements about sense categories and choice categories, whereas the 11 theorems are results of deductions based on the axioms (for a detailed account, I refer the reader to Mammen, 2016a). One of the most important theorems may be Theorem 9, which is also called the Theorem of Correspondence (Mammen, 2016a, p. 222):

> Any finite choice category with more than one object defines a local subspace in Ù where all subsets are both choice categories and local sense categories.

The Theorem of Correspondence states that whenever we have a *finite* choice category (e.g., my office), then any subset of this choice category (e.g., the top shelf of books behind me, or my favorite black pen on my desk) can be demarcated *either* by selecting (i.e., establishing a choice category) *or* solely by means of sensory criteria (i.e., establishing a local sense category). In other words: A finite choice category establishes a 'mini universe' in which the use of selecting/choosing on the one hand and feature discriminations on the other hand lead to the exact same results. In this case the differences between choice categories and sense categories 'disappear' or 'collapse' (Mammen, 2016a, p. 222).

According to Mammen (2016a, p. 222, italics by author) this 'collapse' of choice categories and sense categories that comes into play whenever we make categorical decisions within the context of finite choice categories (e.g., my office, this parking lot, this classroom, or this lab) has been overlooked by contemporary psychology:

> In psychology a situation like the mini-universe is often established in *experimental situations*, e.g. in many experiments within mainstream cognitivism with the lab as a finite choice category. The problem with this is that this choice categorical *framing* is out of focus or even denied and that the sensory discriminations are therefore thought to do the selections without any support. The experimental results are accordingly interpreted as being valid also in the much broader ecology of the *everyday universe* of objects, which they are obviously not. Mainstream cognitive psychologists in this way maintain their blind spot by their experimental tradition ignoring the reality of choice beyond sensory criteria and our dual bodily existence.

As a consequence, the effectiveness of our sensorial discriminative abilities in everyday life outside the laboratory may have been given more credit than they deserve at expense of our (often unnoticed, but equally important) ability to select or delimit mini-universes within which we can operate (Mammen, 2016a; see also Krøjgaard, 2016).

The purpose of this paper is to discuss aspects of the Theorem of Correspondence in particular. I shall attempt to argue that Mammen's axiomatic system and cognitive psychology can actually benefit from each other: On the one hand I will argue that the duality of sense and choice categories in general and the Theorem of Correspondence in particular seem to provide a novel and powerful analytical framework. On the other hand I will present some evidence from the so-called multiple object tracking (MOT) studies and attempt to argue that although these studies are conducted in what Mammen (2016a) likely would consider a mini-universe (a finite choice category), the results from these studies can actually be interpreted to *underscore* the importance of choice categories.

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2. The laboratory and beyond

Ideally, results from psychological experiments conducted in a laboratory setting can be generalized to the everyday world outside the lab. However, when considering in particular the relationship between sense categories and choice categories, more caution may be needed when attempting to generalize results from the lab to the everyday world. Mammen (2016a) states that since an experimental setting can be conceived of as a finite choice category, we risk attributing sensory discrimination too much explanatory power in experimental settings, due to the 'collapse' of sense categories and choice categories (cf. the Theorem of Correspondence). We simply tend to overlook the dependency on establishing choice categories when making categorical decisions in the real world. Consequently, Mammen (2016a) argues, the results concerning sense categories and choice categories obtained in experimental settings (i.e., finite choice categories) may not be directly generalizable to the world outside the lab, because sensory discrimination is far less powerful in an infinite world of objects (that is, outside the lab, cf. quote above).

In Mammen's (2016a) paper these consequences of the Theorem of Correspondence are based exclusively on the presentation of the axiomatic system and the derived theorems. However, some readers may prefer to see specific examples of this supposed flaw in the reasoning within cognitive psychology. Actually, in his doctoral theses in which the axiomatic system was originally presented at length in Danish, Mammen (1996, pp. 105-106) referred to a seminal book on categorical decisions and concept formation (Bruner, Goodnow, & Austin, 1956) as an illustrative example of this aforementioned overgeneralization. However, since the work by Bruner and his collaborators was only referred to in parsing and was written in Danish, I shall here revisit the classical work by

Bruner and colleagues in order to provide a concrete example of the way of thinking that Mammen (2016a) criticize.

Bruner and his colleagues were interested in categorical decision and concept formation (Bruner et al., 1956). In their book they reported about 20 experiments of which many were based on the same basic material: 81 custom made cards. Each card had a figure and a border. The figures varied in *shape* (square, circle, or cross), *color* (red, green, or black), as well as in *number* (one, two, or three) whereas the *borders* only varied in number (one, two, or three). Thus, each card could vary on four dimensions of which each dimension had three possible values, leading to a total of 3 x 3 x 3 x 3 = 81 possible combinations (Bruner et al., 1956, pp. 41-42). One of the tasks was to establish conjunctive concepts, that is, a subset of cards defined by the joint presence of several attributes as for instance "all cards containing red squares and two borders" (Bruner et al., 1956, p. 83). Given the nature of the material used in the tasks it may not seem surprising that subjects used the cards' attributes to establish conjunctive concepts (i.e., local sense categories using Mammen's terms) whereas a strategy of keeping track of distinct cards (i.e., choice categories) was less salient due to the finite number of cards. In the final chapter of the book Bruner and his colleagues gave their thoughts on how the results obtained in their experiments might be *generalized* to the real worlds outside the laboratory (Bruner et al., 1956, p. 232):

> The research we have reported has mainly been drawn from the field of "concept formation" so-called, but we would propose that our conclusion are applicable to any phenomenon where an organism is faced with the task of identifying and placing events into classes on the basis of using certain critical cues and ignoring others.

Thus, Bruner et al. (1956) suggested that the results obtained in the laboratory should be broadly applicable to the real world outside the laboratory. However, using Mammen's (2016a) terms Bruner and his colleagues seemed to overlook, that contrary to the real world outside the laboratory, the laboratory constituted a finite choice category in which the sense and choice categories collapse, whereby the effectiveness of establishing a finite choice category was neglected.

The effectiveness of establishing such *ad hoc* finite choice categories is, however, not restricted to the lab, but also comes into play in everyday life (Mammen, 2016a; Mammen & Mironenko, 2015). For instance, when I look for my bicycle, I definitely use sensory criteria (a black, male bike with bags on both sides of the rear wheel). However, prior to the time when these sensory criteria come into play, I have established a finite choice category (i.e., the shed where I left my bicycle) in order to look for the bicycle in the shed (and not in any other place). Establishing this finite choice category before actually employing sensory criteria makes the task of finding my bicycle tremendously easier than if I were to look for my bicycle at *any* place in the world. This may seem trivial, since that is exactly how we typically find our things, but the point is, that the establishment of the finite choice category is often carried out more or less automatically or unnoticed – simply because it falls so natural and easy to us.

The limitations present in the classical work on categorical decision making by Bruner and his collaborators outlined above as well as being unaware of how the ability to establish choice categories is a huge asset in everyday life may be difficult to pinpoint unless we possess the adequate analytical tools. In my view, Mammen's (2016a) thought-provoking axiomatic system is exactly such a highly versatile analytical tool. Now, back to the lab!

3. Evidence from the laboratory: The MOT studies

In the following I will present some evidence from experimental studies on MOT. To anticipate, the point of presenting these studies is that although these studies are clearly experimental (cf. the precautions cited from Mammen above), and although the studies are not framed within the terminology of sense categories and choice categories, they provide compelling evidence *supporting* the claim that the ability to establish finite choice categories is simply a necessary requirement in order to solve the task.

Almost four decades ago, Pylyshyn and his colleagues, while attempting to build a model of geometrical reasoning, were lead to the conclusion that a highly specific *mechanism* would be needed (Pylyshyn et al., 1978, cited in Pylyshyn, 2009). This special mechanism was dubbed a *visual index* or *FINST* (i.e., FINgers of INSTantiation). The visual index refers to a kind of 'mental pointer' or 'mental finger' that can be attached to a given visual object regardless of possible changing properties of the object. One important feature of the proposed visual index is that it is assumed to be 'sticky', that is, if the visual object moves, the index moves with it (Pylyshyn, 1989, 2001, 2009).

In the late 1980's Pylyshyn began a series of experiments designed to test this proposed mechanism. These experiments are typically called MOT studies. The basic design is as follows: A number of simple, identical objects (typically 8 squares or 8 circles) are scattered randomly on a screen. Then the objects in a subset of these objects (i.e., 3-5 objects) are highlighted briefly. These highlighted objects are the targets, and the observer is instructed to try to keep track of these targets. The 'highlighting' of the targets is terminated and hereafter all objects again become equally salient. Then all objects start moving around randomly and independently (typically for 5-10 sec). When the motion stops, the observer is asked to identify the targets (or to decide whether a given object was a target, or not).

Results from MOT studies have shown that observers are capable of tracking 4 (and at times even 5) objects successfully (e.g., Sears & Pylyshyn, 2000; Yantis, 1992) – which was far better than initially expected by Pylyshyn when the paradigm was launched (Pylyshyn & Storm, 1988). Note, that in the MOT paradigm the specification of the targets invariably takes place *before* the objects actually start moving around. As soon as the objects start moving, they are completely identical with regard to their physical properties (Pylyshyn, 2004). Therefore, when observers succeed identifying the targets in MOT studies after the objects have stopped moving, they cannot have done so by relying on the objects' featural information. The observers simply have to have consulted other cognitive resources. According to Pylyshyn the observers solve the MOT tasks by means of visual indexes or FINSTs (outlined above).

One might ask whether the MOT paradigm seems somewhat artificial relative to the tracking tasks human beings typically encounter in the real world outside the laboratory. This is exactly the point raised by Horowitz, Klieger, Fencsik, Yang, Alvarez, and Wolfe (2007, p. 173) as they wrote:

> Although the MOT task can be informative, it differs from such real-world tasks in critical and related ways. First, objects in the real world (cars, children, etc.) are rarely identical; they can differ in visual features as well as in characteristic motion. Second, the type of real-world answer that we demand of our visual system is typically different from the answer demanded of the observer during MOT. In the standard MOT task, observers are asked to differentiate between tracked targets and untracked nontargets. However, out in the world we rarely ask questions like "which children are you tracking now?"

I find it difficult to refute the criticism put forth by Horowitz and his colleagues. Thus, on the face of it one might get the impression that the MOT paradigm would belong to the kind of cognitivist psychology that Mammen criticized in the previously cited quote (i.e., experimental designs with low ecological validity). However, such an interpretation would in my view be mistaken. Although the standard MOT task may be somewhat artificial, it does not follow that the results have no bearing in the real world. An experimental setting does not have to resemble the outside world in order to be ecologically valid (Krøjgaard, 2001). In my view, the results from the standard MOT tasks provide substantial empirical evidence in support of Mammen's (2016a) theory, not *despite* of using an artificial experimental paradigm involving identical objects, but actually *because* of doing so: By using completely identical visual objects, the MOT task effectively *excludes* the possibility of using featural information to solve the task. While we rarely, if ever, encounter situations outside the lab where we should track completely identically looking objects (cf. Horowitz et al., 2007), the somewhat artificial task confronting the observer in a standard MOT task allows us to examine whether human beings are capable of tracking objects in the highly unusual situation in which discriminative featural information is simply not at hand, and the results are, as we have seen, unambiguously affirmative.

4. Interpreting MOT studies within the frame of the Theorem of Correspondence

How do the results from the MOT tasks relate to the Theorem of Correspondence? Recall, that the Theorem of Correspondence states that in a finite choice category (i.e., the visual display of typically 8 objects), any subcategory (one or several targets) can be decided *either* by means of selecting/choosing (i.e., establishing a choice category) *or* by means of using sensory criteria (i.e., establishing a local sense category), as both routs lead to the same

results due to the 'collapse' of choice categories and sense categories. Now, in the MOT task sensory criteria are made ineffective by design, as the objects involved are completely identical. Nevertheless the observers succeed solving the task.[1]

According to Pylyshyn, MOT tasks are solved by means of the visual index or FINST. Recall that the visual index was described by Pylyshyn as a 'mental finger' or 'mental pointer' that was 'sticky': If the object moved, the index moved along. Note further that the index was assumed to be *insensitive* to the features of the object it followed. This description is very close to the phenomenological contents of Mammen's (2016a, p. 204, italics by author) choice category:

> […] we can make further selections by *taking* objects or just *pointing* at them irrespective of their properties. I can *choose* one of those apples from the tree without in any way having to define what properties distinguish it from the other apples.

Thus, the overlap between Pylyshyn's visual index and Mammen's choice category concerns not only the *result* of the use (keeping track of a given object), but also the *process* by which it operates (a selection independent of the features of the object).

To summarize, due to their design features, which for practical purposes exclude the use of featural information, the results from the MOT studies provide compelling evidence

[1] For the sake of simplicity true duplicates are excluded in Mammen's (2016) model. If the identical objects in MOT studies should be considered true duplicates in a philosophical sense, then it does not change the verdict. Actually, it just makes the argument in support of Mammen's theory even stronger, since the existence of true duplicates would increase the relevance and importance of being able to establish choice categories even further, as features would be ineffective.

that human beings are indeed capable of establishing choice categories (i.e., tracking objects through space and time) even when featural information is effectively made useless in order to solve the task.

The Theorem of Correspondence provides us with a genuinely thought provoking novel and powerful analytical framework allowing us to specify *how* and understand *why* we may tend to attribute too much explanatory power to featural information, when attempting to single out and track specific objects through space and time in a lab setting. In addition, the Theorem of Correspondence and more generally the duality of sense categories and choice categories offer an overarching schematic for understanding and relating a range of specific areas of research in which featural discrimination (sense categories) and keeping track of individuals (choice categories) are related and compared – as for instance the MOT studies. While Pylyshyn's proposed mechanism, the visual index or FINST, is restricted to the parsing of visual objects (Pylyshyn, 2009), Mammen's (2016a) formal account is generic and hence generally applicable to *any* domain concerning establishing object categories by means of sensory criteria (sense categories) or actively selecting/choosing (choice categories).

Meanwhile, I have attempted to show that the contributions are bilateral: Due to the design features inherently present in the MOT task in which the visual object are intentionally made identical, the results from these studies provide proof of concept evidence underscoring the importance of being able to establish finite choice categories when singling out objects.

5. The Theorem of Correspondence and literature: The Little Prince revisited

In his comment to the Mammen and Mironenko (2015) paper, Neumann (2016) refers to 'The Little Prince' by Saint-Exupéry (1996). Neumann (2016) points to the parallel between becoming tame in the story and establishing choice categories. I very much agree with this parallel and have also referred to this parallel previously (see Krøjgaard, 1999a, 1999b, 2009). In the present context I would attempt to argue that the analogies between The Little Prince and his relationship with his rose, and the formal description provided by Mammen (2016a), may be even more profound than it may immediately appear to our senses(!)

In the fairytale, the Fox explains to The Little Prince the difference between objects by whom we share a history, and objects by whom we do not. The Fox teaches The Little Prince, that the gradual establishments of bonds over time to objects, living or inanimate, make a crucial difference. Note, that whereas the Fox explains his secrets to the Little Prince on planet Earth, where the number of objects for practical purposes are infinite, The Little Prince has lived most of his life on a very small planet inhabited with very few (and hence countable) objects. If we convert these two universes of objects to the terminology employed in Mammen's (2016a) formal description, then planet Earth with its countless (infinite) number of objects corresponds to the universe of objects, Ù, whereas The Little Prince's planet with its very few and countable objects corresponds to a finite choice category with more than one object, which in accordance with the Theorem of Correspondence defines a local subspace in Ù where all subsets are both sense categories and choice categories. In such a subspace or mini-universe the differences between sense categories and choice categories collapse as previously noted (Mammen, 2016a). Because The Little Prince has lived most of his life in a subspace (the small planet) in which sense categories and choice categories are indistinguishable, the difference between his unique rose by whom he share a history and any other rose has been invisible to him. It takes an infinite universe of objects to

become aware of this prominent difference. The Fox, who knows the difference, lives on planet Earth (an infinite universe of objects). Only when The Little Prince leaves his planet and visits Earth, the difference between sense categories and choice categories become salient to him too. I do not know whether the 'homes' chosen for the Fox and The Little Prince respectively were deliberate choices on Saint-Exupery's side, but in relation to the way in which each of them conceive of objects in the world, it seems to make a fit so perfect that I find it hard to believe that it should be coincidental!

6. Conclusion and a look ahead

I have attempted to argue that Mammen's (2016a) axiomatic system in general and the Theorem of Correspondence in particular does indeed provide us with a powerful analytical tool allowing us to see the important relevance of being able to establish choice categories – not only when considering experimental evidence, but also in everyday life, and even in literature. Meanwhile, I have also argued, that evidence from the so-called MOT studies provides compelling evidence in support of Mammen's theory. On the face of it might not have been expected that evidence from a somewhat artificial experimental procedure like the MOT studies would lend strong support to a theory that argues, convincingly in my opinion, that results from experimental studies on sense and choice categories in general have overestimated our discriminative abilities. However, this seems to be the case here, and shows the sheer beauty of experimental methodology where even experimental settings, that we may *never* encounter in the real world, can be examined under controlled conditions, allowing us in this case to rule out explanations otherwise considered indispensable (i.e., the use of featural information for keeping track of objects). Thus, evidence from experimental developmental research (Krøjgaard, 2016), from experimental cognitive psychology

(Pylyshyn, 2009) as well as from theoretical general psychology (Mammen & Mironenko, 2015) including a formal account (Mammen, 2016a) seem to constitute what has been termed *converging validity* (Schaughnessy, Zechmeister, & Zechmeister, 2015, p. 181) regarding the proposed dual ontology of sense and choice categories.

What needs to be done? One important question is to what extent Mammen's (2016a) proposed duality of sense and choice categories are uniquely human. Although adult human beings clearly employ their understanding of sense and choice categories at an entirely different level than any other animal (see Mammen, 2016b, pp. 275, 377-378), some precursors definitely seem to exist in the animal kingdom as for instance evidenced by apes' ability to pass object individuation tasks (e.g., Mendes, Rakoczy, & Call, 2008; Santos, Sulkowski, Spaepen, & Hauser, 2002) equivalent to those presented to human infants (e.g., Kingo & Krøjgaard, 2012; Van de Walle, Carey, & Prevor, 2000; Xu & Baker, 2005). The question is: Where is the leap? Specifying the *particular* difference(s) in this regard between adult human beings and other living animals seems to be a very interesting task. In order to answer this question I suspect that further insights from comparative and developmental psychology would be needed. Along the same lines, we may want to specify the neuro-psychological correlate of the duality of sense and choice categories, and how this for instance may relate to the so-called ventral and dorsal streams (e.g., Ungerleider & Mishkin, 1982; Milner & Goodale, 1995).

Compliance with Ethical Standards

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