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STUDI

Object individuation by iconic content: How is numerosity represented in iconic representation?

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Abstract Fodor argues that perceptual representations are a subset of iconic representations, which are distinguished from symbolic/discursive representations. Iconic representations are nonconceptual (NCC) and they do not support the abilities afforded by concepts. Iconic representations, for example, cannot support object individuation. If someone thinks that perception or some of its parts has imagistic NCC, they face the following dilemma. Either they will have to accept that this NCC does not allow for object individuation, but it represents instead conglomerations of properties and at some stage of visual processing it must interface with cognition and its conceptual capacities for the visual objects to be individuated. Or, they will have to hold that the imagistic, NCC of (or, a stage of) perception, allows for object individuation. I opt for the second thesis because I think there is strong empirical evidence that objects are individuated during early vision. I also think that early vision individuates objects by means of, what I had previously called nonconceptual perceptual demonstrative reference. I argue, first, why Fodor's view that iconic NCC does not enable object individuation is false. I also argue, contra Fodor, that early vision allows the perception of the cardinality of sets of objects.
KEYWORDS: Early Vision; Analog Representations; Object Individuation; Arithmetic Cognition; Cardinality of Sets

Riassunto *L'individuazione di oggetti mediante il contenuto iconico: come è rappresentata la numerosità nella rappresentazione iconica?* – Per Fodor le rappresentazioni percettive sono un sottoinsieme delle rappresentazioni iconiche, distinte dalle rappresentazioni simbolico/discorsive. Le rappresentazioni iconiche sono nonconcettuali e non supportano le abilità richieste dai concetti. Le rappresentazioni iconiche, per esempio, non supportano l'individuazione di oggetti. Se si pensa che la percezione o qualche sua parte abbia un *contenuto nonconcettuale* (NCC) come immagine, si ci si imbatte nel seguente dilemma. O si accetta che il NCC non permetta di individuare oggetti, ma che rappresenti conglomerati di proprietà e che (durante il processamento visivo) si interfacci con la cognizione e le sue capacità concettuali, per individuare gli oggetti visivi. O si dice che l'immagine, il NCC (o una su stadio), della percezione consenta di individuare oggetti. Propendo per la seconda tesi, poiché penso che ci sia solida evidenza empirica per cui gli oggetti vengono individuati durante le prime fasi della visione, in cui l'individuazione avviene mediante quanto definito come riferimento dimostrativo del contenuto nonconcettuale percettivo. Chiarirò le ragioni per cui la concezione di Fodor, per cui il contenuto nonconcettuale iconico non supporta l'individuazione di oggetti, è falsa. Inoltre, *contra* Fodor, sosterrò che le prime fasi della visione permettono la percezione della cardinalità di insiemi di oggetti.
PAROLE CHIAVE: Prime fasi della visione; Rappresentazioni analogiche; Individuazione di oggetti; Cognizione aritmetica; Cardinalità degli insiemi

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1 Introduction

FODOR ARGUES THAT PERCEPTUAL REPRESENTATIONS are a subset of iconic representations, which are distinguished from symbolic or discursive representations.[1] Iconic representations are nonconceptual because only discursive representations can support the abilities afforded by concepts, and iconic representations, by being non-discursive (which means that they have no formally defined constituent structure) do not support these abilities. Iconic representations, for example, lacking discursive structure, cannot support object individuation. Individuation requires that a representation express predication, which in turn presupposes that it allows the distinction between terms that contribute to the representation of individuals and terms that contribute the representation of properties. Object individuation requires that a representation contain terms that refer to individuals and terms that refer to universals/properties. Iconic representations do not support that distinction because they lack formal structure.

According to Fodor, conceptualization is subsuming things under a concept, and a concept is expressed by the predicate of a mental representation; conceptualizing and predicating come down to the same thing.[2] This means that conceptualization requires the apparatus of predication, which, if a representation has, it allows object individuation. Thus, the question concerning the existence of nonconceptual representations amounts to the question whether there are mental phenomena in which representation and individuation are dissociated. Representations that do not support object individuation are nonconceptual.

Fodor's view concerning the iconic, nonconceptual character of perceptual representations seems to clash with his earlier views that perception is a module that outputs the percept,[3] because the formation of the percept obviously presupposes that the perceptual system has individuated the objects in a visual scene. If, object individuation requires the application of some concepts and if perception has NCC, how could the percept be formed? Fodor has an escape route.

According to Fodor,[4] sensory concepts for visible properties of objects are embedded within the visual system and can be used only by it, which is why they are not inferentially promiscuous like the concepts in cognition, but this is enough to confer perceptual representations with conceptual capacities that allow object individuation. Fodor could argue that during processing within the perceptual module eventually the concepts embedded in the module are applied to the iconic content of perception to enable object individuation. Note that this way out is available to Fodor owing to his views of atomistic concepts, which is intertwined with his view that the semantics of a concept term is exhausted by its reference;[5] there is no space for meanings, modes of presentation and other intensional contents.

If one does not endorse Fodor's atomistic construal of concepts, and also thinks that perception or some of its parts has iconic NCC, they face the following dilemma. Either they will have to accept that this NCC does not allow for object individuation, but it represents instead conglomerations of properties[6] and at some stage of visual processing NCC interfaces with cognition and its conceptual capacities for the visual objects to be individuated, most likely through the role of attention. In this view, early vision has iconic representational states that have NCC and represent complexes of properties. During the conceptually modulated late vision the visual objects are individuated and identified.

Or, they will have to hold that the iconic NCC of perception allows for object individuation. Burge,[7] Crane,[8] Haugeland,[9] Peacocke,[10] and Raftopoulos[11] think that the NCC has a rich structure that (re)presents objects and their properties. Crane,[12] for example, claims that even though the NCC of perception does not have the structure of judgeable content, it still represents a manifold of objects, properties and events. Peacocke argues that the NCC of experience represents things, events, or places and times in a certain way, as having certain properties or standing in certain relations, «also given in a certain way».[13] I opt for the second thesis because, as I have argued,[14] there is strong empirical evidence that objects are individuated during early vision. Early vision, a stage of visual perception, involves states that are iconic and have NCC. In early vision objects are referred to and individuated by means of what I have called nonconceptual perceptual demonstrative reference.

In this paper, I aim to show, first, why Fodor's view that iconic NCC does not enable object individuation is false. I also aim to explain in which sense iconic content shows three as opposed to four giraffes, and why it shows three giraffes and not a family of giraffes or an odd number of giraffes.

2 Fodor's argument and its background

Fodor discusses analog and symbolic representations, which he calls iconic and discursive representations respectively.[15] His analysis attempts to illuminate the nature o these representations by relying on the criterion of homogeneity to distinguish between them. Fodor starts by pointing out that symbolic representations are syntactically and semantically compositional or structured; they have a discursive structure. A representation is syntactically compositional if and only if its syntactic analysis is exhaustively determined by the grammar of the relevant language together with the syntactic analyses of its lexical primitives. A representation is semantically compositional if and only if its semantic interpretation is exhaustively determined by its syntax together with the semantic interpretations of its lexical primitives. Having syntactic structure means that some parts of the representation are constituents and others parts are not; "Φ" is a constituent of the representation "Φ(a)" but "Φ(" is not a constituent. Thus, discursive structures are not homogeneous. Therefore, symbolic representations are discursive and can be recombined the right sort of way.

Fodor argues that pictorial and perceptual representations are iconic and cannot recombine. Iconic representations have no canonical decomposition, in that, although they have interpretable parts, they have no formally defined constituent parts because they are homogeneous. Their compositionality rests on the Picture Principle (PP)[16] that states that if P is a picture of X, then parts of P are pictures of parts of X. Carey[17] and Kosslyn[18] share the same view of iconic content. According to the former, analog representations are iconic exactly in the sense that their parts represent parts of what the representation as a whole represents. This means that iconic representations are homogeneous. By not having discursive structure, iconic representations lack syntactic and semantic structure, since both require discursive compositionality.

Since iconic representations satisfy PP and are homogeneous, all the parts of a picture are among its constituents and, thus, an icon is compositional whichever you curve it up, that is, no matter how you cut the picture you always get a picture of something. To appreciate the difference between iconic and discursive representations think of it in the following way: any part of the picture of the ocean is a picture of a part of the ocean, whereas not any part of the discursive representation Φ (a) is a representation of a part of what Φ (a) represents. So perceptual representations being pictorial are structurally unlike conceptual discursive representations. This entails that iconic representations decompose into syntactically and semantically homogeneous parts and, thus, have no logical forms.

Fodor thinks that the contents of perceptual states are nonconceptualized.[19] The reason is that only discursive representations allow the application of the apparatus of predication, which is required in order for a representation to have conceptual content. Iconic representations lacking discursive structure do not allow predication and are, thus, nonconceptual. Concurrently, by lacking discursive structure, perceptual representations do not support abilities such as object individuation and identification.

Joining forces with Quine,[20] Fodor argues that individuation presupposes the capability to quantify over domains and pictorial representations do not offer this capability. Thus, «there is no right answer to the question 'which things (how many things?) does this iconic symbol represent».[21] Fodor things that the lack of the capability to individuate is the hallmark of iconic representations that sets them apart from symbolic, discursive representations, so much that the question about whether nonconceptual representations exist amounts to the question whether there are mental phenomena in which representation and individuation are dissociated.

Fodor understands that this may sound counterintuitive and this is why he hastens to add that a photograph may show three giraffes in the field, but, he adds, it also shows a family of giraffes, an odd number of Granny's favorite creatures, or a number of Granny's favorite creatures, and the picture itself provides no means to determine which one is the correct interpretation. Fodor's view that perceptual representations, by themselves, cannot support object individuation because they have NCC and object individuation requires some sort of conceptual apparatus has a long standing history in the Analytic tradition. The idea that object individuation requires more than mere perception may be traced back, in modern philosophy at least, to Frege and from there to Strawson, Evans, and Quine.

Frege thought that to represent the world perception should be complemented with something non-perceptual, to wit, the capability to understand abstract, structured, propositional thoughts. Only when perception is supplemented with judgments does the representation of the world become possible. Frege does not seem to argue for this thesis, but Strawson, Evans, and Quine do provide such arguments.

Strawson's holds that reference to objects requires more than a description of these objects, no matter how accurate this description might be.[22] It requires that one be in a demonstrative perceptual relation with them. Demonstrative reference cannot be reduced to descriptions that do not contain indexicals because it is essentially contextual. The proposition expressed by a perceptual belief is not detachable from the perceptual context in which is believed, and cannot be reduced to another belief in which some objective content from the perspective of a third person is substituted for the indexicals that figure in the thought, because the belief is tied to an idiosyncratic viewpoint of the viewer by making use of the viewer's physical presence and occupation of a certain location. Thus, the singular element in the perceptual content «is an occurrent context-bound application of "that" referring to a non-repeatable property-instance such as an object or event or a trope».[23]

According to Strawson, reference to worldly objects presupposes a minimum amount of constitutive conditions. Without them we perceive just bundles of features and the perception of a bundle of features does not necessarily mean perception of a thing that carries these features. One may respond to the presence of certain features that one has encountered before without being able to single out the object as an object that carries these features. To be able to refer to particulars, viewers should have the conceptual ability to distinguish between the way things seem to be and the way they really are, the conceptual ability to distinguish the subject from the predicate (which means that a viewer should be able to apply sortal concepts). They should possess the concept of causality, and they should be able to represent spatial relations within a spatiotemporal framework. In the absence of these conceptual capabilities, a perceptual experience is not the experience of particulars, individuated objects, but the experience of feature-placing universals that represent that certain conditions are instantiated somewhere in the environment. To pass from the stage of pure perception to the stage of experiential representation of particulars, the viewer must have the conceptual capacity to individuate objects, to recognize or re-recognize the objects in a visual scene and this presupposes that the viewer apply certain criteria.

For Evans,[24] the representation of particulars in perception or in perceptual beliefs presupposes that someone know which is the object to which they refer and can provide a definite description that could individuate this object from other objects, determine what category the object belongs to, and place it in a determined place in space and time. Viewers should be able to individuate and categorize the object, which means that they can conceptualize the reasons that set an object apart from others. In addition, they should have propositional knowledge of the concepts involved in these capabilities, that is, they must know and represent what differentiates an object from another, and what makes this object to be the object that it is. It follows that perception has a representational content that refers to particular objects only if perception is related to certain concepts that allow demonstrative propositional thought that is required for an objective perceptual representation.

Evans, however, endorses two further theses that pave the way to a different consideration of what perception could do. He introduces the notion of "nonconceptual content" even though this content cannot secure reference to particulars. Evans underlines the role of perception as a demonstrative act whose content is determined within a specified spatio-temporal framework. He introduces the idea that perception is inherently "centered". Evans thinks that a perceptual concept F refers through the demonstration "That O is F" while one points to the object O. A perceptual concept is about an object or of some of its properties if the attitudes of the viewer with respect to the contents that contain the concept are sensitive in the appropriate way to perceptual information about O. Evans thinks that this perceptual information cannot be conceptual because then we could not explain how the concept connects to the world. Thus, the essential perceptual causal relation has as *relata* the visual objects and their properties, and the nonconceptual information of the viewer.

Discussion of reference brings inevitably to the fore Quine's *Gavagai* problem that purports to show the indeterminate character of translation from a set of speech or mental acts of a person.[25] Quine's conclusion is that the reference of the terms in an unknown language is underdetermined by the set of linguistic expressions, since the observers of the behavior of the members of the tribe that use the language, even if they possess the entire set of the natives' linguistic expressions, cannot know whether "gavagai" that the natives use each time they see what the observers perceive as a hare refers to the hare or to a set of undetached parts of the hare that always move together. The observers' experience cannot settle this issue because each time a hare is present so is the set of undetached hare-parts. The only way to solve the problem is for the observer to have decided beforehand the applicable ontological framework.

According to Quine, the determination of the ontological framework that fixes the referents of the terms of mental states is related to the possession and application of criteria that individuate and categorize objects allowing object identification. These criteria are expressed in a language and, thus, language possession is a necessary condition for reference. Without these criteria, Quine's reification problem,[26] that is, how one passes from the feature-placing level of experience to the particular involving level of experience, could not be solved. Since the expression of the criteria of individuation and identification of objects in a language presupposes the existence of existential and universal quantifiers, the ability to refer to objects presupposes a complex logical arsenal.

Underlying all these views is the thesis that in order to individuate an object one must be able to refer to it, which, following Russell's principle that one can refer to O only if one knows what O is, presupposes that one know both what the object is and how it differs from other objects. Since at the nonconceptual level at which the contents of perceptual representations reside neither knowledge of an object's identity, nor knowledge of what sets this particular object apart from others is possible, Fodor's view that perceptual content does not allow object individuation follows naturally.

To support the claim that iconic representations do not allow object individuation, Fodor says that a picture that depicts a number of giraffes shows three giraffes, or a family of giraffes, or an odd number of giraffes, and which one of this is correct is undeterminable. His point seems to be that picture parts cannot fix any referents, which is why they cannot individuate the objects in the picture; individuation takes place just in case the parts of the representational vehicle refer to elements in the represented scene and, hence, if reference fails there is no object individuation. What does the statement that a picture shows three giraffes or a family of giraffes, or an odd number of giraffes mean? Specifically, what does "show" mean? It is intuitive to think that it is cashed out in terms of what a viewer of the picture sees upon viewing the picture. What do viewers see when they observe such a picture? Do they see three giraffes, or a family of giraffes, or an odd number of giraffes?

When viewers perceive a picture, they form a mental perceptual state with some NCC. They are in an internal mental state whose content is somehow causally related to the visual scene through a demonstrative act. In examining demonstratives, I do not mean to examine the linguistic expressions of the form "That X" (or, as Kaplan put it, "dthat + [demonstration]"),[27] but the mental perceptual state that could be linguistically articulated by such demonstrative expressions. Such a mental conscious "demonstrative" state occurs when some object is picked up in a visual scene and indexed (more about this in the next section). Were perceivers asked to report what they see, they would reply "that *X*" pointing to the object. To be in that perceptual state, they need not be able to identify *X* or describe it using any concepts; they need not even possess the concept "objecthood." Suppose one perceives a square-shaped object, one possesses the concept "square", and utters the perceptual judgment "that is square". When one perceives the square object, the natural analogue in the perceptual act of the term "that", which occurs in the linguistic expression of the demonstrative, is the occurrence of the perception itself that constitutes a demonstrative reference to the world. Thus, the perception of square has the cognitive force of "that is square".

In view of this, the question can be recast as follows. To what does "That" in the perceptual experience of the picture with the giraffes refer; to three giraffes, to a family of giraffes, or to an odd number of giraffes? This relates directly to Quine's extended *Gavagai* problem. When the natives see a scene containing what we would call a rabbit, what does their perceptual "That" refer to? A whole animal or undetached rabbit parts? According to Fodor, and Quine, this question cannot be answered because pictorial representations do not individuate.

Since perceptual representations have NCC, a perceptual representation of the giraffe-scene cannot have as content a family of giraffes or an odd number of giraffes because that would presuppose the application of the concepts FAMILY, ODD, and GIRAFFES. Fodor, of course is aware of that and, therefore, his point is that the perceptual content of this scene cannot support or evidence any of the corresponding perceptual beliefs; it is in this sense that this content fails to fix the referents of its parts. In addition, the perceptual content does not support the belief "there are three giraffes" in the picture, since the viewers, lacking the ability to individuate at the level of perception, cannot see "Three giraffes".

If perceptual contents cannot do this, in what sense are objects individuated in perception? To answer that we should examine the way the numerosity of sets could be represented in the iconic NCC of perception in view of the fact that this content does contain symbols. Numbers are symbols and if symbols are not available how could numerosity be represented? This is a pressing problem because if viewers can perceptually individuate objects, they should be able somehow to represent three giraffes, or, equivalently, the perceptual state they are in should be able to refer to three giraffes in a nonconceptual, that is, non-symbolic, manner. Moreover, in order for the belief "there are three giraffes" to be preferred over the beliefs "there is a family of giraffes", or "there is an odd number of giraffes", there must not be a mechanism that could represent in an iconic manner the concepts "family", or "odd number".

3 How are objects individuated in early vision

In previous work,[28] I argued for the following theses. First, cognitively driven attention or concepts are not necessary for object individuation. Second, the main burden of parsing a scene and selecting discrete objects falls on object-centered pre-attentional segmentation processes that provide the basis for the perception of objecthood. Third, feature integration in working memory is not necessary for the perception of objects as discrete entities – that is, for object individuation. Objects in a scene are singled out before any feature encodings take place, that is, before any features are assigned to the object in working memory. Fourth, object identification is not necessary for fixing the reference of perceptual demonstratives; object individuation is enough to single out the *demonstrata* of perceptual demonstratives. I succinctly discuss here object-files as important factors in establishing the existence of a nonconceptual object individuation. What follows is partly drawn from the discussion of this problem in previous work.[29] To save space, I do not adduce the empirical evidence supporting my claims; the reader could find it in my previous work.

Let me start by discussing "object files". A preattentive segmentation process of the visual objects in a visual scene results in the segmentation of objects from ground. (In fact these are the so-called proto-objects that differ from objects, but in order not to complicate things I will keep referring to objects even. Fortunately, this does not affect the arguments presented here). Once objects have been segmented, the visual system assigns to them visual object indices. This completes the process of object individuation, which according to Pylyshyn consists of two parts,[30] the segmentation of the scene in objects, and the assignment of visual indices to the segmented objects. Object indices allow the visual system to follow the objects as they move in space and time, and also allow the higher levels of vision, after attention focuses on some of them, to process further the selected objects by applying to them various object related cognitive processes. The indexing results in the visual system opening "object-files" for the segmented objects in a scene.

The object-centered segmentation processing individuates objects in a visual scene and creates object-files for the discrete objects it parses in a scene. The object-files index objects as discrete persisting entities. Once an object file for a visual object has been opened, the object's properties are stored in it and eventually are encoded in working memory. The object-centered segmentation processes are mainly pre-attentional, which means that initially the object file is not created in working memory, which is why the features that are used to individuate the object are not initially encoded and attached to the object and, as a result, can change without threatening the object's identity.

Echeverri writes that object files are depositions of information in working memory.[31] If that were true, object files could not be created pre-attentionally and non-conceptually as Echeverri intends them, and as Pylyshyn and I have argued. The reason is that working memory is inseparable from cognitively-driven attention and the activation of concepts. Echeverri, however, notes that the property instances used to open the object files are not encoded in working memory.[32]

Although object segmentation takes place at many levels and may involve semantic information relying on top-down flow of information, the visual system performs in a first pass an initial or provisional object segmentation of a scene, before attentional bottlenecks occur. Although features (e.g., color and shape) retrieved by early vision in a data-driven way may be used for parsing a scene and segmenting its objects, which allows opening and allocating object-files, the object-files are allocated and maintained primarily on the basis of spatio-temporal information, to wit, temporal synchrony or continuity and proximity, which in turn is based on information pertaining to location, relative position, and motion. Individuated objects can be parsed and tracked without being identified, and even when an object is mis-identified and then correctly recognized it is all the time deemed to be one and the same object.

Studies confirm that featural information is also used to individuate objects when the scene is complex enough, and that feature individuation (i.e., the perception of features as distinct properties of objects without the exercise or possession of concepts) precedes feature identification (i.e., the application of sortals that conceptualize these features).[33] To the extent that spatio-temporal information is retrieved from a scene faster than any other featural information, object individuation precedes representations that support awareness of all other features. 10-month-old infants, for example, use spatio-temporal information to individuate objects but do not use featural information, such as shape or color, to individuate objects, whereas 12-month-old infants do. This may mean that although feature information is available for other purposes, is not used to individuate objects except when spatio-temporal information fails to achieve this. It is clear (a) that spatio-temporal information retrieved directly from a visual scene precedes and overrides feature information retrieved directly from the scene, and (b) that both sorts of information are used first to individuate objects and then to identify objects. This goes against the view that feature perception requires the application of sortals, or, equivalently, the view that perception inherently involves the exercise of concepts.

The information on which individuation is based does not play the role of the binding parameter that binds the features observed at one location, as spatial information does in Campbell's account,[34] but it ensures that a single object is being individuated. In other words, it provides the object that will eventually carry the features observed at one location rather than binding first the features that are found in one location to form the object. Once an object has been individuated, it becomes the carrier of properties. The properties that are first attached to objects are those retrieved by early vision from the visual scene. (Early vision involves bottom-up, lateral, and top-down processes that are restricted within the visual areas of the brain and do not involve any cognitive signals).

The ways features that are used to individuate objects are combined or bound together in order for object individuation to take place are determined by processes that reflect a set of what were initially called "principles" that concern regularities detectable in the behavior of solid object in our world; some of these are the famous Spelke object principles. Studies by Spelke[35] support the assumption that infants from the beginning of their life are constrained by a number of domain-specific principles about material objects and some of their properties. These constraints involve attention biases toward particular inputs and a certain number of principled predispositions constraining the computation of those inputs. Among these predispositions are object persistence, and four basic principles (boundness, cohesion, rigidity, and no action at a distance).

Because the retinal image underdetermines both the distal object and the percept, perception would not be feasible if information processing in perception was not constrained by "assumptions" that substantiated reliable generalities about the physical world and its geometry.[36] These assumptions function, as it were, to fill in the missing information. Most computational theories endorse this view, and there is evidence that physiological visual mechanisms implement such constraints in their design, from cells for edge detection to mechanisms implementing the epipolar constraint. These constraints are "hard-wired" in the visual system.

Burge calls the constraints "formation principles".[37] Wishing to avoid the use of the term "principles", I have called them "operational constraints". Echeverri calls them "object constraints".[38] One might think that these constraints suggest that there is a deeply rooted conceptual framework in perception and that perception operates using discursive, doxastic inferences.[39] To decide whether such constraints entail that perceptual processing is depends on concepts, one should examine these constraints and determine their epistemic status.

The operational constraints allow us to lock perceptually onto medium size lumps of matter in the world by providing the discriminatory capacities necessary for the individuation and tracking of objects in a nonconceptual way,[40] and allow perception to generate perceptual states that present objects in the world as cohesive, bounded solids, and as spatio-temporally continuous entities. These constraints can be seen as the rules that guide the various grouping principles (that extend and occasionally override Gestalt grouping principles) that the perceptual system uses to segregate objects from ground.

The processes and the constraints involved in indexing or individuating objects by means of their spatio-temporal or other transducable features are not cognitively accessible. One does not "know" or "believe" that an object moves in continuous paths, or that it persists in time, even though one uses this information to index and follow the object. Their role is to guide the processes of object individuation by combining in appropriate that underlies object individuation.

What, then, about the claim that knowledge of objects is needed for the filling in that allows the construction of the percept? If the operations that effectuate the filling-in are not represented in the system but are performed by hardwired computational processors, is it legitimate to talk about these processors realizing some object knowledge in the form of a set of rules concerning the physical environment and its geometry? This depends on what one is willing to count as knowledge.

The constraints function outside consciousness, are not available for introspection, and cannot be attributed as acts to the viewer. They are not perceptually salient but viewers must be "sensitive" to them if they are to be described as perceiving the world. They constitute the *modus operandi* of the perceiver and need not be represented in an accessible form of "knowledge." In fact, they may not be states of the system. The constraints are not a set of rules used by the perceptual system either as premises in inferences, or as rules in inferences. They consist in operations describable in terms of computation principles and which characterize the functioning of perception and can be used only by perception.

I have said that the operational constraints may not be states of the visual system. They could be computational processors and, as such, they are not representations or beliefs of any form, either implicit or explicit. (Explicit beliefs are representations that are activated, while implicit beliefs are representation stored in long-term memory but not currently activated.) If the constraints are not states of the system, what is the epistemic status of the information included in the constraints? One view is that by not being states of the system, the operational constraints do not have any contents; they are not semantic or mental entities. To think that they are, is a mistake committed by cognitive scientists,[41] who when dealing with an input and an output state that are both contentful mental states, they usually assume that the processes that connect them are also mental states with representational contents. The processes that connect the inputs with the outputs, however, are mere causal connections. If this is so, the function of the operational constraints in perception does not entail that perception is guided by "object knowledge". They are, simply, combinatorial principles.

Some philosophers think that such operational constraints constitute a "tacit knowhow", a term used to denote the information carried by states that are built into the system in a way that does not require that the states be represented in the system.[42] This tacit knowhow is not represented anywhere in the system and is not a kind of knowledge. So, for these philosophers, too, the operational constraints are not represented anywhere in the system.

Other philosophers think that hardwired computational processors realize tacit *knowledge* of a particular set of rules: «The rules would not have to be explicitly represented in any representational state of the system. Still less would knowledge of the rules be realized in a state of the same kind as an attitude state».[43] Davis claims that tacit knowledge is not realized by attitude states because tacit knowledge has two main characteristic. First, it is subdoxastic knowledge since it is not inferentially integrated with other attitude states and exists in special-purpose, separate sub-systems. Second, attitude states require that the concepts that are part of the states' contents be concepts that are possessed by the person who is in these states. The contents of tacit states, however, are not conceptualized. When persons are in a tacit state, they do not have simply by being in that state access to the state's content, as the persons who are in attitude states are. Thus, the operational constraints that realize tacit, representational knowledge of some regularities are not conceptual representations.

Irrespective of how on conceives of the information realized by the operational constraints, the constraints are not rules of inference that the visual system looks-up implicitly or explicitly to perform its interstate transformations, or premises used in such transformations. Hence, their existence does not entail that there is some sort of knowledge that determines or simply affects perceptual processing).[44] So, in general, the grouping principles that underlie the operational constraints do not constitute cognitive influences on perception, but are considered to be bottom-up biases affecting perceptual competitions.

To summarize the discussion, the perception of "objecthood" relies on spatio-temporal, or, on further feature information (shape, color, orientation, size, and so forth), which allow tracking of the spatio-temporal history of the object and render its individuation possible, but this information is not encoded, that is, stored in memory and conceptually represented. The representation of objects based on spatio-temporal or featural information allow object individuation and precede representations based on semantic information that allow object identification. The former representation allows access to the object for further investigation, but it does not encode any of its properties. The object is indexed as an individual rather than as something that exists at a certain location and/or has a certain shape and color, although this information is used to allocate an object-file to that object.

Object individuation and the retrieval of the transducable features of objects occur in a nonconceptual manner since this information is retrieved from visual scenes by early vision that is conceptually encapsulated. The mechanisms of vision that process this information induce perceptual states whose NCC consists in information about the existence of individuated persisting objects and their shape, size, surface properties, orientation, motion, affordances, color, etc. Object individuation amounts to perceptual demonstrative reference,[45] which involves indexicals and is essentially contextual. Against Strawson, however, perception can refer without having to employ the conceptual apparatus of the perceiver.

How are all these related to whether in an iconic representation perceivers see three giraffes and not a family of giraffes, or an odd number of giraffes? If perceptual, iconic representations allow object individuation and it is also true that they have NCC, one is able to perceive a visual scene without exercising any concepts whatsoever. Hence, one cannot see three giraffes because that presupposes the possession of the concept "Three". Similarly, someone cannot count up to three giraffes because at the preconceptual level they do not possess the concepts "One", "Two", "Three", neither do they possess the concept of addition. Granting that the iconic, NCC individuates objects, in what sense does one see three giraffes? This depends on the way arithmetic facts are handled at a pre-conceptual level and the answer lies in how arithmetic facts are registered in the brain.

4 Iconic perceptual representations

In the next section, I shall discuss the analog or iconic nature of perceptual representations of magnitudes in a visual scene. However, a visual scene contains not only magnitudes (that is, attributes of objects) but also objects that are perceptually represented. Assuming that the perceptual representation of magnitudes is iconic, what about the representation of objects themselves? Do they induce a discrete and symbolic element in the otherwise iconic perceptual representations? This is very important because, as we saw, object individuation is an essential function of perception. It is also important because the segmentation of a visual scene into discrete objects with attributes introduces a semantic structure and, if Fodor is right, iconic representations are not semantically structured. In addition, what exactly is an iconic representation and what is its relation to analog representations to which I shall refer discussing the perceptual representations of magnitudes. Finally, what is the evidence that early vision involves iconic representations?

Let me start by discussing the nature of iconic representations, the relationship between analogicity and iconicity, and the evidence supporting the thesis that perception (or some part of it) has purely iconic content. Cognitive and perceptual states are held by many to be cast in different representational formats, namely, digital or symbolic, and analog or iconic formats respectively.[46] Among those who think that perception (or early vision for those of us who think that only early vision is unaffected by concepts and, thus, is a possible candidate for having purely iconic or analog states) does not have propositionally/symbolically structured format but an iconic or analog format, all parties involved agree that at a minimum perceptual states are iconic and some among them go further to argue that in addition to this iconic format, perceptual states also display some of, or all, properties traditionally assigned to analog representations.

Before I discuss iconic representations let me say first a few things about symbolic representations that contrast with iconic representations. According to Goodman, a representation is symbolic or digital if it contains discrete symbols, signs that refer through a convention ("cat", for example, refers to the relevant animal through an agreement of a linguistic community). A symbolic notation is discrete or differentiated, according to Goodman, if it is semantically and syntactically disjoint, as opposed to semantically and syntactically dense. [47] A representational system or scheme is differentiated if «for every two characters K and K' and a mark m that does not actually belong both, determination either that m does not belong to K or does not belong to K' is theoretically possible».[48] Since symbols refer only through some convention, any composition of symbols that is also a (complex) symbol refers through conventions and does not bear any other relation to its referendum. Consider the symbol/concept "CAT". "CAT"'s structure is that of a simple concatenation of less complex symbols that themselves refer solely by convention, and, so, no part of "CAT" refers to cat body parts or to their features and there is no natural correspondence between the constituents of the representing symbolic structure and the constituents of a cat (its body parts and features).

Some iconic representations are dense, continuous, and homogeneous,[49] unit fee,[50] and come in information packages,[51] a set of properties traditionally assigned to analogicity (analogtr). A set is dense if between any two elements in the set there is always a third element; the set of real numbers is dense but the set of natural numbers is not because between two consecutive natural numbers there is not a third number. In the brain, some neurons have continuous activation functions, which means that the set of the activation values of a neuron is dense. Consider a neuronal assembly that represents red and has continuous activation values; "red" is being represented by a continuous, dense set of activation values. Or, consider a mercury thermometer in which the magnitude of mercury represents temperature. Both the representing magnitude and the represented temperature vary continuously and are dense.

Blachowicz[52] examines the properties that analogtr representations are supposed to have and concludes that many analog representations exhibit all these properties,[53] but, excepting, "relational identity" they are not necessary for a representation to be analog, which means that if a representational scheme satisfies relational identity it should be considered to be analog despite the fact that it is not continuous or dense. Reference to a similar condition for analog representations is found in Beck;[54] a representation is analog if it mirrors (that is, it is isomorphic to, or bears some structure-preserving relation toward) what it represents; similarities among the elements in the represented domain are mirrored by similarities among the elements in the representational scheme. Maley offers a covariational account in which a representational medium R of a domain Q is analog just in case there is some property P of R such that the quantity of P determines Q and as Q increases or decreases by an amount d, P increases or decreases as a monotonic function of Q + d or Q-d.[55]

This demand is further developed by Kulvicki.[56] Kulvicki argues that analog representations are those that bear a certain mirroring relationship to the domain they represent, a requirement that may be satisfied by non-dense representational schemes. Analog representations require structure preserving syntactic-semantic links (syntactic refers to the representing medium, while semantic refers to the represented domain) that result in representations with vertically articulated content. A representation has a vertically articulated content when it represents objects as being P but also represents them as being Q, where Q is an abstraction from P. A mercury thermometer is such a representation because it represents temperatures and when it designates a certain temperature T1 through the measurement of some measured height of the mercury, it also represents indefinitely many abstractions from T1, that is, other temperatures that correspond to heights that are very close to the measured type that, as such cannot be discriminated from that height.

In these accounts, the traditional properties assigned to analog representations are dropped and analogicity is defined in terms of an appropriate mapping of the representation onto the represented domain that captures semantical properties and relations in the represented domain. Thus, the defining character of analogicity is the iconic character of the representation.

A way to discriminate between quasi-pictorial representations and sentential representations is offered by Palmer's distinction between notational systems (such as set of propositions) and iconic representations according to which iconic representations represent properties and relations intrinsically, whereas symbolic systems represent them extrinsically.[57] For example, in a symbolic representation of an object that is taller than another, the relation "taller" must be explicitly represented by a distinct symbol. Iconic representations, on the other hand, just show this relation and do not need to represent it by importing an extrinsic symbol. The reason is that in iconic representations «the representing relation has the same inherent constraints as the represented relation. That is, the logical structure required of the representing relation is intrinsic to the relation itself rather than imposed from outside».[58] Extending Palmer's views, one could say that the intrinsic logical structure of the representing relations in iconic representations, which mirrors the structure of the represented relations entails that all information in the represented structure is explicitly shown in the representing structure. This is not the case with quasi-linguistic, sentential representations in which the requirement that relations be represented extrinsically entails that there is a clear distinction between what is represented explicitly and what is represented implicitly, in the sense that some sort of inference is needed for that information to be extracted from the explicitly represented information.

What is the empirical evidence for iconic representations in perception? I cannot go into any depth here, so I will say that empirical support to the idea that representations in perception even though are not literally arrayed in space can be iconic representations of spatially arrayed properties comes from our knowledge of the topologies involved in perception and their inter-mappings. Recall that a representation is iconic if it has an inherent structure that maps naturally onto the structure of the represented entity. The iconic nature of perceptual representations is grounded successively in the layout of the retinal cells that maps onto the spatial layout of the environment, and in the orderly retinotopic mapping of the visual world onto the surface of the cortex through the retinotopic mapping of the surface of the cortex onto the retinal cells. The physical layout of the retinal cells and the other receptors higher in the hierarchy of the brain renders registration of information from the retinal image iconic. The iconic registration of the retinal image maps onto representational states in the brain rendering them in turn iconic, and both map onto to visual perceptual representation in experience rendering it iconic as well. These mappings are grounded in the mapping of the topology of information registration in the retina onto the topology of spatial and featural structures in the environment and this results in perceptual representations that preserve the spatial and featural structure of the scene. Beck argues that perception of magnitudes is analog because it satisfies Weber's law, which states that the ability to discriminate two magnitudes is determined by their ratio. As the ratio approaches 1:1, the ability to discriminate the magnitudes decreases.[59]

Let us move now to the problem of whether perception, by individuating objects in a visual scene, contains discrete symbols representing these objects, and of whether perception *qua* iconic representation has semantic structure in view of the fact that it satisfies PP. Quilty-Dunn argues that perception cannot have purely iconic nature owing to the fact that in parsing and individuating objects in a visual scene it uses labels, (pointers or indices) which, by their nature, are symbolic components, whose presence indicates that perceptual representations has some sort of semantic structure that allows for a canonical decomposition of perceptual representations into constituents, namely the objects, their properties, and relations.[60] The representations of objects through such labels segment the scene into discrete objects, each representation standing for a particular individual. This goes against Fodor's view that iconic representation cannot contain symbols since they have to satisfy the PP and, hence, have no semantic structure and do not admit of a canonical decomposition being homogeneous. Thus, iconic representations do not come segmented since they do not allow for the presence of symbols that do the segmenting. It follows that perceptual representations are (at best) hybrid since they contain both iconic elements that represent magnitudes and symbolic elements that represent objects.

I think that early vision has purely iconic format even though objects are individuated and indexed during early vision. This means that I have to argue, *pace* Quilty-Dunn, that the segmentation and representation of objects during early vision does not involve any symbolic elements. For lack of space, I only sketch an account here. The argument consists of two parts. First, even though early vision does indeed segment objects and assigns to them object files that are addressed through pointers or labels, there is nothing conventional involved in this process; the segmentation and indexing is the result of purely causal interactions between light emanating from the visual scene and the perceptual system of the perceiver without any conceptual involvement. It is, thus, a natural process that establishes a natural correspondence between object representations in perception and the features of environmental objects and there is nothing conventional involved in the process. *Per* the definition of symbolic representations, object representations in early vision are not symbolic but iconic.

Quilty-Dunn would object that object segmentation requires attention that may be cognitively driven and, thus, involves conceptual contents. Quilty-Dunn is wrong, however to think that object segmentation during early vision requires attention. He relies on Treisman's well-known theory,[61] which however, has been systematically discredited the last twenty years or so; the consensus is that the initial object segmentation does not require attention.[62]

Even if this the case, however, a problem remains, namely that the labels or pointers are discrete elements in early vision representations and this goes against the view that iconic views are dense and continuous and, thus, homogeneous, which is why they satisfy PP. Recall that density and homogeneity are the demands of the traditional view of analog representations. We have seen that in the revised view, the only condition that makes a representation analog is that it satisfy some appropriate notion of a mapping principle form the representing to the represented world. Even if someone does not agree that such representations should be called analog, they would agree that, at a minimum, perception has iconic content that meets the mapping requirement. A representation can be iconic even if it involves discrete elements provided that these elements are mapped in a systematic and natural, non-conventional way onto elements in the environment. Since the deictic pointers associated with object files are not conventional, there is nothing to bar the conclusion that the representations in early vision are iconic despite the fact that they involve such pointers.

Now, however, a new problem emerges. If the abovementioned account is correct, how about PP that iconic contents satisfy? Does the introduction of discrete elements in iconic representations undermine PP? And, relatedly, what about the demand that iconic representations have no semantic structure since they admit of no canonical decomposition? Let me start with the second problem.

It is an essential characteristic of the iconic structure of perceptual representations that it does not support logical operations. Logical connectives and quantifiers cannot be among the analog representational content of perception, as they can be part of the content of propositional states. This can be inferred from two facts. First, that there are no logical contradictions in perception (illusions are not logical contradictions), while a proposition whose form is p v -p is a logical contradiction. Second, from the fact that if one tries to take a picture of a situation expressed by a disjunction, say that O1 is either to the left of O2 or to the right of O2, one gets a picture either of O1 being to the left of O2, or a picture of O1 being to the right of O2, depending on the actual spatial configuration. This, however, is not a picture that displays the disjunctive fact described above; one cannot analogically express the fact of the occurrence of a logical connective. This is uncontroversial but does it entail that perceptual iconic representations have no semantic structure?

Recall, first, that representation is semantically structured if and only if its semantic interpretation is exhaustively determined by its syntax together with the semantic interpretations of its lexical primitives. Recall, second, the brief account of object segmentation offered in section 3. Perception acts so as to individuate objects in the visual scene by parsing them from other objects and by segmenting them from the background. It does that by demonstratively referring to them. Object individuation occurs through the processing of the object-features (primarily spatio-temporal information) even though these features are not permanently assigned to the objects. The individuated objects are assigned object-files that initially contain only transient featural information that may change; these files are accessed by pointers or labels. It follows that the representational states of early vision consist of objects that have some properties, namely those properties used in the process of object-individuation. The representations of a visual scene in early vision, therefore, represent a manifold of objects, properties and events. One could render this representational content in the form of a set of subject-predicate structures. It follows that perceptual iconic representations have a rich semantic structure that is similar to the subject-predicate structure of linguistic representation, or of all representations. Let me say in passing that the compositionality involved is not that of concatenative compositionality that characterizes symbolic representations but that of part-whole structures that involve different kinds of restrictions as to what counts as a proper part of the representation. To give one example of what I mean by part-whole compositionality, 2-D surfaces are composed of edges that, in turn, are composed of line-segments. When one perceives in realistic conditions a line segment, one sees it as part of an edge, which is also a part of a surface, despite the fact that the perceptual system constructs first line segments, then edges, and then 2-D surfaces.

This account has repercussions for the PP, If iconic perceptual representations have semantic structure, then they have some form of canonical decomposition since one cannot parse a perceptual representation into arbitrary parts and still obtain representational parts, which seems to undermine PP. If PP is taken literally, it is simply false. A perceptual representation cannot be cut into arbitrary parts that still represent parts of the visual scene. There are some limitations to what constitutes a proper part of an image. Not all combinations of features could be considered genuine parts of the image. Consider, for example, the back part of an object and a part of the immediate background and combine them. In perceptual terms, that is, in terms of what is computationally relevant in perception, it is highly unlikely that this complex part of the image is represented by anything in perception. In this sense it is not true that any part of the representation represents a part of the image that the representation represents; only parts that are admissible as components of perceptual processes are admitted; which parts are these is an empirical issue. Thus, the *Picture Principle* holds only for admissible parts of the image. Which parts are admissible depends on the perceptual system; line-segments, edges, 2-D surfaces, 3-D bodies, for example are all admissible parts, combinations like the one discussed before are not.

5 Pre-conceptual numerical and arithmetic competencies, and iconic *perceptual representations*

Let me say first that in what follows I will keep referring to analog representations of magnitudes since this is the term used in the literature on arithmetic cognition. The reader should bear in mind, however, the preceding discussion concerning the relation between analog and iconic representations and the nature of analogicity.

Extensive research provides evidence that infants have numerical sensitivities regarding sets of one, two, or three entities.[63] Infants habituated to sets of two objects, dishabituate when shown arrays of one or three objects, which shows that infants are sensitive to numerical distinctions. Using the methodology of violation of expectancy shows that infants may be representing some of the relations between sets of one, two, and three objects; they represent, for example, the relations $1 + 1 = 2$ and $2 - 1 = 1$.[64]

These findings do not support a unique interpretation of the representations and processes underlying infant numerical sensitivities. There are currently two theories purporting to explain infants' numerical performance. Infants may represent the numerosity of sets, that is, they may store symbols corresponding to the cardinality of sets of objects (integers), a cardinality at which they arrive by means of a counting algorithm. This set of theories is called Integer-Symbol-Models (ISM*)*. ISM hold that the number of items in a set of objects is represented by the last item reached during the counting process, which is executed by means of an accumulator of the kind proposed by Meck and Church.[65] The counting process results in an abstract symbol for the integer corresponding to the last item enumerated being stored somewhere in short term memory.

Other theories argue that infants represent objects by opening object files, and the process at work in the various tasks is the one-to-one matching of objects, not a counting algorithm.[66] These are the Object-Files-Models (OFM), according to which infants build a representation or a model of the objects in a scene, store it in short term memory, and update the model each time a change occurs. The objects are represented in terms of object-files. A set of two objects is accordingly represented as "O_i O_j". This representation stores the information that there are two distinct entities that are objects and these are the only objects in the scene. When a new array appears the model is updated. If one object shows in the new array, they build a model that contains one representation, "O_k". The two models are compared through a process that detects a one-to-one correspondence between object files in the two representations. Note that the comparison does not rely on any conceptual background since it occurs in preconceptual infants.

Both theories face problems and researchers proposed a compromise: both theories are correct, each within its own domain. *OFM* explain numerical competence with small (up to three or four) numbers, whereas *ISM* explain numerical competence with larger numbers.[67] This theory posits two core systems of number: one system for representing large approximate numerical magnitudes, and another system for precisely representing small numbers of objects. The former stores cardinalities, whereas the latter opens object files, constructs models, and compares them. There are challenges for this theory as well. First, if counting of numerosities is based on the function of an accumulator, how are we to explain that this accumulator comes on line only with sets with numerosity larger than three? Second, how can the subitizing[68] slope be explained by a search for one-to-one correspondence between models of the objects in a set based on object-files?

5.1 Arithmetic capacities and analog or iconic representations

We saw that subitizing poses problems for the theories purporting to explain infants' numerical capacities. Most studies explain subitizing by appealing to inherent structural limitation of the processing system, in that the human brain can index and track in parallel only up to three or four objects by attaching to each one an attentional tag that individuates it and allows its tracking.[69]

Studies in the connectionist paradigm show that subitizing could be explained by a process of pattern recognition rather than by a counting procedure.[70] Recognition is implemented as a simple pattern matching procedure that matches a configuration of objects to a configuration of objects with known numerosity that is stored in memory. This explains that the phenomenon is related to the ability (a) to recognize a certain configuration of a set of objects, (b) to identify the arithmetical magnitude of the set (the cardinality of the set), and (c) to compare this magnitude to the known magnitude of another set that is stored in memory, and not to the ability to count fast the objects in a set. Pattern matching does not require concept possession, as evidenced by the fact that animals and infants do subitize, and, moreover, applies to pictorial representations. This by itself is evidence that pictorial representations allow object individuation because subitizing presupposes object individuation.

What about arithmetic capabilities of infants beyond subitazing? We have seen that, as OFM theories posit, it is likely that infants' ability to perform successfully in tasks of addition and subtraction with one to three objects is explained by positing that infants construct models of the objects in a scene on the basis of object files. However, these tasks involve a small number of, up to three or four objects. If as I argued, pattern recognition is preferred in subitization in which a small number of objects is present, why should infants not use pattern matching in all cases and deploy, instead, the cognitively more costly mechanism of opening object files, construct a model of the scene, and compare this model with others stored in memory for one-to-one correspondence? The answer to that is that the set up of the tasks (objects appear and disappear behind screens, time elapses, infants must update information about objects, etc.) renders the pattern matching procedure inapplicable. This is why object files are employed in such arithmetical tasks but not in subitization. For the same reason, the function of the accumulator that allows the representation of numerosities of larger sets (I will discuss next this problem) is interrupted. Counting presupposes sequential and within relatively small-time intervals presentation of objects. These conditions are violated in the aforementioned experimental settings.

The construction of object files which, as we saw, is inextricably related to object individuation takes place in early vision and is, thus, independent of concepts. Since object individuation, as I also argued above, is supported by pictorial/analog representations, and since the construction of models of object configurations in a visual scene and model matching is also supported by pictorial representations, as the literature on mental images evidences, the arithmetic abilities as explained by OFM theories can be accommodated by nonconceptual, analog representations.

Pattern matching and the usage of object files to build models of the objects in a visual scene could explain arithmetic abilities, including the representation of the numerosity of sets, within a framework of analog, nonconceptual representations for sets that number up to four members. What happens with larger sets? Could they be represented by analog, pre-symbolic systems? Given that at a preconceptual level someone does not know any arithmetic and does not know the numerals and cardinalities, how do they exactly represent the numerosity of larger sets? Given that the concept "number" cannot be applied, how is numerosity represented? The possibility of using and storing cardinal numbers a symbols in memory having been excluded, there is only one way this could be achieved, namely by corresponding the number of items to magnitudes, which are analog representations.

This brings forth the notion of the accumulator,[71] and the explication of its function by Galistel and Gelman.[72] Thus, it is plausible that an accumulator carries out the counting procedure. When it comes to sets with larger numerosity, there is consensus that humans and many animals use a counting procedure that is implemented by an accumulator.[73] This system represents magnitudes that have scalar variability; signals that encode these magnitudes are noisy, and vary for trial to trial. The accumulator presupposes object individuation; one can count things only if one perceives them as different entities and as we saw in the previous section, object files index objects and allow tracking. Thus, the accumulator relies on the operation of the object indexing mechanism.

In general, it seems that a counting procedure that represents magnitudes is present from the beginning in more than one species. However, when it is more efficient, an organism employs pattern recognition for comparing numerosities overriding the counting procedure. Other times, the organism takes recourse to the object files created by the visual system, when the rapid pattern matching mechanism ceases to function reliably. The object indexing system is omnipresent in perception and individuates objects and in arithmetic tasks involving a small number of objects, which do not overtax the visual system's capacity for opening object files and, thus, the capacity to construct models of the scene, object files are used in the way described above. With larger sets of objects, neither pattern matching, nor modeling can work. In these cases, the inbuilt counting

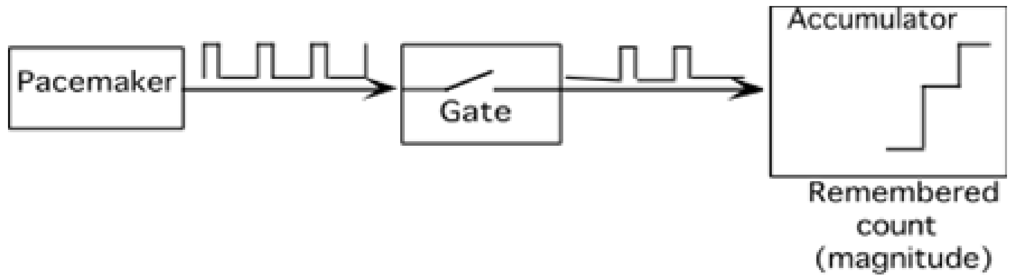

Figure 1. The accumulator model of Meck and Church. Each time the pacemaker sends a signal, the gates open and let it pass through, incrementing the magnitude in the accumulator. Cf. W.H. MECK, R.M. CHURCH, *A mode control model of counting and timing processes*, cit.

mechanism comes on-line.

There is a problem, however, for those who wish to defend the view that analog representations at the nonconceptual level can represent numerosities. Granting that both pattern matching mechanisms, and the employment of object files can be supported by analog representations and do not require concepts, how could the numerosity of larger sets that rely on the counting mechanism be nonconceptually represented in an analogical format? How could an organism implement an analog representation of numerosities?

To answer this question, Meck and Church[74] proposed the accumulator model and adduced psychological evidence to support it. In this model, number is represented by a physical magnitude that is a function of the entities enumerated. In such an analog system, the animal or child does not have to learn which number a given state of the accumulator represents because it is an analog mechanism in which its state is a direct linear function of number. According to the model, the nervous system has an equivalent to a pulse generator that generates activity at a constant rate. Each time an entity is encountered in a sequence, the pacemaker sends a signal. This activity is gated so that energy passes through to an accumulator that registers how much has been let in (see *Figure 1*). The magnitude in the accumulator at the end of the counting sequence is proportional to the number of entities in the sequence, and thus, serves as an analog representation of the numerosity of the sequence.

The accumulator is an analog mechanism in which each state (the magnitude) is a direct linear function of number. The magnitude is not something arbitrary with respect to the number that stands as a symbol of it. The accumulator links the experience of a sequence with a physical variable in the organism, not with an abstract construction whose link to the cardinality of the set of the sequence must be independently established by some kind of correspondence. The analog representation, because of the isomorphism between the physical operations applied to the representing magnitude and the arithmetical operations, provides the immediate link between the mind and the world. In this sense, the analog system provides the content that grounds the symbolic representations of numbers that will be established later with development.

Experimental studies[75] adduce evidence that animals and infants use an analog system to represent numerosities, that is, that infants and animals use magnitudes to stand for numerosities, and not arbitrary symbols. The Meck and Church analog system is called a system for *preverbal* counting, since is shows how animals and children can count and perform elementary arithmetical computations before the onset of any symbolic conceptual system.

Dehaene and Cohen suggest that there are two distinct neural pathways that process differently arithmetic knowledge, though in most normal cases both pathways are active and interact during arithmetic operations.[76] One route, involving the inferior parietal areas, accounts for quantitative number processing. The other, involving a left-laterized corticostriatal loop, accounts for rote verbal arithmetic memory. Dehaene and Cohen proposed the "triple-code model" of the cognitive and anatomical architectures for arithmetic.[77] According to the model, there are three kinds of representations of numbers:

(a) A visual code in which numbers are represented as identified strings of digits; visual form is subserved by bilateral inferior ventral occipitotemporal areas;

(b) An analog quantity or magnitude code, subserved by bilateral inferior parietal areas. In this code, numbers are represented as distributions of activation on an oriented number line. This code is involved in semantic knowledge about quantities (proximity, smaller or larger than, relations for example). In this code, numbers are represented in an analog form as configurations in space;

(c) A verbal code, localized in left-hemispheric perisylvanian areas, in which numbers are represented as sequences of words.

The verbal code provides a verbal symbol for the numeral, which is added to the visual symbol of the first code. Both the visual and verbal form constitute the symbols that stand for numerals and function as the representational vehicles of the numerals in the mind. Their initial meaning consists in the representation involved in the second analogical code, which functions both as the initial definition of numbers and as the initial number concept, which is in effect a figural concept since it relates the number to some spatial configuration expressing a magnitude. In due course, the concept of number is enriched through the relation of each numeral with the other numerals in the structure of arithmetic and, thus, acquires content that exceeds the initial spatial meaning of the number.

Judgments about quantitative relations involve the second part that represents numbers as magnitudes. When mathematical operations are performed, these quantities undergo semantically meaningful manipulations, and the resulting quantity is transferred to the appropriate neural language network for naming. These suggest the existence of a neural network in which numbers are represented in an analog way as magnitudes, and not as discrete symbols. This means that the analog representation of numbers as magnitudes operates even with adults that possess numerical knowledge. More importantly, however, the preceding discussion suggests a way that numerosity can be represented analogically.

One might object at this juncture that even if the analogical accumulator account of magnitude representation that I have offered is on the right track, the analogical representation of the number of giraffes in the scene presupposes prior conceptualization of the giraffes and, so, the relevant representational content cannot be NCC but must contain conceptual elements because concepts are required for object categorization.[78] Concepts, however, are not essential for object categorization and, thus, some sort of categorization, namely perceptual categorization can take place in early vision. Although it is true that categorization in language and thought requires concepts (how could one categorize an animal as a giraffe if one does not apply the concept GIRAFFE?) there is another sort of categorization that is purely perceptual and it may be achieved even in a pure feedforward manner.

Early vision includes a feed forward sweep (FFS) in which signals are transmitted bottom-up. In visual areas (from LGN to FEF) FFS lasts for about 100ms. Early vision also includes a stage at which lateral and recurrent processes that are restricted within the visual areas and do not involve signals from cognitive centers occur. Recurrent processing starts at about 80–100 ms. Lamme calls it local recurrent processing (LRP).[79] The unconscious FFS extracts high-level information and results in some initial feature detection that could lead to categorization, Indeed, a confluence of electrophysiological studies[80] and psychophysical studies[81] suggest that early visual processing can be fast and mainly feedforward and may even lead to object categorization. Potter and colleagues argue that early visual processing can be fast and mainly feedforward and may even lead to object categorization, and point out that a possible role for such rapid visual categorization, which leads to a rapid understanding of the visual scene, would be to provide almost immediate activation of the relevant concepts, or concept-like analogs, which, in turn, enables immediate action when necessary without the need for the organism to await for the time consuming recurrent processing to recognize and categorize the objects in the visual scene and, even, acquire conscious awareness of the visual scene. Note, however, that the view that perceptual categorization can occur in a purely feedforward manner should be met with skepticism since we know that there very early top-down perceptual (and not cognitive) processes even at the latency of 60 ms after stimulus onset.[82]

Familiarity plays a pivotal role in early perceptual categorization. Familiarity, including repetition memory, may also affect object classification (e.g., whether an image portrays an animal or a face), a process that occurs in short latencies (95-100 ms and 85-95 ms after stimulus onset respectively).[83] These effects pose a threat to the CI of early vision since they occur relatively early and cannot be considered post-sensory. The threat would materialize should the classification processes either require semantic information, or require that representations of objects in working memory be activated, since that would entail conceptual involvement. However, most researchers agree that the early classification effects result from the feed forward sweep and do not involve semantic information, nor do they require the activation of object memories. The main reason for this claim is simple. If they did require any of these two things, they could not be that fast. The brain areas involved are low level visual areas (including the front eye fields) from V1 to V4,[84] and, a bit more upstream to posterior IT, and lateral occipital complex-LO.[85]

The early effects of familiarity may be explained by invoking contextual associations (context spatial relationships) that are stored in early sensory areas to form unconscious perceptual memories,[86] which, when activated from incoming signals that bear the same or similar target-context spatial relationships, modify the FFS of neural activity resulting in the facilitating effects mentioned above. This is not a case of top-down effects on early vision. The brain areas involved are low level visual areas (including the front eye fields) from V1 to V4,[87] and, a bit more upstream to posterior IT, and lateral occipital complex-LO.[88]

The early effects may also be explained by invoking configurations of properties of objects or scenes stored in visual circuits. Neurophysiological research,[89] Psychological research,[90] and Computation modeling suggest that what is stored in early visual areas are implicit associations representing fragments of objects and shapes ("edge complexes"),[91] as opposed to whole objects and shapes. One of the reasons that researchers hold that it is object and shape fragments that are used in rapid classifications instead of hole objects and shapes is this; if these associations affect figure-ground segmentation, in view of the fact that figure-ground segmentation occurs very early (80-100 ms),[92] they must be stored in early visual areas (up to V4, LO and posterior IT); early visual areas store object and shape fragments that speed up FFS and LRP in early vision.

To summarize, perceptual categorization can occur as early as 80-90 ms. after the onset of stimuli presented at very brief exposures (20 ms.) in the absence of attentional and semantic (conceptual) effects. A stimulus is categorized, of course, not as a giraffe (for that would require the application of the relevant concept) but as a giraffe-shaped (that is, as an object having a specific shape) 3-D object. As Block notes,[93] perceptual systems can mobilize even under very brief stimulus presentations body- and shape-attributions that are purely perceptual and are grouped in a such a manner as to make the kinds that we think as natural kinds and which elicit later in thought the relevant concepts.

6 Concluding discussion

Let us assess the situation. There are three ways arithmetic tasks that involve the numerosity of sets of objects can be handled. Pattern matching, model building based on object files and assessment of one-to-one correspondences between models, and, for larger, numerosities, the analog counting mechanism. All these can occur in an analog manner and do not require the application of concepts, which means that the three ways are available at the nonconceptual level of early vision.

Let us return to the picture of the three giraffes. Which one of the abovementioned mechanisms might be used to determine the numerosity of the set of giraffes in the picture? The viewer is simply looking at a picture that portrays a number of giraffes. The viewer is not asked to discriminate between sets of two or three items, which excludes the subitizing mechanism. The viewer's reactions are also not observed when objects disappear and reappear, when they move in continuous or discontinuous ways behind screens and so forth, and, thus, there is no reason for models of the objects in different scenes to be created and compared, which means that this mechanism is excluded as well. This leaves us with the accumulator, which as we saw is omnipresent and is being used for sets of all sizes, unless overridden by the demands of the task at hand. It follows that the viewer of the giraffe picture assesses the size of the set of animals by the magnitude corresponding to the outcome of the function of the accumulator. This occurs at a pre-conceptual level and the ensuing representation is an analog representations of the number of the animals.

Since there exists in place a mechanism that allows the analogical representation of the numerosity of a set of objects, a picture of three giraffes gives rise to an analogical representation of three giraffes. Of course, being at a nonconceptual level, viewers of the picture do not see what they report (if they possess the relevant concepts) as three giraffes but, rather, a representation with NCC that consists in the analogical representation of the magnitude "three" applied to the pictorial representation of a number of distinct individuals with a certain size, shape, color, and whatever information is represented by the states of early vision.

The same story cannot be told with respect to seeing a family of giraffes or an odd number of giraffes. "Family", "odd", "number" are semantic terms and, as such, cannot be nonconceptually represented. It follows that, since early vision is the first visual stage, the analogical, nonconceptual representation of "three individuals sized, shaped, colored, etc., so and so" takes precedence and, as a matter of fact, is the only one that can be nonconceptually represented. Based on, or grounded in, this representation, further conceptually modulated processing in late vision may produce states whose contents are "a family of giraffes" or an odd number of giraffes. Thus, the three representations are not equivalent in being equally acceptable representations of the giraffe picture as Fodor assumes.

Notes

[1] Cf. J.A. FODOR, *The revenge of the given*, in: B.P. MCLAUGHLIN, J. COHEN (eds.), *Contemporary debates in the philosophy of mind*, Blackwell, Malden (MA) 2007, pp. 105-116.
[2] *Ibid.*, p. 110.
[3] Cf. J.A. FODOR, *The modularity of mind*, MIT Press, Cambridge (MA) 1983.
[4] Cf. J.A. FODOR, *Concepts. Where cognitive science went wrong*, Clarendon Press/Oxford University Press 1998; J.A. FODOR, *The revenge of the given*, cit.

[5] Cf. J.A. FODOR, Z.W. PYLYSHYN, *Minds without meanings: An essay on the content of concepts*, MIT Press, Cambridge (MA) 2014.
[6] Cf. M. JOHNSTON, *Better than mere knowledge: The function of sensory awareness*, in: T.S. GENDLER, J. HAWTHORNE (eds.), *Perceptual experience*, Clarendon Press, Oxford 2006, pp. 260-290; WV.O. QUINE, *From stimulus to science,* Harvard University Press, Cambridge (MA) 1995; R.M. SAINSBURY, *Reference without referents*, Oxford University Press, Oxford 2005; R.M. SAINSBURY, *Attitudes on display*, in: A. GRANKOWSKI, M. MONTAGUE (eds.), *Non-propositional intentionality*, Oxford University Press, Oxford 2018, pp. 234-258. Johnston thinks that the NCC of perception is not propositional but a host of interconnected exemplifications of properties, relations, and kinds (cf. M. JOHNSTON, *Better than mere knowledge*, cit., pp. 282-283).
[7] Cf. T. BURGE, *Origins of objectivity*, Clarendon, Oxford 2010.
[8] Cf. T. CRANE, *The nonconceptual content of experience*, in: T. CRANE, *The contents of experience: Essays on perception*, Cambridge University Press, Cambridge 1992, pp. 136-157; T. CRANE, *Is perception a propositional attitude?*, in: «The Philosophical Quarterly», vol. LIX, n. 236, 2009, pp. 452-469.
[9] Cf. J. HAUGELAND, *Having thought*, Harvard University Press, Cambridge (MA) 1998.
[10] Cf. C. PEACOCKE, *Does perception have a nonconceptual content?*, in: «The Journal of Philosophy», vol. XCVIII, n. 5, 2001, pp. 239-269.
[11] Cf. A. RAFTOPOULOS, *Cognition and perception: How do psychology and neural science inform philosophy?*, MIT Press, Cambridge (MA) 2009; A. RAFTOPOULOS, *Cognitive penetrability and the role of perception*, Palgrave Macmillan, London 2019.
[12] T. CRANE, *Is perception a propositional attitude?*, cit., p. 465.
[13] C. PEACOCKE, *Does perception have a nonconceptual content?*, cit., p. 241.
[14] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.; A. RAFTOPOULOS, *Cognitive penetrability and the role of perception*, cit.
[15] Cf. J.A. FODOR, *The revenge of the given*, cit.
[16] *Ivi*, p. 108.
[17] Cf. S. CAREY, *The origin of concepts*, Oxford University Press, Oxford 2009.
[18] Cf. S.M. KOSSLYN, *Image and brain*, MIT Press, Cambridge (MA) 1994.
[19] J.A. FODOR, *The revenge of the given*, cit., pp. 175-177.
[20] Cf. W.V.O. QUINE, *Word and object*, MIT Press, Cambridge (MA) 1960.
[21] J.A. FODOR, *The revenge of the given*, cit., p. 110.
[22] Cf. P. STRAWSON, *Individuals*, Methuen, London 1959.
[23] N. BLOCK, *Seeing-as in the light of vision science*, in: «Philosophy and Phenomenological Research», vol. LXXXIX, n. 3, 2014, pp. 560-572, here p. 560, ft.1.
[24] G. EVANS, *The varieties of reference*, Clarendon Books, Oxford 1982.
[25] Cf. W.V.O. QUINE, *Word and object*, cit.
[26] Cf. W.V.O. QUINE, *From stimulus to science*, cit.
[27] Cf. D. KAPLAN, *Afterthoughts*, in: J. ALMOG, J. PERRY, H. WETTSTEIN (eds), *Themes from Kaplan*, Oxford University Press, Oxford 1989, pp. 565-614.
[28] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.; A. RAFTOPOULOS, *Cognitive penetrability and the role of perception*, cit.
[29] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.
[30] Cf. Z.W. PYLYSHYN, *Visual indexes, preconceptual objects, and situated vision*, in: «Cognition», vol. LXXX, n. 1-2, 2001, pp. 127-158, especially p. 145.
[31] Cf. S. ECHEVERRI, *Indexing the world? Visual tracking, modularity, and the perception-cognition interface*, in: «The British Journal of Philosophy of Science», vol. LXVII, n. 1, 2016, pp. 215-245, especially p. 224.
[32] Cf. S. ECHEVERRI, *Visual reference and iconic content*, in: «Philosophy of Science», vol. LXXXII, n. 4, 2017, pp. 761-781, especially p. 771.
[33] For a discussion see A. RAFTOPOULOS, *Cognition and perception*, cit.
[34] Cf. J. CAMPBELL, *Reference and consciousness*, Bradford Books, Oxford 2002.
[35] Cf. E.S. SPELKE, *Object perception*, in: A.I. GOLDMAN (ed.), *Readings in philosophy and cognitive science*, MIT Press, Cambridge (MA) 1988, pp. 447-461; E.S. SPELKE, R. KESTENBAUM, D.J. SIMONS, D. WEIN, *Spatio-temporal continuity, smoothness of motion and object identity in infancy*, in: «British Journal of Developmental Psychology», vol. XIII, n. 1, 1995, pp. 113-142.
[36] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.; A. RAFTOPOULOS, *Cognitive penetrability and the role of perception*, cit.
[37] Cf. T. BURGE, *Origins of objectivity*, cit.
[38] Cf. Cf. S. ECHEVERRI, *Visual reference and iconic content*, cit.

[39] Cf. P. CAVANAGH, *Visual cognition*, in: «Vision Research», vol. LI, n. 13, 2011, pp. 1538-1551; I. ROCK, *The logic of perception*, MIT Press, Cambridge (MA) 1983; E.S. SPELKE, *Object perception*, cit.
[40] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.
[41] Cf. J.R. SEARLE, *Consciousness, explanatory inversion and cognitive science*, in: C. MACDONALD, G. MACDONALD (eds.), *Philosophy of psychology: Debates on psychological explanation*, Blackwell, Oxford 1995, pp. 331-355.
[42] Cf. D.C. DENNETT, *Styles of mental representation*, in: «Proceedings of the Aristotelian Society», vol. LXXXIII, n. 1, 1983, pp. 213-226.
[43] M. DAVIES, *Tacit knowledge and subdoxastic states* (1989), in: C. MACDONALD, G. MACDONALD (eds.), *Philosophy of psychology: Debates on psychological explanation*, cit., pp. 309-330, here p. 329.
[44] For a similar argument see R.G. MILLKAN, *The varieties of meaning*, Bradford Book, Oxford 2004.
[45] Cf. A. RAFTOPOULOS, *Cognition and perception*, cit.
[46] Cf. M. AYERS, *Knowing and seeing: Groundwork for a new empiricism*, Oxford University Press, Oxford 2019; J. BECK, *The generality constraint and the structure of thought*, in: «Mind», vol. CXXI , n. 483, 2012, pp. 563-601; J. BECK, *Analog mental representation*, in: «WIREs Cognitive Science», vol. IX, n. 6, 2018, Art.Nr. e1479 - doi: 10.1002/wcs.1479; J. BECK, *Perception is analog: The argument from Weber's law*, in: «The Journal of Philosophy», vol. CXVI, n. 6, 2019, pp. 319-349; T. BURGE, *Origins of objectivity*, cit.; S. CAREY, *The origin of concepts*, cit.; D.C. BURNSTON, *Cognitive penetration and the cognition-perception interface*, in: «Synthese», vol. CXCIV, n. 9, 2017, pp. 3645-3668; T. CRANE, *The mechanical mind*, Routledge, London 2003, 2nd edition; R. CUMMINS, M. ROTH, *Meaning and content in cognitive science*, in: R. SCHANTZ (ed.), *Prospects for meaning*, De Gruyter, Berlin/Göttingen 2012, pp. 365-382; F. DRETSKE, *Knowledge and the flow of information*, MIT Press, Cambridge (MA) 1981; J.A. FODOR, *The revenge of the given*, cit.; N. GOODMAN, *Languages of art*, Hackett, Indianapolis 1976; J. HAUGELAND, *An overview of the frame problem*, in: Z. PYLYSHYN (ed.,) *The robot's Dilemma: The frame problem and artificial intelligence*, Ablex Publishing Company, Norwood (NJ) 1987, pp. 77-94; R.G. HECK, *Are there different kinds of content?*, in: B.P. MCLAUGHLIN, J. COHEN (eds.), *Contemporary debates in the philosophy of mind*, Blackwell, Malden 2007, pp. 117-138; R. JACKENDOFF, *Consciousness and the computational mind*, MIT Press, Cambridge (MA)1987; S.M. KOSSLYN, *Image and brain*, cit.; C. PEACOCKE, *Analogue content*, in: «Proceedings of the Aristotelian Society», vol. LX, n. 1, 1986, pp. 1-18; C. PEACOCKE, *The primacy of metaphysics*, Oxford University Press, Oxford 2019.
[47] N. GOODMAN, *Languages of art*, cit., pp. 148-152.
[48] *Ibid.*, pp. 135-136.
[49] Cf. N. GOODMAN, *Languages of art*, cit.; C. PEACOCKE, *Analogue content*, cit.
[50] Cf. C. PEACOCKE, *The primacy of metaphysics*, cit.; PEACOCKE, *Analogue content*, cit.
[51] Cf. F. DRETSKE, *Knowledge and the flow of information*, cit.
[52] Cf. J. BLACHOWICZ, *Analog representation beyond mental imagery*, in: «The Journal of Philosophy», vol. XCIV, n. 2, 1997, pp. 55-84.
[53] See also J. BECK, *Perception is analog*, cit.
[54] *Ibid.*, pp. 331-333.
[55] Cf. C. MALEY, *Analog and digital, continuous and discrete*, in: «Philosophical Studies», vol. CLV, n. 1, 2011, pp. 117-131.
[56] Cf. J. KULVICKI, *Analog representation and the parts principle*, in: «Review of Philosophy and Psychology», vol. VI, n. 1, 2015, pp. 165-180.
[57] Cf. S. PALMER, *Fundamental aspects of cognitive representation*, in: E. ROSCH, B. LLOYD (eds.), *Cognition and categorization*, Erlbaum, Hillsdale (NJ) Erlbaum 1978, pp. 259-303.
[58] *Ibid.*, p. 271.
[59] Cf. J. BECK, *Perception is analog*, cit.
[60] Cf. J. QUILTY-DUNN, *Iconicity and the format of perception*, in: «Journal of Consciousness Studies», vol. XXIII, n. 3-4, 2016, pp. 255-263.
[61] Cf. A. TREISMAN, *The perception of features and objects*, in: A. BADDELEY, L. WEISKRANTZ (eds.), *Attention: Selection, awareness and control*, Oxford University Press, Oxford 1993, pp. 5-35; A. TREISMAN, *The binding problem*, in: «Current Opinions in Neurobiology», vol. VI, n. 2, 1996, pp. 171-178.
[62] For an extensive discussion of the relevant scientific literature see T. BURGE, *Origins of objectivity*, cit.; A. RAFTOPOULOS, *Cognition and perception*, cit.
[63] Cf. S. CAREY, *Continuity and discontinuity in cognitive development*, in: E.E. SMITH, D.N. OSHERSON (eds.), *An invitation to cognitive science, vol. III: Thinking*, MIT Press, Cambridge (MA) 1995, 2nd edition, pp. 101-129; K. WYNN, *Infants' individuation and enumeration of actions*, in: «Psychological

Science», vol. VII, n. 3, 1996, pp. 164-169; C. ULLER, S. CAREY, H. FENNER, L. KLATT, *What representations underlie infant numerical knowledge?*, in: «Cognitive Development», vol. XIV, n. 1, 1999, pp. 1-36; F. XU, *Numerosity discrimination in infants: Evidence for two systems of representations*, in: «Cognition», vol. LXXXIX, n. 1, 2003, pp. B15-B25.

[64] Cf. K. WYNN, *Origins of numerical knowledge*, in: «Mathematical Cognition», vol. I, n. 1, 1995, pp. 36-60; K. WYNN, *Infants' individuation and enumeration of actions*, cit.

[65] Cf. W.H. MECK, R.M. CHURCH, *A mode control model of counting and timing processes*, in: «Journal of Experimental Psychology: Animal Behavior Processes», vol. IX, n. 3, 1983, pp. 320-334.

[66] Cf. S. CAREY, *Continuity and discontinuity in cognitive development*, cit.; C. ULLER, S. CAREY, H. FENNER, L. KLATT, *What representations underlie infant numerical knowledge?*, cit.

[67] Cf. L. FEIGENSON, S. DEHAENE, E. SPELKE, *Core systems of number*, in: «Trends in Cognitive Sciences», vol. VIII, n. 7, 2004, pp. 307-315.

[68] The ability of infants to recognize and compare the numerosities of small sets of objects is known as subitizing. The same ability is observed in other species. Given the nature of the organisms with this ability, subitizing cannot be attributed to some knowledge of arithmetic or to verbal counting. Subitizing presents two characteristic signatures: (a) there is an upper limit to the cardinality of the set that can be subitized; it is the number three or four; (b) within the range of cardinalities in which the phenomenon is observed, increase in the cardinality of the set is accompanied by a very small increase in reaction times (subitizing slope).

[69] Cf. L. TRICK, Z.W. PYLYSHYN, *What enumeration studies can show us about spatial attention: Evidence for limiting capacity preattentive processing*, in: «Journal of Experimental Psychology: Human Perception and Performance», vol. XIX, n. 2, 1993, pp. 331-351; L. TRICK, Z.W. PYLYSHYN, *Why are small and large numbers enumerated differently? A limited capacity preattentive stage in vision*, in: «Psychological Review», vol. CI, n. 1, 1994, pp. 80-102.

[70] Cf. S.A. PETERSON, T.J. SIMON, *Computational evidence for the subitizing phenomenon as an emergent property of the human cognitive architecture*, in: «Cognitive Science», vol. XXIV, n. 1, 2000, pp. 93-123.

[71] Cf. W.H. MECK, R.M. CHURCH, *A mode control model of counting and timing processes*, cit.

[72] Cf. C.R. GALLISTEL, R. GELMAN, *Nonverbal numerical cognition: From reals to integers*, in: «Trends in Cognitive Sciences», vol. IV, n. 2, 2000, pp. 59-65.

[73] Cf. C.R. GALLISTEL, R. GELMAN, *Nonverbal numerical cognition*, cit.; A. NIEDER, D.J. FREEDMAN, E.K. MILLER, *Representation of the quantity of visual items in the primate prefrontal cortex*, in: «Science», vol. CCXCVII, n. 5587, 2002, pp. 1708-1712; J. WHALEN, C.R. GALLISTEL, R. GELMAN, *Nonverbal counting in humans: The psychophysics of number representation*, in: «Psychological Science», vol. X, n. 2, 1999, pp. 130-137.

[74] Cf. W.H. MECK, R.M. CHURCH, *A mode control model of counting and timing processes*, cit.

[75] Cf. E. BIALYSTOK, *Symbolic representations of letters and numbers*, in: «Cognitive Development», vol. VII, n. 3, 1992, pp. 301-316; C.R. GALLISTEL, *The organization of learning*, MIT Press, Cambridge (MA) 1990; C.R. GALLISTEL, R. GELMAN, *Preverbal and verbal counting and computation*, in: «Cognition», vol. XLIV, n. 1, 1992, pp. 43-74.

[76] Cf. S. DEHAENE, L. COHEN, *Cerebral pathways for calculation: Double dissociation between verbal and quantitative knowledge of arithmetic*, in: «Cortex», vol. XXXIII, n. 2, 1997, pp. 219-250.

[77] Cf. S. DEHAENE, L. COHEN, *Towards an anatomical and functional of number processing*, in: «Mathematical Cognition», vol. I, n. 1, 1995, pp. 83-120.

[78] I would like to thank an anonymous reviewer for raising this objection.

[79] Cf. V.A.F. LAMME, *Why visual attention and awareness are different*, in: «Trends in Cognitive Sciences», vol. VII, n. 1, 2003, pp. 12-18.

[80] Cf. C. KEYSERS, D.K. XIAO, P. FÖLDIAK, D. PERRETT, *The speed of sight*, in: «Journal of Cognitive Neuroscience», vol. XIII, n. 1, 2014, pp. 90-101.

[81] Cf. M.C. POTTER, B. WYBLE, C.E. HAGMANN, E.S. MCCOURT, *Detecting meaning in RSVP at 13ms per picture*, in: «Attention, Perception, Psychophysics», vol. LXXVI, n. 2, 2014, pp. 270-279.

[82] For a discussion see A. RAFTOPOULOS, *Cognition and perception*, cit., pp. 90-118.

[83] Cf. S.M. CROUZET, H. KIRCHNER, S.J. THORPE, *Fast saccades toward faces: Face detection in just 100 ms.*, in: «Journal of Vision», vol. X, n. 4, 2010, pp. 1-17; H. LIU, Y. AGAM, J. MADSEN, G. KRELMAN, *Timing, timing, timing: Fast decoding of object information from intracranial field potentials in human visual cortex*, in: «Neuron», vol. LXII, n. 2, 2009, pp. 281-290.

[84] Cf. H. KIRCHNER, S.J. THORPE, *Ultra-rapid ob-*

ject detection with saccadic movements: visual processing speed revisited, in: «Vision Research», vol. XLVI, n. 11, 2006, pp. 1762-1776.

[85] Cf. K. GRILL-SPECTOR, T. KUSHNIR, T. HENDLER, S. EDELMAN, Y. ITZCHAK, R. MALACH, *A sequence of object-processing stages revealed by fMRI in the Human occipital lobe*, in: «Human Brain Mapping», vol. VI, n. 4, 1998, pp. 316-328.

[86] Cf. M. CHAUMON, V. DROUET, C. TALLON-BAUDRY, *Unconscious associative memory affects visual processing before 100 ms.*, in: «Journal of Vision», vol. VIII, n. 3, 2008, pp. 1-10.

[87] Cf. H. KIRCHNER, S.J. THORPE, *Ultra-rapid object detection with saccadic movements*, cit.

[88] Cf. K. GRILL-SPECTOR, T. KUSHNIR, T. HENDLER, S. EDELMAN, Y. ITZCHAK, R. MALACH, *A sequence of object-processing stages revealed by fMRI in the Human occipital lobe*, cit.

[89] Cf. K. GRILL-SPECTOR, R. HENSON, A. MARTIN, *Repetition and the brain: neural models of stimulus-specific effects*, in: «Trends in Cognitive Sciences», vol. X, n. 1, 2006, pp. 14-23.

[90] Cf. M.A. PETERSON, J. ENNS, *The edge complex: implicit memory for figure assignment in shape perception*, in: «Perception & Psychophysics», vol. LXVII, n. 4, 2005, pp. 727-740.

[91] Cf. S. ULLMAN, M. VIDAL-NAQUET, E. SALI, *Visual features of intermediate complexity and their use in classification*, in: «Nature Neurosciences», vol. V, n. 7, 2002, pp. 682-687.

[92] Cf. V.A.F. LAMME, P.R. ROELFSEMA, *The distinct modes of vision offered by feedforward and recurrent processing*, in: «Trends in Neuroscience», vol. XXIII, n. 11, 2000, pp. 571-579.

[93] Cf. N. BLOCK, *Seeing-as in the light of vision science*, cit., pp. 562-563.

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