RICERCHE

An associative account of inferences: The development towards the prototype

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Abstract According to a traditional view, inferences are personal-level entities pertaining to the domain of reasons, and therefore they cannot be accounted for in causal terms – specifically, as mere associations. I intend to argue that this is at the very least a drastic simplification, for two reasons. First, the word "association" is polysemous, so we should specify in which of its possible senses an inference is not a mere association. Second, personal-level inferences based on formal rules are only the extreme end of a complex developmental trajectory. As the last decades of research in the field have shown, we should refrain from identifying the entire domain of reasoning with that final stage, which is in fact mostly contingent upon extensive logical training. In this paper, I try to disentangle some major stages in the development of full-fledged (prototypical) inferences, and then to show that all of them – till the final one – can be considered associative in appropriate senses of the word.
KEYWORDS: Reasoning; Association; Consciousness; Inference; Development

Riassunto *Un approccio associativo alle inferenze: l'evoluzione verso il prototipo* – Secondo una concezione tradizionale, le inferenze sono entità collocate al livello della persona e appartenenti al dominio delle ragioni, e pertanto non è possibile ridurle a un resoconto causale – più specificamente, a mere associazioni. Intendo sostenere che questa è quanto meno una drastica semplificazione, per due ragioni. Primo, la parola "associazione" è polisemica, quindi dovremmo precisare in quale senso un'inferenza non è una mera associazione. Secondo, inferenze al livello della persona e basate su regole formali sono solo il punto estremo di una complessa traiettoria di sviluppo. Come gli ultimi decenni di ricerca in questo campo hanno mostrato, dovremmo evitare di identificare l'intero dominio del ragionamento con questo stadio finale, che di fatto dipende da un esteso addestramento logico. In questo articolo, provo a discriminare alcuni stadi essenziali nello sviluppo delle inferenze in senso pieno (prototipiche), e quindi a mostrare che ciascuno di essi – incluso quello finale – possono essere considerati associativi in qualche opportuno senso della parola.
PAROLE CHIAVE: Ragionamento; Associazione; Coscienza; Inferenza; Sviluppo

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According to a traditional view, inferences are personal-level entities typically involving consciousness. However, in the last decades there has been growing interest in the idea that reasoning may be performed by a variety of processes. In particular, the dual-process theory has convinced many that besides conscious, controlled reasoning we may also rely on another kind of reasoning which is automatic, associative and parallel instead.

Here we have a first sense in which low-level inferences may be considered associative: they are automatic – in opposition to more demanding forms of conscious reasoning. I endorse this dual view, but with important qualifications. Most of all, I propose to adopt towards it the attitude that Gilbert has so well described:

> Psychologists who champion dual-process models are not usually stuck on two. Few would come undone if their models were recast in terms of three processes, or four, or even five. Indeed, the only number they would not happily accept is one, because claims about dual processes in psychology are not so much claims about how many processes there are, but claims about how many processes there aren't. And the claim is this: There aren't one.[1]

In particular, with regard to the role of consciousness, Keith Stanovich and others (most notably, Daniel Kahneman) have emphasized that, besides automatic reasoning, it is important to distinguish between low-level and high-level forms of conscious reasoning.[2] We will come back to this distinction below. However, for different purposes it might be convenient to provide an even finer-grained analysis than that. As a matter of fact, I will propose a model which distinguishes five types of "inferences" (in the generic sense of "transitions between mental contents"), that only at one extreme of the scale fully satisfy the prototypical definition of inference. This puts into perspective the full-fledged notion of inference, by calling attention to the fact that it is presumably the end point of an evolutionary and developmental course.

In this sense I speak of "development towards the prototype": by this I mean a developmental course toward inferences as they are prototypically conceived. Generally speaking, the notion of prototype has played an influential role as an account of concepts, after it has been proposed by Eleanor Rosch.[3] Prototypes can be thought of as typical exemplars, or even better, as collections of typical features, with respect to which something is judged as being a member of the category at issue: the more an instance has the typical features, the more it is perceived as a good instance of the category.

To be sure, traditional accounts of reasoning have taken conscious formal inferences as providing the normative standard – not just the prototypical case – for the domain. I think this is correct in the following sense: formal reasoning allows us to deliberately control for correctness, so as to discriminate between spontaneous inferences which are justified and others which are not. However, this is quite different from saying that, in the general case, reasoning is formal and conscious. Cognitively speaking, this is mostly an idealization of normal reasoning practices, providing the benchmark for less sophisticated forms of inferences (e.g., content-based or unconscious ones) in which this or that typical feature (respectively, formal structure or consciousness) is absent. In the next sections I will proceed as follows.

In section 1 I am going to consider an influential analysis of inference – the one proposed by Boghossian (but with a qualification based on Finn)[4] – in order to show that philosophical analyses of this sort provide us with a quite composite notion. It is therefore possible to decompose that notion into a number of cognitive features, that can be present or not when we engage in actual reasoning. I consider three major features: (a) the use of cognitive schemas that are taken to justify the transition from the premise(s) to the conclusion; (b) the fact that this "taking" occurs at a personal, conscious level; (c) the formal nature of the schema, which must provide an abstract inference rule. I will then propose an associative account of those features. As far as feature (b) is concerned, this clearly requires that a second meaning of "associative" is considered. We introduced above the idea that reasoning can be associative in the sense of automatic and unconscious. If we now say that *conscious* reasoning is associative, too, then we must be using "associative" in a different sense. In section 1.2 I will provide theoretical reasons to distinguish three different uses of the term.

In section 2 I will explore some of the psychological literature on conditional reasoning in order to provide further support for the claim that formal inferences are not the standard: there is strong evidence that spontaneous reasoning is largely based on content, not on formal schemas. I will also briefly discuss recent work from developmental and comparative psychology, in support of the idea that inferential abilities develop both in evolutionary and developmental perspective. This survey of the literature is also intended to show how the polysemy of the word "association" can cause confusion, and how associations come in various and variably complex forms even at lower levels of reasoning.

1 What are inferences?

1.1 A philosophical analysis

As I said, in the philosophical literature on the topic it is a widespread opinion that inferences are personal-level entities involving consciousness.

This is sometimes expressed by saying that reasons cannot be reduced to mere causes, in line with a traditional perspective tracing back to Wittgenstein and Wilfrid Sellars. For a recent example, let us consider how Boghossian puts it:

> It's not sufficient for my judging (1) and (2) to *cause* me to judge (3) [where (1) and (2) are premises, and (3) is the conclusion] for this to be inference. The premise judgments need to *have caused* the conclusion judgment "in the right way".[5]

Interestingly, Boghossian adopts here a somewhat moderate view of the reasons/causes distinction. Taken at face value, what he says is not that causes cannot account for reasons at all; the claim is rather that one cannot account for inferences just by saying that the premises cause the conclusion, since this wording is unable to distinguish between cases in which the conclusion is caused *in the right way* and cases in which it is not. This "right way" is specified in terms of what Boghossian calls the "Taking Condition": «Inferring necessarily involves the thinker *taking* his premises to support his conclusion and drawing his conclusion *because* of that fact».[6] He further explains the intuition behind the Taking Condition as follows:

> no causal process counts as inference, unless it consists in an attempt to arrive at a belief by figuring out what, in some suitably broad sense, is supported by other things one believes. In the relevant sense, reasoning is something we *do*, not just something that happens to us. And it is something *we* do, not just something that is done by sub-personal bits of us.[7]

In sum, while not entirely excluding the possibility that inferences are accounted for by causal models, his point is that such models are not in the general case (i.e., without further qualification) sufficient to capture the right kind of processes: that is, processes involving us as conscious persons that infer beliefs from other beliefs, insofar as we take that transition to be justified.

Although his emphasis is on the fact that inferences are personal-level entities, there is another assumption clearly lurking behind Boghossian's Taking Condition: there must be a reason of the right sort for why one takes a mental transition to be justified. This reason is what is called in the literature an "inference rule". Finn has provided a precise characterization of what is involved in the adoption of a logical inference rule.[8] This amounts to the following three components:

(A) The acceptance of the logical rule R
(B) The practice of inferring in accordance with that rule R
(C) Doing B in virtue of A

There is here a shift in focus: while the Taking Condition provides the criterion for what it is to perform *inferences*, Finn focusses instead on the criterion for what it is to adopt *(logical) inference rules*. Except for this difference in focus, however, the two analyses are clearly consistent and overlapping. What Finn's perspective adds to the Taking Condition is the role that inference rules must play in it. According to the Taking Condition – let us repeat it – the thinker takes his premises to support his conclusion, and draws his conclusion because of that fact. However, for this to happen there must be a rule that, in the eyes of the thinker, is the reason why the premises support the conclusion. In the absence of such a rule, it is difficult to imagine what, for a thinker, might justify an inference.

The analysis proposed by Finn has an important consequence. In her view, all inferential rules necessarily have a General Structure that is *conditional* and can be formulated as follows:

(GS) If the premises are an instance of structure X, then infer conclusion Y.

This gives a special status to the inference rule known as *modus ponens*, according to which from the two premises "A" and "if A then B" (A → B) one can draw the conclusion "B":

A
A → B

B

This inference rule has a special status, since GS (the General Structure of inference rules) *presupposes* it. In order to apply any inference rule (be it *modus ponens* or any other), we have to reason conditionally from premises of structure X to the conclusion Y, based on the bridging between X and Y provided by the rule at issue. However, this is the very form of *modus ponens*, which thus appears to be the basic inference rule underlying any inference rule (including itself).[9]

Against this background, the present section will proceed as follows. First, I will focus on the role played by inference rules, and draw a parallel with the role played by more concrete schemas within associative networks. Second, I will focus on how the development from concrete schemas to formal inference rules might have occurred. Finally, I will come back to the conscious character of prototypical inferences.

1.2 The glue of thought: Schemas in cognitive science

According to the analysis provided in the previous section, an associative model of inference cannot be adequate unless it can also account for the role played by inference rules. It is these rules that explain why the thinker takes certain premises to support the conclusion; and therefore, it is especially these rules that must be explained in associative terms. We focussed on *logical* inference rules, but the problem is more general: it affects relations between mental contents of any sort, not only between propositions in logical inferences. In particular, we are going to consider how it affects the relation between concepts within a single proposition or thought.

Cognitive science has often contrasted associative processes, conceived as mere causal transitions, and more sophisticated processes based on some understanding of the relation between contents. An illustration of the opposition is the following quotation from Fodor's *Hume variations*:

> If you read "MRJAMES → BITES" as saying that tokens of MRJAMES are disposed to cause tokens of BITES, you can't also read it as saying that Mr James bites. [...] I think Hume just gets this wrong; he fails to distinguish the thesis that association is what determines the (causal) succession of ideas in thought from the thesis that association is, as one might say, the glue that holds complex ideas (and/or propositional thoughts) together.[10]

What Fodor actually suggests is that Hume made an appeal to associations, which may account at most for causal succession of ideas, as if they also explained how ideas (and thoughts) are related to each other in a way that is represented by the thinker. Fodor is here echoing the criticism levelled by Kant against Hume. According to Kant, the mere fact that the idea of FIRE associatively causes the idea of SMOKE cannot account for the judgment FIRE CAUSES SMOKE. While in genuine judgments the thinker entertains complex thoughts (such as FIRE CAUSES SMOKE), in its associative counterpart she can at most think one idea after the other (FIRE, and then SMOKE).

This sort of criticism to Humean associationism is often repeated, or presupposed; but what exactly is at issue is less clear than it should be. One major purpose of this paper is precisely to analyse this issue, in order to avoid confusions which sometimes occur in the literature. To this purpose, a crucial distinction is that between two conceptions of associations. First, we can think of our brain as a network of nodes connected to each other through excitatory and inhibitory synaptic connections – let us call this the neuroscientific notion of associative network. This is consistent with a general model of cognition, according to which cognitive processing is based on the activation of nodes via their associations.[11] Second, we can think of associations as the detection and coding of simple co-occurrences of stimuli in the environment, as in the following quotation by Fodor:

> The basic point about association was, surely, that it offered a mechanism for bringing about co-occurrence relations among mental events which mirror the corresponding relations among environmental ones. The feature of experience to which the formation of associations was supposed to be most sensitive was thus relative frequencies of spatiotemporal contiguities among stimuli [...].[12]

Fodor's mention of "spatiotemporal contiguities" is not to be understood here as meaning that associations *represent* that information. As the previous quotation about Humean associationism should have made clear, Fodor thinks of associations as mechanisms by which mental tokens cause the activation of other mental tokens, without any representation of their relation. Thus, the association between any two mental tokens would be sensitive to the spatiotemporal contiguity between the respective stimuli, merely in the sense that it can "mirror" it. Just as the stimuli co-occur in the environment, so the tokens co-occur in mental processing (since one causes the other).

The important point here is that an "associative network" in the first sense needs not be "associative" in this second sense (i.e., as mere detection of co-occurrence of stimuli). The network can in principle contain a representation of – let us say – Token 1 and Token 2 *and of their relation*, so that associative activation of Token 2 by Token 1 is mediated by activation of the representation of that relation.

As an example, let us consider a very simple mental transition between contents: we see a fin over the water and, as a consequence, we imagine the rest of the body of a shark. How is this transition accomplished? One possibility is that this occurs as a direct transition from the shape of fins to the shape of the rest of the body of sharks. But there is another possibility. That is, the overall shape of sharks, encoded in memory, may function as an intermediary between what is seen and what is predicted: given the sight of the fin, and the pattern in memory that predicts a certain relation between fins and the rest of the body, we anticipate the actual presence of the rest of the body. By this account, a schema in memory may provide – so to speak – the major premise for an inference, specifically a *modus ponens*: from A, and from a schema that represents the prediction A → B, then the conclusion B can be drawn.

As a matter of fact, the point I am making here has been important for the history of cognitive science. First attempts to represent and simulate cognition employed what have been called "associative networks": this phrase was intended in the specific sense – which also characterized Fodor's previous quotation – of a network where the semantic relations between nodes are not represented. However, it became immediately evident that cognition requires more complex representations, where relations between contents are represented, too. This was accomplished first by "semantic networks" in which nodes are linked by labelled links, with labels expressing a restricted number of abstract relations.[13] Even this, however, turned out to be far from satisfying, since there seems to be an indefinite number of relations that we need to represent. Consider again our example of the shape of the shark: we need a pattern that captures all the relevant parts and how they are spatially related to each other. This has led to notions such as schema, frame, script and so on. The general idea is that information is organized into structures that capture different relations (spatial, temporal, causal, functional, etc., and also combinations of these) that are specific to the concept at hand.[14]

The important point is that schemas allow for inferences in a relatively robust sense of this term. In cognitive science "inference" is sometimes used – in a very loose sense – even for causal transitions that are not mediated by schemas. However, although in such cases the system may occasionally behave in the same way as if it used a schema to cause that transition, in fact it did not. Only when a schema is present and act as an intermediary between contents is the transition motivated by something which plays the role of the major premise in *modus ponens*. In other words, schemas not only cause transitions; they *motivate* them on the basis of information about the relation between contents. These transitions need not be conscious: in a number of cases, schemas can be expected to play their role even by automatic processing. Nevertheless, they provide the sort of information that can be appealed to in conscious reasoning, too.

Thus, we have here a scale of meanings of "inference": from very loose (non-mediated automatic transitions), to moderately loose (automatic transitions mediated by schemas), to prototypical (conscious transitions mediated by schemas). On the other hand, the steps of this scale can be described as "associative" in different senses. While transitions of the first kind are associative in the sense that they do not make use of information about relations (mere co-occurrences), transitions of the second kind – though mediated by such information – are associative in the sense of automatic. As for conscious transitions, they are not associative in either of those senses, but they can nevertheless be implemented within "associative networks" – in the neuroscientific sense of the phrase, which allows accounting for implementation of any cognitive process: we will come back to this in section 1.4.

The fact that the representation of structured information enables inferences has been observed in many domains of cognition. For one example from the field of concept theory, Lawrence Barsalou has claimed:

> The situated conceptualization [i.e., any of the wider schemas in which concepts are embedded] that becomes active constitutes a rich source of inference. The conceptualization is essentially a pattern, namely, a complex configuration of multimodal components that represent the situation. When a component of this pattern matched the situation, the larger pattern became active in memory. The remaining pattern components–not yet observed-constitute inferences, that is, educated guesses about what might occur next. Because the remaining components co-occurred frequently with the perceived components in previous situations, inferring the remaining components is justified.[15]

It is interesting to note that, in this quotation, reference to associative mechanisms (becoming active in memory, frequent co-occurrence in perception) and to inferential transitions (source of inference, inferences about what might occur next, inferring is justified) are mixed together. Most of all, the mechanism described is precisely that sort of associative activation mediated by schemas that we described above as modelled on *modus ponens*: an input (component A) activates the schema (A → B, C, D, etc.), and this activates in turn its other components (B, C, D, etc.).[16]

Another example of this mechanism is provided by Ray Jackendoff in his reinterpretation of Chomsky's Generative Grammar. According to him, an associative mechanism – instead of a set of specialized syntactic processes – can explain generativity of syntax, provided that the relevant structural information is captured by patterns stored in memory. Thanks to such patterns, an initial word sets up grammatical expectations about the possible sentence structures, then «further words in the sentence may be attached on the basis of the [previously activated] top-down structure».[17] In other words, syntactic rules stored in memory provide the schemas (top-down structures) which act as associative intermediaries between their components: they function as the major premise in a *modus ponens*.

In sum, schemas are the glue that holds mental items together, insofar as they provide information on how those items are related to each other. At the same time, schemas provide justification for inferences from one mental item to another. For example, a causal schema allows thinking of the relation between fire and smoke, but it also allows inferring smoke from fire; a perceptual schema allows thinking of the spatial relation between the fin and the rest of the body of a shark, but it also allows inferring the rest of the body from the fin; and the syntactic schema for sentences allows thinking of the relation between nominal phrase and verbal phrase, but it also allows inferring the presence of a verbal phrase from the presence of a nominal phrase.

Inference rules between propositions seem to be only a special case of this general phenomenon. They link together premises and conclusions in meaningful patterns, and at the same time allow inferring conclusions from premises. To be sure, logical inference rules have their specificities, too. First, they are formal, not only in the sense that they are expressed in formal notation, but also in that their validity does not depend on specific contents. Second, they are normally performed at a conscious level, which is not necessarily the case with our previous examples – syntactic rules, for instance, are generally thought to be applied automatically. In the next two sections, we are going to consider these two features in turn.

1.3 From concrete to formal schemas

In the examples I provided in the previous section, schemas have contents that are specific to the categories and domains at issue. The spatial structure of sharks is specific to sharks – and possibly, in a generic form, to other sea creatures. And the sequence of nominal and verbal phrase within sentences is specific to syntax. Generally speaking, specific conceptual schemas allow for specific inferences. Although those inferences all conform to *modus ponens*, they are not explained by adoption of *modus ponens* as an inference rule. Let us recall Finn's analysis of what is involved in adopting a logical inference rule:

(A) The acceptance of the logical rule R
(B) The practice of inferring in accordance with that rule R
(C) Doing B in virtue of A

Clearly, whenever it is our schema for shark that causes an inference from the fin to the rest of its body, then we are not drawing this inference in accordance with *modus ponens* "in virtue of" our acceptance of *modus ponens* (as prescribed by condition C). We are instead drawing the inference in virtue of the acceptance of a much more specific schema.[18]

Now, which of the two does actually occur in spontaneous reasoning? Do we usually make inferences which conform to *modus ponens* "in virtue of" the fact that we adopt *modus ponens* as an abstract inference rule? Or do we do that in virtue of adopting schemas that are specific to the content at hand?

As I will summarize in section 3, decades of psychological research have shown that our spontaneous reasoning abilities do not depend on the application of formal rules: they are largely dependent, instead, on the specific content involved. On the other hand, this allows for a more economical explanation of inference than it would be otherwise. Associative networks (in the neuroscientific sense) naturally provide a general mechanism for inferences: to the extent that we have a specific schema connecting Token 1 and Token 2, associative inferences from the former to the latter can be drawn without need of a formal rule for *modus ponens*. On the contrary, it is difficult to understand how having such a formal rule could help to draw a specific inference from Token 1 to Token 2, unless one also has a specific schema connecting them. Otherwise, how could one know whether *modus ponens* applies to this or that specific couple of tokens?

None of this implies that we cannot form schemas at different degrees of abstraction, through generalization of experience (we will come back to this in section 2.1). And of course, we can learn formal logic through explicit education. The point, however, is that the acquisition of abstract and even formal schemas for inferences seems to add further layers to already existing inferential abilities. Explicit logical rules are presumably the point of arrival, not of departure, of the development of human inferential abilities.

As a matter of fact, not all human societies have developed formal logic. This suggests that logical abilities might show the same pattern as mathematical ones: these latter build on basic innate skills, but do not show any significant development until appropriate cultural devices are in place.[19] Be it as it may, mastery of logical rules requires a specific training, which is not effortless. It involves learning formal symbols together with rules for their manipulation. This presumably amounts to form cognitive schemas as the ones described in the previous section, except that they do not apply to concrete objects or properties, but to formal symbols devoid of any specific content – a fact suggesting that handwriting as a means for abstraction may have been a prerequisite.

Although this is speculative, one might suppose that the format of logical symbolism is crucial to account for another essential feature of logical inferences: their universal validity.[20] Formal symbols do not stand for any specific category of objects: they stand instead for unspecified objects and properties, and invite us to think of rules which apply without exception to abstract individuals and sets. In this way, schemas encoded within associative networks might account for the emergence of rules endowed with universal validity.

1.4 Conscious inferences (or more or less so)

Up to this point, I have explained how cognitive schemas in associative networks (neuroscientific sense) may account for spontaneous inferences, due to simple chains of activation from component 1, to schema, to component 2. Moreover, I suggested that logical inference rules are just a special case of schemas encoded in associative networks. They require social training aimed at mastery of specific cultural devices (formal symbols), which may explain why logical inferences develop late, both in human history and in individual development.

Now it is time to address the last feature that we identified in prototypical inference: its conscious character. The first question we need to ask is: how can conscious processes, and not only automatic ones, be implemented by associative networks (in the neuroscientific sense)?

Leaving aside details that might be disputed, there is a rather easy and well-established answer to this question. Automatic processing only requires what is sometimes called "spreading activation", that is, activation that spreads locally in associative networks and is characterized by rapid decay; conscious processing requires instead temporally sustained activation through circuits that are widely distributed in the cortex.[21] In other words, conscious processing is characterized by recurrent loops of activation thanks to which even remote representations can be maintained active together in working memory, as long as required for the task at hand. In sum, if by "associative" we mean a model of explanation based on a network of nodes and their reciprocal accessibility, then such a model is able to account for both automatic and conscious processes, in terms of two different dynamics of activation: respectively, local activation with rapid decay, and distributed activation sustained through time.

Let us turn back to the Taking Condition. One plausible cognitive interpretation of it is that, in genuine inferences, premises are consciously taken as justification for certain conclusions. As Boghossian suggests, not all causal transitions in the brain are conscious, but full-fledged inferences are. However, there is a simple explanation for this in associative networks. It is enough that the transitions at issue occur in working memory, that is, that the appropriate representations are maintained active through recurrent loops.

A couple of comments on this picture are in order.

First, conceiving of consciousness as a phenomenal property of working memory strongly suggests that conscious processes operate (at least in part) on the same mental representations as automatic ones. The general idea is that information structures encoded in long term memory can be reactivated either in a more robust and sustained manner – so that they enter into working memory – or in a more automatic way. In his well-established model of consciousness as a "global workspace", Baars speaks of a plurality of automatic activations which compete for access to working memory,[22] a view that is shared by Dehaene's neuroscientific version of consciousness as a "global neuronal workspace".[23]

This is important to ensure that automatic and conscious inferences are similar enough to warrant generalizations. To the extent that both are associative transitions mediated by schemas (except for the different dynamic of activation), one can legitimately attempt to provide conscious reconstructions of automatic inferences.

A case in point is that of "conversational implicatures" in language comprehension. From Grice on, the idea that utterance comprehension is inferential is widespread: human communication is more than a simple coding-and-decoding process, it also involves production and understanding of inferences from decoded "sentence meaning" to actual "speaker meaning". On the other hand, communication is very fast and smooth, so the consensus is that communicators are not engaged in actual conscious inferencing: they need not be entirely aware of the sentence meaning, the speaker meaning, and the relation between the two. The transition is likely to occur in some more implicit form. As Grice put it:

> We have [...] a "hard way" of making inferential moves: [a] laborious, step-by-step procedure [which] consumes time and energy [...]. A substitute for the hard way, the quick way, [...] made possible by habituation and intention, is [also] available to us.[24]

As a matter of fact, rational reconstruction of implicit inferences is common practice in pragmatics. Recanati argues that this practice is justified by the fact that implicit pragmatic inferences are as such accessible to consciousness.[25] This can be disputed: for instance, Sperber and Wilson suggest that, in order for a process to be genuinely inferential, it is enough that the mental mechanisms at issue «tend to favour warranted conclusions».[26] In this case, there seems to be no commitment that rational reconstructions must, and can, make explicit the actual schemas employed by implicit inferencing. Be it as it may, the fact that a mental transition is at least accessible to consciousness seems a relevant step in the development of inferential abilities, opening the possibility for further reflective processing.

A second consideration concerns whether the distinction between automatic and conscious processing is as clear-cut as it may seem at first glance. A simple argument for a negative answer is the following: while «we live in a supraliminal world»[27] – that is, we are conscious of our cognitive life most of the time – full-fledged conscious reasoning is quite slow and effortful, which means that it cannot be our standard mode of processing. We should therefore distinguish between effortful conscious inferences on the one hand, and, on the other, largely automatic transitions where consciousness is present but plays only a marginal role.

To be fair, dual-process theorists have always been ready to accept a more complex picture than the simple automatic-conscious dichotomy. Kahneman proposes that automatic processing is always subject to lazy monitoring from consciousness in a "low-effort mode", which is quite different from fully conscious processing.[28] In the same vein Keith Stanovich, one of the first proponents of the dual-process theory, has proposed a triadic model characterized by postulation of an intermediate stage between automatic and reflective processing. He calls this stage "serial associative cognition" and describes it as a serial, conscious way of processing, which is relatively slow when compared to pure automatic processing, but – unlike actual reflective reasoning – is bound to passive acceptance of the «most easily constructed model», that is, the model provided by automatic processing.[29]

> The thinker is driven forward in his/her thinking simply by the most salient association in the current mental model being considered. At each stage in the process, the thinker does not explore all of the options. The thinking is only about the current objective that has popped into consciousness via an associative process.[30]

According to Stanovich, what is characteristic of reflective processing – that is, conscious processing at its full potential – is «decoupled cognitive simulation», a process by which we can go beyond the acceptance of «what is directly presented» and «most easily constructed» in search for alternative models of the situation.[31] This is related to another important feature: reflective processing is resistant to mind wandering,[32] which on the contrary is intrinsic to serial associative cognition.

> In serial associative cognition, models do not stay clamped long enough for all the possibilities surrounding them to be fleshed out. The thinking sequence shifts to anything that temporarily becomes focal.[33]

In sum, with regard to the possibility of automatic inferences the picture is mixed. On the one hand, given the schematic structure of information in long term memory, even automatic processing allows for inferential transitions, meaning by this transitions that are actually driven, and logically motivated, by appropriate schemas. However, those inferential transitions are part of a «spreading cascade of activation»[34] which is subject to mind wandering, as well as to any sort of automatic biases. Only in effortful reflective processing can we stick to a specific inference, carefully control it and launch a search for alternative models or counterexamples. As Stanovich puts it, «the reflective mind [...] is the mechanism that sends out a call to begin cognitive simulation or hypothetical reasoning».[35]

Well beyond the stance taken by the Taking Condition, with its focus on single inferences, these considerations provide a more complex picture of human inferential abilities – a picture involving, at the highest level, reflective vigilance over our own automatic inferences and search for alternative models (and counterexamples).

1.5 Taking stock

Let us summarize what we have found so far, with the help of *figure 1*. First of all, the figure aims to capture the idea that inferences develop along two different dimensions of variation. One is the progression of the mechanisms involved, from direct associations to reflective processing; the other concerns the more or less concrete *versus* abstract nature of the schemas involved.

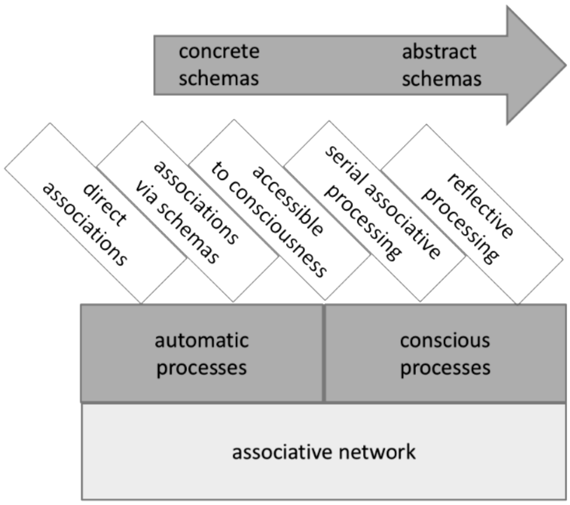

Fig. 1: *Analysis of inference: Dimensions of variation*

With regard to the mechanisms involved, we have focussed on five different steps; the first three of them in the domain of automatic processing, the final two in that of conscious processing. At the bottom of the figure, I represent the fact that both automatic and conscious processes can be accounted for in associative terms: in fact, they can be described as different dynamics of activation within associative networks (in the neuroscientific sense). At a different level, the word "associative" is often used as synonymous with "automatic" (processing). At yet another level, it has been used to refer to "mere associations", that is, associations that are not mediated by representation of the relation between associates:

here I label them "direct associations". However, since associative networks (neuroscientific sense) can encode information about relations via schemas, they can provide associations that are not "associative" in this last sense.

We are now in a position to distinguish between five uses of the term "inference". The weakest case is when transitions are based on mere direct associations. Second, associations may be mediated by schemas, even when these schemas are not accessible to consciousness (associations via schemas). Third, some schemas – and the related transitions – are actually accessible to consciousness. Fourth, there are cases in which schematic transitions not only are accessible to consciousness, but also actually gain access to working memory, although with very little conscious monitoring (serial associative processing). Finally, schematic transitions can be consciously attended to the point that the thinker can launch a search for possible counterexamples and alternative models (reflective reasoning).

2 Theories of reasoning

In the previous section, I have defended the view that inferential abilities develop with regard to both the kind of processes and the schemas involved. I have referred to this as a "development towards the prototype", since conscious transitions based on formal inference rules are considered the most typical instances of the category.

On the other hand, what is most typical in terms of exemplarity may not be typical at all in terms of distribution and frequency. As a matter of fact, in the recent past, theories of reasoning have shifted from focusing on formal rules towards pursuing more concrete, content-based approaches, according to which formal rules are not a reliable model of how we spontaneously reason most of the times.

In this section, I will first survey such a transition from formal to content-based views in the domain of conditional reasoning; then I will examine what comparative and developmental psychology have to say about how inferences develop.

2.1 Conditional reasoning

The study of conditional reasoning has long been dominated by "logicism", meaning by this (as is current in the recent debate) the thesis that reasoning is about classical logic.[36] In this view, when people reason they draw logical inferences based on formal operations – an approach that is eminently represented by Piaget. However, decades of research based on the Wason selection task have shown that logic is a poor descriptive model.

In this task there are four cards and participants are told that each card has a letter on one side and a number on the other, but they can only see one side. Then a rule of the form "if there is an X on one side, then there is a Y on the other" is provided, and the participants have to say which cards it is necessary to turn over in order to see if the rule applies. For instance, cards may show D, K, 5 and 8, and the rule may be "if there is a D on one side, then there is an 8 on the other". In this case, the correct answer is D and 5, because these are the cards that might falsify the rule. In contrast, most participants choose to turn over either the D card only, or D and 8.

When these results were first reported they came as a surprise, because they seemed to show that we are bad reasoners.[37] However, further research showed that people perform much better with other versions of the task with the same logical structure but based on concrete and (at the time) familiar correlations such as "if a letter is sealed, then it has a 5 pence stamp on it".[38] In other words, there seems to be a thematic facilitation effect, as a function of prior experience, suggesting that we are not so much bad reasoners as bad *formal* reasoners. Two other results are important in this perspective.

First, Cheng and Holyoak have observed that not only specific correlations, but entire domains of experience have facilitatory effects on conditional reasoning: specifically, there is now overwhelming evidence that this is the case with deontic logic, that is, when reasoning involves permissions and obligations.[39] Griggs and Cox have shown this effect with conditionals such as "If a person is drinking beer, then the person must be over 19".[40] Cheng and Holyoak propose that facilitation in these contexts is explained by pragmatic schemas, conceived as rules that do not apply universally but are bound instead to specific domains of experience. One possibility is that these schemas are an intermediate step towards formal rules, and that they are formed as generalizations from experience in familiar domains. This would be consistent both with the hypothesis of inferences drawn via content-specific schemas, and with the evidence of facilitatory effects due to specific correlations ("if a letter is sealed, then it has a 5 pence stamp on it"). The general idea is, again, that inferential abilities might show a developmental course from instance-based information to domain-specific pragmatic schemas to universal formal rules.

Another important discovery concerns what is called "perspective effect" in reasoning. Manktelow and Over were the first to observe that even in deontic reasoning there are differences in performance due to the different utilities associated to social roles.[41] Consider the classic example of a mother telling her son: "if you tidy your room, then you may go out to play". Clearly, the mother and the son have different desires, and therefore different utilities. As a consequence, subjects perform differently in conditional reasoning, depending on the perspective they are asked to adopt.

All these data provide convergent evidence that reasoning depends on domain-specific representations based on experience. One possible interpretation of this is in terms of Stanovich's notion of serial associative cognition. The idea is that, in appropriate settings, previous experience may enable thinkers to automatically recognize the structure of logical problems, without need for reflective reasoning. With specific regard to the Wason selection task, domain-specific information might increase one's sensitivity to relevant counterexamples to the conditional rule. For example, given the rule "If a person is drinking beer, then the person must be over 19", previous experience makes us aware that persons under 19 might drink beer, and that this would violate the rule. Experience can make us *see* – so to speak – what can go wrong with a conditional rule, in cases where permissions and obligations are at issue.[42]

Importantly, however, even in the abstract version of the Wason task there is a minority of subjects who respond correctly. Stanovich has emphasized this point, suggesting the possibility that these subjects use a different, more reflective cognitive style – possibly also due to formal training.[43]

In sum, the pattern of results in the Wason selection task suggests that spontaneous reasoning is mostly content-based and characterized by little conscious control, although some individuals might develop reflective abilities allowing them to explore alternative models and counterfactual reasoning.

The crisis of logicism, however, has a much wider scope than conditional reasoning alone. Similar problems have arisen in decision theory and theory of probability as well, a fact that has contributed to the development of alternative approaches such as dual-process theory (and its successors), and the heuristics and biases approach.

Elqayam has described the most recent situation in terms of a (further) paradigm change, whose origin may be traced back to Oaksford and Chater: a turn from logicism (or "the traditional paradigm") to a "new paradigm" (also referred to as "probabilistic", "Bayesian" or "decision-theoretic").[44] In line with our previous considerations, the key characteristics of the new paradigm are two: first, «truth and falsity no longer occupy centre stage; they are replaced by beliefs (or, more precisely, degrees of belief) expressed as probabilities»; second, «formal decision-theoretic models also take into account utility, the positive or negative value we assign to things happening in the world [...] utility is the bridge to action».[45] In practice, reasoning is now conceived as strongly dependent on content and experience: it depends, on the one hand, on probabilistic representations based on experienced regularities and, on the other, on perspectives related to action goals.

To be sure, Bayesian models are not hostile to abstraction. For instance, hierarchical Bayesian models have been proposed in order to explain how humans may perform inferences on multiple levels of abstraction,[46] while Tenenbaum and colleagues have shown how these models may simultaneously extract probabilistic hypotheses at different levels of abstraction.[47] However, in this approach formal rules are conceived as resulting from a process of progressive abstraction upon contents of experience.

2.2 Developmental and comparative psychol-ogy: The power of associative processes

If we look at the state-of-the-art in developmental psychology, the hypothesis of a developmental course of inferential abilities is confirmed. This is how Markovits summarizes the evidence:

> First, there is clear evidence that young children can make correct inferences under the right conditions. Second, there is equally clear evidence that the ability to make correct inferences increases consistently with age.[48]

This does not imply that we must attribute logical reasoning to young children: it depends on what we mean by "logical". As a matter of fact, «there are important differences in the definition of what constitutes "logical" reasoning».[49] However, this said,

> most existing theories do acknowledge developmental change. Thus, irrespective of whether logical reasoning is seen as a relatively primitive ability, or as requiring very high-level representational abilities, there is a general consensus that in the former case, reasoning abilities continue to develop, or that, in the latter case, there exist earlier forms of reasoning that precede the more complex levels.[50]

In other words, while there is consensus that the abilities at issue develop, what may be disputed is whether this is best described as a development from logical to *more* logical, or from *proto*-logical to logical reasoning.

Based on our previous considerations, my suggestion is that this depends on which criterion for logical reasoning (or inference) is used. At the lowest level, even automatic transitions mediated by conceptual schemas can be considered as logical inferences, if we are satisfied with the presence of logical structure: in our example, the spatial schema for sharks allows for transitions that can be structurally described in terms of *modus ponens*. However, we might impose more stringent requirements, such as the involvement of conscious or formal (content-independent) processing. As far as I can tell, this is just a terminological decision. What is objective is that these transitions are different from one another, and that there seems to be a developmental course between them. Crucially, this picture presupposes a clear distinction between the following three senses of "associative": (a) non-mediated by schemas, (b) automatic, and (c) implemented by associative networks (neuroscientific sense). As a matter of fact, confusion between (b) and (c) is frequent even in scholars who are sympathetic with associative accounts of cognition.

For one example from comparative psychology, in his review *Associative learning and animal cognition* Dickinson says:

> distinguishing between the behavioural predictions of cognitive (in the imperial sense) and associative accounts is not straightforward because associative theory can *mimic* rational and inference-driven explanations. The issue remains, however, of whether associative processes can not only finesse but also *implement* at least aspects of imperial cognition.[51]

Of course, it is one thing to say that associative mechanisms provide mental transitions that *mimic* conscious inferences, it is quite another to say that they *implement* those inferences. The point is, however, that the word "associative" has not the same meaning in these two cases. While in the hypothesis of mimicking the issue is whether *automatic processing* may account for results that are usually thought to require conscious processing, in the hypothesis of implementation the issue is instead whether *associative networks* may account (not only for automatic but also) for conscious processing.

As to developmental psychology, Shanks has reviewed theories of «learning: from associations to cognition» (this is the title of the paper). A summary of the state-of-the-art is the following:

> associative theory has, over the decades, often succeeded in explaining phenomena initially thought to be beyond its bounds, and there are solid reasons to believe that the same may apply to some of the findings described here.[52]

This observation concerns the fact that a growing number of behaviours are being accounted for in terms of automatic processes, instead of conscious ones. However, this is not clearly distinguished from a different issue concerning the most recent models which

> incorporate cognitive constructs such as attention and awareness while also assigning a fundamental role to association formation [...]. Such models demonstrate massive "emergentism", in that processes that seem cognitive and high level emerge from the operations and interactions of very elementary processing units. These processes yield knowledge structures and states of activation which, when sufficiently strong and stable, constitute the contents of consciousness.[53]

This idea – that the strong and stable activation of encoded patterns can account for consciousness – clearly goes in the same direction as the account provided here in section 1.4: consciousness is seen as "emerging" from the functioning of associative networks. However, we should be careful in distinguishing the fact that automatic processes are much smarter than previously thought, in that they can mimic conscious ones, and the fact that conscious processes are presumably implemented by associative networks.

In both cases, "associative" processes appear more powerful than is usually thought, but not in the same sense of the word!

2.3 The variety of associative processes

As we just saw, developmental psychology supports our claim of a developmental course of inferences. Moreover, surveys in comparative and developmental psychology show a growing appreciation both of the role of low-level automatic processes in reasoning and of the possibility that associative networks implement high-level conscious reasoning, although these issues are easily confused under the common heading of "associative processing".

In this section I want to consider a last aspect with regard to the development of inferential abilities. Until now, we have considered how basic mechanisms of associative networks allow not only for the detection of simple co-occurrences but also for the encoding of schemas representing relations between mental contents. This is important to explain how inferences modelled on *modus ponens* can occur both automatically and consciously. However, this only scratches the surface of the complexity that characterizes the basic mechanisms of associative networks. Comparative psychology, in particular, shows us a complex picture, where a variety of associative mechanisms – possibly with an evolutionary course – is at play.

The most analysed example is that of "retrospective revaluation" or "backward blocking". This is the case in which animals are first exposed to a compound stimulus S1 + S2 (for instance, both lime and orange drink), and then to S1 alone (lime drink). As a consequence of this second exposure, when the association between S1 and a certain outcome is increased the association between S2 and the same outcome is reduced (and viceversa).

Retrospective revaluation is problematic for

> classic associative theory, which assumes that learning about a stimulus can only occur when that stimulus is present.[54]

On the contrary, in our example the organism learns something about the orange drink even when it is exposed to the lime drink alone. Now,

> this form of retrospective revaluation invites an account in terms of reasoning by a disjunctive syllogism: either the lime or the orange drink is nutritious; the lime is not nutritious; therefore, the orange is nutritious.[55]

However, the currently accepted explanation is based on the low-level associative notion of mediated learning, along the lines of Holland:[56] in his proposal

> associative theory should be liberalized to allow animals to learn not only about directly perceived stimuli, but also about associatively retrieved representations.[57]

In practice, since in the first stage of the experiment S1 and S2 are associated with one another, in the second stage (when the animal is exposed to S1 alone) S2 is associatively activated, too, and this allows for learning about it, even in its absence.

This can hardly count as a case of genuine rational inferencing: as a matter of fact, it causes dumb application of disjunctive syllogisms, even in cases in which we human reasoners would easily see that it is inappropriate. Nevertheless, as Dickinson observes, «this form of learning greatly enhances the apparent inferential power of the associative system».[58]

A close consideration of the data from animal cognition suggests that there is an entire range of similar low-level mechanisms of varying complexity. Specifically, scholars have proposed a variety of associative learning mechanisms based on prediction errors, which has led to "hybrid theories" that combine those mechanisms as different stages of an evolutionary course.

> Such a hybrid account makes evolutionary sense. The ancestral form of associative learning may have been based on simple temporal contiguity between events. However, this simple system was prone to developing superstitious "beliefs" based on fortuitous event pairings. Consequently, a Rescorla-Wagner process evolved in which the fundamental contiguity process was modulated by a prediction error signal […]. This ensured that learning only occurred when the outcome was unexpected or surprising. However, even this more complex system failed to capture knowledge about the general causal structure of the environment so that natural selection led to the superimposition of a modulating system that deployed prediction errors to control associability in the way envisaged by Mackintosh.[59]

Leaving aside the details, the general message should be clear. Even limiting ourselves to low-level automatic processing, the picture is by far richer than what is assumed when inferences are contrasted with "mere associative" processes, or reasons with causes. Associations are definitely not blind statistical correlations, entirely unable to license forms of reasoning. On the contrary, within the limits of low-level automatic processing there is a variety of mechanisms that are able to mimic (with different degrees of complexity) "real" (high-level) inferences.[60]

3 Conclusions

This paper aimed to provide a framework for understanding inferences, conceived as complex entities with an evolutionary and developmental course.

Normative views of inferences, according to which these are personal-level and based on formal inference rules, have been described here as idealizations. In practice, conscious formal inferences are proposed to be the point of arrival of a developmental trajectory – a final stage characterized by a reflective style of reasoning (possibly due to logical training). Nevertheless, those inferences are usually perceived as the prototypical case, as shown by traditional views both in philosophy and psychology of reasoning.

As a matter of fact, the evidence suggests that spontaneous reasoning is most of the time content-based: it depends on (more or less) concrete schemas based on experience. And it is mostly automatic. Or, to be more precise, it is a case of serial associative processing: the inferences we make are processed moment by moment automatically, and although some of them gain access to consciousness, they are rarely subject to full conscious control – there is no search for alternatives or counterexamples.

An important feature of my view is that not only the word "inference", but also "association" is polysemic: inferences at different stages of development are associative in different senses of the word. First, direct associations are associative in the sense of non-mediated by schemas. Second, both direct associations and schematic associations can be reactivated by associative (i.e., automatic) processes. Third, even conscious processing – supporting both serial associative and reflective inferencing – can be implemented by associative networks (in the neuroscientific sense).

Finally, I showed that even low-level associative processing is much more complex and various than usually assumed. This may importantly contribute to explanation of how automatic processing can mimic (in fact, anticipate) high-level reasoning.

Notes

[1] D.T. GILBERT, *What the mind's not*, p. 3-4.
[2] Cf. K. STANOVICH, *Rationality and the reflective mind*; D. KAHNEMAN, *Thinking, fast and slow*.
[3] For example, cf. E. ROSCH, *Principles of categorization*.
[4] P. BOGHOSSIAN, *What is inference?*; S. FINN, *Limiting logical pluralism*.
[5] P. BOGHOSSIAN, *What is inference?*, p. 3.
[6] *Ibid.*, p. 5 - his emphases.
[7] *Ibidem* - his emphases.
[8] Cf. S. FINN, *Limiting logical pluralism*, cit.
[9] In the analysis proposed by Finn, another inference rule – the one known as Universal Instantiation – is basic, too. However, this is not relevant for our purposes.
[10] J.A. FODOR, *Hume variations*, p. 92.
[11] For a discussion, cf. C. BUCKNER, *Two approaches to the distinction between cognition and "mere association"*.
[12] J.A. FODOR, *The modularity of mind*, pp. 33-34.
[13] Cf. A.M. COLLINS, M.R. QUILLIAN, *Retrieval time from semantic memory*.
[14] This historical reconstruction is based on W. KINTSCH, *Comprehension: A paradigm for cognition*. The notion of schema in its modern sense was introduced by F.C. BARTLETT, *Remembering*; and it was made famous in cognitive science by U. NEISSER, *Cognitive psychology*; M. MINSKY, *A framework for representing knowledge*. For a short introduction to schemas, cf. W.F. BREWER, *Schemata*.
[15] L.W. BARSALOU, *Situated conceptualization*, p. 628.
[16] I am here representing schemas in a very rough way, with the only purpose to make their contribution to inferences explicit. We might as well adopt a different notation, as the one adopted in Generative Grammar (see next paragraph): for example, a simplified schema for sentences would have the form "S → NP – VP", which means "the constituents of a sentence are a nominal phrase followed by a verbal phrase". In this notation, the arrow has not the meaning of logical implication; it tells us instead that the category on the left of it can be expanded into the components on the right. An advantage of this notation is that all components are located on the right of the arrow, which helps to make clear that any of them can be equivalently inferred from any other (given the rule S → NP – VP, you can both infer NP from the presence of VP and VP from the presence of NP). On the contrary, in the above notation (component A; schema A → B, C, D, etc.; inferred components B, C, D, etc.) one component (A) is arbitrarily represented as the one from which others can be inferred.
[17] R. JACKENDOFF *A parallel architecture perspective on language processing*, p. 8.
[18] I leave aside for the moment the fact that, in prototypical inferences, acceptance and application of inference rules are conscious. I will address this issue in the next section.
[19] Cf. S. DEHAENE, *The number sense: How the mind creates mathematics*.
[20] Cf. S. FINN, *Limiting logical pluralism*.
[21] Evidence in favour of this model is surveyed by S. DEHAENE, *Consciousness and the brain. Deciphering how the brain codes our thoughts*.
[22] Cf., for instance, M. SHANAHAN, B. BAARS, *Applying global workspace theory to the frame problem*.
[23] Cf. S. DEHAENE, *Consciousness and the brain*; S. DEHAENE, J.P. CHANGEOUX, L. NACCACHE, J. SACKUR, C. SERGENT, *Conscious, preconscious, and subliminal processing: A testable taxonomy*.
[24] H.P. GRICE, *Aspects of reason*, p. 17.
[25] Cf. F. RECANATI, *Literal meaning*.
[26] D. SPERBER, D. WILSON, *Beyond speaker's meaning*, p. 137.
[27] A.B. SATPUTE, M.D. LIEBERMAN, *Integrating automatic and controlled processing into neurocognitive models of social cognition*, p. 91.
[28] Cf. D. KAHNEMAN, *Thinking, fast and slow*, p. 24
[29] Cf. K. STANOVICH, *Rationality and the reflective mind*, p. 67.
[30] *Ibid.*, p. 69.
[31] *Ibid.*, p. 67.
[32] For a similar insistence on the claim that consciousness is in the service of stability and persistence – more than flexibility – in processing, see also B. HOMMEL, *Between persistence and flexibility: The Yin and Yang of action control*.
[33] K. STANOVIC, *Rationality and the reflective mind*, p. 69.
[34] D. KAHNEMAN, *Thinking, fast and slow*, p. 97.
[35] K. STANOVIC, *Rationality and the reflective mind*, p. 48.
[36] Cf. S. ELQAYAM, *The new paradigm in psychology of reasoning*.
[37] Cf. P.N. JOHNSON-LAIRD, J. TAGART, *How implication is understood*.
[38] Cf. P.C. WASON, D. SHAPIRO, *Natural and contrived experience in a reasoning problem*; P.N. JOHNSON-LAIRD, P. LEGRENZI, M.S. LEGRENZI, *Reasoning and a sense of reality*.
[39] Cf. P.W. CHENG, K.J. HOLYOAK, *Pragmatic reasoning schemas*.
[40] Cf. R.A. GRIGGS, J.R. COX, *The elusive thematic-materials effect in Wason's selection task*.
[41] Cf. K.I. MANKTELOW, D.E. OVER, *Social roles and utilities in reasoning with deontic conditionals*.
[42] Sensitivity to counterexamples is crucial to the Wason task, since this requires the application of *modus tollens* (from premises "A → B" and "not B", one can draw the conclusion "not A"). According to a standard interpretation of the Wason task, the pattern of errors is explained by the "confirmation bias", that is, a tendency to look for cases that confirm the conditional rule (cases where *modus ponens* apply), instead of cases that may falsify it (counterexamples in which it is the case that "not B", and nevertheless "A").
[43] Cf. K. STANOVICH, *Rationality and the reflective mind*.
[44] Cf. S. ELQAYAM, *The new paradigm in psychology of reasoning*, p. 130; M. OAKSFORD, N. CHATER, *A rational analysis of the selection task as optimal data selection*.
[45] S. ELQAYAM, *The new paradigm in psychology of reasoning*, cit., p. 131.
[46] Cf. T.L. GRIFFITHS, N. CHATER, C. KEMP, A. PERFORS, J.B. TENENBAUM, *Probabilistic models of cognition: Exploring representations and inductive biases*, p. 361.
[47] Cf. J.B. TENENBAUM, C. KEMP, T.L. GRIFFITHS, N.D. GOODMAN, *How to grow a mind: Statistics, structure, and abstraction*.
[48] H. MARKOVITS, *The development of logical reasoning*, p.

394. Incidentally, the content-based, context-dependent nature of reasoning is acknowledged as well, since the quotation continues as follows: «Third, there are inferential systems tied to social reasoning that allow some intuitive forms of inference that can generate logically appropriate responses in appropriate contexts» (*ibidem*).

[49] H. MARKOVITS, *The development of logical reasoning*, cit., p. 394.

[50] *Ibidem*.

[51] A. DICKINSON, *Associative learning and animal cognition*, p. 2738, my emphases.

[52] D.R. SHANKS, *Learning: From association to cognition*, p. 285.

[53] *Ibidem*.

[54] A. DICKINSON, *Associative learning and animal cognition*, p. 2734.

[55] *Ibid.*, p. 2735.

[56] Cf. P.C. HOLLAND, *Event representations in Pavlovian conditioning: Image and action*.

[57] A. DICKINSON, *Associative learning and animal cognition*, p. 2735.

[58] *Ibidem*.

[59] *Ibid.*, p. 2737.

[60] Just to give a hint of the computational complexity of associative networks, we should consider that there is much more than Hebb's rule in their functioning. According to Hebb, the general law of neuronal associations is a direct relation between co-occurrence of stimuli and co-occurrence of neurons (or neurons assemblies), as in Fodor's quotation above: neurons that are repeatedly activated together by stimuli strengthen their reciprocal connection. Within the limits of Hebbian associations, schemas might nevertheless be accounted for as hierarchical patterns, that is, assemblies of assemblies. However, now we know that there are also anti-Hebbian associations, where the associative relation (between co-occurrence of stimuli and co-occurrence of neurons) is not direct but inverse. This allows for a second mechanism besides Long Term Potentiation, which is called Long Term Depression and operate in the opposite direction. Moreover, these two mechanisms may combine together, as in spike-timing-dependent-plasticity where the deployment of a Hebbian/anti-Hebbian switch is thought to account for the capacity to represent causal relationships between events (cf. A. PLEBE, M. MAZZONE, *Neural plasticity and concepts ontogeny*, p. 3899).

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