Structural priming to study scopal representations and operations

Emmanuel Chemla (LSCP, CNRS) and Lewis Bott (Cardiff University)

Squib to appear in *Linguistic Inquiry*

Abstract

Sentences can be ambiguous with respect to which expressions “take scope” over others. For example, *Every student read a book* can be understood as meaning that all students read a (possibly different) book or that there is a single book read by all students. Previous work by Raffray and Pickering (2010) has shown that if people are exposed to one of the two interpretations, they can be *primed* to interpret subsequent scopally ambiguous sentences with that same interpretation. This could be seen as evidence for a Logical Form representation capturing scopal properties or as evidence for a scope reversal operation, whose application could be facilitated by a previous application (c.f. Quantifier Raising). We discuss the usefulness of such simple priming studies in linguistics. Based on the scope ambiguity example, we show that priming of representation and priming of operation can be distinguished. In an experiment testing the relevant predictions for our test case, we obtain that (1) priming is based not on operations but on representations, but (2) the relevant level of representation encodes only scopal relations between specific quantified expressions.

1. Introduction: representations and priming, the case of scopal relations

1.1. Scopal relations and representations

Sentence (1) contains a universal quantifier *every* and an indefinite, existential quantifier *a*. Depending on which of these two elements takes scope over the other, we obtain two possible interpretations, as paraphrased unambiguously in (2).

(1) Every student read a book.

(2) a. *Universal-wide scope interpretation:*
For every student *s*, there is a book *b(s)* that *s* read.

b. *Universal-narrow scope interpretation:*
There is a book *b*, such that every student read *b*.

The universal interpretation in (2)a is *surface scope:* the scopal relation between the universal quantifier *every* and the existential quantifier *a* matches the order and hierarchy in which they appear in (1). The interpretation in (2)b is *reverse scope*: the scopal relation is reversed between the sentence and the interpretive level.

Our point of departure is an interesting finding by Raffray and Pickering (2010), who demonstrated that people can be *primed* to derive particular scopal interpretations (see details below). In this paper we emphasize that such priming results are useful to either characterize realistic layers of linguistic representations or to confirm the existence of linguistic operations of certain kinds. We do so by discussing two possible interpretations of Raffray and Pickering’s results and testing between them in an experiment.

1.2. Layers of representations and priming

Raffray and Pickering’s (2010) study involved a structural priming paradigm (e.g., Bock, 1986; Branigan, Pickering & McLean, 2005; Pickering & Branigan, 1998; Thothathiri & Snedeker, 2008; for a review see Pickering & Ferreira, 2008). Participants completed a sentence-picture verification task that involved matching one of two pictures to a scopally ambiguous sentence, such as (1). There were prime trials and probe trials. In prime trials, participants were forced to interpret the sentence with universal wide-scope (or universal narrow-scope) by the nature of the target picture, which contained a wide-scope image (or a narrow-scope image), and the foil picture, which contained an image that was inconsistent with the sentence. In the probe trials, which immediately followed prime trials, one of the pictures corresponded to the universal wide-scope interpretation of the sentence and the other to the universal narrow-scope interpretation. Participants were therefore "free" to choose either interpretation in the probe trials. Across two experiments, Raffray and Pickering found that participants were more likely to select the picture matching the wide-scope interpretation following a wide-scope prime trial than after a narrow-scope prime trial. In other words, participants were primed to derive sentence interpretations with particular scopal relations. From these results they concluded that participants formed disambiguated abstract representations that specify quantifier-scope relations.

Concretely, the claim is that there exists a level of representation which looks like the following semi-abstract patterns for the two possible interpretations of (1):

(3) Representations underlying the two interpretations:
  a. *Universal-wide representation:* **Every** … is such that there is **a**…
  b. *Universal-narrow representation:* There is **a** … such that for **every** …

These representations abstract away from some information, e.g., the content of the lexical material filling in the … parts. If these representations exist, we can understand why the activation of one of these patterns for a given sentence (the prime) can strengthen the activation of the same pattern for a subsequent sentence.

1.3. Linguistic operations and priming

Priming effects can reveal a level of representation at which prime and probe are made equivalent, as discussed above. But they can also be evidence for the existence of some operation that applies equally to the prime and probe. In our concrete case, there might be an operation that transforms an interpretation of the (a) type, into an interpretation of the (b) type. This operation would correspond to a scope reversing operation, call it O_{SR}. (An alternative plausible candidate for such an operation when indefinites are involved would be a domain narrowing operation, we come back to this in the discussion section). Such O_{SR} operations would traditionally fall under the label of "movement" operations in the syntactic literature (e.g., Quantifier Raising, see e.g., Fox 2000). Formal and experimental results argue for the existence of such operations. For instance, developmental inquiries show that children under a certain age mostly access surface scope interpretations for a variety of configurations and only later the whole set of their corresponding reverse scope interpretations. This suggests that scope reversal is indeed a single piece in the system, a coherent operation that kids do not use early on but then, in one step, they master it across the board (see, e.g., Conroy, Lidz & Musolino 2009 for more detailed discussion).

In terms of this O_{SR} operation, the (a) interpretation would follow from a representation at which hierarchical order and linear order have been aligned. The O_{SR} operation could apply to this representation and reverse the scopal relations. In representational terms, we obtain: (b) = O_{SR}(a).

We can now describe an alternative interpretation of the priming effects we discussed, as evidence for this O_{SR} operation. Indeed, if the application O_{SR} has been applied once to the prime, it may apply again to the probe, more so than if the operation was not applied to the prime. Hence, we see that priming results may be seen as evidence for layers of representation (section 1.2) or for linguistic operations involved in these representations (the current section 1.3).

1.4. Distinguishing representations and operations

We will provide new evidence in favor of the linguistic layer interpretation, which was Raffray and Pickering's (2010) original interpretation of their data and which may not be the most naturally available from a linguistic standpoint. Our strategy will be to study priming effects between sentences of different profiles. Specifically, we will study sentences such as (4).

(4) A student read every book.
(in our experiment: "There is a star above every heart", see discussion below)

(5) a. *Universal-wide scope interpretation:*
For every book *b*, there is a student *s(b)* that read *b*.
b. *Universal-narrow scope interpretation:*
There is a student *s,* such that every book was read by *s*.

Such sentences have the same two types of interpretations as our original example (1), the universal-wide interpretation and the universal-narrow interpretation. Crucially, however, the order of the quantifiers are reversed in the sentence: the indefinite *a* now occurs before the universal quantifier *every*. Hence, the two interpretations are obtained differently in (1) and (4) in terms of the O_{SR} operation. Specifically, the O_{SR} operation is involved to obtain the existential interpretation in the case of (1) and the universal interpretation in the case of (4). Hence, the surface scope interpretation of one sentence is the reverse scope interpretation of the other.

If the interpretation account is correct, then we should find priming of interpretation across sentence of types (1) and (4): the universal interpretation of one should prime the universal interpretation of the other. If the operation account is correct, then we should find the opposite type of priming across these sentence types, such that the surface scope of one primes the surface scope of the other, i.e. a universal-wide interpretation of one sentence primes a universal-narrow interpretation of the other.[1]

1.5. Extension of the prediction

The operation interpretation based on O_{SR} makes broader predictions. First, priming may occur across sentences using completely different pairs of quantifiers: sentences of the form Q1 V Q2 and Q3 V Q4 (where Q1, Q2, Q3 and Q4 are quantified DPs involving four different quantifiers) could prime each other's surface and reverse interpretations, even though their impoverished representations as in (3) have nothing relevant in common. Second, radically different types of sentences require scope resolutions which may involve the O_{SR} operation. For instance, negation may interact with a quantifier in roughly the same way in which two quantifiers (*every* and *a*) may

[1] We note that Raffray and Pickering (2010) tested whether sentences like (4) primed sentences like (1) (Experiment 3), just as we present in this paper. They reported that there was no significant priming effect, and that across experiments, priming was significantly greater within sentences like (1) than between sentences like (1) and (4). They further argued that this provided evidence against a straightforward representational account such as that which we suggest above. To foreshadow our findings, we find significant priming effects involving sentences like (4), in contrast to Raffray & Pickering, Experiment 3. We discuss the difference further in the General Discussion.

interact. Consider sentence (6), which may receive the two interpretations paraphrased in (7) depending on whether negation takes scope over or below the universal quantifier *every*.

(6) Every square is not red.
(7) a. Every square is of a color that is not red = No square is red.
    b. Not every square is red (some may be red).

Descriptively, one may recognize a surface scope interpretation and a reverse scope interpretation, obtained by way of an operation that could have a lot in common with the O_{SR} operation. If this is correct and if Raffray and Pickering's (2010) priming effect is of the second type (priming of operation), then we predict priming to occur within negative sentences such as (6) and between sentences of this type and those with two quantifiers, such as (1). If the priming effect is based on interpretation and representations of the type in (3), then no such priming is expected.[2]

2. Experiment

Our experiment tests whether scopal priming occurs because a representation is primed or because an operation is primed. Participants completed a sentence-picture verification task, similar to Raffray and Pickering (2010). Each trial consisted of a sentence and two pictures, and participants clicked on the picture that best matched the meaning of the sentence. The experimental trials all involved scopally ambiguous sentences. There were *prime* trials, in which the pictures dictated that only one meaning was acceptable, and *probe* trials, in which either meaning was acceptable (see Figure 1). Following Raffray and Pickering, we expected that the (forced) meaning of the sentence in the prime trials would influence the (free) meaning of the sentence in the probe trials. Sentences could either share the same abstract interpretation (e.g., universal-wide scope) across trials, or the presence of the O_{SR} operation (e.g., reverse scope). Of interest was whether scope operation or interpretation would predict priming direction.

We used three types of configurations (sentences): *Universal-Existential* (U-E), as in (1); *Existential-Universal* (E-U), as in (4); and *Universal-Negation* (U-neg), as in (6). Each configuration could result in two interpretations: the *universal-wide* (U-wide) interpretation, as described in the a) examples of (2), (5) and (7), or as universal-narrow (U-narrow), as in the corresponding b) examples (see the Interpretation column of Table 1). The interpretations could also be classified with respect to the direction of the scopal relation, *surface scope* or *reverse scope*; but, crucially, the mapping between interpretation and the presence of a scope operation needed to obtain reverse scope varied across sentences (see the Operation column in Table 1). The dissociation between interpretation and operation meant that the priming accounts could be differentiated.

Priming was tested between all configurations. Thus, there were *within-configuration trials*, in which prime-probe pairs used the same configuration (e.g., E-U primes followed by E-U probes), and *between-configuration trials*, in which prime-probe pairs used different configurations (e.g., E-U primes followed by U-Neg probes). For within-configuration trials, the interpretation and operation accounts make the same predictions. For between-configuration U-E/E-U trials, however, the

[2] If the scopal operation at stake with negation is different than the one for quantifiers, we also expect no priming for these sentences.

interpretation and operation accounts make different predictions. The interpretation account predicts that between-configuration priming will show U-wide primes leading to U-wide responses, whereas the operator account predicts that U-wide primes should lead to U-narrow responses. Predictions for U-neg sentences can be extracted from Table 1.

<u>Table 1.</u> Experimental sentences with the correspondence between interpretation and operation oriented descriptions
The Interpretation column lists interpretations of each configuration and the Operation column describes the relation of this interpretation with the linear order of the words in the sentence, an operation being needed in reverse scope *configurations. Note that the U-wide and U-narrow interpretations are different for U-neg sentences than for the two-quantifier configurations. This is because the universal quantifier interacts with negation and not with an existential quantifier, as it does for U-E and E-U configurations.*

Label	Example	Interpretation	Operation
U-E	*Every club is above a heart*	U-wide U-narrow	Surface Reverse
E-U	*There is a club above every heart*	U-wide U-narrow	Reverse Surface
U-Neg	*Every heart is not red*	U-wide U-narrow	Surface Reverse

<u>2.1. Participants</u>

Eighty participants were recruited online using Amazon Turk. Two participants were removed because their native language was not English, and a further five were removed because their accuracy on the prime sentences was less than 90%.

<u>2.2. Materials</u>

Sentences. Experimental sentences were constructed according to one of three frames.

- For U-E sentences: Every [Shape 1] is [*above*/*below*] a [Shape 2]
- For E-U sentences: There is a [Shape 1] [*above*/*below*] every [Shape 2]
- For U-neg sentences: Every [Shape 1] is not [Color]

An important remark is in order. The E-U sentences used an expletive construction instead of a plain indefinites, which are degraded in subject position (see discussion and corpus studies in Michaelis & Hartwell, 2007 and references therein). One may worry that this could block the possibility of a reverse scope interpretation, no matter how it comes about, but jumping ahead a bit, Table 2 shows that even though there is a bias towards a U-narrow reading, our participants also accessed the U-wide reading, which thus leaves room for us to investigate possible priming effects.[3]

Shapes were hearts, squares, dots, triangles, stars or notes, and colors were black, blue, green, or red. Examples are shown in Figure 1. The list of stimuli was obtained by inserting colors, shapes, “above”/“below” randomly into the appropriate sentence frame. This meant different primes had different combinations of shapes/colors. However, there was only a single list of stimuli used for all participants.

[3] Thanks to reviewers for *Linguistic Inquiry* for prompting us to put this information back in focus.

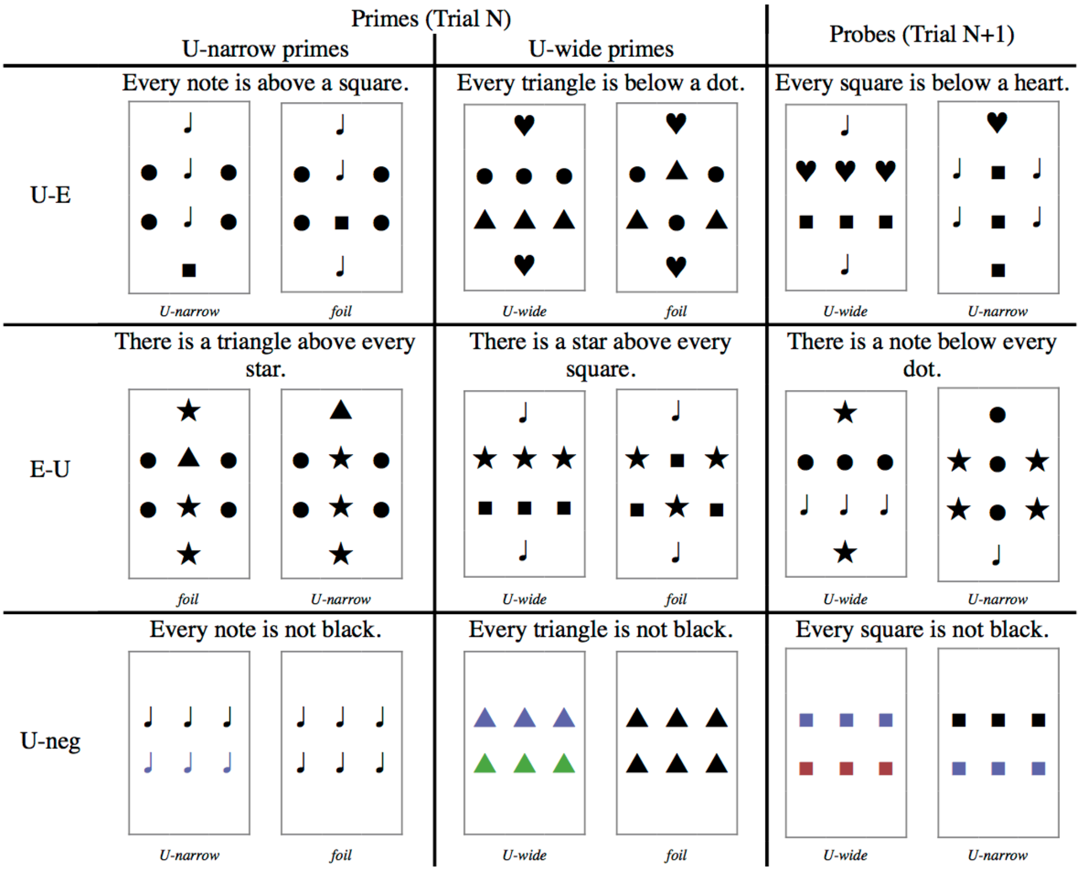
Table 2. Counts of responses to probes.

wide *and* narrow *refer to U-wide and U-narrow respectively. Pairs of numbers correspond to responses for a given condition. For example, in the U-E wide -> E-U condition, 231 responses were U-wide and 56 were U-narrow.*

			Probes					
			U-E		E-U		U-neg	
			wide	narrow	wide	narrow	wide	narrow
Primes	U-E	wide	203	83	231	56	251	39
		narrow	185	98	214	70	246	41
	E-U	wide	212	79	228	61	247	43
		narrow	183	108	204	83	252	40
	U-neg	wide	199	90	227	63	244	39
		narrow	193	92	213	74	238	47

Figure 1. Examples of prime trials and probe trials.

Sentence configurations are shown in rows. Each cell in the table represents a single trial. Participants read the sentence and selected one of two pictures that best matched the meaning. Each prime-probe trial pair involved either a U-wide or a U-narrow prime, followed by a probe trial. In prime trials, only one of the two pictures was consistent with the sentence, whereas in probe trials both were consistent (possible interpretations are indicated below each picture). Prime-probe pairs could be formed by using probes of the same type as the primes (the same row in the table) or a different type (a different row).



Images. For each sentence, we constructed three types of images: a foil F consistent with none of the interpretations, a target image T1 consistent only with the first interpretation and a target image T2 consistent only with the second interpretation.[4] Each trial consisted of a sentence and two of its three associated images as follows:

- Prime trials paired a sentence with its foil image F and one of the target images. The choice of the target image T1 or T2 thus forced one of the two interpretations.
- Probe trials were obtained by pairing a sentence with its two target images T1 and T2. The interpretation was thus left open and the choice between T1 and T2 would determine which of the two interpretations was favored by the participant.

Control trials. We included control trials using the same sentence frame, "Every [shape] is [color]" with one out of the two images making the sentence true.

2.3. Design

Primes and probes formed pairs of experimental trials. Prime trials were formed from one of the three sentence configurations and expressed as one of two interpretations (U-wide or U-narrow). Probe trials were one of 3 configurations. A complete experimental set therefore consisted of (3×2)×3 = 18 prime-probe pairs. We counter-balanced the position of the target image for the prime trials (left or right) and whether the target probe response was on the same side as the target prime response to obtain 4 replications of 18 experimental pairs = 72 pairs. There were also 32 control trials, making the total number of trials 72×2+32=176. Experimental pairs and control trials were presented in a different random order for each participant.

2.4. Results

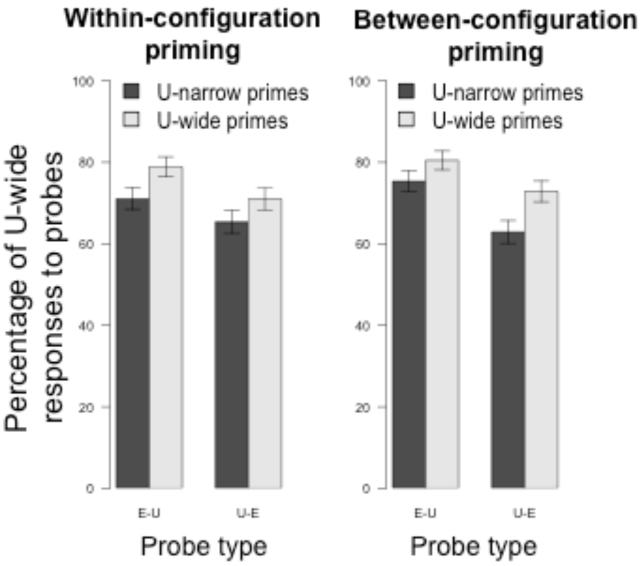
We analyzed our data by modeling response-type likelihood using logit mixed-effect models (Jaeger, 2008). The random effects structure was maximal in the sense recommended by Barr, Levy, Scheepers & Tily (2013), that is, random intercepts and slopes were included for all repeated measures factors (all factors where subjects were random effects) but only intercepts were included for between-element factors (where items were used as a random effects). In addition to the factors reported for the individual analyses below, we included prime-probe position consistency as a fixed factor, that is, whether the correct response to the prime was on the same side as the subsequent probe[5]. We report *p*-values derived from χ^2 likelihood ratio test comparing the more complex models to simpler models, and the Wald Z *p*-values resulting from the best-fitting model. Treatment coding was used throughout.

Trials with incorrect responses to the primes were discarded, as in Raffray and Pickering (2010), and also extremely rare (E-U primes: 1.3%; U-E primes: 1.4%; U-neg primes: 1.4%). Control trials were answered accurately (2.7% error rate) and were also discarded.

[4] The two interpretations stand in an entailment relation but see Footnote 8.

[5] The probe position effect was never significant but its inclusion nonetheless reduced residual variability.

Figure 2. Within and between configuration probe responses.



E-U & U-E responses – within configuration priming
Consider first the results from the E-U and U-E sentences (those tested by Raffray & Pickering, 2010). The left panel of Figure 2 illustrates responses when primes and probes involved the same configuration, that is, within-configuration trials (E-U -> E-U and U-E -> U-E trials; raw counts are shown in Table 2). When the probe is preceded by a U-Wide prime, there are more U-wide responses to the probes, regardless of the probe type. Both the operation and the interpretation accounts predict this pattern. Model analyses involving prime interpretation (U-wide vs U-narrow) and probe type (E-U vs U-E) revealed a significant effect of prime interpretation (see Table 3 at the end of the document), $\chi^2(1) = 6.51$, $p = .010$, but no interaction, $\chi^2 = 1.82$, $p = .18$. Simple effects revealed that for E-U sentences there was a robust priming effect, $\chi^2(1) = 6.79$, $p = .019$, but not for U-E sentences, $\chi^2(1) < 1$. Thus, while the priming effects we observe seem weaker than those of Raffray and Pickering, we obtain substantial within-configuration priming with the same sorts of sentences.

E-U & U-E responses – between configuration priming
When primes and probes involve different configurations, the interpretation and operation accounts make different predictions. The interpretation account predicts that between-configuration priming will show similar effects to the within-configuration sentences, but the operation account predicts priming for the E-U sentences will occur in the opposite direction to priming for the U-E sentences. The right panel of Figure 2 shows the between-configuration U-E and E-U probe responses. We observe substantial priming effects for these sentences, consistent with an interpretation account. More specifically, there was a main effect of the prime interpretation (U-wide vs. U-narrow), $\chi^2 = 11.97$, $p < .001$, and no interaction between the probe type (E-U vs. U-E) and the prime interpretation, $\chi^2 < 1$. Simple effects analysis reveal prime interpretation had a significant effect when the prime was E-U, $\chi^2(1) = 5.38$, $p = .020$, and when it was U-E, $\chi^2(1) = 9.38$, $p =. 0022$. It is also possible to encode the prime interpretation as surface or reverse scope (see Table 1), in which case reverse scope priming leads to greater U-wide responses for the U-E sentences but fewer U-wide responses for the E-U sentences, i.e., an interaction, $\chi^2(1) = 13.19$, $p < .001$.

Both analyses indicate that interpretation is a good predictor of priming whereas order is a bad predictor.[6]

U-neg sentences
There was no significant effect of any of the prime sentences on the U-neg sentences, regardless of whether the prime types were considered separately, U-neg -> U-neg, $\chi^2(1) < 1$, E-U -> U-neg, $\chi^2(1) = 1.50$, $p = .22$, or U-E -> U-neg, $\chi^2(1) < 1$, or combined, with prime interpretation (U-wide vs U-narrow) and prime type (U-neg, E-U, U-E) as factors, $\chi^2(2) < 1$, nor did the U-neg sentences prime either U-E or E-U probes, $\chi^2(1)$'s < 1. Although these results are consistent with an interpretation account, the lack of within-configuration priming makes the lack of between-configuration priming difficult to interpret, as we discuss below.

3. General Discussion

The interpretation of scopally ambiguous sentences can be primed. Our experiment pitted priming of representations against priming of a scopal "movement" operation. We found evidence for the former, representation-based priming. (There may still exist the latter, operation-based type of priming but it is at best hidden by the former).

Before diving into discussing their implication, we would like to discuss the possibility that our findings could be driven by mere "visual priming" between images. In essence, one may wonder whether participants are not recognizing patterns in the images, such that after having clicked on a U-wide picture, e.g., they would be attracted by a U-wide picture again (e.g., because they both embed two recognizable rows of three identical objects). In some of its variants, this explanation is hard to distinguish from priming at the semantic level, for the attraction of a particular pattern in an image, is very close at least extensively to attraction for a particular meaning (i.e. possibly a mere description of a visual pattern). There may be ways to disentangle the two possibilities however. One would be to make the images so that the U-wide "pattern" is hidden as much as possible, but that is a matter of subjective appreciation of salience (note that the relevant pattern has to remain visible, for otherwise, by definition, it would not be possible to evaluate whether the corresponding interpretation (=description of the pattern) is true). Raffray and Pickering's (2010) obtain similar results as ours and yet their images were different than ours, in such a way that the pattern being tracked would have to be rather abstract to account for the whole dataset. An alternative control for visual priming may consist in maintaining the same images, but to alter the sentences in such a way that linguistic elements could not contribute to any observed priming effect. For example, removing the scopally ambiguous quantifiers in the prime sentence and replacing these with generic expressions, such as, "There are triangles below the dots." The absence of significant priming when there was no sentence similarity would indicate that priming effects were not due to visual priming. Indeed, Raffray and Pickering, Experiment 4, conducted just such a study and did not observe

[6] It is also possible to compare the within-expression priming effect with the between-configuration priming effect. This is similar to the significant cross-experimental interaction obtained by Raffray and Pickering (2010; Experiment 3). Unlike Raffray and Pickering, however, we did not observe significantly greater within-expression priming than between expression priming, $\chi^2(1) < 1$, likely because we observed significant between-configuration priming in the same direction as the within-configuration priming effect, whereas Raffray and Pickering did not.

significant priming. In so far as our study is similar to theirs, we would expect that our effects were also not caused by visual priming.

Our results surprisingly confirm Raffray and Pickering's (2010) original interpretation in terms of the existence of a certain level of semantic representation. This level of representation is impoverished. It seems to crucially concern scope taking elements such as universal and existential quantifiers, to the exclusion of content words (even the distinction between close class words such as *above* and *below*[7]), and other scope taking elements such as negation. Impoverished levels of representations had also been motivated on completely independent grounds, e.g., by Gajewski (2002, 2009) or Fox and Hackl (2006), to separate mere tautologies or contradictions from plain grammatical violations. In the future, it would be interesting to evaluate how the two notions can be compared and how the two enterprises can inform each other.

While we find general support for Raffray and Pickering's (2010) representational priming hypothesis, rather than an operational priming account, our conclusions differ with respect to the exact form of primed representation. Raffray and Pickering tested whether sentences similar to those in (4) primed sentences like (1), just as we have done here (see Footnote 1), but they did not observe between-configuration priming (whereas we did). They thus concluded that comprehenders tended to repeat scope assignment to quantified thematic roles, rather than the more straightforward representation we describe in (3) and in the paragraph above (something like the *quantifier-order account* referred to by Raffray and Pickering). There are many methodological differences between our study and theirs, such as the inclusion of U-neg sentences in our study and the format of the pictures, and we cannot identify which of these is responsible for the difference in results, or indeed whether Raffray and Pickering simply observed a Type II error. Future studies may be able to isolate the deciding factor. We feel the important distinction, however, is not between different forms of representational priming, but between representational and operational priming, which has been the focus of this study and in which there is no conflict between our conclusions.

At this point one may wonder about the status of the U-neg sentences, for which we failed to find priming altogether. Two broad explanations can be considered. First, that we failed to find priming because of some aspect of the design, such as our choice of stimuli. For instance, a reviewer mentioned that these sentences were signaled by the presence of colors in our material, such that participants could be guided by these colors to detect the conditions they would be seeing and therefore rely on a shallow processing of these sentences which would not reach the level of representation or processing required to trigger priming. If this is the explanation then further studies may be more successful in obtaining these effects. Second, U-neg sentences might resist priming in a more fundamental way. Possibly the general difficulty people have with negative operators (e.g., Clark & Chase, 1972) means that

[7] When we analyzed the between expression results with predicate as a fixed factor we found a significant effect of prime interpretation, $\chi^2 = 10.63$, $p = .0011$, consistent with the analysis above, and no effect of predicate (same vs. different), $\chi^2 < 1$, nor any significant higher order effects involving predicate, $\chi^2 < 1$. This analysis suggests that the preposition is not represented at the layer of representation that is responsible for the priming effect we observe and at the same time argues against a visual priming account of our effect.

the scope representation quickly becomes deactivated across trials. Our data cannot distinguish between these possibilities, but interestingly, evidence from the developmental literature suggests that negative scope ambiguities can indeed be primed under the right circumstances, suggesting the former explanation. Viau et al. (2010) showed that the U-narrow interpretation of U-neg sentences could be primed with children using a different, unambiguous sentence (which would amount to "Not every triangle is blue"). Although this is a different type of priming, with a different population, it is compatible with the view that U-neg priming operates at an impoverished level of semantic representation.

A strong interpretation of the U-neg findings may also be useful in eliminating a potential source of the priming effect: The two possible interpretations stand in an entailment relation,[8] and this could drive the priming effects: a weak interpretation may prime a weak interpretation. This could be understood as a bias towards charitability: attributing a weak reading to a sentence is a way to be "charitable" by maximizing the chances to make it true, and in an experimental setting as this one, biasing towards charitability may induce strategical behaviors which may be confounded with priming effects. This explanation would predict priming within and from U-neg sentences as well, which we did not find. However, this argument is based on the interpretation of a null-result, which may be explained in several other ways, as we discussed above. All in all, further priming investigations of how linguistic elements beyond quantifiers interact would be of interest not only to address this methodological issue, but also to evaluate whether or not similar scopal mechanisms apply to different kinds of scopal elements.

Our results situate priming effects at a semantic level, at which some elements are interpreted (the distinction between universal vs existential quantifiers is made) and at which other linguistic elements are ignored. For future research, however, it would be interesting to evaluate whether other *kinds* of scopal mechanisms could explain the current results. For instance, one may consider that narrowing the domain down to a singleton may be the source of wide-scope interpretation of indefinites (see Schwarzschild, 2002), such that it is narrowing down of the domain that is primed, rather than the interpretation it leads to (thanks to Klaus Abels and Philippe Schlenker for discussion). To understand more, we would need to gather more information. For instance, one may ask whether priming is tied to the presence of an indefinite or some other element that plays a crucial role in the various competing approaches of quantifier scope taking. More generally, one could test priming across sentences involving different pairs of quantifiers altogether, so that the possible interpretations are not comparable at any level. Priming may disappear, or priming of scope operations may then become detectable.

---

[8] This logical relation holds at the level of literal meaning. However, it is broken when further considerations are taken into account. In particular, the wide interpretation may come with an additional inference to the effect that the narrow interpretation is not compatible with it. The enriched wide interpretation would thus be: *For every student, there is a book that this student read, <u>and not all students have read the **same** book</u>*. This enrichment may arise systematically if the two interpretations of the sentence are in competition: the weaker interpretation will naturally come with the inference that the stronger interpretation is unwarranted (see Mayr & Spector, 2012, for much deeper discussion, whose theories of available readings crucially rely on the logical relations between surface and reverse scope interpretations).
Note that breaking the entailment pattern is what allowed us to construct pictures that unambiguously correspond to one or the other of the interpretations.

Acknowledgments
We thank Isabelle Dautriche, Danny Fox, Julien Musolino, Philippe Schlenker, Benjamin Spector, Lyn Tieu and the editors and reviewers for *Linguistic Inquiry* for critical comments and discussions. The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013) / ERC Grant Agreement n.313610 and was supported by ANR-10-IDEX-0001-02 PSL* and ANR-10-LABX-0087 IEC.

References

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language, 68*(3), 255-278.

Bock, J. K. (1986). Meaning, sound, and syntax - lexical priming in sentence production. *Journal of Experimental Psychology: Learning Memory and Cognition, 12*(4), 575-586. doi: Doi 10.1037//0278-7393.12.4.575

Branigan, H. P., Pickering, M. J., & Cleland, A. A. (2000). Syntactic co-ordination in dialogue. *Cognition, 75*(2), B13-B25.

Branigan, H. P., Pickering, M. J., & McLean, J. F. (2005). Priming prepositional-phrase attachment during comprehension. *Journal of Experimental Psychology: Learning Memory and Cognition, 31*(3), 468-481. doi: Doi 10.1037/0278-7393.31.3.468

Conroy, A., Lidz, J. and Musolino, J. (2009). The fleeting isomorphism effect. Language Acquisition,16:2,106-117. doi: Doi 10.1080/10489220902769242

Clark, H. H., & Chase, W. G. (1972). On the process of comparing sentences against pictures. *Cognitive Psychology*, 3, 472–517.

Fox, D. (2000). Economy and semantic interpretation. Cambridge, Massachusetts: MIT Press.

Fox, D., & Hackl, M. (2006). The universal density of measurement. *Linguistics and Philosophy*, *29*(5), 537-586.

Gajewski, J. (2002). On Analyticity in Natural Language. Ms. MIT.

Gajewski, J. (2009). L-triviality and Grammar. Ms. UConn.

Jaeger, T.F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language*, 59, 434–446.

Mayr, C. & Spector, B. (2013) Generalized Scope Economy - Not Too Strong! Under review.

Michaelis, L. A. and Hartwell S. F. (2007). “Lexical Subjects and the Conflation Strategy”. In N. Hedberg and R. Zacharski, (eds.), Topics in the Grammar-Pragmatics Interface: Papers in Honor of Jeanette K. Gundel. Amsterdam: Benjamins. 19-48.

Pickering, M. J., & Branigan, H. P. (1998). The representation of verbs: Evidence from syntactic priming in language production. *Journal of Memory and Language, 39*(4), 633-651. doi: Doi 10.1006/Jmla.1998.2592

Pickering, M. J., & Ferreira, V. S. (2008). Structural priming: A critical review. *Psychological Bulletin, 134*(3), 427-459. doi: Doi 10.1037/0033-2909.134.3.427

Raffray, C. N., & Pickering, M. J. (2010). How do people construct logical form during language comprehension? *Psychological Science, 21*(8), 1090-1097. doi: Doi 10.1177/0956797610375446

Schwarzschild, R. (2002). Singleton indefinites. *Journal of Semantics*, *19*(3), 289-314.
Thothathiri, M., & Snedeker, J. (2008). Give and take: Syntactic priming during spoken language comprehension. *Cognition, 108*(1), 51-68.
Viau, J., Lidz, J., & Musolino, J. (2010). Priming of abstract logical representations in 4-year-olds. *Language Acquisition, 17*(1-2), 26-50.

Table 3. Analyses of two-quantifier sentences

Within-configurations (E-U -> E-U, U-E->U-E)				
Omnibus Analysis				
Predictor	Coefficient	SE	Wald Z	*p* - value
best-fitting model included prime interpretation, $\chi^2(1) = 6.51$, $p = .010$, LL = -528				
Intercept	0.66	0.33	2.00	.045
Probe	1.06	0.33	3.18	.0015
Interpretation	0.66	0.20	3.26	.0011
Simple effects				
E-U only				
best-fitting model included prime interpretation $\chi^2(1) = 6.79$, $p = .0092$, LL = -258				
Intercept	1.71	0.39	4.33	< .001
Interpretation	1.16	0.29	4.04	< .001
U-E only				
best-fitting model did not include prime interpretation $\chi^2(1) < 1$				
Intercept	0.91	0.40	2.28	.020
Interpretation	0.14	0.29	0.50	.62
Between-configurations (E-U -> U-E, E-U -> U-E)				
Omnibus Analysis				
best-fitting model included prime interpretation, $\chi^2(1) = 11.97$, $p < .001$, LL= -518				
Intercept	0.98	0.34	2.93	.0035
Probe	0.64	0.26	2.44	.015
Interpretation	0.88	0.19	4.56	< .001
Simple effects				
E-U -> U-E				
best-fitting model included prime interpretation, $\chi^2(1) = 5.38$, $p = .020$, LL = -252				
Intercept	1.52	0.32	4.79	< .001
Interpretation	0.93	0.27	3.41	< .001
U-E -> E-U				
best-fitting model included prime interpretation, $\chi^2(1) = 9.38$, $p =.0022$, LL = -298				
Intercept	0.85	0.32	2.67	.0077
Interpretation	1.03	0.26	3.98	< .001