Information Structure of Relative Clauses in English: a Flexible and Computationally Tractable Model

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Sanghoun Song. 2014. Information Structure of Relative Clauses in English: a Flexible and Computationally Tractable Model. *Language and Information 18.2*, 1–29. Relativization is one of the common syntactic operations to merge two different clauses into a single information unit. This operation plays a pivotal role to structuralize multiple clauses cohesively as well as serves to specify the property an individual has within the context. That implies that relativization contributes to information structure of multi-clausal sentences. In this context, this paper delves into information structure of relative clauses in English with an eye toward creation of a computational model from a standpoint of machine translation. The current work employs Head-driven Phrase Structure Grammar (HPSG, Pollard and Sag (1994)) as a theory of grammar and Minimal Recursion Semantics (MRS, Copestake *et al.* (2005) as a meaning representation system. Building upon these formalisms, this paper addresses how information structure of relative clauses can be represented and constrained. The current work makes use of Individual CONStraints (ICONS) for modeling relative clauses with respect to information structure. The current work also investigates which relative clause involves which information structure constraint. The present study argues that non-restrictive relative clauses impose a more specific constraint on information structure than restrictive relative clauses. (**Nanyang Technological University**)

Key words: information structure, individual constraints, relative clauses, topic, focus, HPSG, MRS

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1. Introduction

This paper addresses computational modeling of information structure within a theory of grammar. When we analyze information structure roles, including focus, topic, and contrast, it is preferable to model them as a relation between an expression and a particular clause than as a property of the constituent itself. For instance, in (1), the subject with the A-accent (a.k.a. H* in the ToBI format) should be viewed as the focus of the clause headed by the predicate *barks*.

(1) The DOG barks.

In other words, information structure can be defined as a binary relation between a constituent and a clause that the constituent belongs to, and this relational property represents (i) which constituent is associated with (ii) which information structure role within (iii) which clause.

Most previous studies on information structure treat only fairly simple and monoclausal constructions, which is of course the basic step for delving into how information is packaged in an individual language. However, embedded clauses present another type of construction, in which one element can have different information structure meanings with respect to different clauses. The typical cases in which a single element has multiple relations at the same time with different predicates are found in relative clauses. For example, *the dog* in (2) informatively has to do with both *chases* in the relative clause and *barks* in the main clause.

(2) The dog that the cat chases barks.

In other words, an antecedent of relative clauses has relations with both (a) the verb in the relative clause and (b) the other verb in main clause, whose information structure values are not necessarily identical to each other. Furthermore, within the context of computational processing of human language, capturing these binary relations across clauses is crucial in representing the information structure of various types of utterances. Language applications should process naturally occurring texts, and the texts include many multiclausal utterances. Amongst a variety of multiclausal utterances, the present study pays an exclusive attention to relative clauses with an eye toward to creating a language processing model based on Head-driven Phrase Structure Grammar (HPSG, Pollard and Sag (1994)) and Minimal Recursion Semantics (MRS, Copestake *et al.* (2005)). From a monolingual point of view, since relative clauses are very often and productively used in English, representing the information-structure related properties of relative clauses in English is important for better performance of understanding texts in English. This contributes to higher 'coverage' of a language processing system. From a multilingual angle, relative clauses are important in that different languages employ different strategies of relativization, and thereby constraining these strategies plays a significant role to produce better outputs in machine translation. This improves 'accuracy' of a multilingual processing system.

The present study addresses two points of how information is packaged within relative clauses in English. First, this study looks at how information structure relations are represented via a computational grammar model for generation as well

as parsing. Second, building upon the model, this study also looks at which information structure value is assigned to the head noun modified by relative clauses.

This paper is structured as follows: Section 2 probes into information structure relations that relative clauses have within different clauses. Section 3 proposes using Individual Constraints (hereafter, ICONS) for representing information structure of relative clauses within the HPSG and MRS formalism. Using ICONS, Section 4 shows how the constraints proposed hitherto can be implemented in TDL (Type Definition Language, (Krieger and Schäfer, 1994)) for a computational purpose. Section 5 concludes this paper.

2. Information Structure Relations

This section addresses which restrictions relative clauses have on information structure. In particular, which information structure value is assigned to the head noun modified by relative clauses? Kuno (1976) argues that relative clauses assign topic to their modificands or the relative pronouns, but there are several counterexamples to this generalization. This section looks at the details and provides a hybrid model for the purpose of robust processing of sentences in English.

2.1 Relative Clauses and Relativized NPs

As mentioned above, it has been assumed that relative clauses assign topic to their head nouns or the relative pronouns (Kuno, 1976; Bresnan and Mchombo, 1987; Jiang, 1991; Bjerre, 2011). This argument is conceptualized byBresnan and Mchombo (1987) as exemplified in (3).

(3) The car [which you don't want ___] is a Renault.
TOPIC OBJ
(Bresnan and Mchombo, 1987, p. 757)

This assumption is largely grounded upon the fact that left dislocation is usually disallowed in relative clauses in English, as exemplified in (4a). In a similar vein, Kuno (1973) argues that the topic marker *wa* in Japanese is seldom used in relative clauses. (4b) indicates that *nun*-marked NPs in Korean also have a tendency not to occur in relative clauses.

(4) a. *A man who your book$_i$could buy e$_i$. (Roberts, 2011, p. 1926)
b. Lee-ka Kim-i/??un ilk-un chayk-ul sa-ss-ta.
Lee-NOM Kim-NOM/TOP read-REL book-ACC buy-PAST-DECL
'Lee bought the book that Kim read.' [kor]

The previous studies argue that the main reason why topicalization is not allowed in relative clauses is that the relative clauses have already assigned topic to the head nouns. That is, the slot for topic is filled out when relativization happens. Representatively, Kuno (1976) argues (5a) is derived from not (5b) but (5c), in which *sono hon* 'the book' occurs sentence-initially with the topic marker *wa* to signal topic ('theme' in Kuno's terminology).

(5) a. [Hanko-ga yonda] hon
Hanako-NOM read book
'The book that Hanako read'

b. [Hanko-ga sono hon-o yonda] hon
Hanako-NOM the book-ACC read book

c. [[sono hon-wa]$_{\text{theme}}$ Hanko-ga yonda] hon
the book-WA Hanako-NOM read book [jpn] (Kuno, 1976, p. 417)

Notice that Japanese has the topic-first restriction (Maki, Kaiser, and Ochi, 1999; Vermeulen, 2009). That means that the constituent associated with (non-contrastive) topic normally shows up in the initial position in Japanese. Jiang (1991) also provides a movement-based argument about the relationship between relative clauses and topic constructions in Chinese. The argument is that (i) when an element is relativized, it is derived only from a topic position, and (ii) a constituent moves into the topic position before it is relativized.[1]

Accordingly, Kuno (1976) suggests the following constraint.

(6) The thematic constraint on relative clauses: A relative clause must be a statement about its head noun. (Kuno, 1976, p. 420)

Kuno (1976) provides more examples from English to bolster (6). These include reduced relative clauses, comparative constructions, and *by*-passives.

(7) a. *This is the man that Mary knows a girl jealous of.
b. *This is the man that Mary knows a girl behind.
c. This is the man that I read a statement about.
d. This is the man that I bought a picture of. (Kuno, 1976, p. 425)

(8) a. ??This is the subject that I like linguistics better than.
b. This is the subject that I like better than linguistics. (Ibid., p. 429)

(9) a. ?Here is the man by whom Mary has been wronged.
b. Here is the man by whom many innocent people have been wronged. (Ibid., p. 430)

7 shows that some expressions in English such as *a girl jealous of* and *a girl behind* disallow relativization, whereas other structurally similar expressions such as *a statement about* and *a picture of* do not have such a restriction. Kuno (1976) claims that this contrast means that the head nouns of relative clauses convey topic meaning: In the latter type, the prepositions such as *about* and *of* inherently involve aboutness. Recall that the semantic core of topic is known as aboutness (Reinhart, 1981; Choi, 1999). (8) reveals that complements of the comparative particle *than*

[1] This claim is almost in the same line as Huang (1984)'s analysis about topic-drop in Chinese: Syntactic arguments associated with topic can be freely dropped in Chinese, if and only if the arguments are preposed into the topic position before dropping. So to speak, within their movement-based analyses, topic-fronting is a necessary condition for both relativization and dropping in Chinese.

can hardly be relativized. It is mainly because *than* assigns a focus meaning to its complement, the complement is incompatible with the topic function that the head of relative clauses plays. The demoted argument in *by*-passive constructions in English can be relativized, but there is a constraint on these as well: the relative clauses with *by*-passives do not sound good unless the subjects are indefinite such as *many innocent people* in (9b). If the subject is definite, then the definiteness (i.e. old information) entails topichood, which conflicts with the topic meaning that the relativized NP carries.

Bjerre (2011) provides a similar analysis in Danish, using clefting as a diagnostic tool for identifying focus. She claims that (10b) which has a clefted relative pronoun *den* is of dubious acceptability, while (10a) in which an interrogative pronoun *hvem* is clefted sounds normal. Note that focus and topic are presumed to be mutually exclusive.

(10) a. Som komponist er det naturligvis vigtigt,
as composer is it of course important
at lytterne ved,
that listeners.DEF know
hvem det er der har skrevet den musik,
who it is there has written that music
de lytter til.
they listen to
'As a composer it is of course important that the listeners know who it is that has written the music they are listening to.'

b. ???Som komponist er det naturligvis vigtigt,
as composer is it of course important
at lytterne kender
that listeners.DEF know
den musik hvilken det er der lyttes til.
that music which it is there listen.PRS.PAS to
'As a composer it is of course important that the listeners know that music which it is that is listened to.' [dan]
(Bjerre, 2011, p. 279)

From the linguistic phenomena presented thus far, it seems clear that relative clauses present certain constraints on information structure. Nevertheless, there are some examples that show (6) is not cross-linguistically valid. For instance, some languages allow topicalization inside of relative clauses, as exemplified in Italian below.

(11) Un uomo che, il tue libro$_i$, lo_i potrebbe comprare.
A man who, your book, could buy it. [ita] (Rizzi, 1997, p. 306)

Besides, topicalization can happen within relative clauses if the topicalized NPs convey contrastive meaning as exemplified in (12). The relative clause which modifies the following NP *kkoch* 'flower' delivers a meaning like *The flower smells good,*

but visually it does not look so good.[2]

(12) hyangki-nun coh-un kkoch-i phi-n-ta.
scent-NUN good-REL flower-NOM bloom-PRES-DECL
'A flower with a good scent blooms.' [kor] (Lim, 2012, p. 229)

In a similar vein, Bianchi and Frascarelli (2010), based on a corpus study, classify topics into several subtypes with special reference to so-called root phenomena. Their finding is that aboutness topics (A-Topics in their terminology) cannot appear in non-root clauses, while other types of topics, such as contrastive topics (C-Topics), can show up in non-root clauses such as relative clauses. This implies that topicalization itself is not a seamless test to confirm the topic meaning of relativized NPs.

Other pieces of evidence against (6) can be found in Mandarin Chinese. They show that relative clauses do not always give a topic meaning to the head NPs. Ning (1993) reveals that a relativized construction may be well-formed even though its corresponding topic structure is ill-formed. More recently, Huang, Li, and Li (2009), within the movement-based framework, basically accepts that topics and relative clauses share some characteristics with *wh*-constructions as A′-movement structures. The common properties notwithstanding, they argue that a topic relation does not necessarily license a relative construction in Chinese. For instance, if a topic structure were sufficient for relativization in Chinese, (13b) and its relativized counterpart (13c) would be equally acceptable.

(13) a. yiwai fasheng-le
accident happen-LE
'An accident happened.'

b. tamen, yiwai fasheng-le
they accident happen-LE
'(As for) them, an accident happened.'

c. *[[yiwai fasheng-le de] neixie ren]
accident happen-LE DE those person
'the people such that an accident happened' [cmn] (Huang, Li, and Li, 2009, p. 212-213)

Hence, the well-formedness of a topic structure is neither necessary nor sufficient for the acceptability of the corresponding relative structure at least in Mandarin Chinese. Now, we can say that (6) is vulnerable from a cross-linguistic stance.

2.2 Either Focus or Topic

The previous subsection reveals that relativized NPs tend to be assigned a topic relation by the relative clauses, but not always. Even though relativized NPs are not necessarily associated with topic across languages, such a topic relation might be true language specifically. That is, some languages including English might

[2] If the nominative marker *ka*, instead of *nun*, is attached to *hyangki* 'scent', the sentence still sounds good, but the contrastive meaning disappears.

assign only topic to the relativized NPs. Nonetheless, several pieces of evidence show that it does not seem true. One of them can be found when the relativized NPs are combined with focus sensitive operators. (14a) in which the restrictive relative clause modifies *no one* sounds good, while (14b) in which the relative clause is non-restrictive sounds ungrammatical.[3]

(14) a. No one who had anything to drink suffered ill effects.
b. *No one, who had anything to drink, suffered ill effects. (Arnold, 2004, p. 31)

(15) a. Only the tourists who have any imagination go to visit Sicily.
b. *Only the tourists, who have any imagination, go to visit Sicily. (Fabb, 1990, p. 70)

Negative operators (e.g. *no*, *nothing*, *never*, etc.) are known to be focus sensitive, and thereby they usually and strongly invoke meaning of focus (Lambrecht, 1996). This means that *no* signals focus to the head noun *one*. If *one* in (14a) was assigned topic by the relative clause, the topic meaning would not fit into the focus meaning. The same goes for *only the tourists* in (15). *Only* is one of the well-known focus sensitive operators assigning focus to the head nouns (Beaver and Clark, 2008). Hence, (15a) is a counterexample to (6). This is known to be related to external licensed negative polarity items such as *anything* and *any*. Fabb (1990) and Arnold (2004) argue that ungrammaticality of (14b) and (15b) suggests that the non-restrictive relative clause is outside the scope of the quantifiers. I do not disagree with their argument, but what I would like to focus on herein is the focus sensitivity that *no* and *only* inherently bear. Notice that even though no negative polarity item appears in relative clauses such a distinction between restrictive readings and non-restrictive readings happens, as shown in (16).

(16) a. *No student, who scored 80 or more in the exam, was ever failed.
b. No student who scored 80 or more in the exam was ever failed. (Kim and Sells, 2008, p. 240)

A similar piece of evidence is provided in Song (2014), who provides a corpus study to see information structure relations within multiclausal sentences. Song (2014) makes use of tests proposed by Roberts (2011) in order to identify the topic meaning and marking, and observes that not all restrictive relative clauses undergo the tests.[4] This implies that we cannot decisively say that the relativized NPs are always associated with topic even in English.

In brief, a tendency is a tendency: Topic tends to be assigned to relativized NPs in more than a few cases, but this assignment does not seem to be invariable.[5] Kuno (1976)'s argument (6) seems to be a matter of tendency, rather than a rigorous and

[3] This contrast will be discussed again in the following subsection.
[4] This corpus-based finding will also be addressed in the next subsection.
[5] As computational semantics puts emphasis on robust processing, tendencies and restrictions are strictly distinct in grammar engineering.

absolute restriction. Thus, it is necessary to invent a more flexible constraint that includes (6) by default and also extensively works.

As an alternative way, the present study argues that the information structure values of the constituents modified by relative clauses should be *focus-or-topic* (See Figure 1 in 3.2). This implies that the relativized constituents can be evaluated as delivering either focus in some cases or topic in other cases. This also means that relativized constituents cannot be background (i.e. neither focus nor topic). In other words, the modificands become something informatively salient by means of relativization.

There are two previous studies showing that relativization serves to make the head nouns outstanding. First, Schachter (1973) presents the relationship between focus constructions (e.g. clefts) and restrictive relative constructions, and concludes that they are alike to each other. Building on a cross-linguistic finding taken from four languages including English, Schachter (1973) claims that both constructions necessitate the promotion of a linguistic item from an embedded clause into its main clause, and this promotion involves foregrounding. The structural similarity notwithstanding, we cannot jump into a conclusion that foregrounding necessarily triggers focusing. On the one hand, there is no *a priori* guarantee that what appear to be similar are sufficiently correspondent to justify the comparison of structure. On the other hand, Kim (2012b) reveals that cleft clauses show an ambivalent behaviour between restrictive relatives and non-restrictive relatives, which also submits adverse evidence to Schachter (1973)'s claim. Nevertheless, foregrounding pragmatically refers to making a specific part of a sentence conspicuous at the expense of the rest. In terms of information structure, this implies that the promoted part is distinctive from background. Second, Schafer *et al.* (1996) provide the following hypothesis.

(17) Focus Attraction Hypothesis: It is more likely that a phrase that is neither a complement nor syntactically obligatory will be taken to modify a phrase P if P is focused than if it is not, grammatical and pragmatic constraints permitting. (Ibid. p. 136)

Building upon (17), Schafer *et al.* (1996) check out whether the predictions of the hypothesis can be applied to relative clauses. They conduct two auditory experiments to see which pitch accent tends to fall on the head NPs of relative clauses, and the results verify (17). Although this hypothesis is true, this mainly concerns the information structure relation between the head noun and the matrix clause, not between the head noun and the relative clause. Thus, we cannot apply (17) directly to the question this paper is currently asking. Nonetheless, (17) at least implies that the relativized NPs are informatively more noteworthy than the content in the relative clauses. This also shows that the relativized NPs are evaluated as being either focus or topic (i.e. *focus-or-topic*), not associated with background.

2.3 Non-restrictive Relative Clauses

In addition to the constraint presented in the previous subsection (i.e. *focus-or-topic*), the present study also marks the difference between restrictive reading and non-restrictive readings in terms of assigning information structure values.

Restrictive relative clauses and non-restrictive relative clauses have been regarded as having different linguistic behaviours in many previous studies. In a nutshell, a restrictive relative clauses limits the thing it refers to, whilst a non-restrictive relative clause adds extra and/or non-essential information to the whole sentence. As is well-known, there is an orthographic convention in English of setting off non-restrictive relatives with commas (pause in speech). Since restrictive clauses are essential, they are not set off unlike non-restrictive relative clauses. Syntactically, it has been stated that the distinction between restrictive readings vs. non-restrictive ones yields different bracketing (Heim and Kratzer, 1998), as shown in (18).

(18) a. [[The [dog that the cat chases]] barks.]
b. [[[The dog,] which the cat chases,] barks.]

The restrictive relative clause in (18a) modifies the head noun *dog* itself, and then the entire NP *dog that the cat chases* is combined with the determiner as *head-spec-phrase*. In contrast, the non-restrictive relative clause in (18b) modifies the NP in which the noun *dog* takes the determiner beforehand.[6] Semantically, they may not share the same truth-conditions.

(19) a. Kim has two children that study linguistics.
b. Kim has two children, who study linguistics.

(19b) implies that *Kim* has two and only two children, while (19a) does not. For example, if *Kim* has three children, the proposition of (19b) would not be felicitously used, whereas that of (19a) may or may not be true depending on how many children among them study linguistics. Regarding these properties, non-restrictive relatives are known to display (near-)root phenomena (Heycock, 2007, p. 183-184). This is based on Fabb (1990)'s claim that restrictive relatives modify their host, while non-restrictive relatives do not. In other words, non-restrictive relatives are external to the host.

Other than these three, it has been borne out that there exist quite a few differences between them (Emonds, 1979; Fabb, 1990; Borsley, 1992; Sag, 1997; Arnold, 2004; Arnold, 2007; Pak, 2008; Kim, 2012a; Kim, 2012b; Loock, 2012). Given that they have different properties in general, it is a natural assumption that they behave differently in information structure as well. In particular, the non-root phenomenon is somewhat relevant to information structure in that topic is generally a root phenomenon (Büring, 1997; Portner and Yabushita, 1998; Erteschik-Shir, 1999; Bianchi and Frascarelli, 2010). That is, non-restrictive relative clauses are capable of forming an information structure independent of the matrix clause unlike restrictive ones. Additionally, there is a distributional reason for viewing them differently with respect to information structure.

[6] There are some different points of view. For instance, the ERG (English Resource Grammar, Flickinger (2000)) does not differentiate them in such a way. That is, there is no difference in the syntactic attachment. This approach is quite similar to the argument of Pak (2008): Restrictive relatives and non-restrictive relatives are syntactically the same. In short, this debate is about whether or not non-restrictive relative clauses are 'orphanage.' (Haegeman, 2009). Since this is out of the scope of the current work, I do not draw any conclusion about it in this paper.

Before going into the information structure relations of two types of relative clauses, it is necessary to review the tests for identifying topicality (Roberts, 2011). The tests to vet topicality include (i) the *about* test, (ii) the *what about* test, (iii) the *as for* tests, and (iv) the *speaking of* tests. They are all relevant to meaning and marking of topics, but slightly different from each other: (i) *About ...* is relevant to topic of the utterance, (ii) *What about ...* indicates contrastive topic, (iii) *As for ...* entails a salient contrast set to be compared, and finally (iv) *Speaking of ...* encodes a topic shift. A constituent associated with topic may not pass all the four tests, but it has to undergo at least one of them. For example, (20) passes only the second and the fourth tests.[7]

(20) A: I was at the mall yesterday and I ran into Louise Clark, who was here visiting Sue Topping.

B: Interesting. [interlude of talk about Clark, followed by:]
(i) #About Sue, Louise said that...
(ii) What about Sue? {What's she up to?/I heard she was moving.}
(iii) #(But) as for Sue, did you know...
(iv) But speaking of Sue, did you know she's engaged?
(Roberts, 2011)

These tests can be applied to relative clauses as presented in (21).[8]

(21) a. Kim chases the dog that likes Lee.
b. Kim chases the dog, which likes Lee.
c. Kim chases the dog, and it likes Lee.
d. Kim chases the dog, and as for the dog, it likes Lee.
e. Kim chases the dog, and speaking of the dog, it likes Lee.

Unlike restrictive relative constructions such as (21a), non-restrictive constructions such as (21b) can be paraphrased into (21c-e). (21c) reveals that non-restrictive relatives are almost equivalent to coordinated clauses which clearly involve root phenomena (Heycock, 2007, p. 177). In (21c), a pronoun *it* is used as referring to *the dog* in the previous clause, which means *the dog* cannot receive *focus* from the non-restrictive clause in (21b). Finally, (21d-e) pass the paraphrasing tests proposed by Roberts (2011). They indicate that the antecedent *the dog* in (21b) plays a topic role.

As aforementioned, Song (2014) applies these tests to a corpus study of information structure, and provides a finding that restrictive relative clauses sometimes do not pass the tests, while non-restrictive relative clauses always pass the tests. They are exemplified in (22-24), and they show that Kuno (1976)'s constraint (6)

[7] *What about Sue?* in (20B(ii)) sounds felicitous, given that *Sue* is the contrastive topic in the subsequent utterance. An infelicity with *as for* in (20B(iii)) exhibits that there is no such salient set in the context given. A felicity of using *speaking of* in (20B(iv)) indicates that the speaker merely switches to talking about *Sue* and offers some interesting news about her (Roberts, 2011).

[8] These paraphrases were judged by two English native speakers.

and Bresnan and Mchombo (1987)'s schema (3) can be straightforwardly applied to non-restrictive relative clauses in English.[9]

(22) a. ... he unravelled the problems which were submitted to him.
b. #... he unravelled the problems, and speaking of them, they were submitted to him.

(23) a. I have heard of you from Mrs. Farintosh, whom you helped in the hour of her sore need.
b. I have heard of you from Mrs. Farintosh, and speaking of her, you helped her in the hour of her sore need.

(24) a. This is my intimate friend and associate, Dr. Watson.
b. This is my intimate friend and associate, and speaking of him, he is Dr. Watson.

In fact, such a topichood that an antecedent has with respect to its non-restrictive relative clause is pointed out in several previous studies, though the main concern of the studies is neither pragmatics nor information structure. For instance, Fabb (1990, p. 75) notes that 'aboutness' exists between the antecedent and the non-restrictive relatives.

In addition to the constraint (i.e. 'aboutness' of the head noun), the current work proposes one more constraint: A non-restrictive relative clause is connected to the host sentence as a background (i.e. *bg*).[10] As mentioned previously, there is a consensus that non-restrictive relatives add only extra and/or non-essential meanings to the whole sentence. At least from a point of semantico-pragmatic view in question, it is clear that non-restrictive relatives are informatively unmarked.[11] This implies that a non-restrictive relative clause can be neither focus nor topic of the whole utterance. There are several previous studies to bolster this assumption. Loock (2012), from a viewpoint of information structure, compare appositive ('non-restrictive' in the terminology of this paper) relative clauses to other allostructures in order to determine which linguistic conditions have to do with the choice of allostructures.[12] One of the findings is that appositive relative clauses are used when the informational content is in disjunction with that in the matrix clause (i.e.

[9] Note that non-restrictives are assumed to be a type of apposition in the current study.

[10] One reviewer left a comment that Potts (2005) submitted an opposing point of view to this generalization: Potts (2005) argues that non-restrictive relative clauses and appositive NPs involve new information, and thereby they are not background. I do not say that this analysis is wrong, but the present study takes a slightly different angle. What I want to say herein is that non-restrictive clauses are not informatively subordinated to the main clause and they are unmarkedly expressed with respect to formation structure. Of course, non-relative clauses can give new information to the discourse, but the new information might be better to be represented as the non-restrictive relative clause itself, not as the relation to the main clause.

[11] Regarding this properties, there is a syntactic debate: Fabb (1990) and Haegeman (2009) defer to so-called orphanage approach, but Borsley (1992), Arnold (2007), and Kim (2012a) do not. This paper does not follow any of them, because such a syntactic property is not directly related to the question that I am asking herein.

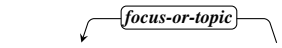
[12] Allostructures refer to semantically equivalent but formally and pragmatically divergent sentence pairs (Lambrecht, 1996, p. 35).

a digression). Kim (2012a) creates some corpus-based findings about the appositive construction in English and also provides a surface-based Construction Grammar (so to speak, an HPSG-like grammar) analysis of the construction. His argument is also supportive: The semantic contribution of appositives is distinct from the at-issue meaning (i.e. what is said or regular assertive content). Building upon these, the present study proposes that the information structure relation between non-restrictive relatives and their host clauses is background.

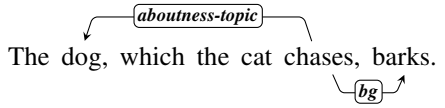
2.4 Summary

The following dependency diagrams are illustrative of the constraints discussed hitherto.

(25) a.



b.



Irrespective of the two types of reading (i.e. restrictive or non-restrictive), all relative clauses basically assign (i) *focus-or-topic* to the head nouns as presented on the arrow from *chases* to *dog* in (25a). In addition to the basic constraint, non-restrictive relative clauses bear more specific values as shown in (25b): (ii-a) *aboutness-topic* on the arrow from *chases* to *dog* and (ii-b) *bg* on the arrow from the semantic head of the embedded clause (i.e. *chases*) to the semantic head of the host (i.e. *barks*).

3. Individual Constraints

The formalism employed to calculate semantic compositionality in the present work is a computationally tractable flat semantics entitled MRS (a.k.a. Minimal Recursion Semantics, (Copestake et al., 2005)). The AVM (Attribute-Value Matrix) of the default MRS is presented in (26).

(26)
$$\begin{bmatrix} \textit{mrs} & & \\ \text{HOOK} & \begin{bmatrix} \textit{hook} & \\ \text{GTOP} & \textit{handle} \\ \text{LTOP} & \textit{handle} \\ \text{INDEX} & \textit{individual} \\ \text{XARG} & \textit{individual} \end{bmatrix} \\ \text{RELS} & \textit{diff-list} \\ \text{HCONS} & \left\langle ! \ldots, \begin{bmatrix} \textit{qeq} & \\ \text{HARG} & \textit{handle} \\ \text{LARG} & \textit{handle} \end{bmatrix}, \ldots ! \right\rangle \end{bmatrix}$$

In addition to this formalism, the current work also makes use of ICONS (Individual CONStraints) suggested by Song (2014) in order to incorporate discourse-related phenomena into semantic representation of human language sentences. Building upon these two (i.e. MRS+ICONS), the current work creates a computational model of information structure that relative clauses contribute to. In other words, the representation method the present work builds on is an extended version of MRS.[13]

3.1 Motivations

Using MRS representation involves two characteristics with respect to computational modeling of human language. First, MRS-based machine translation does not follow an Interlingua method in a pure sense in that the cumulated logical forms remain still ambiguous. Since MRS represents human language sentences into a flat structure and underspecifies quantifier scope, scope ambiguities triggered by quantifiers are not fully disentangled in MRS representation. Moreover, since MRS employs underspecification in a broad way like HPSG, each representation is often interpreted ambiguously. Second, since the MRS representation is exclusively concerned with semantic compositionality, discourse-related items are not dealt with even though modeling them has a potential to improve machine translation. To my understanding, this is largely because MRS is an intrasentential system (i.e. sentence-based processing). Nonetheless, there exist several discourse-related items that can be resolved without seeing adjacent sentences, and they can be harnessed for producing better outputs in natural language processing.[14]

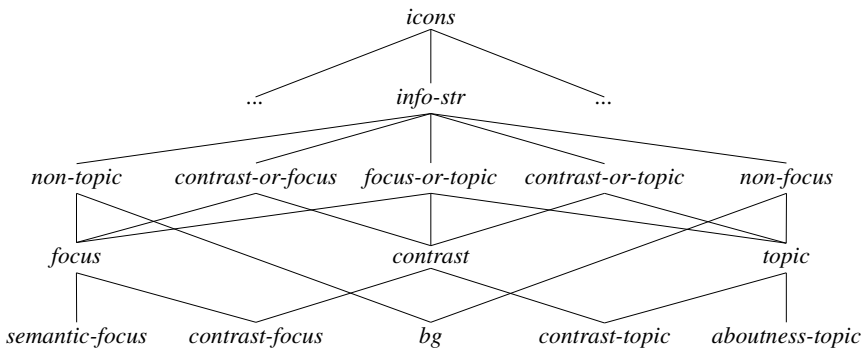
MRS+ICONS is along with these lines. First, the current work manipulates information structure constraints in a way of using underspecification. Information structure values are stored into a bag of constraints (i.e. *diff-list*), and the value is not fully specified unless there is no decisive clue to identify how information is packaged. Second, the current work represents information structure constraints as a binary relation between an individual element and the clause that the element belongs to. This way of representation using a set of binary relations plays a key role in processing multiclausal utterances such as relative clauses in question. For example, as mentioned already, the relativized noun in (2) *dog* is taken as an argument by both the verb in the relative clause *chases* and the matrix verb *barks*.

(2) The dog that the cat chases barks.

Hence, the sentence representation requires at least two information structure relations, and they have to be separate from each other. Given that relativization has a function to assign an information structure value to the head noun, the relations behave as a clue to resolve the partial semantic information. It is natural that the entire interpretation of information structure cannot be identified until the context is wholly analyzed. Yet, given the state-of-the-art in computational linguistics, such partial information often helps to improve language applications

[13] This new version is sometimes spelled out as Meaning Representation System (still abbreviated as MRS), but this paper calls the new version just MRS+ICONS in order to avoid confusion.

[14] For more information about how MRS works, see Copestake et al. (2005) for English and Kim (2006) for Korean.



[Figure 1] Type hierarchy of *info-str*

in terms of speed as well as accuracy (Flickinger, 2011). As of now, MRS+ICONS is one of the available and optimized ways of modeling information structure with flexibility and computational tractability.

3.2 Basic Formalism

Figure 1 shows the type hierarchy of *info-str*. Notice that *info-str* is a subtype of *icons*.[15] Within the hierarchy, the values of information structure are represented as type names. The highest node *info-str* is divided into five immediate subtypes, viz. *non-topic*, *non-focus*, *focus-or-topic*, *contrast-or-focus*, and *contrast-or-topic*. Note that *or* in *focus-or-topic* is exclusive (i.e. either *focus* or *topic*), whilst that in *contrast-or-focus* and *contrast-or-topic* is not. That means that one element cannot be assigned both focus and topic at the same time. *Focus-or-topic* is divided again into *focus*, *contrast*, and *topic*, and the *focus* and *topic* do not have any subtype in common underneath. It is noticeable that *focus-or-topic* does not branch out to *bg* (i.e. background). That means that a constituent associated with *focus-or-topic* is something informative and accordingly plays an information structure role in the sentence. The nodes in the bottom line are responsible for the most specific information structure components.

This type hierarchy is designed for the purpose of maximizing flexibility in computational processing. What is of importance in this way of representation is that the intermediate types in this hierarchy allow for underspecified representations. As is well-known, information structure markings often give only partial information, and thereby the meaning is sometimes ambiguous. In more than a few cases, we cannot exactly say which information structure meaning is assigned to which constituent in many cases, but we can figure out some clue to identify which meanings can be potentially conveyed. Thus, the meaning representation should cover all the potential information structure meanings. In Figure 1, which nodes should be at which level depends on the subsumption relationship of information structure meanings. If a constituent is associated a specific node in the type hier-

[15] Currently, *honorific* is under development as a sibling of *info-str*.

archy presented in Figure 1, the constituent can be interpreted as conveying the meaning of the node name (e.g. *focus*, *non-topic*, etc.) or any other meanings of its all subnodes. For example, if *non-topic* is assigned to a constituent, the constituent can be interpreted as conveying either *focus* or *bg*. That is to say, the upper a node is in the hierarchy, the less specific the information structure meaning is. The less specific a node is, the more flexibly it can be used.

ICONS is newly added to structures of type *mrs* as provided in (27). An ICONS element has two features, viz. IARG1 and IARG2. The former indicates which clause an individual belongs to, and the latter refers to the individual associated with an information structure component, such as topic, focus, etc.[16]

(27)
$$\begin{bmatrix} \textit{mrs+icons} & & \\ \text{HOOK} & \begin{bmatrix} \textit{hook} & \\ \text{GTOP} & \textit{handle} \\ \text{LTOP} & \textit{handle} \\ \text{INDEX} & \textit{individual} \\ \text{XARG} & \textit{individual} \\ \text{ICONS-KEY} & \textit{icons} \\ \text{CLAUSE-KEY} & \textit{event} \end{bmatrix} \\ \text{RELS} & \textit{diff-list} \\ \text{HCONS} & \textit{diff-list} \\ \text{ICONS} & \left\langle ! \ldots, \begin{bmatrix} \textit{icons} & \\ \text{IARG1} & \textit{individual} \\ \text{IARG2} & \textit{individual} \end{bmatrix}, \ldots ! \right\rangle \end{bmatrix}$$

Each type name in the type hierarchy sketched out in Figure 1 indicates which information structure meaning is associated with the Elementary Predicate (EP, a.k.a. distinguished variable), and the connection between them is specified by the co-index between IARG2 and ARG0 (the INDEX of itself). When an element is expressed with respect to information structure and also contributes to RELS introducing an EP, the element is represented as a value of IARG2, which has a coreference with the ARG0 of the EP. On the other hand, the clause that the element is dependent upon is represented as a value of IARG1, which also has a coreference with the INDEX of the predicate that functions as the semantic head of the clause.

3.3 Flexible, but not Naïve

Following the discussion presented in Section 2, the present study argues that (i) the semantic head of relative clauses (i.e. the verb in relative clauses) basically has a *focus-or-topic* relation with relativized dependents, and (ii) non-restrictive

[16] Comparing to (26), MRS+ICONS schematized in (27) includes two extra features under HOOK: namely ICONS-KEY and CLAUSE-KEY. They are required in the compositional construction of the ICONS list in an incremental way. Because they are not directly related to modeling information structure of relative clauses, this paper does not dwell on how these two pointers operate.

relatives additionally have more specific constraints: *aboutness-topic* and *bg*. Recall that *aboutness-topic* is a subtype of *focus-or-topic* in the type hierarchy sketched out in Figure 1. Therefore, these two constraints are not inconsistent with each other within the HPSG and MRS framework. Using these constraints in semantic representation enables to include at least three benefits in language processing.

3.3.1 Benefit in Parsing. This representation system allows a flexible processing in semantic composition. As presented before, the information structure relation between relativized NPs and relative clauses might be sometimes language-specific and sometimes context-sensitive, but at any rate, whichever the constraint is, this system is ready to express it. For convenience sake, (16) is repeated below.

(16) a. *No student, who scored 80 or more in the exam, was ever failed.
b. No student who scored 80 or more in the exam was ever failed.

The non-restrictive relative clause in (16a) assigns *aboutness-topic* to the head noun *student*, which conflicts with *focus* that a focus sensitive operator *no* gives to the head noun. Accordingly, the sentence is ruled out. In contrast, the restrictive relative clause in (16b) assigns *focus-or-topic*, and then *no* signals focus to the head noun *student*. Since no inconsistency happens in the construction, the two values are successfully subsumed into *focus*. Accordingly, the sentence is legitimately formed. In sum, such a bistratal approach works well for parsing both types of relative clauses

3.3.2 Benefit in Generation. The hierarchical constraints also work for sentence generation (See Figure 4 in the next section). Since the constraint on restrictive relative clauses subsumes the additional constraint on non-restrictive ones, the sentence generation from the MRS of restrictive readings includes non-restrictive relative clauses. In terms of robust sentence-based processing, this way of generation is plausible, because the use of comma is just a convention in writing style, rather than a mandatory requirement for a non-restrictive reading. That is, even though the comma does not appear before (and after) a relative clause, we cannot say that the relative is necessarily restrictive until the contextual information is clearly given. What is of interest is the opposite case: Appearance of comma before relative clauses is a sufficient condition for non-restrictive readings. Thus, when a comma shows up, the set of sentences generated from the MRS should not include sentences without comma.[17] Otherwise, the sentence generation would result in a loss of information. The additional information structure constraint between two clauses (i.e. *bg*) is the information that has to be preserved in generation, and thereby facilitates such an ambivalent processing. This strategy of generation will be instantiated in 4.3.

3.3.3 Benefit in Paraphrasing. This way of representation can be on a par with other constructions marking information structure in English, including passives,

[17] For more information, see Nunberg (1990) from a theoretical viewpoint and Adolphs *et al.* (2008) from a perspective of implementing language processing systems.

fronting (a.k.a. topicalization), and clefts. They are exemplified respectively in (28).

(28) a. The dog (that) the cat chases.
b. The dog is chased by the cat.
c. The dog the cat chases.
d. It is the dog that the cat chases.

First, the promoted arguments in passives also involve foregrounding from a pragmatic and functional viewpoint (Shibatani, 1985), and thereby they are associated with either focus or topic (Song and Bender, 2011). That is, if we regard syntactic promotion as a functional operation to make the constituent remarkable within the context, naturally we can say that such a promoted argument in passives and relative clauses (e.g. *the dog* in (28a-b)) are relevant to *focus-or-topic*. Second, information structure in relative clauses can be analyzed analogously to focus/topic-fronting constructions. A focus/topic fronting construction given in (28c) would be ambiguously interpreted but for the help of contextual information (Prince, 1984). One is *As for the dog, the cat chases it.*, and the other is the same as (28d). Gundel (1983) calls these different readings "Topic Topicalization" and "Focus Topicalization", respectively. In order to incorporate these two readings into a single representation, the lowest common supertype of *focus* and *topic* is used: *focus-or-topic*. Recall that semantic ambiguities are represented in MRS by means of underspecification. Finally, as Schachter (1973) and Kim (2012b) present, relative clauses have a striking likeness to cleft clauses. In addition to their claims, one similarity can be additionally found in (29). Notice that semantically empty categories (e.g. expletives, copular, etc.) and syncategorematic categories (e.g. relative pronouns) are presumably informatively empty, too (Song and Bender, 2011). Thus, the struck elements in (29) do not participate in information structure.

(29) ~~It~~ ~~is~~ the dog ~~that~~ the cat chases.

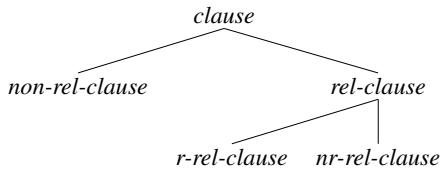
Excluding them, the remaining contentful constituents are in the same order as (28a). That is, the underlying structure of so-called "Focus Topicalization" (28c) may look like (29). In this interpretation, *the dog* in (28a) conveys meaning of focus with respect to the predicate in the relative clause *chases* just like that in (28d).[18] Hence, the linguistic constraint on relativization has to allow *focus* to be assigned to the head noun by the relative clauses. This constraint can be flexibly specified as *focus-or-topic*.

3.4 Phrase Structure Rules

The basic constraint that relative clauses have inherit from what Sag (1997) proposes. The followings deal with only the information-structure related constraints.

The type hierarchy of *clause* is sketched out in Figure 2 in a simplified fashion. *Clause* is divided into *non-rel-clause* and *rel-clause*, and the latter is biparted again into *r-rel-clause* for restrictive relatives and *nr-rel-clause* for non-restrictive relatives. They are constrained as the following AVMs.

[18] In terms of Paggio (2009)'s notion, their sentential forms are all encoded as *focus-bg*.



[Figure 2] Type hierarchy of *clause* (simplified)

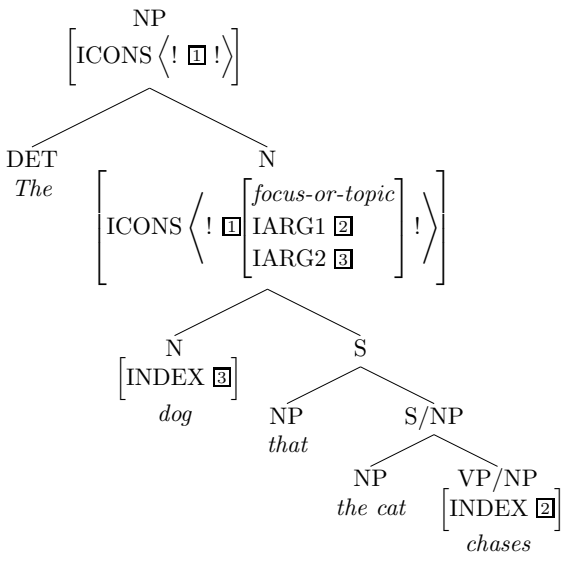
(30) a.
$$\left[\begin{array}{l}\textit{non-rel-clause} \\ \text{HD}\left[\begin{array}{ll}\text{INDEX} & \boxed{1} \\ \text{ICONS-KEY}\,|\,\text{IARG1} & \boxed{1} \\ \text{CLAUSE-KEY} & \boxed{1}\end{array}\right]\end{array}\right]$$

b.
$$\left[\begin{array}{l}\textit{rel-clause} \\ \text{HD}\,|\,\text{INDEX}\,\boxed{1} \\ \text{NHD}\,|\,\text{INDEX}\,\boxed{2} \\ \text{C-CONT}\,|\,\text{ICONS}\left\langle\,!\left[\begin{array}{l}\textit{focus-or-topic} \\ \text{IARG1}\,\boxed{2} \\ \text{IARG2}\,\boxed{1}\end{array}\right],\ldots\,!\right\rangle\end{array}\right]$$

c.
$$\left[\begin{array}{l}\textit{nr-rel-clause} \\ \text{HD}\,|\,\text{CLAUSE-KEY}\,\boxed{1} \\ \text{NHD}\,|\,\text{INDEX}\,\boxed{2} \\ \text{C-CONT}\,|\,\text{ICONS}\left\langle\,!\left[\textit{aboutness-topic}\right],\left[\begin{array}{l}\textit{bg} \\ \text{IARG1}\,\boxed{1} \\ \text{IARG2}\,\boxed{2}\end{array}\right]!\right\rangle\end{array}\right]$$

(30a) is used for all phrase structure rules of non-relative clauses, such as *head-subj-phrase*. The co-reference $\boxed{1}$ in the AVM makes all dependents in a single clause share the same CLAUSE-KEY, and the CLAUSE-KEY is the same as the INDEX of the semantic head of the clause. All relative clauses inherit from (30b).[19] IARG1 is co-indexed with the INDEX (i.e. the semantic head) of the non-head daughter (i.e. the relative clause) as $\boxed{2}$, and IARG2 is co-indexed with the INDEX of the head daughter (i.e. the antecedent) as $\boxed{1}$. Note that the information structure relation that the relativized NPs have to the relative clauses should be constructionally added using C-CONT, because the meaning is specified at the phrasal level. Because there can be more values in the list of ICONS, the list is not closed (as described as ', ...'). (30c) is responsible for the phrase structure rule of non-restrictive

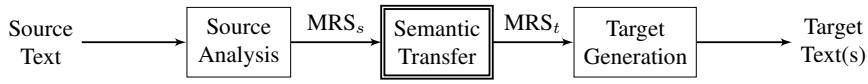
[19] Note that Figure 2 is just a simplified version of the entire type hierarchy presented in Sag, Wasow, and Bender (2003). One reviewer left a comment that the constraints presented in (30b-c) are assigned not to *rel-cl*, but *hd-rel-ph*. This comment is correct in theory. For instance, in *the dog which the cat chases*, *rel-cl* is only responsible for *which the cat chases*. Yet, this paper simplifies the division for ease of exposition.



[Figure 3] A sample derivation

relatives. Since (30c) comes under (30b), all constraints that (30b) has also go for (30c). (30c) includes several additional constraints: First, the first element in the ICONS list is more specified as *aboutness-topic*. This *aboutness-topic* element in (30c) inherits arguments of IARG1 and IARG2 from (30b). In other words, the value becomes more specific (i.e. from *focus-or-topic* to *aboutness-topic*), but the co-indices on arguments are the same. Second, the second element is specified as *bg*. The IARG1 is co-indexed with the CLAUSE-KEY of the antecedent as $\boxed{1}$, and the IARG2 is co-indexed with the INDEX of the relative clause as $\boxed{2}$. These co-indices mean that the non-restrictive relative clause has an information structure relation to the main clause, and the relation is background.

A sample derivation is provided in Figure 3. There are two individuals that participate in information structure: the head noun *dog* and the verb in the relative clause *chases*. The INDEXes of these two individuals are respectively co-indexed with IARG1 and IARG2 when a relative construction is built up. The element in the ICONS list is incrementally gathered up to the parse tree, and consequently the NP node at the top contains the element tagged as $\boxed{1}$. The value is specified as *focus-or-topic* because there is no clue to confirm that the relative clause has a non-restrictive reading. It is noticeable that the relative pronoun *that* is not a decisive clue for identifying a restrictive reading in this case. An ordinary prescriptive grammar insists that *that* should not be used for non-restrictive relative clauses, but in more than a few cases *that* occurs with non-restrictive readings in practice. Given that robustness is important in language applications, such a colloquial usage has to be reflected on computational modeling of human language.



[Figure 4] MRS-based architecture

4. Implementation

Semantics-based machine translation is composed of three components: namely parsing, transfer, and generation. Within this infrastructure, the representation form of MRS is crucially used as an input and an output between two components (i.e. parsing to transfer, transfer to generation, and sometimes directly parsing to generation) (Oepen *et al.*, 2007). Figure 4 is illustrative of the infrastructure based on the MRS framework, in which MRS goes between each component.

4.1 Data and Software

The grammar source I made use of is the ERG (English Resource Grammar, Flickinger (2000)), which is a broad-coverage, linguistically precise HPSG-based grammar of English. I created a branch of the ERG subversion trunk (`http://svn.delph-in.net/erg/trunk`) for this experimental implementation, and then added information-structure related statements (i.e. ICONS) into the grammar.[20] In particular, (30b-c) were described in TDL (Type Definition Language, Krieger and Schäfer (1994)) as presented in (31). Whilst (31a) corresponding to (30b) has one element in the list of C-CONT|ICONS (i.e. `focus-or-topic`), (31b) corresponding to (30c) has two elements. The first one is `aboutness-topic`, and the second one is `bg`. The first line of (31b) defines `n_adj_relcl_prpnct` as a subtype of `n_adj_relcl_phrase`. On the other hand, (31c) presents the constraint on the relative clauses in which a comma is not overtly used. Notice that all relative clauses inherit from either (31b) or (31c). In (31c), the difference list of C-CONT|ICONS is terminated with only one element. Since (31c) inherits from (31a), the value of the element is likewise specified as *focus-or-topic*.

[20] Notice that this does not mean that the current ERG officially includes the constraints I propose in this paper. ICONS is basically implemented in the ERG, but incorporating information structure into the grammar is still under discussion.

(31) a.
```
n_adj_relcl_phrase := n_adj_int_phrase & isect_mod_phrase &
  [ SYNSEM [ MODIFD #modif & [ RPERIPH na_or_+ ],
             NONLOC.REL [ LIST #first, LAST #last ] & 0-dlist ],
    NH-DTR.SYNSEM [ LOCAL [ CAT [ HEAD verbal &
                                    [ TAM indic_tam &
                                          [ TENSE real_tense ],
                                      INV - ],
                                  VAL.SUBJ *olist_or_prolist* ],
                            CONT.HOOK.INDEX #index1 & [ SF basic-prop ] ],
                    NONLOC.REL [ LIST #middle, LAST #last ],
                    MODIFD #modif ],
    HD-DTR [ INFLECTD +,
             SYNSEM [ LOCAL [ CAT [ VAL.SPR.FIRST [ --MIN quant_or_deg_rel ],
                                    HEAD.MINORS.NORM non_number_rel ],
                              CONT.HOOK.INDEX #index2 ],
                      NONLOC.REL [ LIST #first, LAST #middle ] ] ],
    C-CONT.ICONS.LIST.FIRST focus-or-topic & [ IARG1 #index1,
                                               IARG2 #index2 ] ].
```

b.
```
n_adj_relcl_prpnct := n_adj_relcl_phrase &
  [ SYNSEM.PUNCT.PAIRED #paired,
    HD-DTR.SYNSEM [ LOCAL.CONT.HOOK.CLAUSE-KEY #clause,
                    PUNCT [ PNCTPR #pnctpr,
                            PAIRED #paired,
                            RPUNCT comma_or_pair_punct ] ],
    NH-DTR.SYNSEM [ LOCAL.CONT.HOOK.INDEX #index,
                    PUNCT [ PAIRED #pnctpr,
                            PNCTPR #paired ] ],
    C-CONT.ICONS <! aboutness-topic, bg & [ IARG1 #clause,
                                            IARG2 #index ] !> ].
```

c.
```
n_adj_relcl_nopair := n_adj_relcl_phrase &
  [ SYNSEM.PUNCT.PNCTPR #ppair,
    HD-DTR.SYNSEM [ LOCAL.CAT.VAL.SPR.FIRST.--MIN i_or_e_quant_or_deg_rel,
                    PUNCT.RPUNCT pair_or_no_punct ],
    NH-DTR.SYNSEM.PUNCT [ RPUNCT comma_or_rbc_or_clause_or_no_punct,
                          PNCTPR #ppair ],
    C-CONT.ICONS <! [] !> ].
```

The software package I used is ACE+yzlui. ACE (Answer Constraints Engine, `http://sweaglesw.org/linguistics/ace`) is a processor for parsing and generating sentences using the DELPH-IN resources (`http://www.delph-in.net`).[21] The current work deploys this processor for both parsing (4.2) and generation (4.3). When using ACE, ICONS can be separately invoked by adding the following lines into the configuration.

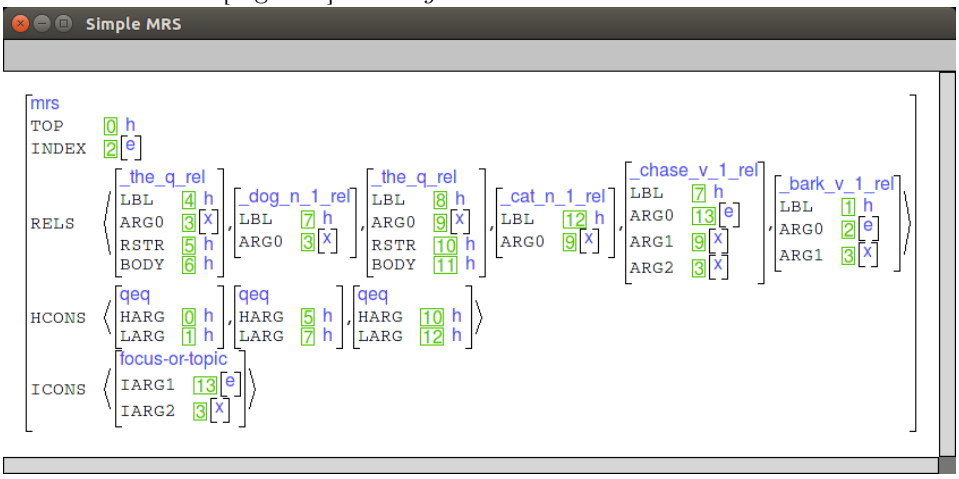
(32)
```
enable-icons := yes.
mrs-icons-list := ICONS LIST.
icons-left := IARG1.
icons-right := IARG2.
```

Speaking of the user interface, yzlui plays the function.[22] This is a visualization tool (Linguistic User Interface) for the most common object types in constraint-based grammars, such as trees, feature structures, MRSs, charts, and so on. ACE

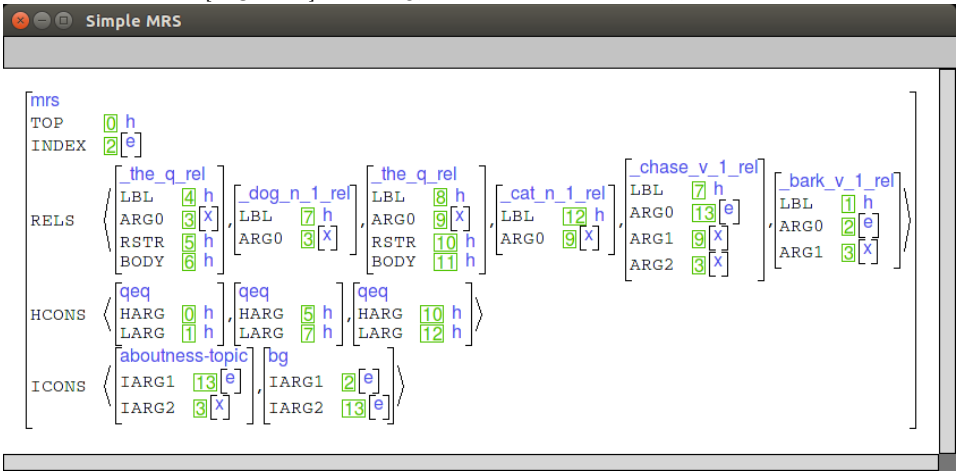
[21] ACE works on Linux and Mac OS X, but not on Windows. The precompiled binary working on 64-bit machines is distributed, the latest version of which is 0.9.19, as of 2014-10-22. The source code is also downloadable (`http://sweaglesw.org/svn/ace/trunk`).

[22] `http://yz-windows.sourceforge.net`

[Figure 5] *The dog that the cat chases barks.*



[Figure 6] *The dog, which the cat chases, barks.*



can call the interface as a command option when parsing sentences.[23]

[23] For more information, see the DELPH-IN wiki (`http://moin.delph-in.net`).

4.2 Parsing

Figure 5 and Figure 6 are the screenshots of the simple MRSes of two sentences.[24] Recall that the sentence used in Figure 5 can have either a restrictive reading or a non-restrictive reading, because the non-existence of comma and the relative pronoun *that* are not regarded as a clue of restrictive relatives in the current work. In Figure 5, the ICONS list contains one element of which the value is *focus-or-topic*. The IARG1 is specified as $\boxed{13}$, and this number also appears as a value of ARG0 of *_chase_v_1_rel* in the RELS list (i.e. co-reference). On the other hand, the IARG2 value is $\boxed{3}$, and this is the same as the ARG0 values of the first *_the_q_rel* and *_dog_n_1_rel* in the RELS list. This co-indexation indicates the binary relation between two individuals. That is, *dog* has the *focus-or-topic* relation to *chases*. In Figure 6 with a non-restrictive reading, there are two ICONS elements. The indices in the first element is the same as those in Figure 5, but the value is more specific (i.e. *aboutness-topic*). In the second one valued as *bg*, the IARG1 is co-indexed with the ARG0 of *_bark_v_1_rel* (i.e. $\boxed{2}$) and the IARG2 is co-indexed with the ARG0 of *_chase_v_1_rel* (i.e. $\boxed{13}$). This indexation represents that the relative clause serves as a background of the main clause. Other than these two elements, these two MRSes share the same representation. In other words, only the two ICONS elements in Figure 6 make non-restrictive relatives more informatively specific.

4.3 Generation

If a computational grammar is truly generative in theory, the grammar should be able to generate well-formed sentences. In other words, a well-created computational grammar can be used for generating natural language sentences as well as understanding them. What follows checks if the computational model implemented thus far also fits into generation.

The basic mechanism of how ICONS works in generation is as follows: First, ACE carries out ICONS-based generation via subsumption check, using the type hierarchy of *info-str* (presented in Figure 1). ACE generates all sentences that logically fit in the input MRS, not considering the constraints on ICONS. After that, if the grammar is compiled with the parameters provided in (32), ACE filters out a set of sentences mismatching the values in the ICONS list. Second, if there is an element in the ICONS list of the input MRS, the element must exist in the source MRS, too. The value should be either the same as that in the input MRS or its supertype. A completely underspecified output for each ICONS element is not allowed in generation. Third, the opposite direction is acceptable. That is to say, even if a constituent introduces no ICONS element in the input, the output can include an information structure-marked constituent.

Based on this mechanism, the two parsed sentences result in the following sentences. All sentences presented in (33) are created by using the MRSes provided in Figure 5 and Figure 6 as the inputs (see Figure 4).

[24] These MRSes are constructed via building up the parse trees. Since only contentful elements can be inserted into the RELS list, the relative pronouns (a.k.a. syncategorematic items) do not turn up in the MRSes.

(33) a. The dog that the cat chases barks.
(i) The dog, which is chased by the cat, barks.
(ii) The dog, who is chased by the cat, barks.
(iii) The dog, that is chased by the cat, barks.
(iv) The dog which is chased by the cat barks.
(v) The dog that is chased by the cat barks.
(vi) The dog who is chased by the cat barks.
(vii) The dog, which the cat chases, barks.
(viii) The dog, who the cat chases, barks.
(ix) The dog, that the cat chases, barks.
(x) The dog which the cat chases barks.
(xi) The dog that the cat chases barks.
(xii) The dog who the cat chases barks.
(xiii) The dog the cat chases barks.
b. The dog, which the cat chases, barks.
(i) The dog, which is chased by the cat, barks.
(ii) The dog, who is chased by the cat, barks.
(iii) The dog, that is chased by the cat, barks.
(iv) The dog, which the cat chases, barks.
(v) The dog, who the cat chases, barks.
(vi) The dog, that the cat chases, barks.

Note that the sentences given in (33b) is a subset of those given in (33a), and all sentences presented in (33b) contain commas. As aforementioned, the use of comma is regarded as a sufficient condition for non-restrictive readings. Although a comma does not appear, the relative clause can be interpreted as conveying a non-restrictive reading. In contrast, if a comma appears, the relative clause is always non-restrictively interpreted. The subset relation between (33a) and (33b) shows that the constraint imposed on the sentence used in (33a) subsumes the constraint imposed on the sentence used in (33b). Thus, the sentence (33a) can be either restrictive or non-restrictive, whereas the sentence (33b) is exclusively non-restrictive. As a result, the two lists of generated sentences provided in (33) substantiate that the implementation of the current work works for generation as well as parsing exactly in the expected way.

5. Conclusion

This paper provides a flexible and computational tractable model of approaching information structure of relative clauses in English. Relative clauses in English and many other languages are commonly used to link multiple clauses into a single information unit. Since relativization contributes to information structure in such a way, it is rewarding to include information structure of relative clauses into semantic representation for better performance in language processing.

The grammatical theory the present study is based on is HPSG (Pollard and Sag, 1994), and MRS+ICONS is employed as a meaning representation system with an eye toward semantics-based machine translation (Copestake *et al.*, 2005; Song,

2014). There are two necessities for using MRS+ICONS for representing information structure: First, because information structure of human language sentences is often ambiguous, the representation should be described as parsimoniously as possible for robust computation (i.e. underspecification). Second, the best way of incorporating information structure values into grammatical components is to use a binary relation between an information-structure marked individual and the clause the individual belongs to. Building upon these two, a type hierarchy of information structure values is presented in Figure 1.

This paper surveys several previous studies about information structure of relative clauses, including Kuno (1976), Bresnan and Mchombo (1987), and so forth. On top of them, the present work proposes two constraints: First, relativized NPs are assigned *focus-or-topic*. This constraint means that the relativized NPs play a role of either focus or topic with respect to the relative clauses. Second, non-restrictive relative clauses place more specific constraints on information structure. The antecedents of non-restrictive relative clauses have *aboutness-topic*, and the non-restrictive relatives are informatively background (i.e. *bg*) of the host sentences.

All proposals offered in the current work are implemented in TDL in order to check out the computational feasibility. The grammar source that I used is the ERG, and the software package consists of ACE plus yzlui. An illustration of implementation is provided in Figure 5 and Figure 6.

Further studies include the followings: First, non-restrictive relatives are assumed to be a subtype of appositive clauses in the current work, but appositive clauses need to be more researched. Especially, appositive clauses are often devoid of verbal predicates as shown in (24). In this case, the binary relation between an individual and the clause (i.e. ICONS) may not be satisfactorily resolved under the current system. Second, in order to concentrate on semantic representation the current work bypasses several information structure-related components, and these include contrastiveness within relative clauses, pragmatic properties of the relativized nouns, and interaction between information structure and discourse layer with respect to relativization. They must be researched more in future work. Third, information structure of relatives in other languages will be continuously implemented on a par with that in English. Relative clauses are important in quite a few languages to build up longer sentences, and computational linguistics has to pay attention to them for a practical purpose. Finally, it is necessary to conduct an evaluation of multilingual machine translation, focusing on multiclausal utterances such as relative clauses. I am optimistic that this representation system helps improve machine translation in that successful translation should mean reconstructing the ways of packaging information units in a sentence.

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