Towards Semantic Role Labeling of Hand-drawn Sketches

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Abstract

In this paper we propose an exploratory study for the application of Computational Linguistics techniques such as the Semantic Role Labeling of natural languages (SRL) to the case of sketch understanding. Our approach originated from a preliminary psychological experiment in which participants were asked to produce hand-drawn sketches from sentences embedding various semantic features; the effectiveness of so-obtained sketches was then assessed by other participants who were asked to match the sketches with the original sentences. This paper will present a preliminary study for automating the extension of Semantic Role Labeling to the case of hand-drawn sketches and will provide an initial example of its applications consisting in the evaluation of the drawing style consistency of sketches. This study will seek to enrich the body of research related to semantic sketch understanding.

1. Introduction

Nowadays many visual languages, intended as sets of pictures, are used to communicate concepts in an intuitive and synthetic way. Examples include the instructional material for assembling furniture or computers, graphical layouts drawn by teachers for learners, road signs, engineering graphical notations, etc. In all these cases, for the pictures to have an advantage with respect to verbal communication, the target users must easily reconstruct the intended semantic coded in the pictures.

Also in the human case, knowing the semantic roles played by the entities that appear in a hand-drawn sketch is of major importance for understanding its underlying meaning. The inherent picture ambiguity and the way its constituents are spatially related can lead to very different interpretations of the same sketch.

Research on sketch understanding has taken many directions in the past decade and mostly it has tended to concentrate on the interpretations of the strokes forming the sketches [5, 12] and also when semantics is involved it is used for improving syntactic recognition [22]. In this paper we present our main ideas on how computational linguistics techniques can be used to address the problem of semantic sketch understanding. This is achieved by manually tagging constituents of sketch sentences with corresponding constituents of natural language sentences. We believe that the proposed approach may be a good starting point also to be used when considering verbal descriptions in multimodal interactive interfaces, especially when meanings of speech and drawing have to be merged [1].

In particular, we are interested in the use of semantic role labeling [8], one of the most promising approaches lately developed for natural language processing with interesting applications in the field of information extraction, question-answering, natural language database querying, spoken dialogue systems, machine translation, text summarization, story merging, and others. While some of these applications are common for hand-drawn sketches, such as for query-by-sketch, [11], the others can provide new insights in the use of sketches.

The main contribution of this study is a first example of the application of Semantic Role Labeling of natural languages (SRL) to the case of hand-drawn sketches in order to obtain automatic Sketch Semantic Role Labeling (SSRL). We believe that, once this has been achieved, many of the applications of SRL can be extended to the case of hand-drawn sketches.

This paper intends to provide a starting basis for:

- creating a corpus for semantic analysis of sketches, consistent with a more general conceptual representational format and
- automating sketch analysis, to help evaluate their efficacy in communication.

In order to be able to consistently identify correspondences between conceptual and semantic features and their actual pictorial implementation, an experimental survey was undertaken involving human subjects [9], and the resulting empirical data was analyzed.

The following sections will discuss the empirical experiment, recall the main features of Semantic Role

Labeling of natural languages - as described in the current literature, - describe Sketch Semantic Role Labeling, and then illustrate an example of the potential applications to evaluate a weak form of hand-drawn style consistency of a sketch with respect to already semantically labeled sketches.

2. Experiment

The main goal in designing the experiment was to empirically identify correspondences between semantic features and pictorial elements and to explore a method for analyzing efficacy: operationally defined as the difficulty in matching pictures with original sentences.

The experiment was divided into two stages and utilized two separate groups of participants – one for each stage of the experiment. In the first stage, the participants acted as "subjects" whilst in the second stage the participants acted as "judges".

Table 1 - General properties of situations

case 1 - Relationships expressible by pictorial elements
- a) No relationships
- b) Topological or ordinal spatial location
  e.g.: above / between / adjacent
- c) Metric spatial location
  e.g.: near to…, far from…

case 2 - Properties expressible only by numbers
Non concretely countable objects
e.g.: one hundred houses

case 3 - Properties that require conventional symbols
- a) Qualification
  e.g.: is red / is green
- b) Single belonging or possession
  e.g.: Alan's
- c) Multiple belonging or possession
  e.g.: Alan & Burt's

case 4 - Mixed (can be expressed as pictures, symbols, or both)
- a) Concretely countable objects
  e.g.: two houses
- b) Comparison, difference, correspondence
  e.g.: more than / less than / how many

case 5 - Transformation
Reduction, addition (in this case there are two boxes, representing first-after times)
e.g.: Alan had …, then he gave … / , then he bought …

Table 2 - Sentences

1. A house
2. Two houses
3. One hundred houses
4. Alan's house
5. The house where Alan, Burt, and Chris live
6. The house on the mountain
7. Alan's house on the mountain
8. Two houses on the mountain
9. One hundred houses on the mountain
10. A house with 100 windows
11. A house has 50 windows on the 1st floor and 50 windows on the 2nd floor
12. A house has 50 windows on the 1st floor and 50 windows on the 2nd floor. The 1st floor belongs to Alan; Burt and Chris live on the 2nd floor
13. A house near the mountain
14. In Alan's garden there are 50 trees. Burt has more trees than Alan
15. Alan's house is in Park Street between the town council and the chemist
16. There are red books and green books
17. There are red books and green books. There are 34 red books and 85 books in all
18. Alan has 34 books. He read 12 of them, he, now, has 22 books to read
19. Burt had 15 books. He bought 8 more, now he has 23 books

In the first stage, participants were asked to represent graphically a series of sentences (as presented in Table 2), describing a number of different types of situations (as presented in Table 1) that included some interesting, from our point of view, conceptual aspects or relations. This taxonomy is not meant to be exhaustive but was devised as a starting point.

There were spatial situations (relations such as "above", "nearby", etc.), set situations like in arithmetic situations (where a set is divided into parts or subsets), and time situations (where events occur at different stages in time).

In the second stage, other participants acted as judges; their task was to match pictures drawn by the subjects in stage 1 (in random order) with the sentences from Table 2. The aim of this procedure was to evaluate the appropriateness of the pictures to their intended purpose, i.e. communicating information to other people. Participants in stage 2 were not taught explicit procedures, in order to encourage them to develop their own implicit procedures as they encountered more and more complex and abstract situations.

Stage 1 - Method

Participants

40 adults participated in the experiment. All of them were volunteers, students at the University of Genoa.

Materials

Descriptions referred to situations of different kinds, as shown in Table 1 depicting general characteristics of situations, with examples. There were five cases: 1) no pictorial-symbolic integration was required (relations could be expressed only by pictorial elements); 2) use of numbers was implicitly required; 3) use of conventional symbols was implicitly required; 4) information could be expressed indifferently by pictorial or symbolic elements; 5) a double representation was required in order to account for transformations that implied a first-after sequence.

Table 2 shows how characteristics were embodied into different sentences, in various combinations. Situations described by the sentences were arranged in increasing order of complexity and level of abstraction. Some picture examples with respect to sentence number 14 are shown in Section 4.

Procedure

The participants were given a 19-page booklet; each page contained a verbal description of a situation printed on top of an empty box. Their task was “to represent without words” each situation. Drawings, single letters, numbers, and symbols were allowed; only a monochrome (black) pen was available. Subjects were instructed that the representation should be "clear enough in order that another person could reconstruct the sentence from the picture only". Sentences were presented in booklet pages in the same order as in Table 2, by increasing complexity.

Stage 2 Method

Participants

8 subjects, students at the University of Genoa, participated in the experiment as volunteers.

Materials and procedure

8 sets of sketches produced by 8 participants in stage 1 were randomly selected for this stage. Each set was composed of all 19 pictures, so that in each set all 19 sentences had been depicted and there was one correct picture-sentence match. Each new subject here acted as a “judge”.

Table 3 - The ordered list of sentences

Sentence	Mean	Mean st.dev.
17. There are red books and green books. There are 34 red books and 85 books in all	.39	.49
11. A house has 50 windows at the 1st floor and 50 windows at the 2nd floor	.44	.34
12. A house has 50 windows at the 1st floor and 50 windows at the 2nd floor. The 1st floor belongs to Alan; Burt and Chris live at the 2nd floor	.48	.38
7. Alan's house on the mountain	.52	.36
18. Alan has 34 books. He read 12 of them, now has 22 books to read	.53	.32
4. Alan's house	.64	.39
19. Burt had 15 books. He bought 8 more, now he has 23 books	.64	.40
5. The house where Alan, Burt, and Chris live	.66	.24
10. A house with 100 windows	.69	.42
3. One hundred houses	.72	.23
8. Two houses on the mountain	.72	.31
9. One hundred houses on the mountain	.73	.40
6. The house on the mountain	.73	.44
1. A house	.83	.36
15. Alan's house is in Park Street between the town council and the chemist	.84	.22
16. There are red books and green books	.86	.27
2. Two houses	.95	.13
13. A house near the mountain	.95	.13
14. In Alan's garden there are 50 trees. Burt has more trees than Alan	.97	.09

Their task was to match each picture with the corresponding sentence. Pictures were presented in random order. Sentences were listed in alphabetical order and, in order to avoid that numbers acted as a possible cue for correct picture-sentence matching, all numbers were replaced by x,y,z,.. letters. For example, sentence number 11 became: “A house has x windows at the y-th floor and z windows at the t-th floor”.

Results

In Table 3 the mean proportion and standard deviation of correct matches for each sentence, from the most difficult to the easiest, are shown.

Discussion

A qualitative analysis stemming from the experiment showed that in many cases it is possible to associate parts of the drawings with parts of the originating verbal descriptions. In particular, there is evidence that the expressiveness of the drawings depends on how “well” the parts of the drawing represent the corresponding parts of the verbal descriptions, and how the spatial relations (implicit ones such as nearby, above, etc. and explicit ones such as arrow, link, etc.) between the sketched parts recall the properties described in the verbal description such as possession, location, etc.. Therefore, the appropriateness of the pictures to their intended purpose appears to be enhanced when consistent use of visual and spatial relation descriptions are used.

These considerations allow us to state that it is appropriate to label parts and relations in a hand-drawn sketch with semantic roles in order to enhance sketch understanding and reasoning.

Semantic labeling is a well known technique in computational linguistics formalized as Semantic Role Labeling (SRL). The main idea is then to use the knowledge gained so far in the SRL of natural languages in order to obtain Sketch Semantic Role Labeling (SSRL). Once this has been achieved, applications of SRL can be extended to the case of hand-drawn sketches by using SSRL.

In the next sections the main features of Semantic Role Labeling for the natural languages, as described in the current literature, will be reviewed. In addition we will describe our approach and difficulties encountered, and then illustrate an application of SSRL.

3. Semantic Role Labeling

Let us recall the main characteristics of SRL as presented in [20].

“Semantic Role Labeling involves the determination of domain-independent semantic relations among the entities and the events they participate in.

Given a sentence, one formulation of the task consists of detecting basic event structures such as "who" did "what" to "whom", "when" and "where". From a linguistic point of view, a key component of the task corresponds to identifying the semantic arguments filling the roles of the sentence predicates. These predicates are mainly lexicalized by verbs but also by some verb nominalizations and adjectives. Typical predicate semantic arguments include Agent, Patient, and Instrument; semantic roles may also be found as adjuncts (e.g., Locative, Temporal, Manner, and Cause). The related tasks of determining the semantic relations among nouns and their modifiers, as well as prepositions and their arguments, are clearly important for text interpretation as well, and indeed often draw on similar role labels.

Recently, the compilation and manual annotation with semantic roles of medium-large corpora – the PropBank [16, 17], and FrameNet [6, 7] initiatives – has enabled the development of statistical approaches specifically for the task of semantic role labeling. SRL, especially focused on the labeling of verbal arguments and adjuncts, has become a well-defined task with a substantial body of work and comparative evaluation (e.g., see [8], CoNLL Shared Task in 2004 and 2005, Senseval-3).”, [20].

As an example of SRL let us consider the following sentences referring to the frames of Trading, Judgement and Statement respectively:

[$_{\text{temporal}}$ At the end of the day] , [$_{\text{things being traded}}$ 251.2 million shares] **were traded** . (TRADING)

[$_{\text{Judge}}$ She] **blames** [$_{\text{Evaluee}}$ the Government] [$_{\text{Reason}}$ for failing to do enough to help]. (JUDGEMENT)

[$_{\text{Message}}$ “I’ll knock on your door at quarter to six”] [$_{\text{Speaker}}$ Susan] **said**. (STATEMENT)

The identification of such event frames will have an important impact in many Natural Language Processing applications such as Information Extraction [19], Question Answering [15], Summarization [14], Machine Translation [2], as well as Story Merging [13].

“Although the use of SRL systems in real-world applications has so far been limited, the outlook is promising over the next several years for a spread of this type of analysis to a range of applications requiring some level of semantic interpretation.” [20]. In our opinion these will naturally include semantic sketch understanding.

There are many algorithms for semantic shallow parsing to assign semantic roles. This study will specifically refer to the online UIUC parser [4, 18]. The parser not only provides semantic role labeling of the sentence parts but also outputs a syntactic parse tree according to the Charniak parser [3] allowing us to recover as much information as possible on each part of the sentence.

4. Semantic Sketch Role Labeling

In order to define the semantics of sketches we need to start creating a corpus of annotated sketches similarly to what it has been done with PropBank and FrameNet [16, 17, 7]. To do so we propose a way of semantically labeling sketches according to the following two basic steps:

a) *Sketch-sentence association*

   By starting from the description in natural language, a sketch is drawn and parts of it are annotated with the corresponding parts of the text description.

b) *Sketch semantic role labeling*

   By applying a shallow semantic parser the sentence is analyzed and labeled, together with the annotated sketch, with syntactic (Charniak parser) and semantic roles based on the PropBank and FrameNet corpus.

Step *a)* identifies the semantically dense parts of the picture while step *b)* assigns semantic labels to each of its parts. One of the difficulties with this approach is the alignment of the partitions produced in each step.

Figure 1 shows how this can be realized, each action is represented by a circled number indicating the sequence of execution.

The input sentence is partitioned and its parts are semantically annotated through the SRL technique (action 1 in Figure 1). Parts of the hand-drawn sketch are then labeled with the resulting sub sentences (action 2). Finally, the semantically labeled sketch is derived by merging results from the previous actions (action 3).

The parts of the hand-drawn sketch to be labeled must be chosen accordingly. In fact, a hand-drawn sketch is composed of a set of (spatially) related visual symbols or constituents [21].

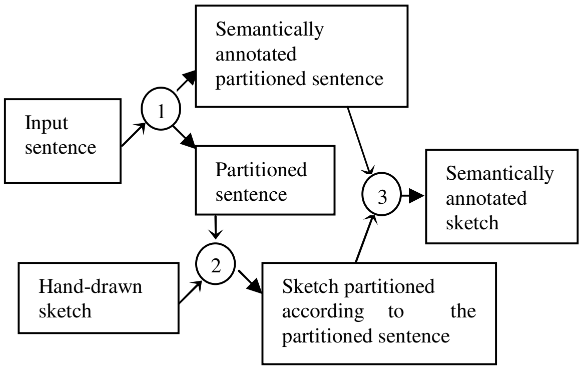


Figure 1. The Sketch Semantic Role Labeling methodology

An important task in the user sketch-sentence association is then the identification of the visual symbols and of the (spatial) relations to be labeled. It must be noted that, as detailed in [21], relations in a picture can be either *implicit* such as the spatial relations nearby, below, above, etc. or *explicit* such as arrows, links, etc., i.e., relations with a visual representation.

As an example let us consider the sentence number 14 from Table 2. This sentence has been chosen because it resulted to be the easiest to match in stage 2 of the experiment.

In Alan's garden there are 50 trees. Burt has more trees than Alan

Sketch-sentence association

Figure 2. shows the results of the analysis obtained by applying the shallow semantic parser in [4], while Figure 3 and 4 on the next page show two hand-drawn sketches produced by two participants in stage 1 graphically depicting the sentence.

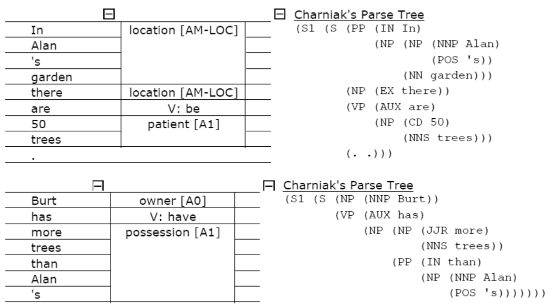


Figure 2. Semantic role labeling and Charniak annotation

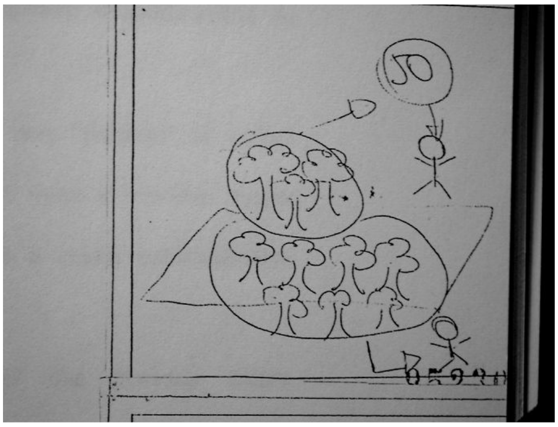
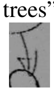
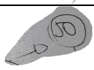
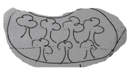


Figure 3. Participant 1 hand-drawn sketch

Table 4. Sketch Semantic Role Labeling for Fig. 3

Sentence	**Participant 1 sketch**	**Charniak parser annotations**	**PROP-BANK annot.**
In			location [AM-LOC]
Alan		NNP (Proper noun, singular)	
's	nearby ("Alan", "garden")	POS (Possessive ending)	
garden		NN (Noun, singular)	
there	nearby ("garden", "50 trees");  arrow ("50", "Alan")		
are			V: be
50		CD (cardinal number)	patient [A1]
trees.		NNS (Noun, plural)	
Burt			owner [A0]
has	 arrow ("more trees", "Burt")		V: have
more		JJR (Adjective, comparative	possession [A1]
trees		NNS	

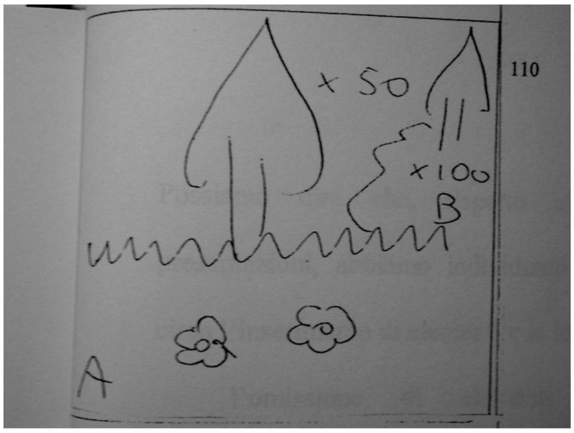
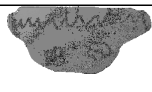
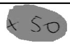
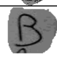
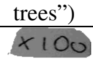
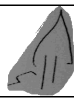


Figure 4. Participant 2 hand-drawn sketch

Table 5. Sketch Semantic Role Labeling for Fig. 4

Sentence	**Participant 2 sketch**	**Charniak parser annotations**	**PROP-BANK annot.**
In			location [AM-LOC]
Alan		NNP (Proper noun, singular)	
's	nearby("Alan", "garden")	POS (Possessive ending)	
garden		NN (Noun, singular)	
there	nearby("garden", "50 trees")		
are			V: be
50		CD (cardinal number)	patient [A1]
trees.		NNS (Noun, plural)	
Burt			owner [A0]
has	nearby("Burt", "more trees")		V: have
more		JJR (Adjective, comparative)	possession [A1]
trees		NNS (Noun, plural)	

In Figure 3 participant 1 drew the garden as a four-sided figure, the two sets of trees as circles including tree shapes, Alan and Burt as human shaped sketches (stick figures). In Figure 4, Alan and Burt are depicted as letters A and B, respectively, the garden as a waved line with flowers underneath, the two sets of trees as two tree shaped figures with the multiplication sign and a number to indicate quantity. We note that in Figure 3 there is an inconsistent use of the arrow shape which is used both for meaning quantity (50 trees) and possession (Alan has 50 trees, Burt has more).

Sketch semantic role labeling

Table 4 and 5 provide a potential manual labeling of semantic roles for both pictures in Figure 3 and 4 resulting from the methodology proposed in Figure 1. The tables are based on SRL and Charniak annotation of Figure 2.

In particular, each row in Table 4 and Table 5 contains a part of the hand-drawn sketch (in the 2nd column) drawn by the participant, the substring of the sentence with which the sketch has been manually annotated (in the 1st column) and the annotations on the sub-sentence resulting from the Charniak parser and the Prop-Bank corpus are presented in the 3rd and 4th column, respectively. While the association between the sub sentence and the sketch have been done manually, the Charniak parser and Prop-Bank annotations are done automatically based on the SRL techniques quoted in Section 3.

These tables then show how parts of the hand-drawn sketches (column 2) inherit the semantic roles (columns 3 and 4) of the corresponding sub sentences (column 1).

As an example let us consider Table 4.

In the row with sub sentence "**Alan",** Alan is associated to  and the system (the UIUC parser) describes the syntactic role of **Alan** as a singular proper noun and gives the semantic role of part of a location specification to it.

In the row in Table 4 with sub sentence "**has**", possession is depicted by drawing an arrow between the visual representations of Burt and his garden. Note that the grey text in the sixth row ("are") of Table 4 corresponds to the arrow between 50 and Alan. As previously mentioned, this arrow does not actually have a direct correspondence in the original text sentence: it stresses the fact that Alan has 50 trees.

In this example the inconsistency is due to the fact that the sketch has been drawn with no knowledge about the sentence partitioning since the experiment precedes the design of our procedure. In a real application the semantic annotation will have to be created while drawing the sketch.

5. An SSRL Application

One of the features that a "good" visual language should have is the semantically consistent use of graphical forms and spatial relations in its pictures.

In this application we are interested in checking the semantic consistency of a hand-drawn sketch with respect to a pre-built corpus. We will use Tables 4 and 5 of Section 4 as a corpus. By "checking the consistency" we mean checking if the drawing style is compatible with one of the drawing styles coded in the corpus. In particular, in the following we restrict the drawing style to the case of consistent use of spatial relations.

As an example let us consider the following sentence:

Fred owns a house

and its semantic and syntactic labeling as produced by [4], as shown in Figure 5.

Fred	owner [A0]
owns	V: own
a	possession [A1]
house	

Charniak's Parse Tree

```
(S1 (S (NP (NNP Fred))
       (VP (VBZ owns)
           (NP (DT a)
               (NN house)))))
```

Figure 5. Semantic role labeling and Charniak annotation

Two possible hand-drawn sketches corresponding to the given sentence are shown in Figure 6 below.

(i) (ii)

Figure 6. Hand-drawn sketches for the sentence **Fred owns a house.**

In both cases (i) and (ii) a user will associate  with "Fred" and  with "house". In case (i) the verb "owns" will be associated to the relational fact nearby("Fred", "house") or, more specifically, nearby(owner, possession). In case (ii), "owns" will be associated to the relational fact arrow(owner, possession).

By properly matching the semantic role labeling of the sentence "Fred owns a house" and considering its visual associations against the labeling and associations of tables 4 and 5 it becomes possible to state that the hand-drawn sketch of Figure 5(i) is in the same relational drawing style of Participant 2, while the hand-drawn sketch of Figure 5(ii) is in the same relational drawing style of Participant 1.

6. Conclusions

In this paper we have presented a way for annotating hand-drawn sketches semantically. The study was originated from the results of a preliminary psychological experiment and based its proposed implementation on the computational linguistics technique of Semantic Role Labeling.

We would stress the relevance of this research on multiple and multidisciplinary grounds: for the implementation of effective techniques of automatic analysis, for a more comprehensive understanding of the relationships of sketch representation, considered as a language, with natural language, and for the understanding of cognitive processes implied in sketch representation.

Another important issue, worth to be explored for practical purposes, regards the investigation of pragmatic aspects, [10], since the effectiveness of communication is somehow dependent upon the task at hand.

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