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Graph-based Constraint Propagation for Massively-Parallel Natural Language Processing

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1 Constraint Propagation in Memory

We propose the model of massively-parallel natural language processing based upon the propagation of graph represented constraints. The central notion of the proposed model is the **propagation of constraints** in the semantic memory network. We call the model of massively-parallel memory extended with the capacity to propagated graphs *Graph-based Constraint Propagation Network (GCPN)*. While retaining the semantic (and pragmatic) expressivity of memory-based schemes, the syntactic expressivity of the graph-based constraint propagation scheme is significantly greater than that of traditional memory-based schemes and their extensions. In fact, a significant number of current linguistic theories are based upon the formulations of constraints based upon feature-structures and unification operations on them (such as FUG [Kay, 1984], HPSG [Pollard and Sag, 1987] and LFG [Bresnan and Kaplan, 1982]), which are captured through directed graph representations and graph-unification operations[1] on them. The GCPN is configured hierarchically in terms of conceptual inheritance. Graph propagation occurs upward in the inheritance hierarchy and when propagated constraint graphs of complement nodes meet postulated conceptual constraint nodes of head nodes, constraint graphs are unified one another.

2 From Direct Memory Access to Graph Propagation

The so called 'direct memory access' (or memory-based) paradigm of natural language recognition seems to have established itself as an important approach to natural language processing and machine translation[2]. Originated by Quillian ([Quillian, 1969]), this model of natural language processing views natural language understanding as the activity of identifying the input utterance with existing memory structures. While these memory structures have taken various forms depending upon underlying theoretical approaches (such as MOPs of [Riesbeck and Martin, 1985] and Cases in [Martin, 1989]) and upon levels commitments to the massively-parallel processing assumption (such as the weak assumption in [Riesbeck and Martin, 1985] and the strong assumption in [Waltz and Pollack, 1985]), the underlying control structure has remained the same, namely, spreading activation and marker passing. The advantage of this control structure is that since spreading activation takes place directly in the memory network, direct memory-based inferential processing can be employed at any point of recognition. Also since the underlying control structure is essentially massively-parallel, the models have taken advantage of massively-parallel hardware that has become recently available[3].

The weakness in the existing massively-parallel models of natural language processing to handle syntax is due to the fact that syntactic constraints are often highly structural and are assigned dynamically based upon particular structural patterns of the constituent buildup at the time of utterance. For example, a syntactic *case* of a particular noun phrase is dynamically determined at the time of the utterance based upon the particular syntactic configuration and is essentially impossible to capture *a priori* in the semantic network (otherwise we will have to specify infinitely many sentential patterns as well as many redundant subcategories of concepts based upon *case* variety simply to capture the *case* agreement phenomenon). Similarly a recognition of *Sue said that Mary ran* under the memory-based paradigm would require instantia-

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[1] Recently some fast graph-unification algorithms have been developed enhancing the appeal of graph unification-based constraint processing such as [Wroblewski, 1987], [Kogure, 1990], and [Tomabechi, 1991].

[2] Such as my own DMTRANS ([Tomabechi, 1987]) which was the first MT attempt under the Direct Memory Access paradigm.

[3] Such as [Kitano and Higuchi, 1991a].

超並列制約伝播による自然言語処理手法

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tion of two sequences of concepts in memory [***person** ***mtrans**-word that ***action**] and [***person** ***run**] (i.e., a typical sentential recognition methodology currently employed under this paradigm using patterns of concepts). The first sequence is probably attached to a root node such as ***mtrans-event** and the second sequence is attached to ***run-action** which is a subclass of ***action**. The last element of the first sequence ***action** will be activated by the recognition of any subclass of ***action** including ***run-action**, ***sleep-action**, etc.. However, there is no way to ensure that if the ***mtrans**-word is *said*, the set of entities that caused the activation of ***action** contain (be headed by) a finite verb (unless we create a possibly infinite number of concepts for different combinations of syntactic features such as ***finite-form-running-action-taking-nominative-subject**). Thus, it is essentially impossible to capture the grammaticality of *John said Mary runs* and the ungrammaticality of *John said Mary run* (or *John said Mary to run*) within the constraints capturable inside the semantic memory network. By the same token handling the so called *obligatory control* phenomenon (such as *persuade*) has been a problem in the past massively-parallel models. In our proposed model, none of these phenonema poses any problem due to the expressivity of graph-based constraint formulations. Structured constraints such as *binding* and *control* can be handled through graph-based constraint application (i.e., graph-unification) no different from the way these constraints are handled in the unification-based grammars.

3 Conclusion

The paradigm of natural language recognition based upon the direct recognition in a semantic memory has been appealing from different view points. These included the appeal from the cognitive view-points as well as the phenomenological ones (especially the assumed massive-parallelism). On the other hand, with few exceptions, syntactic constraints have been either ignored or handled in an *ad hoc* manner (such as requiring a triggering of arbitrary prestored daemons that handle particular constraints). In our model, syntactic phenomena problematic to existing memory-based models such as *case*, *agreement*, *control*, *binding*, and *long-distance dependency* can be handled in a generalized manner most straightforwardly as formulated by the modern linguistic theories based upon feature structures and unification. Because no separate (and essentially serial) control structure is required for handling syntax, uniformity of processing is maintained coherent to the underlying massively-parallel processing hypothesis of the memory-based architectures so that advantage of such processing as demonstrated by [Waltz, 1990] will not be sacrificed. With the expressivity of our model in capturing the constraints as postulated in the modern linguistic theories while retaining the advantages of memory-based recognition, our model seems viable as a base for the future generation natural language processing efforts[4].

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[4] See [Tomabechi, ms] for details of GCPN used under such a direction.