Formal & Computational Aspects of

Dependency Grammar

– Historical development of DG –

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Goal & Overview

- **Goal**: To provide an overview of the historical development of dependency grammar, set within the context of theoretical linguistics.
- **History in overview**
  1. DG in Ancient and Medieval times ($\pm$350 BC – $\pm$1500 AD)
  2. The formalisation of syntax (1950's, 1960's)
  3. Meaning enters the stage (1970's)
  4. The trouble with word order (1970's, 1980's)
  5. Formal grammar meets logic (1990's)

Contents

DG in Ancient and Medieval times

- Greek scholars like Thrax and Apollonius, later Latin scholars like Priscian.
- Pāṇini's formal grammar of Sanskrit (written 350/250 BC).
- The first known *theory* (systematic treatment) of Arabic grammar, including various levels of linguistic information, was based on concepts that now form the core of dependency grammar: *Kitāb al-Uṣūl* of Ibn al-Sarrāǧ (d.928).
  - Codifying the tradition, epitomized in Sībawayhi's (d.798) *Kitāb* and al-Xalīl's (d.791) *Kitāb al-'Ayn* (lexicography: first Arab dictionary)
  - The *uṣūl* ('foundations'), covering all linguistic facts, and the *'ilal* ('causes')
  - Syntax (*naḥw*) distinguishes a head (*āmil*) and its dependents (*ma'mūl fī-hi*). Nominal dependents can have different roles, such as *fā'il* ('actor,subject'), *mafā'īl* ('object'), *mubtada'* ('topic') or *khabar* ('comment').
- In medieval Europe, dependency-based notions were used by speculative and modistic grammarians, particularly Thomas of Erfurt or Martin of Dacia.

References: (Covington, 1984; Owens, 1988; Bohas et al., 1990; Fraser, 1994).

A history of modern formal grammar

- We are looking at the developments starting in the 1950's, dividing (sometimes parallel) historical developments into four phases:
  1. Formalisation: Away from descriptive linguistics and behavioralism
  2. Including meaning: Compositionality
  3. Word order: Needing stronger formalisms
  4. Grammar meets logic & computation
- In these phases, theoretical linguists addressed similar issues, but worked them out differently depending on the perspective they took – constituency-based, or dependency-based.
- These historical developments help explain why people lost their interest in DG, and why their interest is now renewed – without needing a (biased) comparison between constituency & dependency perspectives.

The formalisation of syntax

- What preceeded:
  - The 1930's: Bloomfield's (descriptive) notion of constituency, behaviorism in linguistics
  - The 1930's-1940's: Groundbreaking work in mathematical logic, computers (Gödel, Church, Kleene, Turing, Post)
- Chomsky's impact on the enterprise of syntax:
  - Mathematical results establishing formal language theory and the scale of types of grammar (nowadays called the Chomsky Hierarchy)
  - Critical review of B.F. Skinner's (1957) book *Verbal Behavior*
  - Chomsky's (1957) *Syntactic Structures*

References: (Chomsky, 1957; Davis, 1965; Sag and Wasow, 1999).

Chomsky's *Syntactic Structures*

- The preface of *Syntactic Structures* emphasizes the heuristic role of formalization in clarifying linguistic analyses, supporting empirical testing and falsification:

> "... The search for rigorous formulation in linguistics has a much more serious motivation than mere concern for logical niceties or the desire to purify well-established methods of linguistic analysis. Precisely constructed models for linguistic structure can play an important rolem, both negative and positive, in the process of discovery itself. By pushing a precise but inadequate formulation to an unacceptable conclusion, we can often expose the exact source of this inadequacy and, consequently, gain a deeper understanding of the linguistic data. More positively, a formalized theory may automatically provide solutions for many problems other than those for which it was explicitly designed. Obscure and intuition-bound notions can neither lead to absurd conclusions nor provide new and correct ones, and hence they fail to be useful in two important respects."

Chomsky's generative grammar

- **Generative grammar**: A context-free component, generating "kernel sentences", and a transformation component (cf. Harris (1957))

  (A) Generate a (finite) set of elementary sentences, and use transformations to broaden it to the class of representations of all sentences for a language.

  (B) Generate a (finite) set of representations of all sentences of a language, and then use transformations to arrive at surface forms.

- Variant (B) lead to *stratificational grammar*,
  - Stratificational grammar, cf. e.g. (Hays, 1964; Lamb, 1966).
  - Chomsky's (1965) *Aspects of the Theory of Syntax* adopts (B), and would later develop into Government & Binding theory (Chomsky, 1981), cf. (Haegeman, 1991; Higginbotham, 1997)

Tesnière, and stratificational DGs

- The modern notion of dependency grammar is usually attributed to Tesnière (1959) (dating back to 1939):
  - Tesnière aimed at a notion of grammar that would be useful in teaching foreign languages.
  - Tesnière's theory has two parts: The dependency theory, and the translation theory.
- Employing Tesnière's ideas about dependency, various formalisations in the form of stratificational DGs were proposed, e.g.:
  - Functional Generative Description: Sgall *et al* (1969; 1986), Petkevič (1987; 1995)
  - Meaning-Text Theory: Gladkij & Mel'čuk (1975), Mel'čuk (1988)
  - Abhängigkeitgrammatik: Kunze (1975)

The generative strength of DG

- Chomsky's formal language theory made it possible to ask for the *generative strength* of a grammar.
- For dependency grammar, various authors established such results:
  - Gross (1964), Hays (1964), Gaifman (1965), Robinson (1970).
  - Most authors established that a *class* of DGs are weakly equivalent to context-free PSGs.
  - But, Gross (1964)(p.49) claimed that "The dependency *languages* are exactly the context-free languages." Similar (mistaken) claims were made frequently in the literature.
  - Unfortunately so! Early on, CFGs were shown to be inadequate to model natural language, though; cf. Postal (1964), Peters & Ritchie (1971), also Ross (1967; 1970).
- This might have been one of the reasons why people lost interest in dependency grammar.

Early non-transformational approaches

- The landscape of formal grammar was not covered solely by generative (transformational) approaches.
- Bar-Hillel focused primarily on categorial grammar (Bar-Hillel, 1953), elaborating Ajdukiewicz's (1935) syntactic calculus, though provided with his algebraic linguistics (Bar-Hillel, 1964) a notion that was intended to cover a broader range of approaches to formal description of grammar (including dependency grammar).
- Lambek (1958; 1961) similarly focused on categorial grammar, though of a more logical (proof-theoretical) kind than Bar-Hillel's.
- Bar-Hillel, Gaifman and Shamir showed in 1964 though that, like DG, Bar-Hillel's categorial grammar was context-free; cf. (Bar-Hillel, 1964). Chomsky (1963) conjectured that Lambek's grammars were also context-free; cf. (Pentus, 1997) for the proof of that conjecture, and (Buszkowski, 1997).

Meaning enters the stage

- Chomsky was, in general, sceptical of efforts to formalize semantics. *Interpretative semantics* or the autonomy of syntax: Syntax can be studied without reference to semantics (cf. also Jackendoff).
- Criticism on both transformational and non-transformational approaches:
  - Transformations do not correspond to syntactic relations, relying too much on linear order.
  - Similarly, Curry (1961; 1963) criticized Lambek for the focus on order (directionality). Instead, Curry proposed a system of *functors* (i.e. valency, alike (Peirce, 1898)), including a type hierarchy, and considers functors to be "what Harris and Chomsky call transformations." (1961) This leads to *tectogrammatical* structures, which Curry distinguishes from *phenogrammatical* structures.

Meaning enters the stage

- Different ongoing efforts:
  - Developing a notion of (meaningful) logical form, to which a syntactic structure could be mapped using transformations. Efforts either stayed close to a constituency-based notion of structure, like in *generative semantics* (Fodor, Katz), or were dependency-based (Sgall *et al*, particularly Panevová (1974; 1975); Fillmore (1968)). Cf. also work by Starosta, Bach, Karttunen.
  - Perlmutter, Postal and relational grammar: "Syntactic relations are primitive, and indispensible notions."
  - Montague's formalization of semantics – though Montague and the semanticists in linguistics were unaware of one another, cf. (Partee, 1997)

Logical form, dependency, and stratificational grammar

- Formulation of a notion of *logical form*, describing the linguistically expressed/expres meaning, in terms of dependency relations.
- Panevová, Sgall focused on meaningful dependency relations like Actor, Patient, that could be differentiated on the basis of behavior in surface syntax (Panevová, 1974; Panevová, 1975).
- Following Curry (1961; 1963), Sgall *et al* would later talk of functors, and tectogrammatical representations. Unlike the logical form in generative semantics, a (Praguian) tectogrammatical representation do need further interpretation; cf. (Sgall et al., 1986), also (Partee, 1997).
- This set the Praguian approach apart from Fillmore (1968), who defined a set of dependency relations (*cases*) without providing overt (syntactic) criteria for distinguishing them.
- In a stratificational setting, a logical form ("deep structure") is transformed in successive stages into a representation of surface form. This makes it important for there being a mapping between dependency relations and form!

Montague and the development of formal semantics

- The foundational work by Frege, Carnap, and Tarski had led to a rise in work on modal logic, tense logic, and the analysis of philosophically interesting issues in natural language. Philosophers like Kripke and Hintikka added model theory.
- These developments went hand-in-hand with the "logical syntax" tradition (Peirce, Morris, Carnap), distinguishing syntax (well-formedness), from semantics (interpretation), and pragmatics (use).
- Though the division was inspired by language, few linguists attempted to apply the logician's tools inlinguistics as such. This changed with Montague.
- "I reject the contention that an important theoretical difference exists between formal and natural languages." (Montague, 1974)(p.188)
- A *compositional* approach, using a "rule-by-rule" translation (Bach) of a syntactic structure into a first-order, intensional logic. This differed substantially from transformational approaches (generative or interpretative semantics).

References: (Partee, 1996; Partee, 1997; Gamut, 1991)

The trouble with word order

- Traditional phrase-structure grammar (Bloomfield) is context-free (CFPSG), and therefore not strong enough to model natural language syntax.
- Chomsky (1957) therefore added transformations on top of a CFPSG.
- But, there are linguistic problems with transformations (no corresponding linguistic concept), and formal problems, Peters & Ritchie (1971; 1973).
- Moreover, Chomsky's arguments against CFPSG (incapable of generalization, mathematical proof concerning string languages) were shown to be flawed (e.g. by Gazdar, Pullum).
- Finally, studies in 'nonconfigurational' languages (e.g. Australian) starting in the 1970's gave rise to a more relational view on structure, in contrast to the configurationality of English.
- These problems led to the development of new, non-transformational grammar frameworks like Relational Grammar and Arc Pair Grammar, LFG, GPSG

Heads enter the scene

- Heads (asymmetric relations) start entering the scene, in various guises.
- Studies in nonconfigurational languages revealed that relations rather than phrases are typologically significant for the expression of meaning (cf. also (Bresnan, 2001)); Relational Grammar, Arc Pair Grammar, LFG.
- Distinction between rules for *Linear Precedence* (LP) and *Immediate Dominance* (ID).
  - Similar distinction proposed earlier (Curry, 1961; Šaumjan and Soboleva, 1963) but criticized in (Chomsky, 1965). In transformational grammar, several authors in the 1960's and 70's had considered *unordered* trees.
  - Transformations are too strong (Peters and Ritchie, 1973) if unconstrained. The best way to constrain a component of grammar is to eliminate it (Gazdar): Back to CFPSG, but a *generalized* form thereof using ID/LP and metarules – GPSG (Gazdar et al., 1985).
- (Uszkoreit, 1987) generalizes GPSG, defining more powerful LP rules.

Heads enter the scene: Categorial Grammar

- Related work was going on in categorial grammar (functional rather phrasal structure): (Venneman, 1977) binding dependency and functional structure – again, combining vertical and horizontal organization.
- In general though, categorial grammar tried to deal with flexible word order by introducing means of composition that were more powerful than application:
  - Bach's wrap operations (1984).
  - Ades and Steedman's combinatorial rules (1982) (also Jacobson, Szabolcsi, and later Hoffman (1995), Baldridge (1998), Steedman (1996; 2000)).
  - Moortgat's generalized connectives (cf. (1988), also work by Oehrle, Morrill, Van Benthem).
  - Only towards the end of the 1980's, early 1990's is dependency again explicitly introduced into categorial grammar: (Steedman, 1985; Hepple, 1990; Pickering, 1991; Moortgat and Morrill, 1991; Barry and Pickering, 1992; Moortgat and Oehrle, 1994).

Heads enter the scene: HPSG

- The developments in GPSG, LFG, and Arc Pair Grammar showed the feasibility of a nontransformational perspective, employing a relational perspective to obtain better generalizations.
- Furthermore, in computer science the 1980's witnessed the development of *feature logics*: Kasper, Rounds, Johnson, Moshier – cf. (Rounds, 1997). Feature logics were rapidly embraced and introduced into formal grammar by e.g. Carpenter (1992), King (1989), Pereira & Shieber (1987).
- Pollard & Sag (1987; 1993) built HPSG on these developments.
  - Levels are related using *structure sharing* (Johson and Postal, 1980) through token identity, rather than by having transformations.
  - A *multilevel* yet *monostratal* sign-based approach, cf. (Ladusaw, 1988).
  - HPSG replaced GPSG's metarules by a lexical account, reinterpreting metarules as lexical rules (*lexicalization*).
- Later word order accounts in HPSG: (Reape, 1994; Kathol, 1995; Penn, 1999).

Other developments

- Joshi *et al*'s Tree-Adjoining Grammar, starting back in 1975.
- Lexicalized TAG, TIG.
- Rambow and Becker's D-Tree grammar, Kahane et al's TAG-based formalization of Mel'čuk's Meaning-Text Theory.

Grammar meets logic and computation

- Logics to specify a grammar framework as a mathematical system:
  - Feature logics: HPSG, cf. (King, 1989; Pollard and Sag, 1993; Richter et al., 1999)
  - Resource-sensitive type logics: categorial grammar, cf. (Morrill, 1994; Kurtonina, 1995; Moortgat, 1997)
- Logics to interpret linguistically realized meaning:
  - Montague semantics: used in early LFG, GPSG, Montague Grammar, Type-Logical Grammar, TAG (Synchronous LTAG)
  - Modal logic: used in dependency grammar frameworks, e.g. (Bröker, 1997; Kruijff, 2001).
  - Linear logic: used in contemporary LFG, (Crouch and van Genabith, 1998)

Grammar meets logic and computation

- Computation of linguistic structures
  - Unification (constraint-based reasoning): LFG, HPSG, categorial grammar (UCG, CUG), dependency grammar (UDG, DUG, TDG)
  - "Parsing as deduction": in extremis, categorial grammar
  - Optimality theory: robust constraint-solving, e.g. LFG

In retrospect

- Dependency grammar has a long history, going back more than two millennia.
- The core concepts of dependency grammar *as a perspective*, namely the relational view arising from the head/dependent asymmetry, has proven useful (and even necessary) for cross-linguistic accounts of grammar (cf. also (Greenberg, 1966; Hawkins, 1983)), particularly in the explanation of word order and the relation between surface structure and meaning.
- Even though dependency grammar had initially lost its appeal by the early 1970's, its core concepts were eventually introduced again in various grammar frameworks to complement constituency.
- Moreover, now that stronger formalisms are available, also dependency grammar *as a framework* arises again.

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