The XDG Grammar Development Kit

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Overview

1. Introduction
2. Extensible Dependency Grammar (XDG)
3. Lexicon specification language
4. XDG Development Kit (XDK)
5. Mozart implementation
6. Conclusions

Declarative grammar formalisms

- long tradition for modeling natural language (Kay 1979), (Bresnan/Kaplan 1982)
- idea: specify linguistic knowledge in grammars independent from processing
- parsers/generators: can be generically created for all grammars in the formalism
- examples:
  - Lexical Functional Grammar (LFG) (Bresnan/Kaplan 1982)
  - Head-driven Phrase Structure Grammar (HPSG) (Pollard/Sag 1994)
  - Tree Adjoining Grammar (TAG) (Joshi et al. 1975), (Joshi 1985)

Grammar development systems

- tools for grammar creation
- concrete syntax for grammar specification
- parsers
- generators
- debugging facilities
- examples:
  - Grammar Writer’s Workbench (Kaplan/Maxwell 1996) for LFG
  - LKB (Copestake 2002) for HSPG
  - XTAG (XTAG Group 2001) for TAG

Constraint programming

- existing grammar formalisms rely on first-order unification of feature structures
- Smolka (Smolka/Uszkoreit 1996): Could more advanced constraint programming techniques improve linguistic processing?
- motivation: languages with freer word order than English (e.g. German, Czech, Hindi etc.) pose problems for existing formalisms

Axiomatization of dependency trees

- (Duchier 1999): axiomatization of valid dependency trees using finite set constraints
- parsing: reduced to finite set constraint programming
- (Duchier/Debusmann 2001): Topological Dependency Grammar (TDG)
- elegant treatment of German word order

Extensible Dependency Grammar (XDG)

- (Debusmann et al. 2004): generalization of TDG
- graph description language flexible for modeling multiple levels of linguistic structure
- same parsing methods by constraint programming (Duchier 2003)
- allows to extend TDG with a concurrent syntax-semantics interface

XDG Grammar Development Kit (XDK)

- first grammar development system for XDG
- new lexicon specification language
- implemented in Mozart/Oz, published in MOGUL (Duchier 2004)
- comprehensive suite of facilities:
  - concrete syntaxes (XML, UL, IL)
  - solver for parsing and generation
  - GUI
  - graphical output tools
  - debugging facilities

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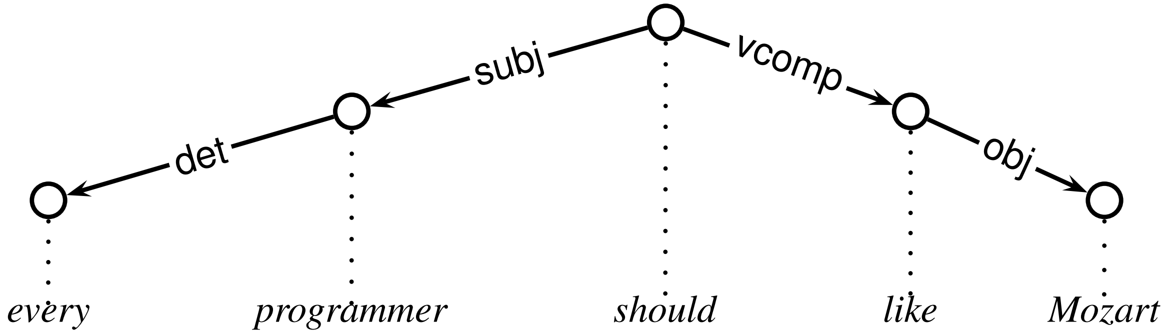
Graphs

- XDG describes labeled graphs
- uses the linguistic notion of dependency grammar
- example dependency graph:

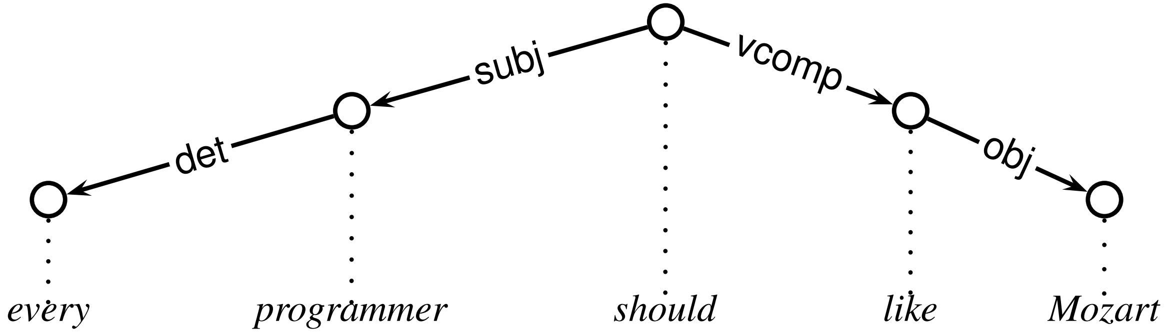


Multiple graphs

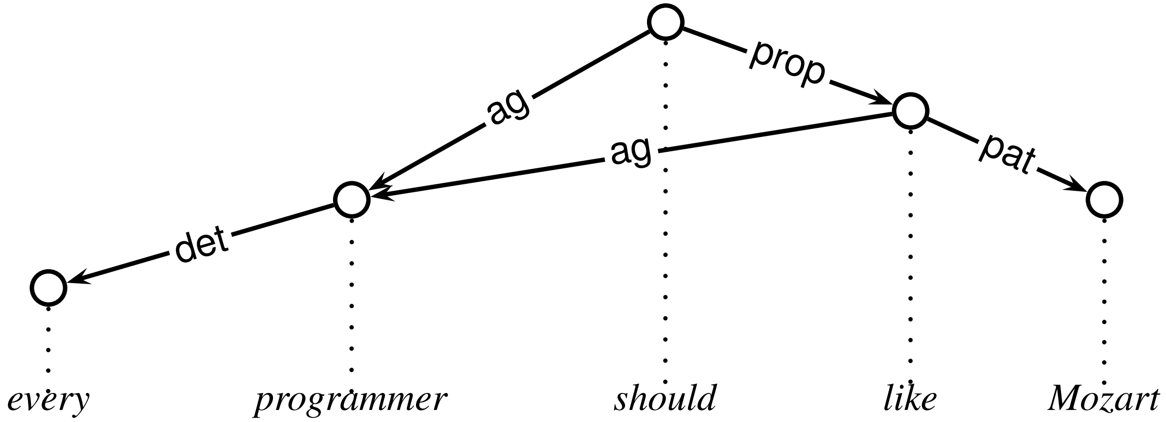
- XDG typically describes an arbitrary number of graphs called dimensions
- same set of nodes, different edges
- elegant treatment of word order (Duchier/Debusmann 2001)
- concurrent syntax-semantics interface (Debusmann et al. 2004)

Example

- Syntax tree:



- Semantic dag:



Graph description language

- well-formedness conditions: interaction of principles and the lexicon
- principles: restrictions on one or more dimensions
- controlled by feature structures, assigned to the nodes by the lexicon
- principles: subset of an extensible principle library
- library covers large fragments of German and English, smaller fragments of Arabic, Czech and Dutch

Example principles

- tree: Dimension i must be a tree
- dag: Dimension i must be a dag
- valency: For each node on dimension i, the incoming edges must be licensed by the in specification, and the outgoing edges by the out specification
- order: Constrains the order of words on dimension i, e.g. subjects precede objects
- linking: Constrains how arguments on dimension i (semantics) must be realized on dimension j (syntax)

Lexical entry

- lexical entry for *like*:

$$\mathit{Like} = \left[\begin{array}{lcl} \mathit{syn} & : & \left[\begin{array}{rcl} \mathsf{in} & : & \{\mathsf{vcomp}?\} \\ \mathsf{out} & : & \{\mathsf{obj}!\} \end{array}\right] \\ \mathit{sem} & : & \left[\begin{array}{rcl} \mathsf{in} & : & \{\mathsf{prop}?\} \\ \mathsf{out} & : & \{\mathsf{ag}!, \mathsf{pat}!\} \\ \mathsf{link} & : & \{\mathsf{ag} \mapsto \{\mathsf{subj}\} \\ & & \mathsf{pat} \mapsto \{\mathsf{obj}\} \end{array}\right] \end{array}\right]$$

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Lexicalization

- XDG: linguistic information mostly specified in the lexicon
- widely accepted in computational linguistics
- lexicon grows huge even for medium-sized grammars
- need facilities for adequate modularization and factorization

Lexical types

- flexible system to define various types of lexical information
- each type: set L and partial function $\sqcap : L \times L \to L$ (combination function of L)
- $\sqcap$: typically greatest lower bound
- domains, records, valencies, sets, tuples, strings

Domain types

- e.g. set of edge labels:

$$\textit{syn.label} \quad = \quad \{\mathsf{det}, \mathsf{subj}, \mathsf{obj}, \mathsf{vcomp}\}$$

- combination function: $a \sqcap a = a$, $a \sqcap b$ undefined for $a \neq b$

Record types

- given set of features $(f_i)_{i=1\dots n}$ and types $T_i = (L_i, \sqcap_i)$:

$$[f_1 : v_1, \dots, f_n : v_n]$$

  where $v_i \in L_i$.

- combination operation defined feature-wise:

$$\begin{array}{l} [f_1 : v_1, \dots, f_n : v_n] \sqcap [f_1 : v'_1, \dots, f_n : v'_n] \ = \\ [f_1 : v_1 \sqcap_1 v'_1, \dots, f_n : v_n \sqcap_n v'_n] \end{array}$$

  when $v_i \sqcap_i v'_i$ defined, undefined otherwise.

Valency types

- e.g. in and out specifications:

$$\textit{syn.valency} \quad = \quad \mathsf{valency}(\textit{syn.label})$$

- defines *syn.valency* to be the record type:

$$[\textit{det} : \textit{mode}, \textit{subj} : \textit{mode}, \textit{obj} : \textit{mode}, \textit{vcomp} : \textit{mode}]$$

- $\textit{mode} = \{0, ?, !, *\}$
- notation:

$$[\textit{det} : 0, \textit{subj} :!, \textit{obj} :?, \textit{vcomp} : 0] \quad = \quad [\mathsf{subj}!, \mathsf{obj}?]$$

- commutative combination operation:

$$0 \sqcap x = x \qquad * \sqcap ! =! \qquad * \sqcap ? =? \qquad ? \sqcap ! =!$$

Meta Grammars

- used for lexicon specification
- CFG-like descriptive device:

$$\begin{array}{rcl} \textit{Clause} & ::= & \textit{Name} \rightarrow \textit{Goal} \\ \textit{Goal} & ::= & \textit{Goal} \wedge \textit{Goal} \mid \textit{Goal} \vee \textit{Goal} \mid \textit{Name} \mid c \end{array}$$

- *Clause* defines a non-terminal *Name*
- *Goal*: non-terminal (lexical class)
- $c \in L$: terminal (feature structure)

Example (1)

- finite verbs can be roots or the root of a relative clause:

$$
\begin{array}{rcl}
\mathsf{finite} & \rightarrow & \mathsf{root} \vee \mathsf{rel} \\
\mathsf{root} & \rightarrow & \left[\begin{array}{lcl} \textsf{\textit{syn}} & : & \left[\begin{array}{lcl} \mathsf{in} & : & \{\} \end{array}\right] \end{array}\right] \\
\mathsf{rel} & \rightarrow & \left[\begin{array}{lcl} \textsf{\textit{syn}} & : & \left[\begin{array}{lcl} \mathsf{in} & : & \{\mathsf{relcl}?\} \end{array}\right] \end{array}\right]
\end{array}
$$

Example (2)

- finite verbs may be either intransitive, transitive or ditransitive:

$$
\begin{array}{rcl}
\mathsf{verb} & \longrightarrow & \mathsf{intr} \vee \mathsf{tr} \vee \mathsf{ditr} \\
\mathsf{intr} & \longrightarrow & \left[\begin{array}{lll} \mathit{syn} & : & \left[\begin{array}{lll} \mathsf{out} & : & \{\mathsf{subj!}\} \end{array}\right] \end{array}\right] \\
\mathsf{tr} & \longrightarrow & \mathsf{intr} \wedge \left[\begin{array}{lll} \mathit{syn} & : & \left[\begin{array}{lll} \mathsf{out} & : & \{\mathsf{obj!}\} \end{array}\right] \end{array}\right] \\
\mathsf{ditr} & \longrightarrow & \mathsf{tr} \wedge \left[\begin{array}{lll} \mathit{syn} & : & \left[\begin{array}{lll} \mathsf{out} & : & \{\mathsf{iobj!}\} \end{array}\right] \end{array}\right]
\end{array}
$$

Example (3)

- finite verb:

$$\mathsf{finite.verb} \quad\longrightarrow\quad \mathsf{finite} \wedge \mathsf{verb}$$

- generative process with start symbol $\mathsf{finite.verb}$:

$$\begin{array}{lll} (\mathsf{root} \wedge \mathsf{intr}) & (\mathsf{root} \wedge \mathsf{tr}) & (\mathsf{root} \wedge \mathsf{ditr}) \\ (\mathsf{rel} \wedge \mathsf{intr}) & (\mathsf{rel} \wedge \mathsf{tr}) & (\mathsf{rel} \wedge \mathsf{ditr}) \end{array}$$

- e.g.:

$$\mathsf{rel} \wedge \mathsf{ditr} \quad\longrightarrow\quad \left[\; \mathit{syn} \;:\; \left[\begin{array}{rcl} \mathsf{in} & : & \{\mathsf{relcl?}\} \\ \mathsf{out} & : & \{\mathsf{subj!}, \mathsf{obj!}, \mathsf{iobj!}\} \end{array} \right] \right]$$

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Concrete syntax

- three concrete syntaxes for different purposes:
  - XML language: automated grammar development
  - User Language (UL): handcrafted grammars
  - Intermediate Language (IL): record-based language, tailored for Mozart/Oz and further processing within the XDK
- UL, XML, IL: conversion into each other

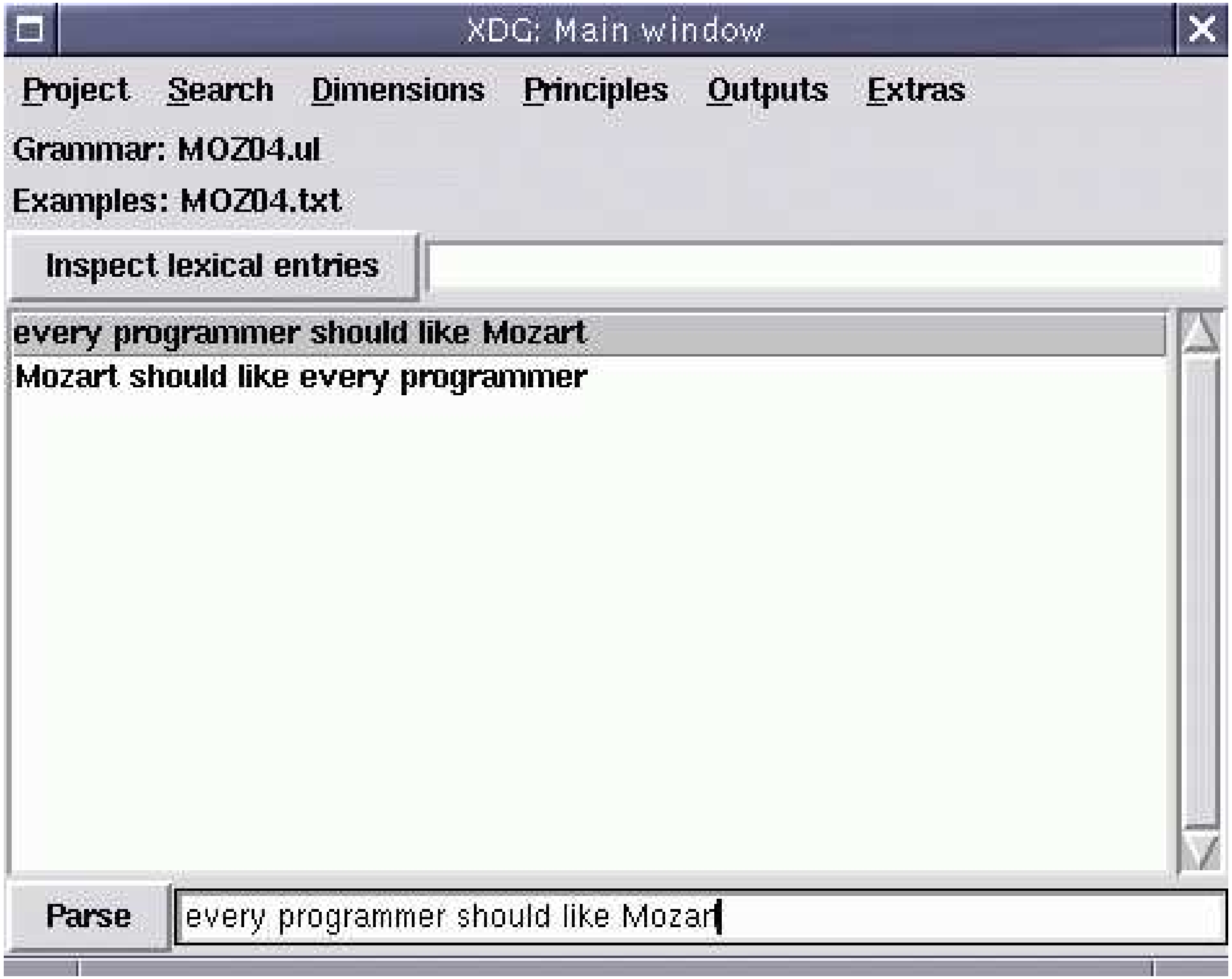
Grammar file compiler

- fast static grammar checker
- fast grammar file compilation
- implemented for IL: i.e. also used for XML language, UL
- compiled grammars stored as pickles (portable) or using Denys Duchier’s GNU GDBM interface (faster)

Graphical interfaces

- comprehensive GUI
- solver search tree visualization: Oz Explorer (Schulte 1997), IOzSeF (Tack 2003)
- visualization of partial/full analyses: output library:
  - Tcl/Tk dag display
  - LaTeX dag output (using Denys Duchier's dtree.sty)
  - internal solver language output using the Oz Inspector (Brunklaus 2000)
- XML output for evaluation, further processing

GUI



Grammar: MOZ04.ul

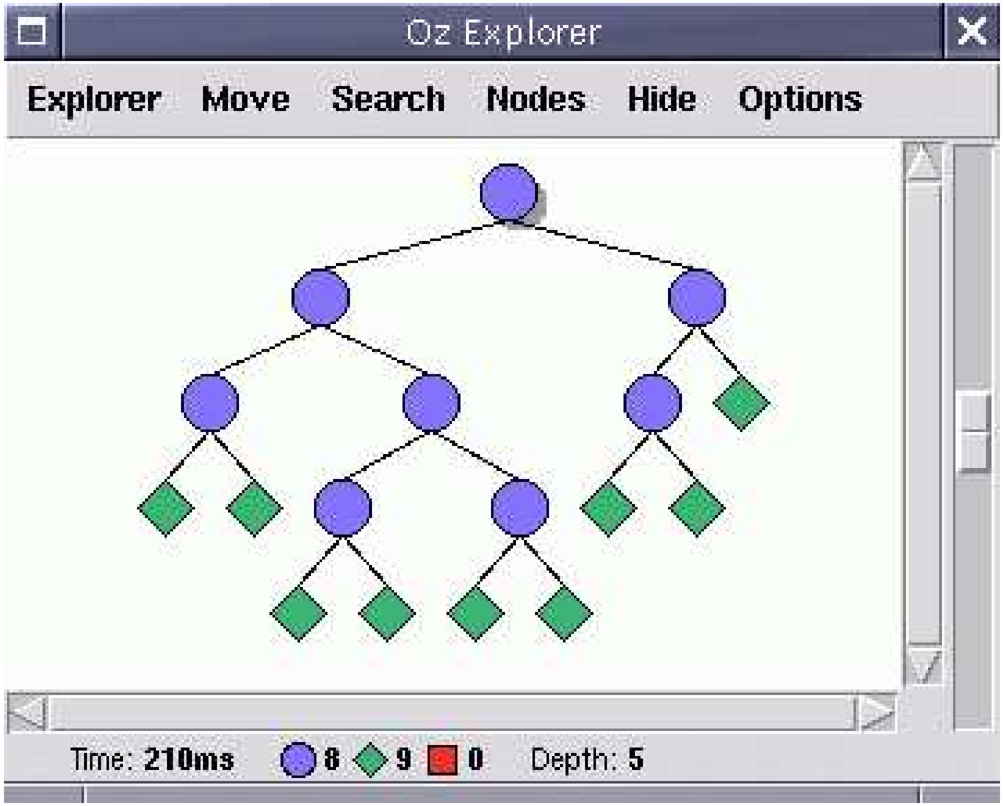
Examples: MOZ04.txt

every programmer should like Mozart

Mozart should like every programmer

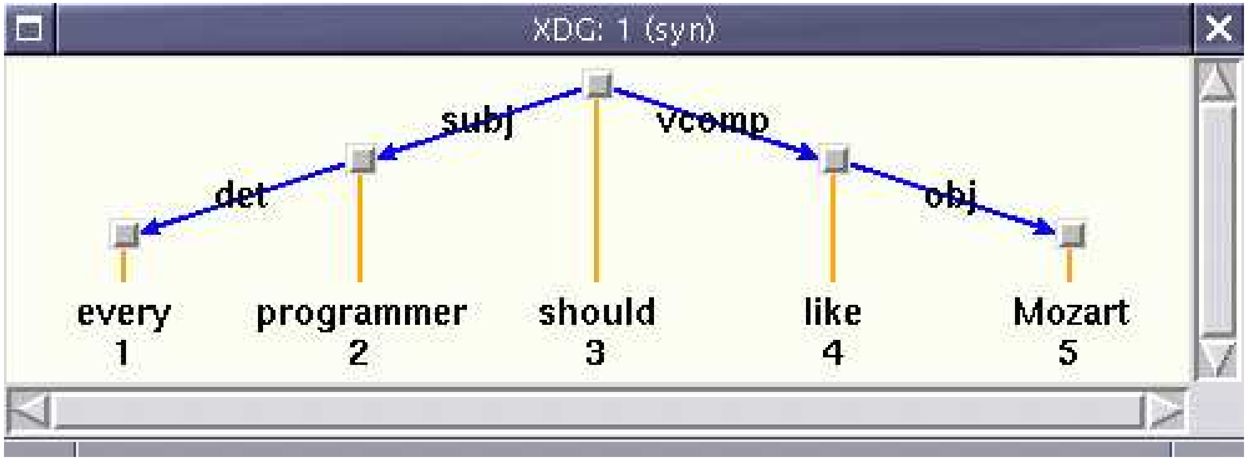
every programmer should like Mozart

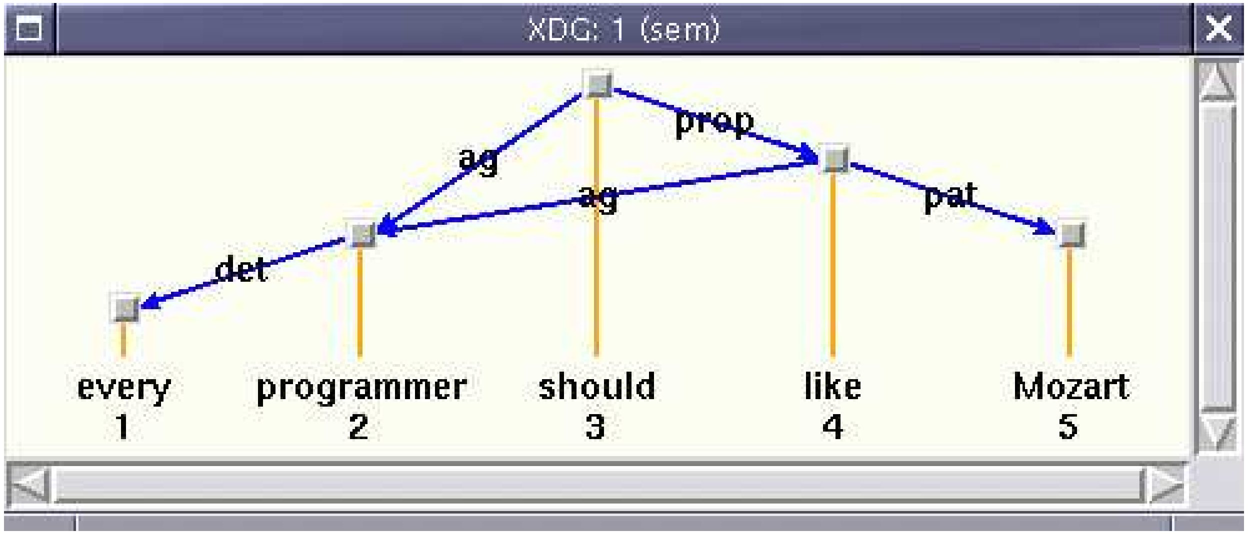
Oz Explorer



Time: 210ms ● 8 ◆ 9 🟥 0 Depth: 5

Dag


XDG: 1 (syn)
subj
vcomp
det
obj
every
1
programmer
2
should
3
like
4
Mozart
5


XDG: 1 (sem)
prop
ag
ag
pat
det
every
1
programmer
2
should
3
like
4
Mozart
5

Solver

- based on axiomatization of dependency parsing in (Duchier 99), (Duchier 2003)
- factorized into modular, extensible principle library
- principles: sets of constraint functors
- e.g. valency principle: in constraint and out constraint
- starting sequence regulated by global constraint priorities to increase efficiency

Preferences and search

- idea: guide the search for solutions by external knowledge sources: oracles
- idea by Thorsten Brants and Denys Duchier, extended in (Dienes et al. 2003)
- oracles interact with solver using sockets
- XDK: supports new standard oracle architecture created by Marco Kuhlmann

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Finite set constraints

- model the graph configuration problem
- e.g. daughters of node w reached by traversing an edge labeled obj represented by set variable $\mathsf{obj}(w)$
- valency specification $\mathsf{obj}?$ corresponds to cardinality constraint $|\mathsf{obj}(w)| \in \{0, 1\}$

Selection constraints

- efficient handling of ambiguity
- typically: word w has multiple lexical entries $L_1, \ldots, L_n$
- variable E_w: ultimately selected entry
- integer variable I_w: index of E_w in the sequence
- selection constraint:

$$E_w = \langle L_1, \ldots, L_n \rangle [I_w]$$

- declarative semantics: $E_w = L_{I_w}$
- can be trivially lifted to record types

Deep guards in disjunctive propagators

- $G_1[]G_2$ enforces complex mutually exclusive well-formedness conditions
- e.g. either a certain edge exists and satisfies additional conditions (G_1) or not (G_2)
- disjunctive propagator for each possible edge

Miscellaneous specialities

- ozmake for convenient compilation and deployment into MOGUL
- principle and output libraries: dynamically linked functors
- two parsers for grammar compilation:
  - flexible LR/LALR parser by Denys Duchier (Gump replacement, fully written in Mozart/Oz)
  - XML parser by Denys Duchier (Mozart Standard Library)
- GUI: Mozart Tcl/Tk interface
- Oz Explorer, IOzSeF, Oz Inspector

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Conclusions

- introduced XDG Development Kit (XDK)
- new lexicon specification language
- large number of development tools implemented in Mozart/Oz
- extensive texinfo documentation (180+ pages)
- no other programming language provides the required expressiveness to combine:
  - set constraints
  - selection constraints
  - deep guards

Future work

- solver: fairly efficient for handcrafted grammars, but not for automatically generated ones
- why? grammar encoding or solver or both?
- theoretical investigation of fragments of XDG
- integration of the new faster GECODE constraint library (Christian Schulte, Gabor Szokoli, Guido Tack)
- super-tagging (lexicon disambiguation before parsing/generation)