The Free Linguistic Environment

Theoretical Concepts and Basic Architecture

Damir Cavar

Department of Linguistics
Indiana University

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Outline

Team
IU Crew

- Hai Hu
- Lwin Moe
- Kenneth Steimel
- Tim Gilmanov
- Joshua Herring
- Michael Czerniakowski

Team
Supporters

Provided advice and ideas:

- Kenneth Beesley
- Lionel Clement
- Thomas Hanneforth
- Ronald Kaplan
- Gerald Penn
- Richard Sproat
- Annie Zaenen

Team
Supporters

- Provided morphologies and grammars to test:
  - Mary Dalrymple (Malagasi)
  - Helge Dyvik and Paul Meurer (Norwegian)
  - Agnieszka Patujek and Adam Przepiórkowski (Polish)
- The BNFC-team fixed several compiler issues for our code generation
- Morally supported and brought up the idea of various kinds of semantic processing, e.g. the Monotonicity Calculus:
  - Larry Moss

LFG Formalism

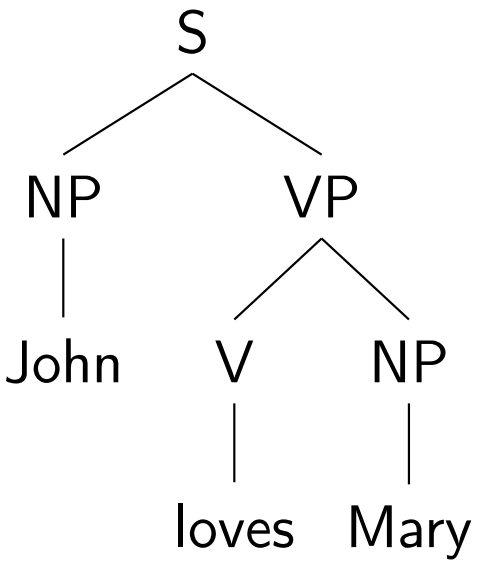
Rules:

$$\begin{array}{lcccc} S & \rightarrow & NP & & VP \\ & & (\uparrow \text{SUBJ})=\downarrow & & \uparrow=\downarrow \\ & & (\downarrow \text{CASE})=\text{NOM} & & \end{array}$$

$$NP \rightarrow \begin{pmatrix} D \\ \uparrow=\downarrow \end{pmatrix} \quad \begin{array}{c} N \\ \uparrow=\downarrow \end{array}$$

$$VP \rightarrow \begin{array}{c} V \\ \uparrow=\downarrow \end{array} \quad \begin{pmatrix} NP \\ (\uparrow \text{OBJ})=\downarrow \end{pmatrix}$$

LFG Formalism



$$\begin{bmatrix} \text{PRED} & \text{`}voli\langle \text{SUBJ,OBJ} \rangle\text{'} \\ \text{SUBJ} & \begin{bmatrix} \text{PRED} & \text{`}Ivan\text{'} \\ \text{NUM} & \text{SG} \end{bmatrix} \\ \text{OBJ} & \begin{bmatrix} \text{PRED} & \text{`}Marija\text{'} \\ \text{NUM} & \text{SG} \end{bmatrix} \\ \text{TENSE} & \text{PRES} \\ \text{NUM} & \text{SG} \\ \text{PERS} & 3 \end{bmatrix}$$

LFG Formalism

John, N
$(\uparrow \text{PRED}) = \text{`}John\text{'}$
$(\uparrow \text{NUM}) = \text{SG}$
$(\uparrow \text{PERS}) = 3$

loves, V
$(\uparrow \text{PRED}) = \text{`}love\langle\text{SUBJ,OBJ}\rangle\text{'}$
$(\uparrow \text{NUM}) = \text{SG}$
$(\uparrow \text{PERS}) = 3$
$(\uparrow \text{TENSE}) = \text{PRES}$

Mary, V
$(\uparrow \text{PRED}) = \text{`}Mary\text{'}$
$(\uparrow \text{NUM}) = \text{SG}$
$(\uparrow \text{PERS}) = 3$

Constraints

C- and F-structure well-formedness

Lexical Integrity
The terminal nodes of c-structures are morphologically complete words.

Uniqueness/Consistency Condition
Every f-structure is such that every attribute has exactly one value.

Governable grammatical functions: SUBJ, OBJ, OBJ_Θ, OBL_Θ, COMP, XCOMP

Discourse functions: TOPIC, FOCUS, SUBJ

Completeness
An f-structure is complete if and only if it contains all the governable grammatical functions that its predicate governs.

Constraints

Coherence
An f-structure is coherent if and only if all the governable grammatical functions it contains are governed by a predicate.

Constraining equation
$(f$ PARTICIPLE$) =_c$ PRESENT

Negative equation
$(f$ CASE$) \neq$ NOMINATIVE
$\neg[(f$ CASE$) =$ NOMINATIVE$]$

Existential constraint
$(f$ CASE$)$

Negative existential constraint
$\neg(f$ CASE$)$

Constraints

Conjunction
Typically implicit or using & or $\wedge$

Disjunction
$\vee$ or $\{X|Y\}$

Grouping
$[\ldots]$

Optionality
$(\ldots)$

Regular Expression Operators
$*$ and $+$

Constraints

Empty categories: *pro*

$$f\begin{bmatrix}\text{PRED} & \text{`}\textit{continue}\langle\text{SUBJ}\rangle\text{'} \\ \text{TENSE} & \text{PRESENT} \\ \text{SUBJ} & \begin{bmatrix}\text{PRED} & \text{`pro'} \\ \text{NUMBER} & \text{SG}\end{bmatrix}\end{bmatrix}$$

Functional Uncertainty

wh-phrases have function FOCUS:

$(f\ \text{FOC})=(f\ \{\text{SUBJ}|\text{OBJ}\})$

Unbounded Uncertainty over Grammatical Functions

$(f\ \text{FOC})=(f\ \{\text{XCOMP}|\text{COMP}\}*\{\text{SUBJ}|\text{OBJ}\})$

Lexical Functional Grammar

Language Documentation and Engineering

- LFG is an attractive language documentation formalism (accessible to documentary, theoretical, and computational linguists).
- It appears to be suitable for computational applications: grammar engineering, real world applications for syntactic and semantic parsing (industry-level grammars).
- Ideal platform for white-box modeling.
- Missing: Induction, Probabilistic Modeling, *RAD*-type of Engineering Platform for Linguists, ...

Lexical Functional Grammar

Parser and Grammar Engineering Workbench

- Xerox Linguistic Environment (XLE) and Xerox Finite State Toolkit (XFST)
  - XLE-Web
  - XFST Homepage
- XLFG by Lionel Clément (University Bordeaux), LaBRI
- HPSG-framework
  - LKB

Probabilistic LFG
Hybrid LFGs

- Probability of c- and f-structure fragment tuples combined to larger structures (Kaplan, 1996), see Rens Bod's *Data Oriented Parsing* (DOP)
- Stochastic LFG (Johnson, 2000): Non-stochastic component: LFG Grammar
  Stochastic component: relation between input and candidate pairs of c- and f-structure
- Learning LFGs from corpora (Cahill, 2004)

Probabilistic LFG
Hybrid LFGs

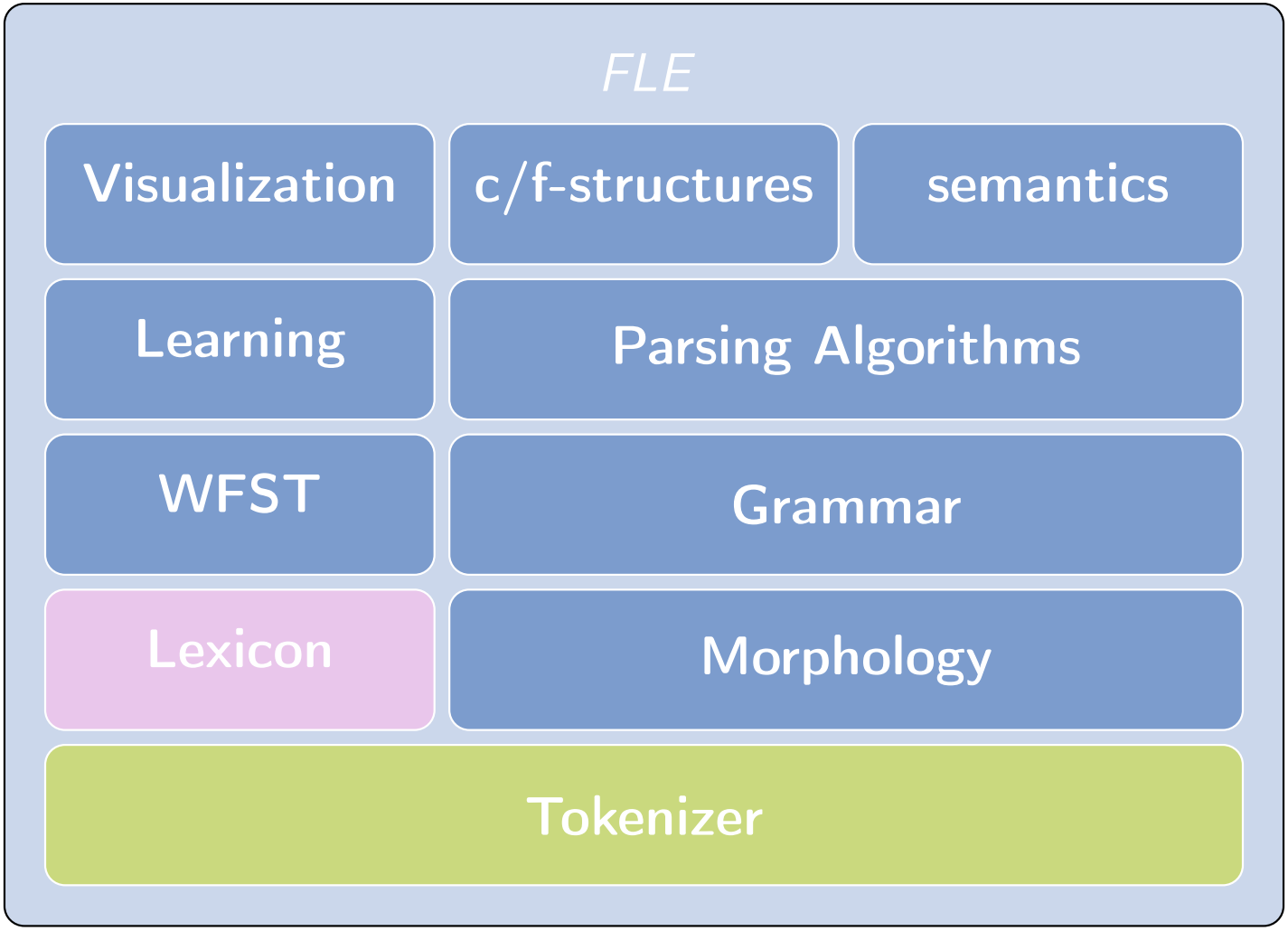
Goals:

- Combination of white-box and black-box modeling with white-box transparency
- Cognitive or Psycholinguistic modeling
- Disambiguation and most probable parse tree
- Large scale data (treebanks) for evaluation and extension of grammars
  - Lexical acquisition
  - Rule induction

Problem:

- Missing software and algorithmic base.

Architecture
General Components



General Environment
Code, Compilers, and Tools

Basic development environment:

- Coding in C++11 and newer using GCC/G++, Clang/LLVM, MS VisualStudio.
- CMake-based compiler configuration.
- BNFC-based grammar to code conversion (using flex and bison).
- Doxygen-based code documentation.
- Git-based code and version management (using Bitbucket).
- Clion IDE.
- On OS: Linux, Mac, Windows

General Environment
Code and Libraries

The following libraries are required:

- C++ Standard Library
- Boost Libraries
- OpenFST
- Foma

The following libraries are optional:

- Ucto for rule-based tokenization (Jain et al., 2012)

All libraries and tools are available for all common OS.

Code-base

Code and Language Data

Some Statistics

Using: 2nd generation i7 CPU and Ubuntu 16.04

- Lines of code (mainly C++, some shell-scripts): > 65,000
- Runtime-behavior:
  - Processing word-list using Foma-based morphology: **112,656 tokens** with some lexical ambiguities (results: 127,713): **300 milliseconds total**
  - Parsing **3,000 structurally ambiguous sentences** (avg. length 4.5) with 7,003 resulting c-structures: **917 milliseconds**. (not optimized, with tokenization, morphological analysis)

Tokenizer

Finite State and rule-based

Components:

- Basic tokenizers as part of the FLE-code (simple C++-functions).
- Foma-based tokenization (Hulden, 2009) for various languages, including Burmese.
- Ucto for rule-based tokenization (Jain et al., 2012). Ucto is coded in C++ and open and free license.

Language Resources:

- Own tokenizer framework for languages like Burmese, Thai, Lao and Khmer.
- Ucto covers English, Dutch, French, Italian, and Swedish.

Morphology
Finite State based Two-level Morphology

Components:

- Foma-based compilation of XFST-compatible morphologies to Finite State Transducer networks (Hulden, 2009)
- OpenFST-based morphologies and parsers (Allauzen et al., 2007)

Language resources:

- Our own open morphologies (English, Croatian, Burmese, . . .)
- Freely available large scale morphologies (e.g. Arabic, Malagasy, Polish, Norwegian, . . .)

Morphology
Mapping Morphology

Mapping of morphological features:

- Morphology output translation:
  - Mapping to category symbols as used in grammar.
  - Mapping of feature-labels to feature structures in syntax and unification algorithm.

Grammars
Processing Grammars

Grammar formalisms defined using Labeled Backus–Naur Form (LBNF):

- Context Free Frammars (CFG)
- Probabilistic Context Free Grammars (PCFG)
- XLE-grammars

Code Generation using BNFC:

- BNFC generates C, C++, Haskell, Java, etc. code from LBNF-grammars.
- Implementation of a Visitor-based parser for all three grammar formats mapping them on one uniform Weighted Finite State Transducer (WFST) model.

Grammars
WFST Mapping

Grammars as WFSTs:
T as a 7-tuple $(Q, \Sigma, \Gamma, I, F, \lambda, \rho)$ with

- Q a finite set of states
- Σ a finite set over the input alphabet
- Γ a finite set over the output alphabet
- I a subset of Q of initial states (we use only one initial state)
- F a subset of Q of final states
- $E \subseteq Q \times (\Sigma \cup \{\epsilon\}) \times (\Gamma \cup \{\epsilon\}) \times Q \times K$, a mapping of a state $\in Q$ and an input symbol $\in \Sigma \cup \{\epsilon\})$ to an output symbol $\in \Gamma \cup \{\epsilon\}$ and a new state $\in Q$; and $\lambda : I \rightarrow K$ mapping initial states and $\rho : F \rightarrow K$ final states to weights.

Grammars
WFST Mapping

Grammars as WFSTs:

- Transitions from one state to another consume a right-hand-side (RHS) symbol and emit ϵ or the corresponding left-hand-side (LHS) symbol of a CFG-rule, and an associated weight w.
- The weight w can be associated with:
  - a transitional probability over the RHS-symbols,
  - the fraction of a rule probability (e.g. PCFG),
  - an abstract function (e.g. unification)

Grammars
XLE-Grammar Part 1

```
S -> e: (^ TENSE);
        (NP: (^ XCOMP* { OBJ | OBJ2 })=!
        (^ TOPIC)=!)
    NP: (^ SUBJ)=!
        (! CASE)=NOM;
    { VP | VPaux }.

VP -> V
     (NP: (^ OBJ)=!
          (! CASE)=ACC)
     PP*: ! $ (^ ADJUNCT).

VPaux -> AUX
         VP.
```

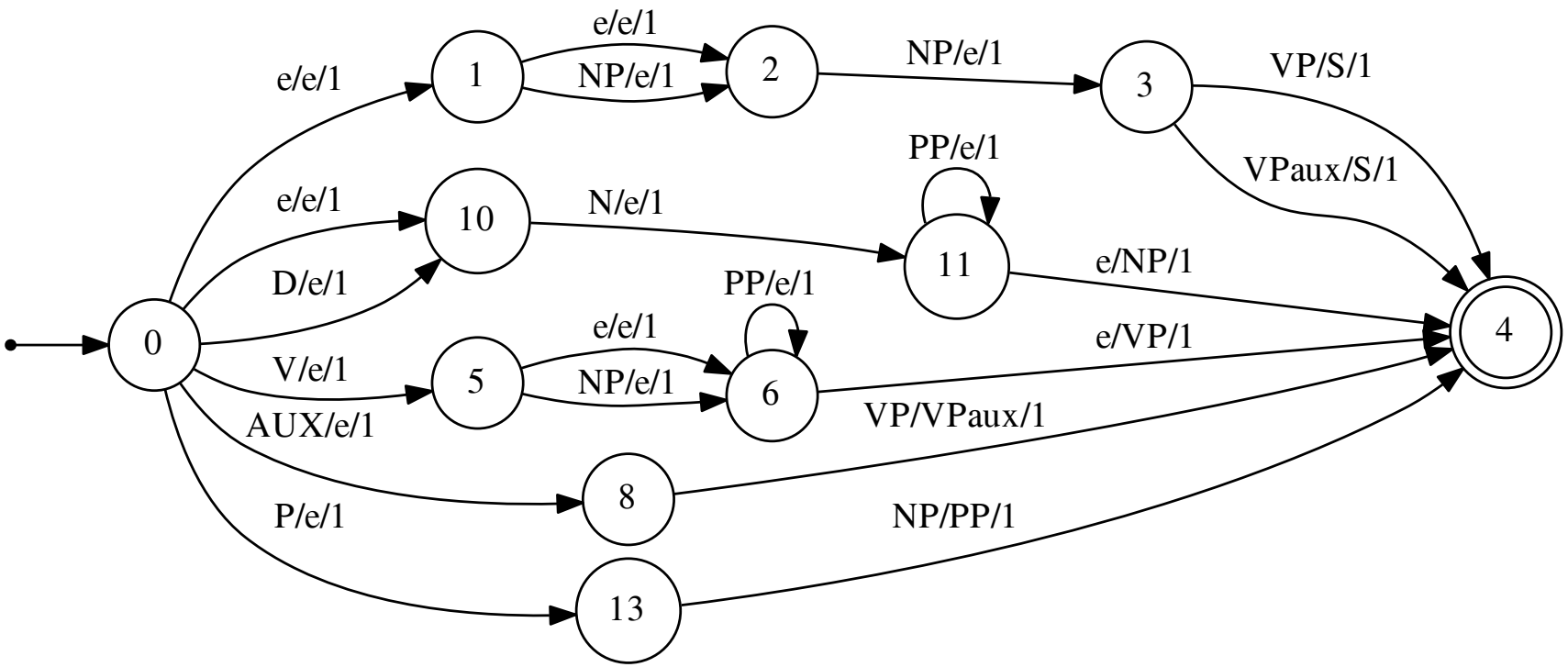
Grammars
XLE-Grammar Part 2

```
NP -> (D)
       N
      PP*: ! $ (^ ADJUNCT).

PP -> P
      NP: (^ OBJ)=!
          (! CASE)=ACC.
```

Grammars
WFST Mapping

Grammars as WFSTs:
(hidden feature structures, showing weight 1)



Parser

WFST-based Early-type Chart-parser

Parsing: Early-like Unification Parser (Earley, 1968, 1970; Aycock and Horspool, 2002; Sikkel, 1997)

- Recursive application of WFST and edge generation on chart.
  - Unification is a filter on the transitions in the WFST, or
  - Unification applies to the complete parse trees after the (P)CFG-backbone terminates (Maxwell III and Kaplan, 1996).
- Chart expansion based on classical Earley-algorithm.
- Unification algorithm: (Aho et al., 1974; Sikkel, 1997)
  - Feature structures are Directed Acyclic Graphs (DAG)
  - Non-destructive Graph-based Unification Algorithm

Solution Algorithm

Currently:

- Nothing yet, except first concept of the graph-based unification algorithm, but necessary:
  - handling of constraints and negation
  - complex processing of feature disjunctions
  - handling of semantic features (beyond the LFG-framework, e.g. lexical semantics, Monotonicity)

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Solution Algorithm

Unification and other feature constraint resolution

Currently:

- Nothing yet, except first concept of the graph-based unification algorithm, but necessary:
  - handling of constraints and negation
  - complex processing of feature disjunctions
  - handling of semantic features (beyond the LFG-framework, e.g. lexical semantics, Monotonicity)

Parser

WFST-based Parsing using OpenFST and Thrax

WFST and Probabilistic Push-down Automata

- WFST using OpenFST with all its rich infrastructure.
- OpenGrm Thrax based on OpenFST (Tai et al., 2011; Roark et al., 2012)
  - Single-stack PDA for CFG
  - Multi-stack (or rather dual-stack PDA) for higher complexity

Parser

WFST and Probabilistic Push-down Automata

- Using WFST in advanced ways:
  - Restriction of certain recursion types to depth of N, e.g. center embeddings
  - Pre-compilation of feature structures to symbols on transducer arches
  - Learning while parsing, generating pre-compiled paths in the WFST on the fly, caching feature structures, etc.

FLE Development
Graphical User Interface

- Classic approach:
  - Qt 5 for Desktops
- New strategy
  - Universal GUI using:
    - JavaScript (and libs) and HTML5
    - Node.js (system access and client-server connectivity)
    - Node-Webkit, now NW.js (using Chromium) embeds Node.js in DOM, Web-technologies and Node.js in one
  - One GUI for web, mobile, platform independent desktops
  - Dynamic applications on- and offline (see JavaScript parser implementation)
  - Rich libraries for graphs (e.g. SVG, DS.js), widgets

FLE Development

Timeline

- Finalization of basic algorithms and pipeline.
- Compilation of executables and libraries for all appropriate platforms, and documentation, grammar engineering binary and runtime binary for efficient application.
- Visualization and grammar engineering front-end: JavaScript and HTML5-based widgets/application, SVG graphs.
- Grammar compilation components: reduction of unification steps, modularization of grammars and morphologies.
- Grammar engineering functionality: chart inspection, tracking of unification errors, parse stepper, feature guessing and induction, rule induction (CFG- or MCS-backbone), etc.
- Semantic components.
- Parallelization and performance tuning.

FLE Development
Reality Timeline

- Debugging
- Debugging
- Debugging
- ...

Git Repositories
on Bitbucket

- Hidden repository for developers and interested observers:
  - `http://btbucket.org/dcavar/fle/`
- Open repository:
  - `http://btbucket.org/dcavar/fle/`
- Mailing list:
  - `http://listserv.linguistlist.org/mailman/listinfo/lfgparser/`

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