Course Roadmap

Informatics 2A: Lecture 2

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1. What Is Inf2a about?
   - Formal and natural languages
   - The language processing pipeline
   - Comparison between FLs and NLs

2. Course overview
   - Levels of language complexity
   - Formal language component
   - Natural language component

Formal and natural languages

This course is about methods for describing, specifying and processing languages of various kinds:

- Formal (computer) languages, e.g. Java, Haskell, HTML, SQL, Postscript, . . .
- Natural (human) languages, e.g. English, Greek, Japanese.
- 'Languages' that represent the possible legal behaviours of some machine or system. E.g. for a vending machine, the following sequence might be legal:

  `insert50p . pressButton1 . deliverMarsBar`

- 'Languages' that represent the legal sequences of moves in a game, e.g. chess.

A common theoretical core

We'll be focusing on certain theoretical concepts that can be applied to each of the above domains:

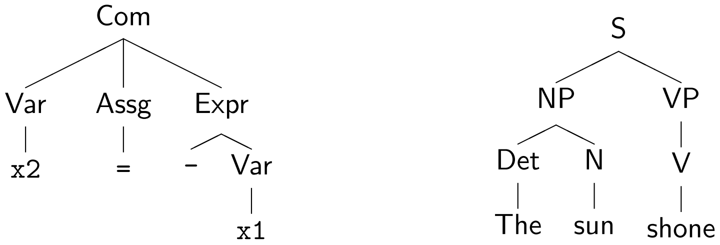
- regular languages
- finite state machines
- context-free languages, syntax trees
- types, compositional semantics

The fact that the same underlying theory can be applied in such diverse contexts suggests that the theory is somehow fundamental, and worth learning about!

Mostly, we'll be looking at various aspects of formal languages (mainly JL) and natural languages (mainly SC). As we'll see, there are some important similarities between formal and natural languages — and some important differences.

Syntax trees: a central concept

In both FLs and NLs, phrases have structure that can be represented via syntax trees.



Determining the structure of a phrase is an important first step towards doing other things with it. Much of this course will be about describing and computing syntax trees for phrases of some given language.

The language processing ‘pipeline’ (FL version)

Think about the phases in which a Java program is processed:

Raw source text (e.g. `x2=-x1`)
⇓ lexing
Stream of tokens (e.g. `x2`, `=`, `-`, `x1`)
⇓ parsing
Syntax tree (as on previous slide)
⇓ typechecking etc.
Annotated syntax tree
⇓ compiling
Java bytecode
⇓ linking
JVM state
⇓ running
Program behaviour

Language processing for programming languages

In the case of programming languages, the pipeline typically works in a very 'pure' way: each phase depends only on the output from the previous phase.

- In this course, we'll be concentrating mainly on the first half of this pipeline: lexing, parsing, typechecking. (Especially parsing).
- We'll be looking both at the theoretical concepts involved (e.g. what is a syntax tree?)
- And at algorithms for the various phases (e.g. how do we construct the syntax tree for a given program)?
- We won't say much about techniques for compilation etc.
- However, we'll briefly touch on how the intended runtime behaviour of programs (i.e. their semantics) may be specified.

Language processing for natural languages

We'll look at fundamental parts of the NL processing pipeline. Our main focus is on how to get computers to perform these tasks, for applications such as

- machine translation (e.g. Google Translate)
- speech recognition and dialogue systems (e.g. Siri, Google Voice)
- question answering (e.g. IBM Watson)
- text summarization and simplification
- speech synthesis

But there'll also be a couple of lectures on scientific studies of how we as humans perform them.

The language processing 'pipeline' (NL version)

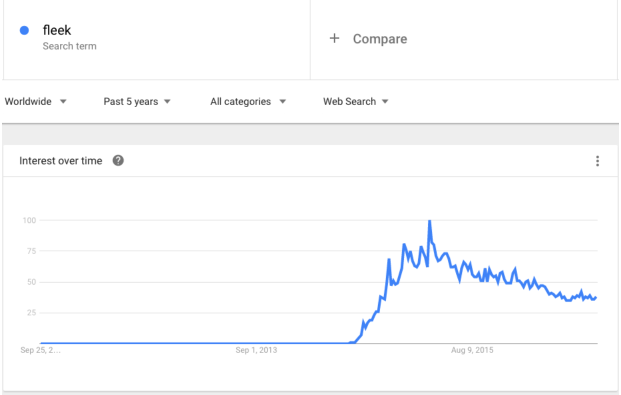
A broadly similar pipeline may be considered e.g. for spoken English:

Raw soundwaves
⇓ phonetics
Phones (e.g. [p^h]–pot, [p]–spot)
⇓ phonology
Phonemes (e.g. /p/, /b/)
⇓ segmentation, tagging
Words, morphemes
⇓ parsing
Parse tree
⇓ agreement checking etc.
Annotated parse tree
⇓ semantics
Logical form or 'meaning'
⇓ ...

Comparison between FLs and NLs

There are close relationships between these two pipelines. However, there are also important differences:

- FLs can be pinned down by a precise definition. NLs are fluid, fuzzy at the edges, and constantly evolving.



Comparison between FLs and NLs (continued)

There are close relationships between these two pipelines. However, there are also important differences:

- NLs are riddled with ambiguity at all levels. This is normally avoidable in FLs.

Comparison between FLs and NLs (continued)

There are close relationships between these two pipelines. However, there are also important differences:

- For FLs the pipeline is typically 'pure'. In NLs, information from later stages is sometimes used to resolve ambiguities at earlier stages, e.g.

  Time flies like an arrow.
  Fruit flies like a banana.

Kinds of ambiguity in NL

- Phonological ambiguity: e.g. ‘an ice lolly’ vs. ‘a nice lolly’.
- Lexical ambiguity: e.g. ‘fast’ has many senses (as noun, verb, adjective, adverb).
- Syntactic ambiguity: e.g. two possible syntax trees for ‘complaints about referees multiplying’.
- Semantic ambiguity: e.g. ‘Please use all available doors when boarding the train’.


Sam
@sambjoyce
Follow
googling 'how long has theresa may been pm' gives you theresa may's height (length?) in picometers
Google
how long has theresa may been pm
All
News
Videos
Images
Shopping
More
Settings
Tools
About 110,000,000 results (0.93 seconds)
Theresa May / Height
1.72 trillion pm
People also search for
Nicola Sturgeon 5′ 4″
Donald Trump 6′ 2″
Angela Merkel 5′ 5″
Feedback
4:07 PM - 9 Jun 2017
20 Retweets 77 Likes
2
20
77

More on the NL pipeline

In the case of natural languages, one could in principle think of the pipeline . . .

- either as a model for how an artificial speech processing system might be structured,
- or as a proposed (crude) model for what naturally goes on in human minds.

In this course, we mostly emphasize the former perspective.

Also, in the NL setting, it's equally sensible to think of running the pipeline backwards: starting with a logical form or 'meaning' and generating a speech utterance to express it. But we won't say much about this in this course.

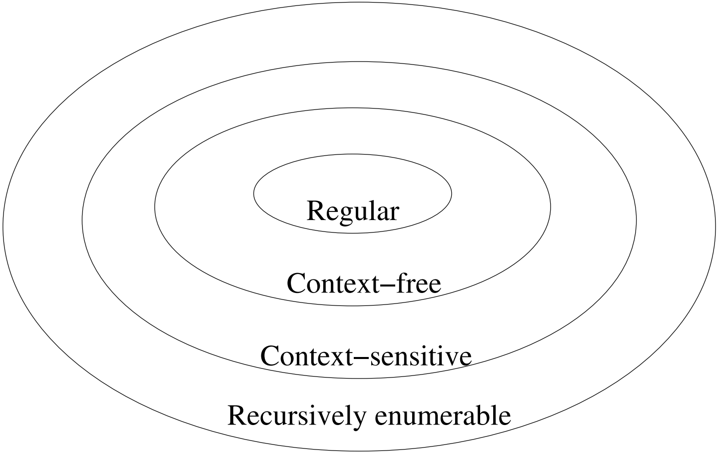
Levels of language complexity

Some languages / language features are 'more complex' (harder to describe, harder to process) than others. In fact, we can classify languages on a scale of complexity (the Chomsky hierarchy):

- Regular languages: those whose phrases can be 'recognized' by a finite state machine (cf. Informatics 1).
- Context-free languages. The basic structure of most programming languages, and many aspects of natural languages, can be described at this level.
- Context-sensitive languages. Some NLs involve features of this level of complexity.
- Recursively enumerable languages: *all* languages that can in principle be defined via mechanical rules.

Roughly speaking, we'll start with regular languages and work our way up the hierarchy. Context-free languages get most attention.

The Chomsky Hierarchy (picture)



Formal Language component: overview

Regular languages:

- Definition using finite state machines (as in Inf1A).
- Equivalence of deterministic FSMs, non-deterministic FSMs, regular expressions.
- Applications: pattern matching, lexing, morphology.
- The pumping lemma: proving a given language *isn't* regular.

Context-free languages:

- Context-free grammars, syntax trees.
- The corresponding machines: pushdown automata.
- Parsing: constructing the syntax tree for a given phrase.
- A parsing algorithm for LL(1) languages, in detail.

Formal Language component: overview (continued)

After a break to cover some NL material, we'll glance briefly at some concepts from further down the pipeline: e.g. typechecking and semantics for programming languages.

Then we continue up the Chomsky hierarchy:

Context-sensitive languages:

- Definition, examples.
- Relationship to linear bounded automata.

Recursively enumerable languages:

- Turing machines; theoretical limits of what's 'computable in principle'.
- Undecidable problems.

Natural language component: overview

Some specific topics:

- Complexity of human languages: E.g. whereabouts do human languages sit in the Chomsky hierarchy?
- Parsing algorithms: Because NLs differ from FLs in various ways, it turns out that different kinds of parsing algorithms are suitable.
- Probabilistic versions of FL concepts: In NL, because of ambiguity, we're typically looking for the most likely way of analysing a phrase. For this purpose, probabilistic analogues of e.g. finite state machines or context-free grammars are useful.
- Use of text corpora: Rather than building in all the relevant knowledge of the language by hand, we sometimes get a NLP system to 'learn' it for itself from some large sample of pre-existing text.

Natural language semantics

Consider the sentence:

Every student has access to a computer.

The ‘meaning’ of this can be expressed by a logical formula:

$$\forall x. (\mathrm{student}(x) \Rightarrow \exists y. (\mathrm{computer}(y) \wedge \mathrm{hasAccessTo}(x, y)))$$

Or perhaps:

$$\exists y. (\mathrm{computer}(y) \wedge \forall x. (\mathrm{student}(x) \Rightarrow \mathrm{hasAccessTo}(x, y)))$$

Problem: how can (either of) these formulae be mechanically generated from a syntax tree for the original sentence? This is what semantics is all about.

The Python programming language

- Invented by Guido van Rossum (pictured)
- Object-oriented programming language (like Java): has classes and objects.
- Dynamic typing (unlike Java). More flexibility but more chance of run-time errors.
- Clear and powerful syntax – very succinct (unlike Java). Especially convenient for string processing.
- Typically driven interactively via a console session (like Haskell).
- Interfaces to many system calls, libraries, window systems, and other programming languages.

Natural language processing with Python

NLTK: Natural Language Toolkit

Developed by Steven Bird, Ewan Klein and Edward Loper; mainly addresses education and research; the book is online: `http://www.nltk.org`

The NLTK provides support for many parts of the NL processing pipeline, e.g.

- Part-of-speech tagging
- Parsing
- Meaning extraction (semantics)

Lab sessions will introduce you to both Python and NLTK.

In Assignment 2, we'll show how one can fit these together to construct a (very simple) natural language dialogue system.

Summary

- What is Inf2a about?
- We will learn about formal and natural languages.
- We will discuss their similarities and differences.
- We will cover finite state machines, context-free grammars, syntax trees, parsing, pos-tagging, ambiguity.
- We will use Python for natural language processing.
- We will have lots of fun!

Next lecture: Finite state machines (revision)
Reading: Kozen chapter 1, 2; J&M[2nd Ed] chapter 1