Course Roadmap

Informatics 2A: Lecture 2

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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 behaviour of some machine or system. E.g. think about 'communicating' with a vending machine via coin insertions and button presses:

```
insert50p . pressButton1 . deliverMarsBar
```

A common theoretical core

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

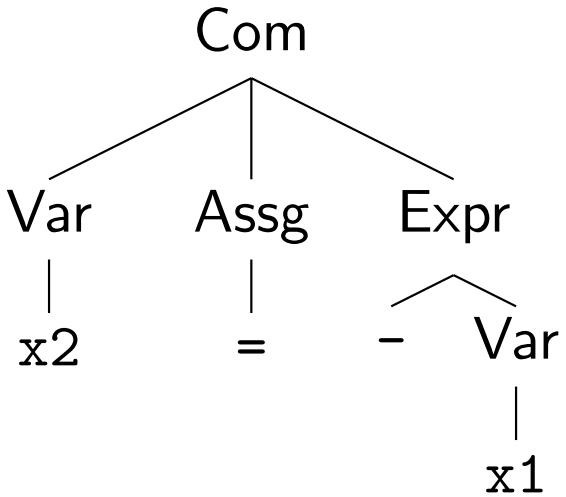
- regular languages
- finite state machines
- context-free languages, syntax trees
- types compositional semantics

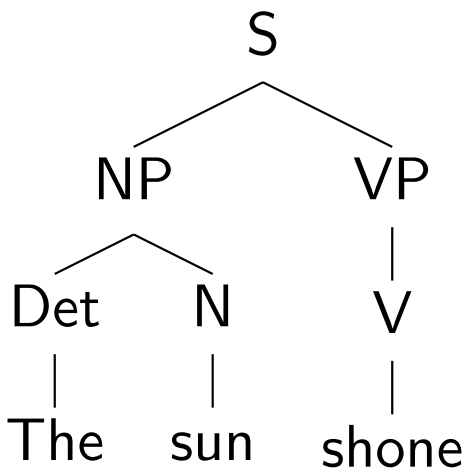
The fact that the same underlying theory can be applied in such diverse contexts suggests that the theory is somehow fundamental, and worth learning about!

Mostly, we'll be looking at various aspects of formal languages (mainly JL) and natural languages (mainly ML). 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`)

$\Downarrow$ lexing

Stream of tokens (e.g. `x2, =, -, x1`)

$\Downarrow$ parsing

Syntax tree (as on previous slide)

$\Downarrow$ typechecking etc.

Annotated syntax tree

$\Downarrow$ compiling

Java bytecode

$\Downarrow$ linking

JVM state

$\Downarrow$ 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 touched on how the intended runtime behaviour of programs (i.e. their semantics) may be specified.

The language processing 'pipeline' (NL version)

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

Raw soundwaves
$\Downarrow$ phonetics
Phones (e.g. [t^h]–toucan, [t]–starfish)
$\Downarrow$ phonology
Phonemes (e.g. /t/, /d/)
$\Downarrow$ segmentation, tagging
Words, morphemes
$\Downarrow$ parsing
Parse tree
$\Downarrow$ agreement checking etc.
Annotated parse tree
$\Downarrow$ semantics
Logical form or 'meaning'
$\Downarrow$ ...

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

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 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.

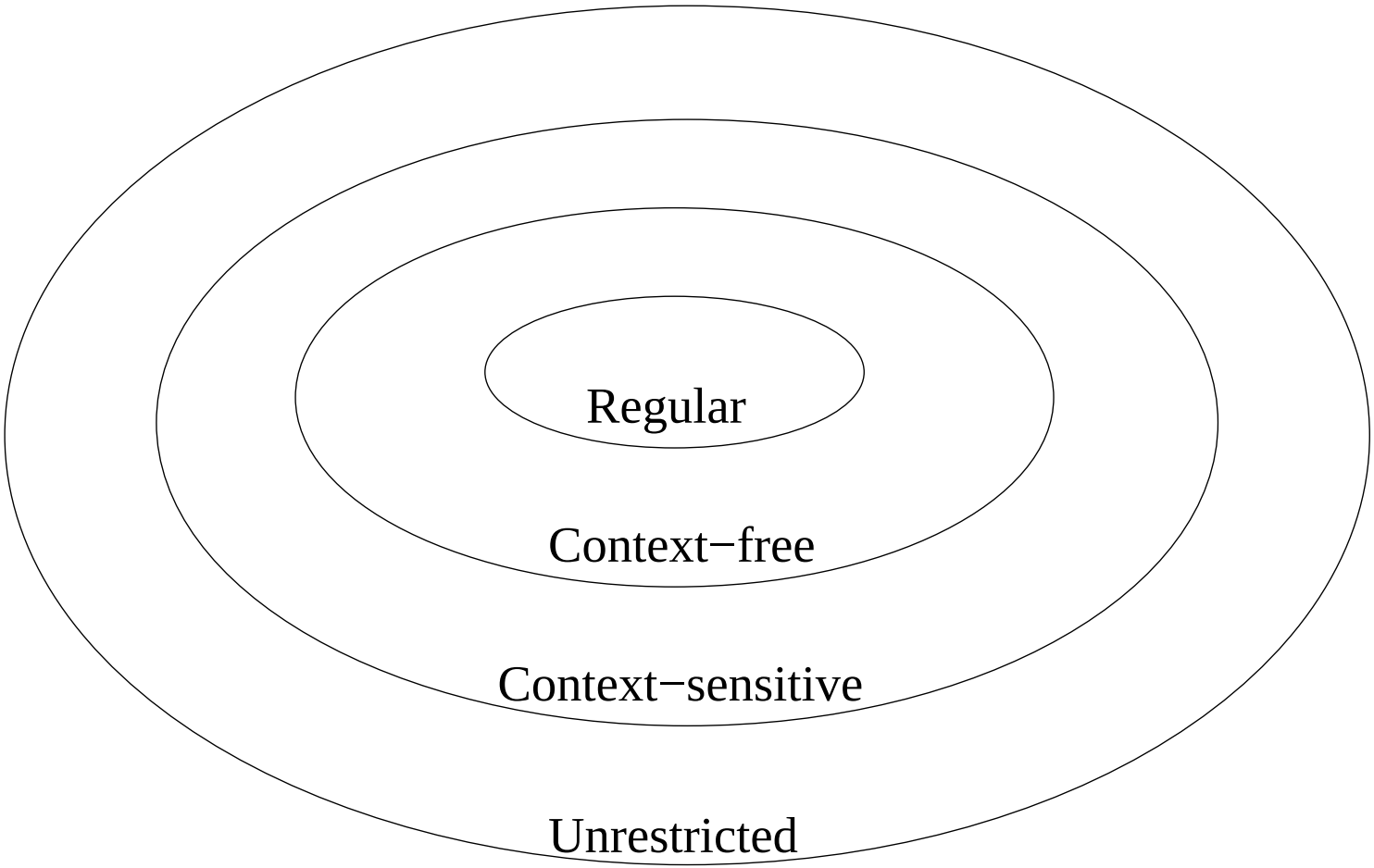
Levels of language complexity

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 1A).
- 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.
- Unrestricted 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.

Unrestricted languages:

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

Natural Language component: overview

What are natural languages made of?

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I made her duck words

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Pro	V	Pro	{V,N}	part of speech categories
I	made	her	duck	words

Natural Language component: overview

What are natural languages made of?

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Natural Language component: overview

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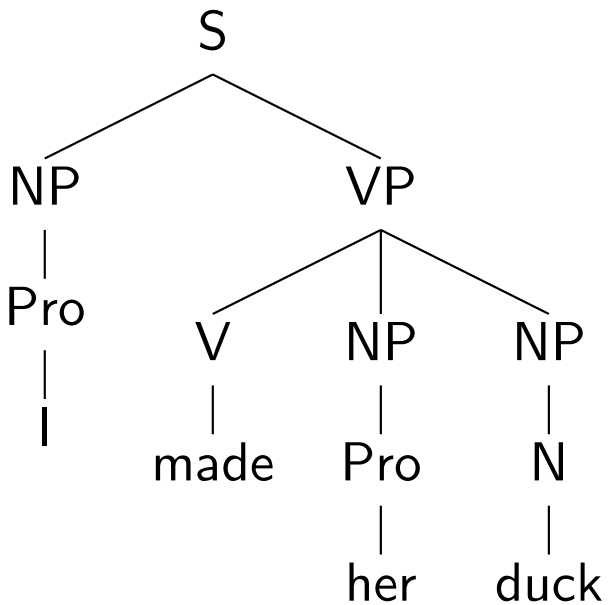

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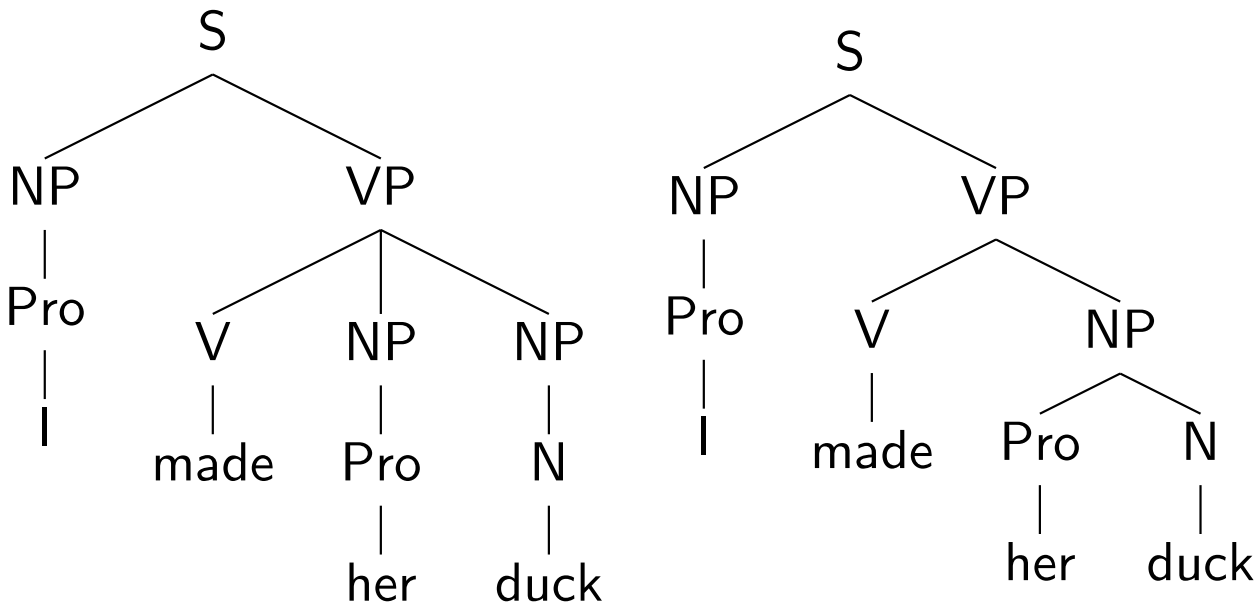

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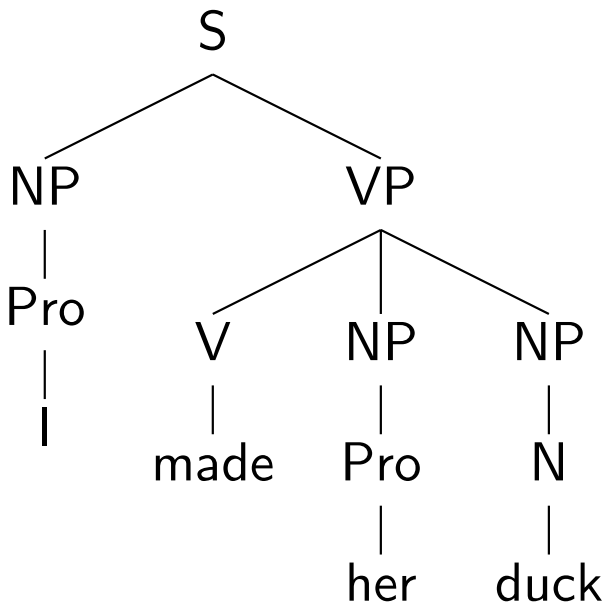

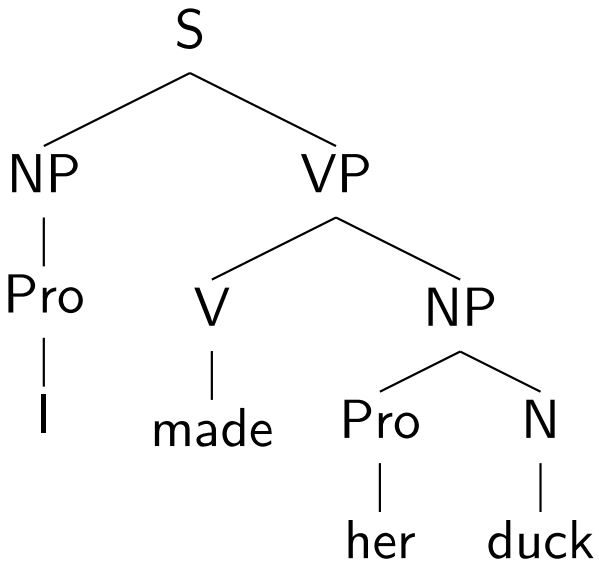

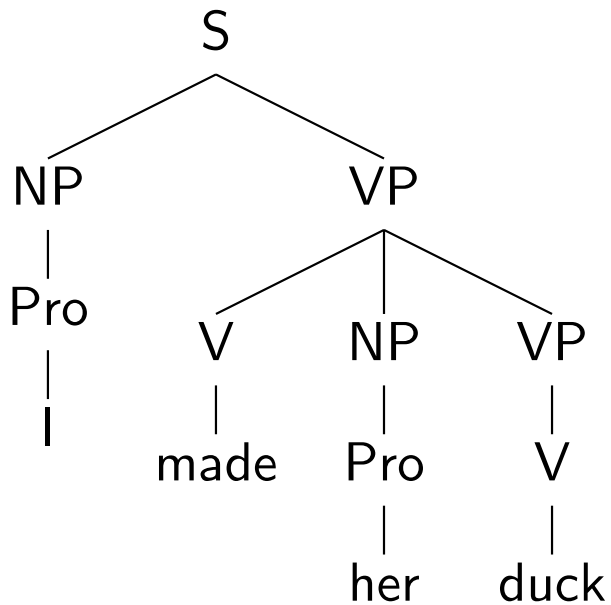

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Natural Language component: overview

Can we analyze natural languages automatically?

Natural Language component: overview

Can we analyze natural languages automatically?

- In this course we will learn how to assign parts of speech automatically (e.g., with HMMs)
- We will introduce many algorithms for parsing (i.e., CYK, Early algorithm, probabilistic parsing)
- We will study the meaning of "*Every man loves a woman*" (e.g., how many women does he love?)
- We will simulate how humans process languages
- And discuss the links between formal and natural languages (e.g., are they regular or context-free?)

Natural Language processing with Python

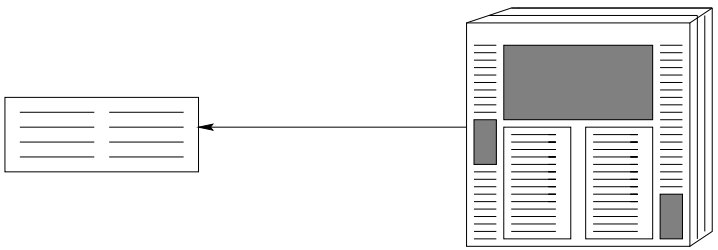
- Invented by Guido van Rossum
- interpreted, object-oriented programming language.
- incorporates modules, exceptions, dynamic typing, very high level dynamic data types, and classes
- combines remarkable power with very clear syntax
- interfaces to many system calls and libraries, as well as to various window systems, and is extensible in C or C++.

NLTK: Natural Language Toolkit

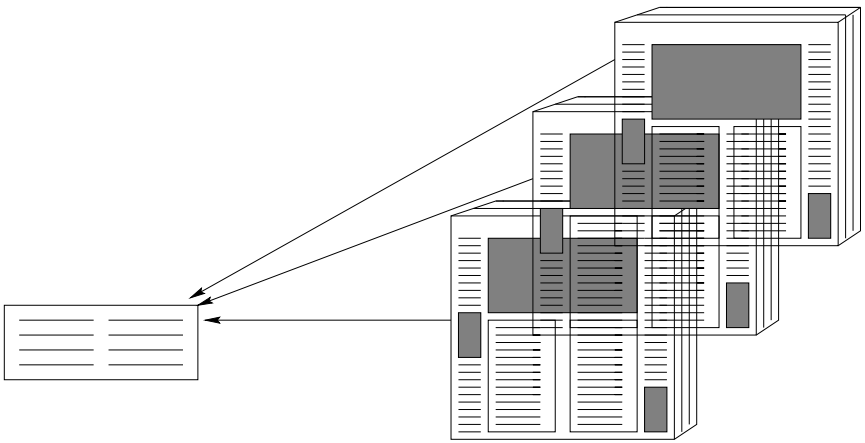
Developed by Steven Bird, Ewan Klein and Edward Loper; mainly addresses education and research; the book is online:
`http://www.nltk.org/book`

Applications: Summarization

Single Document



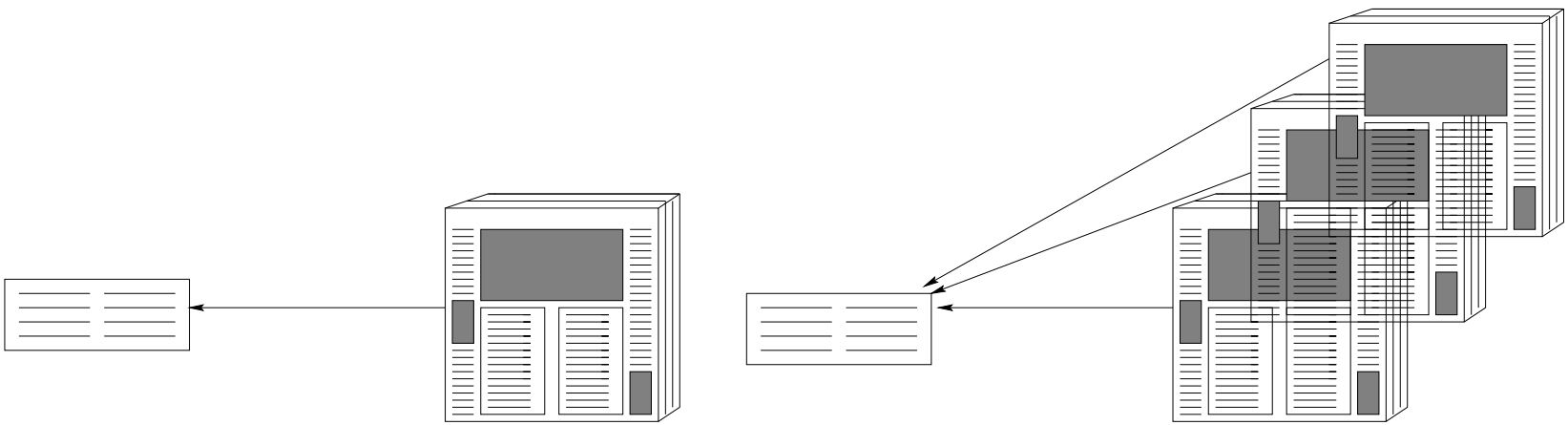
Multiple Document



Applications: Summarization

Single Document

Multiple Document

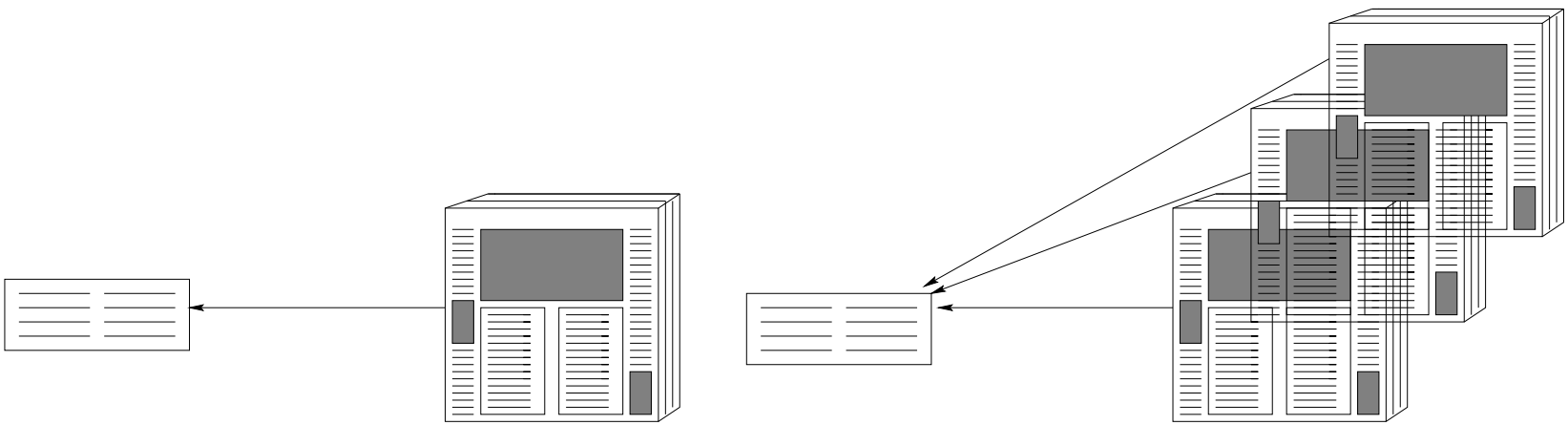


How does summarization work?

Applications: Summarization

Single Document

Multiple Document



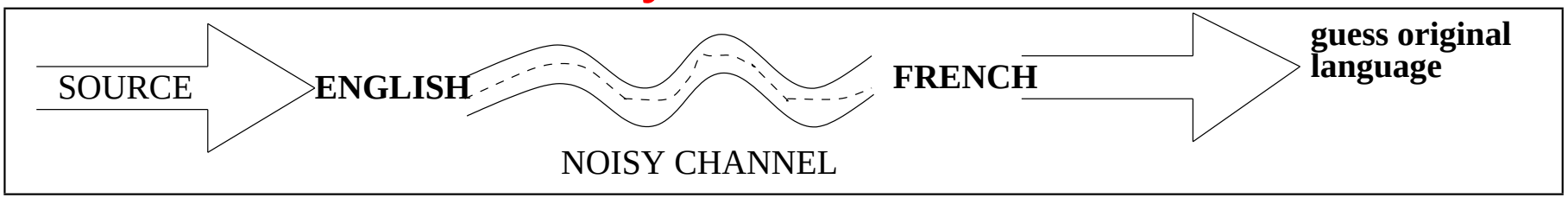
How does summarization work?

- Extract 25% of the initial document
- Sentences, phrases, words
- Select at random, beginning of document, select salient units.

Applications: Machine Translation

Translate text from one language to another automatically (e.g., English to French and vice versa). Very difficult problem!

The noisy channel model



- Write a computer program to do the translation.
- Immense amount of knowledge about language and the world.
- Learn from corpora that are translations of each other.
- Machine translation as encryption!
- Many of the algorithms we learn in this course are used in MT.

Summary

- What is Inf2a about?
- We will learn about formal and natural languages
- We will discuss their similarities and differences
- 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