# IN2110: Språkteknologiske metoder

## *Syntaktisk struktur*

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# Topics for Today

- Short recap: The Viterbi algorithm
  - Filling in the Viterbi trellis
  - Recursive problem definition
- Move on to grammatical structure
  - The case for structure
  - Context-free grammars
  - Treebanks
  - Probability Estimation
- Quick review of anonymous questionnaire

# Recap: From the Diaries of Jason Eisner

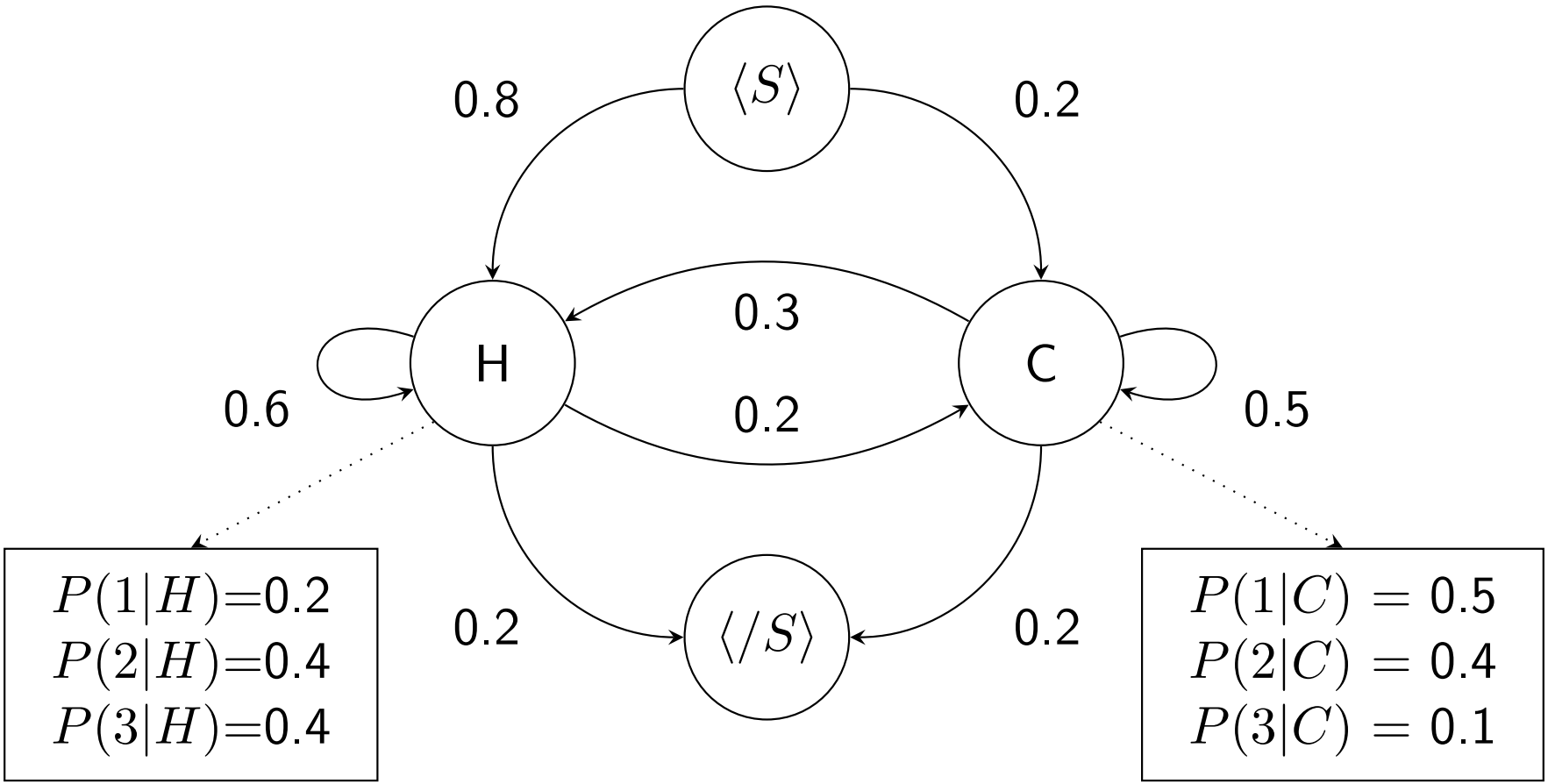
## Missing records of weather in Baltimore, MD, for Summer 2007

- Jason likes to eat ice cream.
- He records his daily ice cream consumption in his diary.
- The number of ice creams he ate was influenced, but not entirely determined by the weather.
- Today's weather is partially predictable from yesterday's.

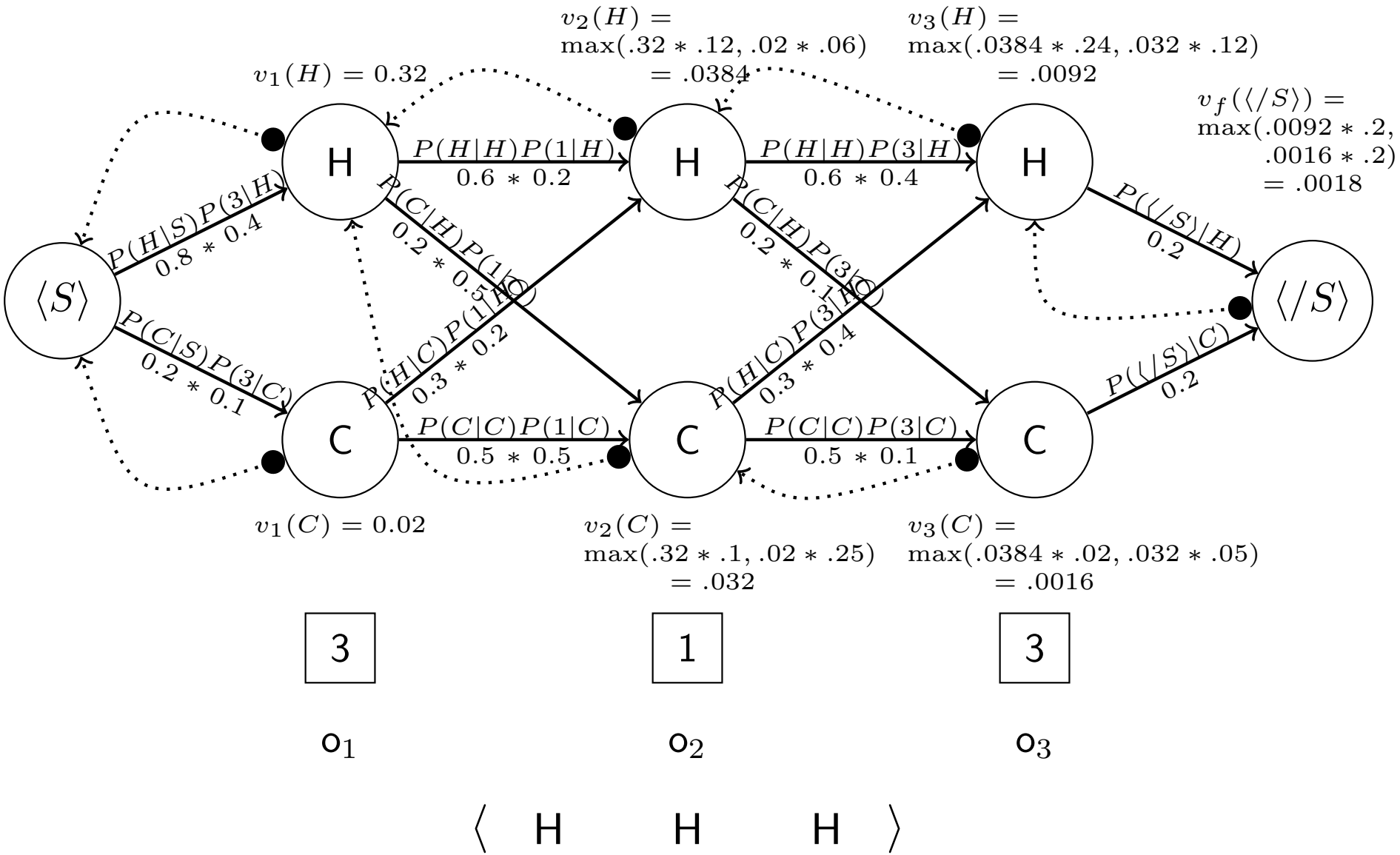
## A Hidden Markov Model

- Hidden states: $\{H, C\}$ (plus pseudo-states $\langle S \rangle$ and $\langle /S \rangle$)
- Observations: $\{1, 2, 3\}$

# Recap: Ice Cream and Weather in Baltimore, MD



# Recap: Viterbi Decoding—Thanks, Bec!



# Recap: Dynamic Programming

Abstract problem: Find the tag sequence $s_1 \dots s_n$ that maximizes

$$P(s_1 \dots s_n | o_1 \dots o_n) = P(s_1|s_0)P(o_1|s_1)P(s_2|s_1)P(o_2|s_2) \dots$$

The Viterbi algorithm uses decomposition into recursive sub-problems:

$$v_i(x) = \max_{k=1}^{L} [v_{i-1}(k) \cdot P(x|k) \cdot P(o_i|x)]$$

Each trellis cell $v_i(x)$ represents the maximum probability that the $i$-th state is $x$, given that we have seen the observation prefix $o_1 \dots o_i$.

At each step, we also record backpointers (in a separate matrix), showing which previous state led to the maximum probability.

# From Linear Order to Hierarchical Structure

- NLP approaches we have considered this far:
  - Distributional representations of documents or words:

    *Cisco acquired Tandberg* $\equiv$ *Tandberg acquired Cisco*
  - $n$-gram language models (Markov chains).
    - Purely linear (sequential) and surface-oriented.
  - sequence labeling: HMMs.
    - One layer of abstraction: PoS as hidden states.
    - Still only sequential in nature.
- Syntax adds hierarchical structure:
  - In NLP, being a sub-discipline of AI, we want our programs to *'understand'* natural language (on some level).
  - Finding the grammatical structure of sentences is an important step towards 'understanding'.
  - Shift focus from bags or sequences to hierarchical structure.

# The Case for Structure (1/3)

**Constituency**

- Words can 'lump together' into groups that behave like single units; these are called *constituents*.
- *Constituency tests* give evidence for syntactic structure:
  - interchangeable in similar syntactic environments.
  - can be co-ordinated (e.g. using *and* and *or*)
  - can be 'moved around' in a sentence as one unit

(1) Kim read [a very interesting book about grammar]$_{NP}$.
Kim read [it]$_{NP}$.

(2) Kim [read a book]$_{VP}$, [gave it to Sandy]$_{VP}$, and [left]$_{VP}$.

(3) [Read the book]$_{VP}$ I really meant to this week.

Examples from *Linguistic Fundamentals for NLP: 100 Essentials from Morphology and Syntax.* Bender (2013)

# The Case for Structure (2/3)

**Constituency**

- Constituents as basic 'building blocks' of grammatical structure.
- Rules of grammar are sensitive to constituents.
- A constituent usually has one head daughter, and is often named according to the type of its head:
  - A noun phrase (NP) has a nominal head:

    (This is) [a book]$_{NP}$
    (This is) [a very interesting book about grammar]$_{NP}$
  - A verb phrase (VP) has a verbal head:

    (She) [eats]$_{VP}$
    (She) [gives books to students]$_{VP}$
    (She) [bet me ten bucks that it would rain]$_{VP}$

# The Case for Structure (3/3)

**Relations among Constituents**

- Notions such as *subject* and *object* describe the grammatical function of a constituent in a larger structure.
- Agreement establishes a symmetric relationship between properties of two constituents.
- Government allows one constituent to require a certain property of another constituent.
- The *decision* of the committee member*s* surprise*s* most of us.
- Why would a purely linear model have problems predicting this phenomenon?
- Verb agreement has to reflect the grammatical structure of the sentence, not merely the sequential order of words.

# Grammars: A Tool to Aid Understanding

Formal grammars describe a language, providing key notions of:

## Wellformedness

- *Kim was happy because _____ passed the exam.*
- *Kim was happy because _____ final grade was an A.*
- *Kim was happy when she saw _____ on television.*

## Meaning

- *Kim gave Sandy the book.*
- *Kim gave the book to Sandy.*
- *Sandy was given the book by Kim.*

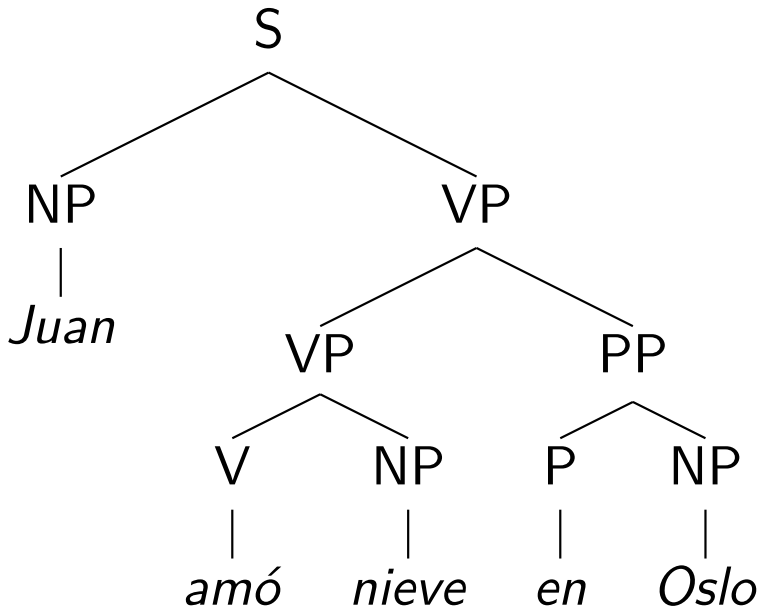
## Ambiguity

- *Kim ate sushi with chopsticks.*
- *Have her report on my desk by Friday!*

# A Simplified Example

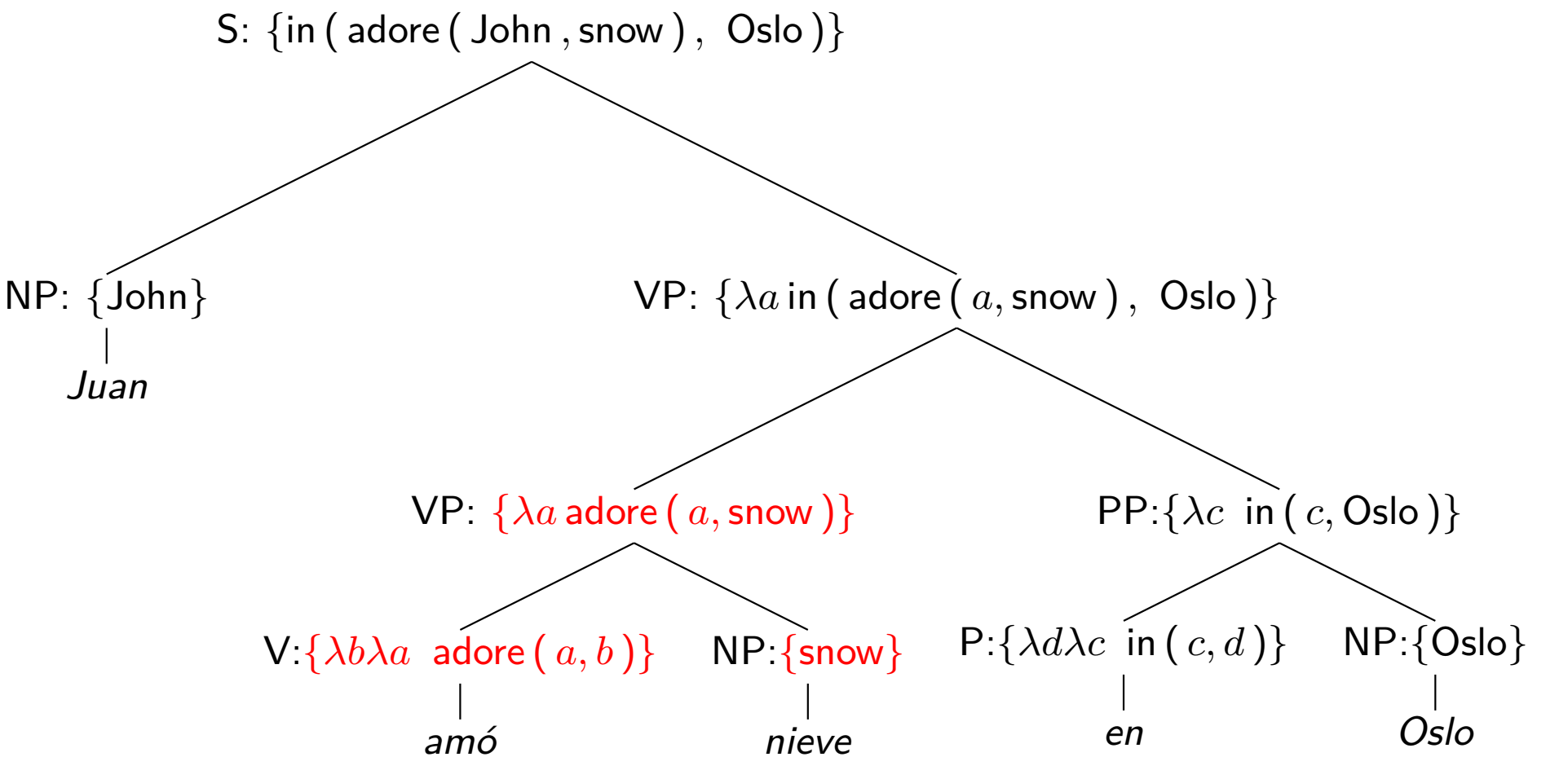
**The Grammar of Spanish**

| | |
|---|---|
| S → NP VP | { VP ( NP ) } |
| VP → V NP | { V ( NP ) } |
| VP → VP PP | { PP ( VP ) } |
| PP → P NP | { P ( NP ) } |
| NP → “nieve” | { snow } |
| NP → “Juan” | { John } |
| NP → “Oslo” | { Oslo } |
| V → “amó” | { $\lambda b \lambda a$ adore ( $a, b$ ) } |
| P → “en” | { $\lambda d \lambda c$ in ( $c, d$ ) } |



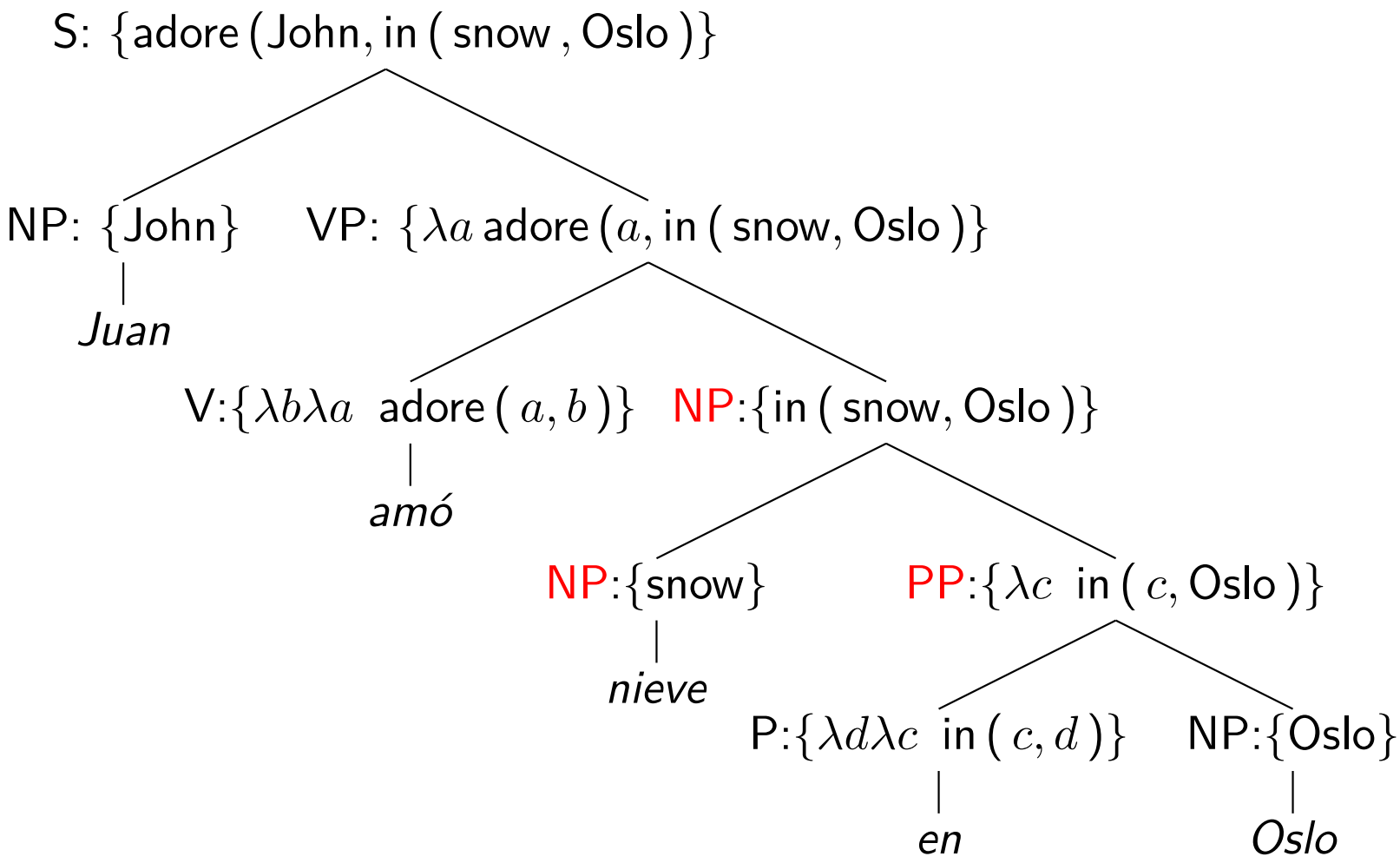

*Juan amó nieve en Oslo*

# Meaning Composition (Still Very Simplified)




VP → V NP  { V ( NP ) }

# Another Interpretation




NP → NP PP { PP ( NP ) }

# Context Free Grammars (CFGs)

- Formal system for modeling constituent structure.
- Defined in terms of a lexicon and a set of rewrite rules.
- Precise, abstract models of 'language' in a broad sense
  - natural languages, programming languages, communication protocols, ...
- Can be expressed in the 'meta-syntax' of the Backus-Naur Form (BNF) formalism.
  - The standard Python documentation (or much other technical writing) often uses BNF.
- Powerful enough to express sophisticated relations among words and constituents, yet computationally tractable.

# CFGs (Formally, this Time)

Formally, a CFG is a quadruple: $G = \langle C, \Sigma, P, S \rangle$

- $C$ is the set of categories (aka *non-terminals*),
  - $\{\mathsf{S}, \mathsf{NP}, \mathsf{VP}, \mathsf{V}\}$
- $\Sigma$ is the vocabulary (aka *terminals*),
  - $\{\mathrm{Kim}, \mathrm{snow}, \mathrm{adores}, \mathrm{in}\}$
- $P$ is a set of category rewrite rules (aka *productions*)

$$\mathsf{S} \rightarrow \mathsf{NP}\ \mathsf{VP} \qquad \mathsf{NP} \rightarrow \mathsf{Kim}$$
$$\mathsf{VP} \rightarrow \mathsf{V}\ \mathsf{NP} \qquad \mathsf{NP} \rightarrow \mathsf{snow}$$
$$\mathsf{V} \rightarrow \mathsf{adores}$$

- $S \in C$ is the *start symbol*, a filter on complete results;
- for each rule $\alpha \rightarrow \beta_1, \beta_2, ..., \beta_n \in P$: $\alpha \in C$ and $\beta_i \in C \cup \Sigma$

# Generative Grammar

**Foundations of formal language theory:**

- For a grammar $G$, the language $\mathcal{L}_G$ is defined as the set of strings that can be derived from $S$.
- To derive $w_1^n$ from $S$, we use the rules in $P$ to recursively rewrite $S$ into the sequence $w_1^n$ (where each $w_i \in \Sigma$)
- The grammar can be seen as generating strings.
- Grammatical strings are defined as terminal sequences that can be generated by the grammar.
- The 'context-freeness' of CFGs refers to the fact that we rewrite non-terminals without regard to the overall context in which they occur.

# Outlook

**Next week**

- Parsing: Computing the language of a CFG
- (More on) Statistical parsing
- Dependency Syntax
- Transition-based dependency parsing