Lecture 11a: Discriminative Sequence Tagging

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HMM + features

- There are variants of the generative HMM that emit features instead of just words.

- However, these suffer from similar problems as features in naïve Bayes (too strong independence assumptions).

- Can we be **discriminative** instead?
  - Yes! In fact, we can reuse the same machinery for discriminative learning with **linear models**.

Recasting HMM as a Linear Model

- Recall that a linear model is one that scores candidate outputs y with $\mathbf{w}^\top\boldsymbol{\varphi}(\mathbf{x},y)$. Decoding = $\arg\max_{y'} \mathbf{w}^\top\boldsymbol{\varphi}(\mathbf{x},y')$.

- Not just classification: we can be predicting a structured output $\mathbf{y}$. Thus $\arg\max_{\mathbf{y}'} \mathbf{w}^\top\boldsymbol{\varphi}(\mathbf{x},\mathbf{y}')$.

- How can we express an HMM in this framework?
  - transitions = features over tag n-grams
  - emissions = tag + word features
  - weights = log probabilities
  - $\arg\max_{\mathbf{y}'}$ = Viterbi decoding

Viterbi for Linear Models

- Essentially, the Viterbi algorithm stays the same:
  - *transition probabilities* replaced by linear score of **transition (multi-tag) features**
  - *emission probabilities* replaced by linear score of **non-transition (single-tag) features**

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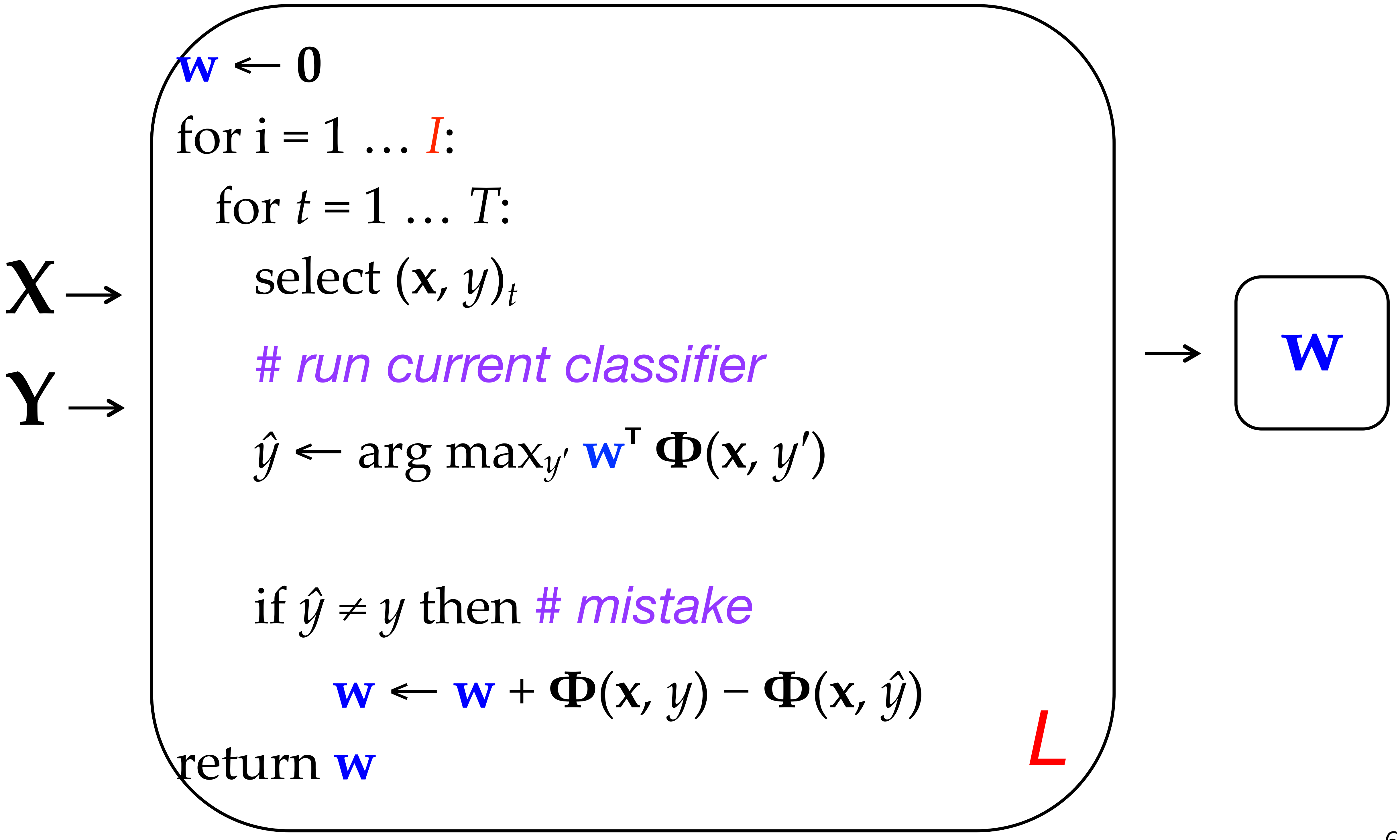
Generative → Discriminative

- If we want to estimate the weights without making independence assumptions about the features...
- ...we can use a discriminative learning algorithm!
- However, the algorithm has to take the **structure** of the output into account. Tag n-gram features mean the prediction of one tag influences what the model thinks about other tags.
- Machine learning with models where the outputs are interrelated is called **structured prediction**.

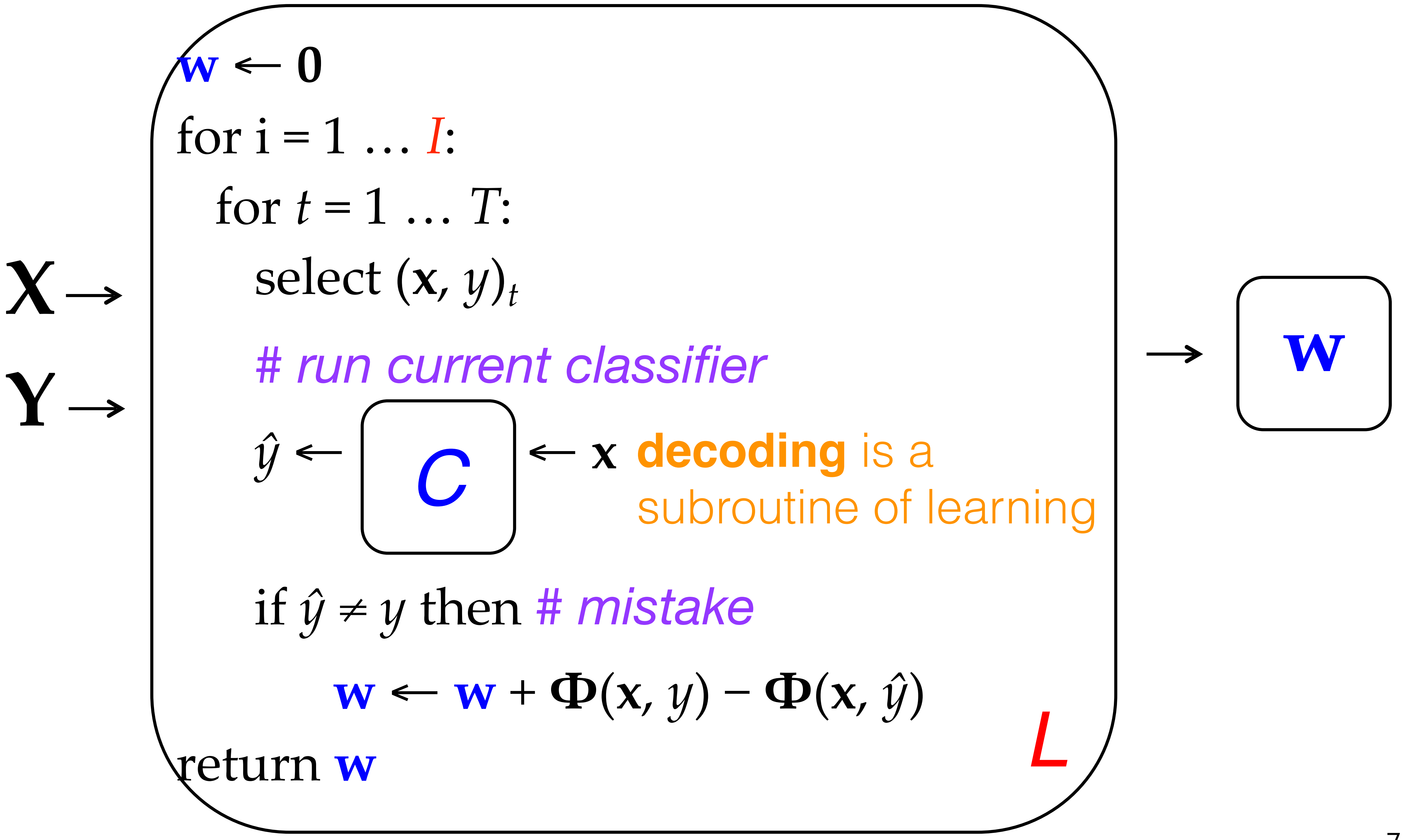
Review: Perceptron Learner



```
$\mathbf{w} \leftarrow \mathbf{0}$
for i = 1 … $I$:
  for $t$ = 1 … $T$:
    select $(\mathbf{x}, y)_t$
    # run current classifier
    $\hat{y} \leftarrow \arg\max_{y'} \mathbf{w}^\intercal \mathbf{\Phi}(\mathbf{x}, y')$

    if $\hat{y} \neq y$ then # mistake
      $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{\Phi}(\mathbf{x}, y) - \mathbf{\Phi}(\mathbf{x}, \hat{y})$
return $\mathbf{w}$
```

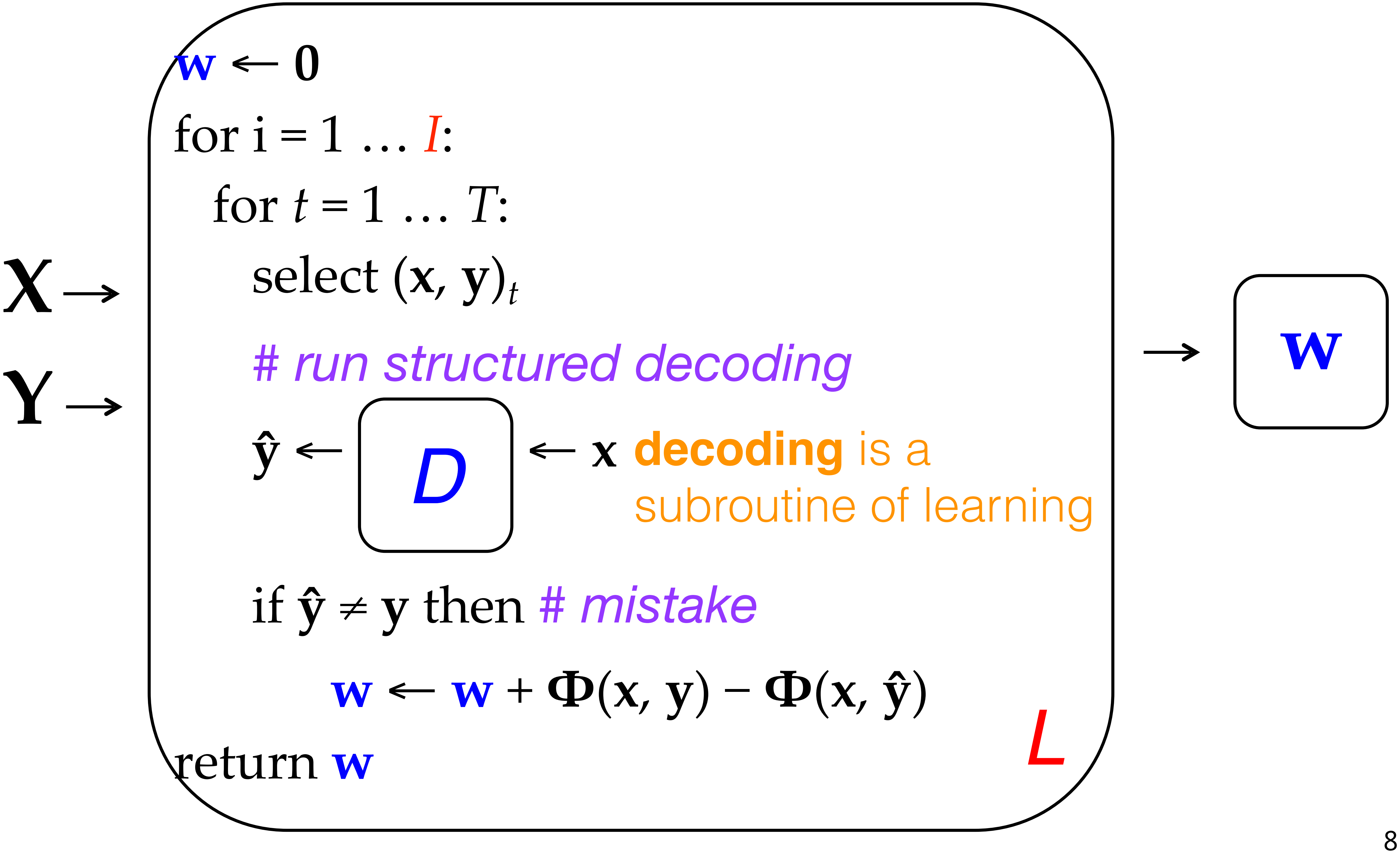
Review: Perceptron Learner



```
$\mathbf{w} \leftarrow \mathbf{0}$
for i = 1 … $I$:
  for $t$ = 1 … $T$:
    select $(\mathbf{x}, y)_t$
    # run current classifier
    $\hat{y} \leftarrow \boxed{C} \leftarrow \mathbf{x}$
    if $\hat{y} \neq y$ then # mistake
      $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{\Phi}(\mathbf{x}, y) - \mathbf{\Phi}(\mathbf{x}, \hat{y})$
return $\mathbf{w}$
```

decoding is a subroutine of learning

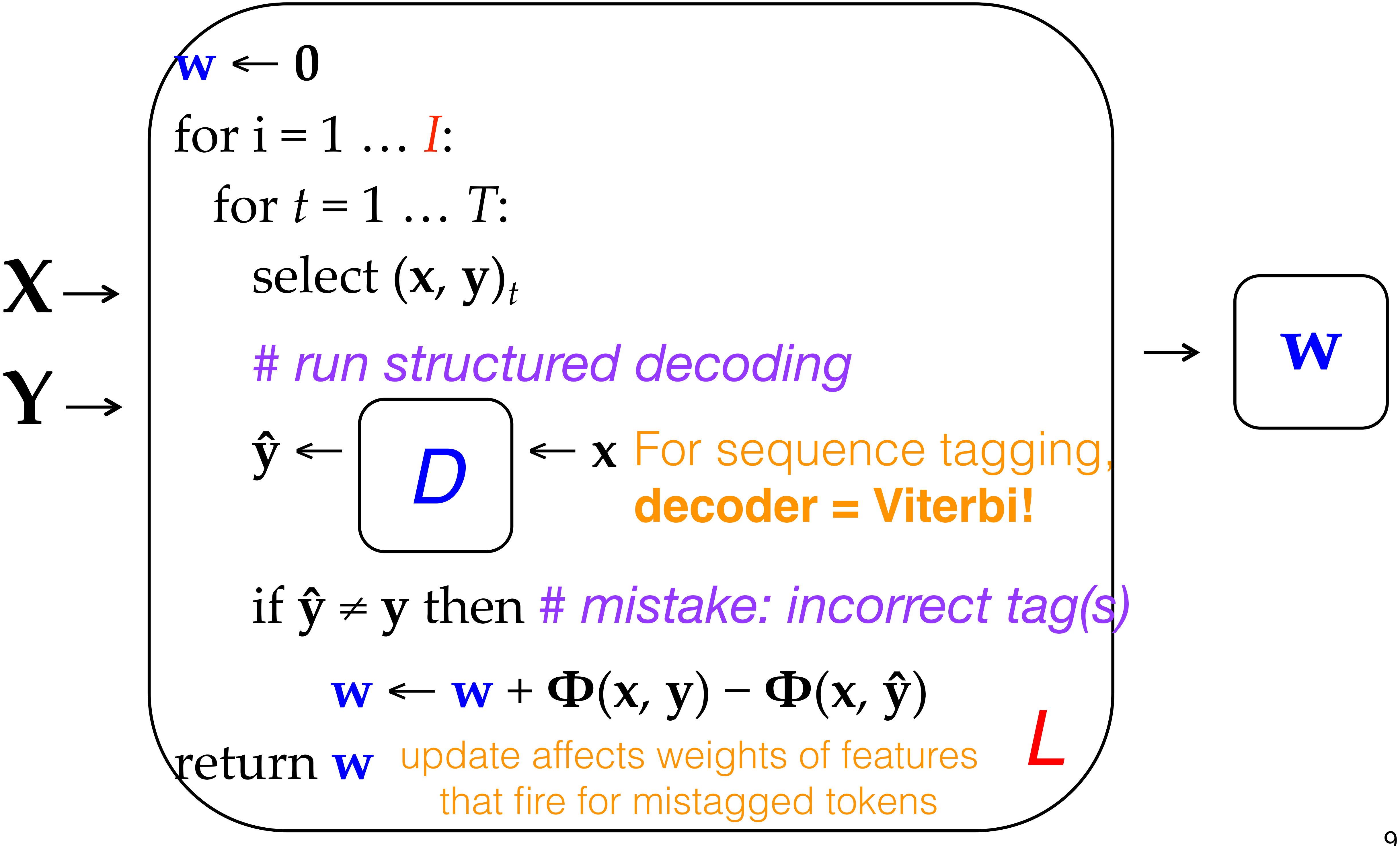
Structured Perceptron Learner



```
$\mathbf{w} \leftarrow \mathbf{0}$
for i = 1 … $I$:
  for $t$ = 1 … $T$:
    select $(\mathbf{x}, \mathbf{y})_t$
    # run structured decoding
    $\hat{\mathbf{y}} \leftarrow \boxed{D} \leftarrow \mathbf{x}$
    if $\hat{\mathbf{y}} \neq \mathbf{y}$ then # mistake
      $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{\Phi}(\mathbf{x}, \mathbf{y}) - \mathbf{\Phi}(\mathbf{x}, \hat{\mathbf{y}})$
return $\mathbf{w}$
```

decoding is a subroutine of learning

Structured Perceptron Learner



```
$\mathbf{w} \leftarrow \mathbf{0}$
for i = 1 … $I$:
    for $t$ = 1 … $T$:
        select $(\mathbf{x}, \mathbf{y})_t$
        # run structured decoding
        $\hat{\mathbf{y}} \leftarrow \boxed{D} \leftarrow \mathbf{x}$
        if $\hat{\mathbf{y}} \neq \mathbf{y}$ then # mistake: incorrect tag(s)
            $\mathbf{w} \leftarrow \mathbf{w} + \mathbf{\Phi}(\mathbf{x}, \mathbf{y}) - \mathbf{\Phi}(\mathbf{x}, \hat{\mathbf{y}})$
return $\mathbf{w}$
```

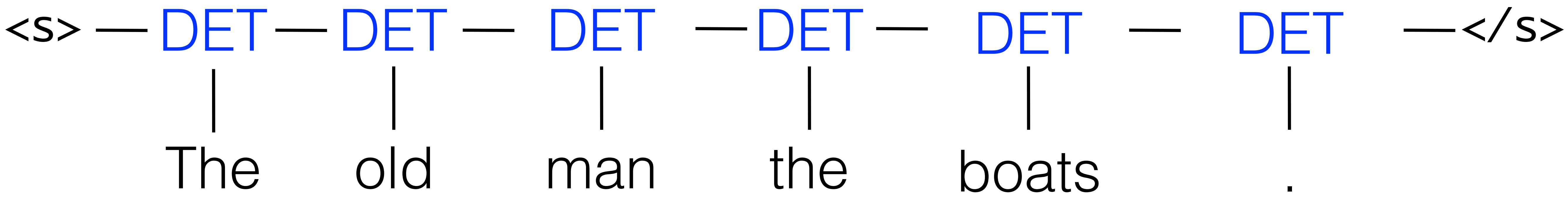
For sequence tagging,
decoder = Viterbi!

update affects weights of features
that fire for mistagged tokens

Structured Perceptron

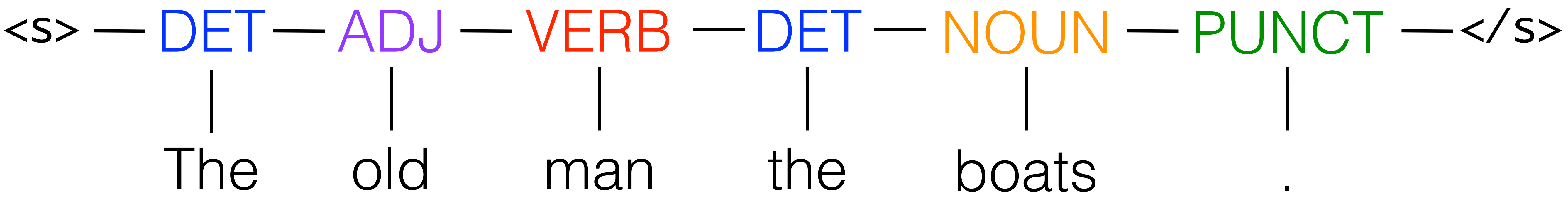
- What are the constraints on the kinds of features we can use? (tag bigrams? trigrams? word bigrams? trigrams?)
  - Remember that discriminative = we don't care about modeling the probability of the language. Thus, every model feature should involve at least one tag.
  - As a sequence model, **Markov order** is still relevant: if we want to use the *bigram* Viterbi algorithm, which is $O(T^2N)$, we can have features over *tag bigrams*, but not trigrams.
  - **local feature** = feature which respects the independence assumptions of the decoding algorithm (e.g., tag bigram Viterbi). Using nonlocal features would require fancier algorithms.
  - Unlike the generative HMM, **no constraint on which words** can be in a feature. E.g., there could be a feature that relates the first tag to the last token! (In POS tagging, perhaps ending with "?" correlates with certain kinds of initial words.)

Predicted (iteration 1):


<s> — DET — DET — DET — DET — DET — DET — </s>

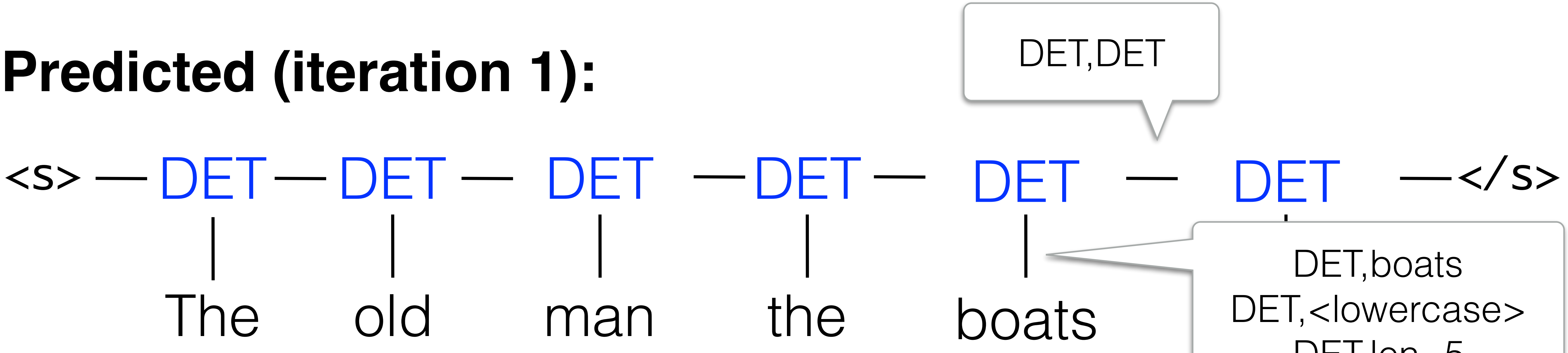
The old man the boats .

Gold:


<s> — DET — ADJ — VERB — DET — NOUN — PUNCT — </s>

The old man the boats .

Predicted (iteration 1):



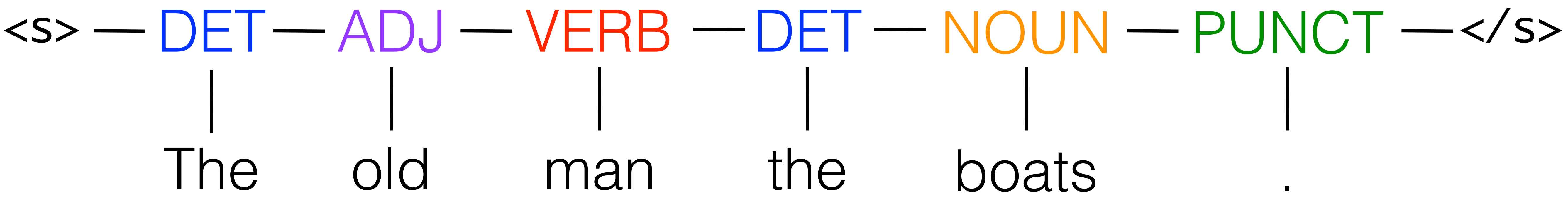
DET,DET

<s> — DET — DET — DET — DET — DET — DET — </s>

The old man the boats

DET,boats
DET,<lowercase>
DET,len=5
DET,suffix=s

Gold:

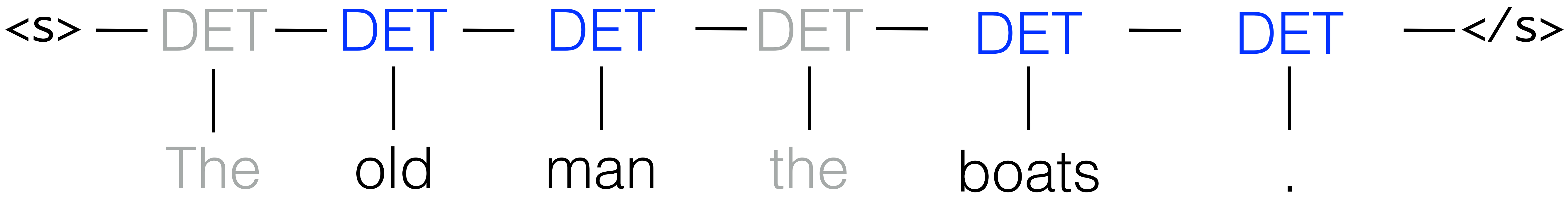


<s> — DET — ADJ — VERB — DET — NOUN — PUNCT — </s>

The old man the boats .

Unlike the generative HMM, each connection can involve multiple weighted features.

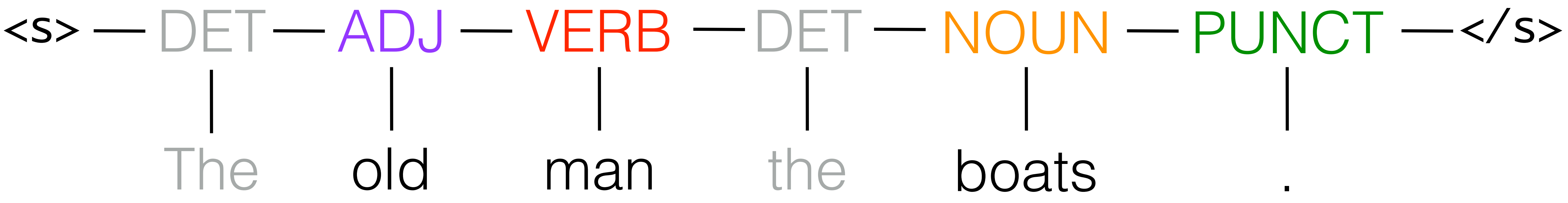
Predicted (iteration 1):



<s> — DET — DET — DET — DET — DET — DET — </s>

The old man the boats .

Gold:



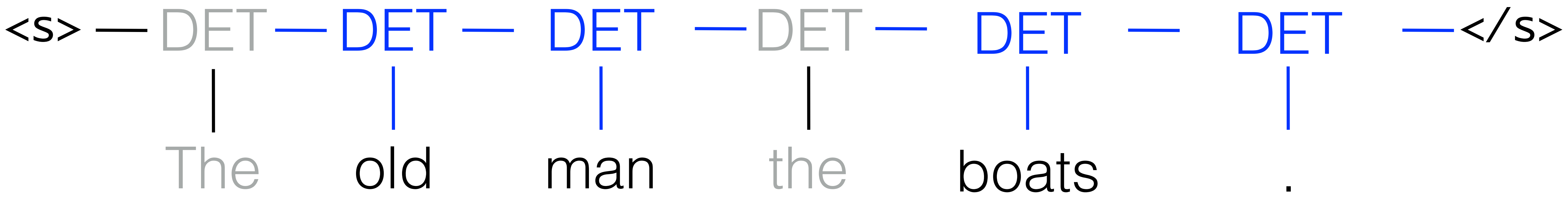
<s> — DET — ADJ — VERB — DET — NOUN — PUNCT — </s>

The old man the boats .

Update parameters!

correct tags: no change to weights

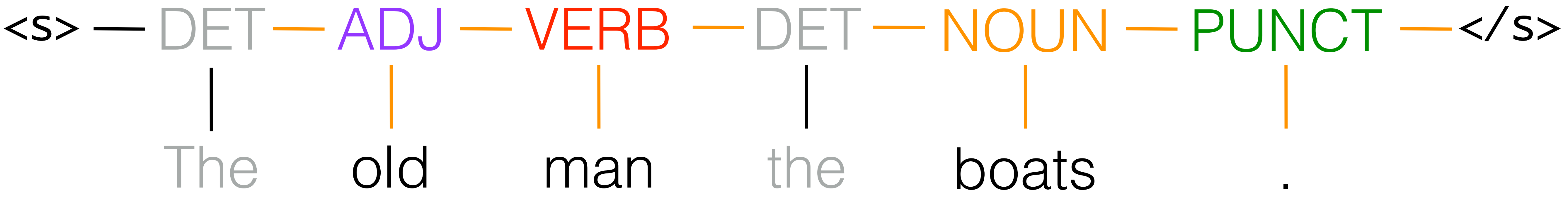
Predicted (iteration 1):



<s> — DET — DET — DET — DET — DET — DET — </s>

The old man the boats .

Gold:



<s> — DET — ADJ — VERB — DET — NOUN — PUNCT — </s>

The old man the boats .

Update parameters!

weights for incorrectly predicted tags get more negative, weights for gold tags get more positive

Discriminative Classifiers: Non-probabilistic

- The structured counterpart of the perceptron classifier is called…the structured perceptron.
  - Also: structural SVM (max-margin).

Discriminative Classifiers: Probabilistic

- The structured counterpart of the logistic regression classifier: **conditional random field (CRF)**.
  - Most common: **linear-chain** structure, i.e., sequence
  - Probabilistic—linear score is exponentiated & normalized
  - Training requires forward-backward algorithm (expensive!)
  - Downloadable implementations include CRF++
  - If you want the gory details: Sutton & McCallum, http://homepages.inf.ed.ac.uk/csutton/publications/crftut-fnt.pdf
- There is also the **Maximum Entropy Markov Model (MEMM)**, which makes simplifying assumptions to reduce computation and is nearly as accurate in practice.