# Learning to Predict Structures
## with Applications to Natural Language Processing

Ivan Titov

# Before we start …

- Fill in the survey:
  - Name
  - Email  (Please make it eligible!)
  - Matriculation number
  - Department:  CS or CoLi
  - BSc or MSc and your semester
- These two points will affect the set of topics and papers
  - Your major and research interests
  - Previous classes attended (or attending now)
    - Machine learning ?
    - Statistical NLP ?
    - Information Extraction?

# Outline

- Introduction to the Topic
- Seminar Plan
- Requirements and Grading

# Learning Machines to Do What?

- This seminar is about supervised learning methods
  1. Take a set of labeled examples $\{(x_i, y_i)\}_{i=1}^n \; x \in \mathcal{X}, \; y \in \mathcal{Y}$

     (  ,"dog"), (  , "dog"), (  , "cat"), …

  2. Define a parameterized class of functions

     $$f(w) : \mathcal{X} \rightarrow \mathcal{Y} : w \in \mathcal{R}^n$$

     - Represent images as vectors of features $\varphi(x)$ (e.g., SIFT features for images)
     - And consider linear functions: $y = \text{argmax}_{y \in \mathcal{Y}} \, w_y \varphi(x)$

Distinct vector for each y: cats, dogs,..

.

# Supervised Classification

- Linear functions:

$$y = \text{argmax}_{y \in \mathcal{Y}} \, w_y \varphi(x)$$

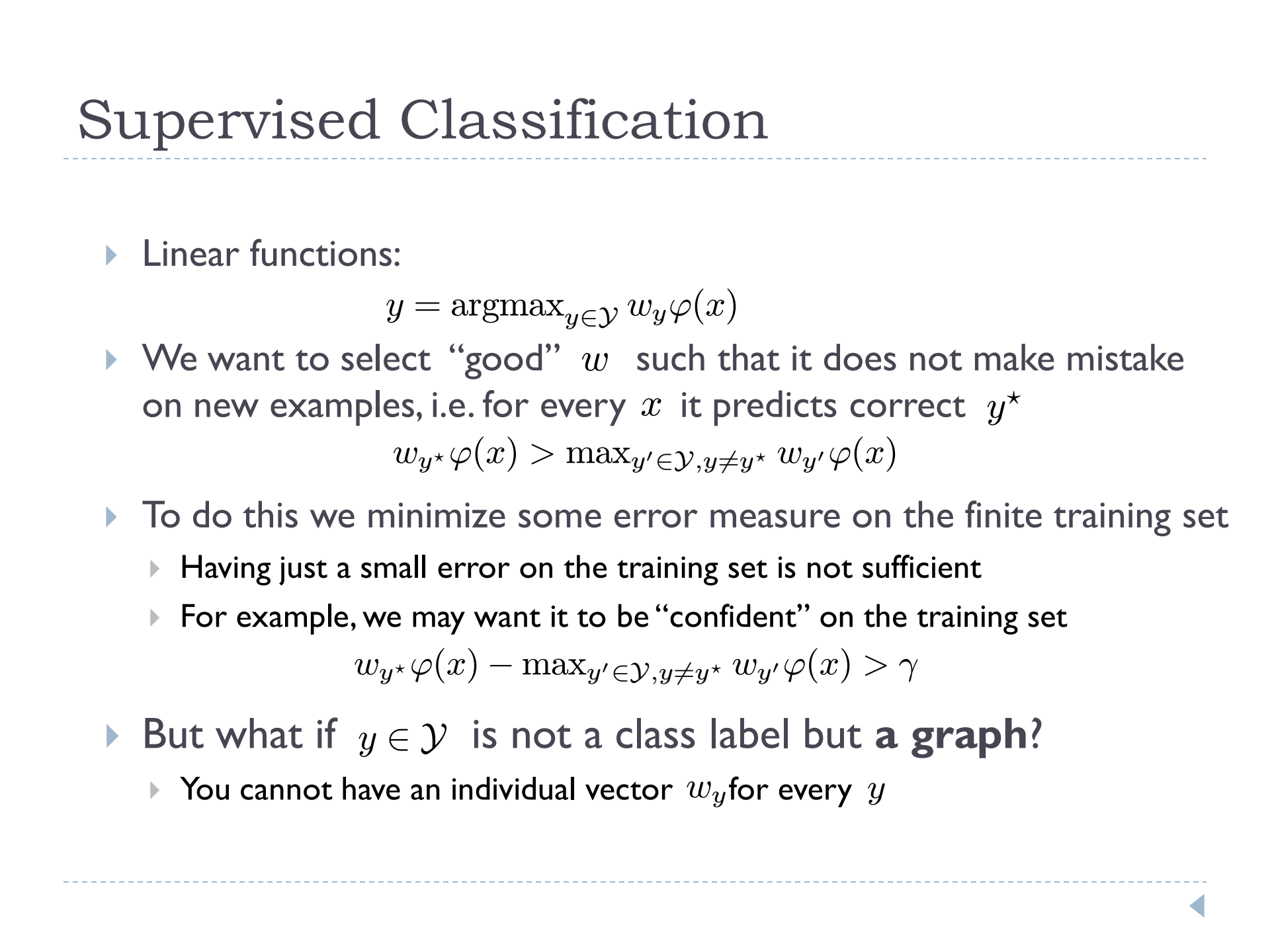
- We want to select "good" $w$ such that it does not make mistake on new examples, i.e. for every $x$ it predicts correct $y^\star$

$$w_{y^\star} \varphi(x) > \max_{y' \in \mathcal{Y}, y \neq y^\star} w_{y'} \varphi(x)$$

- To do this we minimize some error measure on the finite training set
  - Having just a small error on the training set is not sufficient
  - For example, we may want it to be "confident" on the training set

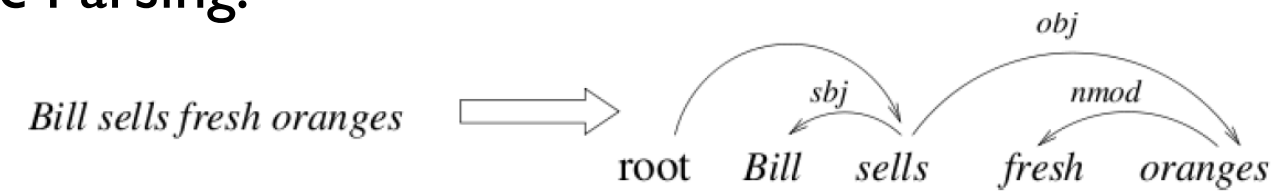
$$w_{y^\star} \varphi(x) - \max_{y' \in \mathcal{Y}, y \neq y^\star} w_{y'} \varphi(x) > \gamma$$

- But what if $y \in \mathcal{Y}$ is not a class label but **a graph**?
  - You cannot have an individual vector $w_y$ for every $y$

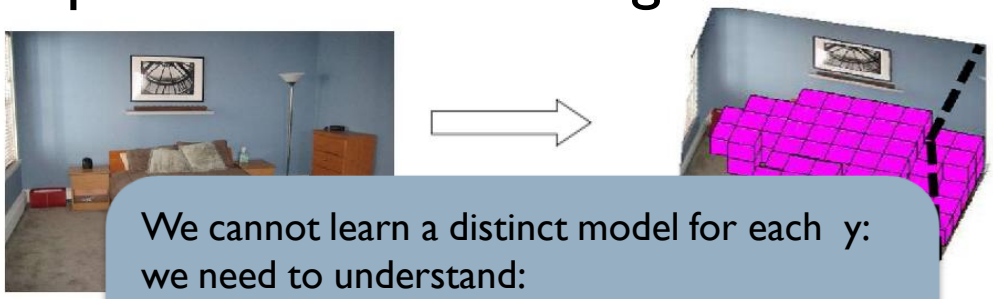


# Example Problems

- Syntactic Parsing:

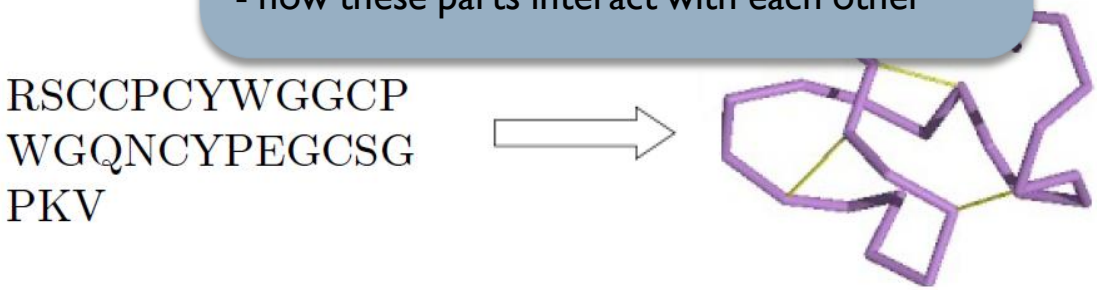



- 3D Layout prediction for an image:



We cannot learn a distinct model for each y:
we need to understand:
- how to break it in parts
- how to predict these parts
- how these parts interact with each other

- Protein struc s)

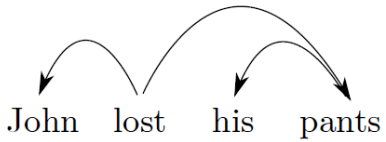


# Skeleton of a general SP methods

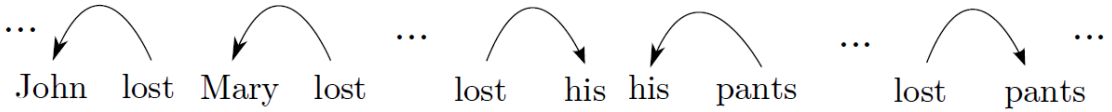
- Decide how to represent your structures for learning

x (input) is the sentence, y (output) is the tree

$(x, y) =$




$\varphi(x, y) =$ ( ..., 1, 0, ... 0, 1, ... 1, .... )

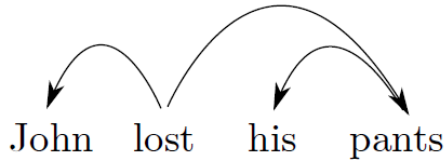



- Note that we have $\varphi(x, y)$ not $\varphi(x)$ or $\varphi(y)$

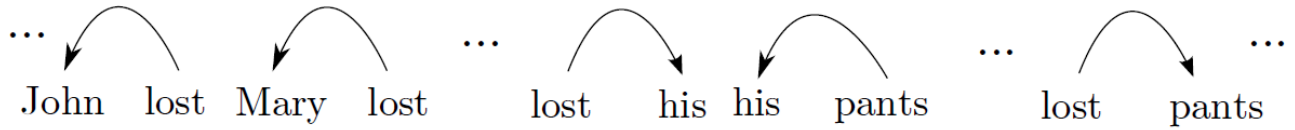
# Skeleton of a general SP methods

- And then you define a vector $w$, for example:

$(x, y^\star) =$




$\varphi(x, y^\star) =$ ( ..., 1, 0, ... 0, 1, ... 1, .... )



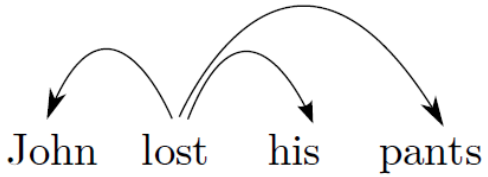

$w =$ ( ..., +5, +5, ... -100, +2, ... , +3, .... )

- Their inner product is: $w\varphi(x, y^\star) = 5 \times 1 + 2 \times 1 + 3 \times 1 = 10$

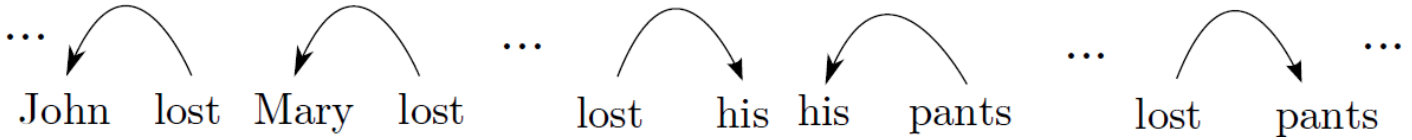
# Skeleton of a general SP methods

- What if we have some bad parse tree:

$(x, y') =$




$\varphi(x, y') =$ ( ..., 1, 0, ... 1, 0, ... 1, .... )




$w =$ ( ..., +5, +5, ... -100, +2, ... , +3, .... )

- Their inner product is:

$$w\varphi(x, y') = 5 \times 1 - 100 \times 1 + 3 \times 1 = -92 << \varphi(x, y^\star) = 10$$

# Structured Prediction

- You use your model:

Dependency trees where nodes are words of the current sentence x

$$y = \text{argmax}_{y' \in \mathcal{Y}(x)} w\varphi(x, y')$$

- We want to select "good" $w$ such that it does not make mistake on new examples, i.e. for every $x$ it predicts correct $y^\star$

$$w\varphi(x, y^\star) > \max_{y' \in \mathcal{Y}(x), y \neq y^\star} \varphi(x, y')$$

- To do this we again minimize some error measure on the finite training set

# Structured Prediction (challenges)

1. Selecting feature representation $\varphi$
   - It should be sufficient to **discriminate correct trees from incorrect ones**
   - It should be possible to decode with it (see (3))
2. Learning
   - Which error function to optimize on the training set, for example

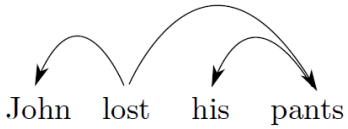
$$w\varphi(x, y^\star) - \max_{y' \in \mathcal{Y}(x), y \neq y^\star} \varphi(x, y') > \gamma$$

   - How to make it efficient (see (3))

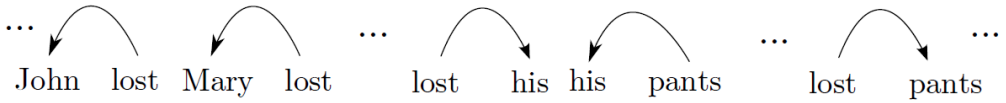
3. Decoding: $y = \operatorname{argmax}_{y' \in \mathcal{Y}(x)} w\varphi(x, y')$
   - Dynamic programming for simpler representations $\varphi$?
   - Approximate search for more powerful ones?

# Decoding: example

$(x, y) =$




$\varphi(x, y) =$ ( ..., 1, 0, ... 0, 1, ... 1, .... )




$w =$ ( ..., +5, +5, ... -100, +2, ... , +3, .... )

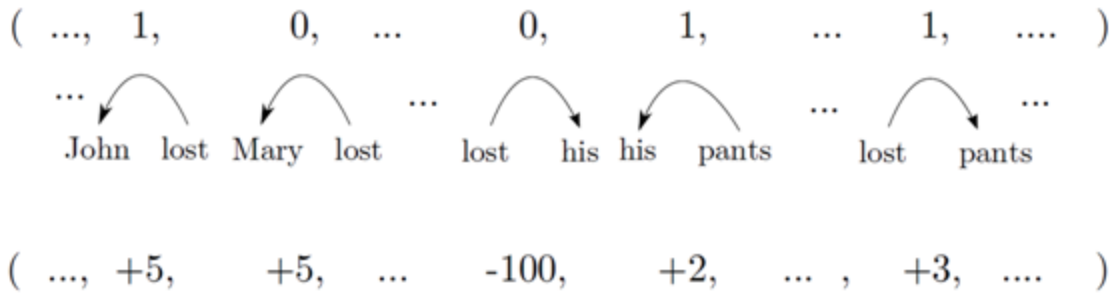
- Decoding: find the dependency tree which has the highest score

$$y = \text{argmax}_{y' \in \mathcal{Y}(x)} w\varphi(x, y')$$

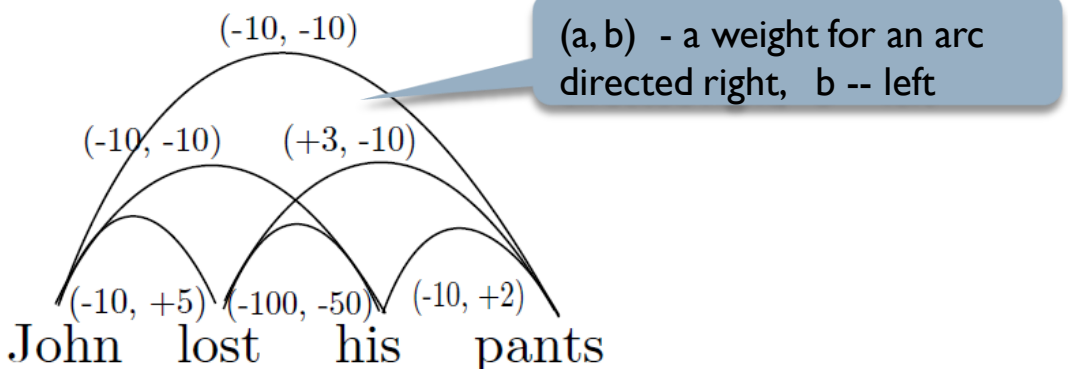
  - Does it remind you something?

# Decoding: example

- Select the highest scoring directed tree:




- For this sentence only a subset is relevant and it can be represented as a weighted directed graph




- Directed MST problem: Chi-Liu-Edmonds algorithm $O(n^2)$

# Decoding: example

- What if we switch to slightly more powerful representation:
  - Counts of all subgraphs of size 3 instead of 2?
- This problem is NP-complete!
  - However, you can use approximations
  - Relaxations to find exact solutions in most cases
  - Consider non all subgraphs of size 3

- It is typical for structured prediction
  - Use a powerful model but approximate decoding or
  - A simpler model but exact search

# Outline

- Introduction to the Topic
- Seminar Plan
- Requirements and Grading

# Goals of the seminar

- Give an overview of state-of-the-art methods for structured prediction
  - If you encounter a structured prediction problem, you should be able to figure what to use and where to look
  - This knowledge is applicable outside natural language processing
- Learn interesting applications of the methods in NLP
- Improve your skills:
  - Giving talks
  - Presenting papers
  - Writing reviews

# Plan

- Next class (November, 5):
  - Introduction continued: Basic Structured Prediction Methods
    - Perceptron => Structured Perceptron
    - Naive Bayes => Hidden Markov Model
    - Comparison: HMM vs Structured Perceptron for Markov Networks
  - Decide on the paper to present (before Wednesday, November 2!)
    - On the basis of the survey and the number of registered students, I will adjust my list and it will be online on today
- Starting from November 13: paper presentations by you

# Topics (method-wise classification)

- Hidden Markov Models vs Structured Perceptron
  - Example: The same class of function but different learning methods (discriminative vs generative)
- Probabilistic Context-Free Grammars (CFGs) vs Weighted CFGs
  - Similar to above but for parsing (predicting trees)
- Maximum-Entropy Markov models vs. Conditional Random Fields
  - Talk about label-bias, compare with generative models,..
- Local Methods vs Global Methods
  - Example: Minimum Spanning Tree algorithm vs Shift-reduce parsing for dependency parsing

# Topics (method-wise classification)

- Max-margin methods
  - Max-Margin Markov Netwoks vs Structured SVM
- Search-based models
  - Incremental perceptron vs SEARN
- Inference with Integer Linear Programming
  - Encoding non-local constraints about the structure of the outputs
- Inducing feature representations:
  - Latent-annotated PCFGs
    - Initial attempts vs split-merge methods
  - Incremental Sigmoid Belief Networks
    - ISBNs vs Max-Ent models

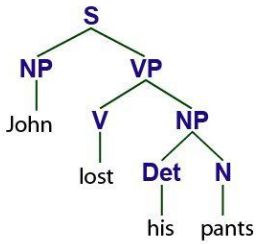
# Topics (application-wise classification)

- Sequence labelling type tasks:
  - Part-of-speech tagging

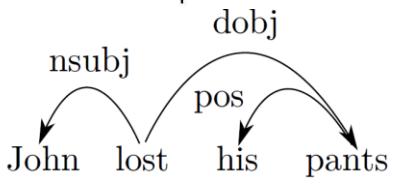
John lost his pants

NNP VBD POS NNS

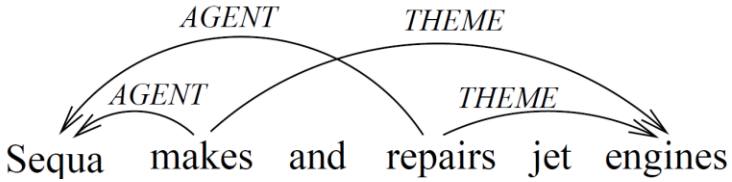
- Parsing tasks
  - Phrase-tree structures




  - Dependency Structures




  - Semantic Role Labeling




  - Information extraction ?

# Requirements

- Present a talk  to the class
  - In the most presentation you will need to cover 2 related papers and compare the approached
  - This way  we will have (hopefully) more interesting talks
- Write 2 critical "reviews" of  2 selected papers (1- 1.5 pages each)
  - Note: changed from 3!!
- A term paper (12-15 pages) for those getting 7 points
  - Make sure you are registered to the right "version" in HISPOS!
- Read papers and participate in discussion
  - If you do not read papers it will not work, and we will have a boring seminar
  - Do not hesitate to ask questions!

# Grades

- Class participation grade: 60 %
  - You talk and discussion after your talk
  - Your participation in discussion of other talks
  - 2 reviews
- Term paper grade: 40 %
  - Only if you get 7 points, otherwise you do not need one
  - Term paper

# Presentation

- Present the methods in accessible way
  - Do not (!) present something you do not understand
  - Do not dive into unimportant details
- Compare proposed methods
- Have a critical view on the paper: discuss shortcomings, any of ideas, any points you still do not understand (e.g., evaluation), any assumptions which seem wrong to you ...
- To give a good presentation in some cases you may need to read one or (maximum two) additional papers (e.g., those referenced in the paper)
- You can check the web for slides on a similar topics and use their ideas, but you should not reuse the slides
- See links to the tutorials on how to make a good presentation w
- Send me your slides 1 week before the talk
  - I will give my feedback within 2 days of receiving
  - Often, we may need to meet and discuss the slides together

# Term paper

- Goal
  - Describe the papers you presented in class
  - Your ideas, analysis, comparison (more later)
  - It should be written in a style of a research paper
- Length: 12 – 15 pages
- Grading criteria
  - Clarity
  - Paper organization
  - Technical correctness
  - New ideas are meaningful and interesting
- Submitted in PDF to my email

# Critical review

- A short critical (!) essay reviewing papers presented in class
  - One  paragraph presenting the essence of the paper (in your own words!)
  - Other parts underlying both positive sides of the paper (what you like) and its shortcomings
- The review should be submitted **before** its presentation in class
  - **(Exception is the additional reviews submitted for the seminars you skipped,  later about it)**
- No copy-paste from the paper

- Length: 1-1.5 pages

# Your ideas / analysis

- Comparison of the methods used in the paper with other material presented in the class or any other related work
- Any ideas on improvement of the approach
- ....

# Attendance policy

- You can skip ONE class without any explanation
- Otherwise, you will need to write an additional critical review (for the paper which was presented while you were absent)

# Office Hours

- I would be happy to see you and discuss after the talk from 16:00 – 17:00 on Fridays (may change if the seminar timing changes):
  - Office 3.22, C 7.4
- Otherwise, send me email and I find the time
  - Even preferable

- Please do meet me:
  - If you do not understand something (anything?)

(Especially important if it is your presentation, but otherwise welcome too)

  - If you have suggestions and questions

# Other stuff

- Timing of the class
- Survey (Doodle poll?)
- Select a topic to present and papers to review by Wed; November 2 (we will use Google docs)

- Note: earlier talks are easier...
  - We need a volunteer for November 12