Intelligent Systems (AI-2)

Computer Science cpsc422, Lecture 31

Nov, 24, 2017

Slide source: from Pedro Domingos UW & Markov Logic: An Interface Layer for Artificial Intelligence Pedro Domingos and Daniel Lowd University of Washington, Seattle

Lecture Overview

- Finish Inference in MLN
  - Probability of a formula, Conditional Probability
- Markov Logic: applications
  - Entity resolution
  - Statistical Parsing!

Markov Logic: Definition

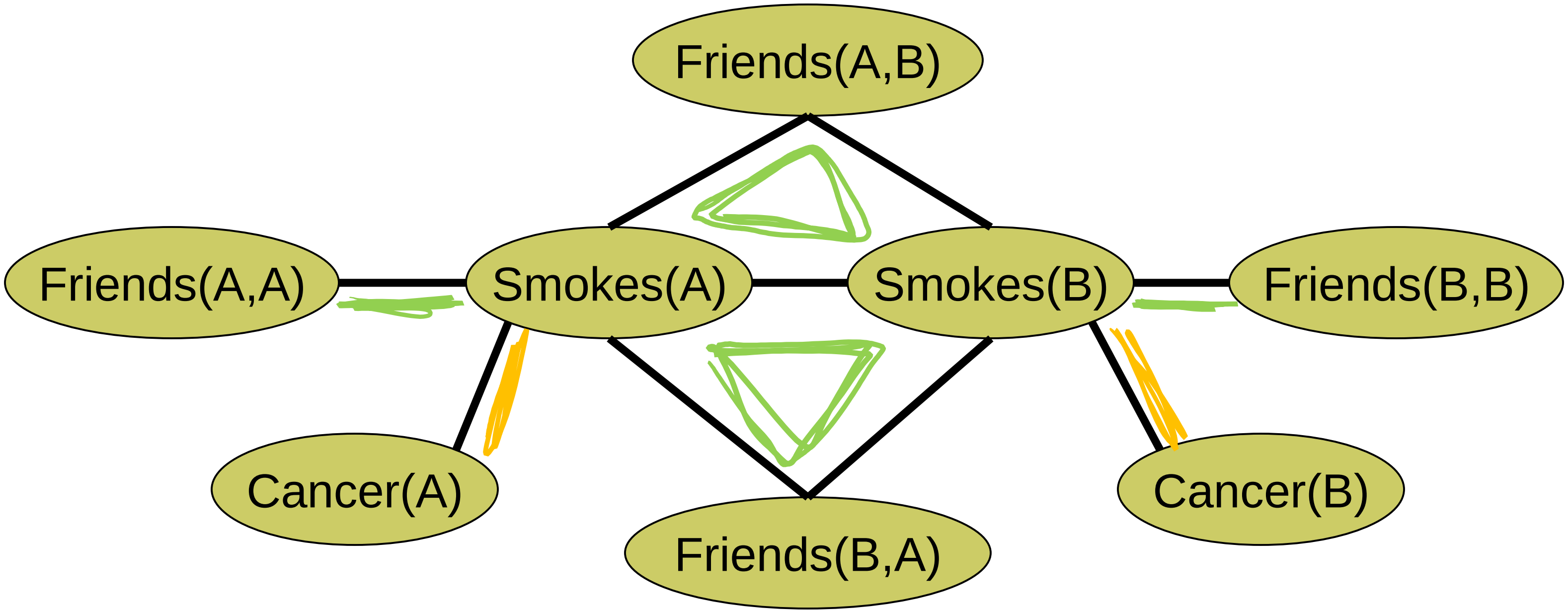
- A Markov Logic Network (MLN) is
  - a set of pairs (F, w) where
    - F is a **formula** in first-order logic
    - w is a **real number**
  - Together with a set C of **constants**,
- It defines a **Markov network** with
  - One *binary node* for each **grounding** of each **predicate** in the MLN
  - One *feature/factor* for each **grounding** of each **formula** F in the MLN, with the corresponding weight w

Grounding: substituting vars with constants

MLN features

1.5	$\forall x\ Smokes(x) \Rightarrow Cancer(x)$
1.1	$\forall x, y\ Friends(x, y) \Rightarrow \left(Smokes(x) \Leftrightarrow Smokes(y)\right)$

Two constants: **Anna** (A) and **Bob** (B)



Computing Probabilities

P(Formula,$M_{L,C}$) = ?

- **Brute force:** Sum probs. of possible worlds where formula holds

$M_{L,C}$ Markov Logic Network

PW_F possible worlds in which F is true

$$P(F, M_{L,C}) = \sum_{pw \in PW_F} P(pw, M_{L,C})$$

- **MCMC:** Sample worlds, check formula holds

S all samples

S_F samples (i.e. possible worlds) in which F is true

$$P(F, M_{L,C}) = \frac{|S_F|}{|S|}$$

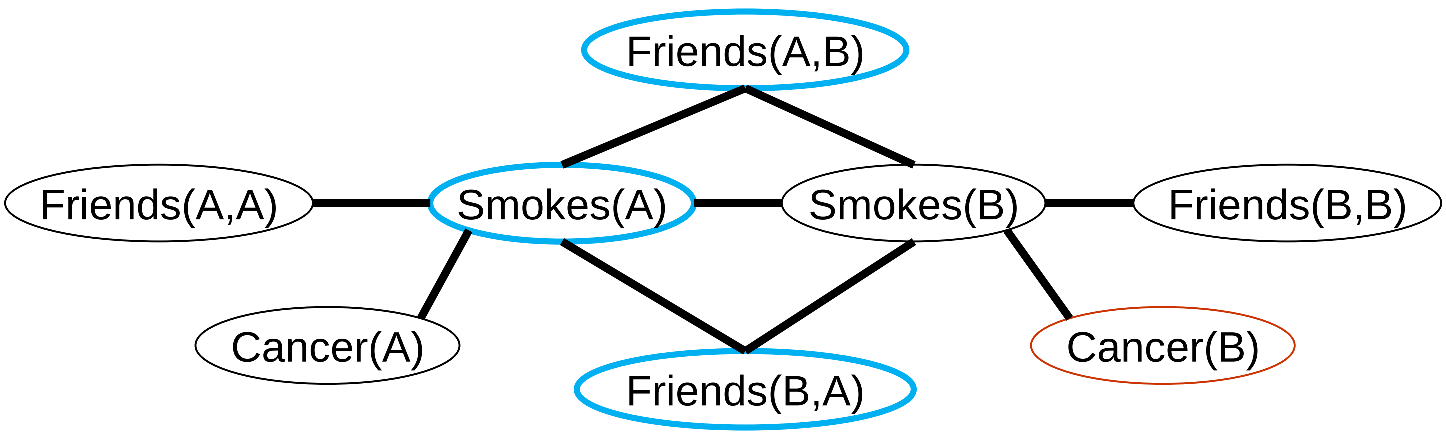
Computing Cond. Probabilities

1.5	$\forall x\ Smokes(x) \Rightarrow Cancer(x)$
1.1	$\forall x, y\ Friends(x,y) \Rightarrow (Smokes(x) \Leftrightarrow Smokes(y))$

Let's look at the simplest case

P(ground literal | conjuction of ground literals, $M_{L,C}$)

P(Cancer(B)| Smokes(A), Friends(A, B), Friends(B, A))



To answer this query do you need to create (ground) the whole network?

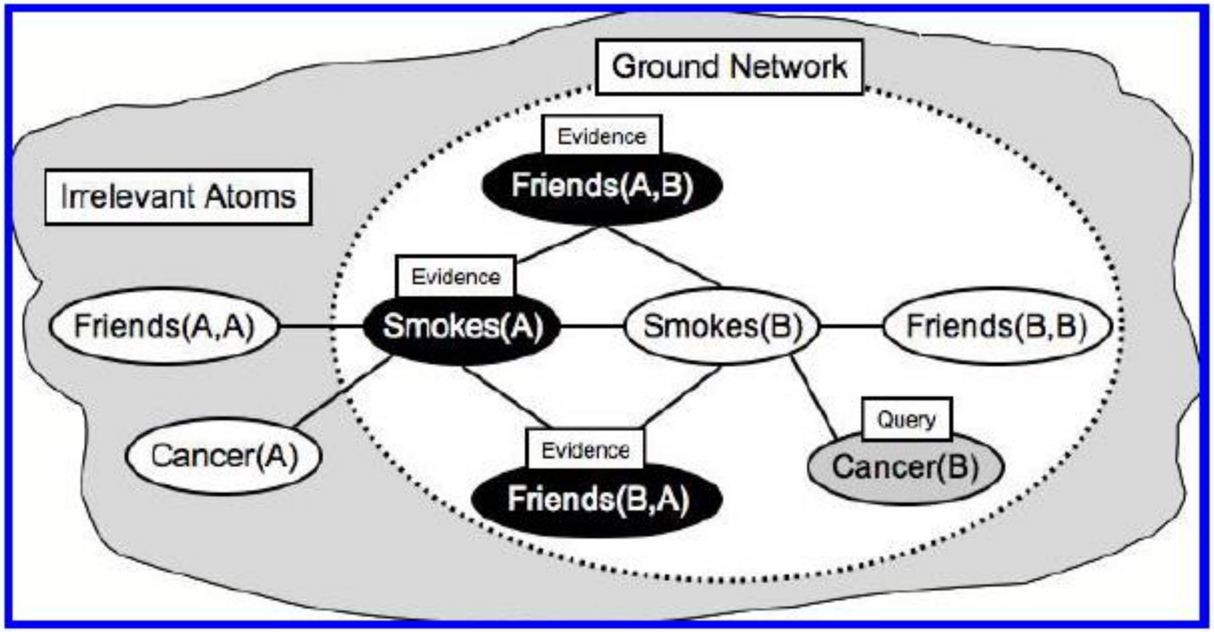
A. Yes B. No C. It depends . . .

Computing Cond. Probabilities

Let's look at the simplest case

P(ground literal | conjuction of ground literals, $M_{L,C}$)

P(Cancer(B)| Smokes(A), Friends(A, B), Friends(B, A))



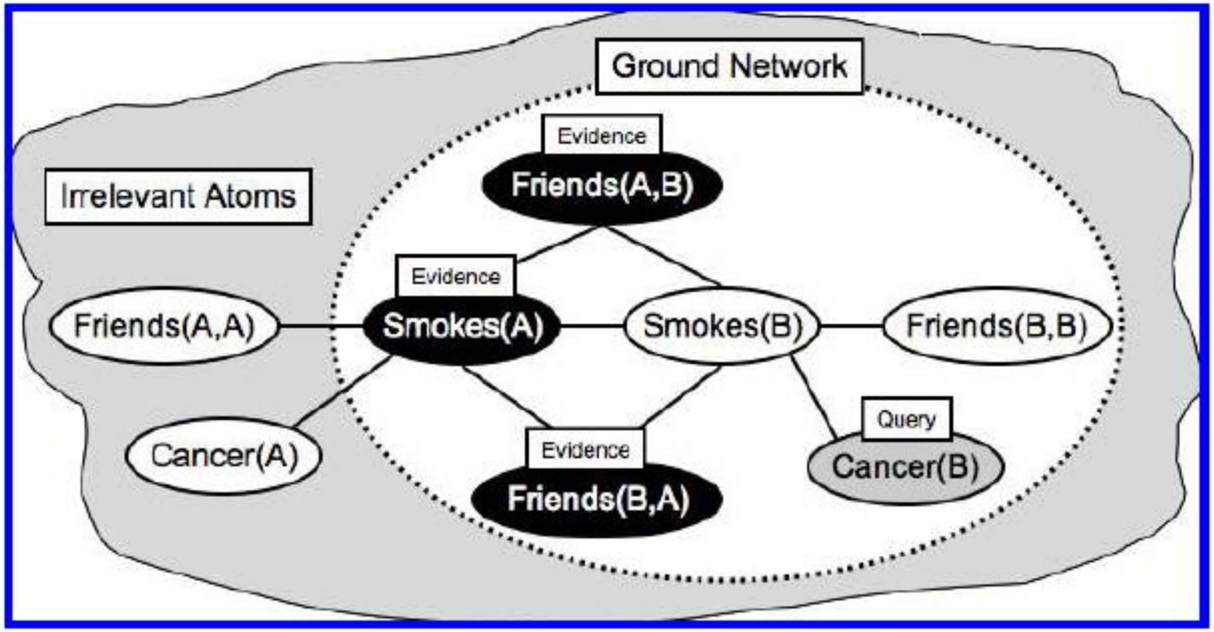
You do not need to create (ground) the part of the Markov Network from which the query is independent given the evidence

Computing Cond. Probabilities

P(Cancer(B)| Smokes(A), Friends(A, B), Friends(B, A))

The sub network is determined by the formulas (the logical structure of the problem)

1.5	$\forall x\ Smokes(x) \Rightarrow Cancer(x)$
1.1	$\forall x, y\ Friends(x,y) \Rightarrow \left(Smokes(x) \Leftrightarrow Smokes(y)\right)$



You can then perform Gibbs Sampling in this Sub Network

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  - Statistical Parsing!

Entity Resolution

- Determining which observations correspond to the same real-world objects

- (e.g., database records, noun phrases, video regions, etc)

- Crucial importance in many areas

(e.g., data cleaning, NLP, Vision)

Entity Resolution: Example

AUTHOR: *H. POON & P. DOMINGOS*
TITLE: *UNSUPERVISED SEMANTIC PARSING*
VENUE: *EMNLP-09*

AUTHOR: *Hoifung Poon and Pedro Domings*
TITLE: *Unsupervised semantic parsing*
VENUE: *Proceedings of the 2009 Conference on Empirical Methods in Natural Language Processing*

AUTHOR: *Poon, Hoifung and Domings, Pedro*
TITLE: *Unsupervised ontology induction from text*
VENUE: *Proceedings of the Forty-Eighth Annual Meeting of the Association for Computational Linguistics*

AUTHOR: *H. Poon, P. Domings*
TITLE: *Unsupervised ontology induction*
VENUE: *ACL-10*

SAME?

SAME?

SAME?

SAME?

SAME?

SAME?

Entity Resolution (relations)

Problem: Given citation database, find duplicate records
Each citation has `author`, `title`, and `venue` fields
We have 10 relations

provided as evidence

```
Author(bib,author)
Title(bib,title)          relate citations to their fields
Venue(bib,venue)

HasWord(author, word)
HasWord(title, word)      indicate which words are present
HasWord(venue, word)      in each field;
```

To be inferred

```
SameAuthor (author, author) represent field equality;
SameTitle(title, title)
SameVenue(venue, venue)

SameBib(bib, bib) represents citation equality;
```

Entity Resolution (formulas)

Predict citation equality based on words in the fields

```
Title(b1, t1) ∧ Title(b2, t2) ∧
HasWord(t1,+word) ∧ HasWord(t2,+word) ⇒
SameBib(b1, b2)
```

1000s of rules one for each word

```
(NOTE: +word is a shortcut notation, you
actually have a rule for each word e.g.,
Title(b1, t1) ∧ Title(b2, t2) ∧
HasWord(t1,"bayesian") ∧
HasWord(t2,"bayesian" ) ⇒ SameBib(b1, b2) )
```

Same 1000s of rules for author

Same 1000s of rules for venue

Entity Resolution (formulas)

Transitive closure

`SameBib(b1,b2) ∧ SameBib(b2,b3) ⇒ SameBib(b1,b3)`

`SameAuthor(a1,a2) ∧ SameAuthor(a2,a3) ⇒ SameAuthor(a1,a3)`

Same rule for **`title`**

Same rule for **`venue`**

Link fields equivalence to citation equivalence – *e.g., if two citations are the same, their authors should be the same*

`Author(b1, a1) ∧ Author(b2, a2) ∧ SameBib(b1, b2) ⇒ SameAuthor(a1, a2)`

…and that citations with the same author are more likely to be the same

`Author(b1, a1) ∧ Author(b2, a2) ∧ SameAuthor(a1, a2) ⇒ SameBib(b1, b2)`

Same rules for **`title`**

Same rules for **`venue`**

Benefits of MLN model

Standard non-MLN approach: build a classifier that given two citations tells you if they are the same or not, and then apply transitive closure

New MLN approach:

- performs *collective* entity resolution, where resolving one pair of entities helps to resolve pairs of related entities

e.g., inferring that a pair of citations are equivalent can provide evidence that the names *AAAI-06* and *21st Natl. Conf. on AI* refer to the same venue, even though they are superficially very different. This equivalence can then aid in resolving other entities.

Other MLN applications

- **Information Extraction**
- **Co-reference Resolution Robot Mapping** (infer the map of an indoor environment from laser range data)
- **Link-based Clustering** (uses relationships among the objects in determining similarity)
- **Ontologies extraction from Text**
- **…..**

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  - **Statistical Parsing!**

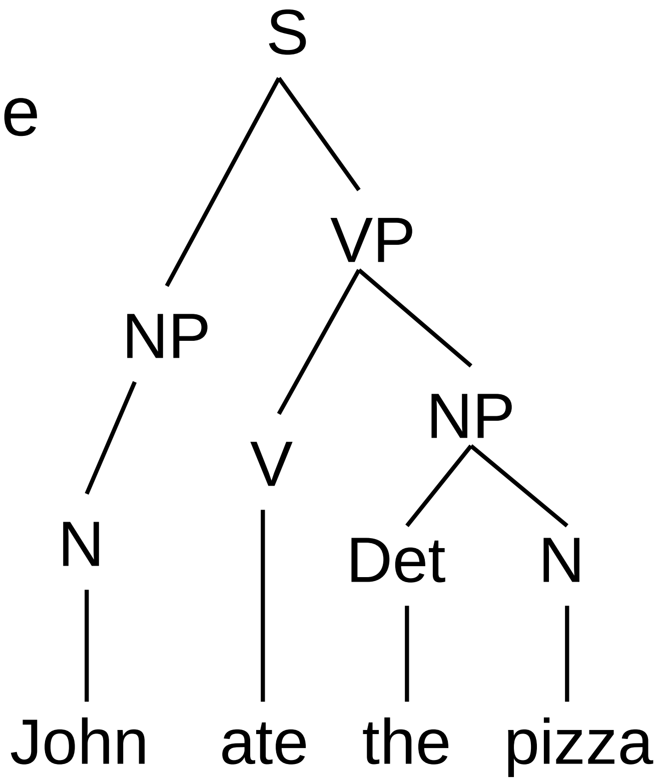
Statistical Parsing

- **Input:** Sentence
- **Output:** Most probable parse
- **PCFG:** Production rules with probabilities

  E.g.: 0.7 NP → N

  0.3 NP → Det N
- **WCFG:** Production rules with weights (equivalent)
- Chomsky normal form:

  A → B C or A → a



Logical Representation of CFG

→ rewrites as ⇒ logical implication

$$S \rightarrow NP\ VP$$

A NP ^ VP => S

B NP(i,j) ^ VP(j,k) => S(i,k)

C S(i,k) => NP(i,j) ^ VP(j,k)

Which one would be a reasonable representation in logics?

0 the 1 dog 2 chases 3 the 4 cat 5

Logical Representation of CFG

$$S \rightarrow NP\ VP$$
$$NP \rightarrow Adj\ N$$
$$NP \rightarrow Det\ N$$
$$VP \rightarrow V\ NP$$

NP(i,j) ^ VP(j,k) => S(i,k)

Adj(i,j) ^ N(j,k) => NP(i,k)

Det(i,j) ^ N(j,k) => NP(i,k)

V(i,j) ^ NP(j,k) => VP(i,k)

Lexicon….

// Determiners

Token("a",i) => Det(i,i+1)

Token("the",i) => Det(i,i+1)

// Adjectives

Token("big",i) => Adj(i,i+1)

Token("small",i) => Adj(i,i+1)

// Nouns

Token("dogs",i) => N(i,i+1)

Token("dog",i) => N(i,i+1)

Token("cats",i) => N(i,i+1)

Token("cat",i) => N(i,i+1)

Token("fly",i) => N(i,i+1)

Token("flies",i) => N(i,i+1)

// Verbs

Token("chase",i) => V(i,i+1)

Token("chases",i) => V(i,i+1)

Token("eat",i) => V(i,i+1)

Token("eats",i) => V(i,i+1)

Token("fly",i) => V(i,i+1)

Token("flies",i) => V(i,i+1)

Det(0,1) N(1,2)

the cat ate the mouse

0 1 2 3 4 5

0 1 2 3 4

Avoid two problems (1)

- If there are two or more rules with the same left side (such as **NP -> Adj N** and **NP -> Det N**

need to enforce the constraint that only one of them fires :

NP(i,k) ^ Det(i,j) => ¬Adj(i,j)

``If a noun phrase results in a determiner and a noun, it cannot result in and adjective and a noun''.

Avoid two problems (2)

- **Ambiguities in the lexicon.**

homonyms belonging to different parts of speech,
 e.g., Fly (noun or verb),
only one of these parts of speech should be assigned.

We can enforce this constraint in a general manner by making mutual exclusion rules for each part of speech pair, i.e.:

$\neg$ Det(i,j) v $\neg$ Adj(i,j)

$\neg$ Det(i,j) v $\neg$ N(i,j)

$\neg$ Det(i,j) v $\neg$ V(i,j)

$\neg$ Adj(i,j) v $\neg$ N(i,j)

$\neg$ Adj(i,j) v $\neg$ V(i,j)

$\neg$ N(i,j) v $\neg$ V(i,j)

$\neg(A \wedge B)$

Statistical Parsing Representation: Summary

- For each rule of the form A → B C:
  Formula of the form **`B(i,j) ^ C(j,k) => A(i,k)`**

  E.g.: **`NP(i,j) ^ VP(j,k) => S(i,k)`**
- For each rule of the form A → a:
  Formula of the form **`Token(a,i) => A(i,i+1)`**

  E.g.: **`Token("pizza", i) => N(i,i+1)`**
- For each nonterminal: state that exactly one production holds (solve problem 1)
- Mutual exclusion rules for each part of speech pair (solve problem 2)

Statistical Parsing : Inference

- **Evidence predicate:** **`Token(token,position)`**

  E.g.: **`Token("pizza", 3) etc.`**
- **Query predicates:**
  `Constituent`**`(position,position)`**

  E.g.: **`S(0,7} "is this sequence of seven words a sentence?"  but also NP(2,4)`**

- What inference yields the most probable parse?

MAP!

Semantic Processing

Example: John ate pizza.

Grammar: S → NP VP   VP → V NP   V → ate
NP → John   NP → pizza

```
Token("John",0) => Participant(John,E,0,1)
Token("ate",1) => Event(Eating,E,1,2)
Token("pizza",2) => Participant(pizza,E,2,3)

Event(Eating,e,i,j) ^ Participant(p,e,j,k)
  ^ VP(i,k) ^ V(i,j) ^ NP(j,k) => Eaten(p,e)

Event(Eating,e,j,k) ^ Participant(p,e,i,j)
  ^ S(i,k) ^ NP(i,j) ^ VP(j,k) => Eater(p,e)

Event(t,e,i,k) => Isa(e,t)
```

Result: `Isa(E,Eating), Eater(John,E), Eaten(pizza,E)`

422 big picture: Where are we?

StarAI (statistical relational AI)

Hybrid: Det +Sto

Prob CFG

Prob Relational Models

Markov Logics

MAP MaxWalkSAT

	Deterministic	Stochastic
Query	*Logics* *First Order Logics* *Ontologies* • Full Resolution • SAT	*Belief Nets* Approx. : Gibbs *Markov Chains and HMMs* Forward, Viterbi…. Approx. : Particle Filtering *Undirected Graphical Models* *Markov Networks* *Conditional Random Fields*
Planning		*Markov Decision Processes and Partially Observable MDP* • Value Iteration • Approx. Inference *Reinforcement Learning*

Templates

Diff dot for Markov BI

rewrite as ops on factors

Applications of AI

Representation

Reasoning Technique

Learning Goals for today's class

You can:

- Compute Probability of a formula, Conditional Probability
- Describe the entity resolution application of ML and explain the corresponding representation

Next Class on Mon

- **Start Probabilistic Relational Models**

Keep working on **Assignment-4**

Due **Dec 1**

In the past, a similar hw took students between 8 - 15 hours to complete. Please start working on it as soon as possible!