Intelligent Systems (AI-2)

Computer Science cpsc422, Lecture 32

Nov, 25, 2019

Slide source: from David Page (MIT) (which were from From Lise Getoor, Nir Friedman, Daphne Koller, and Avi Pfeffer) and from Lise Getoor
422 big picture: where are we?

Deterministic

Stochastic

Logics

First Order Logics

Ontologies

• Full Resolution
• SAT

Query

Planning

Belief Nets

Approx. : Gibbs

Markov Chains and HMMs

Forward, Viterbi....
Approx. : Particle Filtering

Undirected Graphical Models

Markov Networks

Conditional Random Fields

Markov Decision Processes and
Partially Observable MDP

• Value Iteration
• Approx. Inference

Reinforcement Learning

Applications of AI

StarAI (statistical relational AI)

Hybrid: Det + Sto

Prob CFG

Prob Relational Models

Markov Logics

Approx. : Particle Filtering

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Slide 2
A customer C1 will / will not recommend a book B1 depending on the book quality, and the customer honesty and kindness.

When you have two customers and two books.....
A **customer** C1 will / will not **recommend** a **book** B1 depending on the book **quality**, and the customer **honesty** and **kindness**

When you have two customers and two books…..
Lecture Overview

• Motivation and Representation
• Semantics of Probabilistic Relational Models (PRMs)
  • Classes and Relations
  • Attributes and Reference Slots
  • Full Relational Schema and its Instances
  • Fixed vs. Probabilistic Attributes
  • Relational Skeleton and its Completion Instance
  • Inverse Slot and Slot chain
Motivation for PRMs

• Most real-world data are stored in relational DBMS

• Combine advantages of relational logic & Bayesian networks:
  – natural domain modeling: objects, properties, relations;
  – generalization over a variety of situations;
  – compact, natural probability models.

• Integrate uncertainty with relational model:
  – properties of domain entities can depend probabilistically on properties of related entities;
  – uncertainty over relational structure of domain.
Limitations of Bayesian Networks

A Bayesian networks (BNs) represents a pre-specified set of attributes/variables whose relationship to each other is fixed in advance.
How PRMs extend BNs?

1. PRMs conceptually extend BNs to allow the specification of a probability model for classes of objects rather than a fixed set of simple attributes.

2. PRMs also allow properties of an entity to depend probabilistically on properties of other related entities.
Lecture Overview

• Motivation and Representation
• **Semantics of Probabilistic Relational Models (PRMs)**
  • Classes and Relations
  • Attributes and Reference Slots
  • Full Relational Schema and its Instances
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Mapping PRMs from Relational Models

• The representation of PRMs is a direct mapping from that of relational databases

• A relational model consists of a set of classes $X_1, \ldots, X_n$ and a set of relations $R_1, \ldots, R_m$, where each relation $R_i$ is typed
University Domain Example - Classes and relations

- Indicates many-to-many relationship
- Indicates one-to-many relationship

Professor -> Course: M
Course -> Registration: M
Registration -> Student: 1
Student -> Professor: 1

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Mapping PRMs from Relational Models: attributes

- Each class or entity type (corresponding to a single relational table) is associated with a set of attributes $\mathcal{A}(X_i)$ (at least one of which is a primary key)
Mapping PRMs from Relational Models: reference slot

- Each class or entity type is also associated with a set of reference slots $\mathcal{R}(X)$
- correspond to attributes that are foreign keys (key attributes of another table)
- $X.\rho$, is used to denote reference slot $\rho$ of $X$. 

![Diagram of Course and Instructor entities with references to Professor entity]
University Domain Example - Full Relational Schema

Primary keys are indicated by a blue rectangle.

Indicates many-to-many relationship.

Dashed lines indicate the types of objects referenced.

Indicates one-to-many relationship.

Underlined attributes are reference slots of the class.
Book Recommendation Domain - Full Relational Schema

Book
- Title
- Quality

Customer
- Name
- Honesty
- Kindness

Recommendation
- Name
- Book
- Customer
- Rating
PRM Semantics: Attribute values

- Each attribute $A_j \in \mathbb{A}(X_i)$ takes on values in some fixed domain of possible values denoted $V(A_j)$. We assume that value spaces are finite.
- Attribute $A$ of class $X$ is denoted $X.A$

- E.g., $V(\text{Student.Intelligence})$ might be \{ high, low \}
PRM Semantics: Instance of Schema

• An *instance* \( I \) of a schema/model specifies a set of objects \( x \), partitioned into classes; such that there is
  - a value for each attribute \( x.A \)
  - and a value for each reference slot \( x.\rho \)
One professor is the instructor for both courses.

Jane Doe is registered for only one course, Phil101, while the other student is registered for both courses.
University Domain Example – Another Instance of the Schema

There are two professors instructing a course.

There are three students in the Phil201 course.
PRM Semantics: fixed vs. prob. attributes

• Some attributes, such as Name or Social Security Number, are fully determined. Such attributes are labeled as fixed. Assume that they are known in any instantiation of the schema.

• The other attributes are called probabilistic. We may be uncertain about their value.
University Domain Example - fixed vs. probabilistic attributes

Which ones are fixed? Which are probabilistic?
University Domain Example - fixed vs. probabilistic attributes

Fixed attributes are shown in regular font.
Probabilistic attributes are shown in italic regular font.
PRM Semantics: Skeleton Structure

- A *skeleton structure* $\sigma$ of a relational schema is a partial specification of an instance of the schema. It specifies
  - set of objects for each class,
  - values of the fixed attributes of these objects,
  - relations that hold between the objects
- The values of probabilistic attributes are left unspecified

- A *completion* $I$ of the skeleton structure $\sigma$ extends the skeleton by also specifying the values of the probabilistic attributes
University Domain Example - Relational Skeleton

Course
Name
Phil101
Difficulty
???
Rating
???

Registration
RegID
#5639
Grade
???
Satisfaction
???

Student
Name
Jane Doe
Intelligence
???
Ranking
???

Professor
Name
Prof. Gump
Popularity
???
Teaching-Ability
???

Registration
RegID
#5639
Grade
A
Satisfaction
3

Course
Name
Phil101
Difficulty
low
Rating
high

Student
Name
Jane Doe
Intelligence
high
Ranking
average

Professor
Name
Prof. Gump
Popularity
???
Teaching-Ability
???

Registration
RegID
#5639
Grade
???
Satisfaction
???

Course
Name
Phil101
Difficulty
???
Rating
???

Registration
RegID
#5639
Grade
???
Satisfaction
???
University Domain Example - The Completion Instance I

**Professor**
- **Name**: Prof. Gump
- **Popularity**: high
- **Teaching-Able**: medium

**Student**
- **Name**: Jane Doe
- **Intelligence**: high
- **Ranking**: average

**Course**
- **Name**: Phil101
- **Difficulty**: low
- **Rating**: high

**Registration**
- **Name**: #5639
- **Grade**: A
- **Satisfaction**: 3

University Domain Example – The Completion Instance I

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University Domain Example - Another Relational Skeleton

Professor
Name
Prof. Vincent
Popularity
???
Teaching-Ability
???

Student
Name
John Doe
Intelligence
???
Ranking
???

Course
Name
Phil201
Difficulty
???
Rating
???

PRMs allow multiple possible skeletons
University Domain Example - The Completion Instance I

PRMs also allow multiple possible instances and values
PRM Semantics: inverse slot

- For each reference slot $\rho$, we define an inverse slot, $\rho^{-1}$, which is the inverse function of $\rho$.
A slot chain \( \tau = \rho_1 \ldots \rho_m \) is a sequence of reference slots that defines functions from objects to other objects to which they are indirectly related.

Student. Registered-In. Course. Instructor can be used to denote......
Slot chains will allow us...

To specify probabilistic dependencies between attributes of related entities.
Learning Goals for today’s class

You can:

• Explain the need for Probabilistic relational model
• Explain how PRMs generalize BNs
• Define a Full Relational Schema and its instances
• Define a Relational Skeleton and its completion Instances
• Define an inverse slot and an slot chain
Next class on Wed

Finish Probabilistic Relational Models

- Probabilistic Model
- Dependency Structure
- Aggregation
- Parameters
- Class dependency Graph
- Inference

Keep working on Assignment-4
Due Nov 29