Intelligent Systems (AI-2)

Computer Science cpsc422, Lecture 33

Nov, 30, 2015

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?

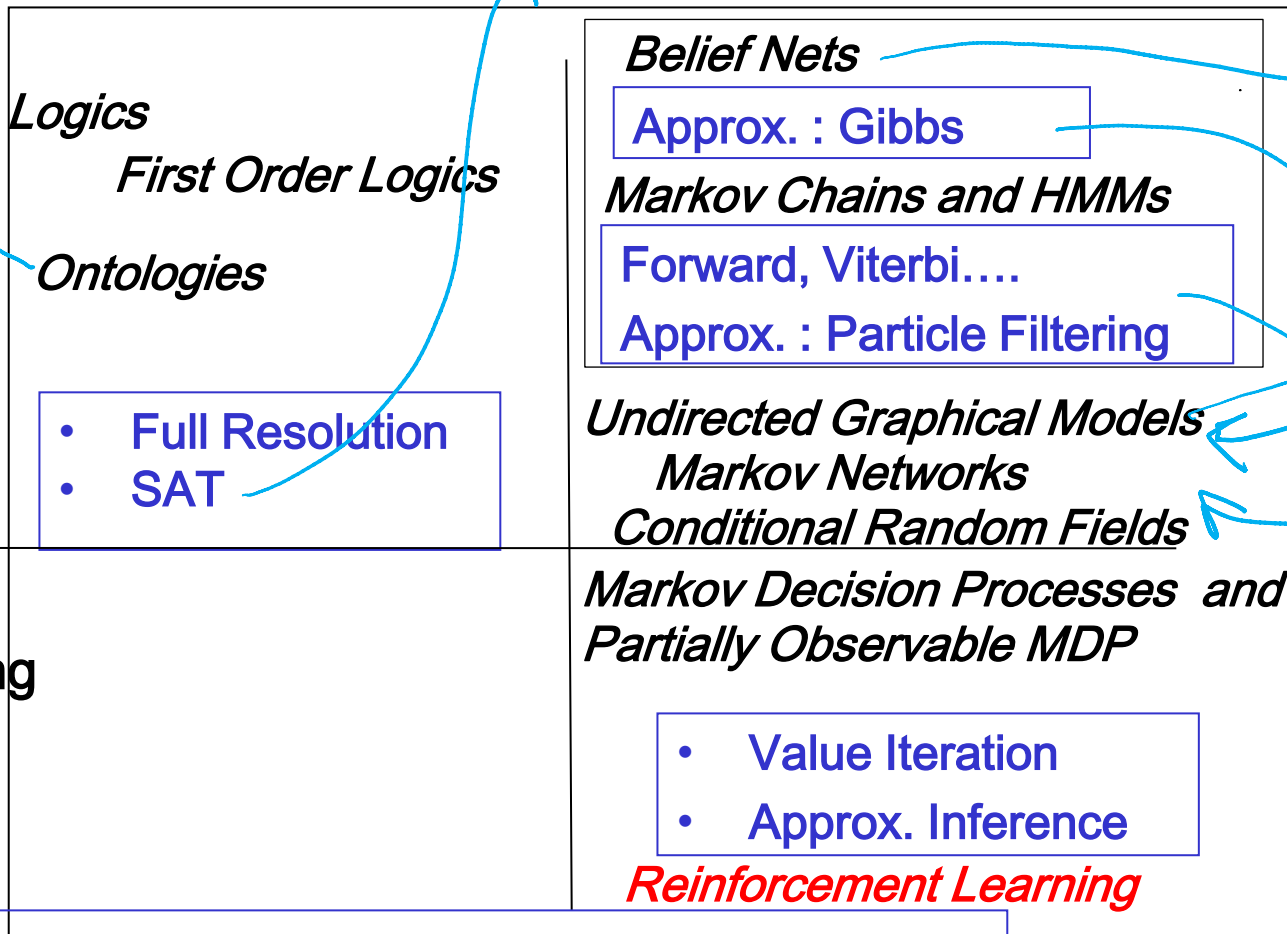StarAI (statistical relational AI)
Hybrid: Det +Sto

Prob CFG
Prob Relational Models
Markov Logics

Deterministic	Stochastic

MAP Max WalkSAT

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 Bl

rewrite as ops on factors

Applications of AI

Representation

Reasoning
Technique

Combining Symbolic and Probabilistic R&R systems
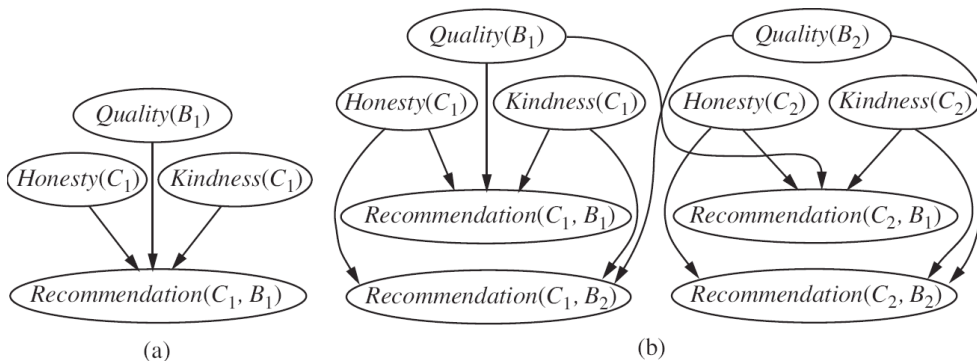
(a) Probabilistic Context-Free Grammars

- Weights are conditional prob. on rewriting rules
- Applications: NLP parsing & Hierarchical Planning
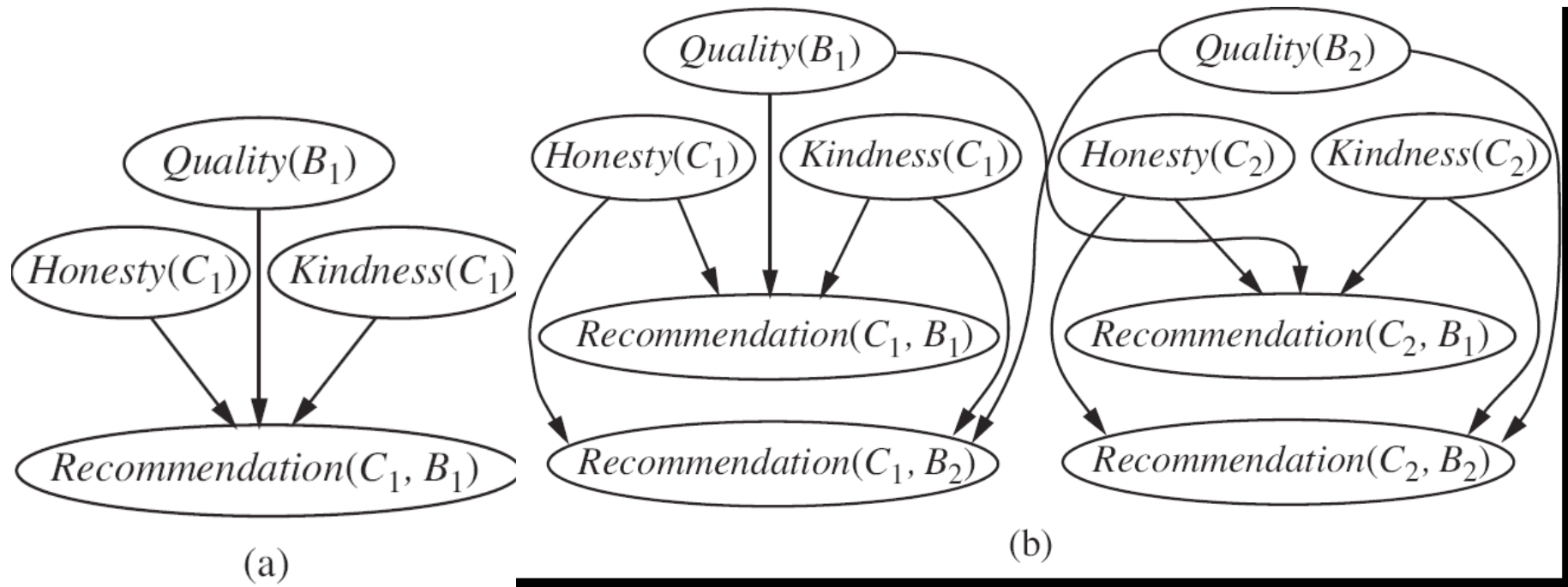
(b) Markov Logics: weighted FOL

$$P(\text{world}) \propto \exp\left(\sum \text{weights of formulas it satisfies}\right)$$

(c) Probabilistic Relational models

- Probs specified on relations

Intuition for Prob. Relational models

$Quality(B_1)$

$Honesty(C_1)$ $Kindness(C_1)$

$Recommendation(C_1, B_1)$

(a)

$Quality(B_1)$

$Honesty(C_1)$ $Kindness(C_1)$

$Recommendation(C_1, B_1)$

$Recommendation(C_1, B_2)$

$Quality(B_2)$

$Honesty(C_2)$ $Kindness(C_2)$

$Recommendation(C_2, B_1)$

$Recommendation(C_2, B_2)$

(b)

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

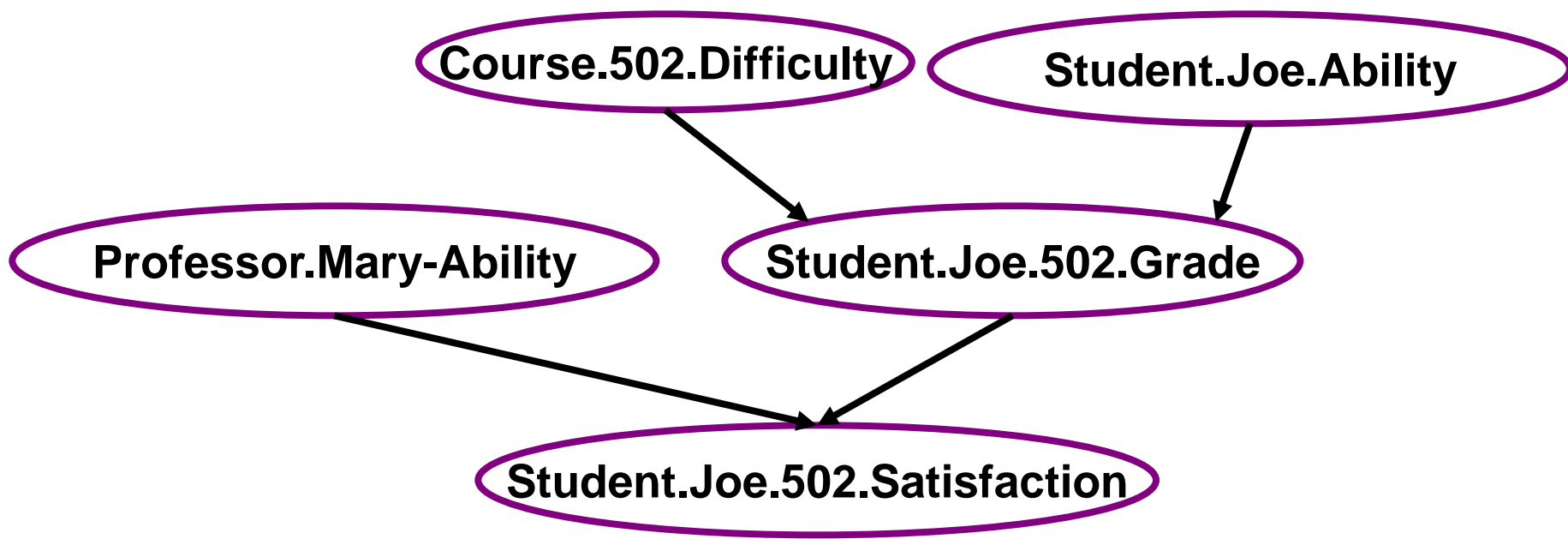When you have two customers and two books…..

Slide 4

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 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

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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

M Professor

1 Student

1 Course

Registration

M

M

M
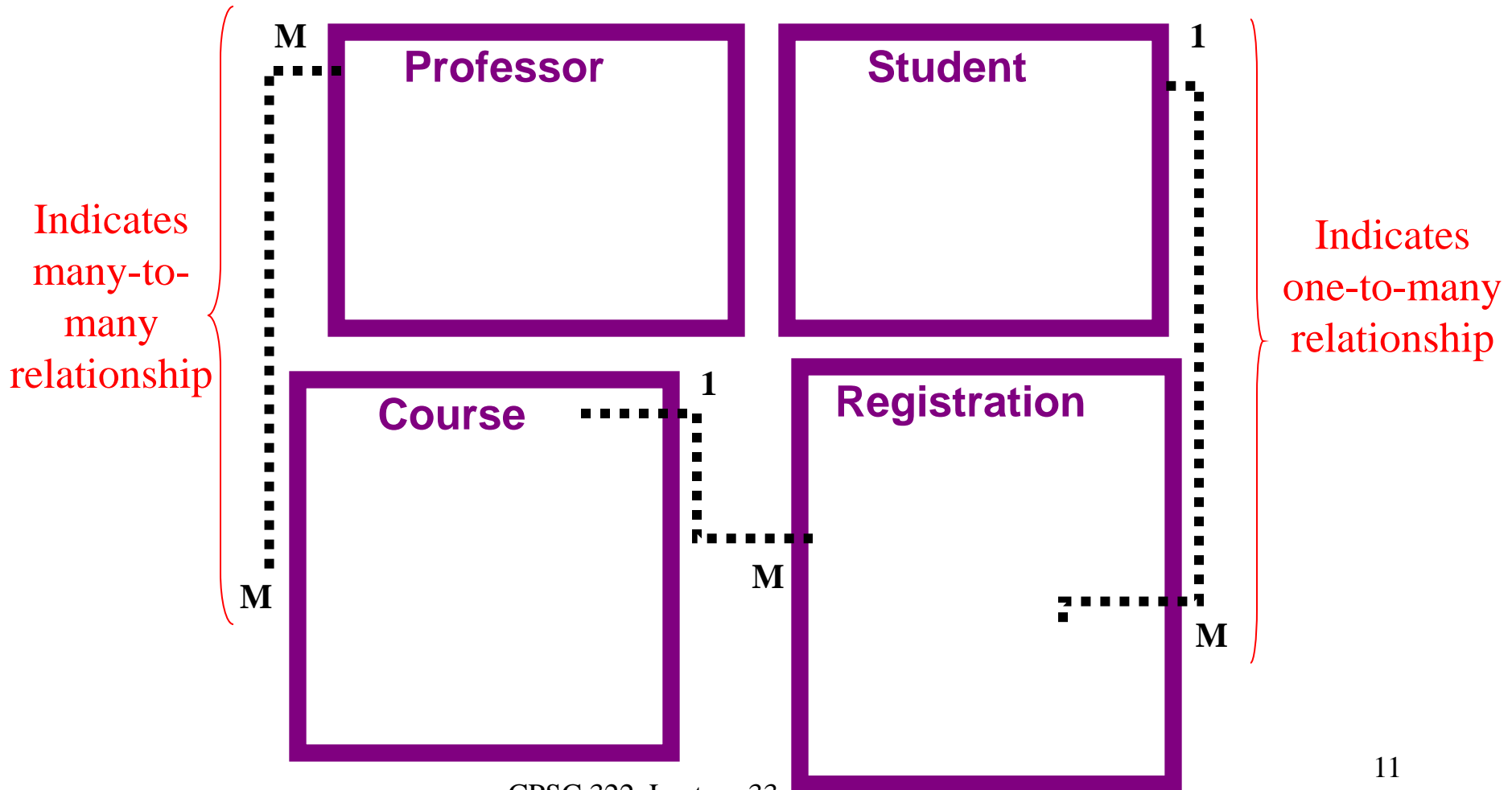
Mapping PRMs from Relational Models: attributes

- **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)**

Course

Name

Rating

Difficulty
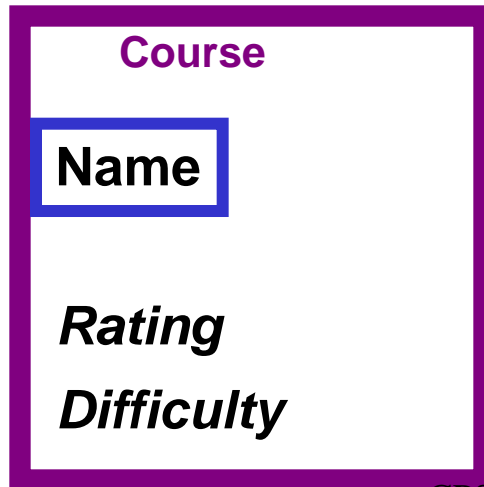
Mapping PRMs from Relational Models: reference slot

- **Each class or entity type is also associated with a set of *reference slots* $\mathscr{R}(X)$**

  - **correspond to attributes that are *foreign keys* (key attributes of another table)**
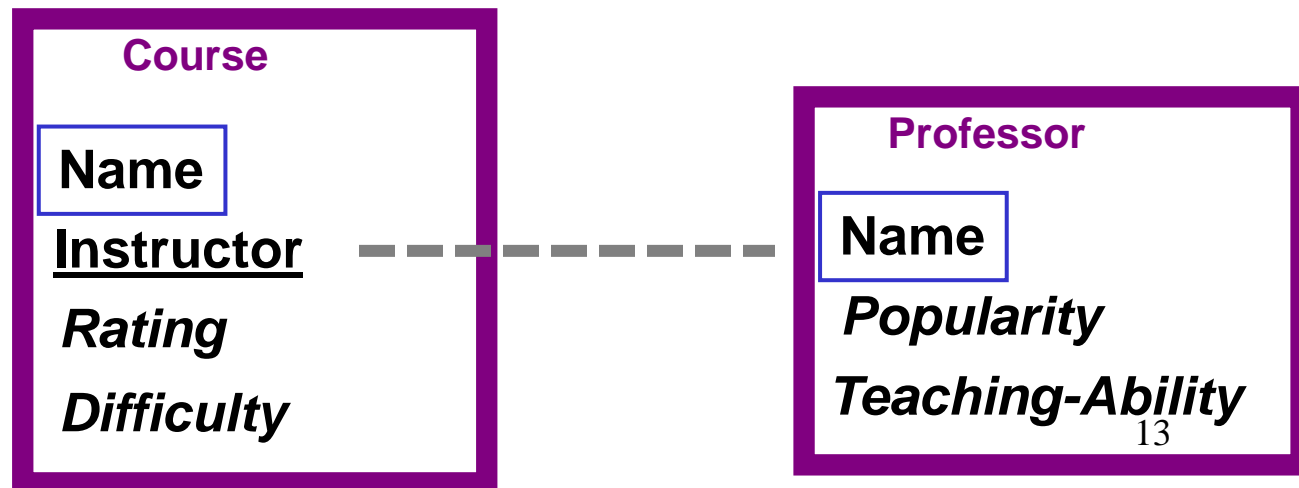
  - **$X.\rho,$ is used to denote reference slot ρ of X.**

Course.Instructor

```
┌─────────────────────┐
│      Course         │
│  ┌──────────┐       │
│  │  Name    │       │
│  └──────────┘       │
│   Instructor  ------ │ - - - - - -
│   Rating            │
│   Difficulty        │
└─────────────────────┘
```

```
                    ┌──────────────────────┐
                    │     Professor        │
                    │  ┌──────────┐        │
    - - - - - - - - │  │  Name    │        │
                    │  └──────────┘        │
                    │   Popularity         │
                    │   Teaching-Ability   │
                    └──────────────────────┘
```

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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

Professor
- Name
- *Popularity*
- *Teaching-Ability*

Student
- Name
- *Intelligence*
- *Ranking*

Course
- Name
- Instructor
- *Rating*
- *Difficulty*

Registration
- RegID
- Course
- Student
- *Grade*
- *Satisfaction*

M   1   1   M   M

Book Recommendation Domain – Full Relational Schema

Customer

Name

Honesty

Kindness

Book

Title

Quality

R_1

Recommendation

Name

Book

Customer

Rating

R_2

i‑clicker

A. $R_1 (1:M), R_2 (M:M)$ C. $R_1 (1:M)\ R_2 (1:M)$

B. $R_1 (M:M), R_2 (1:M)$ D. $R_1 (M:M)\ R_2 (M:M)$

Book Recommendation Domain – Full Relational Schema

Book

Title
Quality

Recommendation

Name
Book
Customer
Rating

Customer

Name
Honesty
Kindness
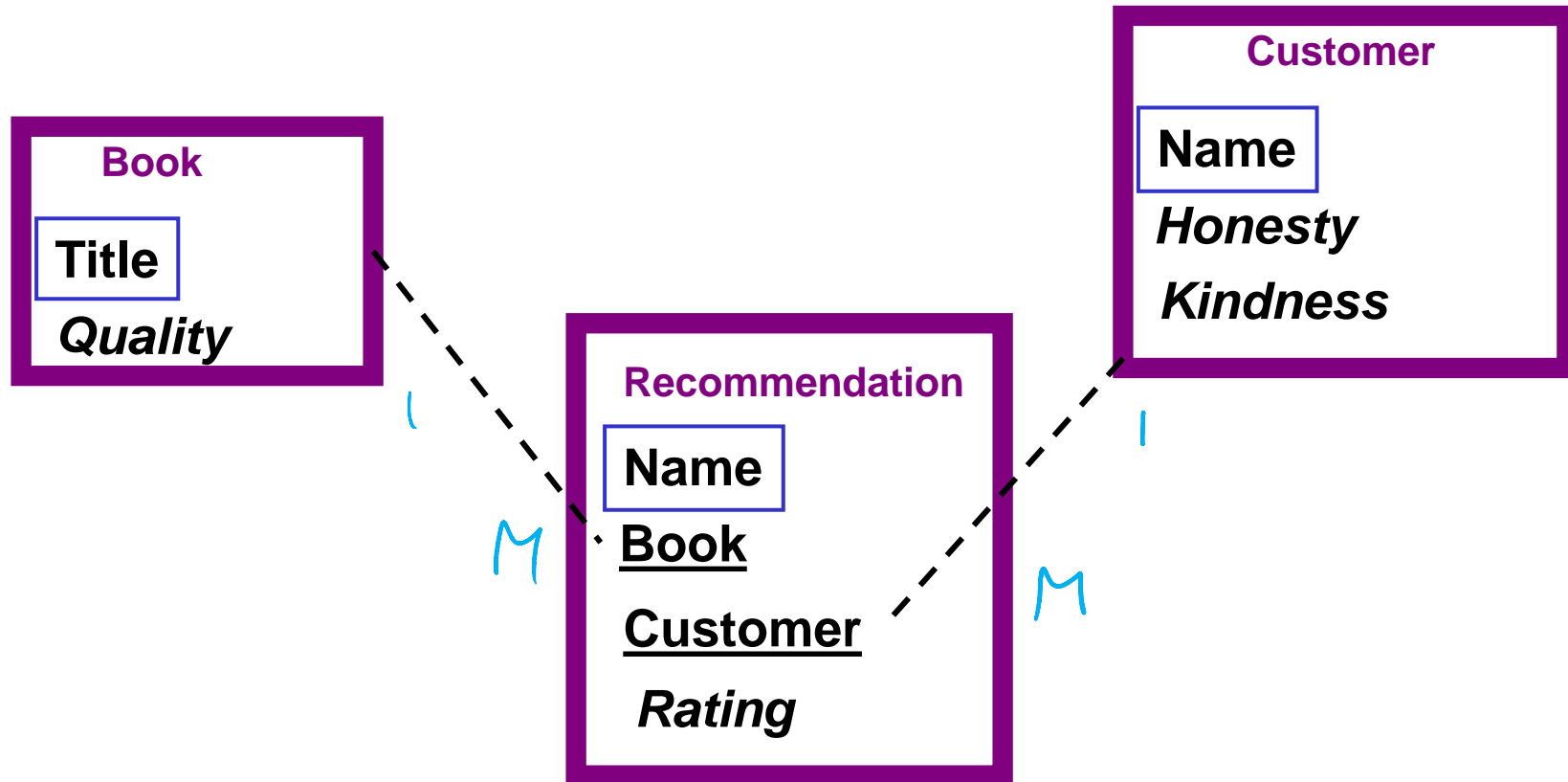
PRM Semantics: Attribute values

- Each attribute $A_j \in \mathcal{A}(X_i)$ 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(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 $x.\rho$

University Domain Example – An Instance of the Schema

Professor
Name
 Prof. Gump
Popularity
 high
Teaching-Ability
 medium

Instructor

Student
Name

Student
Name
 Jane Doe
Intelligence
 high
Ranking
 average
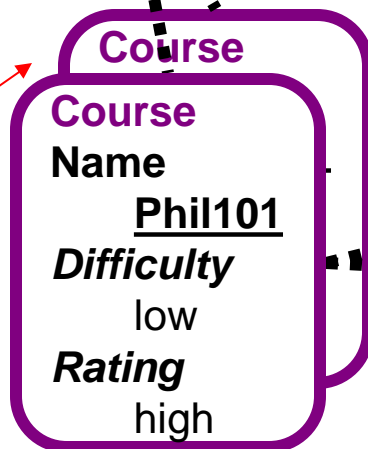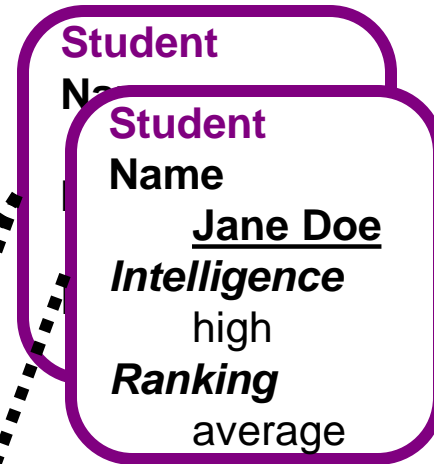
Student

One professor is the instructor for both courses

Course

Course
Name
 Phil101
Difficulty
 low
Rating
 high

Course

Registration

Registration

Registration
RegID
 #5639
Grade
 A
Satisfaction
 3

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

Professor
Name
 Prof. Vincent
Popularity
 high
Teaching-Ability
 high
 ty
 medium

There are two professors instructing a course

Instuctor

Student

Student
Student
Student
Name
 John Doe
Intelligence
 high
Ranking
 average

There are three students in the Phil201 course

Course
Name
 Phil201
Difficulty
 low
Rating
 high

Course

Registration
Registration
Registration
RegID
 #5723
Grade
 A
Satisfaction

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

M

Professor

Name

Popularity

Teaching-Ability

1

Student

Name

Intelligence

Ranking

Course

1

Name

Instructor

Rating

Difficulty

M

Registration

RegID

Course

Student

Grade

Satisfaction

M

M
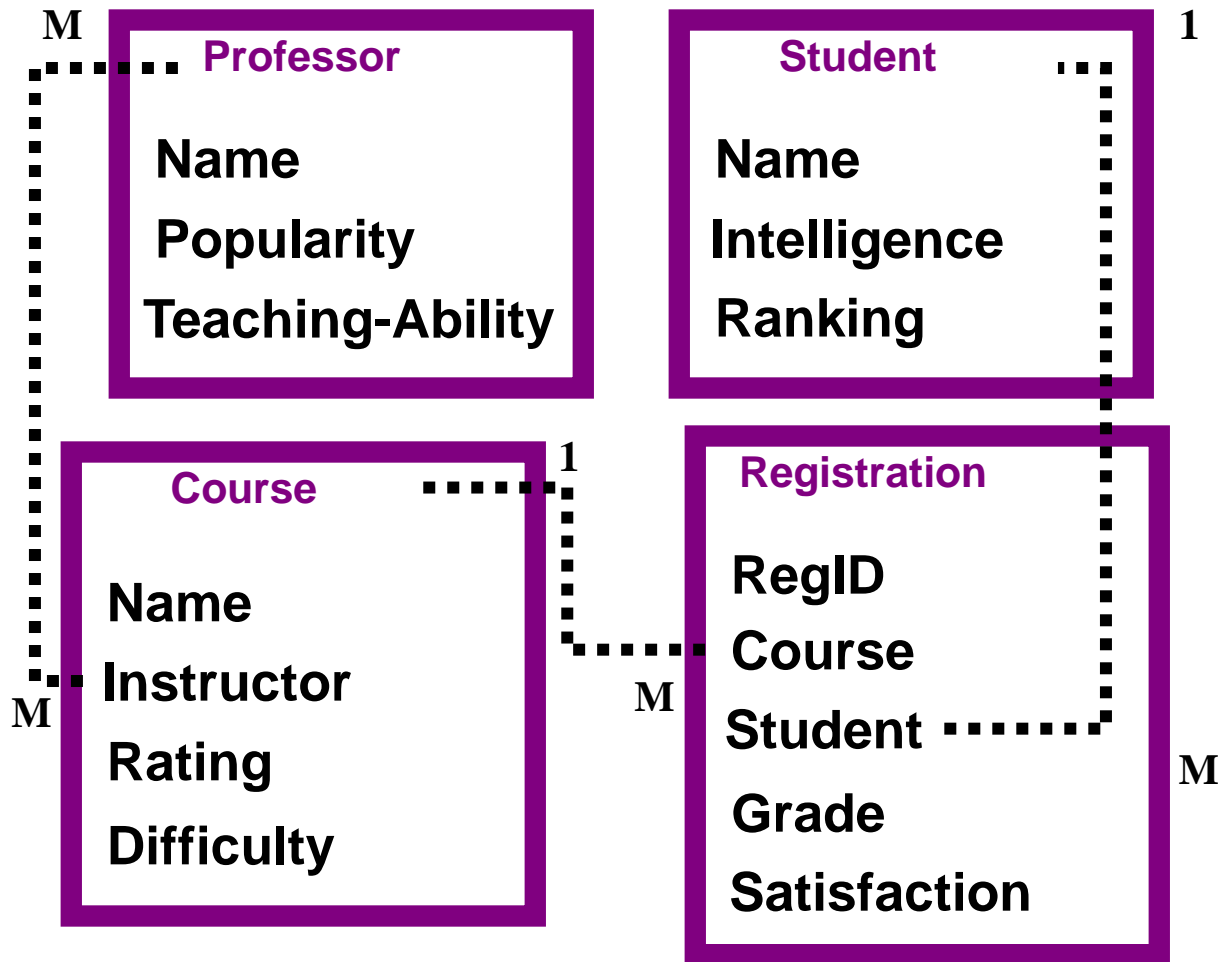
Which ones are fixed? Which are probabilistic?

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University Domain Example – fixed vs. probabilistic attributes

M

Professor

Name

Popularity

Teaching-Ability

Student

Name

Intelligence

Ranking

1

Course

Name

Instructor

Rating

Difficulty

1

M

M

Registration

RegID

Course

Student

Grade

Satisfaction

M

Probabilistic
attributes
are shown in italic

Fixed attributes
are shown in
regular font

Probabilistic
attributes are
shown in italic

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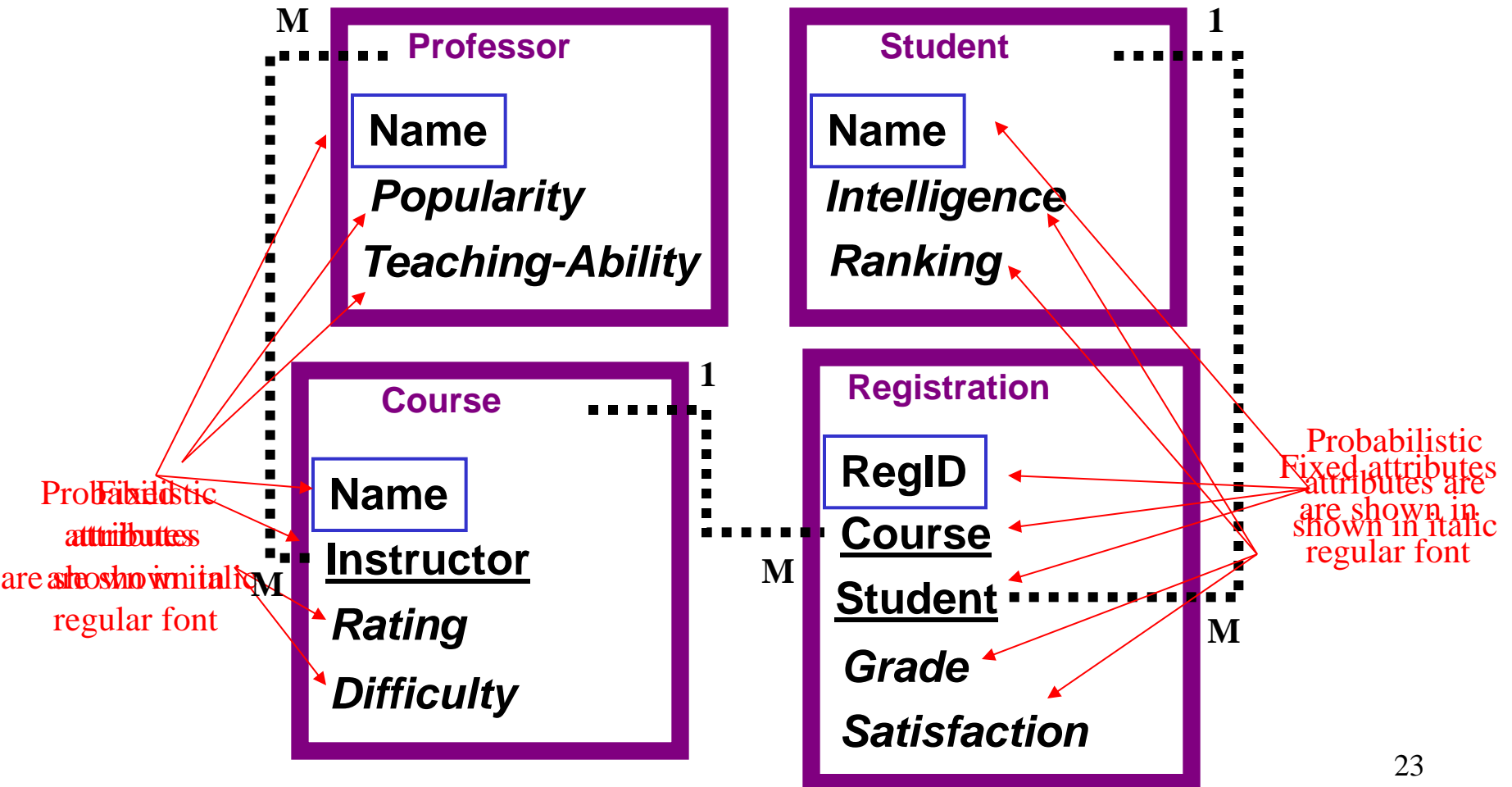
PRM Semantics: Skeleton Structure

- A *skeleton structure σ* 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 σ extends the skeleton by also specifying the values of the probabilistic attributes

University Domain Example – Relational Skeleton

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

Student
Na

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

Registration
R

Registration
R

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

Course

Course
Name
   Phil101
Difficulty
   ???
Rating
   ???

University Domain Example – The Completion Instance *I*

Professor
Name
    __Prof. Gump__
Popularity
    high
Teaching-Ability
    medium

Student
N

Student
Name
    __Jane Doe__
Intelligence
    high
Ranking
    average

Course

Course
Name
    __Phil101__
Difficulty
    low
Rating
    high

Registration
N

Registration
N

Registration
Name
    __#5639__
Grade
    A
Satisfaction
    3

University Domain Example – Another Relational Skeleton

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

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

Course
Name
 Phil201
Difficulty
 ???
Rating
 ???

Registration
Registration
Registration
RegID
 #5723
Grade
 ???
Satisfaction
 ???
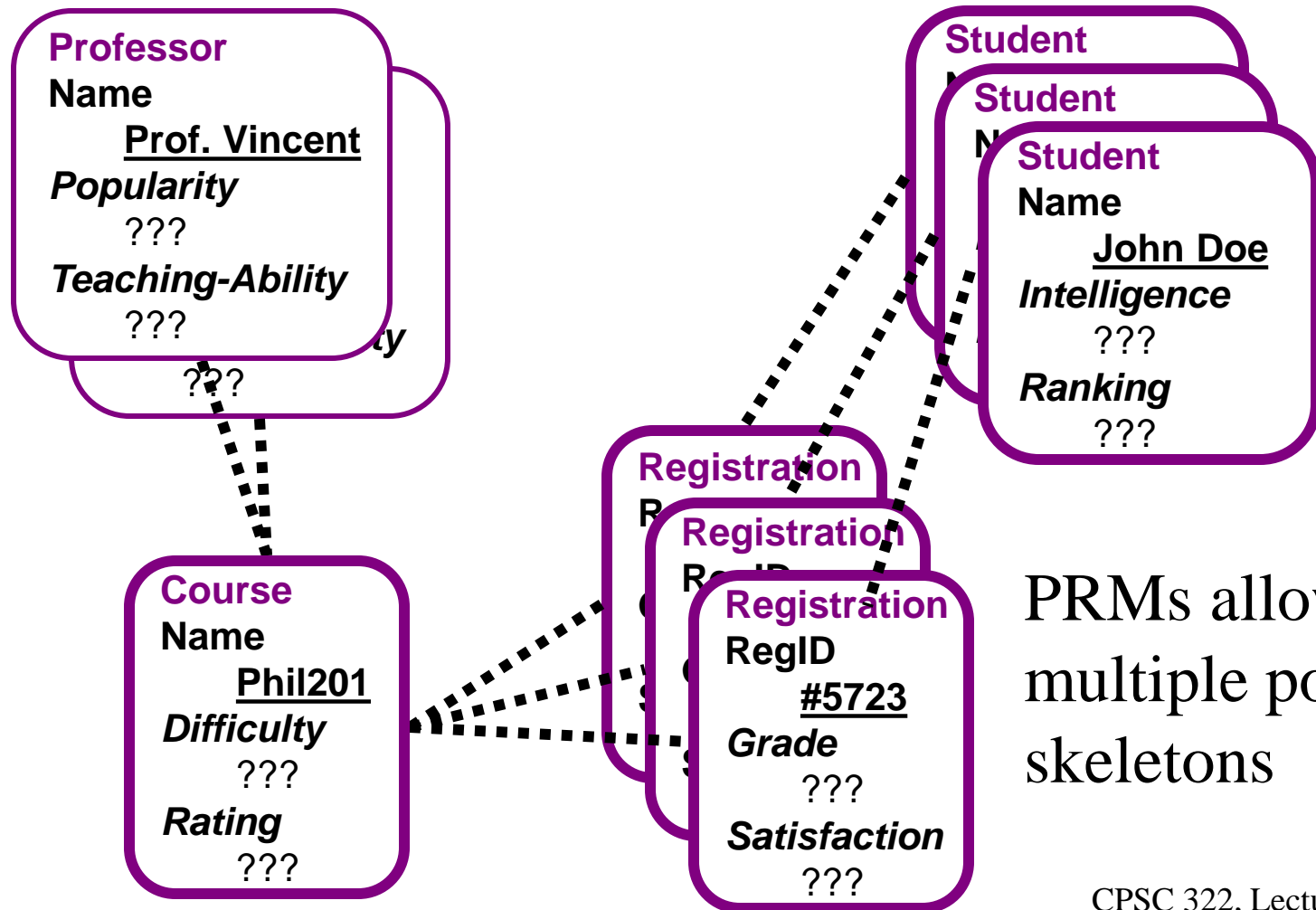
PRMs allow multiple possible skeletons

University Domain Example – The Completion Instance *I*

Professor
Name
Prof. Vincent
Popularity
high
Teaching-Ability
high
...ty
medium

Student

Student

Student
Name
John Doe
Intelligence
high
Ranking
average

Course
Name
Phil201
Difficulty
low
Rating
high

Registration

Registration

Registration
RegID
#5723
Grade
A
Satisfaction
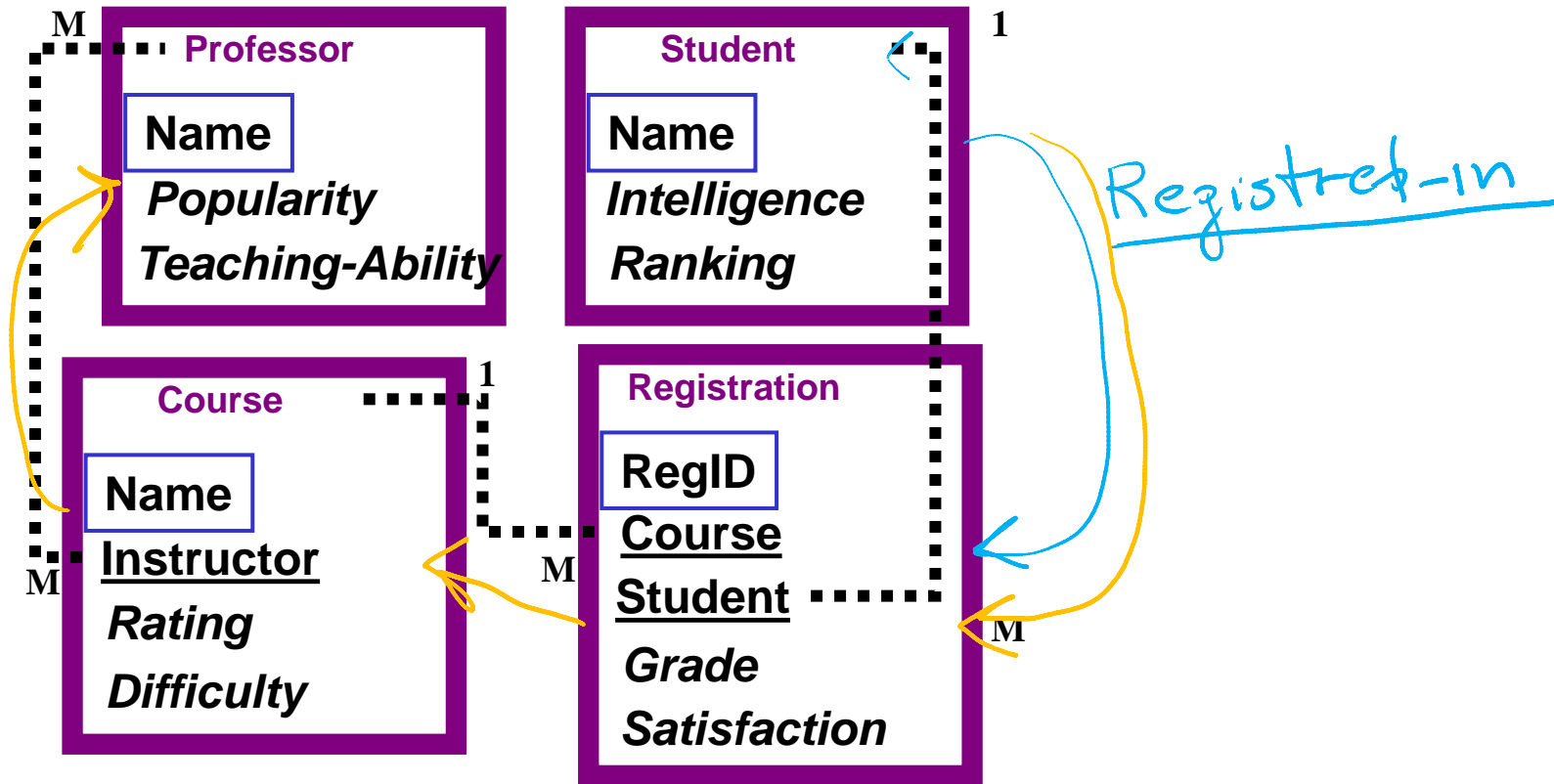3
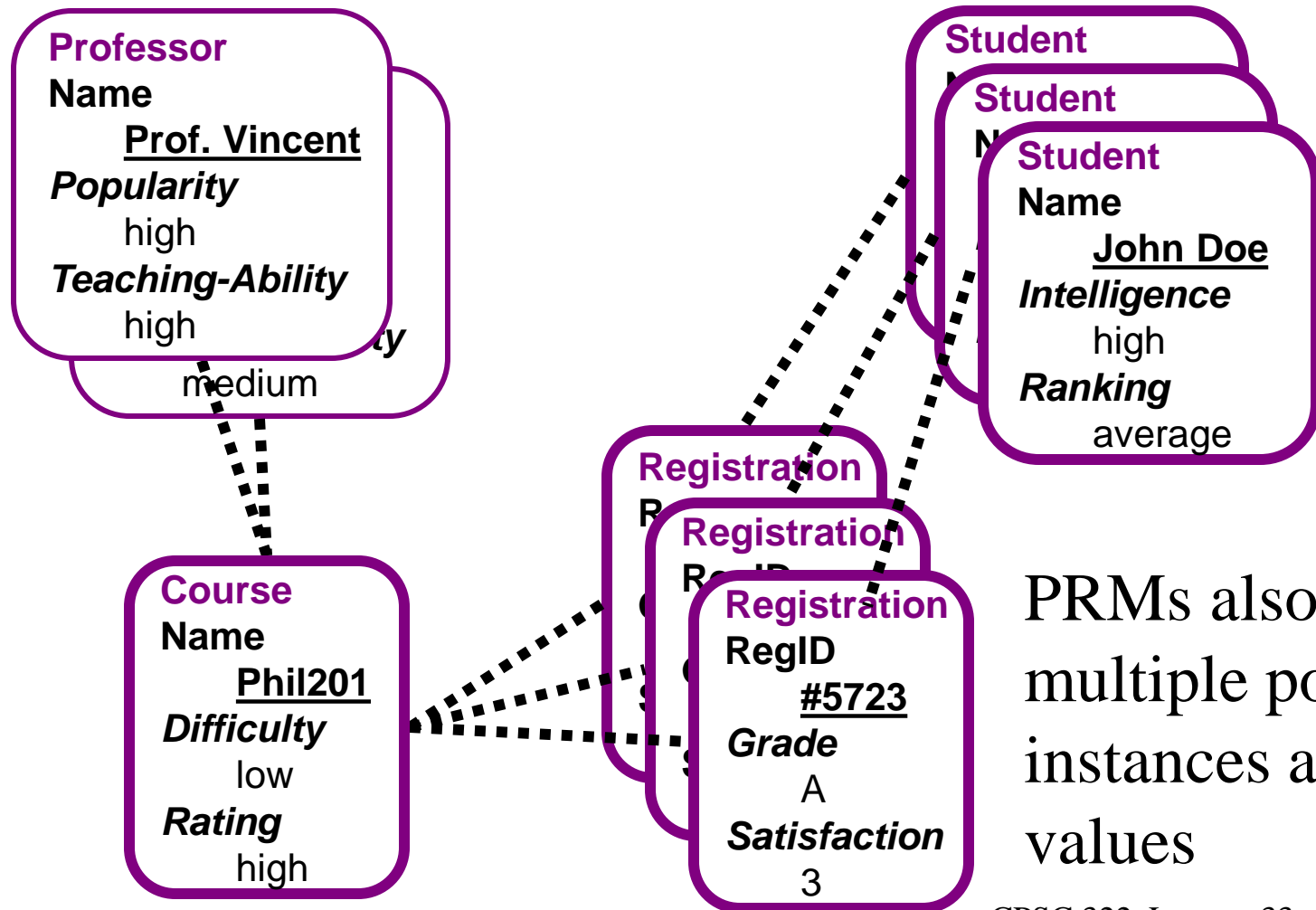
PRMs also allow multiple possible instances and values

PRM Semantics: inverse slot

- **For each reference slot ρ, we define an *inverse slot*, ρ^{-1}, which is the inverse function of ρ**

M

| Professor | | **1** |

Professor

Name

Popularity

Teaching-Ability

Student

Name

Intelligence

Ranking

Course   **1**

Name

Instructor

Rating

Difficulty

M   **M**

Registration

RegID

Course

Student

Grade

Satisfaction

M

Registred-in

ρ = Student

ρ^{-1} = Registred-in

returns a set of Registration objects
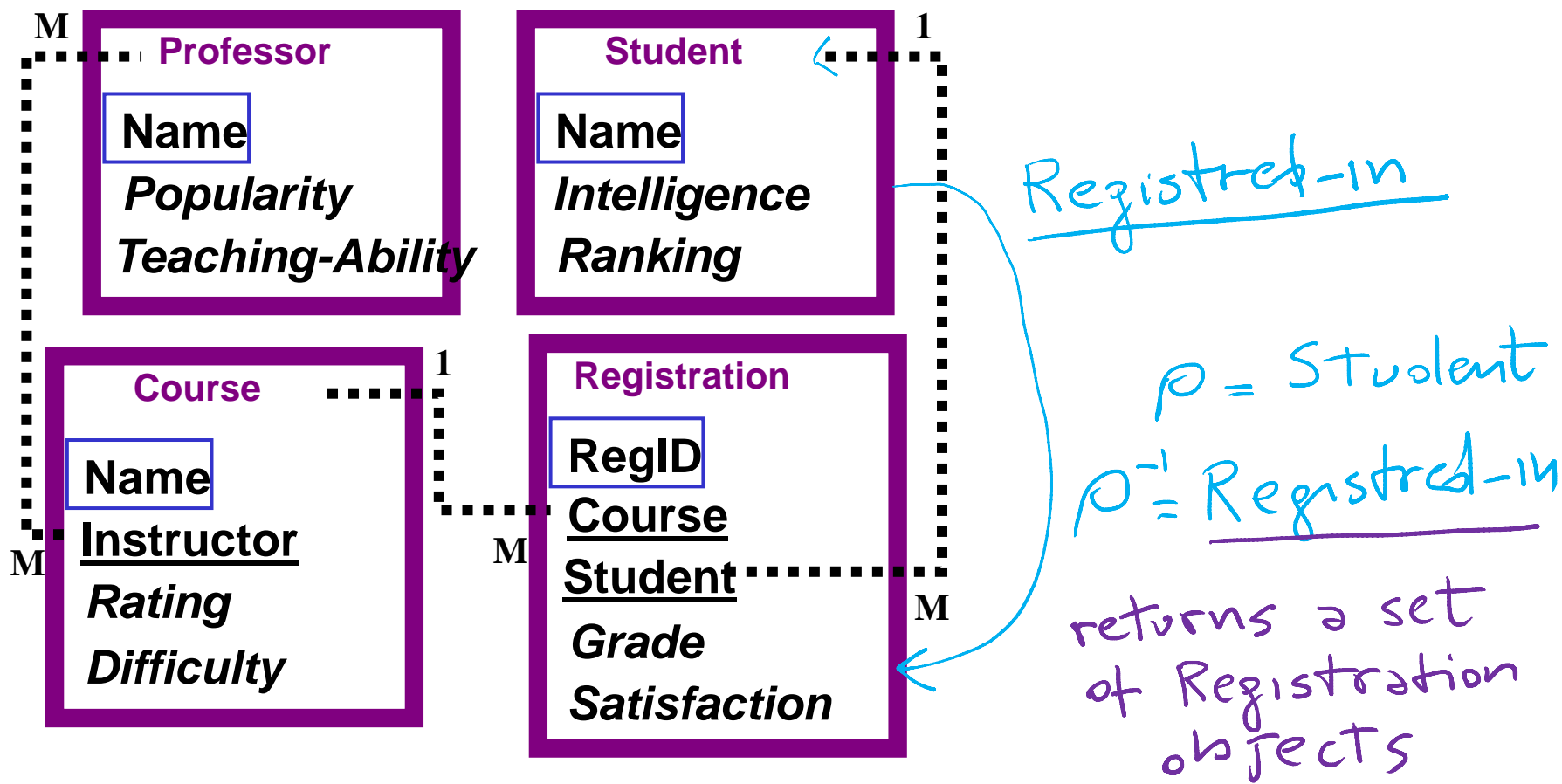
PRM Semantics: slot chain

A ***slot chain*** $\tau = \rho_1 .. \rho_m$ is a sequence of reference slots that defines functions from objects to other objects to which they are indirectly related.

M

Professor

Name

Popularity

Teaching-Ability

Student

1

Name

Intelligence

Ranking

Registred-in

Course

1

Name

Instructor

Rating

Difficulty

M

M

Registration

RegID

Course

Student

Grade

Satisfaction

M

Student.*Registered-In.Course.Instructor*
can be used to denote…… *a student's set of instructors*

Slot chains will allow us...

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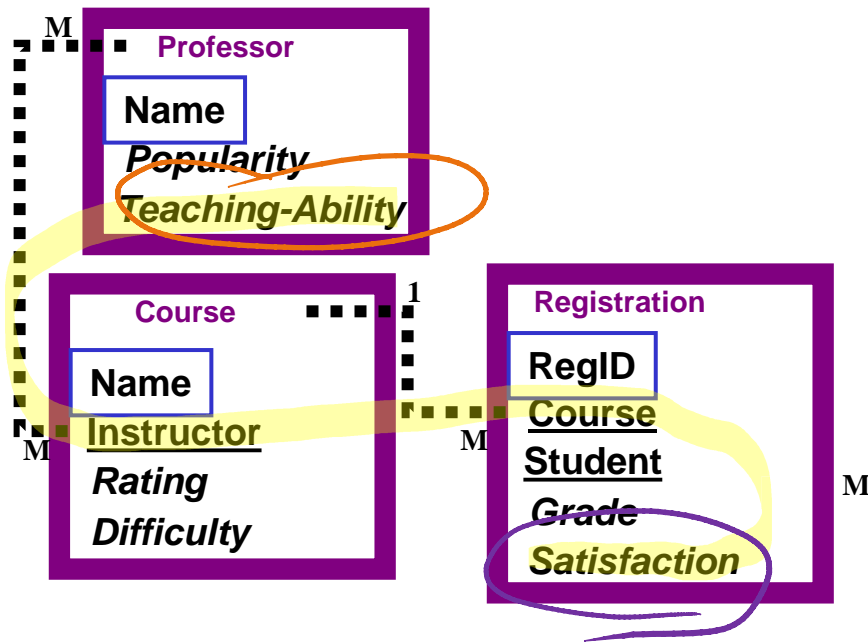
Learning Goals for today's class

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**

Assignment-4 due !